PREDICTION OF LATENT EVAPORATION USING HOURLY METEOROLOGICAL DATA

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Hourly meteorological data were used to improve the accuracy of the estimation of latent evaporation, thus allowing better prediction of the rate of moisture loss to the atmosphere from soils, crops and reservoirs. Regression analysis was employed to develop prediction equations which defined the interrelationships of evaporation and hourly weather parameters. The regression equations facilitate the estimation of hourly latent evaporation from several combinations of up to five variables. Vapor pressure deficit was found to have the largest influence on the variation in evaporation.

INTRODUCTION

The usefulness of meteorological data in the development of estimators for predicting daily, weekly, monthly or yearly loss of moisture to the atmosphere from soils (Baier and Robertson 1966), crops (Hayhoe and Jacson 1974; Hobbs and Krogman 1966, 1970; Stewart and Lievers 1978) and reservoirs (Penman 1948, 1956; Veehmeyer 1964) has been well established. Such estimates employ average or cumulated daily, weekly or monthly weather data. Several workers have shown that evaporation, as measured by an evaporimeter, can be used as the major parameter in such prediction equations.

Wilcox (1963), Pelton (1964) and Baier and Robertson (1965) have shown that daily meteorological data can be correlated to evaporation readings. Baier and Robertson (1965) presented multiple regression equations using several combinations of daily weather data to predict daily latent evaporation. As much as 70-85% of the variation in daily evaporation was accounted for by this approach.

The use of daily or weekly meteorological data to predict the loss of moisture from a freshly cut crop, such as hay, does not allow accurate estimation of the time of day at which the pre-selected crop moisture content can be reached. In the harvesting of crops, the accurate prediction of time required to reach a desired moisture content can have a major impact on the final outcome of the crop. Kemp et al. (1977), in developing an estimator for the moisture content of drying hay crops, employed cumulative latent evaporation data from an atmometer. It was shown that drying equations could be developed using hourly evaporation data.

The usefulness of an estimator for hourly predictions depends upon the availability of hourly evaporation data. At the best, twice-daily evaporation readings taken from a Class A evaporation pan (the international standard) are available from only some accredited weather stations. As hourly weather data are available from weather stations, such as those located at airports, it was decided to attempt to develop an estimator for predicting evaporation at hourly intervals. This paper presents several multiple regression equations, for this purpose, using various combinations of hourly meteorological data.

MATERIALS AND METHODS

During the summer of 1978, selected hourly observations for evaporation and solar radiation were collected at the weather station compound, Research Station, Agriculture Canada, Fredericton, N.B. Corresponding hourly dry bulb and dew point temperatures, along with wind run data, were obtained from Atmospheric Environment Services, Fredericton Airport, located 10 km from the Research Station.

The hourly records of evaporation, as the dependent variable, were correlated with the hourly meteorological data. Correlation and regression analyses were used to establish relationships between the variables. The variables included:

E_L = latent evaporation (mL), hourly cumulation by a black Bellani plate atmometer (Pelton 1964; Robertson and Holmes 1957).

T_{DB} = dry bulb temperature (°C), taken hourly in a ventilated psychrometer screen.

MT_{DB} = mean dry bulb temperature (°C), mean T_{DB} for each hour obtained by averaging the T_{DB} at the beginning and the end of each hour.

T_{DP} = dew point temperature (°C), taken hourly with a MSC Dew Cell.

P_{WS} = saturated vapor pressure (mb), calculated for each recorded temperature using the following equation (Kennan et al 1969),

$$\ln\left(\frac{P_{WS}}{217.99}\right) = \frac{0.01}{T}(374.136-t)\sum_{i=1}^{8} F_i\,(0.65 - 0.01\,t)^{i-1} \quad (1)$$

Where T = absolute temperature (Kelvin)

$$t = T - 273.15\ (°C)$$

$F_1 = -741.9242$ $F_5 = 0.1094098$
$F_2 = -29.72100$ $F_6 = 0.439993$
$F_3 = -11.55286$ $F_7 = 0.2520658$
$F_4 = 0.8685635$ $F_8 = 0.05218684$

Equation 1 gives P_{WS} in terms of atmospheres which was converted to the units of millibars.

