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Short Range, Subsynoptic Surface Weather Prediction

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WEATHER BUREAU

TECHNIQUES DEVELOPMENT LABORATORY

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No. 1 Objective Prediction of Daily Surface Temperature. William H. Klein, Curtis W. Crockett and Carlos R. Dunn. October 1965.

No. 2 Hurricane Cindy Galveston Bay Tides. N. A. Pore, A. T. Angelo and J. G. Taylor. September 1965.

No. 3 Atmospheric Effects on Re-Entry Vehicle Dispersions. Karl R. Johannessen. December 1965.

No. 4 A Synoptic Climatology of Winter Precipitation from 700-mb. Lows for the Intermountain Areas of the West. D. L. Jorgensen, W. H. Klein and A. F. Korte. May 1966.

No. 5 Hemispheric Specification of Sea Level Pressure from Numerical 700-mb. Height Forecasts. William H. Klein and Billy M. Lewis. June 1966.

No. 6 A Fortran Program for the Calculation of Hourly Values of Astronomical Tide and Time and Height of High and Low Water. N. A. Pore and R. A. Cummings. January 1967.

No. 7 Numerical Experiments Leading to the Design of Optimum Global Meteorological Networks. M. A. Alaka and F. Lewis. February 1967.

No. 8 An Experiment in the Use of the Balance Equation in the Tropics. M. A. Alaka, D. T. Rubsam, and G. E. Fisher. March 1967.

No. 9 A Survey of Studies of Aerological Network Requirements. M. A. Alaka. May 1967.

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U.S. DEPARTMENT OF COMMERCE
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Weather Bureau Technical Memorandum TDL-11

SHORT RANGE, SUBSYNOPTIC SURFACE WEATHER PREDICTION

H. R. Glahn and D. A. Lowry

SYSTEMS DEVELOPMENT OFFICE
TECHNIQUES DEVELOPMENT LABORATORY

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SHORT RANGE, SUBSYNOPTIC SURFACE WEATHER PREDICTION

By

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ABSTRACT

An on-going program within the Techniques Development Laboratory of the Weather Bureau to develop an operating system for making objective forecasts of weather variables on a space scale of approximately 50 miles and a time scale of 1 hour up to about 18 hours is described. The system will consist of a combination of numerical (dynamic) and statistical models. Precipitation and cloudiness forecasts for the "Today" period, 7:00 A.M. to 7:00 P.M., over the eastern United States are receiving primary emphasis. Intermediate products are hourly sea level pressure forecasts valid between 7:00 A.M. and 7:00 P.M. It appears the sea-level pressure and precipitation forecasts are superior to the machine produced guidance forecasts presently available within NMC.

Updated version of paper presented at Joint Technical Exchange Conference, Monterey, California, April 4-7, 1967.

In this paper we will describe an on-going program within the Techniques Development Laboratory of the Weather Bureau to develop an operating system for making objective forecasts of weather variables on a space scale of approximately 50 miles and a time scale of 1 hour up to about 18 hours. Our primary interest is in precipitation forecasting as indicated in Table 1. Other variables of interest are also shown. Since numerical models do not forecast some of the variables directly and do not produce probability forecasts which the Weather Bureau is emphasizing, we chose to use a combination of numerical and statistical techniques.

TABLE 1. Weather Variables For Which Objective Forecast Techniques Will Be Devised

VARIABLES TO BE PREDICTED
PRIMARY
1. Precipitation
a. Probability of occurrence at a particular time
b. Probability of occurrence over a specified period
c. Estimate of beginning and ending times
d. Estimate of amount over a specified period
e. Forecast of type--liquid or frozen
2. Cloud Amount
SECONDARY
1. Sea level pressure pattern
2. Surface winds
3. Surface temperature
4. Surface relative humidity
5. Ceiling
6. Visibility

In order to make the problem of manageable size, we are concentrating on the "Today" period of forecast, 7:00 A.M. to 7:00 P.M., for the eastern part of the United States. A forecast for this period is issued by local offices about 4:30 - 5:00 A.M., and guidance must arrive there by about 4:00 A. M. We are using 0800 GMT (3:00 A.M. EST) hourly data as input; but if this technique were implemented, we might have to use 0700 GMT data in order to meet communication schedules.

