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OBJECTIVE FORECASTING OF PAN EVAPORATION - TWO CONTRIBUTIONS

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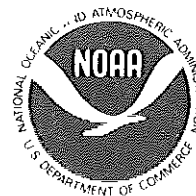
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AN AID TO AGRICULTURAL EVAPORATION FORECASTING

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ABSTRACT

Evaporation estimates are routinely included in many National Weather Service (NWS) agricultural forecasting programs. Heretofore, several evaporation estimation schemes have been devised but these have been either too involved for easy application, or have contained variables not routinely forecast. This paper offers a linear equation which estimates 24-hour pan evaporation as a function of means of temperature, relative humidity, and 20-foot winds. These three variables are routinely forecast, which makes application of this evaporation equation fairly straightforward.

1. INTRODUCTION

Quantitative, or at least qualitative, evaporation forecasts are included in many agricultural forecasting programs of the NWS. To date, several evaporation estimation schemes have been devised but these have been either too involved for easy and fast application, or have contained variables not routinely forecast. One equation by Kohler (1) has been used extensively in the NWS Hydrology program but is difficult to apply to routine agricultural forecasts because it includes two variables not commonly forecast: solar radiation and 2-foot level wind movement. The linear equation offered in this paper is, on the other hand, based on three commonly forecast variables: means of temperature, relative humidity and 20-foot level winds. While this equation is probably not as rigorous as that of Kohler, it does compare favorably when applied to independent data. One advantage is that it is easily applied under real-time forecast conditions.

2. DATA USED IN STUDY

A set of equations was developed for the various months for use in Oklahoma with one general equation which can be used elsewhere. Five years (1966 to 1970) of pan evaporation data were supplied by the Chickasha experiment station which is 25 miles southwest of Oklahoma City. These data (1,025 total cases) were used to develop the April through October equations (for use in Oklahoma) and the general equation (for use in Oklahoma or other areas). The winter equation (for use in Oklahoma) which covers November through March, was developed from data (100 cases) at Oologah reservoir, 25 miles northeast of Tulsa.

The following independent variables were used with 24-hour pan evaporation as the dependent variable.

- a. April through October equations and the general equation
 1. 24-hour pan evaporation (Chickasha)
 2. Mean daily temperature (OKC)
 3. Mean daily relative humidity (OKC)
 4. Mean daily estimated 20-foot level wind (Chickasha)*
 5. Daily solar radiation (OKC)
 6. Mean daily station pressure (OKC)
- b. November through March equation
 1. 24-hour pan evaporation (Oolagah)
 2. Mean daily temperature (Oolagah)
 3. Mean daily relative humidity (TUL)

*Note...The 2-foot level wind was converted to 20-foot level by using the 1/7th power law (2). This is not strictly valid but the performance of the resulting equations suggests no serious error.

3. DEVELOPMENT OF EQUATIONS

A screening regression computer program was used to develop the equations. It was immediately obvious that means of temperature, relative humidity and wind were the controlling influences on pan evaporation. The inclusion of mean station pressure and daily solar radiation offered no significant improvement in the regression equation estimates of pan evaporation. Daily solar radiation, while alone having a good correlation with evaporation (but less than mean temperature), increased the reduction of variance very little when taken in combination with mean temperature.

Many transformations of the independent variables (various powers of the variables) were tested in screening regression runs, but very little improvement in fitting the data was observed. The final linear equations include only means of temperature, relative humidity and wind as independent variables with 24-hour pan evaporation as the dependent variable.

4. THE EVAPORATION EQUATIONS AND THEIR VERIFICATION

The empirical equations are listed in Table I. Many statistics reflecting the value of the equations are available but the true test is how they perform on independent data. Therefore, the statistics presented in Table I are limited to three. Each equation was applied to about 25 independent cases with 196 total cases.

As Table I indicates, generally less than .06 inch error in estimating 24-hour pan evaporation occurred on both the independent and dependent data. This indicates the overall stability of the equations.

