MODEL OUTPUT STATISTICS IN THE WESTERN UNITED STATES*

by

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ABSTRACT

The method called Model Output Statistics (MOS) is a very effective technique for combining statistical and numerical weather prediction. MOS has been successfully applied by the National Weather Service to prepare automated guidance forecasts of numerous weather elements on the synoptic scale in all parts of the United States. This talk will emphasize the use of MOS in forecasting public weather; i.e., temperature, precipitation, clouds, and wind, in the western part of the country. To illustrate the method and its performance under operational conditions, sample forecast equations and teletype output will be presented. The utility of MOS will then be evaluated with the aid of comparative verification figures.

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1. INTRODUCTION

About 20 years ago I became convinced that the best way to prepare objective forecasts of sensible weather is to combine statistical and numerical (dynamical) techniques (Klein, *et. al.*, 1959). Since then, I've worked with several methods of accomplishing this and have obtained best results with a technique called Model Output Statistics (MOS) developed by Glahn and Lowry (1972) in the Techniques Development Laboratory (TDL) of the Systems Development Office. The National Weather Service now applies MOS routinely to make automated forecasts of nearly every weather element in all parts of the United States except Hawaii (Klein and Glahn, 1974).

In this paper I shall limit myself to public weather and to the western United States. I shall explain how TDL applies MOS to forecast temperature, precipitation, winds, and clouds in this mountainous region. I shall then present comparative verification figures to demonstrate that MOS is just as skillful in the West as it is elsewhere in the country.

2. THE MOS SYSTEM

In the MOS technique, observations of local weather are matched with prognostic data produced by numerical models. These data are used as potential predictors, together with station observations and climatological terms. Forecast equations are then derived by using a variety of statistical techniques. In this way the systematic bias of the numerical model and the local climatology are automatically built into the forecast system. Of equal importance, the predictors are selected and weighted in accordance with the accuracy (or inaccuracy) of the numerical model instead of the true relations in the real atmosphere.

Most of the TDL MOS products have been based upon the output of the six-level baroclinic Primitive Equation (PE) model of Shuman and Hovermale (1968) and the 3-dimensional trajectory (TJ) model of Reap (1972). Systematic archiving of output from these models began in July 1969 and has continued to date. Recently TDL added a third model; namely, the Limited Area Fine Mesh (LFM) model (Gerrity, 1977). Archiving of this model began on October 1, 1972.

Local surface weather reports are acquired monthly from the National Climatic Center in Asheville, N. C. for each of 254 basic observing stations. Numerical model output at each of these stations is obtained by biquadratic interpolation from PE, TJ, and LFM model grids. The observations and numerical predictors are then matched on a station by station basis.

Although the numerical predictors are always located at the same point as the predictand weather element, they are not necessarily valid at the same time. Because the numerical models can be systematically slow or fast, predictors within ±

24 hr of the predictand time are also useful in certain cases.

Another procedure which has increased the utility of the numerical predictors is space smoothing. Averaging over 5, 9, or 25 grid points frequently removes spurious perturbations from "noisy" numerical output. Smoothing also introduces information from surrounding grid points to an otherwise local scheme. Considerable experimentation has indicated that smoothing of numerical model output should increase with increasing forecast projections, decreasing elevation of the predictors, and decreasing predictor scale.

3. TEMPERATURE

The application of MOS to develop forecast equations for maximum and minimum temperatures was described by Hammons *et. al.*, (1976). The potential predictors were carefully selected from the output of the PE and TJ models to include all available factors which might influence surface temperature such as height, thickness, temperature, wind, moisture, stability, vorticity, divergence, and vertical velocity at various levels and projections. For the first and second period forecasts, nine surface synoptic reports were included as possible predictors to give the latest observed conditions at the station. These reports were at 0600 and 1800 GMT, 6 hours after the initial time of the numerical models (0000 GMT or 1200 GMT), but still early enough for operational use.

Forecast equations for temperature, which is a continuous nearly normally distributed variable, were derived by a forward stepwise screening regression program (Miller, 1958). Separate equations were developed for each of 228 stations, four projections, two run times, and four seasons, for a total of 7296 multiple regression equations. All equations contained exactly 10 terms since previous research (Glahn and Lowry, 1972) indicated this is approximately the optimum number of predictors for continuous variables and samples of this size.

A sample temperature equation for a western station is given in Table 1 for today's maximum at Las Vegas, Nevada, during the three winter months of December, January, and February. The predictors are listed in the order of selection. As more predictors are added, they contribute irregularly diminishing increments to the reduction of variance. The first and fourth terms selected are observed surface temperatures, while the third predictor reflects the seasonal trend of normal temperatures. The remaining seven terms of the equation are numerical predictors with four coming from the PE model and three from the TJ model.

Table 1. Predictors in order of selection for temperature forecast equation for winter maximum at Las Vegas, Nev., approximately 24 hr after 0000 GMT.

