Use of Primitive-Equation Model Output to Forecast Winter Precipitation in the Northeast Coastal Sections of the United States

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ABSTRACT

The National Meteorological Center's operational primitive-equation multilayer model predictions of relative humidity and vertical velocity are found to be well correlated with relative frequency of observed precipitation in the northeast coastal section of the United States. A technique is presented for using these primitive-equation model predictions to objectively determine the probability of precipitation in each of three consecutive 12-hr periods, the first period starting 12 hr after initial data time.

1. Introduction

The purpose of this study is to assist forecasters in the northeast United States by presenting a procedure for objectively forecasting precipitation using the National Meteorological Center's operational primitive-equation multilayer model output (Shuman and Hovermale, 1968). The technique presented is applicable to the three consecutive 12-hr forecast periods included in the public weather forecast (*viz.*, today, tonight and tomorrow) prepared for the area east of the Appalachian Mountains and north of North Carolina. This technique may be applicable in other areas, too, but tests to determine this have not been completed. The results are suggested for use from 1 October to 30 April.

2. Procedure

A scatter diagram approach was used in this study. The developmental data consisted of 6-hr primitive-equation model forecasts of relative humidity and vertical velocity for Boston, Mass.; New York, N. Y.; Philadelphia, Pa.; and Washington, D. C. during the period 1200 GMT 4 November 1969 through 1200 GMT 31 March 1970. An additional parameter, the primitive-equation model quantitative precipitation forecasts for New York City only, was examined for predictive information. The primitive-equation model quantitative precipitation forecast was found to be a good predictor by itself, but results determined for New York City showed that this predictor adds very little to what is already known from the other predictors used.

The four cities used in this study were chosen to preserve homogeneity of the data sample and at the

same time to secure enough data to permit some conclusions. Forecasts generated for the four cities from the same initial data model run are not independent, but the forecasts generated from different initial data runs of the model are considerably independent.

A field forecaster receives the 6-hr forecasts in a teletype message known as FOUS-1. The FOUS-1 message is transmitted twice a day on teletype service "C" at about 0700 and 1900 GMT, 7 hr after the time of initial data used to generate the primitive-equation model forecasts. Because of the time lost in data handling and communications, the model output for forecast hours 12, 18 and 24 after initial data time corresponds exactly to the first 12-hr period covered by the forecast released to the public soon after the FOUS-1 message is available. Similarly, the model 6-hr output for forecast hours 24, 30 and 36 corresponds exactly to the second 12-hr period in the public weather forecast. Primitive-equation model 6-hr output to 48 hr is available for a third 12-hr period.

The relative humidity forecast used in this study and provided in the FOUS-1 message is the mean relative humidity of the lowest three layers of the primitive-equation model. The lowest three layers extend from the surface to about 500 mb. The vertical velocity forecast used is the vertical velocity at 700 mb, in tenths of microbars per second, averaged over 2 hr. The averaging scheme used to obtain the vertical velocity forecast that appears in the FOUS-1 message is a weighted average equal to one-half of the vertical velocity forecast valid at the indicated time plus one-fourth of the vertical velocity forecast valid 1 hr earlier, plus one-fourth of the vertical velocity forecast valid 1 hr later than the indicated valid time.

In this study the three 6-hr model forecasts applicable to the beginning, middle and end of each 12-hr period

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included in a public weather forecast are examined to determine the highest relative humidity and the highest (algebraic) value of vertical velocity. Also, the algebraic difference between the relative humidity forecast at the end of each 12-hr forecast period and the predicted relative humidity 12 hr earlier, at the beginning of each period, is determined and defined as the predicted relative humidity trend in the forecast period. The predicted relative humidity trend is identified as *positive* (increasing with time) for trend values $\geq +10\%$, negative for trend values $\leq -10\%$, and *steady* for all other trend values.

There are three important reasons for including predicted relative humidity trend as a predictor. First, since we are predicting precipitation for a 12-hr period and not an instantaneous time, we should consider not only the maximum amount of relative humidity expected in the 12-hr period but also when or for how long the predicted maximum amount of relative humidity will be available during this period. Thus, a steady trend indicates that the predicted maximum relative humidity is applicable throughout the 12-hr period, while a negative trend indicates that the maximum relative humidity will occur near the beginning of the period with drying of at least 10% predicted to occur by the end of the 12-hr period.