TABLE 1.

Period Covered by Equation		Correlation Coefficient	Avg Error Dep. Data	Avg Error Indep. Data
1. April	$E = .303 - .0054RH + .0044T + .0003W$	.7835	.05	.04
2. May	$E = .203 - .0050RH + .0059T + .0012W$	.7908	.06	.07
3. June	$E = -.153 - .0040RH + .0093T + .0064W$	.7567	.06	.06
4. July	$E = .341 - .0061RH + .0051T + .0003W$	.7860	.05	.06
5. August	$E = -.304 - .0038RH + .0091T + .0146W$	.7782	.06	.05
6. September	$E = .164 - .0031RH + .0026T + .0026W$	.6224	.05	.06
7. October	$E = .173 - .0023RH + .0019T + .0042W$	.6166	.04	.05
8. Nov - Mar	$E = .082 - .0031RH + .0039T + .0053W$	.6933	.04	.04
9. All Months (General)	$E = -.092 - .0041RH + .0075T + .0113W$	.7211	.07	.07

Table 1. A list of the evaporation equations. In the equations E, RH, T and W are 24-hour pan evaporation, mean 24-hour relative humidity, mean 24-hour temperature, and mean 20-foot level wind, respectively.

Another verification was performed to see how well the equations estimate categories of pan evaporation. The categories used in agricultural forecasts issued by the OKC WSFO are:

- Evaporation Poor - less than .10 inch
- Evaporation Fair - .10 to .15 inch
- Evaporation Good - .16 to .20 inch
- Evaporation Excellent - more than .20 inch

The same independent data used in Table 1 were used in this categorical pan evaporation test with the results shown in contingency Table 2. All 196 cases are combined in Table 2 with equations 1. through 7. and equation 8. (Table 1) being used.

TABLE 2.

FORECAST

		Poor	Fair	Good	Excellent	Total
O B S E R V E D	Poor	3	13	4		20
	Fair	1	9	5	3	18
	Good		1	17	13	31
	Excellent		3	12	112	127
	Total	4	26	38	128	196
% Correct		75	35	45	87	72
Bias		.20	1.44	1.23	1.01	

Table 2 indicates a reasonably good total percent correct (72%) but also shows an average bias of estimating a higher category than observed. The estimated values hit within plus or minus one category 185 times or 95 percent. In general, the equations do reasonably well in categorical 24-hour pan evaporation estimation.

A further check was made by comparing the Oklahoma City monthly pan evaporation estimates using Kohler's equation (calculations supplied by Bill Curry, then Oklahoma State Climatologist) with those given by the above equations. The comparison is listed in Table 3.

TABLE 3.

Month	Table 1 Equations Estimates (inches)	Kohler's Equation (inches)
January	2.23	2.80
February	3.02	3.05
March	4.68	5.74
April	6.75	7.30
May	8.74	(7.44) apparently too low
June	10.95	9.86
July	11.37	11.19
August	10.64	11.10
September	7.37	8.11
October	5.87	6.33
November	4.01	3.86
December	2.78	3.03

Table 3. A comparison of monthly pan evaporation estimates using equations 1. through 7. and equation 8. of Table 1. with Kohler's equation.

The agreement is good with an average difference of 4 percent (excluding May).

5. APPLICABILITY TO OTHER AREAS

How well the general equation (No. 9. in Table 1) applies to other states was investigated by computing the annual pan evaporation (summing the monthly estimates using monthly means of temperature, relative humidity, and wind) for various NWS stations using the general equation, then comparing these values with published values (3). Figure 1 shows the percentage deviations at the 54 selected stations.

While this may be a somewhat arbitrary method of comparison, the results do seem to indicate general applicability over the U.S. except the obvious overestimation along the Gulf and Atlantic coasts, the desert southwest, and the northwest mountain area. The average deviation for all 54 stations is 12 percent. Excluding the areas of overestimation (noted above), the average deviation is 6 percent.