Order	Predictor	Projection	Cumulative RV (%)
1.	Yesterday's max temp	-	71.7
2.	Boundary layer pot temp (PE)	24*	79.4
3.	Cosine twice day of year	-	81.9
4.	Latest surface temp (SS)	6	82.8
5.	500-1000 mb thickness (PE)	12	83.3
6.	Mean relative humidity (PE)	36*	83.9
7.	Surface dewpoint (TJ)	24	84.8
8.	Surface convergence (TJ)	24*	85.1
9.	850-mb temperature (TJ)	24*	85.5
10.	850-mb zonal wind (PE)	24	85.9

Final standard error of estimate = 3.26 °F

SS - surface synoptic observation; PE - primitive equation model; TJ - 3-dimensional trajectory model; * indicates 5-point smoothing operator was applied; projection is valid time of predictor in hours after 0000 GMT; RV is reduction of variance.

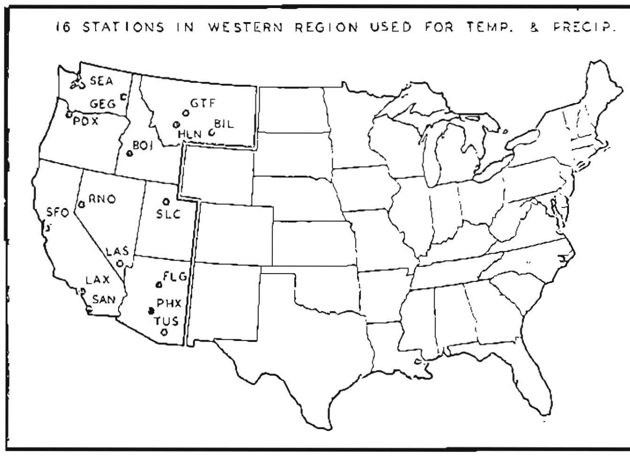

Figure 1. Location and call letters of 16 stations used to verify temperature and precipitation forecasts. The stations are all located within the National Weather Service Western Region, marked by the double line.

In order to evaluate the utility of the MOS temperature forecasts, their accuracy was compared to that of the official forecasts issued to the public at the local level for the 16 stations in the Western Region which are routinely verified (Figure 1). Comparative verification of the MOS and local forecasts at these stations is given in Figure 2 in terms of the mean absolute error averaged for maximum and minimum, two forecast cycles, and the two-year period from October 1974 to September 1976.*

*The MOS forecasts and the verifying observations are for a 24-hr, calendar day period, but the local forecasts are for a 12-hr, daytime period. The exact effect of this difference on the verification scores is not known.

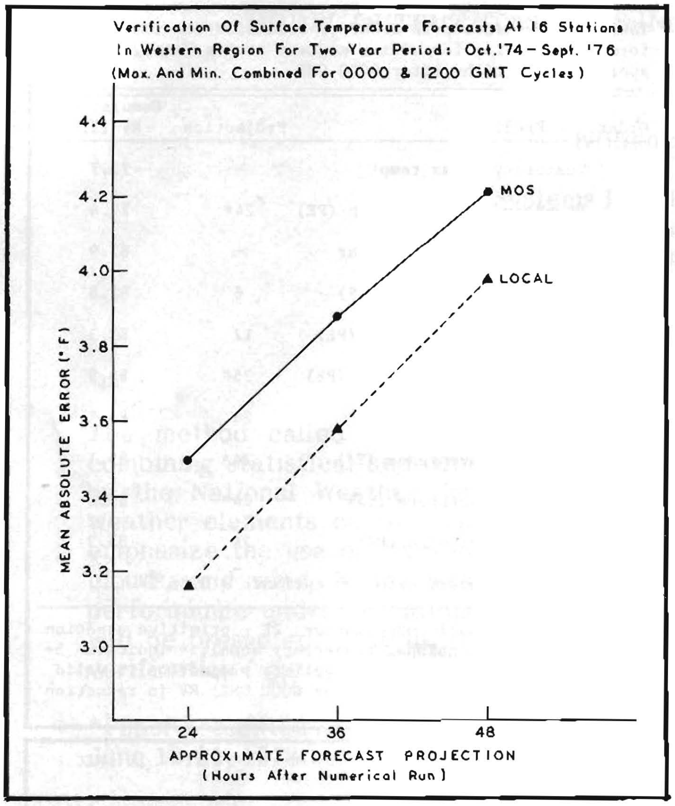

Figure 2. Mean absolute errors (°F) of MOS and local temperature forecasts at 16 stations in the Western Region for 3 projections from 24 to 48 hr after initial model time. The data are combined for maximum and minimum, 0000 and 1200 GMT cycles, and two years from October 1974 through September 1976.

Figure 2 shows that the local forecasters consistently improved upon the MOS forecasts furnished to them as guidance. However, the margin of improvement was quite small, amounting to only 0.3°F in the first period and 0.2°F in the third period. Other stations in the United States show similar results (Cooley, *et. al.*, 1977). Thus, MOS temperature forecasts appear to be about as useful in the West as they are in other parts of the country.

