AN EVALUATION OF THE THORNTHWAITE-HOLZMAN EQUATION FOR EVAPOTRANSPIRATION

AN EVALUATION OF THE THORNTHWAITE-HOLZMAN EQUATION FOR EVAPOTRANSPIRATION

By

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CHAPTER I

INTRODUCTION

Evapotranspiration involves a complex set of processes which relate to the loss of water to the atmosphere. It involves the uptake of water by the root system of plants, its movement through the plant, and its diffusion through the stomata into the atmosphere. The term evapotranspiration (E_T) includes evaporation from the soil and transpiration from vegetation.

Two of the basic reasons for studying evapotranspiration are as follows:

1) Since it is the reverse process of precipitation, it has major consequences in agriculture through its control on plant growth.

2) It is one of the important energy fluxes from the earth's surface and is an integral part of the energy balance.

The research for this dissertation was part of a project carried out during the summer months of 1967 at the Horticultural Experiment Station near Simcoe (lat. 43°, long. 80°). One of the main aims of this project was to evaluate and compare several methods of estimating evapotranspiration. In this thesis the writer is concerned with the Thornthwaite-Holzman (1942) method which has been widely used in the past (Penman and Long, 1960; Pruitt, 1963; Blackwell and Tyldesley, 1965; Mukammal, King, and Cork, 1966). It is based on aerodynamic theory which is discussed in Chapter II.

Also as part of this study computer programs were written to handle all the data from Simcoe, only some of which are used here. The programs and descriptions are given in Appendix (A).

CHAPTER II

LIST OF SYMBOLS

Cp	Specific heat of air at constant pressure	cal/gm/ C
d	Zero plane displacement	cm
E_T	Evaporative flux	$cal/cm^2/sec$
g	Acceleration due to gravity	cm/sec^2
H	Sensible heat flux	$cal/cm^2/sec$
k	von Karmans constant	dimensionless
K_H	Turbulent transfer coefficient (heat)	cm^2/sec
K_M	Turbulent transfer coefficient (momentum)	cm^2/sec
K_W	Turbulent transfer coefficient (water vapour)	cm^2/sec
L	Latent heat of vapourization	cal/gm
p	Total pressure	mb
P	Energy used in photosynthesis	$cal/cm^2/sec$
q	Specific humidity	gm/gm (of moist air)
Ri	Richardson's number	dimensionless
Rn	Net radiative flux	$cal/cm^2/sec$
S	Soil heat flux	$cal/cm^2/sec$
S_H	Shape function (heat)	dimensionless
S_M	Shape function (momentum)	dimensionless

S_W	Shape function (water vapour)	dimensionless
T	Ambient temperature	deg C
u_*	Friction velocity	cm/sec
U	Horizontal wind	cm/sec
Z	Height of measurement	cm
Z_0	Surface roughness parameter	cm
β	Bowen ratio	dimensionless
θ	Potential temperature	deg C
Φ	Correction function for wind profile under unstable conditions	dimensionless
τ	Shearing stress	dyne/cm^2
Θ	Absolute potential temperature	deg K
ρ	Density of air	gm/cc
γ	Psychrometric constant	dimensionless

THEORY

A. THORNTHWAITE-HOLZMAN EQUATION FOR E_T

The following mass transfer equations are fundamental to the derivation of the Thornthwaite-Holzman (1942) equation:

$$E_T = -\rho K_W (\delta q/\delta Z), \qquad (2\text{-}1)$$

$$H = -\rho C_p K_H (\delta \theta / \delta Z), \qquad (2\text{-}2)$$

$$\tau = \rho K_M (\delta U/\delta Z), \qquad (2\text{-}3)$$

$$\tau = \rho u_*^2. \qquad (2\text{-}4)$$

In the above equations fluxes away from the earth are defined as negative. The first three equations relate the vertical fluxes of water vapour, heat, and momentum to their respective density gradients. The fourth equation, by definition, relates the shearing stress to a quantity called the friction velocity u_*. The validity of the above equations is dependent on the following assumptions:

1) a homogeneous surface,

2) constancy of the energy fluxes with height,

3) non-existent horizontal fluxes,

4) steady state conditions,

5) the transfer mechanisms for turbulent flow and laminar flow are similar.

By combining Equations (2-1) and (2-3) in the following manner:

$$\frac{E_T}{\tau} = \frac{-K_W}{K_M} \frac{(\delta q/\delta Z)}{(\delta U/\delta Z)},$$

the evaporative flux may be found from:

$$E_T = - \frac{\tau \, . \, K_W \, (\partial q / \partial Z)}{K_M \, (\partial U / \partial Z)} \; ,$$

$$E_T = - \rho u_*^2 \frac{K_W \, (\partial q / \partial Z)}{K_M \, (\partial U / \partial Z)} \; . \qquad (2\text{-}5)$$

Integrating (2-5) between two levels of measurement Z_1 and Z_2 results in:

$$E_T = - \rho u_*^2 \frac{K_W \, (q_2 - q_1)}{K_M \, (U_2 - U_1)} \; . \qquad (2\text{-}6)$$

Under neutral conditions the change in the wind speed with height is given by:

$$\partial U / \partial Z = u_* / kZ \; . \qquad (2\text{-}7)$$

where k is the proportionality constant (von Karman). It has also been shown that under neutral conditions the wind speed varies directly with the logarithem of the height. Integrating (2-7) then gives:

$$u_* = \frac{k \; (U_2 - U_1)}{\ln \; (Z_2 / Z_1)} \; . \qquad (2\text{-}8)$$

Assuming that $K_W = K_M$, and substituting (2-8) into (2-6) gives the Thornthwaite-Holzman (1942) equation:

$$E_{TH} = - \rho k^2 \; \frac{(U_2 - U_1) \; (q_2 - q_1)}{\ln \; (Z_2 / Z_1)^2} \; . \qquad (2\text{-}9)$$

The wind speed U at any height Z may be found from:

$$U = \frac{u_*}{k} \cdot \ln (Z/Z_0) \quad , \qquad (2\text{-}10a)$$

where Z_0 is the height at which the wind profile extrapolates to zero. Often, especially in tall vegetation, the wind speed is not zero at height Z_0 but rather at some height $(Z_0 - d)$. This new parameter, d, is called the zero plane displacement. Equation (2-10a) then becomes:

$$U = \frac{u_*}{k} \cdot \ln \frac{(Z - d)}{Z_0} \quad , \qquad (2\text{-}10b)$$

and a linear relationship exists between U and ln $(Z_0 - d)$.

The occurrence of a neutral atmosphere is not very common. Suitable conditions for neutrality may be found under cloudy skies with a strong wind. More frequently, however, thermal stratification occurs in the lowest layers of the atmosphere producing daytime lapse conditions and at night inversions. On such days the heat flux passes through zero twice as conditions change from daytime lapse to nighttime inversion and vice versa. Thus neutral stability occurs at least twice daily although only for a short period of time. The most common indicator of stability is Richardson's number:

$$Ri = \frac{g}{\theta} \cdot \frac{(\delta \theta / \delta Z)}{(\delta U / \delta Z)^2} \quad . \qquad (2\text{-}11)$$

Under unstable conditions a correction $\Phi = f(Ri)$ is applied to the logarithmic wind profile in the following manner:

$$\delta U / \delta Z = (u_* / kZ) \, \Phi \quad . \qquad (2\text{-}12)$$

B. THE BOWEN RATIO SOLUTION TO THE ENERGY BALANCE EQUATION

In order to properly examine the Thornthwaite-Holzman equation, a standard was needed against which it could be tested. One of the most accurate methods for measuring E_T uses the energy balance equation in the form as suggested by Bowen (1926). This method of estimating E_T was chosen as the standard in this study because:

1) It is not dependent on a pre-determined form of the wind profile.

2) The work of others has shown that it gives good agreement with measured E_T.*

The general energy balance equation may be written as follows:

$$Rn + S + H + E_T + P = 0.$$

Since the energy used in photosynthesis is small relative to the other components, it is often ignored. The equation the reduces to:

$$Rn - S = E_T + H. \qquad (2\text{-}13)$$

All fluxes away from the earth are considered negative, as in the case of the mass transfer equations. Bowen's (1926) ratio, β, is defined by:

$$\beta = H/E_T. \qquad (2\text{-}14)$$

This ratio of the sensible heat flux to the latent heat flux may be found from Equations (2-2) and (2-1). Combining (2-13) and (2-14)

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* Lake Hefner Studies (1954), Slatyer & McIlroy (1961), Fritschen (1965), Mukammal, King, and Cork (1966), Tanner (1967), Penman, Angus, and van Bavel (1967).

gives:

$$Rn - S = E_T (1 + H/E_T) \quad ,$$

therefore,

$$E_{TB} = \frac{(Rn - S)}{1 + \beta} \quad .$$

Assuming that $K_H = K_W$ and introducing Equations (2-1) and (2-2), Bowen's (1926) equation for evapotranspiration becomes:*

$$E_{TB} = \frac{Rn - S}{1 + \frac{Cp}{L} \cdot \frac{(\delta T/\delta Z)}{(\delta q/\delta Z)}} \quad . \qquad (2\text{-}15)$$

C. ASSUMPTIONS

The validity of both the Bowen (1926) ratio solution and the Thornthwaite-Holzman (1942) equation depends on the assumptions outlined briefly in Section A of this chapter.

A homogeneous surface is critical to both techniques. If the surface is patchy, there will be a horizontal variation of the energy fluxes across the vegetation and instruments will not be recording a representative sample. A patchy surface may also destroy the implicit assumption that $K_H = K_W = K_M$. Tanner (1967) has suggested that for a patchy surface:

$$K_H \neq K_M \approx K_W .$$

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* Here the slight differences between potential temperature and ambient temperature are ignored since at levels of measurement less than one meter the correction is only of the order of 0.01 degrees centigrade.

A homogeneous surface is also necessary to ensure an adequate boundary layer so that the second and third assumptions will hold. As a parcel of air moves from one vegetation surface to another, it gradually adjusts to the new surface from which it acquires new characteristics of temperature, humidity, and wind. The depth of the boundary layer increases downwind from the point of the discontinuity. Since the measurements of wind, vapour pressure, and temperature must be made within this boundary layer, it is critical that the fetch is sufficiently large to ensure a boundary layer deep enough to contain these instruments. It is generally conceded that the height to fetch ratio should be a minimum of 1:50 with a ratio of 1:100 being preferable (Tanner, 1967). Fetch requirements are discussed more fully under the site description in Chapter III.

Steady state requires conditions steady in time so that at any given position there is no change with time of the mean properties of the air (Webb, 1965). In order to ensure this it is necessary to time-average over a period of at least 30 minutes.

Under thermally neutral conditions there will be negligible heat flux in the surface layers of the atmosphere; so that, the dynamics of the air are controlled by mechanical turbulence caused by the horizontal wind. Only under such conditions is the logarithmic wind profile valid. Many attempts have been made to establish a general wind profile equation for all conditions of stability. Most of these generalized profiles break down except under very restricted conditions and are, therefore, of limited application.

In Figure (2-1) King (1967) has plotted E_T values using 3 different wind profile forms. Agreement with lysimeter measurements is poor in all cases.

Recent work by Swinbank and Dyer (1967) has thrown new light on the uncertain assumption that $K_H = K_W = K_M$. They compared three level profiles of temperature, humidity, and wind, and therefore implicitly K_H, K_W, and K_M, using "shape functions" for heat, S_H, water vapour, S_W, and momentum, S_M:

$$S_H = (T_2 - T_1) / (T_3 - T_1) \quad ,$$

$$S_W = (q_2 - q_1) / (q_3 - q_1) \quad ,$$

$$S_M = (U_2 - U_1) / (U_3 - U_1) \quad .$$

If the K's are constant, the S functions should be the same irrespective of the stability of the air. These values were compared over a range of atmospheric stability with Richardson's number as an index of stability. Their plot of shape functions against Ri is shown in Figure (2-2). This shows that the shape functions for heat and water vapour are identical but that of momentum diverges markedly. Thus, the assumption that $K_W = K_H$ in the Bowen ratio method is valid.

Prior to this recent work by Swinbank and Dyer (1967) most researchers, having examined the available data, concluded that the error in assuming $K_M = K_W$ was negligible if $|Ri| < 0.05$. Figure (2-2) shows that this conclusion is invalid at least for $|Ri| > 0.005$. How the S functions behave for $|Ri| < 0.005$ is unknown. They may

FIGURE 2-1 E_T USING VARIOUS WIND PROFILES

(King, 1967)

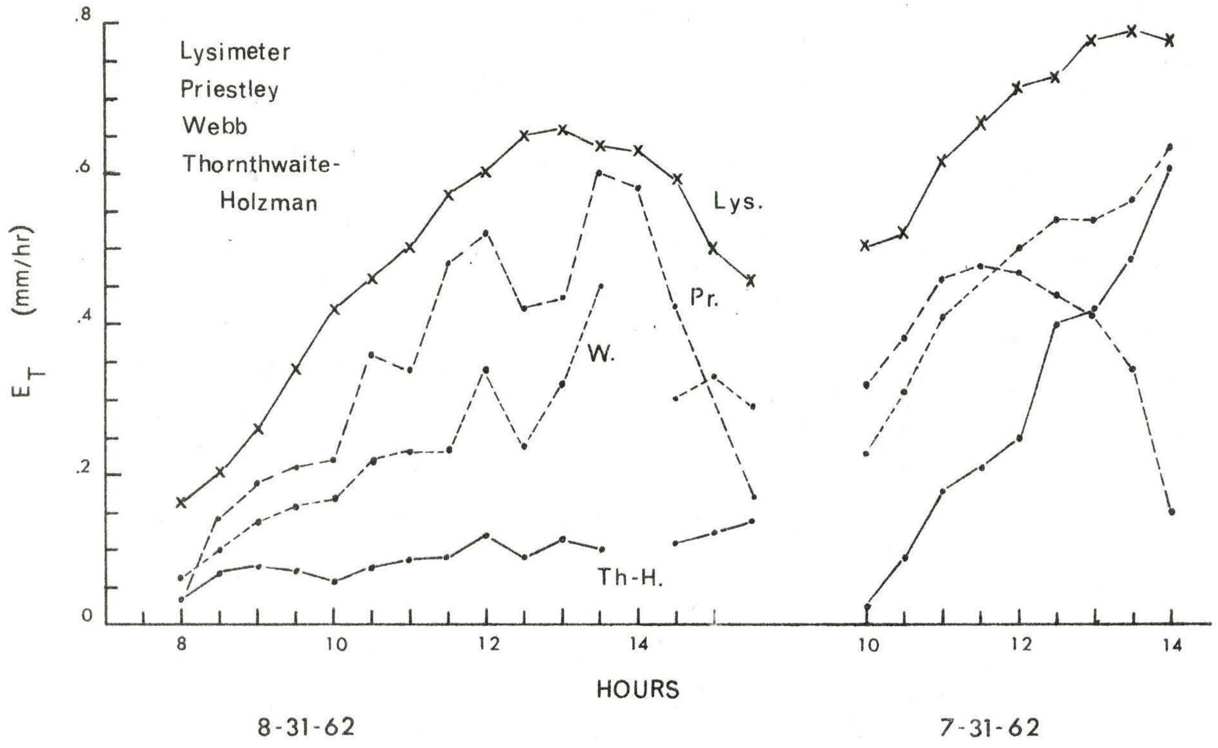
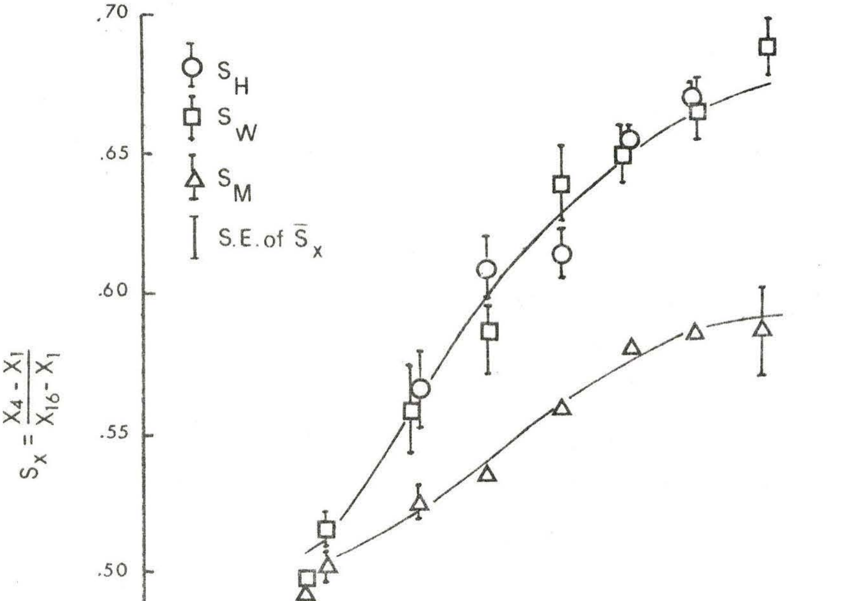


FIGURE 2-2 SHAPE FUNCTIONS S_H, S_W, S_M.