The second reason for considering relative humidity trend as a predictor is an attempt to account for any differences in nature that may exist between the frequency of precipitation in a 12-hr period for approaching weather producing systems (positive trend), receding weather-producing systems (negative trend), and slow moving or stagnant systems (steady trend). This second reason could be considered as similar to the first reason if it is assumed that relative humidity trends are associated with the movement of weather-producing systems.

The third reason concerns the timing bias that may exist in the model predictions of relative humidity. Thus, if the model has been characteristically too slow in moving systems, then a predicted increasing relative humidity trend could be expected to yield a higher frequency of observed precipitation than a decreasing relative humidity trend for the same predicted maximum relative humidity value applicable to the 12-hr period. If systems characteristically move faster than predicted, then an increasing or steady trend would indicate that the maximum relative humidity value predicted for the 12-hr period may still occur in the 12-hr period but perhaps earlier than predicted. Higher relative humidity values could occur at the end of the period. A negative trend in a model with a bias of systems moving too slow would indicate that the maximum relative humidity value predicted could occur prior to the 12-hr period and the relative humidity values that actually occur during the 12-hr period may be lower than the maximum predicted.

The effects of the possibilities discussed above can

TABLE 1. Relative frequency of observed measurable precipitation as a function of forecast relative humidity and relative humidity trend. Numbers in parentheses indicate total number of cases.*

Relative humidity forecast	1st period 12-24 hr				2nd period 24-36 hr				3rd period 36-48 hr			
	Steady trend	Positive trend	Negative trend	Total	Steady trend	Positive trend	Negative trend	Total	Steady trend	Positive trend	Negative trend	Total
90-100%	0.79(90)	0.77(64)	0.43(61)	0.68(215)	0.70(79)	0.82(56)	0.37(63)	0.63(198)	0.55(69)	0.80(41)	0.35(52)	0.55(162)
80-89%	0.58(38)	0.46(41)	0.20(44)	0.41(123)	0.37(30)	0.59(32)	0.29(42)	0.40(104)	0.54(35)	0.66(35)	0.16(32)	0.46(102)
70-79%	0.17(36)	0.30(54)	0.05(61)	0.17(151)	0.21(38)	0.23(48)	0.14(57)	0.19(143)	0.26(35)	0.34(38)	0.11(47)	0.23(120)
60-69%	0.06(62)	0.18(51)	0.03(63)	0.09(176)	0.14(57)	0.25(40)	0.10(39)	0.16(136)	0.12(61)	0.25(53)	0.03(34)	0.14(148)
50-59%	0.00(85)	0.02(46)	0.00(36)	0.01(167)	0.10(83)	0.07(30)	0.06(48)	0.08(161)	0.07(57)	0.14(56)	0.05(37)	0.09(150)
40-49%	0.01(80)	0.00(35)	0.00(20)	0.01(135)	0.00(74)	0.00(27)	0.05(43)	0.01(145)	0.13(52)	0.11(38)	0.10(30)	0.12(120)
30-39%	0.00(29)	0.00(11)	0.00(7)	0.00(47)	0.02(46)	0.00(13)	0.08(12)	0.03(71)	0.06(49)	0.05(20)	0.00(9)	0.05(78)
20-29%	0.00(15)	0.00(3)	0.00(1)	0.00(19)	0.00(22)	0.00(6)	0.00(4)	0.00(32)	0.00(29)	0.10(10)	0.11(9)	0.04(48)
10-19%	0.00(1)	X	X	0.00(1)	0.00(4)	X	X	0.00(4)	0.00(5)	X	0.00(2)	0.00(7)
0-9%	X	X	X	X	0.00(1)	X	X	0.00(1)	X	X	X	X

* X's indicate no available data.

TABLE 2. Forecast vertical velocity as a function of relative frequency of observed measurable precipitation. The numbers in parenthesis indicate the total number of cases.

Vertical velocity forecast ($\mu\text{b sec}^{-1}$)	Relative frequency of observed measurable precipitation		
	1st period 12-24 hr	2nd period 24-36 hr	3rd period 36-48 hr
≥ 3.0	0.76 (86)	0.66 (70)	0.48 (66)
2.0 to 2.9	0.58 (91)	0.56 (100)	0.47 (91)
1.0 to 1.9	0.37 (182)	0.37 (198)	0.32 (215)
0.0 to 0.9	0.16 (284)	0.15 (245)	0.20 (240)
-1.0 to -0.1	0.03 (228)	0.10 (198)	0.11 (207)
-2.0 to -1.1	0.00 (131)	0.00 (138)	0.02 (84)
≤ -2.1	0.00 (32)	0.00 (45)	0.06 (32)
Total	0.23 (1034)	0.23 (994)	0.23 (935)

act in the same direction and be cumulative or can cancel each other by acting in opposite directions. In any event, this is all taken into consideration in the "imperfect prognostic" approach used here.