A 39 x 40 grid shown in Fig. 1 is used which has a grid length of 1/4 that used at NMC. This grid length is about 50 miles and is not much different from the average spacing of hourly reporting stations in the eastern and central United States.

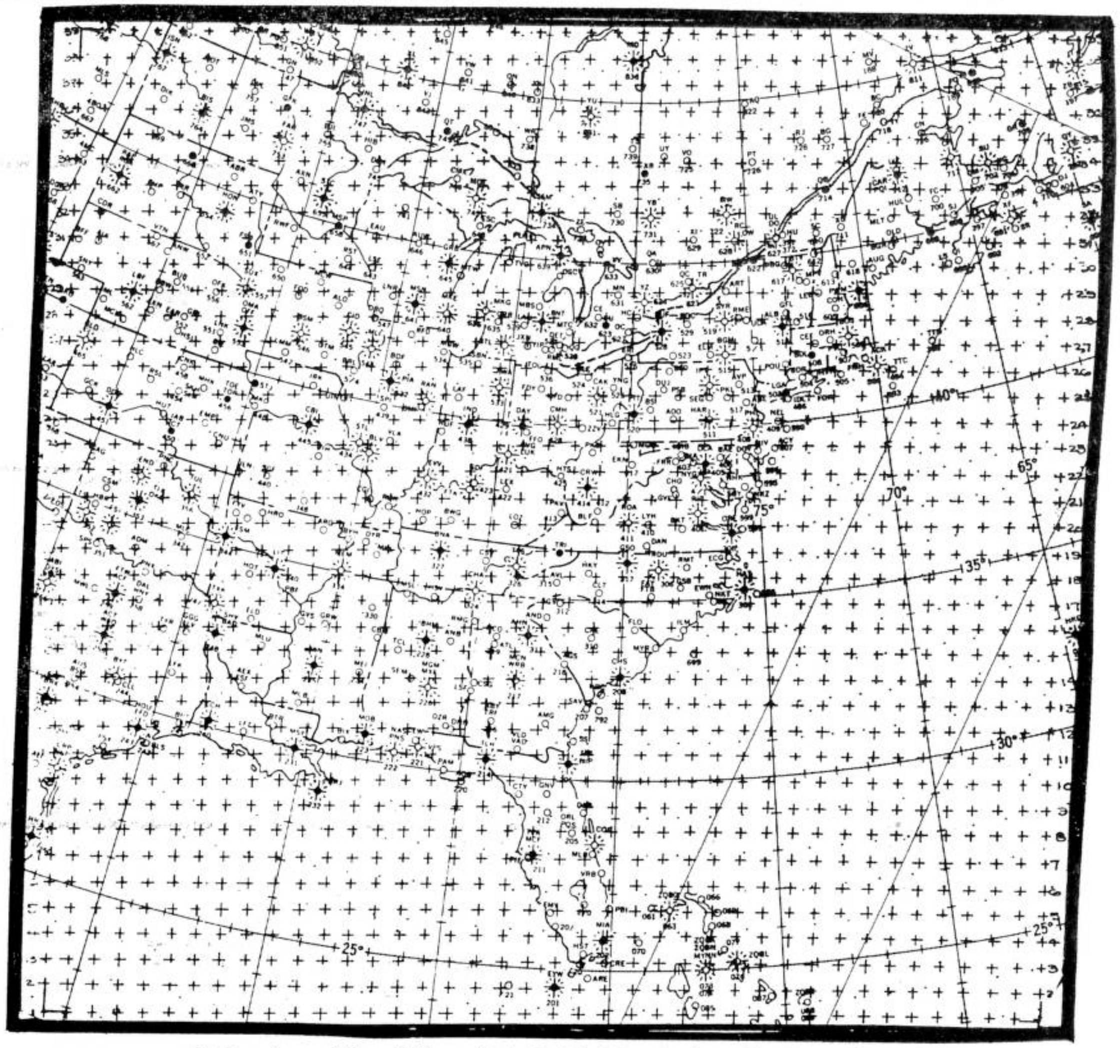

FIG. 1. The 39 x 40 Grid Used in the Study

We are using at the present time a 1000 mb. prediction model much like that developed by Reed* and used at NMC for several years. Computations are done in a Lagrangian framework. The prediction equation is shown below:

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

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

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*Reed, R. J.: "Experiments in 1000 mb. Prognosis." <u>NMC Tech. Memo No. 26</u>, 36 pp, 1963.