(Swinbank & Dyer, 1967)



become coincident or they may cross and continue to diverge. However, the assumption that $K_M = K_W$ in the Thornthwaite-Holzman approach is invalid for $|Ri| > 0.005$. There is some reason to believe that K_M closely approximates K_W under neutral conditions (Tanner, 1967).

CHAPTER III

SITE, INSTRUMENTATION, AND DATA ANALYSIS

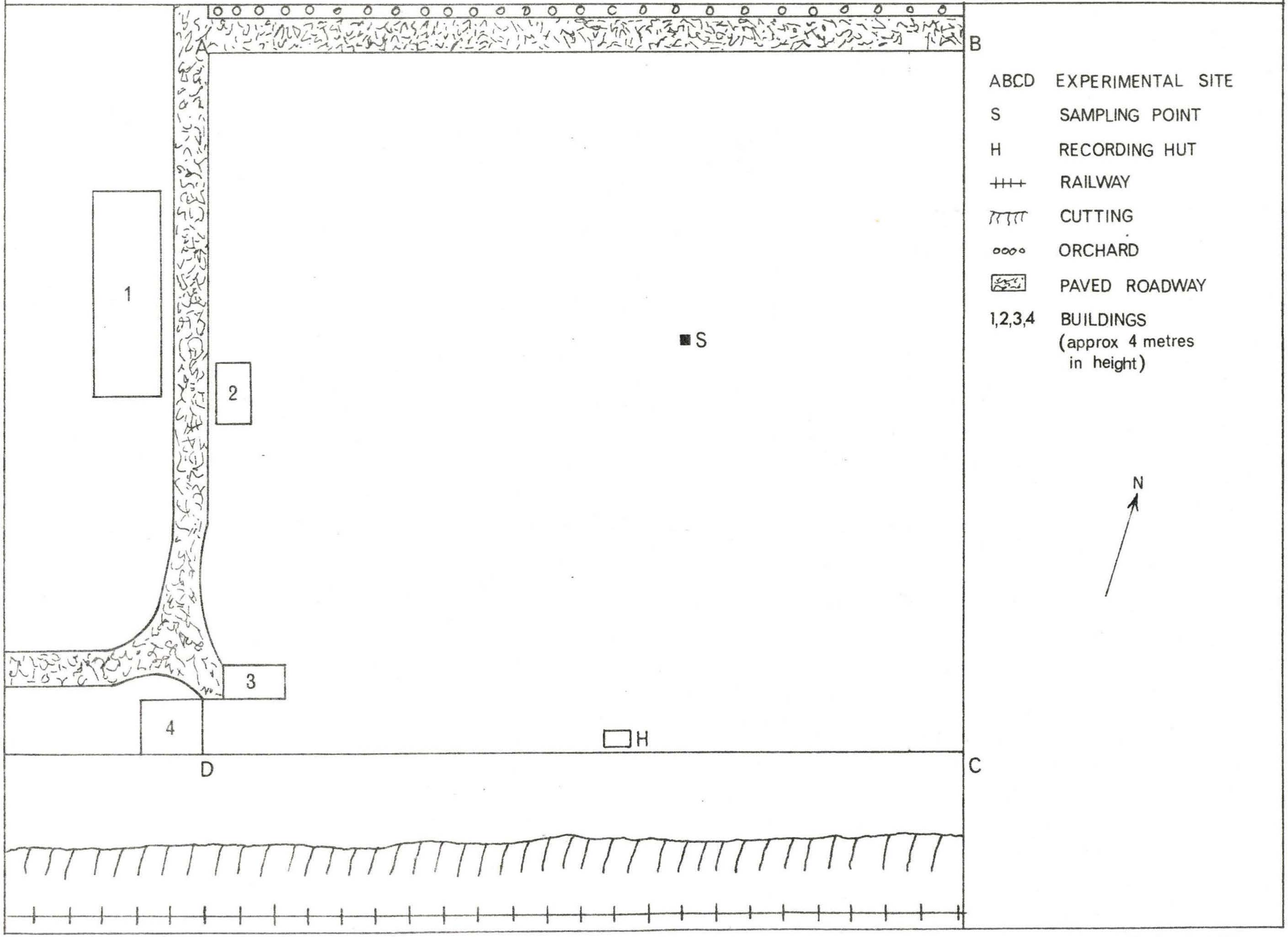
SITE

The site for the Simcoe project was an irrigated plot of ryegrass, 122 metres by 102 metres, with the short side aligned in a north-south direction (see Figure 3-1). The field was bounded on the north by an orchard, on the west by a road, in the south by a railway and sloped gently to a swamp on the east side. There were a few small buildings along the road bordering the western edge of the plot. The field itself was relatively flat. Seeding was done early in May and a workable cover was obtained by early July. The field program commenced on July 5.

The assumption of zero horizontal divergences requires that the measurements of temperature, humidity and wind speeds be within the boundary layer. Tanner (1967) suggests that for the wind profile a fetch to height of measurement ratio of approximately 1:100 is required for reliable results.

The subject of fetch is a controversial one and experimental evidence to date is far from conclusive. Fetch ratios vary from as high as 1:170 (Dyer, 1963), through Deacon's suggested ratio of 1:80 over short green grass (from Taylor, 1962) to Panofsky and Townsend's (1964) ratio of 1:70. van Bavel and Fritschen (in private communication

FIGURE 3-1 SKETCH OF EXPERIMENTAL SITE SCALE 1"≈22m



with Tanner, 1967) suggested that leading edge effects over wet bare soil were minor within 1 metre of the upwind boundary at low windspeeds (1 - 2 m/sec.). Webb (1965) points out that the greater the discontinuity between the two adjacent surfaces, the greater the degree of adjustment required for accurate measurements, hence the fetch requirements vary with the nature of the discontinuity. It is suggested, therefore, the maximum and minimum fetches of 79m and 42m, although inadequate by the standards suggested by most researchers, may be quite adequate for the Simcoe project. Only when the wind came from the north over the orchard was the discontinuity great enough to make the fetch inadequate for satisfactory adjustment of the boundary layer.*

INSTRUMENTATION

Measurements of temperature and humidity for the Bowen ratio were made using aspirated wet and dry thermocouples of 16 gauge copper-constintan placed at 15 and 45 cm above the surface (see Plate 3-1). The wet and dry bulb temperatures were recorded on Thornthwaite Thermocouple Temperature Systems.** The sampling times were at 10 minute intervals and hourly averages were used to approximate steady state.

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* Several plots were made of U vs. ln Z under neutral conditions the resulting line was as near as possible to a perfect straight line fit.

** C. W. Thornthwaite Associates, New Jersey.

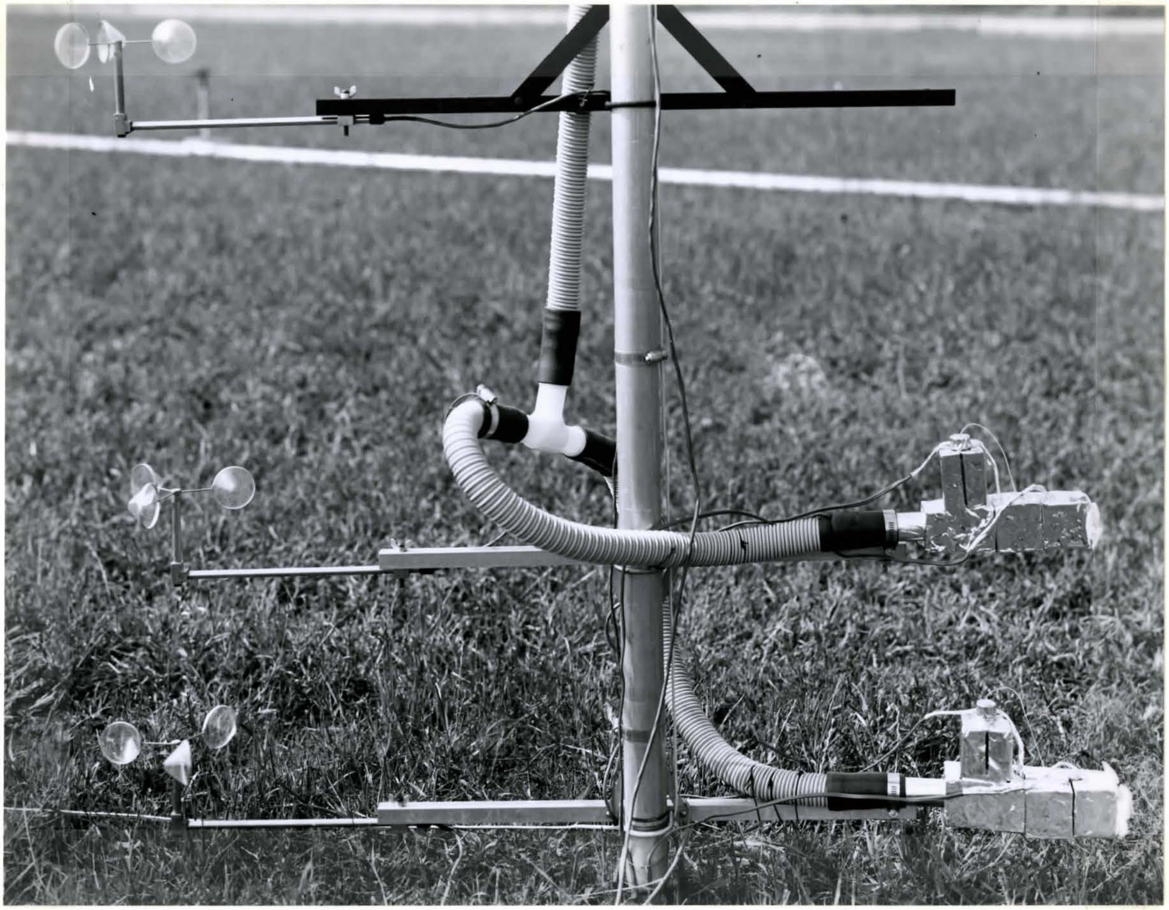

PLATE 3-1 This is a close-up of the wind mast showing the arrangement of the anemometer and the thermocouple housings. The water feed to the wet-bulb thermocouple was gravitational. The thermocouples were aspirated by a vacuum motor located at the top of the mast.

The wind profile was obtained from measurements made at three levels using a Thornthwaite Wind Shear System.* The sensitive anemometers of this system were mounted at 21 cm, 51 cm, and 101 cm. The wind speeds were recorded on digital counters. Wind speeds were sampled at 10 minute intervals and averaged over hourly periods.

DATA ANALYSIS

All of the data at Simcoe were put onto punched cards and were processed by McMaster's IBM 7040 computer. This reduced the analysis time and made it feasible to use large amounts of data.**

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* C. W. Thornthwaite Associates, New Jersey.

** See Appendix A for sample computer programs.

CHAPTER IV

VALUE OF CONSTANTS USED

g = 981 cm/sec^2

k = 0.41

t = 3.60×10^4

Z_1 = 21 cm

Z_2 = 51 cm

Z_3 = 15 cm

Z_4 = 45 cm

ΔZ = 30 cm

$\frac{Cp}{\varepsilon L} = \gamma$ = gamma 0.659

$\frac{\rho \varepsilon}{p} k^2$ = 1.24×10^{-7} gm/cm^3/mb at 20 C and 1000 mb

L = 58.60 cal/mm at 20 C and 1000 mb

DATA AND RESULTS

A. INTRODUCTION

The data for this study were collected, for the most part, under conditions of instability, $Ri < 0$, although a few hours of data were collected under stable conditions, $Ri > 0$. Neutral stability occurred only for a few instantaneous readings. Stability variation was augmented by variable cloud conditions. Often the mornings began under clear skies, but by early afternoon cumulus clouds had developed.

Measurements were made over a perennial ryegrass crop. The crop was cut at least once a week to a height of 6-8 cm. In most cases irrigation was carried out several days before a run. Irrigation ceased after July 26 and the last cutting was made on August 9.

TABLE 4-1

DATE OF RUN	DAYS AFTER LAST IRRIGATION	DAYS AFTER LAST CUTTING
July 5	-	0
July 13	-	1
July 18	-	6
July 20	1	0
July 25	6	5
July 27	1	1
August 4	2	2
August 8	6	6
August 11	9	2

B. EQUATIONS USED IN COMPUTATIONS

Since measurements of vapour pressure and wind speed were not made at the same height, Equation (2-9) was adjusted as recommended by Thornthwaite-Holzman (1942):

$$E_{TH} = \frac{\rho \varepsilon}{p} \cdot \frac{k^2 t \, (U_2 - U_1)\,(e_2 - e_1)}{\ln (Z_2/Z_1)\,\ln (Z_4/Z_3)} , \qquad (4\text{-}1)$$

where Z_1 and Z_2 are the heights at which wind speed was measured, and Z_3 and Z_4 are the heights at which temperature and humidity were measured. ε is a dimensionless constant and t is a time constant which converts the readings in gm/cm/sec to mm/hr of water. $(e_2 - e_1)$ is reversed in this equation to maintain the direction of flux convention. For a close cropped surface such as ryegrass the effect of the zero-plane displacement was ignored since Blackwell and Tyldesley (1965) found it to be equal to zero for short grass.

Richardson's number was found from:

$$Ri = \frac{g}{\bar{T}} \cdot \frac{\Delta Z\,(T_2 - T_1)}{(U_2 - U_1)^2} , \qquad (4\text{-}2)$$

where

$$\bar{T} = 273.16 + (T_2 - T_1)/2 \quad .$$

To correct for non-adiabatic conditions the correction function was evaluated from (Penman, Angus, van Bavel, 1967):

$$\Phi = (1 \pm 10\ Ri). \qquad (4\text{-}3)$$

If $Ri < 0$

$$\Phi = (1 - 10\ Ri) \quad , \qquad (4\text{-}4)$$

and

$$E_{THR} = E_{TH} \cdot \Phi \, . \qquad (4\text{-}5)$$

If Ri > 0

$$\Phi = (1 + 10\ Ri) \quad , \qquad (4\text{-}6)$$

and

$$E_{THR} = E_{TH} / \Phi \, . \qquad (4\text{-}7)$$

Other functions for Φ were tried, such as, Blackwell and Tyldesley's (1965):

$$\Phi = (1 - 10\ Ri + 30\ Ri^2) \quad . \qquad (4\text{-}8)$$

A general form for correction function has been proposed independently by Kazanski and Monin (1956), Ellison (1957), Yamamoto (1959), Panofsky (1961), and Sellers (1962). It is:

$$\Phi = (1 + b\ Ri)^{-1/4} \quad . \qquad (4\text{-}9)$$

An attempt was made to evaluate b, but it was found to vary tremendously from hour to hour so as to make an average value meaningless. Neither of the above attempts were successful in improving the Thornthwaite-Holzman estimate of E_T.