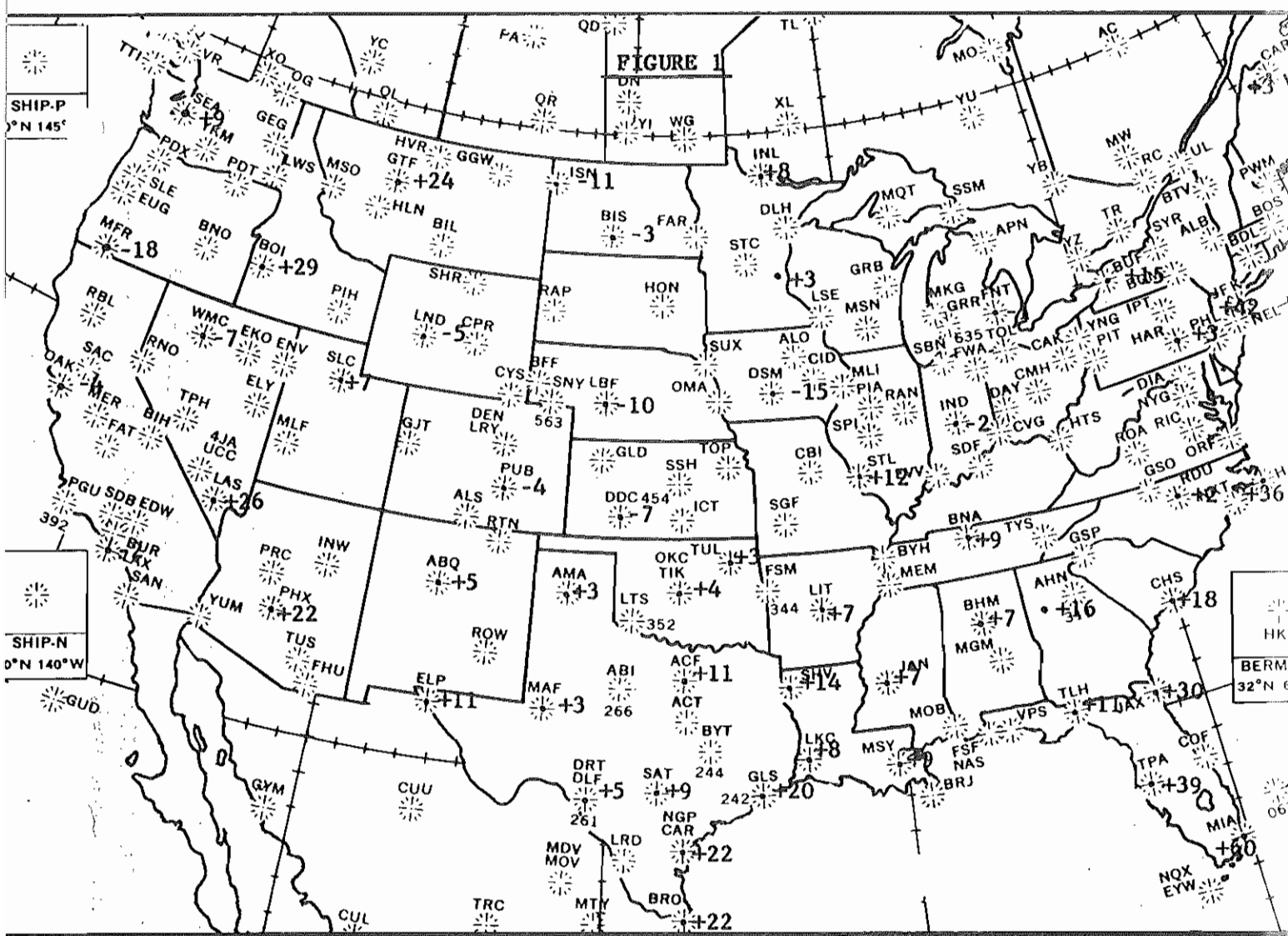


Figure 1. Plots of percent deviations of annual pan evaporation estimates as shown in Reference 3 versus equation 9 in Table 1.

