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AN EVALUATION OF THE SEA LEVEL PRESSURE AND MOISTURE MODELS OF LAMP

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1. INTRODUCTION

The Local AFOS MOS Program (LAMP) (Glahn, 1980) is under development at the Techniques Development Laboratory to provide short range updated guidance forecasts. The guidance is to be produced with Model Output Statistics (MOS) (Glahn and Lowry, 1972a) based partly on simple numerical weather prediction models which can be run locally on minicomputers similar to those used in AFOS (Automation of Field Operations and Services). These models can be run at any hour with the initial field derived from surface hourly observations and radar data. The output from these models can be used with the centrally produced MOS guidance to form a MOS update forecast.

The need for LAMP arises because today's centrally produced guidance is anchored to the times for which upper air data are available (0000 and 1200 GMT). Often, forecasts must be issued based upon guidance which is up to 12 hours old. In addition, the information from these numerical models often does not contain sufficient detail for the time and space scales needed to provide useful very short range forecasts. These models, designed primarily for making forecasts of 12 hours and beyond, smooth or eliminate much of the fine-scale detail from the initial observations needed for making shorter range forecasts.

By being able to operate the system locally, the forecaster will have more control over the product and can examine, in detail, the forecasts or initial analysis if desired. This could allow him/her to bogus data into the initial analysis or to manually withold bad data from it.

To be run on station, the numerical models had to be as simple as possible, with core storage and the number of computations required for execution kept to a minimum. Two models which met this requirement were adapted from a system known as the Subsynoptic Advection Model (SAM) (Glahn and Lowry, 1972b) which ran operationally at the National Meteorological Center (NMC) from 1968 to 1973. SAM consisted of a sea level pressure (SLP) model developed by Reed (1963) and the SLYH moisture model, named from the last initials of its developers, Frederick Sanders, Jerrold LaRue, Russell Younkin, and John Hovermaie (Younkin et al., 1965). These models were driven by output from NMC's PE model (Shuman and Hovermale, 1968) and were initialized with data derived from the most recent surface observations.

The performance of these two models is reviewed here, and their predictions compared to the most recent forecasts from the LFM model (Gerrity, 1977) to illustrate the advantage afforded by the use of more recent and detailed intial data.

2. THE SLP MODEL

2.1 Overview

The sea level pressure model uses a potential vorticity equation at 1000 mb with an upper level forecast provided by a driving model. The 1000-mb heights are adjusted to conserve potential vorticity along a trajectory determined by an advecting wind computed from a smoothed 500-mb geostrophic flow and a terrain field. The initial 1000-mb heights are estimated from hourly observations of sea level pressure with the simple linear relation shown in Eq. (1).

$$Z_o = \frac{(P - 1000)}{.12015}, \tag{1}$$

where Z_o is the 1000-mb height in meters, and P is the sea level pressure in millibars. Because of this very simple relationship, the Reed model is usually referred to as a sea level pressure model.

2.2 The Basic Model

With many simplifying assumptions, a potential vorticity equation can be transformed to the form shown in Eq. (2).

$$Z_o^{fd} = (Z_o - b_1 Z_5 + M - G)^{iu} - (-b_1 Z_5 + M - G)^{fd} \tag{2}$$

Here, Z_5 is the 500-mb height, M is a terrain term, G is a term which depends on latitude, and b_1 is a constant. The superscript "iu" indicates the term is to be evaluated at the initial upstream end of a trajectory, while the superscript "fd" refers to the values at the forecast downstream end of the trajectory. Derivation of this equation can be found in Reed (1963) or Glahn and Lowry (1972b).

The trajectory is calculated from an equivalent advecting wind defined by the 500-mb height field and the terrain field as shown in Eq. (3).

$$\vec{V}_E = \vec{k} \times \frac{g}{f_{45}} \nabla(b_2\bar{Z}_5 - M) \qquad (3)$$

$\vec{V}_E$ is the vector advecting wind, f_{45} is the coriolis parameter at 45° latitude, g is the acceleration due to gravity, $\bar{Z}_5$ is a smoothed 500-mb height field, and b_2 is a constant.