VPD = vapor pressure deficit (deficit (mb), (P_{WS} at T_{DB} − P_{WS} at T_{DP}), calculated by substituting paired hourly readings of T_{DB} and T_{DP} into Eq. 1 for determining P_{WS}.

$MVPD$ = mean vapor pressure deficit (mb), calculated for each hour by averaging VPD at the beginning and the end of the hour.

W = wind run (km), cumulated hourly by MSC 42A anemometer located 10 m above the ground surface.

G_R = global radiation (Langley), cumulated hourly on a pyranometer Kipp CM6 (WMO Designation "K").

N_R = net radiation (Langley), cumulated hourly on a net pyranometer CSIRO (WMO Designation "Q"). (Radiation readings for G_R and N_R were recorded on the basis of apparent local time. During the summer months, this was about 30 min off local standard time. To obtain radiation readings to correspond to a local standard hour, the average of the readings ending and beginning in the local standard hour were employed.)

RESULTS AND DISCUSSION

Simple Correlations

Results presented in Table I, describing the simple correlation coefficients between the variables under study, indicate that the six variables can be placed into two groups. One group involves only wind run, W, which has no correlation with the

TABLE I. SIMPLE CORRELATION COEFFICIENTS† BETWEEN METEOROLOGICAL VARIABLES

	W	G_R	MT_{DB}	N_R	$MVPD$	E_L
W	1	−0.170	−0.032	−0.087	0.074	0.204
G_R		1	0.693	0.967	0.661	0.693
MT_{DB}			1	0.743	0.901	0.764
N_R				1	0.689	0.743
$MVPD$					1	0.901
E_L						1

†For $P = 0.05$, $r = 0.205$; for $P = 0.01$, $r = 0.267$.

second group. The variables in the second group, G_R, MT_{DB}, N_R, $MVPD$ and E_L, are all highly correlated to each other ($r \geq 0.661$). Of particular interest, was the highly significant correlation between mean vapor pressure deficit and latent evaporation. As vapor deficit is the driving force for the movement of water vapor, this high correlation is understandable.

Regression Analyses

A computerized regression program was employed to determine the relationship of evaporation to several combinations of meteorological variables. Linear multiple regression equations employed were of the type

$$Y = a_0 + a_1x_1 + a_2x_2 + \ldots + a_nx_n \quad (2)$$

The developed equations facilitate the estimation of hourly latent evaporation from several combinations of up to five variables. Selected results from the analysis appear in Table II.

The single parameter, mean vapor pressure deficit, accounted for 81% of the variation of evaporation. Mean vapor pressure deficit, in combination with another variable or variables, resulted in correlation values greater than 0.90. However, such values were not significantly higher than 0.90 obtained when the vapor pressure term was used alone. The combinations did slightly reduce the standard error of estimate. Mean dry bulb temperature in combination with either radiation variable resulted in correlation values greater than 0.80. These values were significantly higher than temperature alone (0.76). With any combination in which mean dry bulb temperature or vapor pressure deficit did not appear, correlation values were less than 0.75. The standard error of estimate was lower when the $MVPD$ term was included in the equation. For this reason, any prediction equations should include vapor pressure deficit.

Estimates of hourly latent evaporation were determined by the use of Eqs. I and V. These values were compared to actual recorded results obtained from an atmometer. Table III shows the result over an 8-h period while Table IV is for a 7-h period of a different day. The hourly predicted and actual readings were cumulated at each hour to indicate the cumulated error with time. For both days, the prediction equations gave satisfactory results, Eq. I giving the smaller errors.

