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A TECHNIQUE FOR GENERATING LOCAL POP GUIDANCE DURING STRATIFIED PRECIPITATION EVENTS AT PORTLAND, MAINE

Hendricus J. Lulofs
National Weather Service Forecast Office
Portland, Maine

1. INTRODUCTION

With the planned discontinuation of the Limited-area Fine Mesh (LFM) Model Output Statistics (MOS) in 1994, forecasters will have only one set of Probability of Precipitation (PoP) guidance until MOS guidance from the Aviation run of the spectral model is available. There is no PoP forecast available from the new ETA model and none is planned. Yet, National Weather Service field forecasters are challenged to try to better the Nested Grid Model (NGM) MOS PoPs (Su 1993). The purpose of this study, which expands on a study described in a NOAA technical memorandum (Wasserman and Rosenblum 1970), is to assist forecasters in forecasting the PoP by describing a technique, which could be used to generate PoP forecasts from the ETA model FOUS Relative Humidity/ Temperature guidance (FRH), thereby producing a second set of PoP guidance.

The National Meteorological Center's (NMC) NGM predictions of relative humidity and vertical velocity are found to have a strong relationship with the frequency of observed measurable precipitation (.01 inch or greater). The Automation of Field Operations and Services (AFOS) product that displays a 48-hour forecast of these parameters is the FOUS Relative Humidity/Temperature guidance (FRHT). This paper presents a method for using these NGM FRHT predictions to forecast the probability of precipitation (from here on referred to as the Lulofs Guidance Number or LGN) in 12-hour increments out to 48 hours. Results are presented based on applying the technique to data for Portland, Maine. This technique is applicable to other areas too, but local studies would have to be done to derive relationships for each location. Statistical scores were computed for the LGN PoPS and for the NGM MOS PoPS. Comparisons of the results of these statistical scores were made. The statistical scores and the comparisons are presented in this paper.

LGN PoPs work best for stratified weather systems as opposed to convective systems; for this reason the period when the NGM winter equations are in use (October 1 through March 31) was chosen to develop a database and to verify against. This is because during these months most of the precipitation events at Portland, Maine, are stratified in nature. There are instances during the October 1 through March 31 period when the derived LGN PoPs should not be used, such as when a convective event is expected (in Portland this often happens in October and less frequently during winter months).

2. PROCEDURE

The method described in this paper is based on the basic premise that two important factors for precipitation are moisture (relative humidity) and vertical lift (vertical velocity). Data were obtained by using the NGM relative humidity and vertical velocity forecasts as they appeared on the AFOS product FRHT60 for Portland, Maine, during four model winter seasons. The four seasons were 1988-1989, 1990-1991, 1991-1992, and 1992-1993. Data from both the 0000 and 1200 UTC model runs were used. It was assumed that changes made in the NGM model during these years did not have a large impact on this study.

National Weather Service field forecasters receive FRHT data twice a day at about 0300 and 1500 UTC, or about 3 hours after the time of the initial data used to generate the FRHT forecast. The FRHT output forecast for hours 12 through 24 after the initial data time corresponds to the first 12-hour period covered by the NGM MOS PoP, and to the first period of the public weather forecast. Likewise, the FRHT output for hours 24 through 36, and 36 through 48, correspond to the second and third 12-hour periods of the NGM MOS and public weather forecasts. Even though by the time it is received, the data valid time has partially expired, FRHT output data for the 12-hour period from the initial time through the first 12 hours (hereafter, referred to as the initial period) is considered to be useful in nowcasts and zone forecast updates and was included in this study.

