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An Operational Subsynoptic Advection Model

Technical Memorandum WBTM TDL 23

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U.S. DEPARTMENT OF COMMERCE
Environmental Science Services Administration
Weather Bureau

ESSA Technical Memorandum WBTM TDL 23

AN OPERATIONAL SUBSYNOPTIC ADVECTION MODEL

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OFFICE OF SYSTEMS DEVELOPMENT
TECHNIQUES DEVELOPMENT LABORATORY

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AN OPERATIONAL SUBSYNOPTIC ADVECTION MODEL[1]

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ABSTRACT

An operational numerical model developed within the Techniques Development Laboratory (TDL) of the Weather Bureau is described. The space scale of the model is approximately 50 miles and the time scale is 1 hour out to 17 hours. Direct output from the numerical model includes sea-level pressure predictions and categorical precipitation forecasts for the eastern United States. It appears that the forecasts produced by the model are superior to other machine-produced predictions valid at the same time prepared centrally by the Weather Bureau.

INTRODUCTION

The Subsynoptic Advection Model (SAM) is one of several numerical models run operationally at the National Meteorological Center (NMC) in Suitland, Maryland. The operational SAM is essentially the same as the developmental SAM described by Glahn and Lowry in 1967 [16, 17]. To our knowledge, SAM is the first subsynoptic model to become fully operational on a twice-per-day schedule. Primitive equation (PE) small-scale models such as that developed by Bushby and Timpson [3] still require considerable computer time compared to our model. SAM requires less than 3 minutes for each run on the ESSA CDC 6600 computer at Suitland, Maryland.

If we define synoptic scale as being characterized by the full NMC grid length (381 km at 60° N.), then the SAM (95¼ km) grid length (see fig. 1) can be considered subsynoptic. In all fairness, the present SAM program is not entirely subsynoptic. This is because the forecasts needed at 500 mb, the upper level of the two-level model, are supplied by the synoptic scale NMC PE model [33] and interpolated to the smaller grid over the central and eastern United States. The PE 500-mb height forecasts are time smoothed over the first 36 hours by fitting the values at each grid point to a cubic curve. This is necessary to filter out the undesirable gravity waves. It may be feasible to incorporate a fine-mesh 500-mb model into the SAM system in the near future. Such an effort would draw upon the experiences reported by Howcroft [22], Bermowitz [2], Gerrity and McPherson [15], Wang, Halpern, and Wrotenbery [35], and Hill [20].

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[1] Updated version of Technical Memorandum WBTM TDL-11 (see reference 17).

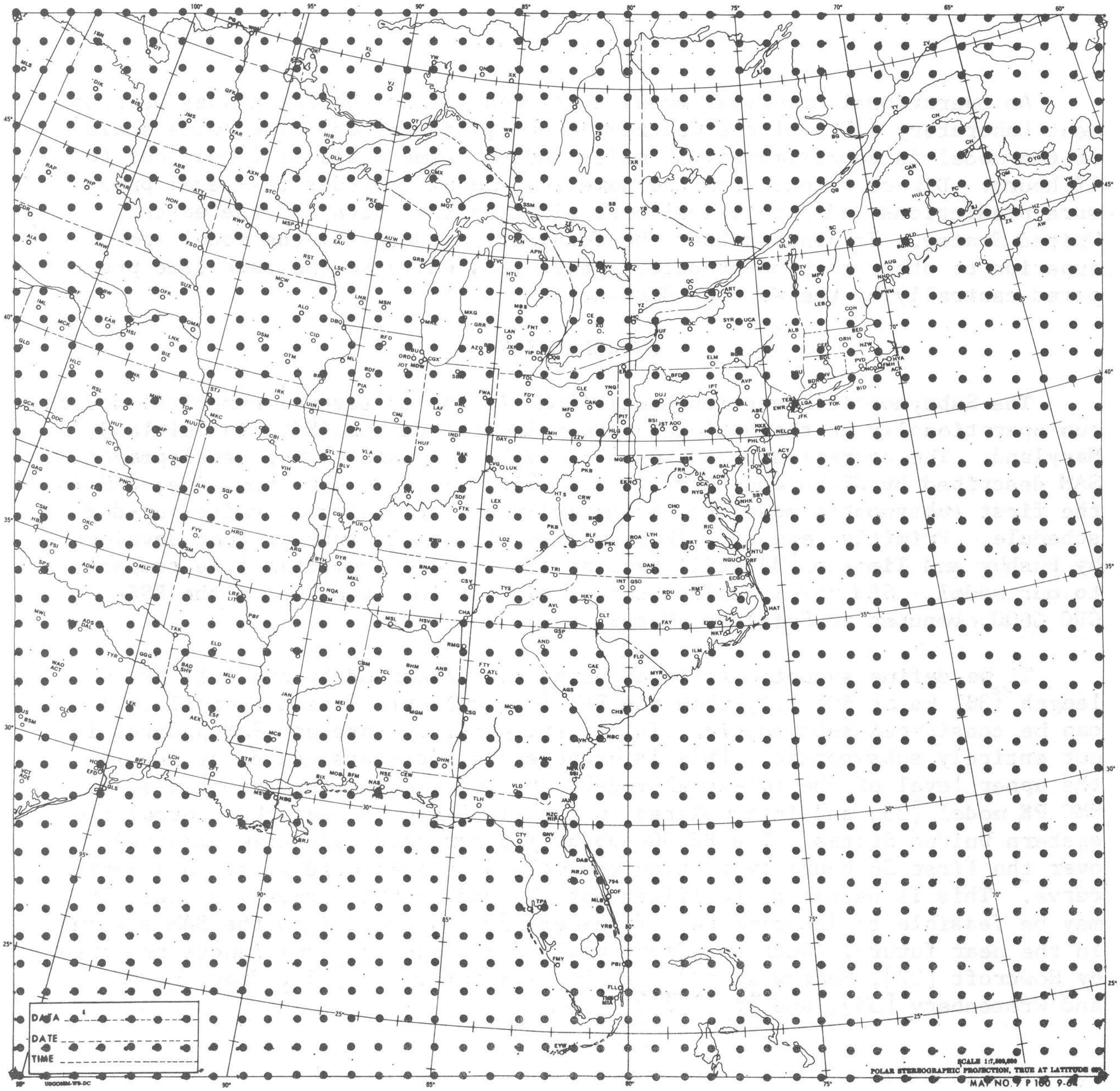

Figure 1. The SAM 39 x 40 grid is shown by dots at grid points. The gridlength is exactly ¼ that used for the NMC synoptic scale products. This is approximately 50 miles, and it is not much different from the average spacing of hourly reporting stations in the eastern and central United States.

