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AUTOMATED FIRE WEATHER FORECASTS

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Boise, Idaho

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AUTOMATED FIRE WEATHER FORECASTS

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ABSTRACT. The Automated Fire Weather Forecast (AFWF) is a computer program designed to forecast seven of the eight fire weather forecast parameters issued daily during the fire-weather season at the Boise Weather Service Forecast Office (WSFO). The program uses the Limited Fine Mesh (LFM) prognosis and various dynamic meteorological equations and forecast studies to compute the forecast. The chief advantage of the AFWF is that it produces fire weather forecast guidance at least four hours before the main fire-weather forecast is issued to the fire-control agencies. This gives the fire-weather forecaster plenty of time to analyze and process the guidance forecast and extra time to concentrate on the more difficult forecast problems.

I. INTRODUCTION

The main fire-weather forecast issued by Boise WSFO for their fire-weather district (Figure 1) is at 4 p.m. MDT daily during the fire-weather season, June through October. The fire-weather district is divided into three forecast areas which are further broken into a total of seventeen zones. General worded forecasts are issued for each area and more specific numbered forecasts, in the form of eight fire-weather-related parameters, are issued for each zone (Figure 2). The eight parameters are the state of the weather at 1400 MDT for the next day; the temperature, humidity, wind speed, and 10-h time lag fuel moisture at 1400 MDT tomorrow; the Lightning Activity Level (LAL) for the period 1400 MDT to midnight this evening and for midnight-to-midnight tomorrow; and the precipitation duration from 1400 MDT today to 0600 MDT tomorrow and 0600-1400 tomorrow. Forecast values for seven out of these eight parameters are obtained from the AFWF output--precipitation duration being omitted. The seven parameters are tailored to one verifying fire-weather station in each of the seventeen zones (Figure 3). The computer is the Boise WSFO upper-air minicomputer which is operated by a Silent 700 electronic data terminal. The program language used is Single User Basic.

II. GENERAL PROCEDURE

The general procedure is to use 12-h and 36-h LFM 1200Z prognoses received from the National Meteorological Center (NMC) and to forecast the fire-weather observation for today (Day 1) and tomorrow (Day 2) at seventeen verifying stations. By subtracting the former from the latter, a change (trend) between the two days is computed for four of the seven parameters--temperature, relative humidity, wind speed, and 10-h time lag fuel moisture. The two-period LAL forecasts are based on each of the progs, respectively, while the state-of-the-weather forecast is based on the 36-h LFM prog. An example of the AFWF computer printout is given in Figure 4. This is the way that numbered forecasts are made by Boise WSFO and the way that they are entered into the Administrative and Forest Fire Information Retrieval and Management System (AFFIRMS) (Helfman, et al, 1975) time-share computerized system for the National Fire Danger Rating System (NFDRS) (Deeming, et al, 1977).

Meteorological data are extracted from the LFM 12- and 36-h progs by using a numbered grid scaled to the LFM maps (Figure 5). The grid has seven forecast points from which numbers for 50-kPa height, 70-kPa height, relative humidity, and sea-level pressure fields are written directly onto the AFWF worksheet (Figure 6). The forecaster, or forecaster aide, only takes a few minutes to move the grid from panel to panel on each prog while recording the data onto the AFWF worksheet. This, along with the month and day of each prog, is the sole input into the computer program. Since the LFM prog series is received by 1100 MDT on the forecast day, the computer run can easily be made by 1200 MDT--four hours before the scheduled issuance of the main fire-weather forecast.

III. INITIAL MANIPULATION OF DATA

The first calculation performed by the computer is to adjust the gridded data to a more usable form for each of the seven grid points. By use of the gridded height fields extracted from the LFM progs and the hypsometric formula, the temperature at 85 kPa and 70 kPa can be computed as follows:

$$T_{85} = \frac{(H_7) \times .34}{\ln {}^{P_s}/_{700}} \qquad T_{70} = \frac{(H_5) \times .34}{\ln {}^{P_s}/_{500}} \qquad (1)$$

where H_7 and H_5 are the geopotential heights at the 70-kPa and 50-kPa levels, respectively, and P_s is the sea-level pressure.

Assuming a standard atmospheric lapse rate of 3.5°F/1000 feet, which approximates 2°C/1000 feet, and a difference of 8000 feet between the 70-kPa and 50-kPa surfaces, the 50-kPa temperature can be approximated sufficiently well by subtracting 16°C from the 70-kPa temperature.

Next, the dew-point temperatures at the 85-kPa and 70-kPa levels need to be calculated. The only moisture input into the program is the relative humidity from the 70-kPa map panel on the LFM progs. This relative humidity is the mean relative humidity in the lowest three tropospheric layers of the LFM model (Forecasters Manual 1976). This corresponds to the 1000-450 millibar interval. In order to keep the technique as simple and efficient as possible, it's assumed that this relative humidity is the humidity at the 70-kPa level. Since the temperature at the 70-kPa level has already been computed, the Clausius-Clapeyron equation can be applied to compute the dew-point temperature.

$$D_pT_7 = \frac{-5420.51}{\ln\left(RH \times e^{(21.65 - 5420/T)}\right) - 21.65} \quad (2)$$

RH = relative humidity at 70 kPa
T = temperature at 70 kPa

Using the dew-point temperature lapse rate of 1°F/1000 feet or .55°C/1000 feet and a difference of 5000 feet between the 70-kPa and 85-kPa levels, the 85-kPa dew-point temperature can be approximated by adding 3°C to the just computed 70-kPa dew-point temperature.

Finally, the K-stability index (George, 1960) is computed from the above calculated data.

K stability = (85-kPa Temperature + 85-kPa dew point) - (70-kPa dew-point depression) - (50-kPa temperature) (3)

The above calculations are computed from the 12-h LFM prog for Day 1 and from the 36-h LFM prog for Day 2. These progs verify at 1800 MDT on each of the days, respectively. At this point, the following meteorological data are available for use at each of the seven grid points for the two days.

1. Sea-level pressure.
2. Relative humidity at 70 kPa.
3. Temperature at the 85-kPa, 70-kPa, and 50-kPa levels.
4. Dew-point temperature at the 85-kPa and 70-kPa levels.
5. The K-stability index.

IV. FORECASTING THE SEVEN FIRE WEATHER PARAMETERS

The above meteorological data are now used to forecast the seven fire-weather parameters. Each of the parameters will be discussed separately. For the convenience of presentation, the forecast parameters are discussed in a different order than they appear on the forecast form (Figure 2). Radians, not degrees, are used in all trignometric functions.

1. Lightning Activity Level (LAL)

Lightning Activity Level is a numerical rating of 1 to 6, keyed to the start of thunderstorms and the frequency and character of cloud-to-ground lightning, forecast or observed on a rating area (an area 25-30 miles in radius) during a rating period (Deeming, et al, 1977). It's a major input into the NFDRS. Only LALs 1 to 5 are considered here. LAL 6 is omitted, because by definition, although it's a special and significant event characterized by a "lightning bust", it's a rare event and does not fit systematically into the other LAL categories.

The forecast of LAL is based on a Boise WSFO fire weather forecast study by McCoy and Gift (1974). The study found a fair correlation between K-stability indexes, daylight cloud cover, and LAL. To allow for length-of-day change and other seasonal effects, McCoy and Gift developed a separate prediction equation for each of the fire weather months of June through September. Due to limited storage in the Boise minicomputer and to simplify the programming, an equation, to cover not only the above four months but also May and October, was written. In addition, McCoy and Gift found the J. R. Sims cloud-cover forecasts (Sims, 1973), although not the best possible, a good predictor for cloud-cover amount over Idaho. The relative-humidity and vertical-velocity forecasts from the NMC LFM FOUS messages were used to forecast Sims' cloud-cover amount. Since a moisture input that can be related directly to cloud cover is already in the program, namely the relative humidity at 70 kPa which in reality is the mean humidity in the 100-45-kPa interval, the more involved Sims' cloud-cover technique was abandoned. The authors feel very little, if anything, is lost in this decision because the dominating term in the McCoy/Gift LAL equation is by far the K-stability index term.