4. SURFACE WIND

MOS has also been used successfully to forecast surface wind, defined as the one-minute average direction and speed for a specific time. Ten-term single-station equations were derived by Carter (1975) at each of 233 stations in the United States by applying screening regression to PE model predictors. As with temperature, surface synoptic reports available 6 hours after numerical model input time were screened for the initial projection. Separate equations were derived for zonal (U) and meridional (V) wind components and for wind speed (S) for seven projections at 6-hr intervals from 12 to 48 hours.

Some constraints were imposed on the selection of predictors. For any given station and projection, the three equations for U, V, and S all contain the same 10 predictors, but with different regression coefficients. Further, the first three predictors were forced to be the boundary layer forecasts of U, V, and S for the valid time of the wind predictand. The remaining seven predictors were selected one at a time by picking at each step the meteorological variable which reduced the variance of any of the three predictands by the largest fractional amount.

As an example, the cool season (6 months Oct.-Mar.) equations valid 12 hr after 0000 GMT at Las Vegas are shown in Table 2. Column 1 gives the selected predictors and columns 6, 7, and 8 give the coefficients. For these particular equations, the three PE boundary layer predictors U, V, and S resulted in reductions of variance of 4, 27, and 20 percent for the U, V, and S predictands respectively. Next, as was the case at most stations for the 12-hr prediction equations, the 0600 GMT observed winds were selected. These predictors, along with four others from the PE model, produced an additional reduction of variance of approximately 10-20 percent for each predictand.

Table 2. Sample equations for estimating the U and V wind components and the wind speed, S, 12 hr after 0000 GMT at Las Vegas, Nevada, during the cool season from PE forecasts and surface observations

	Forecast Projection (hr)	Cumulative reduction of variance			Coefficients			Units
		U	V	S	U	V	S	
Regression Constant					-39.950	-16.880	-6.333	kt
1. Boundary layer U	12	0.028	0.000	0.081	0.073	0.220	0.142	$m\ s^{-1}$
2. Boundary layer V	12	0.035	0.262	0.104	-0.074	0.041	-0.001	$m\ s^{-1}$
3. Boundary layer S	12	0.036	0.270	0.201	0.174	0.166	0.113	$m\ s^{-1}$
4. Observed S	6	0.046	0.270	0.355	0.081	-0.004	0.448	kt
5. Observed V	6	0.048	0.395	0.358	-0.017	0.422	-0.044	kt
6. 850-mb geostrophic U	18	0.067	0.434	0.362	0.119	0.293	-0.007	$m\ s^{-1}$
7. Observed U	6	0.100	0.435	0.362	0.166	-0.066	0.006	kt
8. 850-mb geostrophic S	18	0.108	0.450	0.389	-0.090	-0.214	0.200	$m\ s^{-1}$
9. 500-mb height	12	0.124	0.452	0.389	0.007	0.003	0.001	m
10. 850-mb relative vorticity x 10^5	12	0.136	0.452	0.397	0.316	-0.026	0.302	s^{-1}
Total standard error of estimate		3.40	4.69	3.40				

Since the local forecasts were recorded as calm if the wind speed was expected to be less than 8 knots, the forecasts were verified in two ways. First, for all those cases where both the local and MOS wind speed forecasts were at least 8 knots, the mean absolute error (MAE) of speed and direction was computed. Secondly, for all cases where both local and guidance forecasts were available, skill score, percent correct, and bias were computed from contingency tables for 7 categories of wind speed. The categories were: less than 8, 8-12, 13-17, 18-22, 23-27, 28-32, and greater than 32 knots.

Table 3 shows comparative scores (0000 GMT cycle only) for 18-, 30-, and 42-hr projections for the cool season from October 1976 through March 1977 for 18 western stations with routine wind verification (Figure 3). The results for the direction MAE reveal about equal accuracy for MOS and local forecasts at 18 hr but an edge for

Table 3. Verification scores for objective MOS and subjective local surface wind forecasts for 18 stations in the Western Region of the United States for the cool period: October 1976-March 1977.

FCST. PROJ. (HRS)	TYPE OF FCST.	DIRECTION: MEAN ABS. ERROR (DEG)	NO. OF CASES	SPEED: MEAN ABS. ERROR (KTS)	CONTINGENCY TABLE: SKILL SCORE	PERCENT FCST. CORRECT	BIAS (NO. FCST./NO OBS.): CAT1	CAT2	CAT3	CAT4	CAT5	CAT6	CAT7
18	MOS	35	461	4.2	0.32	69	1.06	0.91	0.88	0.85	0.30	0.56	*
	LOCAL	35		4.2	0.33	67	0.99	1.08	0.97	1.03	0.56	0.78	***
30	MOS	38	437	4.4	0.27	71	1.04	0.87	0.94	1.00	0.43	0.17	0.0
	LOCAL	45		4.7	0.26	70	1.00	1.00	1.11	0.98	0.29	0.50	0.0
42	MOS	44	614	4.8	0.28	66	1.01	1.05	0.91	0.76	1.08	0.38	**
	LOCAL	49		4.7	0.22	61	0.95	1.34	0.83	0.61	0.76	0.75	*

*This category was neither forecast nor observed.
**This category was forecast once but was never observed.
***This category was forecast twice but was never observed.