FRHT output for forecast hours 00, 06, and 12 represent the beginning, middle, and end of the initial period, while FRHT output for forecast hours 12, 18, and 24 represent the beginning, middle, and end of the first forecast period. Likewise FRHT output for forecast hours 24, 30, and 36 represent the beginning, middle, and end of the second forecast period, while FRHT output for forecast hours 36, 42, and 48 represent the beginning, middle, and end of the third forecast period. The relative humidity forecasts used in this study are the FRHT R2 and R3 values and are given in percent. The value of R2 essentially represents the mean relative humidity in the lower and middle troposphere, while the value of R3 represents the mean relative humidity in the upper troposphere. Information on the FOUS, such as model layers and typical top and bottom pressures represented by these values, are described in a pamphlet (National Weather Service Training Center 1991) and in a Technical Procedure Bulletin (National Weather Service 1985). The value of R1 in the FRHT product, which represents the mean relative humidity in the lower part of the boundary layer, was not considered for this study because diurnal fluctuations (early morning maximums and late afternoon minimums) in the lowest layer of the atmosphere would bias these data. The vertical velocity (VVV) forecast in the FRHT represents the vertical velocity at 700 mb in tenths of a microbar per second (microbar/sec). The relative humidity and vertical velocity values given in the FRHT are instantaneous values.

In this study, the three FRHT forecasts corresponding to the beginning, middle, and end of each forecast period were examined for the highest relative humidity (the sum of R2 and R3) and the highest algebraic value of vertical velocity. Note that the highest relative humidity may occur at a different time than the highest algebraic value for vertical velocity as long as they both are within the same forecast period. Surface observations were then used to determine if measurable precipitation occurred during each forecast period. Combinations of R2 and R3 were divided into intervals of 20%, except the cases where R2 and R3 added up to less than 80% were all grouped together. Likewise, the vertical velocities were grouped into intervals of 1.0 microbar/sec, except values less than -1.0 microbar/sec were all grouped together, as were values greater than or equal to 6.0 microbar/sec (see Table 1).

As the vertical velocity increases one would expect the PoP to increase. There were a few instances where the LGN PoP decreased with increasing vertical velocity. Most of these cases had a small database. Smoothing was performed to remove this anomaly in the data. The smoothing was accomplished by using averaging techniques as well as graphical interpolation and extrapolation (Appendix I). In an attempt not to over smooth the data, only LGN PoPs that decreased with increasing vertical velocities were smoothed. As a result, there were times when the LGN PoP stayed constant with increasing vertical velocities. Using graphical interpolation and extrapolation, an attempt was also made to obtain LGN PoPs for R2+R3 and vertical velocity combinations that did not occur in the developmental sample (represented in Table 1 by an X). LGN PoPs after smoothing are shown in Table 2.

3. COMPARISONS TO MOS PoP

Once the data were smoothed, a comparison of the resultant LGN PoPs to the NGM MOS PoPs was performed by using data for 5 dependent months (10/92, 11/92, 12/92, 1/93, and 3/93). The results of this comparison are shown in Tables 3 through 5. A second comparison of 3 independent months (11/89, 1/90, and 3/90) was also done, the results of which are shown in Tables 6 through 8. Note that a comparison for the initial period could not be performed because the NGM MOS does not include a 0-12 hour PoP.

Tables 3 through 8 indicate that most of the time the two PoP forecasts were within 30% of each other. If one accepts that the MOS PoPs show skill, then this generality gives a preliminary indication that the LGN PoPs also show skill. However, to scientifically prove skill one must look at some commonly accepted statistical measures. In this study, the following scores were computed: Brier Skill Score; percent improvement on climatology; False Alarm Ratio (FAR); Probability Of Detection (POD); Critical Success Index (CSI); percent correct; and bias (equations for these verification measures are presented in Appendix II). The results are shown in Tables 9 and 10.

From the verification statistics shown in Tables 9 and 10 the following can be inferred:

1. The MOS PoP had consistently better Brier, FAR, POD, CSI, and percent correct scores when compared to the LGN PoP.

2. Both the MOS and LGN PoPs had a substantial improvement over climatology, indicating that both PoPs showed skill.

3. Both the MOS and LGN PoPs had a bias towards under forecasting occurrences of precipitation.

4. MOS and LGN PoPs showed decreasing skill going toward the later forecast periods. For example, Brier Skill Scores increased and percent correct forecasts decreased for successive forecast periods.

It should be noted that the climatic probability of precipitation was rounded to the nearest 10 percent. This was done to be consistent with the MOS and LGN PoPs, which were rounded to the nearest 10 percent to provide for a large enough data sample for each decile, and to be consistent with public forecasts and verification programs. The climatic probability of precipitation for all months of this study, except October, was the same for both 12-hour periods of the day when rounded to the nearest 10 percent (Jorgensen 1967). Since the independent data did not use the month of October, Brier scores for climatology were identical for all three periods (Table 10).