3. Results

Table 1 presents the relative frequency in which measurable precipitation (≥ 0.01 inch) was observed for different classes of forecast relative humidity and relative humidity trends verifying during forecast hours 12-24, 24-36, and 36-48. As pointed out earlier, the relative humidity value used in each case was the highest of the forecasts for the beginning, middle or end of each period.

Table 2 presents the relative frequency in which measurable precipitation was observed for different classes of forecast vertical velocity verifying during forecast hours 12-24, 24-36, and 36-48. The vertical velocity value used was the highest of the forecasts for the beginning, middle and end of the period.

An excellent relationship exists between relative humidity forecast and relative frequency of observed precipitation (Table 1). With few exceptions, for all forecast periods, and for each relative humidity trend, the higher the forecast relative humidity, the higher the relative frequency of precipitation. The effect of relative humidity trend in all periods is that for relative humidity forecast values $>60\%$, negative trends are accompanied by relative frequencies of observed precipitation significantly less than those for steady or positive trends. Positive trends are accompanied by relative frequencies of observed precipitation higher than those for steady trends in the second and third period. In the first period, for higher relative humidity values, the relative frequency of observed precipitation is higher for steady than for positive trends. The relationship described here between the relative frequency of observed precipitation and forecast relative humidity trend can be interpreted as an indication that the primitive-equation model has a bias in that it moves relative humidity patterns associated with weather too

slowly. The effects of the bias become more significant with time.

An excellent relationship also exists in all forecast periods between forecast vertical velocity and relative frequency of observed precipitation (Table 2). The relationship deteriorates with time, however, with the relative frequency of observed precipitation for each vertical velocity forecast class approaching the climatological frequency of precipitation. The climatological relative frequency of precipitation for the period of this study was 0.23. A deterioration with time is also shown in Table 1 for the relationship between relative humidity forecast and the relative frequency of observed precipitation.

This deterioration is logical since one should expect that a relationship between the prediction of an atmospheric parameter (i.e., relative humidity or vertical velocity) and the occurrence of precipitation should become poorer with time as the model's ability to forecast the parameter in question decreases. From data presented in Tables 1 and 2, it can be inferred that the primitive-equation model has skill in predicting relative humidity and vertical velocity to beyond 48 hr, and furthermore, that there are very good relationships between the frequency of observed precipitation and the predicted values of relative humidity and vertical velocity.

Thus far, we have presented results illustrating the independent relationships that exist in each of three 12-hr forecast periods between relative humidity predictions and observed precipitation, and separately between vertical velocity predictions and observed precipitation. What is desirable, however, is to determine a simultaneous relationship between all predictors considered here (relative humidity, relative humidity trend and vertical velocity) and observed precipitation. This was accomplished by an analysis of nine scatter diagrams, one for each of the three relative humidity trends (steady, negative, positive) for each of three forecast periods. The coordinates on each scatter diagram represented predicted maximum values of relative humidity and vertical velocity. In performing the analysis of the scatter diagrams the following guidelines were followed, based on the results presented in the discussion of Tables 1 and 2:

- 1) The higher the value of forecast maximum relative humidity in a period, the higher the probability of precipitation for that period when maximum vertical velocity and relative humidity trend class are held constant.
- 2) The higher the algebraic value of forecast maximum vertical velocity in a period, the higher the probability of precipitation for that period when maximum relative humidity and relative humidity trend class are held constant.
- 3) The probability of precipitation for negative relative humidity trend in any period cannot exceed

TABLE 3. Probability of precipitation (PoP) in a 12-hr period as determined from 6-hr primitive-equation model forecasts. Probability of precipitation is the highest value for which *both* the maximum relative humidity and vertical velocity forecasts in a 12-hr period are equal to or higher than the values shown for indicated forecast relative humidity trends.