Lower level initial information is supplied on a horizontal scale that is truly subsynoptic (see fig. 1). The automatic decoding of the initial surface weather reports is explained by Hollenbaugh, Glahn, and Lowry [21]. These data are then supplied to a program that performs analyses of moisture and sea-level pressure. This procedure is described by Glahn, Hollenbaugh, and Lowry [18].

Emphasis has been placed primarily on precipitation forecasting and secondarily on sea-level pressure prediction. The direct output precipitation forecasts are in categorical form, and the model that produces these forecasts requires sea-level pressure predictions as input. Therefore, SAM is made up of a sea-level pressure model and a precipitation model (see fig. 2), both dynamical in nature, and both using the subsynoptic grid with a 1-hour time step.

Figure 2 shows the complete time sequence for the early morning forecast (afternoon forecast times are 12 hours later). Upper air input data are 0000 GMT reports. The NMC PE model [33] supplies upper air (500-mb) forecasts out to 24 hours (2400 GMT). Surface input data are 0700 GMT surface weather observations. After decoding [21] and analysis [18], SAM sea-level pressure and precipitation models produce forecasts out to 17 hours (2400 GMT). The forecasts are available approximately 1 hour and 15 minutes after observation time. About half of this time is required just to collect the observations from the teletype lines. The remainder is used to load magnetic tapes, run the program, transfer the computer output to paper tape for teletype transmission (see fig. 3), and generate magnetic tape output for the NMC curve follower. The curve-followed product as it appears on facsimile (see fig. 4) is hand labeled. This is the only point in the procedure when the forecasts are touched by human hands.

Forecasts produced from the morning computer run are valid for the 12-hour "today" period (see fig. 2), 1200 GMT to 2400 GMT. Likewise, forecasts produced from the afternoon computer run are valid for the 12-hour "tonight" period, 0000 GMT to 1200 GMT. In either case, the forecasts are valid for the "first" (by Weather Bureau terminology) 12-hour period following each run. The specific hour chosen for the surface input data was determined by the lead time required with respect to forecast release times. These vary considerably according to Weather Bureau Region, time zone, season, local press, etc. In general, deadlines are tightest in the summer in the Eastern Time Zone. For example, a typical local forecast for the "today" period would be issued at 1000 GMT (see fig. 2). When Eastern Standard Time is used in the colder months this would change to 1100 GMT. Area and zone forecasts are issued prior to release of the local forecasts.

The sea-level pressure and precipitation models in SAM will be discussed separately. Also, examples of direct operational output are presented (see figs. 3 and 4) and discussed. Indirect operational output including probability of precipitation (PoP) as derived from Model Output Statistics (MOS) will not be discussed in this paper but rather will be covered in future Technical Memoranda.

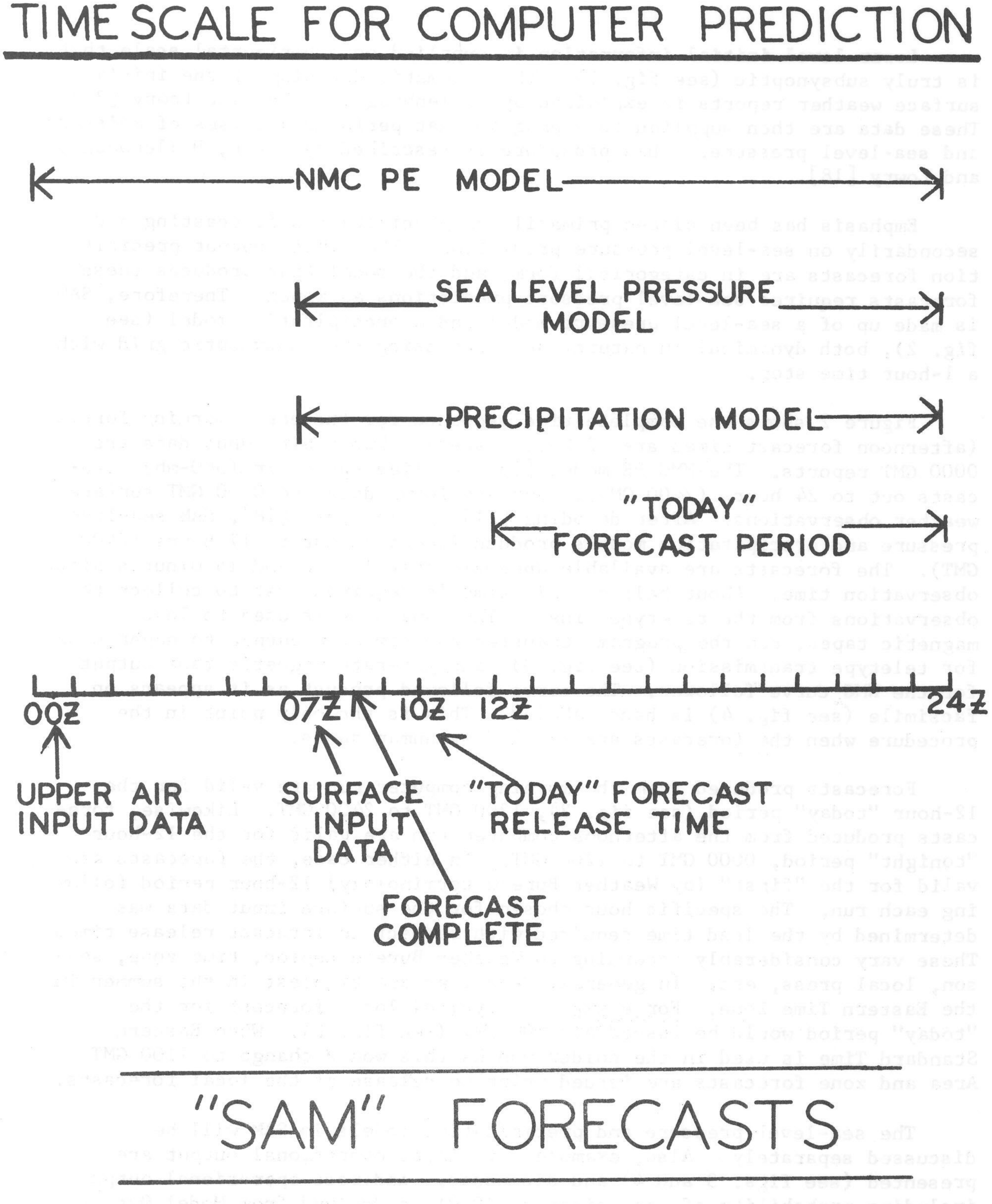

Figure 2. The time scale for computer prediction of weather variables on a subsynoptic scale. The time-step used in the model is 1 hour.