From the verification data in Tables 9 and 10 and the summarization of the statistical results, it is evident that both techniques show skill in forecasting measurable precipitation. As was expected, the MOS PoP did have more skill than the LGN PoP. However, considering that the MOS PoP uses up to 15 variables, while the LGN PoP only uses two, the difference in skill between the two sets of PoPs is understandable. It should be noted that although the MOS can use up to 15 variables, it is dominated by a couple (Maglaras 1993).

When comparing the statistical analyses of the dependent (Table 9) and independent (Table 10) data, one finds that the overall trends for both are very similar. For example, the difference between the LGN and MOS Brier scores is .0137 for the dependent and .0138 for the independent data. Both the MOS PoPs and the LGN PoPs showed less skill during the 3 months used for independent data. Since the Brier scores for climatology of the independent data increased to .3354 from the dependent Brier score of .2135, the independent months appeared to comprise a period that was more difficult to forecast for.

4. DISCUSSION

The technique of deriving NGM LGN PoPs described in this paper could be used to generate ETA LGN PoPs by using ETA FRH developmental data. This technique will work for any site for which FRH output is produced. Since local effects (i.e., topography and proximity to bodies of water, etc.) have a major impact on whether or not measurable precipitation occurs, it is necessary that this study be carried out for each site by using local data. Since the ETA is a new model, there is a limited amount of data available to generate ETA LGN PoPS. Instead of waiting several years to build up an ETA FRH database, it might be possible to use data for one model winter season from two or three nearby sites for which FRH data is available to quickly build up the database. For example, to generate ETA LGN PoPs for Portland, ME, FRH data for Concord, NH, and Bangor, ME, as well as Portland, ME, could be used. This would allow for quicker operational use of the LGN PoP with the trade-off being the likelihood of a less accurate product. Then in future years, as the database for the specific location grows, the data from the nearby sites could be eliminated. In addition, instead of generating PoPs for each period, combining the data for all periods within the appropriate R2+R3 and vertical velocity categories would also help build up the database.

Because the ETA model is still under development, any changes made to the model should be monitored as to their possible impacts on the generation of ETA LGN PoPs. If a change is made that has a large impact on the ETA LGN PoPs developed from data prior to the change, then one would need to reproduce the technique with post-change data. Once a final version of the ETA model is implemented, this problem will be resolved.

Forecasters should be aware that only measurable precipitation (.01 inch or greater) events were put in the "yes" category, with trace events (less than .01 inch) put in the "no" category. Because of this it is possible to have light precipitation events (less than .01 inch) even though the NGM (and future ETA) LGN PoPs are low. This is especially true when high values of R2+R3 are combined with small values of vertical velocity.

The forecaster must also be cautious about PoPs for combinations of R2+R3 and vertical velocity that occurred infrequently. Through graphical interpolation and extrapolation, the procedure attempts to obtain reasonable PoPs for these instances, but the small database could make the PoPs unreliable. As the database is increased by annual updates, occurrences of this problem should decrease.

Once this technique is successfully implemented for a given station, it is recommended that an AFOS program be written to automatically generate the LGN PoPs every time the FRH is sent over AFOS. This will save the field forecasters time and make obtaining the LGN PoPs simple.

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TABLE 1. Relative frequency of observed measurable precipitation versus vertical velocity for R2+R3 = 180% to 198%. Y=measurable precipitation, N=no measurable precipitation, LGN PoP=(Y/(Y+N))*100%, X indicates no cases.