6. 24-HOUR EVAPORATION GRAPH

The general equation (No. 9 in Table 1.) is graphically represented in Figure 2. Enter the graph with 24-hour means of temperature, relative humidity, and wind to get 24-hour pan evaporation (follow the arrows). Categories of pan evaporation used at OKC WSFO are also indicated on the graph.

7. CONCLUSION

This study presented a set of simple linear equations which estimate 24-hour pan evaporation as a function of 24-hour means of temperature, relative humidity, and wind. A set of equations are for use in Oklahoma with one general equation which can be applied in most other areas. While this general equation may not be rigorous enough for hydrological functions, it is a fast and easily applied tool for agricultural forecasters' use.

FIGURE 2

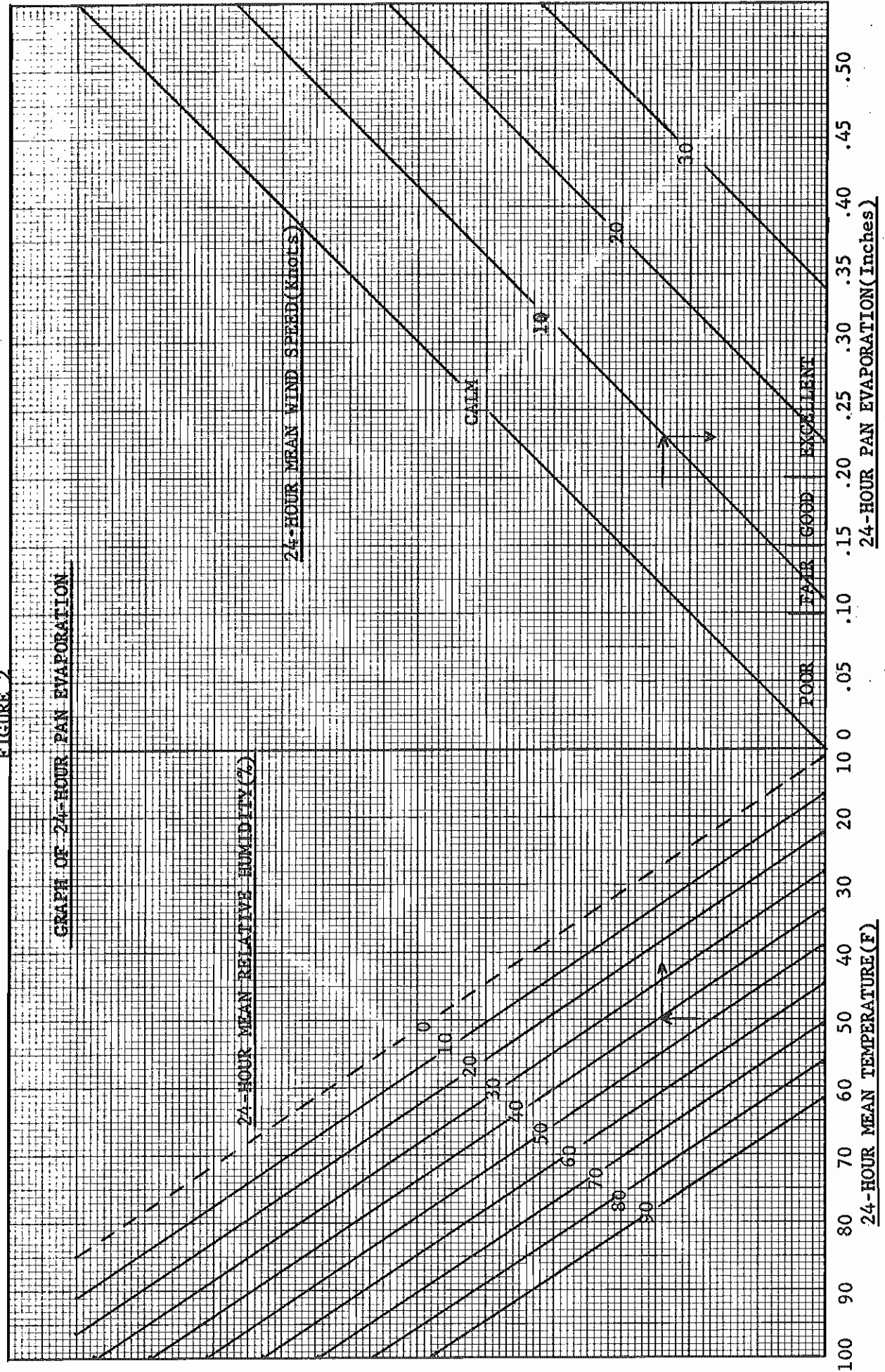


Figure 2. Graph of equation "E= -0.092 - .0041RH + .0075T + .0113W" where RH, T, and W are 24-hour means of relative humidity, temperature, and wind respectively.

REFERENCES

1. Kohler, M. A., T. J. Nordenson and W. E. Fox, Evaporation from Pans and Lakes, U. S. Weather Bureau Research Paper 38, May 1955.
2. Thom, H. C. S., New Distribution of Extreme Winds in the United States, ASCE Environmental Engineering Conference, Preprint 431, Dallas, Texas, February 1967.
3. Climatic Atlas of the United States, ESSA, June 1968.

AN OBJECTIVE METHOD OF FORECASTING TOTAL OPEN-PAN
EVAPORATION FOR A 48 HOUR PERIOD ON THE TEXAS SOUTH
PLAINS, USING SOME PARAMETERS FROM THE FOUS68 MESSAGE

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I. INTRODUCTION AND PURPOSE

The Texas South Plains Area is a semi-arid region where about 5 million acres is under cultivation. Of this area, some 68 percent is put to irrigated crops. When crops undergo stress because of the lack of available water, a loss in growth and yield occurs. Also, on the South Plains, the natural supply of underground water used in irrigation is being steadily depleted and the cost of getting the water to the crops is continually increasing. The unnecessary expenditure of irrigation water is therefore to be avoided and farmers on the South Plains try to irrigate just before this stress situation develops.