Reed defined the terms in Eqs. (2) and (3) as follows:

$b_1 = b_2 = .55$;
$M = a\,PG$, where a is a constant set at .405 (m/mb) and PG is the average surface pressure in mb; and
$G = c \sin^2\phi$, where c is a constant equal to 163 m, and ϕ is the latitude.

The model predicts over the grid shown in Fig. 1. The grid spacing, shown in the lower left, is 95.25 km true at 60° N. This grid is aligned with the one used for the LFM.

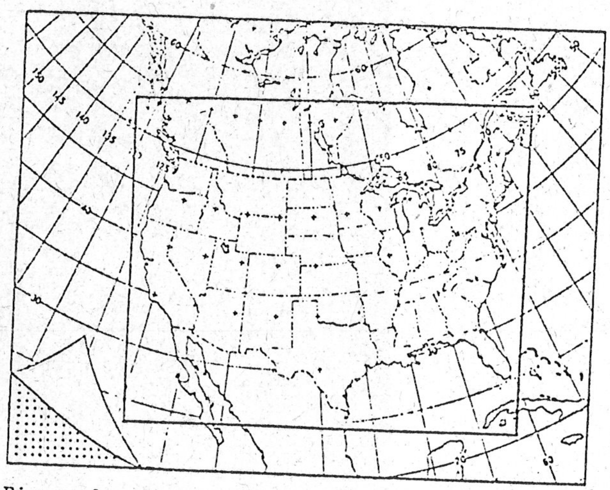

Figure 1. Area over which the SLP and SLYH models are integrated. The forecasts are verified over the smaller area indicated. The grid spacing is shown in the lower left.

The SLP model uses a Lagrangian method of integration with a timestep of one hour. In our application, it uses 500-mb height forecasts from the LFM model. The forecasts, available each 6 hours, are interpolated in time by a cubic polynomial fit by least squares to the seven LFM forecasts for hours 0, 6, ... 36, at every gridpoint to obtain values for each hour. The 500-mb heights are then interpolated to the higher density grid used in LAMP.

2.3 Model Revisions

Two changes were made to the original Reed model to adapt it for LAMP (Unger, 1982). The first change was made to the terrain term to reduce the amount of orographic detail in mountainous regions. The terrain was greatly smoothed, especially for the higher elevations. The terrain term in the development equation was also reduced to one half the value used by Reed (M = .203 PG in Eq. (2) but retains its value of .405 in Eq. (3)).

The other change was made in an attempt to alleviate the tendency of the SLP model to move systems too rapidly in regions of strong 500-mb winds. This was done by reducing the 500-mb winds greater than 41 kt (see Unger, 1982, for details). About 20% of the gridpoints were affected in the cool season, and very few in the warm season.

2.4 Verification Procedures

Although the model will eventually be run locally, its testing and development of MOS equations requires NOAA's large computers. For testing, the forecast area includes the entire United States rather than regional sections to be used when it is run locally.

The SLP model was tuned with 16 cases from January through March 1979 and 14 cases from the summer of 1979. Fourteen cases from the winter of 1977-1978 were selected as independent data. Some of the cases were selected at random, while others were chosen to examine the model's handling of systems in particular regions of the country.

Verification scores used to test the accuracy of the forecasts were the S1 score (Teweles and Wobus, 1954) and the mean absolute error (MAE). Scores were computed on the grid on which LFM data are available; these points coincide with alternate grid points on the SLP model's computational grid. Verifying values were 1000-mb heights which were determined from sea level pressure analyses by Eq. (1).

The S1 score is a measure of the accuracy of the gradient forecasts and is independent of the mean error. A low score represents a better forecast, with scores below 30 generally regarded as highly accurate and those above 80 regarded as valueless (Badner, 1966).

The (MAE) measures the overall magnitude of errors. It is not entirely reliable as an indicator of the pressure pattern forecast; rather, it indicates how close the predicted 1000-mb heights are to the observed ones.