PoP	1st period, hours 12–24		2nd period, hours 24–36		3rd period, hours 36–48	
	Relative humidity*	Vertical velocity**	Relative humidity*	Vertical velocity**	Relative humidity*	Vertical velocity**
<i>Positive trend</i>						
85%	100	2.5	100	2.5		
75%	99	2.2	99	2.2	100	2.2
65%	96	1.5	96	1.5	96	1.6
55%	91	1.0	91	1.0	91	1.0
45%	88	0.5	89	0.5	89	0.5
35%	82	0.0	87	0.0	87	0.0
25%	73	–0.4	73	–0.4	73	–0.4
15%	69	–0.7	67	–0.7	53	–0.7
5%	64	–0.9	56	–1.0	44	–1.0
<i>Steady trend</i>						
85%	100	2.5				
75%	96	2.0	100	3.0		
65%	92	1.6	99	2.3		
55%	89	1.3	97	1.4	97	1.4
45%	86	1.1	93	1.1	93	1.1
35%	82	0.8	90	0.8	90	0.8
25%	78	0.5	78	0.5	78	0.5
15%	72	0.2	68	–0.7	67	–0.7
5%	67	–0.2	56	–1.0	44	–1.0
<i>Negative trend</i>						
55%	100	3.0	100	3.0		
45%	93	2.1	93	2.1	100	3.2
35%	91	1.2	91	1.4	99	2.8
25%	89	0.6	89	1.0	94	1.6
15%	85	0.2	81	0.1	81	0.1
5%	73	–0.2	56	–0.9	44	–1.0

* Mean relative humidity surface to ~500 mb.

** Units; $\mu\text{b sec}^{-1}$.

the probability of precipitation for positive or steady trends in that period when forecast maximum relative humidity and vertical velocity are held constant.

4) For constant forecast values of maximum relative humidity, relative humidity trend class (steady, positive or negative) and maximum vertical velocity, the probability of precipitation approaches 23% with time. As mentioned earlier, 23% is the percent frequency of precipitation that occurred during the data collection period.

The results of the analysis of the scatter diagrams are presented in Table 3 as a technique for determining the probability of precipitation. This table presents, for each of the three forecasts periods and for each of the three relative humidity trend classes, critical relative humidity and vertical velocity forecast values that must be reached in order to have a probability of precipitation as indicated on the far left of the table. *Both* the forecast maximum relative humidity and the forecast maximum vertical velocity must reach, or exceed, values shown in the table before attaining the corresponding probability of precipitation on the left. For example: If in the first period a steady trend is predicted, the maximum relative humidity forecast is 90%, and the maximum vertical velocity forecast is $1.0 \mu\text{b sec}^{-1}$, then the probability of precipitation is between 35% and 45% (or 40% when rounded to the nearest

decile). Note in this example that although 90% relative humidity is necessary for a probability of precipitation of 55%, it is not sufficient. For 55% probability of precipitation a vertical velocity of at least $1.3 \mu\text{b sec}^{-1}$ is also required.

The results as presented in Table 3 contain an adjustment to account for a change that was made 8 September 1970 in the procedure used in the primitive-equation model to predict relative humidity. The effect of this change was to increase the relative humidity forecast at any grid point in the model by 11.1% of the value it would have had prior to the change. A loss in the resolution of uninflated high relative humidity forecasts at grid points also resulted. All uninflated relative humidity forecasts that were equal to or greater than 90% prior to the change would now be inflated to 100%.

Note in Table 3 that the probability of precipitation values are indicated for 10% intervals beginning at 5%. This eliminates any need for interpolation to arrive at the decile values generally included in forecasts released to the public.

4. Evaluation of results

The results presented in Table 3 were evaluated with both dependent and independent cases. A test of the analysis technique used was accomplished by computing the probability of precipitation, rounded to the

TABLE 4. Relative frequency of specified 12-hr precipitation amounts as a function of probability of precipitation. Probability of precipitation was determined using a version of Table 3 (not presented) that contained no adjustment to account for changes made in the primitive-equation model on 8 September 1970. Results are for Boston, New York, Philadelphia and Washington for period 4 November 1969 through 31 March 1970.