At present, a subjective method of forecasting evaporation is in use on the South Plains. These forecasts are made for a 24 hour period -- the criteria for the rates of evaporation were arrived at arbitrarily. These rates are as follows:

Very Light	.00 to .10 inch
Light	.11 to .29 inch
Moderate	.30 to .49 inch
Heavy	.50 to .70 inch
Very Heavy	over .70 inch

A forecast of evaporation is considered correct if the observed open-pan evaporation falls within the specified range. For example, if "Light" evaporation losses are forecast for a 24 hour period, and observed evaporation for that period is from .11 to .29 inch the forecast is considered accurate. From April through September, 1975, evaporation forecasts made and verified in this manner had an accuracy of 78 percent.

It is believed that an objective method of forecasting open-pan evaporation for a 48 hour period may be of greater benefit to the South Plains farmer in determining the most propitious moment for crop irrigation.

This study was undertaken primarily to investigate the relationship between the average of the forecasted values of various parameters computed in the 6-layer (PE) Numerical Prediction Model for a 48 hour period (for the Lubbock, Texas location and contained in the FOUS68 message) and the total open-pan evaporation observed at the Texas A&M University Research and Extension Center in Lubbock for that same 48 hour period.

Secondly, if a valid relationship does exist, to develop an objective method for using the average (for a 48 hour period) of the forecasted values of various parameters contained in the FOUS68 message to determine this 48 hour open-pan evaporation.