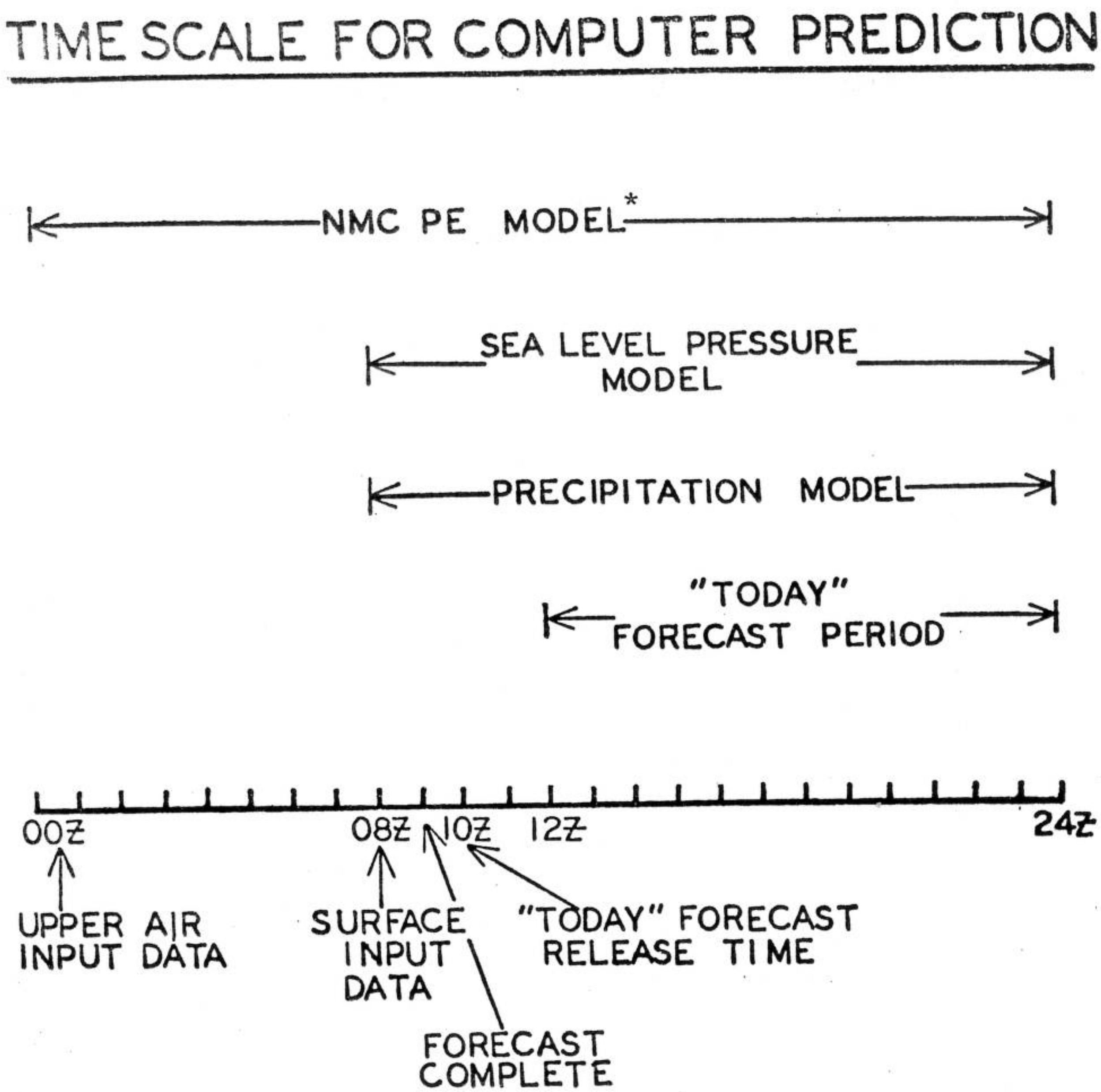

FIG. 2. Time Scale for Computer Prediction of Weather on a Sub-synoptic Scale

The time scale of our forecasts is shown in Fig. 2. Hourly data cut-off time is 0835 GMT, and the forecast can be produced by 0900 GMT for the period 1200 to 2400 GMT.