The LAL forecast equation is:

$$LAL = \underbrace{(0.1K}_{\text{K-stability term}} \times \underbrace{COS\ (.01\times((M\times30) + D - 210)))}_{\text{Time-of-year term}} + \underbrace{SIN^3\ 2\ (RH - .1)}_{\text{cloud-cover term}} \qquad (4)$$

K = K-stability index.
M = Month of year (numbered 5 to 10).
D = Day of month (numbered 1 to 31).
RH = Relative humidity at the 70-kPa level.

The K and RH values are an average of surrounding K and RH values computed at each of the seven grid points. Depending on station location, either one, two, three, or four, surrounding grid points are used to compute the average values. Similar averaging of the other grid-point variables is performed before they are used in subsequent forecast equations.

Possible values for the cloud-cover and time-of-year terms are tabulated below:

Cloud Cover

RH	$\sin^3 2(RH - .1)$
.1	0
.2	0
.3	.1
.4	.2
.5	.4
.6	.6
.7	.8
.8	1.0
.9	1.0

Time of Year

Month/Day	$\cos(.01 \times ((M\times30) + D - 210))$
May 1	.83
May 15	.90
June 1	.96
June 15	.99
July 1	1.00
July 15	.99
August 1	.95
August 15	.90
September 1	.82
September 15	.73
October 1	.61
October 15	.50
October 31	.35

It can be readily seen that as the amount of cloud cover increases, i.e., the moisture in the 100- to 45-kPa interval increases, the more contribution the cloud-cover term will have toward increasing the LAL forecast.

The time-of-year term does little to modify the LAL forecast during the majority of the summer. However, as the daylight hours decrease in the fall, it scales the LAL forecast down rapidly.

Before the K-stability index is used in the LAL equation, a correction for elevation is added on. This is to take into account that mountainous terrain acts as an elevated heat source. The correction is (h/1000 x 3), where h is the station elevation in meters.

LAL forecasts are computed for two periods--1400 MDT to midnight on the day of the forecast and from midnight to midnight on the following day. The first period LAL is forecast from the 12-h LFM prog and corresponds to "L1" in the computer printout. The second period LAL forecast comes from the 36-h LFM prog and corresponds to "L2" in the printout.

2. State of the Weather.

The state-of-the-weather forecast is a forecast of general weather at the 1400 MDT observation time tomorrow (Day 2). Essentially, it's a twenty-four-hour terminal forecast. State-of-the-weather categories are:

0 -- Clear (less than 1/10 of sky cloud covered)
1 -- Scattered clouds (1 to 5 tenths cloud coverd)
2 -- Broken clouds (6 to 9 tenths cloud covered)
3 -- Overcast (more than 9 tenths cloud covered)
4 -- Foggy
5 -- Drizzling or misting
6 -- Raining
7 -- Snowing or sleeting
8 -- Showers (in sight or reaching ground at station)
9 -- Thunderstorm (lightning seen or thunder heard).

Categories 4, 5, and 7 are not forecast by the AFWF. The occurrence of these is fairly rare. It is hoped, however, when larger computer storage is available, that category 7 can be added. Since upper-air temperatures are calculated, a freezing level can be computed and then evaluated against the elevation of each verifying station.

On many days in the summer, air-mass characteristics of stability and moisture take on a greater importance than surface and upper-air charts (MacDonald, 1974). With this in mind, it was decided to make the state-of-the-weather forecast dependent upon the LAL forecast, which is mostly a measure of atmospheric stability and the relative humidity in the 100-45-kPa interval. The state of the weather is chosen by matching the second period LAL Forecast, L2, with the forecast 70-kPa relative humidity. For example, for a LAL forecast of 3 and a relative humidity of 40% or less, the state-of-the-weather category 1 is forecast for 1400 MDT tomorrow. If the humidity forecast is greater than 40% but less or equal to 60%, category 2 is forecast. If the humidity for a station averages out to between 60% and 75%, then category 8 is forecast. If between 75% and 85%, then category 9 is printed out. If above 85%, then category 6, rain, is forecast. Similar relative humidity inquiries are performed on the other LAL categories when they are forecast.

Since the LAL and relative-humidity forecast are based on the 36-h LFM prog, the forecaster should view the state-of-the-weather forecast as the general weather for tomorrow afternoon and evening, and not necessarily as the terminal weather forecast at 1400 MDT. This becomes more evident on days when frontal movements and vertical velocities associated with upper-air troughs come into play. Remembering these limitations will obviously put the state-of-the-weather forecast in a more real context.

3. Temperature.

The surface temperature forecast is calculated by adjusting the already computed 85-kPa temperature to the altitude of each verifying station. This temperature is then modified by the amount of solar radiation expected on the particular day. The amount of solar radiation available for warming on any day is dependent upon the time of the year, the amount of cloudiness, and the stability of the lower atmosphere. This technique was originated by Olsen (1969).

The temperature equation reads:

$$T = T_{85} + \underbrace{\left(\frac{1500-h}{1500}\right) \times 10}_{\text{Altitude Correction}} + \Big[\underbrace{2A}_{\text{Solar Radiation}}\ \underbrace{(1.09 - RH^2)}_{\text{Cloud Cover}} \times \underbrace{(1 - \cot\delta)}_{\text{Stability}}\Big]^{1/2} . \qquad (5)$$

T_{85} = Temperature at the 85-kPa level.

h = Station elevation in meters.

A = .7(80 + 60sin(.02(M(30)) + D − 120)), solar radiation variable.

M = Month of year
D = Day of month

RH = Mean relative humidity in the 100- to 45-kPa interval.

δ = The acute angle between the 85-kPa level and the line drawn between the 85-kPa and 70-kPa temperatures (Figure 7).

$\cot\delta$ = $((T_{85} - T_{70})/17)$, the slope of the temperature sounding between the 85-kPa and 70-kPa temperatures. A measure of the stability of the layer (Figure 7).

The ideas behind modifying the amount of solar radiation available by cloud cover and the stability of the lower atmosphere are straightforward. As cloud cover increases, the amount of sunshine received is reduced; thus, lowering the maximum surface temperature. The less stable the lower atmosphere, the more mixing of the lower atmosphere; thus, the more energy needed to attain a given maximum surface temperature.

Looking closer at the cloud-cover term, it's readily seen that it does little to alter the solar radiation until at least five-tenths of the sky is cloud covered. In like manner, the stability term only becomes significant when the 85-kPa to 70-kPa lapse rate exceeds the standard atmospheric lapse rate and approaches the dry adiabatic lapse rate. The stability term is conservative. At the extremes--an isothermal lapse rate on Day 1 versus a superadiabatic lapse rate on Day 2--the stability term under clear skies on July 1st would cause a surface maximum-temperature change of 23.4°F.

The above temperature calculation is made from each of the two progs for each verifying station for Day 1 and Day 2. Day 1 is then subtracted from Day 2 to obtain the forecast maximum-temperature change.

4. Relative Humidity.

The first step in forecasting the surface relative humidity is to adjust the already calculated 85-kPa dew-point temperature to the altitude of each verifying station. This is accomplished by applying an altitude correction term to the 85-kPa temperature:

$$\text{Surface dew-point temperature} = \text{85-kPa dew point} + ((3000 - h)/3000)) \times 10 \qquad (6)$$

h = station elevation in meters

The Clausius-Clapeyron equation is used to combine the surface dew-point temperature with the previously calculated surface dry-bulb temperature to arrive at the relative humidity.

$$\text{Surface RH} = \frac{\ell^{5420.51(.00366 - 1/T_{\alpha}) + 1.81}}{\ell^{5420.51(.00366 - 1/T) + 1.81}} \times 100 \qquad (7)$$

T_d = surface dew-point temperature
T = surface dry-bulb temperature
ℓ = the exponential function, 2.7138

Again, the above relative humidity calculation is made for each verifying station for Day 1 and Day 2. The Day 1 humidity value is subtracted from the Day 2 value to obtain a forecast relative humidity change.

5. 10-h Time Lag Fuel Moisture.