SEA-LEVEL PRESSURE MODEL

One of our primary interests, when considering different possible models to produce sea-level pressure predictions, was the operational speed factor. The vorticity equation can be solved on the computer much more rapidly than the primitive equations. Considerable work with graphical solutions of the vorticity equation had been reported by Estoque [12, 13, 14] and Reed [29, 30, 31]. In addition, Reed [32] had produced a computer solution which was used for several years at NMC. He used a parabolic vertical velocity profile, assumed constant static stability, and included orographic and latitude terms in his model. Experimentation was performed with both Eulerian and Lagrangian approaches and the latter found to be superior. Also, it was determined that an upstream trajectory model has an advantage over a downstream trajectory model; it assures a solution at each grid point since that is where the trajectories end.

The prediction equation formulated by Reed [32] is in the form of a conservation statement as shown below:

$$Z_o^{fd} = Z_o^{iu} + .55\,(Z_5^{fd} - Z_5^{iu}) + (G^d - G^u) - (M^d - M^u) \quad (1)$$

where Z_o = 1000-mb height
Z_5 = 500-mb height
G = Latitude term
M = Terrain term
fd = Forecast value at downstream point
iu = Initial value at upstream point.

We use this same conservation statement in the SAM program. However, we recognized that certain weaknesses were inherent in the forecasts produced by Reed's method. Basic weaknesses turned out to be overintensification of anticyclones and problems in and near mountains. These weaknesses are probably due in part to the exclusions in the model of ageostrophic effects, nonadiabatic heating, latent heat feed-back, and variable static stability.

The orographic problem did not seem to be serious in our relatively nonmountainous area (see fig. 1). The overintensification of anticyclones was considered to be a serious problem in the computer solutions as well as the graphical solutions. In order to solve the problem, we reconstructed trajectories according to the conservation statement using Reed's equivalent advecting wind [32] (this wind retains the 500-mb and mountain terms but neglects the latitude term). Then we constructed trajectories that would produce perfect predictions. An analysis of the perfect trajectories indicated that a space smoothed 500-mb height field would be of great benefit. After several smoothing functions were examined, we chose one that set the height at each grid point equal to the average of the heights at the 25 NMC grid points centered at that grid point. The orographic term was added and the latitude term neglected in the same manner as Reed [32] handled them. Then 55 percent of the geostrophic wind computed from this smoothed field was used as the advecting wind. By using the smoothed wind, the overintensification of anticyclones has been greatly reduced.

The exclusions in the model that have been mentioned have not been examined fully to determine their individual relative importance. There are indications from previous works with graphical models that some improvements are possible through explicit examinations in these areas of interest. Muench [28] found ageostrophic effects to be considerable at 1000 mb. Nonadiabatic heating was found to be important by Haltiner and Wang [19]. The inclusion of latent heat feed-back in precipitating areas was beneficial in studies made by Danard [4, 5, 6]. The advantages of allowing the static stability to vary were pointed out by Lowry and Danielsen [27].

ACCURACY OF SEA-LEVEL PRESSURE FORECASTS

The sea-level pressure forecasts produced by SAM have been compared with predictions produced by the NMC PE model [33] for the beginning (1200 GMT) and the end (2400 GMT) of the 12-hour "today" period. Both products are available as guidance for the "today" period. Every third point on the SAM grid (see fig. 1) was used to verify both products. This approximates the grid normally used at NMC for this purpose.

Comparative verification of the two numerical products has been in terms of S_1 score, a gradient skill score used at NMC for over 20 years [34]. In theory, a score of zero is perfect and 100 shows no skill. In practice, NMC considers a score of 30 to be perfect and 80 to show no skill for sea-level pressure forecasts [1]. The S_1 score, being gradient oriented, does not indicate the absolute error. Therefore, we have added the root mean square error (RMSE) and mean absolute error (MAE) to the verification. The errors measured by these latter scores do not necessarily affect geostrophic wind forecasts but can affect temperature and rain vs. snow forecasts drastically through false thickness predictions.

Table 1 shows the seasonal and total comparative verification scores for 168 total cases (usually Tuesday and Friday of each week) over a 2-year period. There were 50 spring, 42 summer, 37 fall, and 39 winter cases. Of the various categories shown, SAM is superior to some degree in all except for the hour 2400 GMT in the winter.

Seasonal distribution of S_1 indicates a rather level pattern of spread between the scores of the two products. SAM gave its maximum improvement in the summer and its minimum improvement in the winter. RMSE and MAE scores are consistent with each other and with the S_1 scores when considering that the larger pressure changes occur in the cold season and smaller changes occur in the warm season.

Forecasts for the beginning of the "today" period (1200 GMT) clearly show the value of later surface data in the SAM predictions. SAM forecasts were 31 percent better than those of the PE in terms of the S_1 score. Standard significance tests applied to the data showed SAM to be significantly better at the one-tenth of 1 percent level in all categories in all seasons.

Table 1. Seasonal and yearly comparative verification of SAM and PE sea-level pressure forecasts at the beginning (1200Z) and end (2400Z) of the "today" period. Scores are shown for S_1, root mean square error (RMSE), and mean absolute error (MAE). Low scores are desirable in all cases. RMSE and MAE are in millibars. The 2-year sample was from March 1967 through February 1969.

	Valid 1200 GMT						Valid 2400 GMT					
	S_1		RMSE		MAE		S_1		RMSE		MAE	
	SAM	PE	SAM	PE	SAM	PE	SAM	PE	SAM	PE	SAM	PE
Spring (M-A-M)	28	42	1.8	3.1	1.5	2.6	46	47	3.3	3.6	2.6	3.0
Summer (J-J-A)	36	55	1.3	2.1	1.0	1.7	49	54	2.0	2.6	1.6	2.1
Fall (S-O-N)	27	43	1.4	2.3	1.0	1.9	47	53	2.7	3.0	2.2	2.5
Winter (D-J-F)	31	42	1.8	2.8	1.3	2.3	52	50	4.1	3.9	3.3	3.2
Total	31	45	1.6	2.6	1.2	2.1	48	51	3.0	3.3	2.4	2.7

Verification scores valid at 2400Z, the end of the "today" period, show that the spread, or improvement, of SAM over the PE has been reduced. SAM forecasts were only 6 percent better than the PE in terms of the S_1 score. However, standard significance tests on the totals indicated that Sam was significantly better at the 5 percent level or better in all three categories. Thus, the 6 percent improvement turned out to be small but significant.