2. DATA USED IN INVESTIGATION

The FOUS68 message (Fig. 1) contains the 48 hour forecast of the values of several parameters. Seven (7) forecasted values are given for each parameter, starting with a value valid 12 hours after the initial time and continuing with a value for each 6 hour interval through 48 hours.

```
FOUS68 KWBC 010644
OUTPUT FROM 00Z JUL 01 75
STA RH RIR2R3 WLI HHDDFF TBPBPTT
LBB032 302950 -0301 791715 1282000
18031 332645 -1401 801717 1379000
24028 342440 -0401 821718 1578000
30032 442645 -0101 821818 1379000
36037 533052 -1001 821913 1277000
42036 502947 -0600 811916 1079000
48034 422846 -0600 821816 1479000
```

Fig. 1 Example of Message

Of these parameters, the average of the mean relative humidity of the lowest three layers of the PE model (\overline{RH}_{48}), the average of the mean relative humidity of the 50-mb thick boundary layer of the PE model (\overline{RH}_{48}), the average of the values for the mean potential temperature of the boundary layer for 00Z taken at the mean pressure of the boundary layer and converted to degrees Fahrenheit (\overline{TB}_{00Z}), and the speed in knots of the average of the mean wind in the boundary layer of the PE model (\overline{FF}_{48}), were selected for study. The average minutes of sunshine possible at the Lubbock location for each 48 hour period was used as a seasonal parameter (\overline{SS}_{48}).

The FOUS68 messages from which \overline{RH}_{48} , \overline{RH}_{48} , \overline{TB}_{00Z} and \overline{FF}_{48} were obtained were output from 00Z data from April 8, 1974 through September 30, 1974 (146 cases).

3. PROCEDURES USED IN DETERMINING THE RELATIONSHIP BETWEEN FOUS68 DATA AND 48 HOUR OPEN-PAN EVAPORATION

Using the "Multiple Regression Screening Program" available in the Interactive Realtime Information System (IRIS), each of the four forecasted parameters and the seasonal parameter were correlated with the corresponding 48 hour open-pan evaporation total.

When each of the four parameters were compared with evaporation the following correlation coefficients (r) were obtained:

$$\begin{array}{ll} \text{for } \overline{RH}_{48} & r = -0.67 \\ \overline{RT}_{48} & r = -0.64 \\ \overline{FF}_{48} & r = 0.64 \\ \overline{TB}_{OOZ} & r = 0.46 \end{array}$$

The seasonal parameter, average minutes of sunshine possible at the Lubbock location, had a correlation coefficient:

$$\overline{SS}_{48} \quad r = 0.67$$

4. DEVELOPING AN OBJECTIVE METHOD FOR FORECASTING 48 HOUR OPEN-PAN EVAPORATION

Since the results of the investigation showed a valid relationship between the forecasted parameters \overline{RH}_{48} , \overline{RT}_{48} , \overline{TB}_{OOZ} and \overline{FF}_{48} , as well as the seasonal parameter \overline{SS}_{48} , and observed total open-pan evaporation for the same 48 hour period, the next step was to develop a method of using these parameters to forecast evaporation.

Because of the "deadline" atmosphere in which forecasts are made, the method should be relatively uninvolved and expeditious. With this in mind, only four parameters, \overline{RH}_{48} , \overline{TB}_{OOZ} , \overline{FF}_{48} , and \overline{SS}_{48} were used. \overline{RT}_{48} was omitted because of its probable high intercorrelation with \overline{RH}_{48} .

Using the screening program, the selected parameters were input and the following step by step relationship was developed, where:

$$\begin{array}{ll} E & = \text{the standard error of estimate} \\ R & = \text{the multiple correlation coefficient} \\ E_{048} & = \text{the estimate of the open-pan evaporation for 48 hours} \end{array}$$

The "Regression" program produces linear equations with an increasing number of terms, and by comparing E and R given for each step, the optimum relationship between the four selected parameters (predictors) and the observed 48 hour evaporation (predictand) can be developed.