R2+R3 = 180% to 198%

FCST PERIOD	INITIAL (00-12)			FIRST (12-24)			SECOND (24-36)			THIRD (36-48)		
HOUR MSRBL. PRECIP.	Y	*LGN PoP*	N	Y	*LGN PoP*	N	Y	*LGN PoP*	N	Y	*LGN PoP*	N
VERT. VEL. (microbar/sec) < -1		*X*			*X*			*X*			*X*	
-1 to -.1	0	*0%*	1	0	*0%*	2	0	*0%*	1	0	*0%*	2
0 to .9	3	*50%*	3	5	*56%*	4	3	*38%*	5	8	*50%*	8
1 to 1.9	6	*75%*	2	11	*50%*	11	12	*44%*	15	15	*46%*	18
2 to 2.9	19	*76%*	6	22	*76%*	7	22	*67%*	11	24	*63%*	14
3 to 3.9	13	*77%*	4	18	*75%*	6	18	*72%*	7	21	*62%*	13
4 to 4.9	9	*90%*	1	13	*81%*	3	13	*87%*	2	20	*100%*	0
5 to 5.9	3	*60%*	2	12	*92%*	1	14	*82%*	3	18	*82%*	4
6 OR >	38	*100%*	0	61	*97%*	2	61	*97%*	2	48	*86%*	8

TABLE 2. Smoothed relative frequency of observed measurable precipitation versus vertical velocity for R2+R3 = 180% to 198%.

R2+R3 = 180% to 198%

FCST PERIOD HOUR MSRBL. PRECIP.	INITIAL (00-12) *LGN* *PoP*	FIRST (12-24) *LGN* *PoP*	SECOND (24-36) *LGN* *PoP*	THIRD (36-48) *LGN* *PoP*
VERT. VEL. (microbar/sec) < -1	0%	0%	0%	0%
-1 to -.1	0%	0%	0%	0%
0 to .9	50%	56%	38%	50%
1 to 1.9	75%	63%	44%	54%
2 to 2.9	76%	76%	67%	63%
3 to 3.9	77%	77%	72%	71%
4 to 4.9	90%	81%	87%	78%
5 to 5.9	94%	92%	93%	82%
6 OR >	100%	97%	97%	86%

TABLE 3. First period comparison of MOS PoP forecast values with **dependent** LGN PoP forecast values. The percent of occurrences of measurable precipitation is shown for each combination of forecasts. Also shown are the number of cases with measurable precipitation divided by the total number of cases.

		1st PERIOD MOS PoP FORECAST (rounded to the nearest 10 percent)											
		0	10	20	30	40	50	60	70	80	90	100	All Cases
1st PERIOD LGN PoP FORECAST (rounded to the nearest 10 percent)	0	0% 0/60	0% 0/13	0% 0/2	X 0/0	X 0/0	0% 0/1	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	0% 0/76
	10	0% 0/38	8% 1/13	29% 2/7	50% 1/2	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	7% 4/60
	20	0% 0/7	18% 2/11	0% 0/4	0% 0/1	100% 2/2	0% 0/1	X 0/0	50% 1/2	X 0/0	0% 0/1	X 0/0	17% 5/29
	30	0% 0/5	0% 0/8	0% 0/5	100% 3/3	50% 2/4	33% 1/3	0% 0/2	100% 1/1	X 0/0	100% 1/1	100% 1/1	27% 9/33
	40	0% 0/2	33% 1/3	X 0/0	100% 1/1	50% 1/2	100% 3/3	X 0/0	50% 1/2	67% 2/3	X 0/0	100% 2/2	61% 11/18
	50	0% 0/1	X 0/0	X 0/0	0% 0/1	X 0/0	X 0/0	0% 0/1	0% 0/1	X 0/0	X 0/0	X 0/0	0% 0/4
	60	0% 0/1	X 0/0	0% 0/1	20% 1/5	50% 1/2	67% 4/6	100% 6/6	100% 3/3	100% 2/2	100% 1/1	100% 1/1	68% 19/28
	70	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	100% 2/2	50% 1/2	X 0/0	75% 3/4
	80	X 0/0	X 0/0	X 0/0	0% 0/1	50% 2/4	X 0/0	100% 3/3	100% 4/4	100% 3/3	100% 2/2	100% 6/6	87% 20/23
	90	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	100% 2/2	100% 1/1	X 0/0	X 0/0	100% 3/3	100% 6/6
	100	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	100% 1/1	X 0/0	100% 1/1	100% 2/2	100% 4/4	100% 8/8
All Cases		0% 0/114	8% 4/48	11% 2/19	43% 6/14	57% 8/14	57% 8/14	80% 12/15	79% 11/14	91% 10/11	78% 7/9	100% 17/17	29% 85/289

TABLE 4. As in Table 3 except for second period comparison.