SLP model forecasts intialized at 0800 GMT were compared to LFM 1000-mb forecasts initialized at 0000 GMT. Standard 6-h intervals for which the LFM forecasts are available were chosen for verification, so a 4-h forecast from the SLP model was compared to a 12-h LFM forecast valid at 1200 GMT. Simarly, 10-, 16-, and 22-h SLP model forecasts were compared to 18-, 24-, and 30-h LFM forecasts valid at 1800, 0000, and 0600 GMT, respectively (see Fig. 2). Verification statistics were computed by season. Forecasts for October through March were grouped into the cool season (winter); the remainder of the year was designated as the warm season.

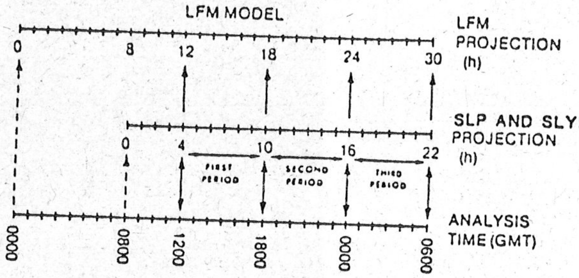

Figure 2. Relationship between initialization time, projection hour, and verification time of the LFM, SLP, and SLYH models. Dashed vertical lines indicate initialization times.

2.5 Results

There were no significant differences between verification statistics for the independent and the dependent sample, so verification results from both data sets were combined. Figs. 3 and 4 compare the S1 score and the MAE of the SLP, LFM, and persistence forecasts for the 30 winter cases.

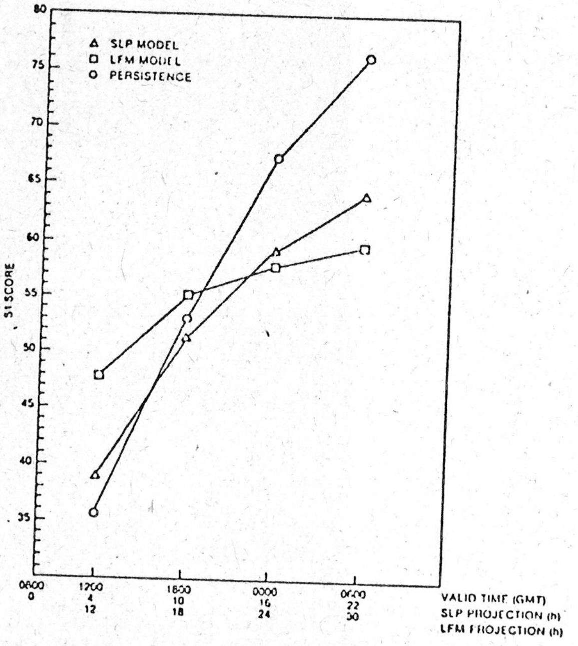

Figure 3. S1 scores over the verification region for SLP model and persistence 1000-mb height forecasts initialized at 0800 GMT and for LFM forecasts initialized at 0000 GMT. S1 scores are from an average of 30 cases from winter 1977-78 and winter 1978-79.

Figure 3 shows that persistence was the best forecast in terms of the S1 score up to 8 hours, with the SLP model best from 8 to 14 hours, and the LFM best beyond that. The 1000-mb height patterns obtained from the SLP model forecasts initialized at 0800 GMT were, on the average, more accurate than the LFM's through 2200 GMT. Persistence scores so well due to local and highly persistent orographic effects over the western U.S. These effects are largely due to pressure reduction.