Fosberg (1977) provides a good discussion on the basic concepts behind fuel moisture calculations in his paper on 10-h time lag fuel moisture forecasting. It's noted that the moisture content of the 10-h time lag fuel moisture sticks is dependent upon the ambient air temperature, the relative humidity, the wind speed, and the precipitation duration and amount in the twenty-four hours before the weather observation. Of all these, relative humidity and precipitation duration play the dominant role in determining the moisture content of the 10-h time-lag fuels.

Cramer (1964) and Fosberg both developed forecast models for forecasting the 10-h time lag fuel moisture sticks. Cramer chose to ignore the effects of precipitation while Fosberg applies a singular precipitation correction of 15 grams if precipitation is forecast in either of the 1400-0600 MDT or 0600-1400 MDT time periods before the 1400 MDT observation time.

The difficulty in forecasting precipitation duration and amount is self-evident, especially when the variability in areal extent and intensity of summertime shower regimes in the Boise fire weather district are considered. Thus, it was decided to use relative humidity as the sole predictor of the 10-h time lag fuel moisture.

This was accomplished by writing an equation for Fosberg's table of potential 10-h time lag fuel moisture values. In analyzing the table, it was decided to ignore the effects of temperature. Looking at all humidity values (except 100%), it's observed that the fuel moisture will change only 2 grams or less as the temperature changes from 30°F to 100°F. For the purposes of the AFWF, this change was considered insignificant. The equation is:

$$\text{10-h Time Lag Fuel Moisture} = \ell^{3RH} \qquad (8)$$

ℓ = 2.7138, the exponential function
RH = surface relative humidity

This calculation is performed for each verifying station for Day 1 and Day 2. The difference in the two is the 10-h time lag fuel moisture forecast change.

Although precipitation duration and amount are disregarded in the AFWF, there are forecast guides available to assist fire weather forecasters in applying this correction to the fuel moisture forecast. Gift (1977) developed a guide to forecast the change in the 10-h time lag fuel moisture due to expected precipitation (Figure 8). This easy, step-through procedure can be applied manually to the AFWF fuel moisture change.

Another problem arises in drying out the fuel moisture sticks after precipitation occurs. Boise WSFO fire weather forecasters have had success in using Cramer's fuel moisture composite aid (Figure 9) to dry out the fuel moisture sticks after precipitation. Again, this is a simple manual calculation which can be applied for each fire weather station as the need arises.

6. <u>Wind Speed</u>.

The wind-speed forecast is based on the surface-pressure gradient, the transfer of momentum of upper-level winds to the surface, and the normal afternoon upslope winds at the seventeen verifying stations.

The normal afternoon upslope winds were determined by looking up past daily weather maps on summer days when surface-pressure gradients over the Boise fire weather district were at a minimum. Ten such daily weather maps were used. The observed wind speed and direction for these days were then obtained from the actual fire weather observations for each of the seventeen verifying stations. These were averaged, and given a slight empirical modification. The upslope winds were then broken down into $\vec{u}$ and $\vec{v}$ components. In the final wind equation these components are modified by the forecast cloud cover. A list of the seventeen stations and their upslope winds are in Figure 3.

The transfer of momentum of upper-level winds to the surface is a function of the stability of the lower atmosphere and the magnitude of the winds at the 70-kPa level. The lower atmospheric stability is determined as in the section on temperature. Again, it's a function of the temperature difference between the 85-kPa and 70-kPa levels.

The 70-kPa wind speed is computed by using the 70-kPa height field from the numbered grid (Figure 5) and the geostrophic wind equation. The 70-kPa geostrophic wind speeds are calculated at points A, B, and C shown on the numbered grid in Figure 5.

The geostrophic wind is scaled down by a transfer of momentum coefficient. This coefficient is determined by how susceptible each verifying station is to receiving winds aloft, i.e., its elevation and whether it's located in a wide open valley, such as the Snake River Valley, or in a "tight-knit" mountain enclosed valley. The proximity of the fire weather station to points A, B, or C determines which geostrophic wind is used in that station's wind-speed calculation.

As with the geostrophic wind, surface-pressure gradients are computed only for points A, B, and C. The pressure gradient used is based on each station's proximity to points A, B, or C.

A $\vec{u}$ and $\vec{v}$ component of the surface-pressure gradient is calculated for points A, B, and C by using the sea-level pressure data from the seven grid points. Since most weather stations are more susceptible to stronger wind speeds from certain directions, the $\vec{u}$ and $\vec{v}$ components are multiplied by constants tailored to take this into account. These components are then adjusted by the $\vec{u}$ and $\vec{v}$ upslope components to form resultant $\vec{u}$ and $\vec{v}$ components whose magnitude is calculated.

This last wind speed is adjusted by the transfer of momentum of the 70-kPa geostrophic wind to arrive at the wind-speed forecast. Forecasts are computed for Day 1 and Day 2, the difference being the forecast change in wind speed.

The formulas are as follows.

$$\text{Wind Speed} = [\{c_x(P_{xi}-P_{xj}) + \vec{u}(1.09-RH^2)\}^2 + \{c_y(P_{ym}-P_{yn}) + \vec{V}(1.09-RH^2)\}^2]^{1/2} + [89\{\frac{(2A(1-\cot\delta))^{1/2}}{(3000(1-\cot\delta)}\} + \frac{h}{3000}] Vg^2\mu.$$

Where,

c_x, c_y	constants used to adjust the strengths of the x and y components of the pressure gradient.
P_{xi}, P_{xj} P_{ym}, P_{yn}	the values of the surface pressure at points i, j, m, n.
$\vec{u}$, $\vec{v}$	x and y components of the upslope wind.
RH	relative humidity at the 70-kPa level.
A	equals $7(80 + 60\ SIN(M(30) + D-120)(1.09-RH^2)$, the expected solar radiation.
$\cot\delta$	slope of temperature sounding between the 85-kPa and 70-kPa levels.
h	station elevation in meters.
Vg	magnitude of the geostrophic wind

$$Vg = \frac{g}{f}\left[\frac{\{(G_{xi}-G_{xj})^2 + (G_{ym}-G_{yn})^2\}^{1/2}}{d}\right]$$

where, g = the force of gravity.
f = Coriolis effect at Lat. 43°18'30"

G_{xi}, G_{xj} G_{ym}, G_{yn} = values of 70-kPa heights at points i, j, m, n.

d = distance between grid points

μ transfer of momentum coefficient.

V. VERIFICATION

Each day during the 1977 fire weather season, the fire weather forecaster filled out an AFWF worksheet using the 12-hour and 36-hour LFM progs from the 12Z NMC computer run and the scaled, gridded overlay map. Obviously, those days were omitted on which the LFM progs were not received or were only partially available. The 1977 season's data were then run through the AFWF program in the fall and winter of 1977-78.

Two program runs were made. After verification of the first run, minor changes were made to some equations. A second computer run and verification were then conducted.

It should be noted that two somewhat different LFM progs were used in verifying the AFWF. On September 1, 1977, the LFM prog received a reduction in grid length. This "new" prog was coined the LFM-II prognosis. Thus, the 1977 verification incorporated three months (June-August) of the "old" LFM prog and one month (September) of the LFM-II prog. It will be interesting to see if any improvement in the AFWF will be noted in the 1978 fire weather season when the LFM-II progs will be used for the entire season.

The AFWF was verified against actual weather observations taken across the Boise fire weather district in 1977. A list of the monthly and seasonal verification for each of the seventeen verifying stations follows. The numbers under the "L1" and the "L2" headings are the percentage of the AFWF LAL forecasts which were either equal to or within one category of the observed LAL. All other numbers are the average AFWF error versus the actual observed weather observation. No monthly or seasonal verification for the individual stations was done for "W", the present weather parameter.