2nd PERIOD LGN PoP FORECAST (rounded to the nearest 10 percent)	2nd PERIOD MOS PoP FORECAST (rounded to the nearest 10 percent) 0	10	20	30	40	50	60	70	80	90	100	All Cases
0	0% 0/44	0% 0/28	0% 0/2	X 0/0	X 0/0	X 0/0	X 0/0	100% 1/1	X 0/0	X 0/0	X 0/0	1% 1/75
10	0% 0/18	3% 1/34	11% 1/9	33% 2/6	0% 0/1	0% 0/2	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	6% 4/70
20	0% 0/6	0% 0/12	20% 1/5	100% 2/2	67% 2/3	X 0/0	0% 0/1	X 0/0	100% 1/1	X 0/0	X 0/0	20% 6/30
30	0% 0/1	0% 0/3	50% 1/2	0% 0/1	100% 2/2	67% 2/3	X 0/0	100% 2/2	100% 1/1	X 0/0	X 0/0	53% 8/15
40	X 0/0	50% 1/2	100% 2/2	33% 1/3	67% 2/3	100% 1/1	X 0/0	33% 1/3	X 0/0	0% 0/1	X 0/0	53% 8/15
50	X 0/0	0% 0/2	60% 3/5	X 0/0	50% 1/2	0% 0/2	0% 0/1	100% 1/1	X 0/0	0% 0/2	X 0/0	33% 5/15
60	0% 0/1	X 0/0	0% 0/1	50% 2/4	0% 0/2	67% 2/3	100% 1/1	X 0/0	100% 2/2	100% 1/1	X 0/0	53% 8/15
70	X 0/0	X 0/0	X 0/0	0% 0/2	50% 2/4	67% 2/3	100% 4/4	100% 3/3	80% 4/5	100% 3/3	X 0/0	75% 18/24
80	0% 0/1	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	100% 1/1	X 0/0	X 0/0	100% 2/2	100% 2/2	83% 5/6
90	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	100% 1/1	100% 4/4	X 0/0	100% 2/2	100% 2/2	100% 9/9
100	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	100% 3/3	100% 1/1	100% 4/4	100% 7/7	100% 15/15
All Cases	0% 0/71	3% 2/81	31% 8/26	39% 7/18	53% 9/17	50% 7/14	78% 7/9	88% 15/17	90% 9/10	80% 12/15	100% 11/11	30% 87/289

TABLE 5. As in Table 3 except for third period comparison.

	3rd PERIOD MOS PoP FORECAST (rounded to the nearest 10 percent)											
3rd PERIOD LGN PoP FORECAST (rounded to the nearest 10 percent)	0	10	20	30	40	50	60	70	80	90	100	All Cases
0	0% 0/28	0% 0/20	33% 2/6	X 0/0	0% 0/1	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	4% 2/55
10	0% 0/28	3% 1/32	10% 1/10	0% 0/1	50% 2/4	100% 1/1	100% 1/1	X 0/0	X 0/0	X 0/0	X 0/0	8% 6/77
20	0% 0/2	15% 2/13	8% 1/13	33% 2/6	100% 2/2	X 0/0	X 0/0	0% 0/1	X 0/0	X 0/0	X 0/0	19% 7/37
30	0% 0/1	38% 3/8	33% 2/6	50% 3/6	0% 0/2	67% 2/3	100% 1/1	67% 2/3	0% 0/1	X 0/0	X 0/0	42% 13/31
40	X 0/0	X 0/0	0% 0/1	X 0/0	100% 1/1	X 0/0	X 0/0	100% 1/1	X 0/0	X 0/0	X 0/0	67% 2/3
50	X 0/0	0% 0/2	22% 2/9	56% 5/9	100% 6/6	100% 3/3	100% 2/2	100% 3/3	X 0/0	X 0/0	100% 1/1	63% 22/35
60	X 0/0	X 0/0	0% 0/1	X 0/0	X 0/0	0% 0/2	100% 4/4	50% 2/4	X 0/0	X 0/0	X 0/0	55% 6/11
70	0% 0/1	X 0/0	X 0/0	X 0/0	50% 1/2	50% 1/2	100% 1/1	40% 2/5	50% 1/2	X 0/0	X 0/0	46% 6/13
80	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	100% 3/3	100% 2/2	67% 2/3	100% 3/3	100% 1/1	92% 11/12
90	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	100% 2/2	X 0/0	100% 4/4	75% 3/4	75% 3/4	86% 12/14
100	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	100% 1/1	X 0/0	100% 1/1
All Cases	0% 0/60	8% 6/75	17% 8/46	46% 10/22	67% 12/18	64% 7/11	100% 14/14	63% 12/19	70% 7/10	88% 7/8	83% 5/6	30% 88/289