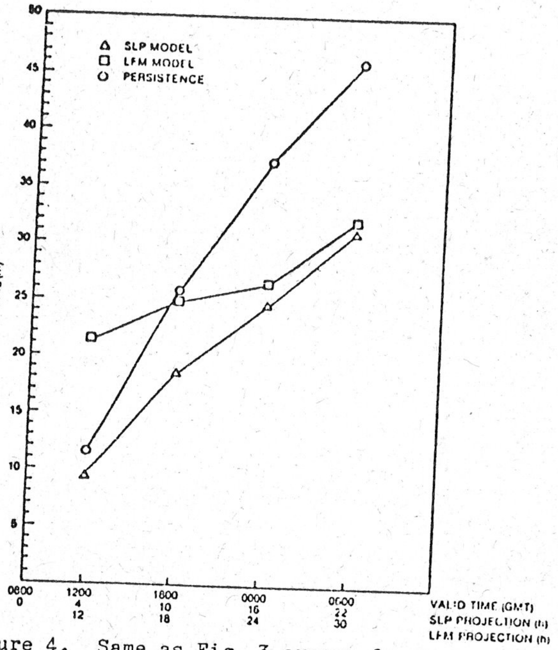

Figure 4. Same as Fig. 3 except for mean absolute error.

The 1000-mb height forecasts from the SLP model gave the lowest MAE for the entire 22-h forecast period. The persistence MAE was better than that of the LFM for 9 hours, although it rapidly deteriorated throughout the forecast period.

Summer results were largely similar, except for slightly better scores by persistence. This reflects the generally weaker synoptic systems and stronger local features of the summer season.

An example of a forecast is shown in Figs. 5-8. The initial map from March 10, 1979, at 0800 GMT is shown in Fig. 5, with the smoothed 16-h SLP model forecast valid at 0000 GMT March 11, 1979, shown in Fig. 6. The 24-h LFM forecast valid at the same time is shown in Fig. 7, and the verifying analysis in Fig. 8. This sample was chosen because of its fairly typical scores and sharply defined pressure systems.

The SLP model overbuilt the high pressure system in the plains, as did the LFM to a lesser extent. The pattern in the mountain states was not predicted particularly well by either model, although the SLP model's S1 scores were slightly better over the West. Pressures over the eastern United States were well-predicted by both models. There, the LFM was very slightly fast; however, due to its better placement of the high, it's S1 score was slightly better. The S1 score for the SLP model's forecast was 60.2 over the verification area, with the LFM's at 57.2. The MAE was 19.0 meters for the SLP model, and 20.4 for the LFM.

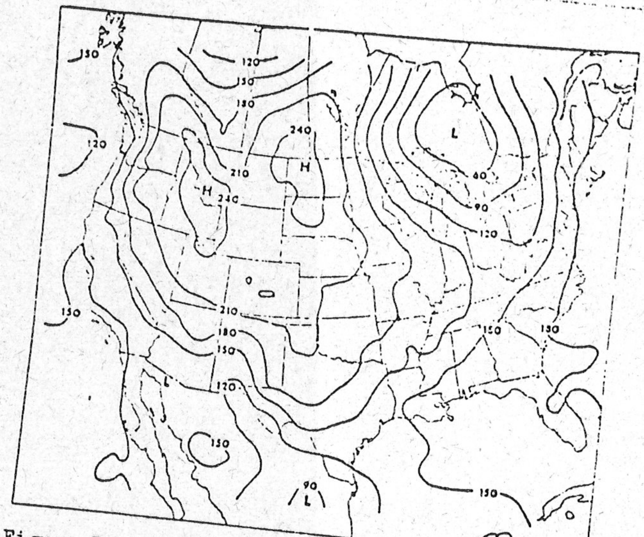

Figure 5. Initial analysis of 1000-mb heights, in meters, valid at 0800 GMT, March 10, 1979.