AFWF Verification for 1977

Code: T = Temperature, R = Relative humidity, S = Wind Speed, L1 = Lightning Activity Level 1400 MDT-midnight, L2 = Lightning Activity Level midnight-midnight (Day 2), F = 10-h Time Lag Fuel Moisture

	McCall						Chamberlain Basin					
	T	R	S	L1	L2	F	T	R	S	L1	L2	F
June	5.1	13.0	3.4	85	70	5.3	4.3	10.4	4.7	94	78	4.3
July	7.1	14.7	4.1	82	79	4.0	6.9	13.2	4.5	89	89	3.4
Aug.	6.4	14.0	4.4	71	68	5.4	5.4	15.1	6.8	69	83	4.1
Sept.	4.6	14.4	3.0	91	68	9.9	6.4	15.2	5.3	82	76	4.6
Season	6.0	14.1	3.8	82	72	5.9	5.8	13.6	5.4	84	84	3.9

	Cascade						Island Park					
June	5.0	12.8	3.0	82	71	4.8	5.7	14.7	4.9	75	83	3.9
July	7.2	11.2	3.2	90	90	3.2	6.7	16.7	4.4	83	83	4.5
Aug.	6.1	11.1	2.9	84	84	4.6	5.7	9.8	2.4	90	76	3.1
Sept.	5.0	16.7	3.3	92	67	5.7	4.5	13.3	3.5	84	84	3.3
Season	6.0	12.7	3.1	87	79	4.5	5.6	13.4	3.6	85	82	3.7

Black Rock

	T	R	S	L1	L2	F
June	5.3	7.8	3.8	92	100	2.5
July	5.8	10.0	3.6	88	83	3.0
Aug.	6.1	14.3	4.7	67	74	5.0
Sept.	5.6	10.5	4.6	100	83	4.1
Season	5.8	11.1	4.2	85	83	3.8

Lester Creek

	T	R	S	L1	L2	F
June	3.2	5.3	2.9	67	87	3.1
July	6.6	14.4	3.0	79	69	3.8
Aug.	6.2	11.4	4.2	77	74	3.9
Sept.	4.2	11.1	4.1	87	87	3.1
Season	5.4	11.2	3.6	79	78	3.6

Burns Junction

	T	R	S	L1	L2	F
June	3.2	6.0	4.6	75	75	1.1
July	5.6	10.5	6.5	76	72	1.0
Aug.	5.2	10.0	6.4	52	52	2.3
Sept.	5.3	12.3	7.2	95	50	4.4
Season	5.0	10.0	6.3	73	60	2.2

Salmon

	T	R	S	L1	L2	F
June	5.1	10.1	7.4	79	68	3.2
July	6.6	14.8	4.3	68	79	2.9
Aug.	5.6	12.3	4.6	77	87	3.0
Sept.	6.2	13.1	3.4	95	74	2.5
Season	5.9	12.8	4.9	77	77	2.8

Challis

	T	R	S	L1	L2	F
June	5.6	11.5	3.3	94	89	4.4
July	6.8	14.4	2.8	90	90	5.3
Aug.	7.2	10.8	2.4	87	77	3.1
Sept.	6.2	11.6	4.1	83	75	3.4
Season	6.5	12.1	3.1	88	82	4.1

Stanley

	T	R	S	L1	L2	F
June	5.5	9.6	3.6	79	86	3.1
July	6.9	15.9	4.8	86	93	3.3
Aug.	5.7	14.2	4.8	87	81	4.7
Sept.	4.9	15.4	5.3	83	79	6.6
Season	6.1	14.5	4.8	85	85	4.6

Boise

	T	R	S	L1	L2	F
June	3.6	10.6	2.7	89	85	3.4
July	6.2	11.2	2.6	83	86	3.9
Aug.	5.8	6.2	3.4	87	81	1.2
Sept.	6.0	14.0	4.7	96	83	5.0
Season	5.4	10.3	3.3	88	84	3.3

Notch Butte

	T	R	S	L1	L2	F
June	3.9	5.7	9.5	76	71	1.5
July	7.0	12.1	6.9	83	86	3.0
Aug.	5.5	9.1	5.5	73	73	1.6
Sept.	5.1	13.7	7.2	86	68	3.0
Season	5.5	10.3	7.1	80	76	2.3

Crystal Ice Caves

	T	R	S	L1	L2	F
June	4.2	9.4	5.2	50	56	1.5
July	6.5	8.3	4.5	72	86	2.6
Aug.	5.8	7.8	5.2	65	71	2.0
Sept.	5.9	13.2	3.9	86	95	3.7
Season	5.7	9.1	4.7	69	79	2.4

Rock Creek

	T	R	S	L1	L2	F
June	4.8	8.1	3.3	93	87	1.6
July	6.0	15.2	3.4	86	86	3.7
Aug.	5.0	9.9	3.7	87	81	3.1
Sept.	7.0	20.9	3.5	87	83	4.1
Season	5.7	13.6	3.5	88	84	3.3

Montpelier

	T	R	S	L1	L2	F
June	4.4	7.2	5.1	100	80	0.8
July	6.1	11.9	2.3	74	84	1.8
Aug.	6.2	12.1	4.0	76	57	3.4
Sept.	4.8	11.5	2.0	92	92	5.8
Season	5.6	10.9	3.5	80	73	2.6

Big Piney

	T	R	S	L1	L2	F
June	5.1	9.2	7.9	75	92	3.3
July	5.2	10.6	6.1	75	83	2.9
Aug.	5.8	11.2	4.4	79	86	3.3
Sept.	6.9	11.6	7.0	87	83	2.6
Season	5.8	10.8	6.1	79	85	3.0

Mammoth

	T	R	S	L1	L2	F
June	6.2	15.2	5.5	88	65	5.2
July	6.7	12.3	4.6	62	72	3.5
Aug.	6.8	13.0	4.7	55	69	7.6
Sept.	5.6	18.6	3.2	88	81	6.2
Season	6.5	14.0	4.6	69	71	5.5

The seasonal AFWF temperature errors were fairly consistent among the seventeen stations. Most stations had seasonal errors between 5.5°F and 6.0°F. The extremes were 5.0°F at Burns Junction and 6.5°F at Mammoth and Challis.

The relative humidity errors show seasonal extremes of 9.1% at Crystal Ice Caves and 14.5% at Stanley. The lower elevation stations had the smaller relative humidity error compared to the higher elevation stations. This may be due to a "moisture lag" at higher elevations. When the LFM prog begins drying out the atmosphere, in reality, it takes a longer time to dry out the higher elevations as compared to the lower elevations. Reasons for this are that the mountain stations are more susceptible to precipitation, in occurrence, areal variability, and amount, which tends to distort the moisture field; mountain stations have more convective cloud activity to restrict drying as compared to the lower elevations; and there is normally less exposure to the free air drying wind, especially in "tight-knit" mountain valleys, which builds a longer lag into the drying period.

The seasonal wind-speed errors are considered outstanding. The greatest wind-speed errors of 6-7 mph occurred only at the normally windier stations. After another season of verification, a change in the constants in these stations' wind equations may be in order.

Eighty percent of the LAL forecasts for all seventeen stations were within one category of the observed LAL. This is felt to be adequate considering the subjectivity involved in observing LAL. The Fire Data (FIRDAT) program (Furman and Helfman, 1973) can be interrogated to observe the past history of each station's lightning activity levels. Thus, a "lightning climatology" can be developed for each station to modify their LAL forecasts in the AFWF. This hopefully will be incorporated into the AFWF for 1979.

The 10-h time lag fuel moisture errors are good considering that relative humidity is the only predictor. This speaks for the persistent and dry summer weather across the Boise fire weather district.

Since the AFWF only puts the LFM progs into fire weather terminology, its performance is only as good as the LFM progs and its interpreting technique. Thus the weaknesses and strengths of these two systems should be spelled out to the forecaster. For example, our experience at Boise WSFO indicates that the LFM progs often tend to force West Coast troughs inland too fast or too deeply. This results in excessively low height fields and distorted moisture fields. This obviously would affect the AFWF output. On the other hand, when the LFM prog is correct on the movement and intensity of inland moving troughs, the AFWF gives an admirable account of the resultant weather change.