TABLE 6. First period comparison of MOS PoP forecast values with **independent** LGN PoP forecast values. The percent of occurrences of measurable precipitation is shown for each combination of forecasts. Also shown are the number of cases with measurable precipitation divided by the total number of cases.

	1st PERIOD MOS PoP FORECAST (rounded to the nearest 10 percent)											
1st PERIOD LGN PoP FORECAST (rounded to the nearest 10 percent)	0	10	20	30	40	50	60	70	80	90	100	All Cases
0	0% 0/36	22% 2/9	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	4% 2/45
10	0% 0/20	5% 1/19	0% 0/4	0% 0/3	25% 1/4	0% 0/2	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	4% 2/52
20	X 0/0	0% 0/5	X 0/0	50% 1/2	33% 1/3	100% 1/1	X 0/0	100% 1/1	100% 1/1	X 0/0	100% 1/1	43% 6/14
30	0% 0/4	0% 0/5	50% 1/2	67% 2/3	50% 2/4	50% 2/4	0% 0/1	X 0/0	X 0/0	100% 2/2	X 0/0	36% 9/25
40	X 0/0	0% 0/1	X 0/0	0% 0/1	33% 1/3	50% 1/2	0% 0/1	100% 1/1	50% 1/2	X 0/0	X 0/0	36% 4/11
50	X 0/0	X 0/0	X 0/0	X 0/0	0% 0/1	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	0% 0/1
60	X 0/0	100% 1/1	X 0/0	X 0/0	100% 1/1	0% 0/2	50% 1/2	50% 1/2	X 0/0	X 0/0	75% 3/4	58% 7/12
70	0% 0/1	X 0/0	X 0/0	X 0/0	X 0/0	100% 1/1	0% 0/1	100% 1/1	X 0/0	X 0/0	100% 1/1	60% 3/5
80	X 0/0	X 0/0	X 0/0	X 0/0	100% 1/1	100% 1/1	100% 1/1	X 0/0	X 0/0	X 0/0	100% 2/2	100% 5/5
90	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	100% 1/1	X 0/0	X 0/0	100% 2/2	X 0/0	100% 3/3
100	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	100% 1/1	100% 1/1	100% 2/2	100% 3/3	100% 7/7
All Cases	0% 0/61	10% 4/40	17% 1/6	33% 3/9	41% 7/17	46% 6/13	43% 3/7	83% 5/6	75% 3/4	100% 6/6	91% 10/11	27% 48/180

TABLE 7. As in Table 6 except for second period comparison.