*Shuman, F. G. and J. B. Hovermale. "An Operational Six-Layer Primitive Equation Model." Abstract in Bulletin of the AMS, vol. 48, No. 3, p. 200, March, 1967.

Our models produce hourly forecasts of sea level pressure, 1000 mb. geostrophic winds, and saturation deficit. We also have available 0800 GMT data and the NMC PE model output. Many of these variables are saved on magnetic tape for statistical analysis as indicated in Table 2. We are receiving from the National Weather Records Center in Asheville, North Carolina observations to be used as predictand data; the variables are weather, sky condition, 6-hourly precipitation amounts, ceiling, visibility, surface wind, surface temperature, surface dew point, and daily maximum temperature. Once we have finalized our numerical models, we will gradually acquire a data sample and will develop statistical relations, probably by regression techniques, between the predictands and predictors.

The only major change we have made in the model as originally formulated was in the use of a smoothed, rather than an unsmoothed, 500 mb. advecting wind. We smooth the 500 mb. height field by setting the height at each grid point equal to the average of the 25 NMC grid points centered at that grid point. Then 55% of the geostrophic wind computed from this smoothed field is used as the advecting wind. By using the smoothed wind, the blowup of the highs has been greatly reduced and the shape of the "teardrop high" has been improved. This simple change resulted in an improvement of 12% in S1* scores for 15 test cases of 12-hour forecasts made in 1966. It is not known how this change would affect longer, say 36-hour, forecasts.

The precipitation model is very similar to the SLYH** model developed by Sanders, LaRue, Younkin, and Hovermale and used for a time at NMC. The prediction equation is

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

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

The advecting wind is a combination of the 500 mb. and 1000 mb. winds; we are currently using 33% of the 500 mb. smoothed geostrophic wind plus 50% of the smoothed 1000 mb. geostrophic wind. The moisture variable is the saturation deficit defined as

$$(3) \quad S_d = h_5 - S_T$$

Where S_T = Saturation thickness

* Teweles, S., Jr. and H. B. Wobus. "Verification of Prognostic Charts." Bulletin of the AMS, vol. 35, No. 10, pp 455-463, Dec. 1954.

** Younkin, R. J., J. A. LaRue, and F. Sanders. "The Objective Prediction of Clouds and Precipitation Using Vertically Integrated Moisture and Adiabatic Motions." Journal of Applied Meteorology, vol. 4, No. 1, pp 3-17, Feb. 1965

TABLE 2. The Variables Saved on Magnetic Tape for Statistical Analysis

VARIABLES SAVED ON MAGNETIC TAPE		
Variable	Time (GMT)	Source
Surface dew point	08	OBS
Weather (coded)	08	OBS
Height of lowest clouds	08	OBS
Surface temperature	08	OBS
Ceiling	08	OBS
Visibility	08	OBS
500 mb. height	08-24	PE
500 mb. geostrophic U-wind component	08-24	PE
500 mb. geostrophic V-wind component	08-24	PE
1000 mb. W-wind	09-24	PE
850 mb. W-wind	09-24	PE
500 mb. W-wind	09-24	PE
Sea level pressure	08-24	TDL
1000 mb. geostrophic U-wind component	08-24	TDL
1000 mb. geostrophic V-wind component	08-24	TDL
Upslope component of 1000 mb. geostrophic wind	08-24	TDL
Saturation deficit	08-24	TDL

For our purposes, saturation thickness is defined as that thickness between 1000 and 500 mbs. for which precipitation will occur for a given amount of moisture between those levels.

We estimate the saturation thickness at 0800 GMT from 0800 GMT surface observations. Regression equations have been determined for each month which specify saturation thickness as a function of surface dew point, sky condition, weather, and station elevation.* This regression estimate is

*Lowry, D. A. and H. R. Glahn. "Integrated Moisture - Surface Variable Relationships." Abstract in Bulletin of the AMS, vol. 48, No. 3, p. 205, March, 1967.

overridden for stations where precipitation is occurring and the regression estimate indicates otherwise, and also for stations where precipitation is not occurring and the regression estimate indicates otherwise. This specification of integrated moisture from surface observations is, of course, a crucial point in our procedure. With the overriding feature, we feel we can do better than we could by using only the moisture computed from 0000 GMT soundings.