The value of the Bowen ratio was determined from:

$$E_{TB} = \frac{(Rn - S)/L}{1 + \gamma((T_1 - T_2)/e_1 - e_2))} \quad . \qquad (4\text{-}11)$$

C. RESULTS AND DISCUSSION

In Figure (4-1) hourly values of E_{TB} and E_{TH} are plotted for July and August. The scatter is clearly around the 1:1 line but the degree of scatter is considerable. This is indicated by

FIGURE 4-1 E_{TH} v E_{TB} for July & August

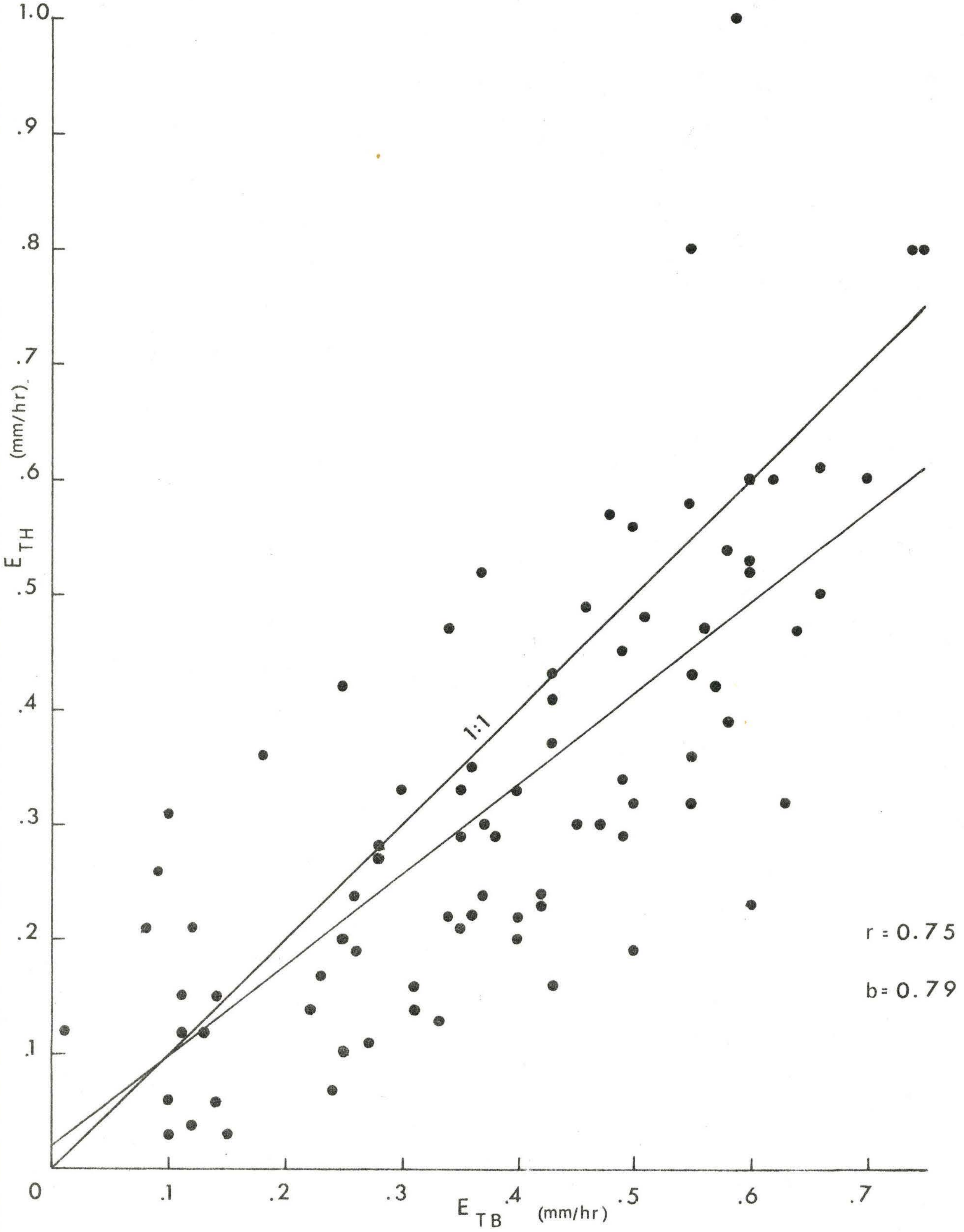

FIGURE 4-2 E_{TH} v E_{THR} for July & August

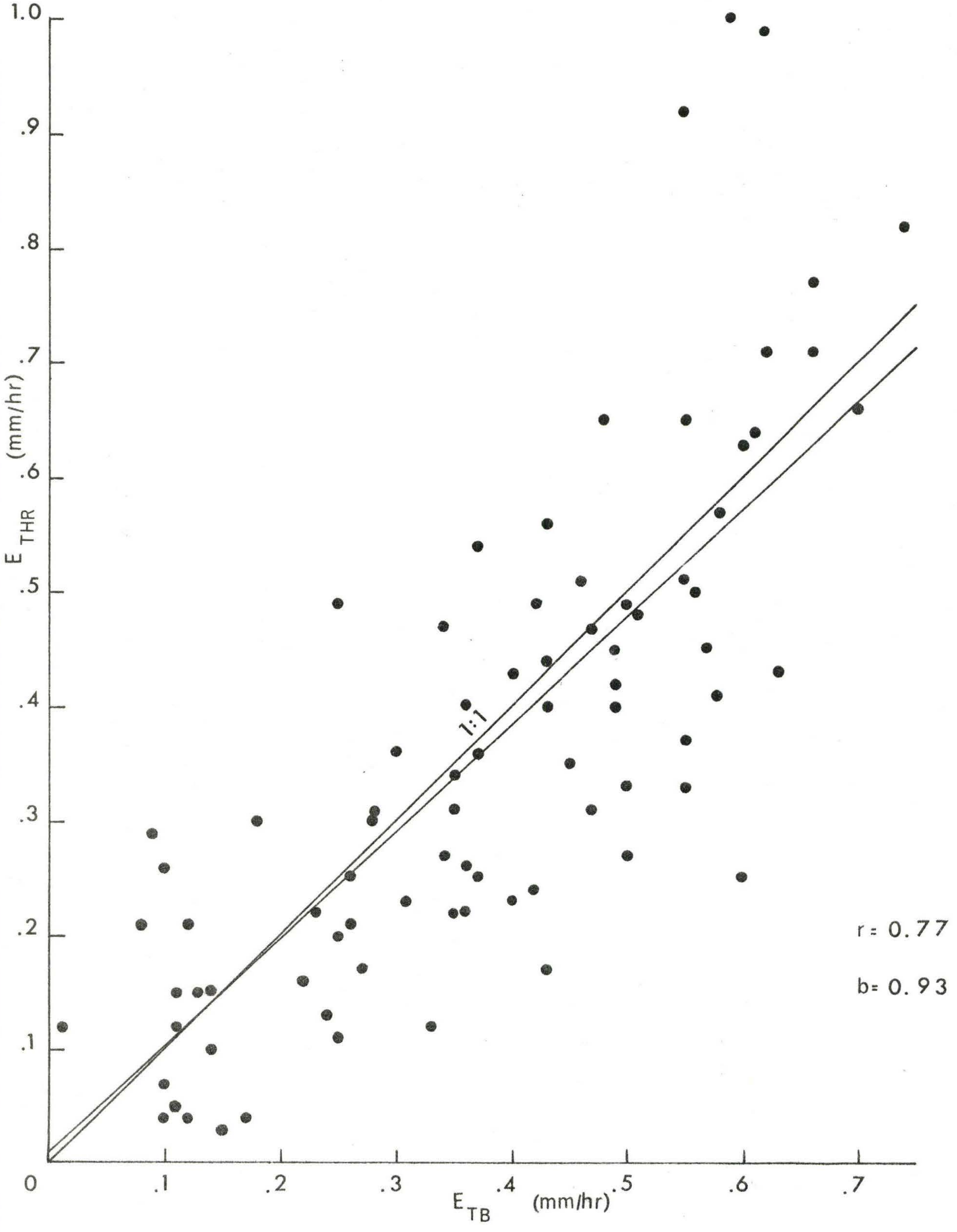

TABLE (4-2)

List of correlation coefficients and slopes of the regression line for daily plots of E_{TH} and E_{THR} against E_{TB}.

DATE	E_{TH}		E_{THR}	
	r	b	r	b
July 5	0.47	0.55	0.55	0.80
July 13	0.74	0.92	0.74	1.07
July 18	0.90	0.83	0.90	0.88
July 20	0.77	0.70	0.91	1.16
July 25	0.83	0.93	0.83	0.99
July 27	0.66	0.76	0.69	0.83
August 4	0.46	0.62	0.50	0.69
August 8	0.94	0.97	0.92	0.98
August 11	0.86	0.55	0.90	0.76

the correlation coefficient of 0.75. When the Richardson's number correction factor is applied for non-adiabatic conditions, the scatter is scarcely improved ($r = 0.77$). The main effect of applying r is to bring the slope, b, of the least squares regression line closer to the 1:1 line. The value of b is changed form 0.79 to 0.93.

When daily plots of the data were made (Figure 4-3, 4-4, 4-5) there was little improvement on the scatter of points shown in Figures (4-1) and (4-2). The correlation and slope values are given in Table (4-2). Generally r is higher and b is closer to the 1:1 line when Φ is applied. The effect of Φ is to increase the value of E_{TH} and thus raise the slope of the regression line. It must be remembered, however, that the smaller the sample size the higher r needs to be to indicate a statistically significant relationship and the less accurate is the regression line.

In order to examine the behavior of E_{TH} under changing conditions of stability, the ratio E_{TB}/E_{TH} was plotted against Ri for negative values of Ri since only 5 out of 87 hourly averages had a positive Ri. As Figure (4-6) indicated, the scatter of points is virtually random and shows no grouping around $E_{TB}/E_{TH} = 1$, even for small values of Ri ($Ri < 0.005$).* A plot of E_{TB}/E_{THR} vs. Ri (Figure 4-7) shows a slight leftward shift of the ratios and a very diffuse scatter about $E_{TB}/E_{THR} = 1$. This was to be expected since

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* The value of $Ri = 0.005$ is significant in that the work of Swinbank and Dyer (1967) did not show the relationship of K_M and K_W for $Ri < 0.005$ except to indicate that the shape functions may converge.