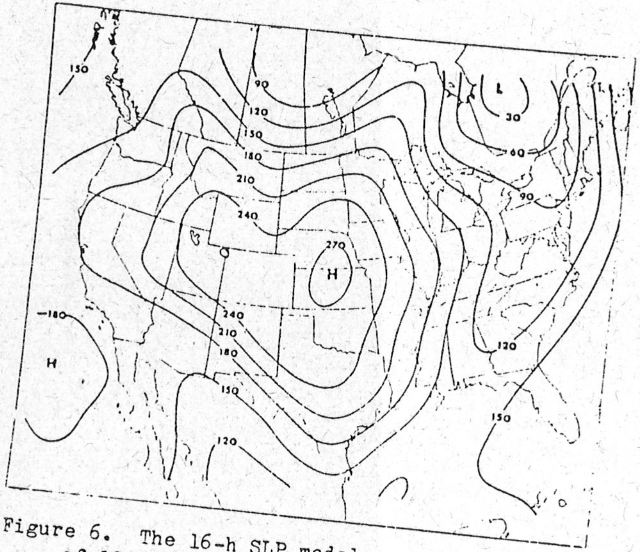

Figure 6. The 16-h SLP model smoothed forecast of 1000-mb heights, in meters, valid at 0000 GMT, March 11, 1979.

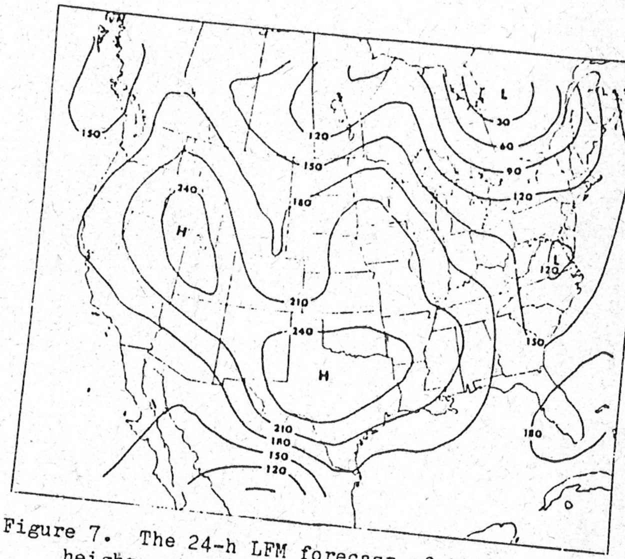

Figure 7. The 24-h LFM forecast of 1000-mb heights, in meters, valid at 0000 GMT, March 11, 1979.

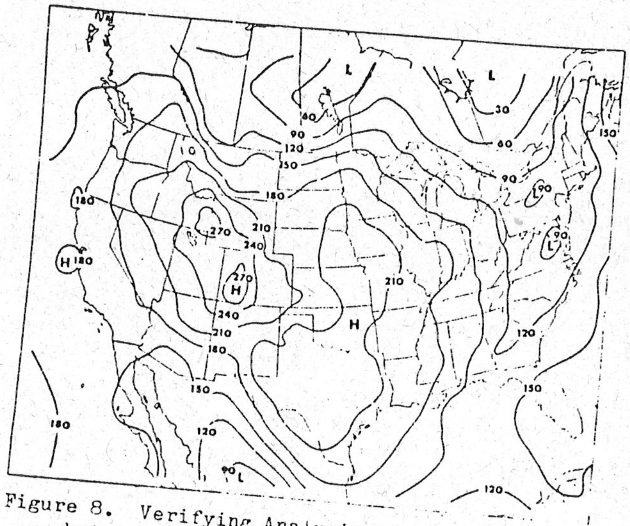

Figure 8. Verifying Analysis of 1000-mb heights, in meters, for 0000 GMT, March 11, 1979.

3. THE MOISTURE MODEL

3.1 Overview

SLYH is a very simple moisture prediction model which was developed in the early 1960's at NMC. It predicts a single layer moisture quantity known as the saturation deficit (Sd) defined as the difference between the observed 1000-500 mb thickness and the saturation thickness. The saturation thickness is defined as the 1000-500 mb thickness which would result in a sufficient degree of saturation to initiate precipitation, given the actual amount of moisture present in the column between 1000 and 500 mb. Sd is set to zero when precipitation is observed at a station. Condensation of excess moisture prevents the saturation thickness from being lower than the observed thickness, and therefore, Sd is never less than zero. Sd values less than 120 m generally indicate considerable cloudiness or overcast conditions, and an Sd greater than 400 m indicates a very dry atmosphere.