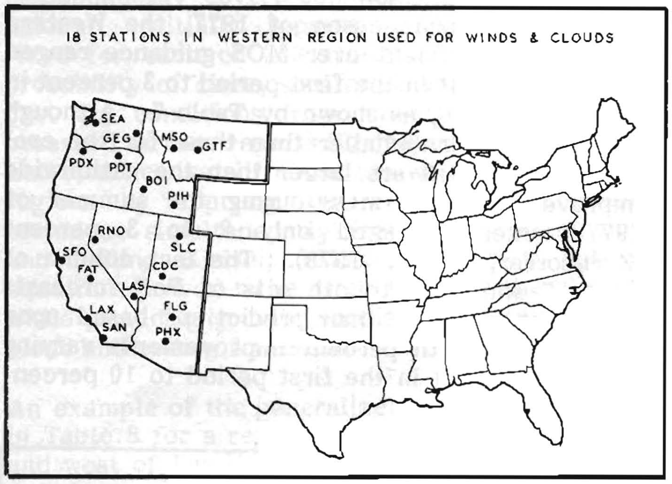

Figure 3. Location and call letters of 18 stations used to verify wind and cloud forecasts. The stations are all located within the National Weather Service Western Region, delineated by the double line.

MOS at 30 and 42 hr. A similar conclusion applies to the various scores for wind speed, even if only strong wind speeds are considered. The biases by category indicate that both MOS and the local forecasters had a tendency to underestimate winds stronger than 22 knots. These results are generally similar to those obtained by Bocchieri *et. al.* (1977) for the entire country.

During the summer season (Zurndorfer *et. al.*, 1978), MOS wind forecasts verify even better than they do during the cool season. In fact, Table 4 shows that MOS was consistently more accurate than the local forecaster, even for 18-hr projections, during the period April-September 1977, in the Western Region.

5. PRECIPITATION

Forecasts of the point probability of precipitation (PoP) during 12-hr periods have been issued by the National Weather Service since 1965, and nationwide MOS guidance for those forecasts has been produced operationally since 1972 (Lowry and Glahn, 1976). Since measurable precipitation ($\geq$ .01 inches) does not occur often enough in a small data sample to allow derivation of reliable single-station equations, TDL combines data from a number of stations within each of several homogeneous regions and then derives a single equation for each region. In application, the equation is used at each station within the region with input data appropriate to that particular station
a generalized operator technique
(Harris et. al., 1963).

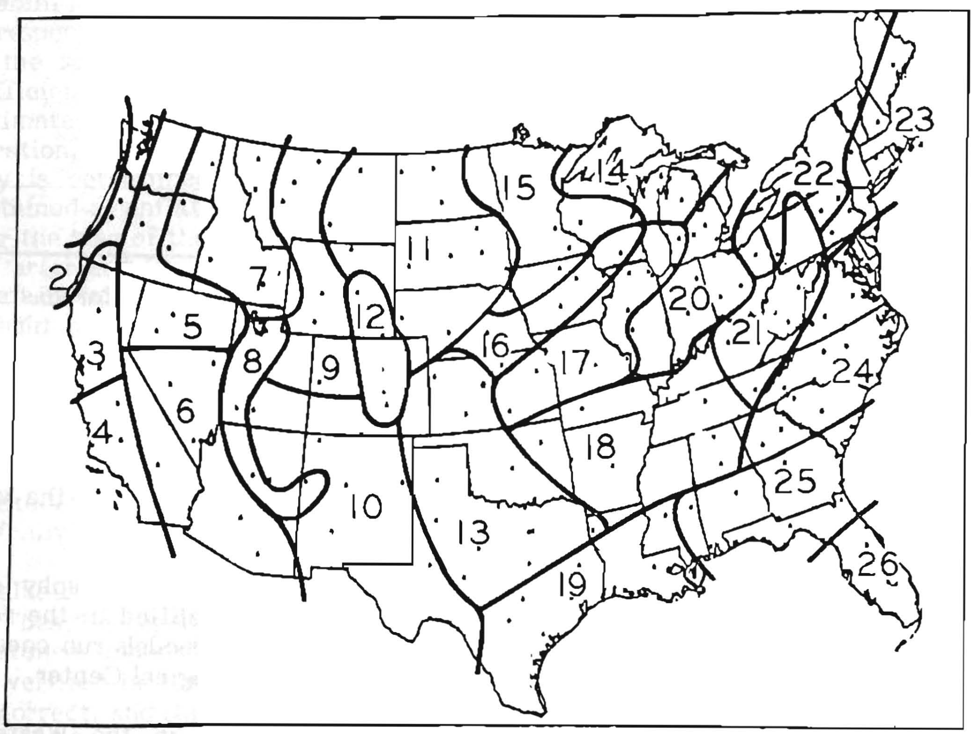

Figure 4. Twenty-six regions used to derive MOS cool season equations for forecasting the probability of precipitation during the first period from LFM data. The dots locate stations whose data were used in the development. Each region has one set of equations applicable to any station within that region.