PRECIPITATION MODEL

The precipitation model is similar to the SLYH model [36] that was used at NMC from September 1964 until moisture was included in the PE model in February 1967. A variation of the SLYH method for use on-station was developed by Kulawiec [24]. The prediction equation is

$$S_d^{fd} = S_d^{iu} - 2(h_5^{iu} - h_5^{fd}) + (PMA^u - PMA^d) \qquad (2)$$

where S_d = Saturation deficit

h_5 = 1000 - 500-mb thickness

PMA = Terrain term

fd = Forecast value at downstream point

iu = Initial value at upstream point.

Again, an upstream Lagrangian trajectory method is used. The moisture-advecting wind is a combination of the 500-mb and 1000-mb winds. We are currently using 33 percent of the 500-mb geostrophic wind plus 50 percent of the smoothed 1000-mb geostrophic wind. The moisture variable is the saturation deficit defined as

$$S_d = h_5 - S_T \tag{3}$$

where S_T = saturation thickness. The saturation thickness, for our purposes, is that thickness between 1000 and 500 mbs for which precipitation will occur for a given amount of moisture between those levels.

The initial saturation deficit field is very important and is needed on a space scale commensurate with the grid length being used. Since upper air soundings are neither taken at the right time nor exist at this density, we determined a statistical relationship between the saturation deficit and hourly surface observations [25,26]. We collected about 33,000 1200 GMT hourly surface observations taken during a 2-year period at 56 RAOB stations in the area of interest. These were compared to corresponding surface-to-500-mb precipitable water values. All reports of lowest cloud height, total sky cover, weather, pressure, temperature, and dew point were subjected to computer screening regression analysis to determine their importance as specifiers of precipitable water. Five other specifiers, the U and V components of the surface wind, latitude, longitude, and station elevation, were given a limited 6-month test. Time-grouping was by calendar month.

Surface dew point alone was found to explain 83.4 percent of the variance of the natural logarithm of precipitable water. Another 2.5 percent could be explained by two additional variables, surface weather and total sky cover. This gives 85.9 percent total reduction of variance from three specifiers which amounts to a multiple correlation coefficient of .93. The remaining eight specifiers were shown to contribute insignificantly.

Scatter diagrams of 1000-500-mb thickness versus ln precipitable water allow precipitable water estimated by the three surface specifiers to be converted into saturation thickness values. When the saturation thickness is then subtracted from the initial 1000-500-mb thickness, we get the desired saturation deficit.

This regression estimate of saturation deficit is overridden for stations where precipitation is occurring and the regression estimate indicates otherwise. Also, it is overridden for stations where precipitation is not occurring and the regression estimate indicates otherwise. With the overriding feature, we feel we can do better using 0700 GMT surface observations than we could by using only the moisture computed from 0000 GMT soundings.

Observed variables needed as specifiers are decoded [21] and the necessary fields analyzed [18] before the prediction program is used. From the initial fields, forecasts are made in 1-hour time steps. Since the 1000-mb, or sea-level pressure, information is needed as input for the precipitation model, the sea-level pressure model must precede the precipitation model for each 1-hour time step.

At the end of each time step the negative deficit values are set back to zero. This amounts to precipitating out some of the moisture. Moisture is not added to the model to simulate evaporation, but this is not considered serious in a short range forecast. In fact, the large scale NMC SLYH [36], which has this same feature, showed no signs of drying out in 48 hours.

ACCURACY OF THE PRECIPITATION FORECASTS

Precipitation forecast verification of occurrence or nonoccurrence covers the 12-hour "today" period. Any negative saturation deficit during the period is considered to be a forecast occurrence by SAM. An observed occurrence is .01 inch or more of precipitation actually observed during the period. The numerical PE precipitation (PEP) forecasts were used for this comparison and were supplied by NMC. Persistence was added as a control forecast and is based on occurrence of precipitation at initial data time. Twenty-one stations over the eastern portion of the nation were used for this 1-year evaluation study. A list of these stations is supplied in the appendix and shows distribution by Weather Bureau Region.

Comparative verification of SAM, PEP, and persistence forecasts has produced volumes of statistics. It is therefore necessary to summarize the summaries and decide what is important and meaningful. It is recognized that any verification statistic or set of statistics is limited in useful information. There is one theory that when evaluating a precipitation forecasting technique the threat score of precipitation is the most important single figure. These values are presented throughout this section and labeled A. Another theory provides for skill in forecasting both precipitation and no precipitation by use of the common (Heidke) skill score where the element of chance has been removed. This tends to produce a total skill concept. These values are labeled B. Gross over or underforecasting can be determined from the post agreement and prefigurance. Since we recognized that these two categories are closely associated and that one can be optimized at the expense of the other, we decided that the two should be considered together. Therefore, we have added them and divided by two to produce a single meaningful value C. The actual post agreement and prefigurance are carried in parenthesis. A, B, and C computed from the contingency tables in table 2 are shown in table 3 for the 12-hour "today" period for all cases from March 1, 1967 to February 29, 1968. Table 4 shows a seasonal breakdown of table 3. Twelve-hourly NMC subjective forecast verifications are available and have been added to tables 2, 3, and 4 in order to provide more comparative information. PEP and in some cases SAM were available as guidance for the subjective forecasts.

Next, the same data for the period July 1, 1967, to February 29, 1968, have been divided into period I (1200-1800Z) and period II (1800-2400Z). Following the same format, tables 5 and 6 refer to period I and tables 7 and 8 refer to period II. A, B, and C each have a range from zero to one, where one is perfect, and high numbers indicate desired skill (minus skill scores are possible but are not often encountered).

Table 2. Contingency tables for each of SAM, PEP, persistence, and NMC subjective forecasts for 21 stations covering the "today" period during a 1-year sample (170 total cases). P is precipitation, NP is no precipitation, and T means total.