Summer shower regimes in the Boise fire weather district often originate with moisture moving north from the Desert Southwest. Looking at the AFWF grid in Figure 5, the southernmost grid points are in southwest Wyoming and extreme northern Nevada. The forecaster should be sure that the LFM progs have the moisture field initialized correctly and that its northward movement is at the proper speed. July 24, 1977 was a good example of northward moving moisture not caught by the LFM progs. The LFM prog indicated a dry and warmer forecast. Occasional showers fell over about half of the Boise fire weather district with some clouds and light shower activity elsewhere. This corresponded to the largest daily error recorded by the AFWF in 1977.

This all points to the importance of the man-machine mix concept. The forecaster must first evaluate the overall weather situation against the expected guidance performance of the LFM progs before putting faith into the AFWF. Of course, due to the early reception of the AFWF guidance, the forecaster will have plenty of time for this evaluation.

The following table shows the difference between the Boise WSFO forecast staff and the AFWF during the 1977 fire season. The "L1" and "L2" categories are combined into one parameter, "L", for this comparison.

AFWF and Boise WSFO in 1977

	T	R	S	L	F
AFWF	5.8°F	12.0%	4.4 mph	80%	3.6 gms.
Boise WSFO	4.5°F	10.3%	3.7 mph	83%	3.1 gms.
Difference	1.3°G	1.7%	0.7 mph	3%	0.5 gms.
% Improvement	22.0%	14.0%	15.0%	3%	14.0%

A major weakness of the AFWF is its handling of relative humidity and temperature when showery weather hangs in over the fire weather district for several days. The LFM and AFWF grid lengths are too large to completely handle the variability that relative humidity and temperature experience in such varying precipitation and cloud-cover regimes. In these cases, the fire weather forecaster would be wise to use the AFWF with caution.

Since the Boise WSFO does not verify the "present-weather" forecast, the "W" parameter, no evaluation is presented. However, the AFWF "present-weather" forecasts were compared to the actual observations on a seasonal basis. They were broken down into the number of wet and dry forecasts that verified. Seventeen percent of the wet forecasts verified and 97 percent of the dry forecasts verified. The low verification of the wet forecasts rests in the limited forecasting technique used by the AFWF and in the fact that precipitation must be observed at the 1400 MDT observation time for a wet AFWF to verify. Such verifying stringency speaks for itself.

VI. CONCLUSION

For the first time, the Automated Fire Weather Forecasts provide the fire weather forecaster with a definite set of fire weather forecast guidance. Its comparable performance with the Boise WSFO forecast staff during the 1977 fire weather season dictates its usefulness as fire weather forecast guidance. In addition, the early reception of the AFWF guidance provides plenty of time to evaluate it and to investigate other synoptic and subsynoptic weather events that may be affecting the fire weather district during the forecast period.

VII. EXTENSION

A more advanced technique to develop fire weather forecast guidance is to use Model Output Statistics (MOS) (Glahn, et al., 1972a) for each of the seventeen verifying stations. With the advent of AFFIRMS and FIRDAT, station climatology for Fire Weather/Fire Danger stations is being compiled for use in the MOS technique. However, the time and computer capability for such a task are not available at the WSFO level. Until then, modifications and sophistications of the current AFWF equations can be made as experience is developed with the system.

VIII. ACKNOWLEDGMENTS

Special acknowledgments go to Sandra Ferderber for her typing of this paper; to Donna Evans and Rebecca Bates who helped process the verifying data; to John C. Plankinton, Jr., whose programming expertise helped in the writing of the AFWF program; to John Gilbert whose general assistance with the Boise WSFO minicomputer proved most valuable; and to Leonard W. Snellman for his useful comments.

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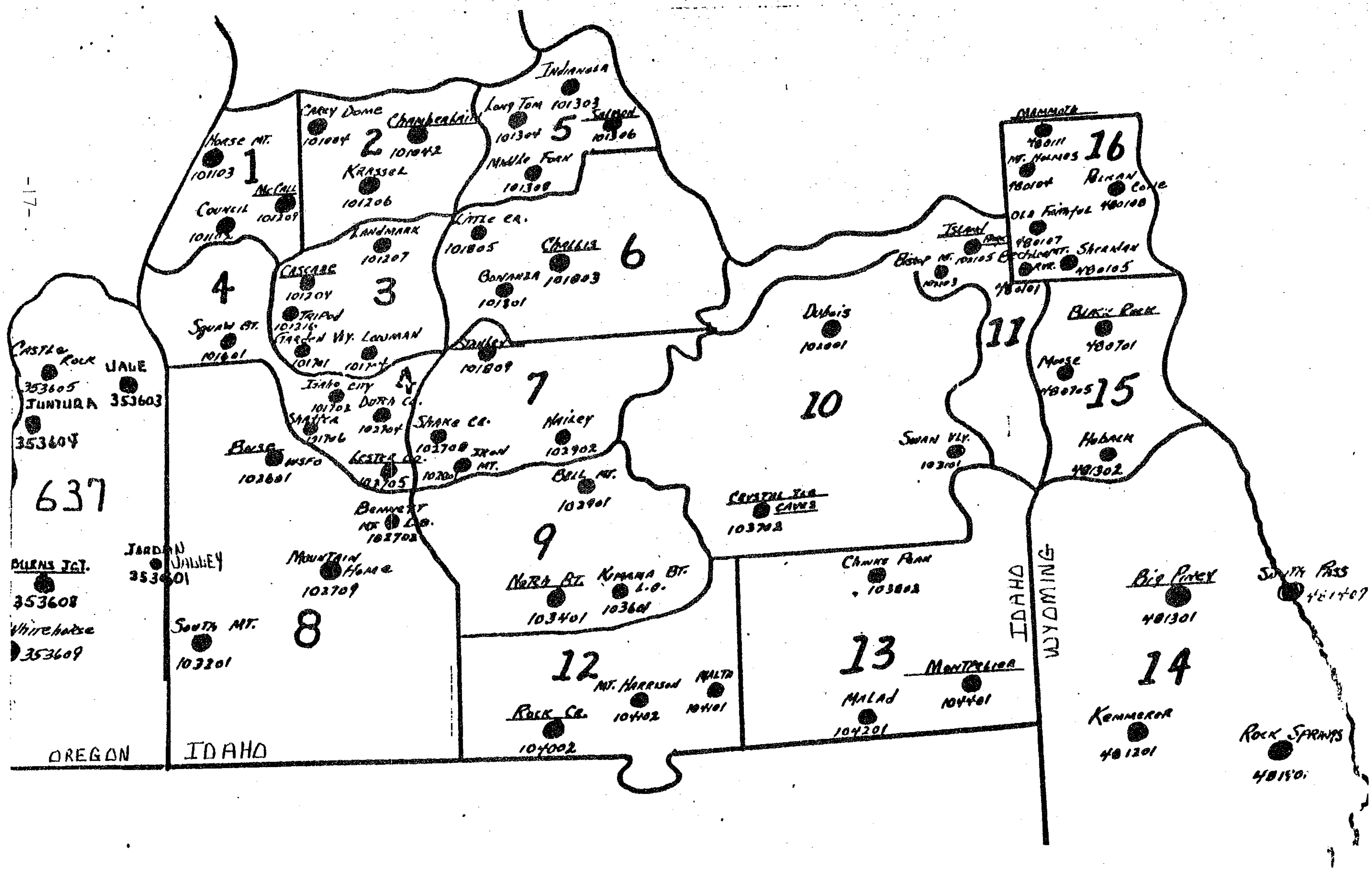


FIGURE I. MAP OF BOISE FIRE WEATHER DISTRICT. UNDERLINED STATIONS IN EACH ZONE ARE THE ZONE'S VERIFYING STATION.

NATIONAL WEATHER SERVICE FORECAST OFFICE, BOISE, IDAHO (date)______
AFTERNOON FIRE WEATHER FORECAST ISSUED 1600 MDT (day)__________

AREA I (ZONES 411-416)

TONIGHT...