FIGURE 4-3 E_{TH} v E_{TB} JULY 5

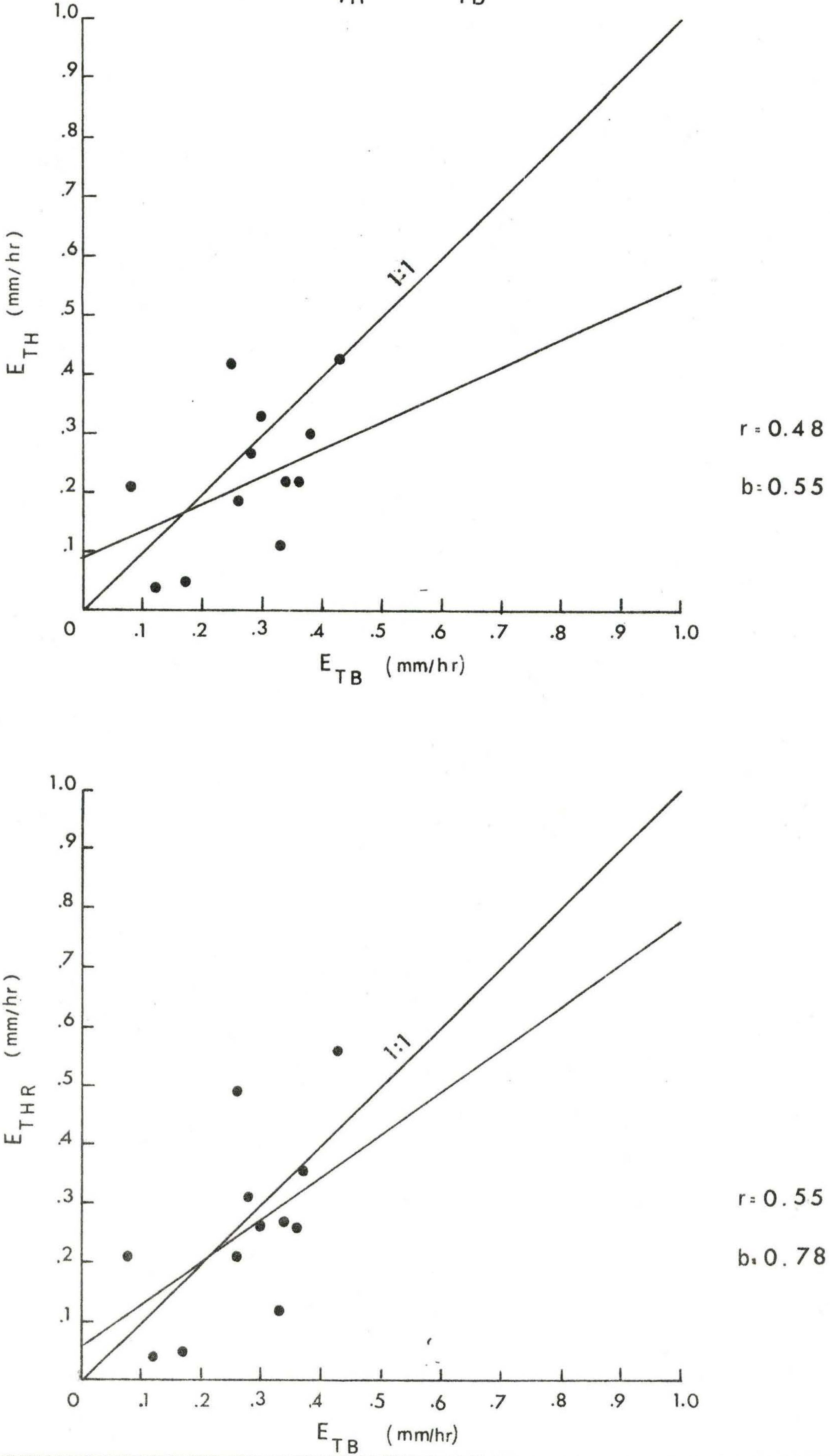


FIGURE 4-4 E_{TH} v E_{TB} JULY 25

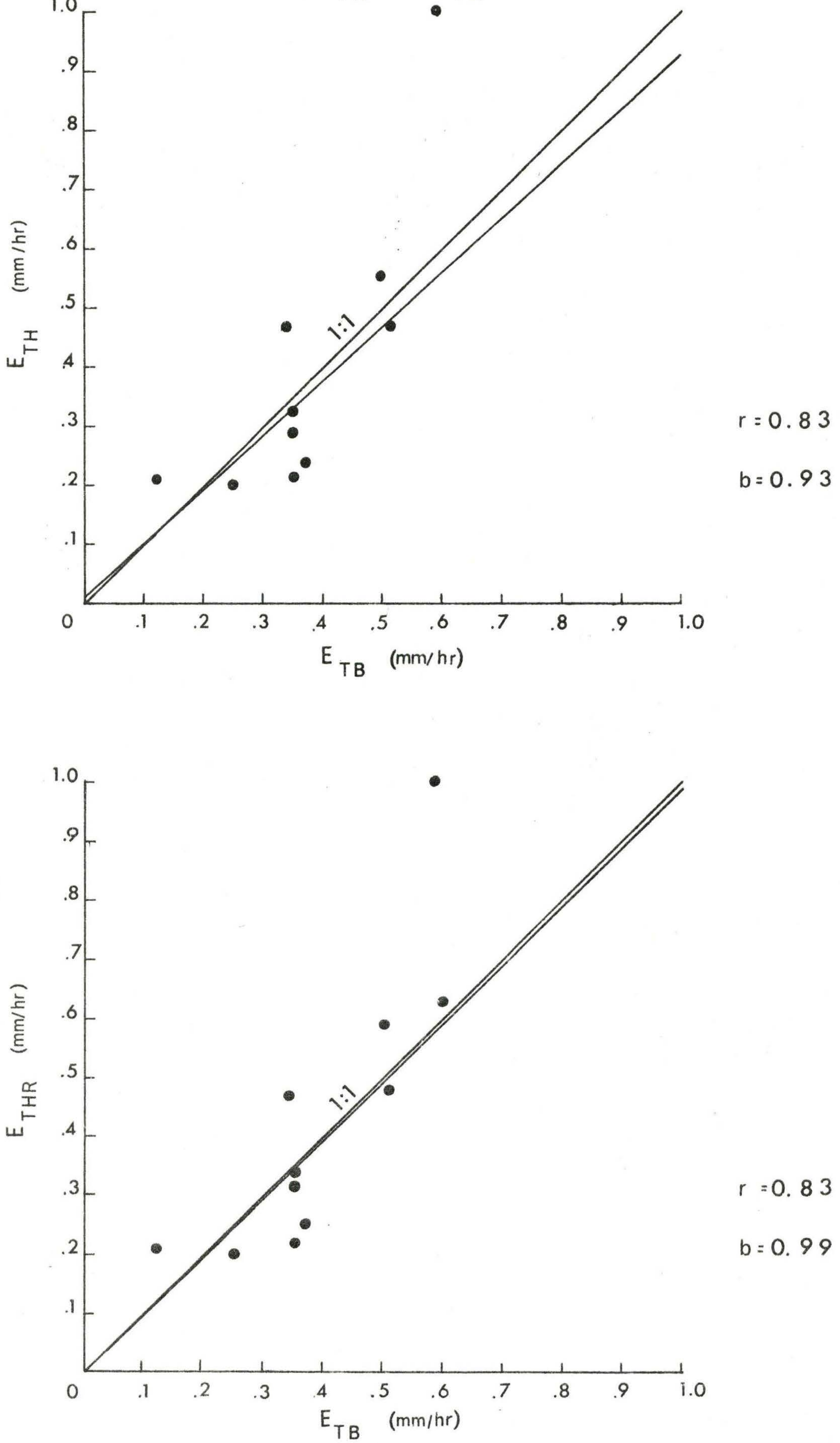
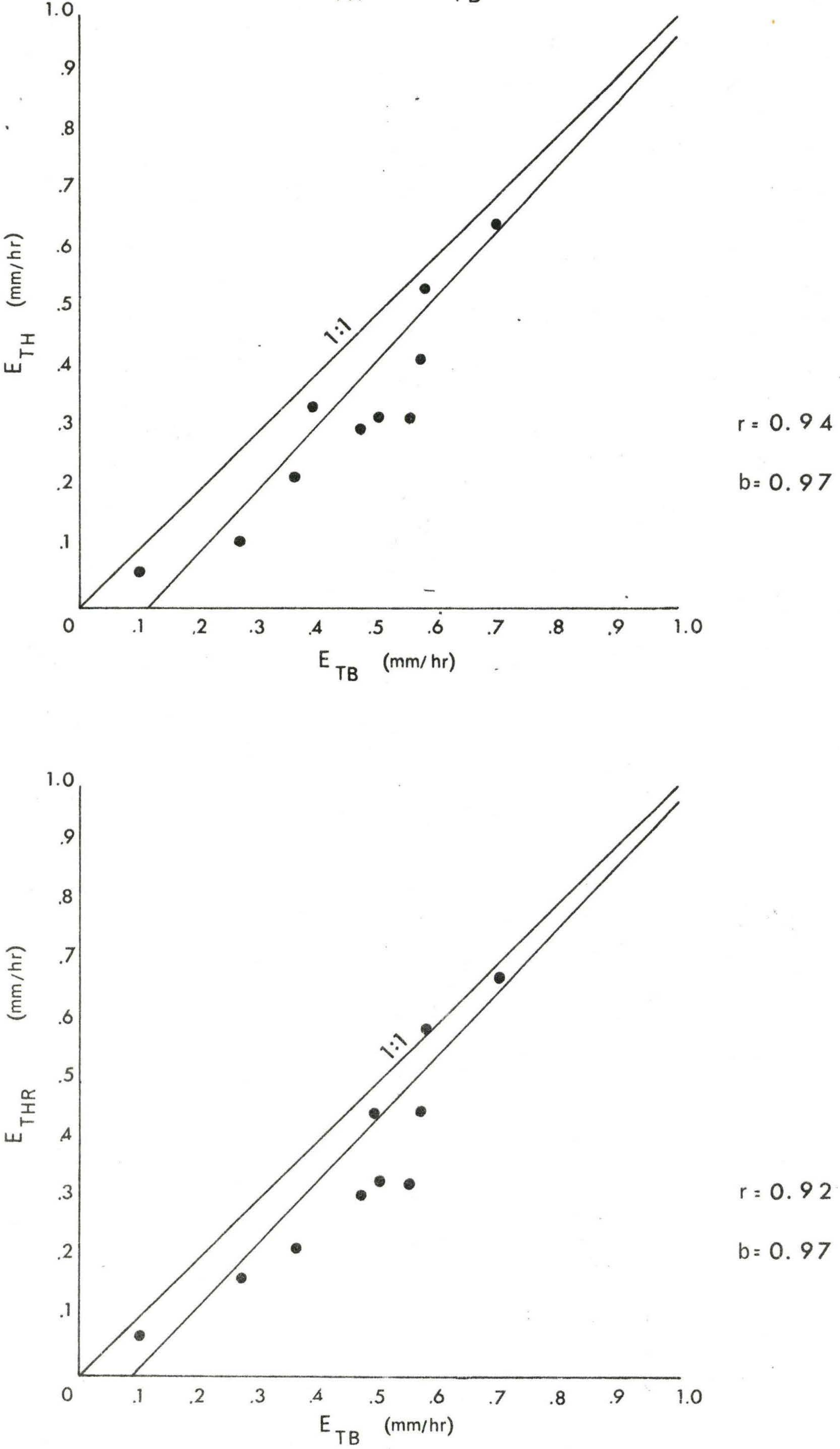


FIGURE 4-5 E_{TH} v E_{TB} AUGUST 8



the effect of Φ was to increase the value of E_{TH}. All data that had an error greater than 60% were omitted from Figure (4-6) and (4-7). As shown by these two plots the performance of the Thornthwaite-Holzman (1942) equation is poor. For example, 33% of the uncorrected estimates (E_{TH}) had an error greater than ± 60%; 58% had an error greater than ± 30%; and 72% had an error greater than ± 15%, which is recognized as the maximum error that is tolerable. When the correction function was applied, the percentage of the data beyond the 60-30-15% limits of error were 20%, 40%, and 59%. Therefore, Φ did reduce the error by some 13%, but since only 41% of the data is within ± 15%, it futher confirms that the Thornthwaite-Holzman equation is inapplicable to the computation of reasonable estimates of evapotranspiration under non-adiabatic conditions.

The Thornthwaite-Holzman equation holds only if the wind profile is logarithmic, and the transfer coefficients, K_M and K_W, are equal or nearly equal. If, as Tanner (1967) suggests, the error in assuming $K_M = K_W$ is negligible for small values of Ri ($- 0.05 < Ri < 0.05$), then one would expect to see a significant grouping about the ratio $E_{TB}/E_{TH} = 1$ for small Ri. As Figure (4-6) and (4-7) show, this is not the case even for Ri smaller than - 0.005. If the wind profile is not logarithmic, the change of wind speed with height is unknown and the quantity u_* cannot be evaluated correctly.

Time plots of the three estimates of E_T were made for

FIGURE 4-6 E_{TB}/E_{TH} v Ri JULY & AUGUST

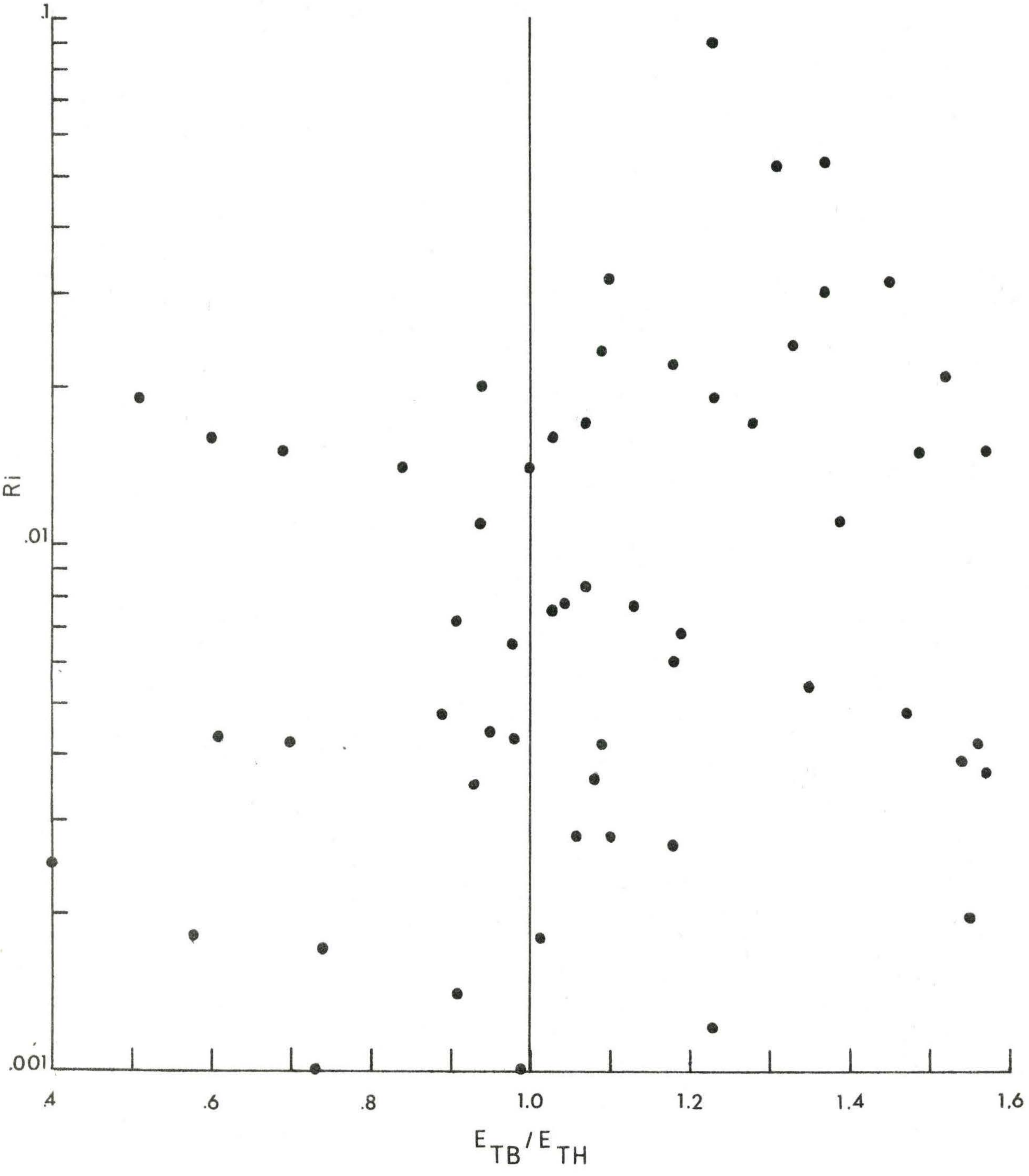
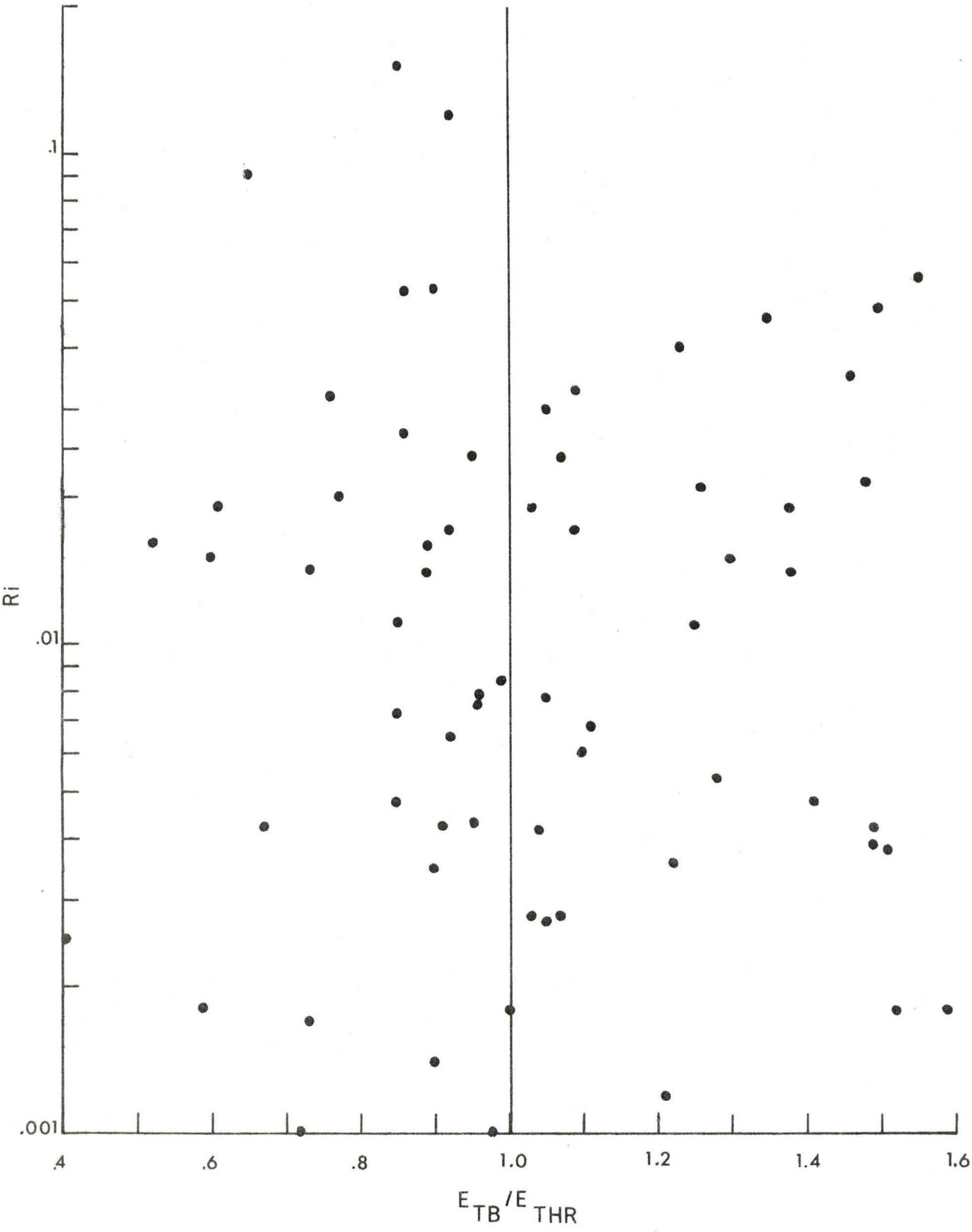


FIGURE 4-7 E_{TB}/E_{THR} v Ri JULY & AUGUST



selected days, July 5, July 25, and August 8 (see Figure 4-8, 4-9, 4-10). The curve for E_{TB} is smoother compared with those for E_{TH} and E_{THR}. An examination of changes in the wind and humidity gradients showed why this is so (see Figure 4-11, 4-12, 4-13). The uneveness in the E_{TH} and E_{THR} curves are the result of:

1) fluctuations in the humidity gradient if the wind gradient is constant

2) fluctuations in the wind gradient if the humidity gradient is constant

3) the combined effect of the humidity and wind gradients if both are fluctuating. This is inherent in the very nature of the equation which multiplies Δq by ΔU. The E_{TB} equation, on the other hand, reduces the effects of fluctuating gradients by dividing ΔT by Δq and adding this to 1 before it is divided into the available energy, Rn - S. It is suggested, therefore, that the Thornthwaite-Holzman (1942) equation under non-adiabatic condition only reflects changes in the humidity and wind gradients rather than changes in the rate of the evaporative flux since the assumption cannot be made that $K_M = K_W$.