SAM

	FORECAST		
OBSERVED	P	NP	T
P	517	269	786
NP	295	2489	2784
T	812	2758	3570

PEP

	FORECAST		
OBSERVED	P	NP	T
P	452	334	786
NP	258	2526	2784
T	710	2860	3570

PERSISTENCE

	FORECAST		
OBSERVED	P	NP	T
P	266	520	786
NP	251	2533	2784
T	517	3053	3570

SUBJECTIVE

	FORECAST		
OBSERVED	P	NP	T
P	554	232	786
NP	288	2496	2784
T	842	2728	3570

The contingency tables presented as table 2 show total (1 year) over or underforecasting of precipitation. There were 786 observed precipitation cases (.01 or more during the period). SAM overforecast by 3 percent by calling for 812 occurrences while PEP underforecast 10 percent by predicting 710 cases. Persistence grossly underforecast by calling for only 517. This is not surprising since the relative frequency of precipitation observed at a specific time is much less than the relative frequency over a 12-hour period. Persistence not only underforecast but faired so poorly in the various skill categories that the discussion will not concentrate on this product but rather will emphasize differences in the numerical models. Persistence scores are carried in all of the tables to establish its weak position and to serve as a rough guideline to show the relative goodness of the numerical forecasts. Also, the discussion will not concentrate on the NMC subjective forecasts (available only for the 12-hour period). Where these scores are carried it is meant to show its relative favorable position compared to the numerical guidance available to the NMC forecaster (i.e. PEP and/or SAM).

Table 3. Skill categories A, B, and C for the 12-hour "today" period computed for SAM, PEP, persistence, and NMC subjective forecasts. High numbers show desirable skill in precipitation forecasting. March 1, 1967, to February 29, 1968.

ALL SEASONS	A	B	C
SAM	.48	.55	.65(.64 - .66)
PEP	.43	.50	.61(.64 - .58)
Persistence	.26	.28	.43(.51 - .34)
NMC Subjective	.52	.59	.68(.66 - .70)

Twelve-hourly comparisons shown in table 3 indicate that SAM was 12 percent better than PEP in threat score (A) 10 percent better in skill score (B) and 7 percent better in the post agreement-prefigurance score (C). A, B, and C seem to be rather consistent in the various tables so they will be weighted equally and usually discussed as a unit. When this system was applied there was shown to be an overall 10 percent increase in accuracy of SAM over PEP. How much of this improvement was due to specifying moisture and integrating on a fine grid, to the superior sea-level pressure forecasts, or to the later data used is not known. Seasonal comparisons (table 4) of the same data showed the maximum spread, or improvement of the SAM over PEP, to be in the spring and the fall. Lesser improvements were shown in the summer and in the winter, but some degree of superiority was shown by SAM in each of the seasons in each of the three categories.

Table 4. Seasonal comparison of skill categories A, B, and C for the 12-hour "today" period computed for SAM, PEP, persistence and NMC subjective forecasts. High numbers show desirable skill in precipitation forecasting. March 1, 1967, to February 29, 1968.

SPRING	A	B	C
SAM	.49	.62	.66(.71 - .61)
PEP	.40	.49	.59(.68 - .50)
Persistence	.31	.37	.49(.57 - .41)
NMC Subjective	.47	.54	.64(.61 - .67)
SUMMER	**A**	**B**	**C**
SAM	.29	.32	.47(.56 - .38)
PEP	.27	.28	.44(.51 - .37)
Persistence	.15	.13	.31(.44 - .18)
NMC Subjective	.41	.43	.58(.54 - .61)
FALL	**A**	**B**	**C**
SAM	.46	.54	.63(.60 - .66)
PEP	.38	.46	.56(.58 - .54)
Persistence	.23	.27	.41(.52 - .29)
NMC Subjective	.49	.57	.66(.63 - .68)
WINTER	**A**	**B**	**C**
SAM	.53	.59	.70(.65 - .75)
PEP	.52	.58	.68(.69 - .67)
Persistence	.29	.29	.45(.51 - .39)
NMC Subjective	.58	.66	.74(.72 - .75)

In order to locate any possible geographical strengths or weaknesses in the various forecasts, Weather Bureau Regional summaries (not shown) were computed. The greatest advantage in accuracy by SAM over PEP for the 12-hour period was shown in the Southern and the Central Regions where 12 percent improvement was shown as compared to the average of 10 percent for all stations. SAM produced only a 6 percent improvement for the Eastern Region. This is all relative, of course. In the Southern Region, SAM produced its poorest forecasts but some of its greatest advantage over PEP. In the Central and Eastern Regions, SAM produced forecasts that are very nearly equal in accuracy, but PEP forecast better in the Eastern Region than in the Central Region; thus, the percent improvement by SAM was not as great in the Eastern Region.

Table 5. Skill categories A, B, and C for the first 6-hours (12Z-18Z) in the "today" period computed for SAM, PEP, and persistence. High numbers show desirable skill in precipitation forecasting. July 1, 1967, to February 29, 1968.

ALL SEASONS	A	B	C
SAM	.41	.50	.61(.50 - .71)
PEP	.38	.47	.55(.51 - .59)
Persistence	.28	.35	.44(.43 - .45)

Looking at the forecasts for period I (1200Z-1800Z) in table 5, we note that all of the scores of the numerical models are lower, or worse, than the scores for the 12-hour period. This is because it is harder to pinpoint the time of precipitation into the shorter time period. The reverse is true for persistence where any real value would be concentrated in the first period and the decay rate would be rather rapid. This was shown to be true, but even persistence at its best in period I was not competitive with the numerical models. For period I there was shown to be an overall 8 percent increase in accuracy by the use of SAM over PEP.

Table 6. Seasonal comparison of skill categories A, B, and C for the first 6-hours (12Z-18Z) in the "today" period computed for SAM, PEP, and persistence. High numbers show desirable skill in precipitation forecasting. July 1, 1967, to February 29, 1968.

SUMMER	A	B	C
SAM	.21	.27	.40(.27 - .52)
PEP	.21	.27	.38(.27 - .48)
Persistence	.20	.26	.33(.30 - .36)
FALL	A	B	C
SAM	.35	.45	.54(.44 - .64)
PEP	.31	.41	.48(.46 - .49)
Persistence	.26	.34	.42(.43 - .40)
WINTER	A	B	C
SAM	.48	.56	.67(.56 - .77)
PEP	.44	.53	.62(.58 - .65)
Persistence	.30	.35	.47(.44 - .49)

The seasonal comparisons (table 6) for period I do show a definite and interesting pattern. Unfortunately, we did not collect 6-hourly PEP forecasts for the period March 1 to June 30, 1967. This means spring figures are not available. Summer cases totaled 14, fall 52, and winter 67. For the limited summer data, it can be seen that SAM was only slightly better than PEP, and PEP was not much better than persistence. This, then, was where persistence reached its peak relatively speaking--in the summer in the first period, when all forecasts were poor. All scores increase in the non-convective seasons. Fall and winter figures were consistent with 12-hourly results by showing a greater improvement by SAM over PEP in the fall (12 percent) than in the winter (8 percent).