__________(DAY)

AIR DISPERSAL... TONIGHT ________ TOMORROW ________ LAL ______

ZONE			10 WX	14 TMP	19 RH	23 WND	PRECIP. D-1	D-2	TEMP MAX	MIN	RH MAX	MIN	28 AL	32 TL	36 FM
411	4	13					O	O	M	M	M	M			
412	4	13					O	O	M	M	M	M			
413	4	13					O	O	M	M	M	M			
414	4	13					O	O	M	M	M	M			
415	4	13					O	O	M	M	M	M			
416	4	13					O	O	M	M	M	M			

AREA II (ZONES 408-410 & 637)

TONIGHT...

__________(DAY)

AIR DISPERSAL... TONIGHT ________ TOMORROW ________ LAL ______

ZONE			10 WX	14 TMP	19 RH	23 WND	PRECIP D-1	D-2	TEMP MAX	MIN	RH MAX	MIN	28 AL	32 TL	36 FM
637	6	13					O	O	M	M	M	M			
408	4	13					O	O	M	M	M	M			
409	4	13					O	O	M	M	M	M			
410	4	13					O	O	M	M	M	M			

AREA III (ZONES 401-407)

TONIGHT...

__________(DAY)

AIR DISPERSAL... TONIGHT ________ TOMORROW ________ LAL ______

ZONE			10 WX	14 TMP	19 RH	23 WND	PRECIP. D-1	D-2	TEMP MAX	MIN	RH MAX	MIN	28 AL	32 TL	36 FM
401	4	13					O	O	M	M	M	M			
402	4	13					O	O	M	M	M	M			
403	4	13					O	O	M	M	M	M			
404	4	13					O	O	M	M	M	M			
405	4	13					O	O	M	M	M	M			
406	4	13					O	O	M	M	M	M			
407	4	13					O	O	M	M	M	M			

IDAHO STATE LANDS DEPT. - BOISE PHONE 384-3488

	WX	TMP	RH	WND	AL	TL	FM
GARDEN VALLEY							
COUNCIL							

ABSOLUTE VALUES - NOT TRENDS
USE WORDED FCST FROM AREA III

FIGURE 2. WSFO, BOISE FIRE WEATHER FORECAST FORM.

Fire Weather Zone	Verifying Station	Elevation (meters)	Upslope Wind (mph)	
401	McCall	1508	SW	3.7
402	Chamberlain Basin	1730	SW	6.8
403	Cascade	1424	W	4.3
404	Lester creek	1448	SW	6.5
405	Salmon	1290	SW	5.6
406	Challis	1553	NE	2.6
407	Stanley	1886	N	6.3
408	Boise	851	NW	6.9
409	Notch Butte	1272	SW	6.2
410	Cyrstal Ice Caves	1548	SW	4.3
411	Island Park	1885	SSW	5.9
412	Rock Creek	2010	NW	7.2
413	Montpelier	1783	S	4.5
414	Big Piney	2046	SW	5.1
415	Black Rock	2040	W	4.2
416	Mammoth	1872	NW	3.2
637	Burns Junction	1185	NE	8.0

FIGURE 3. VERIFYING STATIONS, ELEVATIONS, AND UPSLOPE WINDS.

```
◆READY
5 DATA 583,578,584,583,580,585,584,576,574,580,578,577
6 DATA 580,581,313,310,314,313,311,315,313,306,307,309,309
7 DATA 310,311,311,1010,1010,1010,1009,1009,1009,1007,1003
8 DATA 1007,1004,1005,1008,1005,1005
9 DATA .4,.4,.3,.3,.4,.3,.4,.4,.4,.4,.4,.5,.4,.4
10 DATA 8,12,8,13
RUN
   BOI FIRE WX FCST FOR 8 / 13 /77
                                   W   T    R    S   L1   L2   F
 401                               1   2    2    7    1    2   0
 402                               1   1    1    2    1    2   0
 403                               1   2    2    4    1    2   0
 411                               1   2   -2    1    1    2   0
 415                               1   2    0    0    2    2   0
 404                               1   0    1    4    2    2   0
 637                               1   1    2    2    2    2   0
 405                               1   2    0    0    2    2   0
 406                               1   2    0    1    2    2   0
 407                               1   1    5    5    1    2   0
 408                               1   0    1    1    1    2   0
 409                               1   0    4   -2    1    2   0
 410                               1   0    3    2    2    2   0
 412                               1   0    5    2    2    2   0
 413                               1   0    3    1    2    2   0
 414                               1   0    3    0    2    2   0
 416                               1   0    1    1    1    2   0
```

```
◆READY
5 DATA 571,576,575,577,582,581,583,6_564,570,570,571,578
6 DATA 575,578,306,309,309,310,312,312,313,306,307,308,308
7 DATA 310,310,311,1005,1004,1012,1007,1011,1007,1009,1016
8 DATA 1012,1016,1011,1008,1011,1008
9 DATA .5,.5,.4,.5,.6,.5,.5,.5,.8,.4,.9,.8,.7,.8
10 DATA 7,1,7,2
RUN
   BOI FIRE WX FCST FOR 7 / 2 /77
                                   W   T    R    S   L1   L2   F
 401                               8 -15   15   -3    2    3   1
 402                               8 -18   20   -3    3    3   2
 403                               8 -15   17    0    2    3   2
 411                               6 -13   35   -2    3    4   5
 415                               6 -13   36    0    3    4   6
 404                               9 -13   20   -5    3    4   3
 637                               2 -13   11    3    3    3   1
 405                               2 -17   14   -1    3    3   2
 406                               2 -17   15   -1    3    3   2
 407                               9 -14   23   -3    3    4   4
 408                               9 -13   16    0    3    4   2
 409                               9 -14   21   -1    3    5   3
 410                               9 -16   25   -5    3    5   4
 412                               9 -14   27   -1    3    5   5
 413                               9 -12   24   -1    3    5   4
 414                               9 -12   25   -2    3    5   5
 416                               6 -16   30    0    3    5   6
```

FIGURE 4. AFWF DATA AS ENTERED INTO COMPUTER AND RESULTANT PRINTOUT.