FIGURE 4-8 E_T v TIME JULY 5

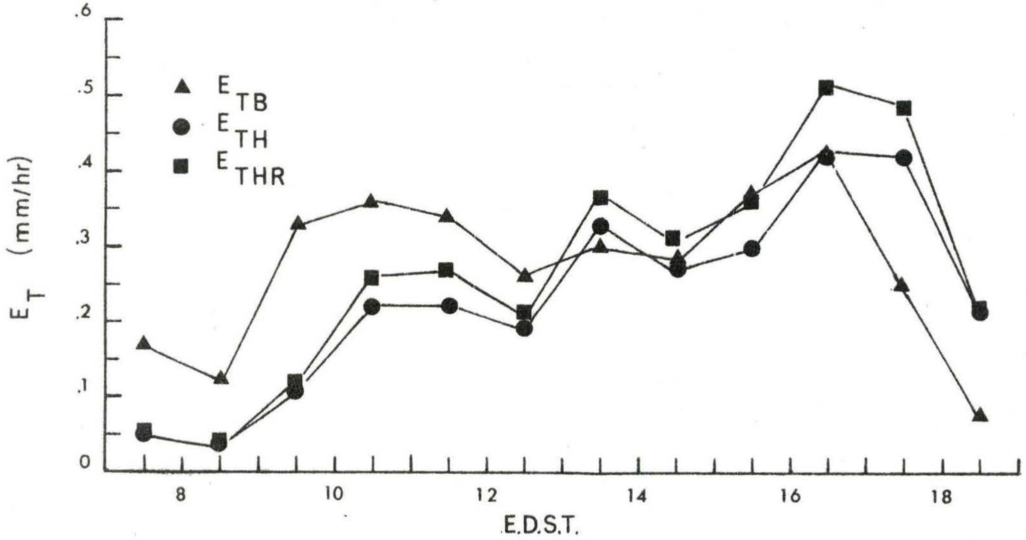


FIGURE 4-9 E_T v TIME JULY 25

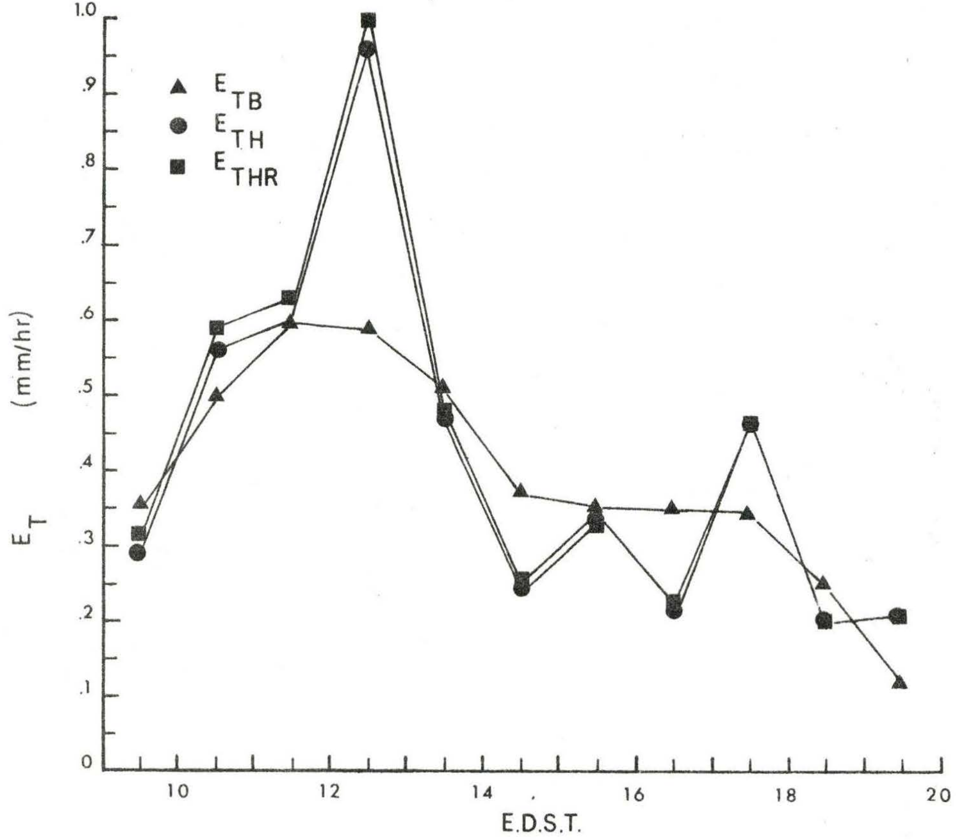


FIGURE 4-10 E_T v. TIME AUGUST 8

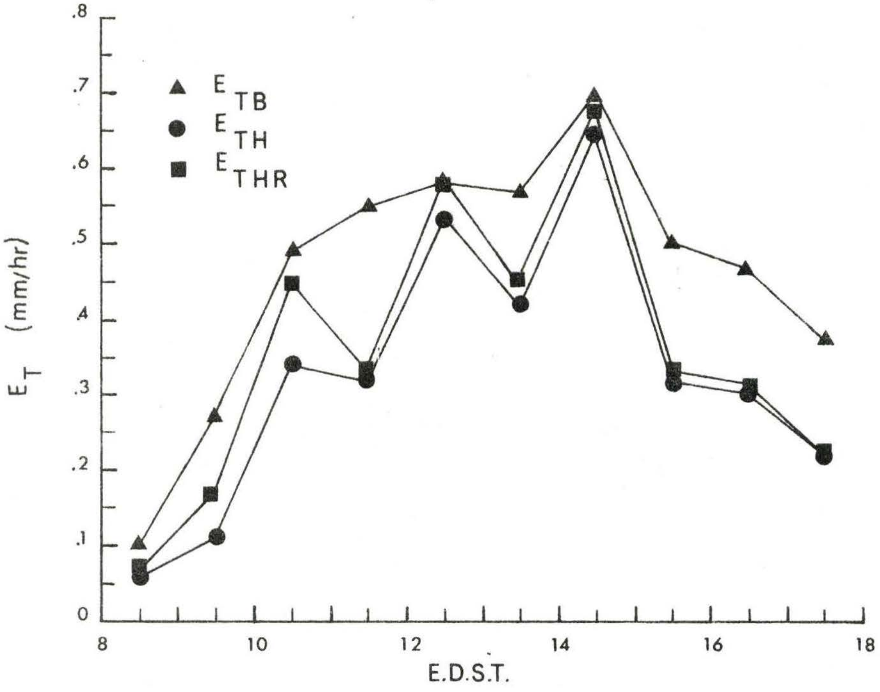


FIGURE 4-11 AERODYNAMIC & ENERGY BALANCE COMPONENTS JULY 5

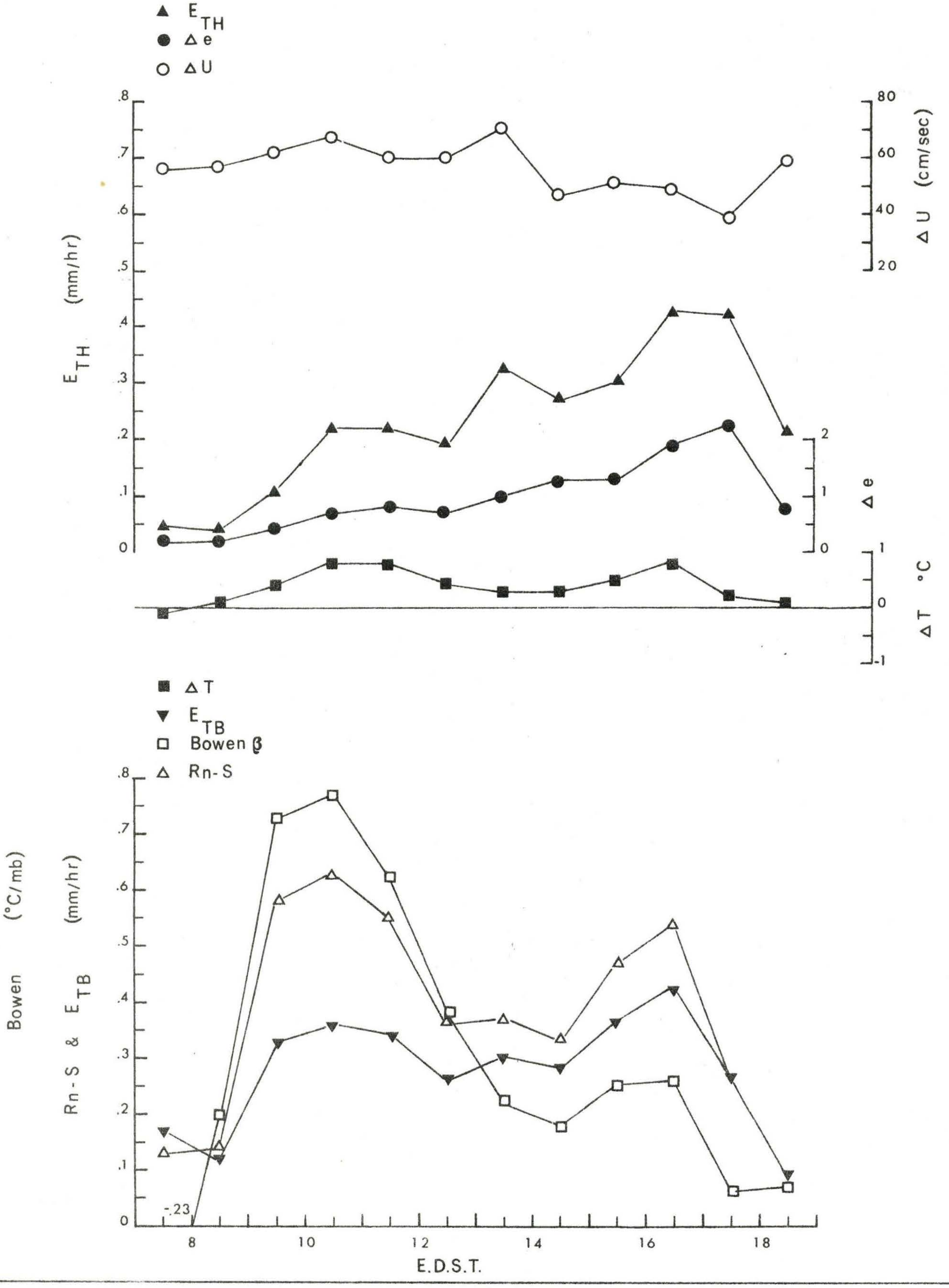


FIGURE 4-12 AERODYNAMIC & ENERGY BALANCE COMPONENTS JULY 25

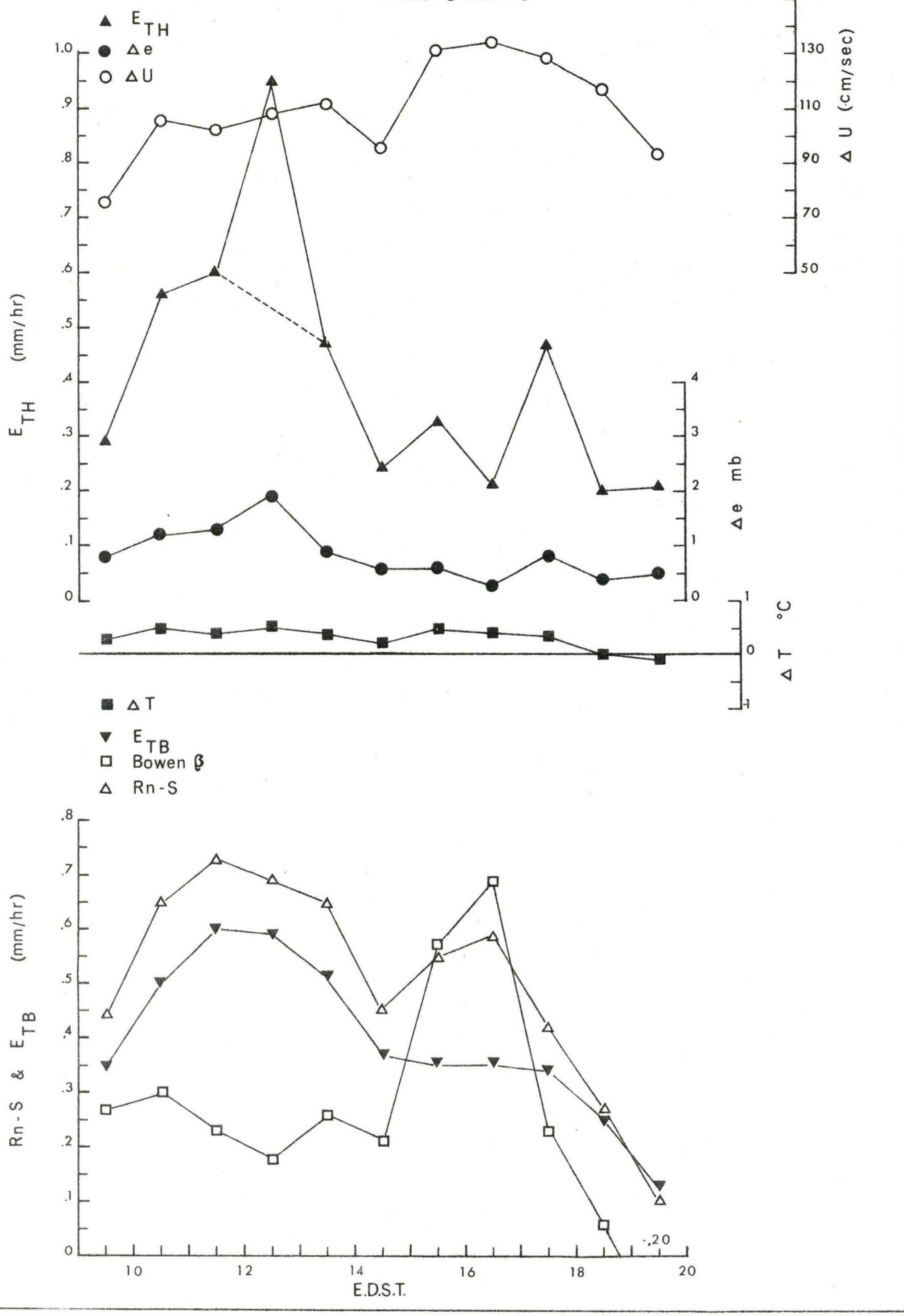
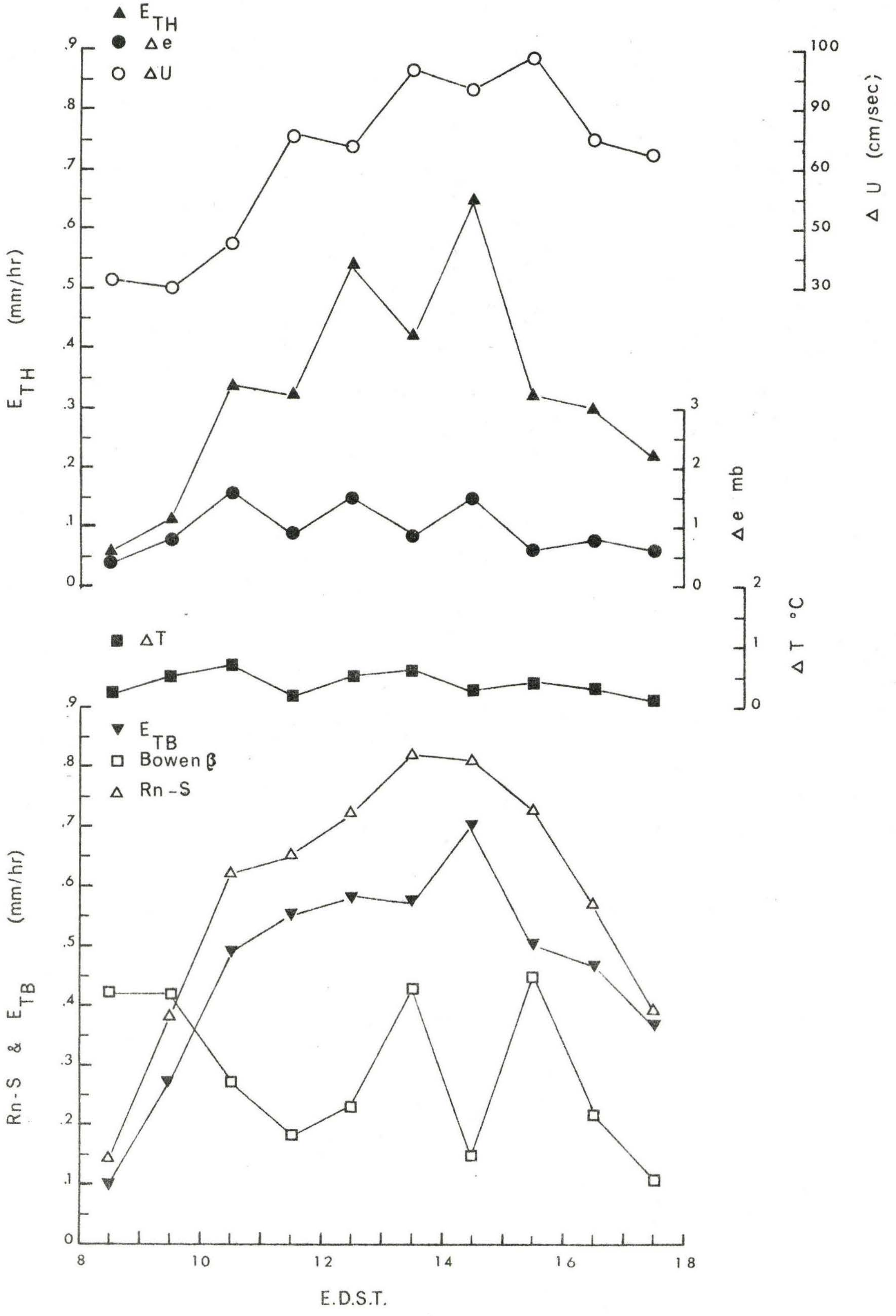


FIGURE 4 - 13 AERODYNAMIC & ENERGY BALANCE COMPONENTS AUGUST 8



CHAPTER V

CONCLUSIONS

From the evaluation of the Thornthwaite-Holzman equation for evapotranspiration using microclimatological measurements made over irrigated ryegrass at Simcoe, the following conclusions were reached:

1) E_{TH} was extremely variable under all conditions of stability. This is contrary to the findings of Blackwell and Tyldesley (1965); E_{TH} showed no tendency to under estimate E_T in lapse conditions or to over estimate during inversions.