The Sd is defined as zero at those stations reporting any form of precipitation in the hourly observation. At those stations not reporting precipitation, Sd is estimated by a regression equation based on elements in the hourly observation and LFM relative humidity forecasts. Occasionally the regression equation estimates Sd $\leq$ 0 at stations not reporting precipitation; for those cases, a small positive value is used for the saturation deficit. These Sd estimates are made for all stations for which hourly reports are available, and are then analyzed with a Cressman-type analysis to gridpoints (Glahn et al., 1969). The analyzed Sd is altered by the insertion of a small positive number at gridpoints at which the manually digitized radar (MDR) reports indicate a radar echo and the Sd is not zero. A small positive value, rather than 0, is inserted so that the analysis will indicate precipitation only when it is observed at a station and yet indicate that saturation is very near at a gridpoint where a radar echo is reported.

3.2 The Basic Model

The SLYH model predicts changes in the saturation deficit based upon the assumption that the amount of moisture in the atmosphere is conserved. A moisture continuity equation which reflects this principle is manipulated with the aid of various assumptions based on climatology to obtain the relation expressed in Eq. (4) (see Younkin et al., 1965).

$$Sd^{fd} = Sd^{iu} - 2(h_5^{iu} - h_5^{fd}) + (PMA^{iu} - PMA^{fd}) \quad (4)$$

The superscripts in Eq. (4) denote "forecast downstream" and "initial upstream" as they do in Eq. (2) for the SLP model. The term h_5 is the 1000-500 mb thickness obtained from the 1000-mb heights of the SLP model prediction and the 500-mb heights from the LFM obtained in the same manner as for the SLP model. PMA is a terrain term which depends only on the terrain height.

The forecast procedure used to find the trajectories is identical to that for the SLP model except that the winds, $\vec{V}_E$, are found from a combination of 1000- and 500-mb geostrophic winds, $\vec{V}_{10}$ and $\vec{V}_5$, respectively, shown in Eq. (5).

$$\vec{V}_E = .33\,\vec{V}_5 + .5\,\vec{V}_{10}. \quad (5)$$

Eq. (4) indicates the saturation deficit is modified along a trajectory by two effects--changes in forecast thickness and changes in the terrain heights. The SLYH model in LAMP predicts Sd with this equation on the same grid as used for the SLP model, shown in Fig. 1. A 1-h timestep is used to make the forecasts.

The SLYH model indicates precipitation at a particular grid point when it forecasts $Sd \leq 0$ at the end of a timestep. This means the amount of moisture in the layer between 1000 and 500 mb is in excess of the amount necessary to initiate precipitation for the forecast thickness. At the end of each timestep any negative Sd's are adjusted to zero. The decrease represents a net loss of moisture in the form of precipitation. In theory, there is a direct relationship between the precipitation amount in a timestep and the magnitude of the negative Sd.

The amount of "precipitation" which occurs at a gridpoint in a time period longer than one hour is estimated by the sum of any negative saturation deficits at the end of the timesteps within the period. This is termed the accumulated saturation deficit (ASd). For consistency, the ASd's for gridpoints at which the saturation deficits do not fall below zero in any timestep within the period are set equal to the average of the Sd's at the end of each timestep for that period. The saturation deficits at the end of each timestep can be regarded as 1-h ASd values.

3.3 Model Revisions

The SLYH model was tuned on 15 cases from the winter of 1978-1979. These were chosen from the same sample as used for the SLP model. One change was made to the SLYH model to improve the consistency between the initial field and the model prediction. The change was necessary because large areas of precipitation that were observed at the initial time were frequently forecast to end in the first timestep. This was caused by initial inconsistencies between the saturation deficit tendency forecast from Eq. (4) and the observed data.

To improve this situation, the Sd is required to surpass a threshold value before precipitation is ended by the model. At a gridpoint where Sd = 0 at the beginning of a timestep and the model predicts it to increase, it is constrained to remain zero unless it is forecast to be higher than some threshold value. This procedure emphasizes the initial precipitation observation in relation to the model development equation.