For example, Figure 4 illustrates 26 regions used to forecast first period PoP from LFM data during the cool season (Oct.-Mar.). The boundaries were determined by analyzing the relative frequency of precipitation when the LFM model predicted $\geq$ 65 percent mean relative humidity or a precipitation amount $\geq$.01 inches. Within each region a standard set of the 70 most valuable binary and continuous LFM predictors was offered for screening, but different predictor sets were required for each of four projections. In addition, surface observations valid three hours after initial data time (0000 GMT or 1200 GMT) and climatic relative frequencies of precipitation were added to the standard list of predictors to contribute information not provided by the LFM. Since the predictand is binary (i.e., precipitation has or has not occurred), this application of regression (Miller, 1964) produces equations which give probability forecasts of precipitation at the forecast site.

Table 5 shows the complete equation for region 6 which includes parts of Nevada, Arizona, and California. The table applies to the "today" period (from 12 to 24 hr after 0000 GMT) during the cool season. Note that many of the predictors selected are in binary form. For instance, a humidity predictor indicated by the symbol "$\leq$ 90%" in the binary column means that the predictor selected was set equal to one if the humidity was less than or equal to 90 percent and set equal to zero otherwise. The table indicates that the mean relative humidity (from surface to 400 mb.) is the most important LFM predictor of PoP, and the forecast precipitation amount is the second most important. Other predictors selected are moisture convergence in the boundary layer, height at 850 mb, zonal winds at 500 mb, observed values of ceiling and weather, and a measure of stability (K index). Generally similar results can be noted in other parts of the United States and for the warm season (Gilhousen, 1977).

Table 4. Comparative verification of MOS and local surface wind forecasts, 0000 GMT, for 18 stations in the Western Region (Apr.-Sept. 1977).

FCST. PROJ. (HRS)	TYPE OF FCST.	DIRECTION: MEAN ABS. ERROR (DEG)	DIRECTION: NO. OF CASES	SPEED: MEAN ABS. ERROR (KTS)	SPEED: SKILL SCORE	SPEED: PERCENT FCST. CORRECT
18	MOS	31	816	3.7	0.24	55
	Local	33		3.9	0.22	53
30	MOS	32	455	3.3	0.26	61
	Local	37		3.5	0.21	59
42	MOS	42	970	4.1	0.20	52
	Local	46		4.1	0.16	50

Although the PoP equations explain less than half the variability of precipitation (R.V. below 50 percent), they produce objective forecasts which are superior to climatological forecasts and competitive with the best subjective estimates. Table 6 verifies PoP forecasts produced by MOS and local offices at the 16 western stations of Figure 1 during a recent cool season. The forecasts were verified by computing half the P-score proposed by Brier (1950). Table 6 shows that the local forecasts were 16 percent better than MOS during the first period, but only 6 percent better during the third period. In the nation as a whole, the local improvement over MOS was smaller in magnitude, but the trend was similar, with amounts varying from 7 percent in the first period to 1 percent in the third period (Bocchieri, *et. al.*, 1977).

During the warm season of 1977, the Western Region improvement over MOS guidance ranged from 10 percent in the first period to 3 percent in the third period, as shown by Table 7. Although these figures are smaller than those for the cool season, they still are larger than the nationwide improvement over MOS during the summer of 1977, which averaged only 2 to 3 percent (Zurndorfer, *et. al.*, 1978). The last column of Table 7 shows that both sets of PoP forecasts were more skillful than predictions based upon climatology, with percent improvements varying from 32 percent in the first period to 10 percent in the third period.

Table 5. The 12 predictors picked for the 0000 GMT winter season first period PoP equation for region 6. R.V. means reduction of variance (square of multiple correlation coefficient).

Predictor	Projection	Smoothing	Binary Limit	Coefficient	Cumulative R.V. (%)
Constant				.4716	
Mean Relative Humidity	18	5	Continuous (%)	.0024	13.7
Mean Relative Humidity	12	1	$\leq$ 90%	-.1275	22.5
Mean Relative Humidity	24	1	$\leq$ 90%	-.0053	23.0
Precipitation Amount	24	5	$\leq$ .20"	-.1291	24.5
Observed Weather	03	-	No precip.	-.1174	25.4
500-mb U	24	5	Continuous (M/S)	-.0025	26.2
350-mb Height	18	5	$\leq$ 1457 M.	.0576	26.8
K Index	24	5	$\leq$ 25 °C.	-.0262	26.9
Mean Relative Humidity	18	5	$\leq$ 75%	-.0765	27.3
Boundary Layer Moisture Convergence	24	5	Continuous ($s^{-1} \times 10^{-8}$)	-.0010	27.5
Observed Ceiling	03	-	$\leq$ 14,000'	.0125	27.6
Mean Relative Humidity	12	5	$\leq$ 80	-.0377	27.7
				Total R.V. =	27.7

Why do Western Region forecasters improve the MOS PoP significantly more than forecasters in other parts of the country? I believe there are three main reasons as follows:

A. Lack of data over the Pacific Ocean impairs the performance of numerical models downstream, particularly in the western third of the United States.