2) No relationship was found between Ri and E_{TB}/E_{TH} which indicates that its use in a correction function is of doubtful value.

3) Even under conditions of neutral or near-neutral stability the assumption cannot be made that $K_M = K_W$ since the accuracy of E_{TH} did not improve under these conditions.

4) The fluctuation in E_{TH} and E_{THR} are due to the combined effects of fluctuations in the wind and humidity gradients, and, therefore, they are not indicative of changes in the rate of the evaporative flux. This is attributed to the inequality of K_M and K_W.

5) Further work is needed to examine the shape

functions of Swinbank and Dyer (1967) over a wider range of stability to determine more precisely the relationship between K_M and K_W.

6) The logarithmic aerodynamic equation, dependent upon a pre-determined form of the wind profile, is of limited value in estimating E_T.

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APPENDIX A

COMPUTER PROGRAMS

The first two programs were used to convert the raw data collected from the temperature and wind systems into a temperatures and wind speeds. The computer then punched these onto cards which, along with another card containing the net radiation, soil heat flux, wind run, and the barometric pressure, served as input data for the third program. This program calculated the evapotranspiration using the Bowen ratio method and the Thornthwaite-Holzman method.

Program 1 - Wind Profile.

Program 2 - Temperature Conversion.

Program 3 - Evapotranspiration.

PROGRAM 1 - WIND PROFILE

(for the calculation of wind speeds, u_* and Z_0 using 3 levels)

```
      DIMENSIØN ID(3)
      DIMENSIØN T(151), C(151,6), TM(151), CNTS(151,6), WS(151,6)
C     VERY FIRST CARD CØNTRØLS THE NØ. ØF TIMES WHØLE PRØGRAMS ARE TØ BE RUN/I3
C     EACH SET ØF DATA MUST CØNTAIN THE FØLLØWING
C     FIRST CARD ØF DATA MUST CØNTAIN THE FØLLØWING,
C     ID(1 TØ 3) NH, MA, JA/ 212,I4,312/
C     IF FØRGØT TØ TURN METER ØN , THEN C(1 TØ 5)=0.0
C     IF SKIPT READING , THEN T, C(1 TØ 5) =0.0
C     T=TIME ØF READING,   C=DIAL READING,  TM= 1/2 WAY TIME,
C     CNTS=NØ ØF METER CØUNTS PER MINUTE,  WS=WIND SPEED PER MINUTE
      READ(5,132) LJ
  132 FØRMAT(I3)
      DØ 777 JL=1,LJ
      READ(5,10)(ID(K),K=1,3), NH,MA,JA
   10 FØRMAT(2A2,A4,3I2)
      NA=NH*MA
      A=11.53841925
      B=2.54943612
      NS=NA+1
      DØ 50 J=1,NS
      READ(5,1) T(J), C(J,3), C(J,2), C(J,1), C(J,4), C(J,5) ,C(J,6)
    1 FØRMAT(F4.0,1X,6F5.0)
   50 CØNTINUE
      DØ 90 J=1,NA
      K=J+1
      IF (T(J).EQ.0.0) GØ TØ 65
      IF(T(K).EQ.0.0) GØ TØ 69
      DELTAT=(T(K)-T(J))
      TM(J)=(T(K)+T(J))/2.0
      IF(DELTAT.LT.41.0) GØ TØ 77
      TMM=((T(K)/100.0)-1.0)*100.0+60.0
      DELTAT=(TMM-T(J  ))
      TM(J)=(TMM+T(J  ))/2.0
   77 IF(C(K,1) . EQ. 0.0) GØ TØ 60
      IF(C(J,1).EQ.0.0) GØ TØ 61
      DØ 51 JK=1,JA
      IF(C(K,JK).LT.C(J,JK).AND.C(K,JK).NE.0.0) GØ TØ 56
      CNTS(J,JK)=(C(K,JK)-C(J,JK))/DELTAT
      GØ TØ 51
   56 CNTS(J,JK)=((100000.0-C(J,JK))+C(K,JK))/DELTAT
   51 CØNTINUE
      GØ TØ 62
   69 TM(J) = 0.0
   60 DØ 52 JK=1,JA
      WS(J,JK)=0.0
   52 CNTS(J,JK)=0.0
      GØ TØ 90
   61 DØ 53 JK=1,JA
```

```
      WRITE(6,15)
   15 FØRMAT(1H0,5X,4HTIME,16X,2HU*,19X,2HZ0,8X,11HPRØFILE NØ.)
      DØ 25 N=1,NH
      NT=0
      ZMM=0.0
      UMM=0.0
      DØ 24 M=1,MA
      ZS=0.0
      US=0.0
      LW=LW+1
      DØ 30 JK=1,JA
   30 U(JK)=WS(LW,JK)
      IF(U(1).NE.0.0) GØ TØ 31
      UM=0.0
      ZM=0.0
      GØ TØ 32
   31 JC=JA-1
      DØ 22 J=1,JC
      JB=J+1
      DØ 23 K=JB,JA
      USTAR=VK*(U(J) /ALØG(Z(K)/Z(J)))
      ZNØT =EXP((U(K)*ALØG(Z(J))-U(J)*ALØG(Z(K)))/(U(K)-U(J)))
      ZS=ZS+ZNØT
      US=US+USTAR
   23 CØNTINUE
   22 CØNTINUE
      ZM=ZS/FLØAT(JA*(JA-1)/2)
      UM=US/FLØAT(JA*(JA-1)/2)
   32 WRITE(6,19) T(LW), UM,ZM,M
   19 FØRMAT(1H ,F10.0,5X,2(F16.8,5X),I4)
      NT=NT+1
      IF(UM.EQ.0.0) NT=NT-1
      ZMM=ZMM+ZM
      UMM=UMM+UM
   24 CØNTINUE
      TN=NT
      UMU=UMM/TN
      ZMZ=ZMM/TN
      WRITE(6,13) UMU,ZMZ,N
   13 FØRMAT(1H0,10HMEAN U* = , F16.8,5X,10HMEAN Z0 = ,F16.8,8X,6HHØUR
     1,I2)
      WRITE(6,16)
   16 FØRMAT(1H0,   )
   25 CØNTINUE
      RETURN
      END
```

```
      JJ=J-1
      IF(C(K,JK).LT.C(JJ,JK).AND.C(K,JK).NE.0.0) GØ TØ 80
      CNTS(J,JK)=(C(K,JK)-C(JJ,JK))/DELTAT
      GØ TØ 53
   80 CNTS(J,JK)=((100000.0-C(JJ,JK))+C(K,JK))/DELTAT
   53 CØNTINUE
      GØ TØ 62
   65 JJ=J-1
      DELTAT=(T(K)-T(JJ))
      TM(J)=(T(K)+T(JJ))/2.0
      IF(DELTAT.LT.41.0) GØ TØ 78
      TMM=((T(K)/100.0)-1.0)*100.0+60.0
      DELTAT=(TMM-T(JJ))
      TM(J)=(TMM+T(JJ))/2.0
   78 DØ 57 JK=1,JA
      IF(C(K,JK).LT.C(JJ,JK).AND.C(K,JK).NE.0.0) GØ TØ 59
      CNTS(J,JK)=(C(K,JK)-C(JJ,JK))/DELTAT
      GØ TØ 57
   59 CNTS(J,JK)=(100000.0-C(JJ,JK))+C(K,JK)
   57 CØNTINUE
   62 DØ 54 JK=1,JA
   54 WS(J,JK)=A+B*CNTS(J,JK)
   90 CØNTINUE
      DØ 100 J=1,NA
      WRITE(7,15) T(J),TM(J),WS(J,1),WS(J,2),WS(J,3),WS(J,4),
     1 T(J),TM(J),WS(J,5), CNTS(J,6)
   15 FØRMAT(2F8.0,4F12.5/2F8.0 ,2F12.5)
  100 CØNTINUE
      CALL ZNAUT(NH,MA,JA,WS,TM,ID,T)
  777 CØNTINUE
      STØP
      END
      SUBRØUTINE ZNAUT(NH,MA,JA,WS,TM,ID,T)
      NA=MA*NH
      DIMENSIØN U(6), Z(3), ID(3), WS(150,6), TM(150), T(150)
C     PRØGRAMME FØR CØMPUTING WIND PRØFILE PARAMETERS U* AND Z0
C     JA=NØ ØF READINGS IN A PRØFILE VK=VØN KARMANNS CØNSTANT
C     MA=NØ ØF PRØFILES U=WIND SPEED Z=HEIGHT ØF MEASUREMENT
C     MA=NØ ØF READINGS IN ØNE HØUR
C     NH=NØ ØF HØURS ØF DATA
      JA=3
      VK=0.41
      LW=0
      Z(1)=21.0
      Z(2)=51.0
      Z(3)=101.0
      WRITE(6,11)(ID(J),J=1,3)
   11 FØRMAT(1H0,32HCALCULATIØN ØF Z0 AT SIMCØE ØN  ,A2,1H/,A2,1H/,A4)
```

PROGRAM 2 - TEMPERATURE CONVERSION

(for conversion of EMF readings into temperature in degrees celcius)

```
C     CØNVERSIØN ØF BØWEN RATIØ DATA TØ TEMPERATURE
C     CØNTRØL CARD NØ. 1 - NP/I3 = NØ. ØF TIMES PRØGRAM TØ BE RUN
C     CØNTRØL CARD NØ. 2 - JA, NH, CD, CW/4I2
C     JA=NØ. ØF READINGS /HØUR
C     NH=NØ. ØF HØURS
C     CD CØNTRØLS CALIBRATIØN USED FØR DRY BULBS ( 1-8)
C     CW CØNTRØLS CALIBRATIØN USED FØR WET BULBS ( 1-8)
C     FIRST SET ØF DATA CØNTAINS TIME, DT, WT/A4,6X,2F10.5
C     SECØND SET ØF DATA CØNTAINS TIME, CØMPD, DT1, DT2, CØMPW, WT1, WT2, RD, RW
C     UNDER A4,1X,2(F4.0,1X,F2.2,1X,F2.2,1X),2F6.0
      DIMENSIØN ID(3),DT(25),WT(25),STD(25),STW(25)
      READ(5,60) NP
   60 FØRMAT(I3)
      DØ 909 LL=1,NP
      READ(5,10)(ID(J),J=1,3), JA, NH, LCD, LWD
   10 FØRMAT(2A2,A4,4I2)
      WRITE(6,11)(ID(J),J=1,3), JA, NH, LCD, LWD
   11 FØRMAT(1H0,40HSIMCØE BØWEN RATIØ TEMPERATURE DATA FØR ,A2,1H/,A2,
     1 1H/,A4,10X,7HCØNTRØL,2X,5HJA = ,I3,2X,5HNH = ,I3,5X,5HCW = ,I3,
     2 5X,5HCD = ,I3//)
      WRITE(6,12)
   12 FØRMAT(1H ,2X,4HTIME,6X,2HD1,18X,2HD2,18X,2HW1,18X,2HW2//)
      NS=NH+1
      DØ 50 JK=1,NS
      READ(5,30) STD(JK),STW(JK)
   30 FØRMAT(10X,2F10.5)
      STD(JK)=(STD(JK)-32.0)*(5.0/9.0)
      STW(JK)=(STW(JK)-32.0)*(5.0/9.0)
   50 CØNTINUE
      DØ 100 J=1,NH
      K=J+1
      DT(J)=(STD(K)+STD(J))/2.0
      WT(J)=(STW(K)+STW(J))/2.0
  100 CØNTINUE
      A592N=47.95737219
      B592N=-26.14185381
      A311AN=43.27915478
      B311AN=-25.70059681
      A385N=44.38041878
      B385N=-25.93146586
      A311BN=45.21845484
      B311BN=-25.86927176
      A311BØ=44.72193241
      B311BØ=-25.16400242
      A311AØ=43.61952114
      B311AØ=-25.22807503
      A385Ø=44.87165833
      B385Ø=-25.71308541
```

```
      A592O=45.570768253
      B592O=-25.84042835
      GO TO (101,102,103,104,105,106,107,108), LCD
  101 BD=B311AO
      AD=A311AO
      GO TO 150
  102 BD=B311BO
      AD=A311BO
      GO TO 150
  103 BD=B385O
      AD=A385O
      GO TO 150
  104 BD=B592O
      AD=A592O
      GO TO 150
  105 BD=B311AN
      AD=A311AN
      GO TO 150
  106 BD=B311BN
      AD=A311BN
      GO TO 150
  107 BD=B385N
      AD=A385N
      GO TO 150
  108 BD=B592N
      AD=A592N
  150 GO TO (201,202,203,204,205,206,207,208), LWD
  201 BW=B311AO
      AW=A311AO
      GO TO 160
  202 BW=B311BO
      AW=A311BO
      GO TO 160
  203 BW=B385O
      AW=A385O
      GO TO 160
  204 BW=B592O
      AW=A592O
      GO TO 160
  205 BW=B311AN
      AW=A311AN
      GO TO 160
  206 BW=B311BN
      AW=A311BN
      GO TO 160
  207 BW=B385N
      AW=A385N
      GO TO 160
```

```
208 BW=B592N
    AW=A592N
    GØ TØ 160
160 DØ 99 M=1,NH
    AJ=JA
    SD1=0.0
    SD2=0.0
    SW1=0.0
    SW2=0.0
    DØ 90 N=1,JA
    READ(5,13) T, CØMPD, DT1, DT2, CØMPW, WT1 ,WT2, RD,RW
 13 FØRMAT(A4,1X,2(F4.0,1X,F2.2,1X,F2.2,1X),2F6.0)
    D1=((CØMPD-DT1*RD)/1000.0)*BD+AD
    D2=((CØMPD-DT2*RD)/1000.0)*BD+AD
    W1=((CØMPW-WT1*RW)/1000.0)*BW+AW
    W2=((CØMPW-WT2*RW)/1000.0)*BW+AW
    SD1=SD1+D1
    SD2=SD2+D2
    SW1=SW1+W1
    SW2=SW2+W2
    IF (DT1.NE.0.0) GØ TØ 20
    AJ=AJ-1.0
 20 WRITE(6,14) T, D1, D2, W1, W2
 14 FØRMAT(1H ,2X,A4,2X,4(F10.5,10X))
 90 CØNTINUE
    D1M=SD1/AJ
    D2M=SD2/AJ
    W1M=SW1/AJ
    W2M=SW2/AJ
    WRITE(6,15)
 15 FØRMAT(1H0,  )
    WRITE(6,16) D1M,D2M,W1M,W2M,M
 16 FØRMAT(1H0, 11HMEAN DT1 = ,F10.5,5X,11HMEAN DT2 = ,F10.5,5X,
   1 11HMEAN WT1 = ,F10.5,5X,11HMEAN WT2 = ,F10.5,10X,9HHØUR NØ. ,I3)
    WRITE(6,18) DT(M),WT(M)
 18 FØRMAT(1H0,20HMEAN SCREEN READINGS,10X,9HDRY BULB ,F10.5,10X,
   1 9HWET BULB ,F10.5)
    WRITE(6,15)
    WRITE(7,17) M, D1M, D2M, W1M, W2M , DT(M), WT(M)
 17 FØRMAT(I3,2X,6F10.5)
 99 CØNTINUE
    WRITE(6,25)
 25 FØRMAT(1H1,  )
909 CØNTINUE
    STØP
    END
```