The threshold value, initially quite large, is reduced in magnitude as the forecast progresses, until after 10 hours when it is entirely eliminated. This creates a smoother transition from the initial observation to the model forecasts, and produces better forecasts as well.

3.4 Verification Procedures

LAMP's SLYH model was used to predict the occurrence of precipitation and was compared to forecasts from the LFM. The 6-h ASd forecasts which ended at 1800, 0000, and 0600 GMT from the 0800 GMT observations were compared to the 0000 GMT LFM precipitation amount (PAMT) forecasts for the same periods. The 1200-1800 GMT forecast period is referred to as the first period, the 1800-0000 GMT period as the second, and the 0000-0600 GMT period as the third (see Fig. 2). The forecasts were interpolated to 437 stations distributed throughout the 48 states and were compared to the 6-h precipitation amounts reported at those stations. For the SLYH Sd, a biquadratic interpolation was used and a negative Sd at a station considered to be a precipiation forecast. For the LFM PAMT, a special interpolation which puts the "zero" line about half way between a gridpoint with PAMT = 0 and one with PAMT > 0 was used and an interpolated PAMT $\geq$ .005 in (.13 mm) was considered to be a precipitation forecast.

These predictions were also compared to precipitaion forecasts produced by only advection of the initial Sd field with the winds used in SLYH (ie., forecasts made with a SLYH model with no development terms). It was found that boarder areas of precipitation were eliminated by interpolations (small positive numbers encroached into the precipitation areas). To compensate, the Sd threshold which denotes precipitation was set to a small positive value. This made the advection forecasts more reasonable.

The forecast verification scores used to determine the accuracy of the predictions are the threat score (TS), prefigurance (PREF), post agreement (POST), and bias. The scores are defined as

$$TS = \frac{H}{F+S-H}, \quad PREF = \frac{H}{S}, \quad POST = \frac{H}{F}, \quad BIAS = \frac{F}{S},$$

where H is the number of stations at which precipitation was correctly predicted, F is the number of stations at which precipitation was forecast, and S the number of stations which reported precipitation. Prefiguration is also known as the probability of detection, and post agreement is equivalent to one minus the false alarm ratio.

Table 1 shows results of 15 forecasts from the winter sample. It is noteworthy that the scores for the SLYH model and LFM remain nearly constant for the three periods, while the advection forecasts show a clear decline in quality. This indicates that both the SLYH and LFM are capable of dynamic development of precipitation areas. The SLYH model scores essentially the same as the LFM in all three periods on this sample.

Table 1. The threat score, TS, prefigurance, PREF, post agreement, POST, and bias for forecasts of measurable precipitation in 6-h periods at 437 stations within the U.S. The SLYH and advection models are initialized at 0800 GMT and the LFM is initialized at 0000 GMT. The data are from 15 forecasts from the winter of 1978-1979.

Score	Model		
	LFM	SLYH	Advection
Period 1			
TS	.42	.43	.33
PREF	.65	.71	.59
POST	.54	.53	.44
BIAS	1.19	1.36	1.33
Period 2			
TS	.38	.39	.21
PREF	.72	.72	.41
POST	.45	.46	.31
BIAS	1.59	1.54	1.33
Period 3			
TS	.41	.42	.18
PREF	.73	.78	.34
POST	.49	.48	.27
BIAS	1.49	1.64	1.27

Table 2 shows the results from the 15-case winter sample combined with 19 cases from October 1977. There are about 13000 individual forecasts in this sample, with approximately 1650 precipitation observations. SLYH outscores the LFM in the first period and is about the same in the second and the third periods.

Table 2. Verification scores for 34 forecasts from the winter of 1978-1979 and Otober 1977.

Model	Score	Period		
		1	2	3
SLYH	TS	.41	.37	.38
	PREF	.64	.64	.68
	POST	.53	.47	.45
	BIAS	1.21	1.35	1.50
LFM	TS	.38	.37	.37
	PREF	.63	.67	.65
	POST	.49	.45	.46
	BIAS	1.26	1.48	1.43

The author subjectively compared the forecasts from the SLYH and LFM models for the same 34 cases. The models were rated on their ability to predict the precipitation patterns in the first period. The author judged SLYH to be superior on 21 forecasts, with the LFM superior in 8, and 5 about the same. A comparison based on the threat score showed SLYH to be superior on 22 days and the LFM produced a better threat score on 12 days.