PoP	1st period, 12-24 hr										2nd period, 24-36 hr										3rd period, 36-48 hr									
	Relative frequency of observed precipitation $\geq$ amount shown*										Relative frequency of observed precipitation $\geq$ amount shown*										Relative frequency of observed precipitation $\geq$ amount shown*									
	Total cases	T	0.01	0.1	0.25	0.50	1.0	1.5	Total cases	T	0.01	0.1	0.25	0.50	1.0	1.5	Total cases	T	0.01	0.1	0.25	0.50	1.0	1.5						
0%	485	0.09	0.01	0.01	0	0	0	0	358	0.09	0.02	0.01	0	0	0	0	188	0.15	0.05	0.02	0.01	0.01	0	0						
10%	111	0.24	0.05	0.03	0.02	0.01	0	0	168	0.23	0.13	0.04	0.04	0.02	0.01	0	249	0.23	0.10	0.05	0	0	0	0						
20%	87	0.43	0.18	0.06	0.02	0.01	0.01	0	170	0.42	0.21	0.08	0.04	0.02	0	0	180	0.33	0.15	0.08	0.05	0.01	0	0						
30%	68	0.57	0.31	0.12	0.07	0.01	0.01	0.01	75	0.62	0.31	0.19	0.10	0.01	0.01	0	115	0.47	0.30	0.20	0.15	0.05	0.01	0.01						
40%	70	0.69	0.36	0.16	0.07	0.04	0	0	38	0.66	0.34	0.16	0.08	0.05	0	0	29	0.73	0.45	0.28	0.21	0.10	0.07	0						
50%	48	0.81	0.52	0.15	0.08	0.02	0	0	41	0.75	0.51	0.29	0.24	0.12	0.02	0.02	37	0.57	0.49	0.24	0.14	0.11	0.05	0						
60%	42	0.86	0.57	0.19	0.14	0.07	0	0	58	0.90	0.64	0.33	0.14	0.09	0.04	0.02	95	0.85	0.63	0.31	0.22	0.09	0.02	0.01						
70%	46	0.83	0.61	0.43	0.15	0.04	0	0	39	0.87	0.77	0.52	0.29	0.16	0.06	0	14	0.93	0.86	0.57	0.50	0.29	0.07	0						
80%	25	0.96	0.92	0.80	0.68	0.36	0.12	0.04	22	0.91	0.82	0.55	0.41	0.14	0.05	0	15	0.87	0.67	0.40	0.33	0.20	0.07	0						
90%	26	0.93	0.81	0.65	0.50	0.27	0.04	0.04	36	0.97	0.89	0.72	0.58	0.31	0.06	0.03	10	0.90	0.90	0.50	0.40	0.10	0	0						
100%	32	1.00	0.97	0.94	0.81	0.58	0.23	0.06	0	—	—	—	—	—	—	—	0	—	—	—	—	—	—	—						

* T, trace; all other amounts in inches.

nearest decile value, using the dependent data that were the basis of the table. Ideally, the percent frequency of cases with measurable precipitation, determined separately for each decile value of probability of precipitation, should be equal to the decile value. Results, presented in Table 4, show that the relative frequency of observed measurable precipitation has a value within plus or minus 0.1 of the expected relative frequency except where there are 25 or fewer cases from which to determine the frequency. Even for probability of precipitation forecast values in which fewer than 25 cases occurred, the relative frequency of observed precipitation never deviated by more than 0.16 from the expected frequency.

Included in Table 4 are the relative frequencies of observed precipitation greater than or equal to other specified amounts in addition to 0.01 inch. It can be seen by examining the data in Table 4 that although the technique described in this paper is designed to present the probability of receiving at least 0.01 inch of precipitation in 12 hr, it is also possible to determine the probability of receiving other specified precipitation amounts. One could use this result to objectively identify a threat of heavy precipitation. For example, if the probability of precipitation for the first period is 100%, then there is a 58% probability of getting at least 0.50 inch of liquid equivalent precipitation, if the results hold up on independent data.

TABLE 5. Brier scores for forecasts prepared from dependent data, 5 November 1969 through 31 March 1970. All forecasts issued by the National Meteorological Center (NMC) and local stations are included.

	Objective forecast	Local forecast	NMC forecast
1st period			
Philadelphia	0.089	0.081	0.108
New York	0.089	0.111	0.118
Boston	0.100	0.110	0.119
Washington	0.075	0.081	0.092
Mean	0.088	0.096	0.109
2nd period			
Philadelphia	0.114	0.108	0.117
New York	0.114	0.143	0.133
Boston	0.143	0.146	0.137
Washington	0.100	0.103	0.109
Mean	0.118	0.125	0.124
3rd period			
Philadelphia	0.137	0.133	0.131
New York	0.131	0.167	0.148
Boston	0.147	0.167	0.147
Washington	0.117	0.129	0.130
Mean	0.133	0.149	0.139

The Brier score is commonly used in verifying probability forecasts and is equal to one-half the P score defined by Panofsky and Brier (1958). Table 5 presents Brier scores for probability of precipitation forecasts determined from the dependent data. The scores are presented separately for each station and for each period. Comparative Brier scores are also presented for forecasts issued as guidance to forecast offices by the National Meteorological Center and for local forecasts prepared by forecast offices for issuance to the public.