Period I regional comparisons (not shown) were similar to 12-hour results with some exceptions. The greatest advantage in accuracy by SAM over PEP was shown in the Central Region where a 24 percent difference was noted. This can be contrasted to a mere 1 percent improvement in the Eastern Region. One of the interesting aspects here is that, like the 12-hourly results, SAM forecast accuracy for the Eastern and Central Regions was nearly equal. It was the PEP that evidently contained a regional accuracy bias, and Chicago seemed to be the largest single station problem. The SAM advantage in the Southern Region was 15 percent which is somewhat higher than the 12-hourly advantage.

Period II (1800-2400Z) comparisons are shown in table 7. This period contains 14 summer, 54 fall, and 66 winter cases. The decay of persistence predictions with time is clearly shown by the low values. The overall increase in accuracy of SAM over PEP in period II was 6 percent.

Table 7. Skill categories A, B, and C for the second 6-hours (18Z-24Z) in the "today" period computed for SAM, PEP, and persistence. High numbers show desirable skill in precipitation forecasting. July 1, 1967, to February 29, 1968.

ALL SEASONS	A	B	C
SAM	.37	.45	.55(.49 - .61)
PEP	.35	.42	.52(.48 - .56)
Persistence	.17	.16	.29(.30 - .28)

Seasonal figures shown in table 8 resemble those of period I. The summer scores were nearly identical for the two numerical models, while the fall figures showed a 13 percent advantage and the winter figures a 2 percent advantage for SAM.

Table 8. Seasonal comparison of skill categories A, B, and C for the second 6-hours (18Z-24Z) in the "today" period computed for SAM, PEP, and persistence. High numbers show desirable skill in precipitation forecasting. July 1, 1967, to February 29, 1968.

SUMMER	A	B	C
SAM	.16	.13	.28(.30 - .26)
PEP	.16	.13	.28(.29 - .26)
Persistence	.12	.10	.24(.30 - .17)

FALL	A	B	C
SAM	.35	.44	.53(.47 - .58)
PEP	.31	.39	.47(.44 - .49)
Persistence	.15	.17	.27(.29 - .24)

WINTER	A	B	C
SAM	.43	.50	.62(.53 - .71)
PEP	.42	.49	.60(.53 - .67)
Persistence	.19	.16	.32(.31 - .33)

Period II regional comparisons (not shown) showed small to moderate decay rates from the period I scores. Similar to the 12-hourly results, the greatest advantage in accuracy by SAM over PEP was shown to be in the Southern Region where a 20 percent improvement was realized. Central Region scores indicated a 13 percent SAM advantage, while Eastern Region scores indicated a 4 percent advantage to PEP. Again, SAM forecast as well in the Eastern as it did in the Central Region but the strong regional accuracy bias in the PEP was evident again. It is interesting to note that the combined A, B, and C figures, when considering total, Seasonal, and Regional comparisons for each of three time periods, shows PEP in front in only one category--in the Eastern Region in the second 6 hours.

To summarize this precipitation forecast evaluation study, predictions based on persistence were not competitive with the two numerical models tested. Direct comparison of the two models showed an overall increase in accuracy of 10 percent for the 12-hour "today" period, 8 percent for period I, and 6 percent for period II by the use of SAM over PEP. The increase was greater in the spring and fall than in the summer and winter. SAM produced its best forecasts in the Central and Eastern Regions and its greatest improvement over PEP in the Central and Southern Regions. NMC subjective forecasts for the 12-hour period showed a favorable increase in skill over the numerical guidance used in their preparation.

OPERATIONAL TRANSMISSIONS

SAM was developed to run at any scheduled or unscheduled time using surface reports that are less than 1 hour old. This could be an important consideration if and when the SAM program is expanded to the western United States. At the present time, however, it is convenient to make two scheduled SAM runs each day, one to cover the "today" period and one to cover the "tonight" period.

We are using two methods of transmitting the SAM forecasts from NMC to the users. These are the Service "C" teletypewriter service and the FOFAX facsimile circuit. Service "C" has a fairly large user coverage while FOFAX is rather limited.

A portion of a typical "today" period teletypewriter bulletin is shown in figure 3. Transmission times for the 79-station SAM bulletin (station list with call letters is shown in appendix) are 0839 and 2039 GMT daily. Contents of the bulletin include a 3-hourly saturation deficit forecast and an instantaneous 1000-mb geostrophic wind forecast for each of four times covering the period of interest.

The four-digit 1000-mb geostrophic wind forecasts are straightforward. These are obtained directly from the gradients indicated on the SAM 1000-mb predictions. It is always the 1000-mb heights that are obtained by solution of the conservation statement (equation 1) and sea-level pressure forecasts, when desired, are derived by a conversion process. Standard direction (tens of degrees) and speed (knots) coding is used in the bulletin.

The three-digit, 3-hourly saturation deficit (S_d) forecasts (in meters) require a bit more explanation. These are obtained as follows. Each of the three hourly values is examined for sign (i.e. 1300, 1400, and 1500 GMT for the 1500 GMT forecast). If one, two, or all three have negative signs (-), indicating forecast precipitation, then the negatives are accumulated and any positive values disregarded. It is assumed that higher negative values carry certain implications as to higher probability and amount of precipitation. If all three values are positive, we show the average positive values since the accumulation of "no precipitation" has no physical meaning. Three examples are given below.