PROGRAM 3 - EVAPOTRANSPIRATION

(for calculation of E_T using the Bowen ratio method, and the Thornthwaite-Holzman aerodynamic method)

```
C  PRØGRAM FØR THE CALCULATIØN ØF EVAPØTRANSPIRATIØN BY THE BØWEN
C  RATIØ METHØD AND BY THØRNTHWAITE-HØLZMAN AERØDYNAMIC METHØD
C
C  FIRST CØNTRØL CARD-ND=NØ ØF DAYS ØF DATA/I2/
C  SECØND CØNTRØL CARD-NH=NØ ØF HRS IN DAY, ZNØT=ZO FØR THIS DAY/I2,
C  F16.8/
C  EACH HØUR ØF DATA CØNSISTS ØF 3 CARDS
C  CARD 1 - DAY,MØNTH,TIME,RN1,RN2,RN3,G,U,BP/2A2,1X,A4,1X,6F10.5/
C  CARD 2 =
C  CARD 2 - DT1,DT2,WT1,WT2,DT,WT,/5X,6F10.5/
C  CARD 3 - U2,U1/18X,2(F10.5,2X)/
C  RN = NET RADIATIØN IN GM-CAL
C  G = SØIL HEAT FLUX UN GM-CAL
C  U = WIND RUN IN MI/DAY
C  BP = PRESSURE IN MB
C  TEMPERATURES IN DEGREES CELSIUS
C  U2,U1 IN CM/SEC
C
C  THIS PRØGRAM ALSØ  CALCULATES ET USING PENMANS METHØD WITH HIS ØWN
C  WIND FUNCTIØN AND A MØDIFICATIØN BY BUSINGER
C
      DIMENSIØN ID(3),IDD(24),ET1(24),ET11(24),ET2(24),ET22(24),ET3(24),
     1 ET33(24),BØWEN(24) , WATER(24)
      DIMENSIØN BLA(132)
      DATA AST/1H*/
      AKARMA=0.41
      Z=170.0
      Z1=21.0
      Z2=51.0
      Z3=15.0
      Z4=45.0
      DZ=Z2-Z1
      DLZ=ALØG(Z2/Z1)*ALØG(Z4/Z3)
      GAMMA=0.659
      READ(5,40) ND
   40 FØRMAT(I2)
      DØ 208 KA=1,130
  208 BLA(KA)=AST
      DØ 999 K=1,ND
      READ(5,30) NH, ZNØT
   30 FØRMAT(I2,F16.8)
      DØ 99 J=1,NH
      READ(5,101) (ID(L),L=1,3), RN1, RN2, RN3, G, U, BP
  101 FØRMAT(2A2,1X,A4,1X,6F10.5)
      READ(5,102) DT1, DT2, WT1, WT2, DT, WT
  102 FØRMAT(5X,6F10.5)
      READ(5,103) U1, U2
  103 FØRMAT(18X,2(F10.5,2X))
```

```
      IF(J.NE.1) GØ TØ 4
      WRITE(6,207)
      WRITE(6,207)
      WRITE(6,205) K
  205 FØRMAT(1H ,56X,5HTABLE,I3)
      WRITE(6,206) (BLA(JP),JP=1,8)
  206 FØRMAT(1H ,56X,8A1//)
      WRITE(6,12) ID(1), ID(2)
   12 FØRMAT(1H ,27X, 34HETB AND ETH  DATA FRØM SIMCØE FØR ,A2,
     1 12H DAY ØF THE ,A2, 14H MØNTH ØF 1967//)
      WRITE(6,209) Z1,Z2,Z3,Z4, DZ,DLZ
  209 FØRMAT(1H0,10X,5HZ1 = ,F8.2,5X,5HZ2 = ,F8.2,5X,5HZ3 = ,F8.2,5X,
     1 5HZ4 = F8.2,5X,5HDZ = ,F8.2,5X/1H ,10X,22HLN(Z2/Z1)*LN(Z4/Z3) = ,
     2 F12.5)
      WRITE(6,202)
  202 FØRMAT(1H0,14X, 4HTIME,6X,2HT1,6X,2HT2,5X,4HDIFT,5X,2HE1,6X,2HE2,
     15X,4HDIFE,5X,2HU2,6X,2HU1,5X,4HDIFU,5X,2HAT)
      WRITE(6,207)
  207 FØRMAT(1H0,   )
    4 T=WT
      SVP    = 6.10797 + T * 0.443496 + T **2 * 0.0142871 + T ** 3 * 0.26
     1674 * 10.0 ** (-3) + T**4*0.306961*10.0**(-5)  +T**5*0.178935*10.0
     2  **(-7)
      T=WT1
      SVP1   = 6.10797 + T * 0.443496 + T **2 * 0.0142871 + T ** 3 * 0.26
     1674 * 10.0 ** (-3) + T**4*0.306961*10.0**(-5)  +T**5*0.178935*10.0
     2  **(-7)
      T=WT2
      SVP2   = 6.10797 + T * 0.443496 + T **2 * 0.0142871 + T ** 3 * 0.26
     1674 * 10.0 ** (-3) + T**4*0.306961*10.0**(-5)  +T**5*0.178935*10.0
     2  **(-7)
      VP    =SVP    -(0.00079*(1.0+0.00115*WT     ))*BP*(DT    -WT    )
      VP1=SVP1-(0.00066*(1.0+0.00115*WT1))*BP*(DT1-WT1)
      VP2=SVP2-(0.00066*(1.0+0.00115*WT2))*BP*(DT2-WT2)
      DIFT=DT1-DT2
       DIFVP=VP1-VP2
      T=DT
      SLØPE =0.443496+2.0*0.0142871*T+(3.0*0.26674*10.0**(-3))*T**2
     1+(4.0*0.306961*10.0**(-5))*T**3+(5.0*0.178935*10.0**(-7))*T**4
      BØWEN(J)=(DIFT/DIFVP)*GAMMA
      W1=0.35*(1.0+U/100.0)*(SVP-VP)
            W2=1.2*U*(((1.0/AKARMA)*(ALØG((Z+ZNØT)/ZNØT)))**(-2))*(SVP-VP
     1)
C     VALUES FØR LATENT HEAT ØF VAPØURIZATIØN
      IF(DT.LE.5.0)    VAPLH=59.73
      IF(DT.GT. 5.0.AND.DT.LE.10.0)  VAPLH=59.45
      IF(DT.GT.10.0.AND.DT.LE.15.0)  VAPLH=59.17
      IF(DT.GT.15.0.AND.DT.LE.20.0)  VAPLH=58.89
```

```
      IF(DT.GT.20.0.AND.DT.LE.25.0)  VAPLH=58.60
      IF(DT.GT.25.0.AND.DT.LE.30.0)  VAPLH=58.32
      IF(DT.GT.30.0.AND.DT.LE.35.0)  VAPLH=58.04
      IF(DT.GT.35.0.AND.DT.LE.40.0)  VAPLH=57.76
      IF(DT.GT.40.0.AND.DT.LE.45.0)  VAPLH=57.47
      IF (DT.GT.45.0) VAPLH=100.0
      IDD(J)=ID(3)
      ET1(J)     =((RN1      -G)/VAPLH)/(1.0+BØWEN(J))
      ET2(J)     =((SLØPE/GAMMA)*((RN1      -G)/VAPLH)+W1)/((SLØPE/
     1 GAMMA)+1.0)
      ET3(J)     =((SLØPE/GAMMA)*((RN1      -G)/VAPLH)+W2)/((SLØPE/
     1 GAMMA)+1.0)
      G = 0.05 * RN1
      ET11(J)    =((RN1      -G)/VAPLH)/(1.0+BØWEN(J))
      ET22(J)    =((SLØPE/GAMMA)*((RN1      -G)/VAPLH)+W1)/((SLØPE/
     1 GAMMA)+1.0)
      ET33(J)    =((SLØPE/GAMMA)*((RN1      -G)/VAPLH)+W2)/((SLØPE/
     1 GAMMA)+1.0)
      WATER(J)=(RN1-G)/VAPLH
      DIMENSIØN RI(24), EPISI(24), ETTH(24) ,ETTHR(24)
      AT1=DT1+273.16
      AT2=DT2+273.16
      AT=(AT1+AT2)/2.0
      RI(J)=(29430.0*(DT2-DT1))/(AT*((U2-U1)**2))
      EPISI(J)=(((SLØPE/GAMMA)*((RN1-G)/VAPLH)+W2)/ET11(J))-(SLØPE/GAMMA
     1 )
      ETTH(J)=0.00569*DIFVP*(U2-U1)
      IF(RI(J).LT.0.0) GØ TØ 60
      IF(RI(J).GT.0.0) GØ TØ 61
      IF(RI(J).EQ.0.0) GØ TØ 62
   60 RC=(1.0-10.0*RI(J))
      ETTHR(J)=ETTH(J)*RC
      GØ TØ 63
   61 RC=(1.0+10.0*RI(J))
      ETTHR(J)=ETTH(J)/RC
      GØ TØ 63
   62 ETTHR(J)=ETTH(J)
   63 DU=U2-U1
      WRITE(6,200) ID(3),DT1,DT2,DIFT,VP1,VP2,DIFVP,U2,U1,DU,AT
  200 FØRMAT(1H ,14X,A4,2X,10F8.3)
   99 CØNTINUE
   70 FØRMAT(1H1,   )
      WRITE(6,207)
      WRITE(6,203)
  203 FØRMAT(1H ,10X,4HTIME,10X,3HETB,12X,3HETH,12X,2HRI,13X,4HETHR,10X,
     1 5HBØWEN,11X,4HRN-G)
      DØ 100 J=1,NH
      WRITE(6,201 ) IDD(J),ET11(J),ETTH(J),RI(J),ETTHR(J),BØWEN(J),
```

```
   U WATER(J)
201 FØRMAT(1H0,10X,A4,6X,6(F10.5,5X,))
100 CØNTINUE
    WRITE(6,70)
999 CØNTINUE
    STØP
    END
```

APPENDIX B

DATA

The following symbols are used:

Z1, Z2 = height at which humidity and temperature were measured (cm)

Z3, Z4 = height at which the wind was recorded

DZ = Z2 - Z1 or Z4 - Z3

T1, T2 = mean hourly temperature at levels 1 and 2 (deg. C.)

DIFT = temperature gradient (T1 - T2)

E1, E2 = mean hourly humidity at levels 1 and 2 (mb.)

DIFE = humidity gradient (E1 - E2)

U1, U2 = wind at levels 1 and 2 (cm/sec.)

DIFU = wind gradient (U2 - U1)

AT = average of T1 and T2 (deg. K.)

ETB = evapotranspiration using the Bowen ratio (mm water/hour)

ETH = evapotranspiration using the Thornthwaite-Holzman equation

RI = Richardson's number (dimensionless)

ETHR = ETH using Richardson's number in a stability correction function (mm water/hr.)

BOWEN = mean hourly Bowen ratio (dimensionless)

RN = net radiation (mm water/hour)

G = soil heat flux (mm water/hour)

Measurements were started on the hour and the time is given in local time (E.D.S.T.).

```
                                        TABLE  1
                                        ********

                 ETB AND ETH  DATA FRØM SIMCØE FØR 05 DAY ØF THE 07 MØNTH ØF 1967


Z1 =      21.00      Z2 =      51.00      Z3 =      15.00      Z4 =      45.00      DZ =      30.00
LN(Z2/Z1)*LN(Z4/Z3) =        0.97480
    TIME        T1        T2      DIFT        E1        E2      DIFE        U2        U1      DIFU        AT

    0730     6.018     6.087    -0.069     7.982     7.785     0.198   145.554    89.466    56.088   279.212
    0830     7.689     7.637     0.052     8.232     8.064     0.168   149.420    92.526    56.895   280.823
    0930    11.048    10.617     0.431     9.284     8.895     0.390   158.301    97.497    60.804   283.993
    1030    15.062    14.235     0.827     9.795     9.084     0.711   182.818   116.150    66.668   287.808
    1130    16.612    15.854     0.758     9.661     8.855     0.807   170.666   110.499    60.167   289.393
    1230    15.561    15.165     0.396    10.384     9.700     0.685   159.491    99.961    59.529   288.523
    1330    16.543    16.199     0.345    11.079    10.037     1.042   181.883   112.156    69.727   289.531
    1430    16.302    15.958     0.345    11.517    10.254     1.263   130.979    84.070    46.910   289.290
    1530    17.086    16.586     0.500    11.759    10.467     1.293   123.204    72.113    51.091   289.996
    1630    19.437    18.680     0.758    12.504    10.600     1.904   130.895    81.903    48.992   292.218
    1730    18.473    18.232     0.241    12.882    10.536     2.347   103.233    63.929    39.304   291.512
    1830    16.113    16.027     0.086    12.308    11.534     0.775   139.010    80.246    58.764   289.230

TIME            ETB             ETH              RI             ETHR            BØWEN            RN-G

0730          0.17338         0.06309         0.00231         0.06167        -0.22968         0.13356

0830          0.11790         0.05438        -0.00167         0.05529         0.20273         0.14180

0930          0.33327         0.13485        -0.01207         0.15113         0.72816         0.57594

1030          0.35765         0.26974        -0.01902         0.32106         0.76633         0.63172

1130          0.33822         0.27616        -0.02129         0.33496         0.61923         0.54766

1230          0.25889         0.23198        -0.01140         0.25844         0.38125         0.35759

1330          0.30378         0.41323        -0.00720         0.44300         0.21799         0.37000

1430          0.27895         0.33711        -0.01593         0.39080         0.17978         0.32910

1530          0.37169         0.37574        -0.01942         0.44872         0.25472         0.46637

1630          0.42805         0.53065        -0.03181         0.69943         0.26240         0.54037

1730          0.25209         0.52479        -0.01576         0.60751         0.06773         0.26916

1830          0.08440         0.25903        -0.00254         0.26561         0.07328         0.09058
```

```
                                              TABLE  2
                                              ********

                    ETB AND ETH  DATA FRØM SIMCØE FØR 13 DAY ØF THE 07 MØNTH ØF 1967


Z1 =     21.00      Z2 =      51.00      Z3 =      15.00       Z4 =      45.00      DZ =     30.00
LN(Z2/Z1)*LN(Z4/Z3) =          0.97480
    TIME        T1        T2        DIFT       E1        E2       DIFE       U2        U1        DIFU       AT


    0730      15.277    15.157     0.121    10.194     9.856     0.338    83.900    64.652    19.248   288.377
    0830      17.853    17.267     0.586    11.562    10.729     0.832   180.226   135.993    44.233   290.720
    0930      19.282    18.628     0.655    12.553    11.348     1.205   205.126   152.862    52.263   292.115
    1030      29.630    28.803     0.827    25.118    22.741     2.377   279.484   205.720    73.764   302.377
    1130      30.281    29.103     1.178    25.554    24.935     0.619   195.395   145.044    50.351   302.852
    1230      20.988    20.695     0.293    13.520    12.717     0.803   241.710   178.611    63.099   294.001
    1330      22.332    21.643     0.689    13.933    12.141     1.792   259.344   189.744    69.600   295.147
    1430      21.126    21.608    -0.482    14.401    12.751     1.650   233.509   171.091    62.419   294.527
    1530      21.367    21.126     0.241    14.775    13.770     1.005   228.325   167.266    61.059   294.406
    1630      20.101    19.894     0.207    13.322    12.715     0.608   314.326   227.306    87.021   293.157
    1730      18.098    18.046     0.052    12.798    12.380     0.418   220.975   159.448    61.526   291.232
    1830      17.181    17.168     0.013    20.060    19.387     0.673   176.147   128.685    47.462   290.334

TIME            ETB             ETH             RI              ETHR            BØWEN           RN-G

0730          0.10250         0.03707        -0.03322         0.04939         0.23477         0.12656

0830          0.23044         0.20952        -0.03030         0.27302         0.46365         0.33728

0930          0.38249         0.35839        -0.02415         0.44493         0.35796         0.51941

1030          0.55423         0.99763        -0.01479         1.14520         0.22925         0.68129

1130          0.30878         0.17730        -0.04516         0.25738         1.25475         0.69622

1230          0.59687         0.28814        -0.00736         0.30936         0.24048         0.74040

1330          0.47876         0.70985        -0.01418         0.81053         0.25334         0.60006

1430          0.87227         0.58610         0.01237         0.52158        -0.19262         0.70425

1530          0.27576         0.34914        -0.00647         0.37172         0.15816         0.31937

1630          0.26123         0.30095        -0.00274         0.30919         0.22414         0.31978

1730          0.10766         0.14649        -0.00138         0.14852         0.08139         0.11642

1830          0.10609         0.18172        -0.00058         0.18278         0.01265         0.10743
```

```
                                          TABLE  3
                                          ********

                ETB AND ETH  DATA FRØM SIMCØE FØR 18 DAY ØF THE 07 MØNTH ØF 1967


Z1 =      21.00      Z2 =      51.00      Z3 =      15.00      Z4 =      45.00      DZ =      30.00
LN(Z2/Z1)*LN(Z4/Z3) =           0.97480
      TIME       T1        T2        DIFT      E1        E2        DIFE      U2        U1        DIFU      AT

      0830     19.933    19.700     0.233    17.944    17.541     0.403   173.734   118.921    54.813   292.976
      1130     25.105    24.537     0.568    20.443    19.086     1.357   277.402   191.996    85.406   297.981
      1230     26.397    25.674     0.724    20.429    19.078     1.351   312.117   215.238    96.879   299.195
      1330     26.604    25.949     0.655    19.735    18.679     1.056   321.592   224.416    97.176   299.437
      1430     26.432    26.139     0.293    21.157    19.239     1.918   306.083   215.323    90.760   299.445
      1530     26.948    26.363     0.586    21.306    19.567     1.740   257.750   184.518    73.233   299.816
      1630     26.845    26.311     0.534    19.687    18.583     1.104   274.173   192.888    81.285   299.738
      1730     26.604    26.363     0.241    20.820    19.313     1.507   250.973   175.510    75.463   299.643
      1830     33.925    33.485     0.439    22.797    21.891     0.905   203.978   141.177    62.801   306.865
      1930     22.521    22.624    -0.103    10.615    10.048     0.566   150.993   103.658    47.335   295.733

TIME           ETB            ETH            RI             ETHR           BØWEN          RN-G

0830         0.24877        0.12558       -0.00778        0.13534        0.38065        0.34346

1130         0.60048        0.65943       -0.00770        0.71019        0.27608        0.76626

1230         0.61681        0.74455       -0.00758        0.80101        0.35301        0.83456

1330         0.55742        0.58399       -0.00681        0.62378        0.40845        0.78510

1430         0.74150        0.99067       -0.00349        1.02528        0.10060        0.81610

1530         0.54569        0.72492       -0.01072        0.80264        0.22187        0.66676

1630         0.42521        0.51039       -0.00794        0.55089        0.31891        0.56081

1730         0.36559        0.64719       -0.00416        0.67411        0.10544        0.40414

1830         0.08808        0.32354       -0.01068        0.35810        0.31974        0.11625

1930         0.01399        0.15250        0.00459        0.14581       -0.12030        0.01230
```