The lower the Brier score, the greater the skill; therefore, the results obtained with dependent data indicate that the best forecasts were generated by the objective technique, except at Philadelphia where the local forecast was better. The official National Weather Service forecast verifications were used in determining the Brier scores for the National Meteorological Center and the local forecast. No attempt was made to remove forecasts for dates on which objective forecasts were not available.

Table 6 presents Brier scores for a seven-month period, 1 October 1970 through 30 April 1971, of independent data. Brier scores presented in this table for the local forecasts and National Meteorological Center forecasts were determined after removing the forecasts that were issued when there were no comparable primitive-equation model forecasts available. The results obtained with this independent data sample indicate that for this period the objective forecasts were competitive

TABLE 6. Brier scores for 379 forecasts prepared from independent data, 1 October 1970 through 30 April 1971. Excluded from consideration are forecasts issued by the National Meteorological Center and local stations when there were no comparative objective forecasts available.

	Objective forecast	Local forecast	NMC forecast
1st period			
Philadelphia	0.102	0.074	0.086
New York	0.112	0.084	0.095
Boston	0.120	0.103	0.111
Washington	0.082	0.070	0.080
Mean (1516 forecasts)	0.101	0.082	0.093
2nd period			
Philadelphia	0.096	0.103	0.114
New York	0.114	0.109	0.116
Boston	0.130	0.121	0.136
Washington	0.094	0.098	0.130
Mean (1516 forecasts)	0.109	0.108	0.117
3rd period			
Philadelphia	0.109	0.103	0.122
New York	0.127	0.122	0.134
Boston	0.135	0.138	0.144
Washington	0.125	0.113	0.118
Mean (1516 forecasts)	0.124	0.119	0.129

TABLE 7. Observed relative frequency of precipitation ≥ 0.01 inch as a function of probability of precipitation. Results are for independent data, 1 October 1970 through 30 April 1971, for Boston, New York, Philadelphia and Washington. The number of cases are shown in parentheses. The probability of precipitation was determined using Table 3.

Probability of precipitation	Observed relative frequency of precipitation		
	1st period	2nd period	3rd period
90%	0.95 (56)	0.73 (11)	
80%	0.87 (47)	0.90 (42)	0.68 (21)
70%	0.80 (50)	0.87 (54)	0.74 (39)
60%	0.66 (64)	0.75 (75)	0.70 (122)
50%	0.65 (49)	0.68 (68)	0.55 (51)
40%	0.39 (102)	0.52 (59)	0.46 (37)
30%	0.30 (105)	0.33 (174)	0.37 (177)
20%	0.16 (80)	0.14 (149)	0.18 (286)
10%	0.15 (131)	0.11 (287)	0.08 (400)
0%	0.04 (832)	0.04 (597)	0.04 (383)

with the National Meteorological Center and local forecasts prepared for the second and third period, but not as good as the National Meteorological Center and local forecasts prepared for the first period. In the second and third period the objective forecast, when considering all stations combined, was actually better than National Meteorological Center forecasts, as measured by mean Brier scores.

An additional evaluation performed on the independent data involved the preparation of a table in which, for each forecast period the observed relative frequency of precipitation ≥ 0.01 inch is determined for cases with the same probability of precipitation decile value. The results for the four stations combined (presented in Table 7) can be compared to the dependent data results presented in Table 4.

5. Conclusions

A technique has been developed and successfully tested for objectively preparing forecasts of the probability of specified precipitation amounts using the National Meteorological Center's multilayer primitive-equation model output. Probability of precipitation values can be determined manually from Table 3 or can be automatically generated on a computer as a by-product of the primitive-equation model. Computer-generated probability of precipitation forecasts using results presented here have been prepared experimentally since February 1971 and have been transmitted on teletype to the stations for which the technique was developed. These objective forecasts are received about the same time as the FOUS-1 message, in time for consideration as guidance. This technique can aid forecasters until such time as more data and more sophisticated statistical treatment of the data are used to develop a new and, hopefully, better technique.

Future modifications of the primitive-equation model may require new changes in the prediction table presented here. When and if changes are made to the model or when new models are developed such that the model output cannot be made compatible with the output used in this study as development data, the prediction table now presented will have to be replaced by a new prediction table. New tables can be prepared shortly after the introduction of a new or revised model, following the approach presented here. If new models exhibit

a better ability to predict the relative humidity and vertical velocity, then these future models would make it possible to prepare better objective precipitation probability forecasts.

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