B. The complex topography of the Western Region is oversimplified in the relatively coarse grid of numerical models run operationally at the National Meteorological Center.

C. Forecasters in the Western Region are strongly motivated by management emphasis on competition with MOS (Snellman, 1977).

As a result of these factors, the local forecasts of PoP in the Western Region are considerably more accurate than those produced by MOS. This difference is particularly marked in the first period, when the forecaster makes intelligent use of later surface, radar, and satellite data which are unavailable to MOS.

6. CLOUD AMOUNT

Another weather element for which probability forecasts have been derived by the MOS technique is opaque sky cover, commonly known as cloud amount. Initially, separate equations were derived for each of 233 stations to estimate the probability of clear, scattered, broken, and overcast sky conditions from numerical models and observed surface reports (Carter and Glahn, 1976). Later, a new set of equations was derived for 21 regions by applying the generalized operator technique simultaneously for both cloud amount and ceiling (Crisci, 1977). The new set of equations proved to be as accurate as the old set, while providing greater consistency between MOS cloud and ceiling forecasts.

An example of the generalized equations is shown in Table 8 for a region (not shown) located south and west of Las Vegas including parts of Nevada, Arizona, and California. As in Table 5, the predictors are expressed in both binary and continuous form and are taken from both the LFM model and surface observations. However, Table 8 has four binary predictands, instead of one, and therefore contains four separate equations which give the probability of clear, scattered, broken, and overcast, respectively. The equation for each category has the same 15 predictors, but with different coefficients, to insure that the four probability estimates always sum to unity (Miller, 1964). In operation, after the probability of each cloud category is determined, the "best" single category is obtained by inflating the probabilities and minimizing the bias of the resultant categorical forecast (Carter and Glahn, 1976). Of the 15 predictors listed in Table 8, 9 are taken from the LFM model, 5 from surface observations, and 1 from the station elevation. Most of the predictors, such as temperature-dew point spread, relative humidity, and sky cover, are directly related to cloud amount, while others, such as winds, visibility, stability (G index), and elevation, are indirectly related. Thus the MOS technique results in physically reasonable equations.

In order to evaluate the utility of the MOS cloud equations, the "best" category forecast was compared to a matched sample of local (subjective) forecasts and verified in terms of bias by category, percent correct, and skill score. The results are given in Table 9 for three different forecast projections at the 18 Western Region stations of Figure 3 for the period from February 10, 1977 to March 31, 1977 when the regional equations were verified. Columns 3-6 show that the bias values for the MOS forecasts were somewhat better (closer to 1.00) than those for the local forecasts, especially for categories 2 and 3 which were overestimated by the locals. MOS was also superior to the local forecasts in terms of percent correct and skill score for the 30- and 41-hr projections. However, the locals in the Western Region were more skillful at 18 hr, when they could benefit from later reports and satellite data not available to MOS. Generally similar results were obtained for the warm season (Table 10) and for the rest of the country, except that MOS was more skillful than local forecasters at 18 hr in other regions of the nation (Bocchieri, *et. al.*, 1977; Zurndorfer, *et. al.*, 1978).

Table 6. Verification scores for objective MOS and subjective local forecasts of probability of precipitation at 16 stations in the Western Region and at all stations in the United States for the period October 1976 through March 1977, 0000 GMT cycle.

Projection	Region	Forecast	Brier Score	Improvement Over MOS (%)
12-24 hr (1st period)	Western	MOS	.0731	
		Local	.0615	16.0
	Nation	MOS	.0821	
		Local	.0767	6.7
24-36 hr (2nd period)	Western	MOS	.0768	
		Local	.0702	8.6
	Nation	MOS	.0988	
		Local	.0973	1.5
36-48 hr (3rd period)	Western	MOS	.0848	
		Local	.0800	5.7
	Nation	MOS	.1035	
		Local	.1028	0.7

TABLE 7. COMPARATIVE VERIFICATION OF MOS AND LOCAL PoP FORECASTS FOR 16 STATIONS IN THE WESTERN REGION (APRIL-SEPTEMBER 1977).

PROJECTION	TYPE OF FORECAST	BRIER SCORE	IMPROVEMENT OVER GUIDANCE (%)	IMPROVEMENT OVER CLIMATOLOGY (%)
12-24 H (1ST PERIOD)	MOS	.0795		24.1
	LOCAL	.0717	9.9	31.6
24-36 H (2ND PERIOD)	MOS	.0842		17.9
	LOCAL	.0804	4.5	21.7
36-48 H (3RD PERIOD)	MOS	.0982		9.9
	LOCAL	.0898	3.2	12.9

Table 8. Winter MOS equations for estimating cloud amount categories at 1800 GMT in a region near Las Vegas from the 0000 GMT run of the LFM model during the cool season (Oct.-Mar.).