The input needed for the sea level pressure model is 0800 GMT sea level pressure reports, 500 mb. forecast heights (which we get from the NMC PE model) and a smooth terrain field. The input needed for the precipitation model is 0800 GMT saturation thickness, 1000 mb. forecast heights (from the sea level pressure model), 500 mb. forecast heights, and a smooth terrain field.

The present status of our program is:

1. Automatic hourly data decoding, error checking, and analysis programs are completed.

2. The sea level pressure model and the precipitation model are completed.

3. Beginning the first of March, 1967, the entire package including ADP and numerical predictions is being run twice a week. The program runs on the CDC 6600 in about 6 minutes.

4. Comparative verification of NMC Primitive Equation and TDL sea level pressure forecasts is complete for 29 cases (Table 3). These are "independent" cases in the sense that the model was not adjusted during the period of test--all development was accomplished prior to the test period. Precipitation prediction comparisons of objective NMC machine forecasts (PEP), NMC subjective forecasts, and objective TDL machine forecasts are also available for the same 29 cases (Table 4).

Sea level pressure forecasts for 1200 GMT are 4-hour forecasts for our model and 12-hour forecasts for the PE model; also, forecasts for 2400 GMT are 16-hour forecasts for our model and 24-hour forecasts for the PE model. These products are the latest that would be available to the forecaster at about 4:00 A.M. The verification statistics cover the area roughly east of the Mississippi River, which is the region not usually affected by the boundaries to our model.

It can be seen from Table 3 that the TDL model has significantly better average verification scores in all categories at 1200 GMT. A paired T-Test on 2400 GMT results indicates significance at the 1% level for both RMSE and MAE. The improvement in S1 scores shown by the TDL model did not indicate statistical significance.

TABLE 3. Root Mean Square Error, Mean Absolute Error, and S1 Scores for Currently Available Guidance and TDL Experimental Model. RMSE and MAE values are in millibars. Low scores are desirable in all categories.

SEA LEVEL PRESSURE VERIFICATION

DATE	VALID 1200 GMT						VALID 2400 GMT					
	RMSE		MAE		S1		RMSE		MAE		S1	
1967	TDL	NMC	TDL	NMC	TDL	NMC	TDL	NMC	TDL	NMC	TDL	NMC
MARCH 1	1.5	2.7	1.1	2.4	29	52	5.4	5.9	4.6	4.8	51	73
7	1.7	3.2	1.3	2.5	22	49	4.3	4.6	3.6	3.4	76	59
10	1.3	4.2	1.1	3.7	23	50	1.9	3.8	1.6	3.6	30	24
14	1.4	2.8	1.1	2.4	30	47	2.8	4.5	1.9	4.0	42	46
21	1.6	3.1	1.3	2.5	30	51	3.8	5.0	3.0	3.9	55	69
24	2.3	5.1	1.9	4.8	34	50	3.1	7.2	2.4	6.7	45	53
29	1.8	2.2	1.6	1.7	30	57	1.9	2.2	1.5	1.8	41	50
31	2.1	3.5	1.7	2.9	18	30	2.4	2.9	2.0	2.2	37	41
APRIL 4	2.6	3.9	2.4	3.6	28	48	3.7	4.5	2.9	4.1	58	38
13	1.4	3.4	1.2	3.0	18	31	2.1	3.0	1.5	2.4	33	29
14	1.2	2.3	0.9	2.2	19	16	2.5	3.9	2.0	3.4	35	43
18	3.2	3.7	2.9	3.3	28	35	4.7	6.2	3.8	5.7	49	44
21	2.4	5.2	2.1	5.0	26	31	2.5	5.6	2.2	5.2	30	34
25	1.9	4.8	1.6	4.6	23	32	3.4	6.0	2.9	5.3	50	47
MAY 2	1.5	2.1	1.2	1.7	21	38	2.8	2.7	2.4	2.2	40	54
10	1.6	2.5	1.4	2.2	23	36	2.1	2.3	1.4	2.0	35	38
11	2.6	3.7	2.3	3.2	23	43	5.9	4.9	4.6	4.4	54	56
12	2.8	4.7	2.6	4.4	27	41	4.7	5.6	4.4	5.1	48	49
19	1.9	3.4	1.7	3.1	18	32	2.5	2.7	1.9	2.2	38	43
24	1.6	2.8	1.3	2.4	27	57	1.3	2.1	1.0	1.6	31	55
25	2.2	3.0	1.7	2.5	41	53	2.8	2.9	1.5	1.8	48	60
26	1.8	2.4	1.4	2.0	29	38	2.5	1.5	1.9	1.1	52	48
30	1.2	2.0	1.0	1.6	24	44	4.6	1.4	3.9	1.1	56	33
JUNE 8	1.5	3.2	1.3	2.8	25	58	1.5	3.2	1.3	2.8	25	59
9	1.2	2.5	1.0	2.2	21	46	1.6	2.5	1.2	2.2	34	33
20	1.5	1.8	1.1	1.2	48	66	1.7	2.5	1.3	1.8	74	74
23	1.8	1.8	1.7	1.4	28	47	2.3	2.0	2.0	1.6	43	53
27	1.3	2.4	1.2	2.0	48	99	1.5	2.2	1.1	1.7	74	72
30	1.3	1.6	1.0	1.4	42	60	1.6	1.5	1.2	1.2	59	47
Average	1.8	3.1	1.5	2.7	28	46	2.9	3.6	2.3	3.1	46	49