	1300 GMT	1400 GMT	1500 GMT	1500 GMT Value Transmitted
Example 1	-15	-10	-05	-30
Example 2	020	005	-10	-10
Example 3	020	030	040	030

Since we define any negative value as a forecast of measurable precipitation, the -00 forecast is not considered to be a "trace." Any 3-hourly S_d forecast giving an accumulated value greater in the negative than -99 is set to -99 so the prediction will always fit within the three digits allowed in the bulletin (Example: -110 is set to -99).

```
ZCZC
FOUS KWBC 030800
SAM FORECASTS
       15Z          18Z          21Z          00Z        POP 12  6  6
CAR 049 0204   058 0506   068 0508   080 0509   021 05 18
BTV 060 3105   057 3604   059 0405   066 0507   018 08 13
PWM 113 3207   116 3205   117 3503   117 0304   010 02 09
BOS 116 0106   124 0204   127 0303   130 0503   007 01 06
PVD 102 0406   109 0406   116 0405   121 0504   008 01 07
BDL 105 0304   107 0203   107 0203   107 0403   005 01 04
LGA 084 0512   096 0409   108 0406   115 0405   010 02 08
ALB 101 3003   092 3303   085 0204   082 0406   010 02 08
BGM 064 2705   050 3103   041 0203   043 0505   021 09 18
SYR 056 2703   046 3402   046 0304   055 0505   017 04 14
BUF 010 3002   014 0302   027 0704   044 0807   031 26 19
CLE 031 1806   019 1706   015 1306   017 1108   030 15 19
DTW 009 1408   017 1109   028 1010   041 1010   032 26 20
BTL 013 1010   027 0910   043 1009   057 1208   034 25 23
FWA 010 2103   014 1002   023 0905   031 1106   036 27 24
IND 030 2507   025 2404   020 1903   -02 1606   036 17 24
CVG 048 2511   033 2411   020 2409   -02 2207   033 15 22
SDF 063 2411   045 2312   -00 2212   -06 2111   027 10 19
```

Figure 3. A portion of a typical SAM teletypewriter bulletin showing direct output forecasts of saturation deficit and 1000-mb geostrophic winds for four separate forecast times (transmitted for 79 stations). Probability of precipitation (PoP) predictions are also shown but are derived from Model Output Statistics (MOS) as opposed to direct output. This example is for the same case as shown in figure 4.

Probability of precipitation (PoP) predictions are also shown in figure 3. However, these forecasts are derived from an extension to the basic model that we call Model Output Statistics (MOS) [23]. Since the MOS derived products are not direct SAM output they will not be discussed in this paper.

The upper two panels of the SAM facsimile transmission are shown in figure 4. These are transmitted on FOFAX at 0849 and 2045 GMT daily. The dashed isolines show sea-level pressure forecasts for the beginning (left panel) and middle (right panel) of the "first period." The solid isolines on the right panel are 1000-500-mb thickness predictions for the middle of the "first period." Those on the left panel are PoP forecasts.

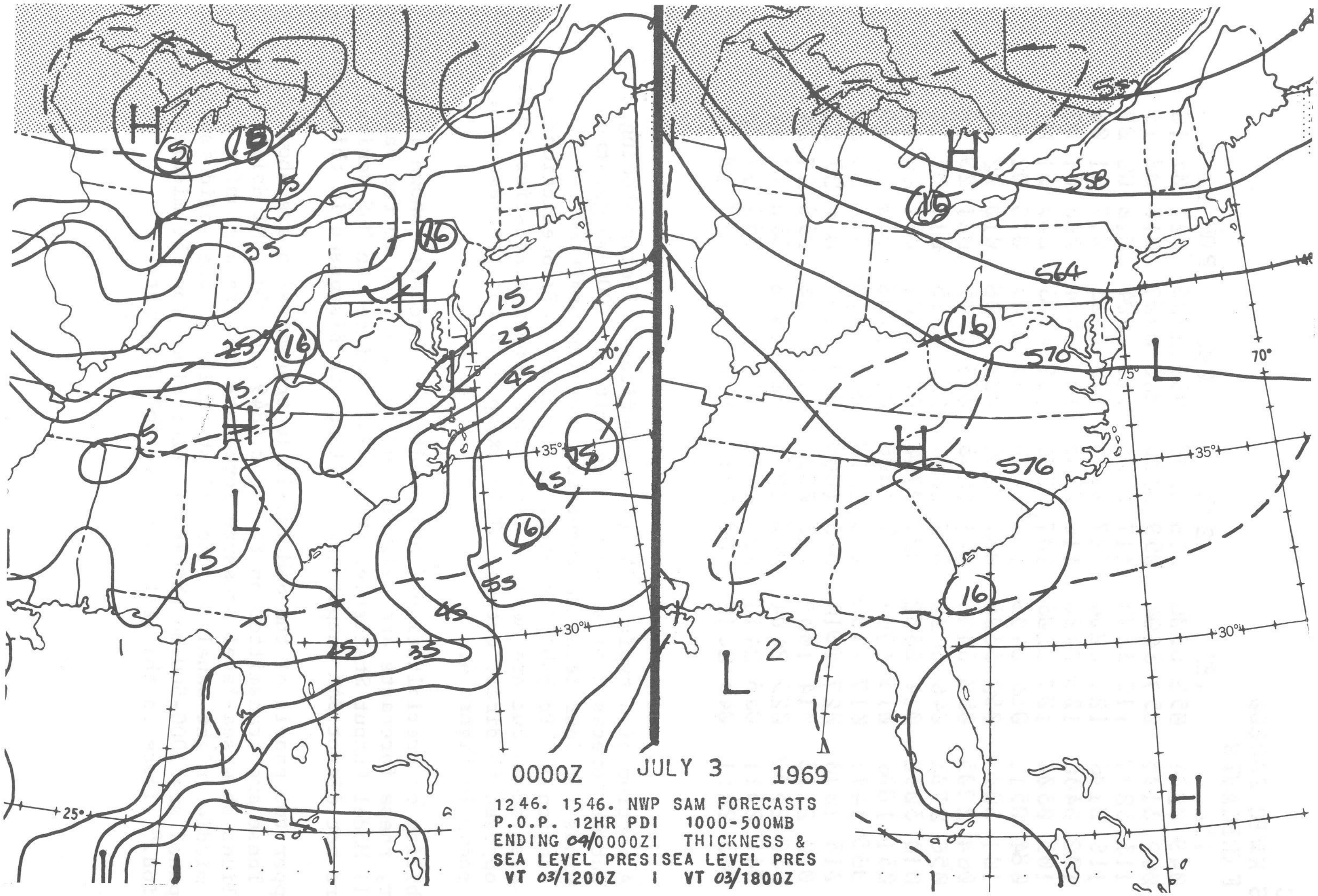

Figure 4. The upper two panels of a typical SAM facsimile transmission showing three direct output fields; 1) Five-hour SAM sea-level pressure forecast on left panel (dashed), 2) Eleven-hour SAM sea-level pressure forecast on right panel (dashed), and 3) Eleven-hour 1000-500-mb thickness forecast on right panel (solid). This example from July 3, 1969, is referred to as a 0000 GMT run because that was the time of the initial upper-air input data.