Predictor	Limit	Tau	Smoothing	Coefficients Clear	Scattered	Broken	Overcast
LFM mean rel. hum	Continuous	24	5 Pt.	-.01531	.00709	.00567	.00235
LFM temp-dewpoint (1000 mb)	4° K	24	5 Pt.	-.04228	-.01521	.03185	.02565
Obs sky cover	B.5	06	None	-.06829	.09775	-.03008	-.1360
Obs ceiling	2950 (ft.)	06	None	-.1164	.1409	-.04497	.02044
LFM mean rel. hum.	90%	18	5 Pt.	-.03477	.2078	-.04924	-.1238
Obs sky cover	0.5	06	None	.1400	-.06210	-.05529	-.02263
LFM G index	-2725 (m.)	24	5 Pt.	.00940	.05254	.001261	-.06618
LFM rel. hum. (L1)	70%	24	5 Pt.	.03536	.04383	.01542	-.09460
LFM rel. hum. (L1)	Continuous	24	5 Pt.	.00878	-.00401	-.00343	-.00134
LFM bound. lay. rel. hum.	Continuous	16	5 Pt.	.00117	-.00111	-.00133	-.00073
LFM mean rel. hum.	Continuous	18	5 Pt.	-.00694	.00204	.00392	.00098
Station elevation	Continuous (ft.)	D	None	-.00001	.00001	-.00001	.000001
Obs vision obstruct.	0.0	06	None	-.1710	.1450	.08109	-.05305
Obs U wind	Continuous (kts.)	06	None	-.00151	.00715	.00132	-.00297
LFM mean rel. hum.	90%	24	5 Pt.	-.09921	.00671	.1529	-.06044
			Constants	1.174	-.4842	-.2103	.5206

7. OPERATIONAL ASPECTS

The MOS equations are applied twice daily on the large NOAA computer in Suitland, Maryland, immediately after the numerical models of the National Meteorological Center are run. The MOS forecasts are then distributed to field stations by means of both teletypewriter and facsimile.

Table 9. Verification scores for objective MOS and subjective local forecasts of four categories of cloud amount (clear, scattered, broken, and overcast) for 18 stations in the Western Region of the United States for the period: Feb. 10, 1977 to Mar. 31, 1977.

PROJECTION (HRS)	TYPE OF FORECAST	BIAS (NO. FCST/NO. OBS)				PERCENT CORRECT	SKILL SCORE
		CAT 1	CAT 2	CAT 3	CAT 4		
18	MOS	1.18	0.81	1.26	0.66	48.8	.295
	LOCAL	0.82	1.19	1.27	0.84	50.7	.337
30	MOS	0.95	1.09	0.64	1.29	51.7	.300
	LOCAL	0.65	1.64	1.73	0.74	44.4	.248
42	MOS	1.08	0.79	0.98	1.10	46.5	.268
	LOCAL	0.69	1.47	1.36	0.69	39.7	.196

TABLE 10. COMPARATIVE VERIFICATION OF MOS AND LOCAL FORECASTS OF FOUR CATEGORIES OF CLOUD AMOUNT (CLEAR, SCATTERED, BROKEN, AND OVERCAST), 0000 GMT CYCLE, FOR 18 STATIONS IN THE WESTERN REGION (APR.-SEPT. 1977).

PROJECTION (HRS)	TYPE OF FORECAST	PERCENT CORRECT	SKILL SCORE
18	MOS	52.6	.327
	LOCAL	52.7	.349
30	MOS	50.6	.266
	LOCAL	46.7	.253
42	MOS	48.3	.259
	LOCAL	43.4	.216

Figure 5 illustrates one of the teletypewriter bulletins for Las Vegas and Phoenix. It gives the MOS forecasts prepared from the 1200 GMT numerical cycle on August 2, 1977. The first line gives the probability of precipitation for 12-hr periods ending 1200 GMT August 3 (10%), 0000 GMT August 4 (5%), and 0000 GMT August 5 (10%). The second line gives the minimum and maximum temperature ($^{\circ}$F) expected on these days with forecasts of 82, 106, 81, 106, and 78 respectively at LAS.