Precipitation forecasts of occurrence or non-occurrence are for the 12-hour "Today" period. Any negative saturation deficit during the period is considered to be a forecast occurrence. An observed occurrence is .01 inch or more of precipitation actually observed during the period. Twenty-one stations over the eastern portion of the nation were used for comparison.

TABLE 4. PRECIPITATION FORECAST VERIFICATION 29 CASE SUMMARY

Total Hits (number of correct precipitation and no-precipitation forecasts), Threat Score of Precipitation, and Threat Score of No Precipitation for Currently Available Guidance and TDL Experimental Model. High scores are desirable in all categories.

NATIONAL METEOROLOGICAL CENTER PEP FORECASTS

OBSERVED \ FORECAST	P	NP	T
P	60	71	131
NP	25	453	478
T	85	524	609

Total Hits = 513

Threat Score (Precipitation) = .38

Threat Score (No precipitation) = .83

NATIONAL METEOROLOGICAL CENTER SUBJECTIVE FORECASTS

OBSERVED \ FORECAST	P	NP	T
P	82	49	131
NP	53	425	478
T	135	474	609

Total Hits = 507

Threat Score (Precipitation) = .45

Threat Score (No precipitation) = .81

TECHNIQUES DEVELOPMENT LABORATORY FORECASTS

OBSERVED \ FORECAST	P	NP	T
P	71	60	131
NP	26	452	478
T	97	512	609

Total Hits = 523

Threat Score (Precipitation) = .45

Threat Score (No precipitation) = .84

P = Precipitation
NP = No precipitation
T = Total

$$\text{Threat Score} = \frac{\text{Hits}}{\text{Forecast} + \text{Observed} - \text{Hits}}$$

Table 4 lists three categories of comparison; total hits, threat score of precipitation, and threat score of no precipitation. It can be seen that during the four-month test period the TDL machine-produced forecasts were superior in all categories to the NMC machine-produced forecasts (PEP). Also, the TDL product was somewhat superior overall when compared to the subjective NMC hand-produced forecasts (SUBJECTIVE).

In summary, we feel we can improve the guidance to forecasters who issue the "Today" forecast in the early morning. This improvement would be due to:

1. More recent data (by 7 or 8 hours).

2. More detailed analysis over the relatively dense data regions of the eastern and central U. S.

3. Inclusion of observed weather in the saturation deficit analysis.

4. Statistical analysis of actual model output to produce forecasts of the variables in which the forecaster is interested and in the terms in which he needs them, such as the probability of precipitation.

(Continued from inside front cover)

No. 10 Objective Determination of Sea Level Pressure from Upper Level Heights. W. H. Klein, F. Lewis, and J. D. Stackpole. May 1967.