TABLE 4

****

ETB AND ETH DATA FRØM SIMCØE FØR 20 DAY ØF THE 07 MØNTH ØF 1967

Z1 = 21.00 Z2 = 51.00 Z3 = 15.00 Z4 = 45.00 DZ = 30.00
LN(Z2/Z1)*LN(Z4/Z3) = 0.97480

TIME	T1	T2	DIFT	E1	E2	DIFE	U2	U1	DIFU	AT
0830	18.972	18.731	0.241	13.496	12.624	0.872	84.401	67.065	17.336	292.012
0930	22.297	21.591	0.706	20.108	18.328	1.780	106.632	82.285	24.347	295.104
1030	24.140	23.227	0.913	23.468	21.677	1.791	122.184	92.763	29.420	296.844
1130	25.277	24.278	0.999	24.219	20.788	3.431	154.113	120.989	33.125	297.938
1230	26.208	25.105	1.103	22.675	20.434	2.241	178.951	133.571	45.380	298.816
1330	26.518	25.364	1.154	21.813	19.457	2.355	175.765	129.237	46.527	299.101
1430	26.742	26.156	0.586	22.512	19.254	3.258	201.896	148.401	53.496	299.609
1530	26.759	26.225	0.534	22.658	20.278	2.380	206.273	150.015	56.258	299.652
1630	26.793	26.432	0.362	21.863	19.771	2.092	170.326	125.243	45.083	299.773
1730	26.742	26.449	0.293	22.285	20.617	1.668	172.875	126.773	46.102	299.755
1830	24.106	24.485	-0.379	22.601	20.857	1.744	157.111	112.199	44.913	297.455
1930	22.245	22.693	-0.448	21.371	20.032	1.339	174.787	124.308	50.479	295.629

TIME	ETB	ETH	RI	ETHR	BØWEN	RN-G
0830	0.24367	0.08605	-0.08087	0.15564	0.18219	0.28807
0930	0.39866	0.24661	-0.11883	0.53964	0.26148	0.50290
1030	0.41799	0.29990	-0.10458	0.61353	0.33586	0.55838
1130	0.64057	0.64669	-0.08995	1.22838	0.19191	0.76350
1230	0.63821	0.57875	-0.05273	0.88392	0.32416	0.84509
1330	0.65598	0.62354	-0.05246	0.95066	0.32294	0.86782
1430	0.75063	0.99157	-0.02010	1.19091	0.11849	0.83957
1530	0.65801	0.76184	-0.01657	0.88809	0.14787	0.75531
1630	0.55099	0.53662	-0.01747	0.63039	0.11397	0.61379
1730	0.35501	0.43765	-0.01353	0.49686	0.11568	0.39608
1830	0.18343	0.44578	0.01859	0.37590	-0.14318	0.15717
1930	0.09597	0.38460	0.01750	0.32732	-0.22044	0.07482

TABLE 5
****

ETB AND ETH DATA FRØM SIMCØE FØR 25 DAY ØF THE 07 MØNTH ØF 1967

Z1 = 21.00 Z2 = 51.00 Z3 = 15.00 Z4 = 45.00 DZ = 30.00
LN(Z2/Z1)*LN(Z4/Z3) = 0.97480

TIME	T1	T2	DIFT	E1	E2	DIFE	U2	U1	DIFU	AT
0930	21.694	21.350	0.345	18.404	17.559	0.845	231.895	156.176	75.718	294.682
1030	23.796	23.262	0.534	18.805	17.640	1.165	327.371	221.782	105.589	296.689
1130	25.053	24.606	0.448	19.320	18.026	1.294	318.151	216.088	102.062	297.990
1230	25.364	24.847	0.517	20.382	18.460	1.922	338.419	229.430	108.988	298.265
1330	24.985	24.623	0.362	19.976	19.067	0.909	348.956	236.696	112.260	297.964
1430	23.882	23.710	0.172	19.133	18.581	0.552	293.209	197.902	95.306	296.956
1530	24.313	23.830	0.482	18.989	18.432	0.557	393.826	263.253	130.574	297.232
1630	24.640	24.278	0.362	17.722	17.375	0.347	409.165	274.215	134.950	297.619
1730	24.072	23.796	0.276	16.933	16.141	0.792	391.277	262.870	128.407	297.094
1830	22.745	22.711	0.034	16.668	16.294	0.374	356.095	238.651	117.444	295.888
1930	20.867	21.022	-0.155	16.498	16.009	0.489	275.065	181.798	93.267	294.105

TIME	ETB	ETH	RI	ETHR	BØWEN	RN-G
0930	0.34613	0.36411	-0.00600	0.38596	0.26866	0.43912
1030	0.49942	0.70003	-0.00475	0.73329	0.30205	0.65026
1130	0.59836	0.75134	-0.00425	0.78324	0.22814	0.73487
1230	0.58587	1.19191	-0.00429	1.24308	0.17720	0.68969
1330	0.51353	0.58049	-0.00284	0.59695	0.26234	0.64825
1430	0.37355	0.29916	-0.00188	0.30479	0.20578	0.45042
1530	0.35380	0.41401	-0.00280	0.42561	0.57045	0.55562
1630	0.35109	0.26621	-0.00196	0.27144	0.68766	0.59252
1730	0.34332	0.57871	-0.00166	0.58829	0.22933	0.42205
1830	0.25161	0.24992	-0.00025	0.25055	0.06072	0.26689
1930	0.12094	0.25933	0.00178	0.25479	-0.20908	0.09566

TABLE 6

ETB AND ETH DATA FRØM SIMCØE FØR 27 DAY ØF THE 07 MØNTH ØF 1967

Z1 = 21.00 Z2 = 51.00 Z3 = 15.00 Z4 = 45.00 DZ = 30.00

LN(Z2/Z1)*LN(Z4/Z3) = 0.97480

TIME	T1	T2	DIFT	E1	E2	DIFE	U2	U1	DIFU	AT
0930	21.953	21.711	0.241	20.755	19.998	0.756	171.414	126.518	44.896	294.992
1030	24.364	23.865	0.500	22.634	21.474	1.160	207.565	150.304	57.260	297.275
1130	25.656	25.381	0.276	22.116	21.507	0.609	277.402	198.964	78.438	298.679
1230	25.631	25.303	0.327	22.898	21.784	1.114	310.485	222.734	87.752	298.627
1330	25.975	25.631	0.345	23.835	22.630	1.206	302.786	214.677	88.109	298.963
1430	23.460	23.408	0.052	23.389	22.971	0.418	269.031	193.228	75.803	296.594

TIME	ETB	ETH	RI	ETHR	BØWEN	RN-G
0930	0.42595	0.19322	-0.01194	0.21629	0.21013	0.51545
1030	0.45368	0.37781	-0.01508	0.43480	0.28391	0.58248
1130	0.39543	0.27178	-0.00441	0.28378	0.29828	0.51338
1230	0.48694	0.55627	-0.00419	0.57957	0.19361	0.58122
1330	0.46438	0.60437	-0.00437	0.63077	0.18834	0.55184
1430	0.14418	0.18049	-0.00089	0.18210	0.08139	0.15591

TABLE 7

ETB AND ETH DATA FRØM SIMCØE FØR 04 DAY ØF THE 08 MØNTH ØF 1967

Z1 = 21.00 Z2 = 51.00 Z3 = 15.00 Z4 = 45.00 DZ = 30.00
LN(Z2/Z1)*LN(Z4/Z3) = 0.97480

TIME	T1	T2	DIFT	E1	E2	DIFE	U2	U1	DIFU	AT
1130	23.438	23.044	0.394	18.814	17.865	0.949	299.922	209.800	90.123	296.401
1230	24.621	24.209	0.411	17.994	17.228	0.766	334.637	232.320	102.317	297.575
1330	24.107	23.901	0.206	18.091	17.125	0.966	335.317	230.153	105.164	297.164
1430	23.747	23.627	0.120	16.820	16.093	0.726	315.006	216.173	98.833	296.847
1530	23.952	23.695	0.257	16.245	15.715	0.529	299.200	204.573	94.627	296.984

TIME	ETB	ETH	RI	ETHR	BØWEN	RN-G
1130	0.57726	0.48688	-0.00482	0.51033	0.27352	0.73515
1230	0.55411	0.44575	-0.00388	0.46306	0.35393	0.75022
1330	0.47207	0.57790	-0.00184	0.58854	0.14030	0.53831
1430	0.40305	0.40838	-0.00122	0.41335	0.10884	0.44692
1530	0.42001	0.28506	-0.00284	0.29317	0.31991	0.55437

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                                        TABLE  8
                                        ********

              ETB AND ETH  DATA FRØM SIMCØE FØR 08 DAY ØF THE 08 MØNTH ØF 1967


Z1 =     21.00      Z2 =       51.00       Z3 =      15.00       Z4 =       45.00      DZ =      30.00
LN(Z2/Z1)*LN(Z4/Z3) =          0.97480
    TIME         T1        T2        DIFT       E1        E2        DIFE     U2        U1        DIFU       AT

    0830       18.932    18.692     0.240    16.317    15.942     0.375  108.799    76.252    32.548   291.972
    0930       20.885    20.371     0.514    17.477    16.673     0.804  110.202    79.906    30.296   293.788
    1030       23.267    22.599     0.668    19.736    18.088     1.647  150.780   105.910    44.870   296.093
    1130       22.907    22.667     0.240    19.726    18.869     0.857  258.154   176.190    81.964   295.947
    1230       25.392    24.860     0.531    20.386    18.891     1.495  242.900   163.825    79.075   298.286
    1330       25.649    25.066     0.583    18.904    18.011     0.893  304.426   201.131   103.295   298.517
    1430       25.511    25.169     0.343    20.123    18.651     1.472  281.609   184.858    96.751   298.500
    1530       25.700    25.254     0.445    17.660    17.014     0.646  316.578   208.652   107.926   298.637
    1630       25.580    25.306     0.274    17.530    16.705     0.825  244.472   164.632    79.840   298.603
    1730       25.306    25.203     0.103    18.596    17.956     0.640  233.679   158.513    75.166   298.414

TIME            ETB                ETH                RI                  ETHR               BØWEN             RN-G

0830          0.10114            0.06937          -0.02282              0.08521            0.42199           0.14381

0930          0.27024            0.13866          -0.05610              0.21645            0.42112           0.38404

1030          0.49203            0.42054          -0.03299              0.55928            0.26734           0.62356

1130          0.54948            0.39964          -0.00355              0.41383            0.18447           0.65085

1230          0.58061            0.67269          -0.00838              0.72907            0.23412           0.71654

1330          0.57116            0.52507          -0.00538              0.55334            0.42972           0.81659

1430          0.70433            0.81030          -0.00361              0.83955            0.15342           0.81239

1530          0.49996            0.39684          -0.00377              0.41180            0.45429           0.72708

1630          0.46987            0.37489          -0.00424              0.39078            0.21892           0.57274

1730          0.35628            0.27365          -0.00179              0.27856            0.10588           0.39401
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TABLE 9
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ETB AND ETH DATA FRØM SIMCØE FØR 11 DAY ØF THE 08 MØNTH ØF 1967

Z1 = 21.00 Z2 = 51.00 Z3 = 15.00 Z4 = 45.00 DZ = 30.00
LN(Z2/Z1)*LN(Z4/Z3) = 0.97480

TIME	T1	T2	DIFT	E1	E2	DIFE	U2	U1	DIFU	AT
1230	18.727	17.973	0.754	11.358	9.934	1.424	223.227	167.054	56.173	291.510
1330	19.138	18.470	0.668	10.942	9.357	1.584	180.778	136.716	44.063	291.964
1430	20.200	19.378	0.822	10.892	9.937	0.954	182.606	139.648	42.958	292.949
1530	20.645	19.772	0.874	10.943	9.620	1.322	192.123	145.044	47.080	293.369
1630	19.515	18.915	0.600	10.580	9.639	0.941	161.105	125.031	36.075	292.375
1730	19.172	18.727	0.445	10.554	10.095	0.458	135.314	104.678	30.636	292.109
1830	18.384	18.350	0.034	10.212	9.959	0.253	118.785	93.885	24.900	291.527

TIME	ETB	ETH	RI	ETHR	BØWEN	RN-G
1230	0.43252	0.45529	-0.02412	0.56511	0.34877	0.58337
1330	0.62852	0.39720	-0.03469	0.53500	0.27796	0.80322
1430	0.50400	0.23328	-0.04477	0.33773	0.56787	0.79021
1530	0.49063	0.35424	-0.03955	0.49434	0.43547	0.70428
1630	0.30828	0.19323	-0.04638	0.28285	0.41981	0.43770
1730	0.14284	0.07989	-0.04782	0.11809	0.64057	0.23435
1830	0.15299	0.03585	-0.00558	0.03785	0.08923	0.16664

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                                   TABLE 10
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          ETB AND ETH  DATA FROM SIMCOE FOR 24 DAY OF THE 08 MONTH OF 1967


Z1 =      21.00        Z2 =      51.00        Z3 =      15.00        Z4 =      45.00        DZ =      30.00
LN(Z2/Z1)*LN(Z4/Z3) =             0.97480
     TIME        T1        T2       DIFT       E1        E2       DIFE      U2        U1       DIFU      AT


     0930      19.951    19.585     0.366     2.066     1.840     0.225  190.721  151.927   38.794  292.928
     1030      20.439    19.846     0.593     6.710     6.163     0.546  209.885  162.847   47.037  293.302
     1130      20.787    20.404     0.383     8.838     8.266     0.571  212.264  160.001   52.263  293.756

TIME           ETB            ETH            RI             ETHR           BOWEN          RN-G

0930           0.12358        0.04977        -0.02443       0.06193        1.06965        0.25577

1030           0.12879        0.14620        -0.02687       0.18549        0.71483        0.22086

1130           0.21520        0.16995        -0.01406       0.19385        0.44213        0.31034
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