Thickness forecasts are computed by using a combination of SAM and PE model information. The 500-mb PE heights we use have been time smoothed to eliminate the gravity waves but have not been space smoothed. The SAM 1000-mb forecast heights are used directly. A simple subtraction produces the desired thickness forecasts that are useful in temperature-related prediction problems. The accuracy of the thickness forecasts is not known since no verification has been carried out. However, we do know that both the PE 500-mb and SAM 1000-mb forecasts contain considerable skill.

Solid isolines on the left panel are spacial representations of the same 12-hour PoP forecasts included in the teletypewriter bulletin for specific cities.

The operational transmissions discussed are the result of an evolution over a period of several years. Descriptions of the various operational SAM products and the changes with time are included in the ESSA Weather Bureau Technical Procedures Bulletin Series [7, 8, 9, 10, 11].

Only two possible changes in the basic SAM are being considered at this time.

1. We plan to look into the feasibility of incorporating a fine-mesh 500-mb forecast scheme into the model.

2. We plan to study the feasibility of extending SAM to the western United States.

However, at this time, most of our effort is being directed toward forecasting weather variables through the use of MOS which are not forecast directly from SAM. The MOS approach is different from the "perfect prog" concept since actual model outputs are matched with observations [23]. Therefore, the SAM outputs as well as PE and initial data, are being saved on magnetic tape for this purpose.

CONCLUSIONS

It appears that the forecasts produced by the sea-level pressure and precipitation models within the SAM are superior to other machine produced predictions for the same time and area that are prepared centrally by the Weather Bureau.

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Appendix A

PRECIPITATION VERIFICATION STATIONS BY WEATHER BUREAU REGION

EASTERN

1. Albany, New York
2. Boston, Massachusetts
3. Charleston, South Carolina
4. Charleston, West Virginia
5. Buffalo, New York
6. Washington, District of Columbia
7. Norfolk, Virginia
8. New York, New York
9. Raleigh, North Carolina
10. Cleveland, Ohio

CENTRAL

11. Chicago, Illinois
12. St. Louis, Missouri
13. Louisville, Kentucky

SOUTHERN

14. Miami, Florida
15. Jacksonville, Florida
16. Atlanta, Georgia
17. New Orleans, Louisiana
18. Jackson, Mississippi
19. Memphis, Tennessee
20. Nashville, Tennessee
21. Tallahassee, Florida

Appendix B

SAM TELETYPE BULLETIN STATIONS (79)
IN ORDER OF TRANSMISSION

	STATION	CALL LETTERS
1.	Caribou, Maine	CAR
2.	Burlington, Vermont	BTV
3.	Portland, Maine	PWM
4.	Boston, Massachusetts	BOS
5.	Providence, Rhode Island	PVD
6.	Hartford, Connecticut	BDL
7.	New York, New York	LGA
8.	Albany, New York	ALB
9.	Binghamton, New York	BGM
10.	Syracuse, New York	SYR
11.	Buffalo, New York	BUF
12.	Cleveland, Ohio	CLE
13.	Detroit, Michigan	DTW
14.	Battle Creek, Michigan	BTL
15.	Ft. Wayne, Indiana	FWA
16.	Indianapolis, Indiana	IND
17.	Cincinnati, Ohio	CVG
18.	Louisville, Kentucky	SDF
19.	Lexington, Kentucky	LEX
20.	London, Kentucky	LOZ
21.	Roanoke, Virginia	ROA
22.	Beckley, West Virginia	BKW
23.	Charleston, West Virginia	CRW
24.	Parkersburg, West Virginia	PKB
25.	Columbus, Ohio	CMH
26.	Pittsburgh, Pennsylvania	PIT
27.	Philipsburg, Pennsylvania	PSB
28.	Harrisburg, Pennsylvania	HAR
29.	Philadelphia, Pennsylvania	PHL
30.	Washington, District of Columbia	DCA

Appendix B (continued)

	STATION	CALL LETTERS
31.	Richmond, Virginia	RIC
32.	Norfolk, Virginia	ORF
33.	Raleigh, North Carolina	RDU
34.	Wilmington, North Carolina	ILM
35.	Charleston, South Carolina	CHS
36.	Savannah, Georgia	SAV
37.	Columbia, South Carolina	CAE
38.	Augusta, Georgia	AGS
39.	Asheville, North Carolina	AVL
40.	Knoxville, Tennessee	TYS
41.	Chattanooga, Tennessee	CHA
42.	Atlanta, Georgia	ATL
43.	Albany, Georgia	ABY
44.	Jacksonville, Florida	JAX
45.	Daytona Beach, Florida	DAB
46.	Miami, Florida	MIA
47.	Tampa, Florida	TPA
48.	Tallahassee, Florida	TLH
49.	Montgomery, Alabama	MGM
50.	Birmingham, Alabama	BHM
51.	Huntsville, Alabama	HSV
52.	Nashville, Tennessee	BNA
53.	Meridian, Mississippi	MEI
54.	Mobile, Alabama	MOB
55.	New Orleans, Louisiana	MSY
56.	McComb, Mississippi	MCB
57.	Jackson, Mississippi	JAN
58.	Greenwood, Mississippi	GRW
59.	Memphis, Tennessee	MEM
60.	Walnut Ridge, Arkansas	ARG

Appendix B (continued)

	STATION	CALL LETTERS
61.	Dyersburg, Tennessee	DYR
62.	Paducah, Kentucky	PUK
63.	Bowling Green, Kentucky	BWG
64.	Evansville, Indiana	EVV
65.	Terre Haute, Indiana	HUF
66.	West Lafayette, Indiana	LAF
67.	South Bend, Indiana	SBN
68.	Chicago, Illinois	MDW
69.	Rantoul, Illinois	RAN
70.	Peoria, Illinois	PIA
71.	Springfield, Illinois	SPI
72.	St. Louis, Missouri	STL
73.	Vichy, Missouri	VIH
74.	Columbia, Missouri	CBI
75.	Quincy, Illinois	UIN
76.	Kirksville, Missouri	IRK
77.	Ottumwa, Iowa	OTM
78.	Burlington, Iowa	BRL
79.	Moline, Illinois	MLI

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(Continued from inside front cover)

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