TABLE II. MULTIPLE CORRELATION AND REGRESSION COEFFICIENTS OF METEOROLOGICAL VARIABLES WITH EVAPORATION

Equation	Meteorological variables	Regression coefficient	Constant	Regression data R†	SE (mL)
I	$MVPD$	0.161	−0.88	0.93	0.60
	N_R	1.112			
	W	0.041			
	MT_{DB}	0.024			
	G_R	−0.060			
II	$MVPD$	0.181	0.082	0.92	0.66
	N_R	0.855			
	MT_{DB}	0.920			
III	$MVPD$	0.175	0.551	0.93	0.60
	N_R	1.035			
	W	0.040			
IV	$MVPD$	0.224	0.347	0.91	0.68
	W	0.032			
V	$MVPD$	0.277	0.835	0.90	0.71
VI	N_R	1.638	−2.094	0.84	0.84
	MT_{DB}	0.169			
VII	N_R	1.743	−3.161	0.88	0.79
	W	0.059			
	MT_{DB}	0.166			
VII	MT_{DB}	0.261	−1.913	0.76	1.05

†All values of R shown are highly significant at the 1% level.

Tanner and Pelton (1960) tested the usefulness of Penman's equation for the estimation of potential evaporation and found it useful for periods as short as 1 day. To be used for hourly prediction, hourly weather parameters, which are not readily available, would be required. The same basic argument could be used against the usefulness of the equations presented here. However, Eq. V does offer a way out of this predicament.

Equation V requires hourly dry bulb temperature and hourly vapor pressure deficit. At present, stations reporting dew point temperatures generally provide two readings daily, one at 0800 h and the second at 1600 h. A fact that can be taken into consideration is that dew point temperatures change very little during the day unless a change in air mass occurs. With this thought in mind, the average of these two readings was used as a basis for calculating hourly vapor pressure deficits. For the time periods in Tables III and IV, the estimated cumulated amounts of evaporation were 29.3 and 29.8 mL, respectively.

Potential evaporation (E_p) can be obtained by multiplying E_L by 0.0094 as determined by Baier (1971). This conversion could be used in Eq. 2 which would then appear as

$$E_p = 0.0094\,(a_0 + a_1x_1 \ldots a_nx_n) \quad (3)$$

TABLE III. COMPARISON OF ACTUAL AND PREDICTED LATENT EVAPORATION CUMULATED HOURLY OVER AN 8-H PERIOD

Hour	Predicted Eq. I	Evaporation (mL) Eq. V	Actual evaporation (mL)
1	2.0	2.1	2.8
2	4.8	4.5	4.7
3	7.8	7.0	8.4
4	10.9	10.7	11.0
5	14.5	12.9	15.0
6	19.2	17.2	19.0
7	24.5	22.1	24.6
8	28.7	26.4	29.9

TABLE IV. COMPARISON OF ACTUAL AND PREDICTED LATENT EVAPORATION CUMULATED HOURLY OVER A 7-H PERIOD

Hour	Predicted Eq. I	Evaporation (mL) Eq. V	Actual evaporation (mL)
1	1.3	1.8	1.1
2	3.6	4.0	3.8
3	6.4	6.9	6.9
4	10.1	10.6	11.2
5	14.7	15.3	15.7
6	19.5	20.6	20.7
7	24.5	26.3	24.7

CONCLUSIONS

The use of hourly meterological data increased the accuracy of estimators for latent evaporation over previously published estimates based on daily data. With five meteorological factors, *MVPD*, N_R, *W*, MT_{DP} and G_R, 87% of the variation in evaporation, E_L, could be explained. Of the variables employed, hourly mean vapor pressure deficit yielded the largest simple correlation coefficient with evaporation. With the vapor pressure deficit term in an estimator, over 80% of the variation of evaporation could be accounted for by this single parameter.

The true usefulness of prediction equations for predicting the drying rates of crops is the prediction before the fact or, in the use of past weather data, in estimating future probabilities of good drying periods or of selected drying times. Equation V does open up this possibility if reliable hourly dry bulb temperature predictions are available along with twice-a-day dew point temperatures for the one use and, if available, as past weather data for the second use.

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