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HDNG    MOS FCSTS     FINAL MAX/MIN/POP        8/02/77    1200 GMT

DATE/GMT    03/12   04/00   04/12   05/00   05/12

LAS POP12     10       5       5      10
    MN/MX     82     106      81     106      78

PHX POP12      2       5      10       5
    MN/MX     83     107      80     107      78
```

Figure 5. Example of FOUS 22 MOS teletypewriter bulletin issued on August 2, 1977 from the 1200 GMT cycle. Forecasts are given for Las Vegas and Phoenix for probability of precipitation during 12-hr periods ending as shown on date/time line and for calendar day minimum and maximum temperatures occurring approximately at the time and date given above.

Figure 6 illustrates a more complex teletypewriter bulletin. It gives the MOS forecasts prepared for Reno from the 1200 GMT cycle on June 2, 1978. Line 1 contains PoP forecasts for 6-hr periods ending at the date and time shown on the top line. Line 2 gives 12-hr PoP forecasts out to 60 hr from initial time (similar to Figure 5). The next two lines show forecasts of quantitative precipitation in both probabilistic and categorical form for 6- and 24-hr periods (Bermowitz and Zurndorfer, 1978). Line 5 gives the probability that the precipitation, if any, will be frozen (snow or sleet) (Bocchieri and Glahn, 1976). Line 6 gives the same forecasts of maximum and minimum temperatures shown in Figure 5. Line 7 gives MOS forecasts of surface temperatures every 3 hours from 6 to 51 hours in advance (Carter, *et. al.*, 1978).

Line 8 gives the surface wind forecasts described in section 4. The forecasts are valid every 6 hr from 12 to 48 hr in advance. For example, the wind is expected to blow from 310 degrees with a speed of 10 knots at 0000 GMT on June 3. Line 9 illustrates the cloud amount forecasts dscribed in the previous section. The forecasts are given in increments of 6 hr from 12 to 48 hr after run time. The first four numbers indicate the probability (in tens of percent) of clear, scattered, broken, and overcast, while the fifth number gives the "best" category. The next two lines give the probability of each of six categories of ceiling and visibility at 6-hr intervals from 12 to 48 hr after the 0000 GMT cycle, while the last line shows the "best" category (Crisci, 1977).

```
HDNG  FOUS12 MOS FCSTS  EARLY GUIDANCE   6/02/78   1200 GMT

DATE/GMT   02/18  03/00  03/06  03/12  03/18  04/00  04/06  04/12

RNO POP06             0      0      0      0      0
    POP12                           0             0             2
    QPF06                000/1  000/1  00X/1
    QPF24                                                  0000/1
    POF         0      0      0      0      0      0      0      0
    MN/MX                           41            82           45
    TEMP    67 74  75 68  59 50  45 55  70 77  79 74  65 55  49 58
    WIND     1103   3110   3206   2003   0302   3111   3304   2002
    CLDS   9100/1 4330/2 8110/1 8110/1 7111/1 6220/1 7110/1 8210/1
    CIG    XX0009 XXX028 XX0009 X00009 XX0019 XXX019 XX0009 X00009
    VIS    XX0009 XX0009 XXXX09 0X0009 XXX009 XX0009 XXXX09 0X0009
    C/V       6/6    6/6    6/6    6/6    6/6    6/6    6/6    6/6
```

Figure 6. Example of FOUS 12 MOS teletypewriter bulletin issued on June 2, 1978 from the 1200 GMT cycle. Forecasts for Reno are given on 12 different lines for 6 to 24 hrs in advance, valid at the date/time shown in line 2.

8. CONCLUSION

MOS forecast bulletins of the type illustrated in Figures 5 and 6 are now available twice a day for approximately 360 civilian and military stations in the United States. They provide good guidance for almost all weather elements needed by the public. The objective centralized MOS forecasts are about as skillful as subjective manual predictions produced by experienced forecasters at the local level, at least for projections of 24 to 60 hr on the synoptic scale.

Although the MOS forecasts are approximately as accurate in the Western Region as in other parts of the country, the local forecaster there can make considerably more improvement over PoP guidance, especially in the first period. Western Region forecasters also improve the 18-hr MOS cloud amount guidance more than forecasters in other parts of the United States.

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NATIONAL WEATHER DIGEST

NEWSLINE

On March 10, the local Atlanta chapter of *The American Meteorological Society* was hosted to a dinner sponsored by WSB-TV and Johnny Beckman - local TV meteorologist. Johnny told us about his new Color Action Radar (CAR). This weather radar detects precipitation rate and displays it on TV in three color tints. One-hundredth of an inch/hour is in green; one-tenth of an inch per hour is in yellow; and greater than one-half inch per hour is in red. The grid of the local freeways is superimposed on the picture to give the viewer a frame of reference. With few exceptions, we have had a drought since the color radar has been installed!

At the same meeting we learned of Georgia Tech's new Atmospheric Sciences Program. The emphasis is on: Solar & Wind Power - Dr. Justus; Chemistry (Aerosols) - Dr. Davis; Radar - Dr. Metcalf; Radio Physics - Dr. Metcalf.

Bachelor's and Master's Degree programs are offered at present. Ph.D. programs will be available in two years.

LETTERS TO THE EDITOR

To the Editor:

In your "Newsline" on p. 35 of the *National Weather Digest*, Volume 3, No. 1, you mention "humiture." You should also have mentioned the "humit," which is the unit of humiture. Both words were coined by Osborn Fort Hevener in 1937. The complete story can be found in O. F. Hevener, 1959: All About Humiture. *Weatherwise*, Vol. 12, p. 56.

Sincerely Yours,

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