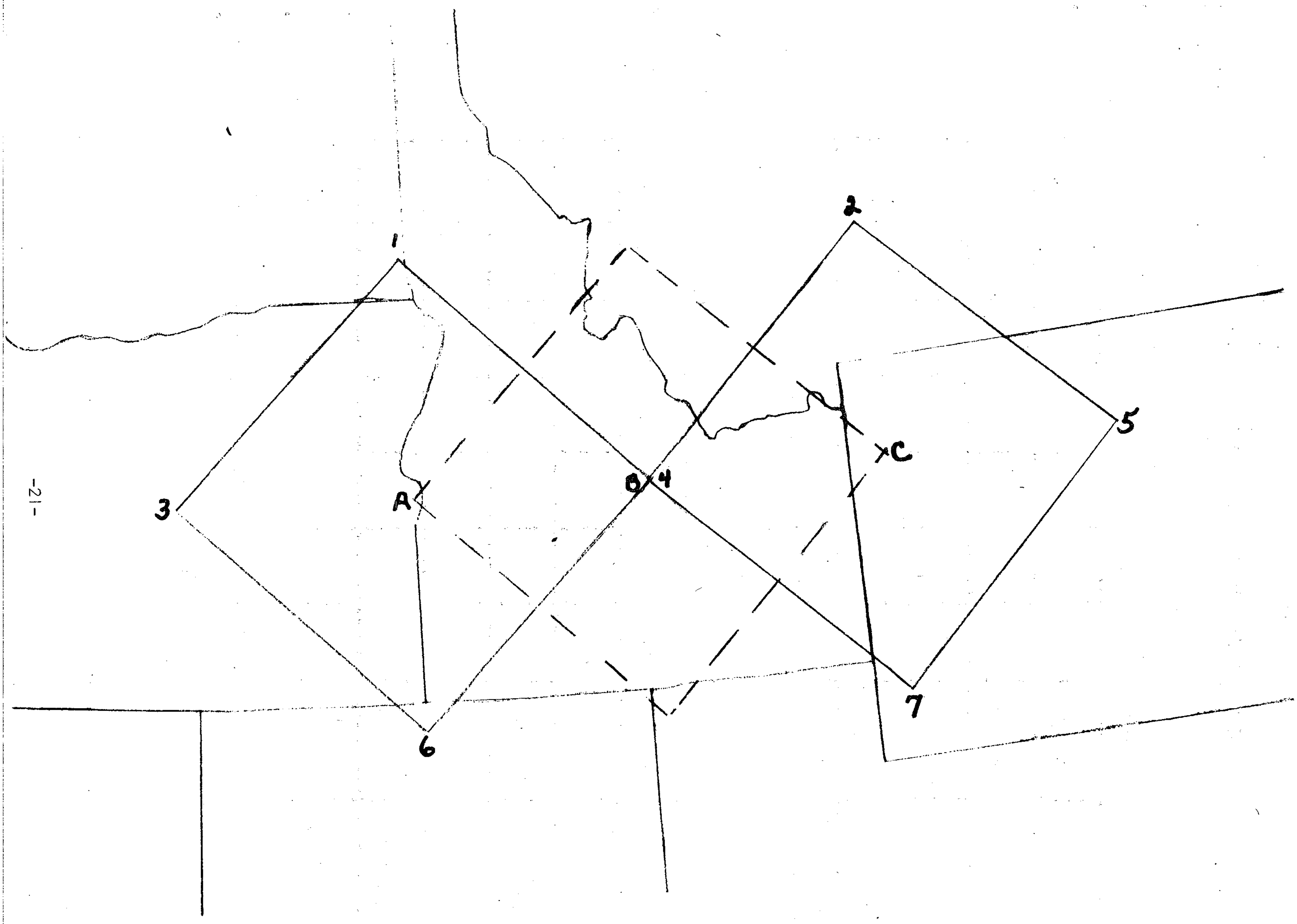


FIGURE 5. AFWF FORECAST GRID.

AUTOMATED FIRE WEATHER FORECAST WORKSHEET

DAY 1--12-HR LFM

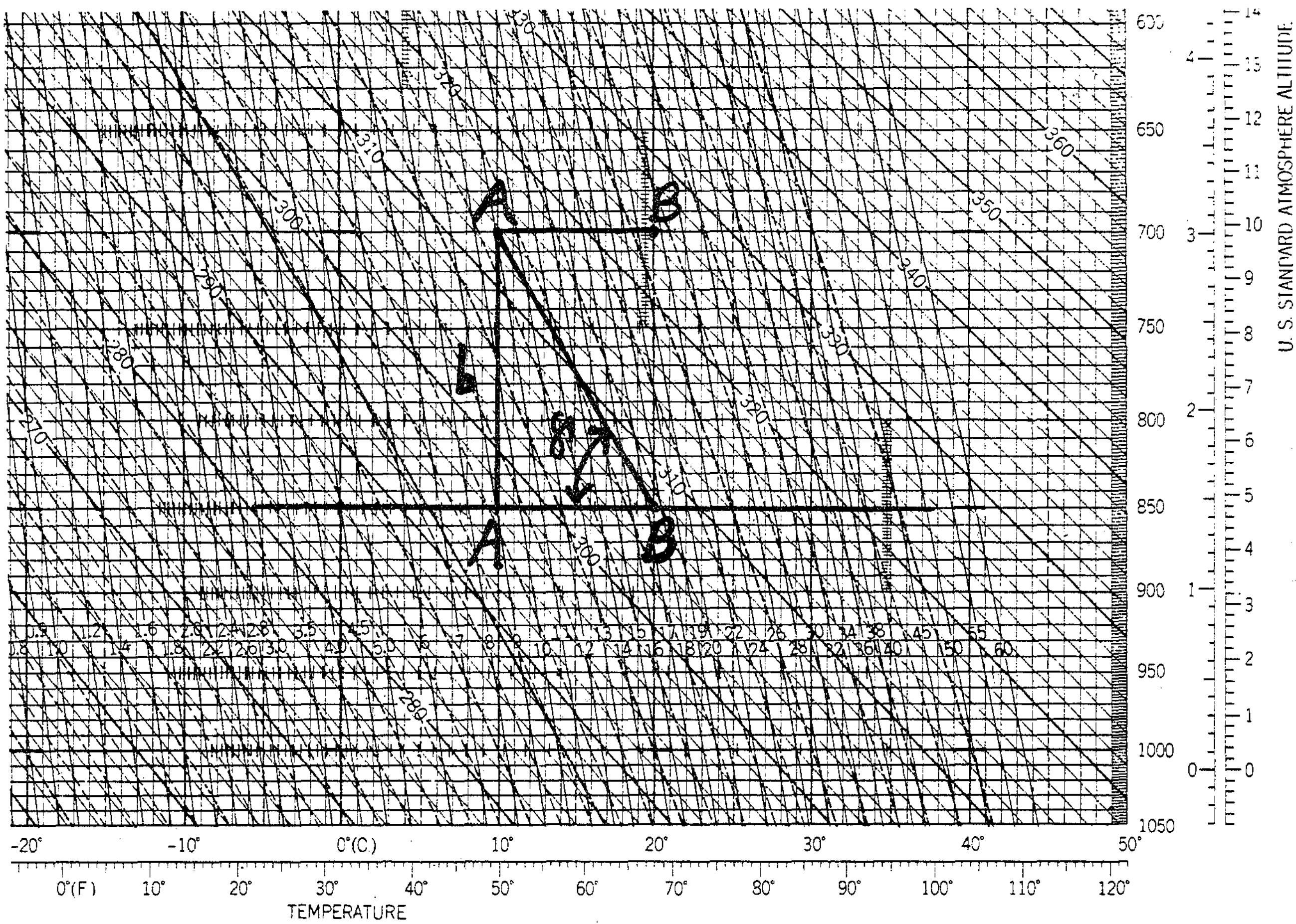
	POINT	1	2	3	4	5	6	7
500-MB HEIGHT	5 DATA							
700-MB HEIGHT	6 DATA							
700-MB R.H.**	7 DATA							
SURFACE PRESSURE	8 DATA							
DATE Month/Day	9 DATA							

DAY 2--36-HR LFM

	POINT	1	2	3	4	5	6	7
500-MB HEIGHT	15 DATA							
700-MB HEIGHT	16 DATA							
700-MB R.H.**	17 DATA							
SURFACE PRESSURE	18 DATA							
DATE Month/Day	19 DATA							

**NOTE: R.H. MUST BE ENTERED IN TENTHS, I.E., 70% EQUALS .7.

FIGURE 6



The $\cot \delta = \left[\frac{B-A}{b}\right]$, the slope of the temperature sounding between the 85 kPa and the 70 kPa levels.

B = the 85 kPa temperature
A = the 70 kPa temperature

The slope of the line is dependent on A and B, which is a measure of the stability of the layer
b is constant

FIGURE 7. EXPLANATION OF δ, cot δ.

'GIFT' PCPN FACTOR FOR 10-HR T.L. F.M.

PCPN FACTOR = [Pcpn Duration (Hours) ×
Pcpn Amount (Factor) ×
Time Period (Factor)]

Pcpn Amount Factor:

Pcpn	Factor
.01	= .1
.10	= 1.0
1.0	= 10

Time Period Factor:

Period	Factor
1	.5
2	1.0
3	2.5
4	5.0

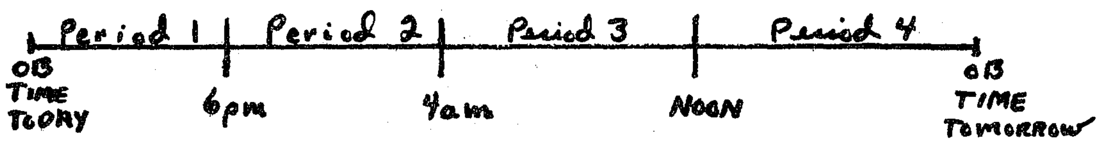


Figure 8. GIFT PRECIPITATION FACTOR FOR 10-HR TIMELAG FUEL MOISTURE

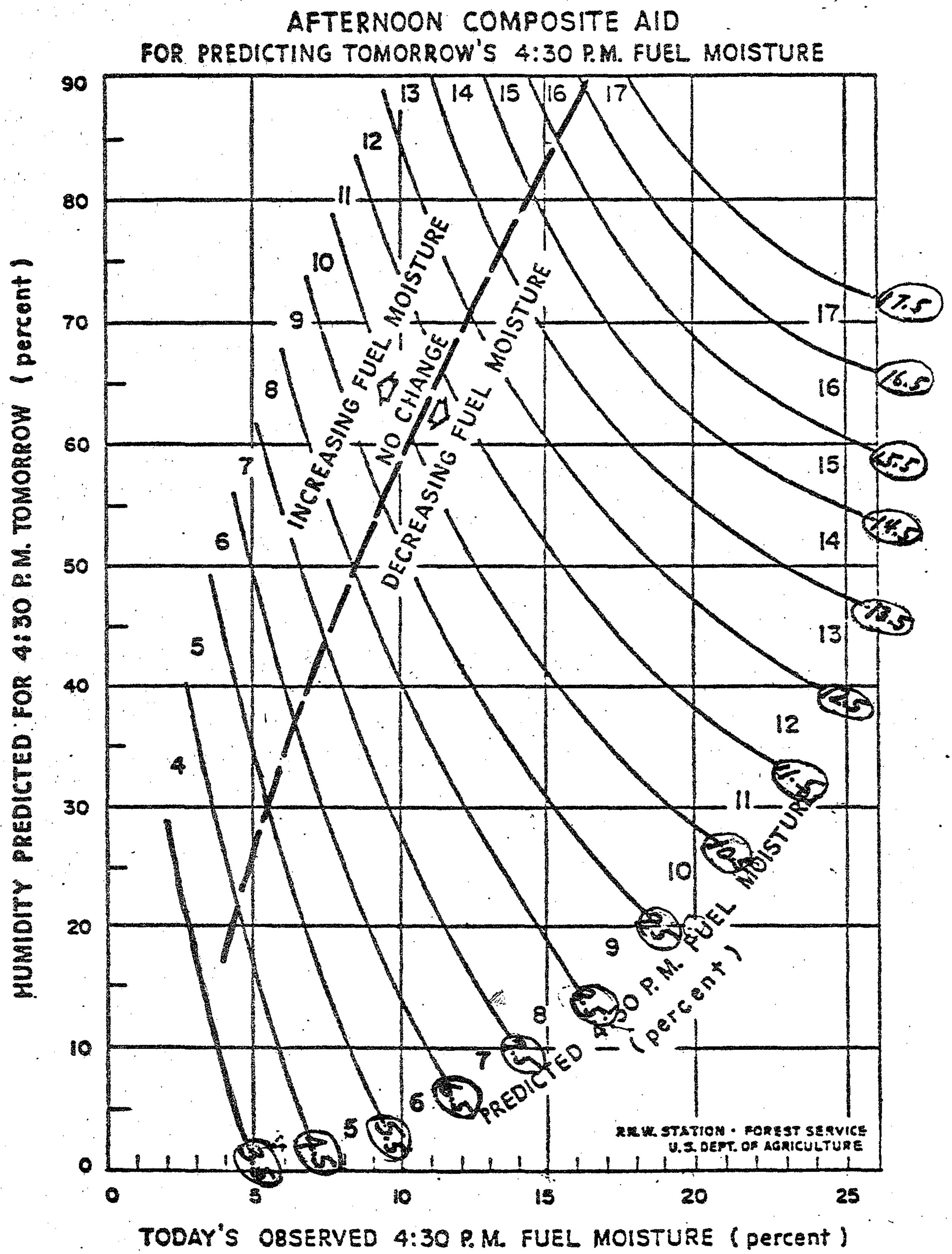


FIGURE 9. CRAMER'S AID FOR DRYING OUT THE 10-HR TIME LAG FUEL MOISTURE STICKS AFTER PRECIPITATION.

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93 An Operational Evaluation of 500-mb Type Stratified Regression Equations. Alexander E. MacDonald, June 1974. (COM-74-11407/AS)
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95 Climate of Flagstaff, Arizona. Paul W. Sorenson, August 1974. (COM-74-11678/AS)
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98 Study on a Significant Precipitation Episode in the Western United States. Ira S. Brenner, April 1975.(COM-75-10719/AS)
99 A Study of Flash Flood Susceptibility--A Basin in Southern Arizona. Gerald Williams, August 1975. (COM-75-11360/AS)
100 A Study of Flash-Flood Occurrences at a Site Versus Over a Forecast Zone. Gerald Williams, Aug. 1975.(COM-75-11404/AS)
102 A Set of Rules for Forecasting Temperatures in Napa and Sonoma Counties. Wesley L. Tuft, Oct. 1975. (PB-246-902/AS)
103 Application of the National Weather Service Flash-Flood Program in the Western Region. Gerald Williams, January 1976. (PB-253-053/AS)
104 Objective Aids for Forecasting Minimum Temperatures at Reno, Nevada, During the Summer Months. Christopher D. Hill, January 1976. (PB-252-866/AS)
105 Forecasting the Mono Wind. Charles P. Ruscha, Jr., February 1976. (PB-254-650)
106 Use of MOS Forecast Parameters in Temperature Forecasting. John C. Plankinton, Jr., March 1976. (PB-254-649)
107 Map Types as Aid in Using MOS PoPs in Western United States. Ira S. Brenner, August 1976. (PB-259-594)
108 Other Kinds of Wind Shear. Christopher D. Hill, August 1976. (PB-260-437/AS) (PB-273-677/AS)
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110 Cool Inflow as a Weakening Influence on Eastern Pacific Tropical Cyclones. William J. Denney, November 1976. (PB-264-655/AS)
112 The MAN/MOS Program. Alexander E. MacDonald, February 1977. (PB-265-941/AS)
113 Winter Season Minimum Temperature Formula for Bakersfield, California, Using Multiple Regression. Michael J. Oard, February 1977. (PB-273-694/AS)
114 Tropical Cyclone Kathleen. James R. Fors, February 1977. (PB-273-676/AS)
116 A Study of Wind Gusts on Lake Mead. Bradley Colman, April 1977. (PB-268-847)
117 The Relative Frequency of Cumulonimbus Clouds at the Nevada Test Site as a Function of K-value. R. F. Quiring, April 1977. (PB-272-831)
118 Moisture Distribution Modification by Upward Vertical Motion. Ira S. Brenner, Apnil 1977. (PB-268-740)
119 Relative Frequency of Occurrence of Warm Season Echo Activity as a Function of Stability Indices Computed from the Yucca Flat, Nevada, Rawinsonde. Darryl Randerson, June 1977. (PB-271-290/AS)
121 Climatological Prediction of Cumulonimbus Clouds in the Vicinity of the Yucca Flat Weather Station. R. F. Quiring, June 1977. (PB-271-704/AS)
122 A Method for Transforming Temperature Distribution to Normality. Morris S. Webb, Jr., June 1977. (PB-271-742/AS)
123 Study of a Heavy Precipitation Occurrence in Redding, California. Christopher E. Fontana, June 1977. (PB-273-624/AS)
124 Statistical Guidance for Prediction of Eastern North Pacific Tropical Cyclone Motion - Part I. Charles J. Neumann and Preston W. Leftwich, August 1977. (PB-272-661)
125 Statistical Guidance on the Prediction of Eastern North Pacific Tropical Cyclone Motion - Part II. Preston W. Leftwich and Charles J. Neumann, August 1977. (PB-273-155/AS)
126 Climate of San Francisco. E. Jan Null, March 1978. (PB-279-975/AS)
127 Development of a Probability Equation for Winter-Type Precipitation Patterns in Great Falls, Montana. Kenneth B. Mielke, February 1978. (PB-281-387/AS)
128 Hand Calculator Program to Compute Parcel Thermal Dynamics. Dan Gudgel, April 1978. (PB-283-080/AS)
129 Fire Whirls. David W. Goens, May 1978. (PB-283-866/AS)
130 Flash-Flood Procedure. Ralph C. Hatch and Gerald Williams, May 1978. (PB-286-014/AS)

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