Step #1

$$E_{0_{48}} = -3.52327 + .00526622 (\overline{SS}_{48})$$
$$E = .242213 \quad R = 0.671797$$

Step #2

$$E_{0_{48}} = -3.49559 + .00448702 (\overline{SS}_{48}) + .0528023 (\overline{FF}_{48})$$
$$E = .170812 \quad R = 0.853824$$

Step #3

$$E_{0_{48}} = -2.69547 + .00404433 (\overline{SS}_{48}) + .0363056 (\overline{FF}_{48}) - .00562679 (\overline{RH}_{48})$$
$$E = .145861 \quad R = 0.896539$$

Step #4

$$E_{0_{48}} = -2.70923 + .00415061 (\overline{SS}_{48}) + .0359659 (\overline{FF}_{48}) - .00576447 (\overline{RH}_{48})$$
$$- .00077782 (\overline{TB}_{00Z})$$
$$E = .146229 \quad R = 0.89676$$

It can be seen by comparing \bar{E} and R at Step #4 with those at Step #3, that addition of the predictor \overline{TB}_{00Z} adds little to the estimate of $E_{0_{48}}$. The Step #3 equation accounts for 80% of the variance in the predictand for the developmental sample. (NOTE: Reduction of variance is equal to the square of the correlation coefficient.)

To test the relationship in Step #3, a set of independent data were used. The predictors \overline{RH}_{48} and \overline{FF}_{48} were obtained from 00Z FOUS68 messages during the period May 9 through September 30, 1975. The predictor \overline{SS}_{48} was obtained from the sunshine charts developed for the Lubbock, Texas location.

Using the simplified equation:

$$E_{0_{48}} = -2.70 + .0040 (\overline{SS}_{48}) + .0363 (\overline{FF}_{48}) - .0056 (\overline{RH}_{48})$$

132 forecasts of the total open-pan evaporation for 48 hours ($E_{0_{48}}$) were made, and the forecast error with respect to the observed 48 hour evaporation was calculated.

The average observed 48 hour evaporation during the 1975 test period was .68 inch. The average forecast error (\bar{e}) for the period was .15 inch. This average error represents 22% of the average observed 48 hour evaporation.

Next the data were divided by month and the average error computed. The results were as follows:

- \bar{e} for May 1975 was .18 inch (14 forecasts)
- \bar{e} for June 1975 was .16 inch (30 forecasts)
- \bar{e} for July 1975 was .18 inch (30 forecasts)
- \bar{e} for August 1975 was .10 inch (30 forecasts)
- \bar{e} for September 1975 was .13 inch (28 forecasts)

For 132 forecasts, where e_{48} is the error for a 48 hour forecast, $e_{48} \leq .15$ inch 61% of the time, $e_{48} \leq .10$ inch 39%, and $e_{48} \leq .05$ inch 27%.

During May the bias was toward overforecasting $E_{0,48}$ 88% to 12%, that is, 88% of the errors were positive and 12% were negative. In June this bias was 74% to 26%. In July this bias was 79% to 21%, and in August 58% to 42%.

In September the bias was toward underforecasting $E_{0,48}$ by 76% to 24%.

5. CONCLUSIONS

It is felt that the data base used to develop the Step #3 equation was broad enough to produce a realistic relationship between the selected parameters and observed 48 hour open-pan evaporation. The results of the test using independent data indicate that this equation can be used to produce meaningful forecasts of 48 hour open-pan evaporation observed at the Texas A&M Research and Extension Center at Lubbock, Texas. Also, since the A&M Center is centrally located on the Texas South Plains, this method can be used to infer 48 hour evaporation at most points on the Texas South Plains.

6. ACKNOWLEDGEMENTS

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