Figure 9 shows an example of a first period forecast from the SLYH model initialized at 0800 GMT on March 10, 1979. The precipitation is associated with a cold front (see Figs. 5-8 for the 1000-mb height analysis and the SLP and LFM model 1000-mb height forecasts). The areas of observed and forecast precipitation are outlined. The shaded areas indicate successful precipitation forecasts. Figure 10 shows the precipitation forecast from the LFM model forecast from 0000 GMT.

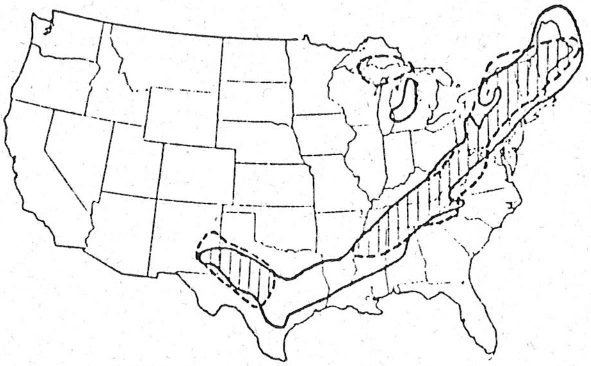

Figure 9. The SLYH model forecast, initialized at 0800 GMT, of measurable precipitation in the 6-h period from 1200 to 1800 GMT on March 10, 1979. The observed precipitation areas are outlined by the solid line with the forecast areas outlined by the dashed line. Regions of correctly forecasted precipitation are shaded.

It is well within each model's capabilities to forecast the general pattern of precipitation at this projection. Each model occasionally misses areas of precipitation, as well as predicts areas of precipitation that do not verify. Frequently, as in the example shown, the LFM and SLYH models both incorrectly forecast areas of precipitation in a similar fashion. This may indicate sudden development or dissipation of precipitation which is not detected by either model, or, since SLYH is driven in part by the LFM 500-mb height forecasts, errors in the LFM 500-mb height predictions may adversly affect both models in similar ways.

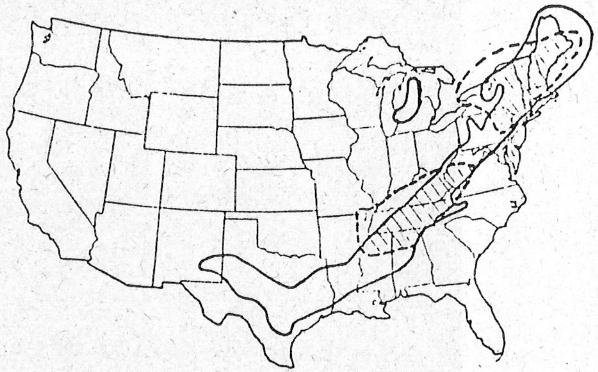

Figure 10. Same as Figure 9 except for the LFM forecast initialized at 0000 GMT.

4. CONCLUSIONS

The SLP and SLYH models in LAMP initialized at 0800 GMT show some improvement over central guidance forecasts in the very short range. These 0800 GMT forecasts can conceivably be used to update guidance for the early morning forecast.

The SLP model showed clear advantage over the equivalent forecasts from the LFM for up to 10 hours after 0800 GMT and some advantage through nearly 16 hours.

Results from the SLYH model show that the 6-h precipitation forecasts are better than the LFM through 10 hours, and are of similar quality through 22 hours after 0800 GMT. Since much of the advantage from LAMP will come from its ability to more accurately determine the timing of significant weather changes such as the onset of precipitation, the 6-h precipitation forecasts may cover too long a period to show the full advantage of LAMP. Thus, we feel that the results presented here only partly illustrate the value of the SLYH model.

5. ACKNOWLEDGMENTS

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