2nd PERIOD LGN PoP FORECAST (rounded to the nearest 10 percent)	2nd Period MOS PoP FORECAST (rounded to the nearest 10 percent) 0	10	20	30	40	50	60	70	80	90	100	All Cases
0	0% 0/27	27% 3/11	0% 0/1	0% 0/1	X 0/0	0% 0/1	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	7% 3/41
10	0% 0/22	0% 0/16	14% 1/7	0% 0/6	0% 0/3	50% 1/2	X 0/0	0% 0/1	X 0/0	X 0/0	X 0/0	4% 2/57
20	0% 0/5	0% 0/4	50% 1/2	0% 0/2	33% 1/3	33% 1/3	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	16% 3/19
30	100% 1/1	0% 0/3	X 0/0	100% 2/2	0% 0/1	X 0/0	100% 1/1	100% 1/1	X 0/0	X 0/0	X 0/0	56% 5/9
40	0% 0/1	0% 0/2	X 0/0	0% 0/3	100% 3/3	X 0/0	X 0/0	100% 2/2	100% 1/1	X 0/0	X 0/0	50% 6/12
50	X 0/0	0% 0/1	0% 0/1	100% 2/2	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	50% 2/4
60	0% 0/1	0% 0/1	0% 0/1	0% 0/2	X 0/0	100% 1/1	50% 1/2	X 0/0	X 0/0	X 0/0	50% 1/2	30% 3/10
70	X 0/0	X 0/0	100% 1/1	0% 0/2	100% 1/1	100% 1/1	50% 1/2	100% 2/2	X 0/0	100% 2/2	100% 2/2	77% 10/13
80	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	100% 1/1	100% 1/1	X 0/0	100% 1/1	X 0/0	100% 3/3
90	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	100% 1/1	50% 1/2	100% 1/1	100% 1/1	100% 1/1	86% 6/7
100	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	100% 1/1	100% 2/2	100% 1/1	100% 1/1	100% 5/5
All Cases	2% 1/57	8% 3/38	23% 3/13	20% 4/20	46% 5/11	56% 5/9	63% 5/8	89% 8/9	100% 4/4	100% 5/5	83% 5/6	27% 48/180

TABLE 8. As in Table 6 except for third period comparison.

3rd PERIOD LGN PoP FORECAST (rounded to the nearest 10 percent)	3rd PERIOD MOS PoP FORECAST (rounded to the nearest 10 percent) 0	10	20	30	40	50	60	70	80	90	100	All Cases
0	0% 0/20	8% 1/12	X 0/0	X 0/0	X 0/0	X 0/0	0% 0/1	X 0/0	X 0/0	X 0/0	X 0/0	3% 1/33
10	6% 1/16	0% 0/17	11% 1/9	33% 1/3	0% 0/1	50% 1/2	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	8% 4/48
20	0% 0/3	13% 1/8	29% 2/7	33% 1/3	100% 2/2	33% 1/3	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	27% 7/26
30	0% 0/4	0% 0/3	20% 1/5	20% 1/5	100% 1/1	0% 0/1	33% 1/3	100% 1/1	X 0/0	X 0/0	X 0/0	22% 5/23
40	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	100% 1/1	X 0/0	X 0/0	X 0/0	100% 1/1
50	X 0/0	33% 1/3	0% 0/1	0% 0/3	75% 3/4	X 0/0	60% 3/5	50% 1/2	X 0/0	100% 1/1	X 0/0	47% 9/19
60	X 0/0	X 0/0	X 0/0	X 0/0	0% 0/1	X 0/0	75% 3/4	100% 1/1	X 0/0	X 0/0	X 0/0	67% 4/6
70	X 0/0	X 0/0	X 0/0	0% 0/1	0% 0/1	100% 1/1	100% 1/1	100% 1/1	50% 1/2	100% 1/1	X 0/0	63% 5/8
80	X 0/0	X 0/0	100% 2/2	X 0/0	100% 1/1	50% 1/2	0% 0/2	67% 2/3	X 0/0	100% 1/1	X 0/0	64% 7/11
90	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	100% 2/2	X 0/0	100% 3/3	100% 5/5
100	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0	X 0/0
All Cases	2% 1/43	7% 3/43	25% 6/24	20% 3/15	64% 7/11	44% 4/9	50% 8/16	78% 7/9	75% 3/4	100% 3/3	100% 3/3	27% 48/180

TABLE 9. Statistical data derived from the dependent data represented in Tables 3 through 5.

BRIER SCORES:

	1ST PERIOD	2ND PERIOD	3RD PERIOD	OVERALL
MOS PoP	0859	.0983	.1281	.1041
LGN PoP	.1051	.1083	.1399	.1178
CLIMATOLOGY	.2115	.2142	.2147	.2135

% IMPROVEMENT ON CLIMATOLOGY:

	1ST PERIOD	2ND PERIOD	3RD PERIOD	OVERALL
MOS PoP	59.4%	54.1%	40.3%	51.3%
LGN PoP	50.3%	49.4%	34.8%	44.8%

FALSE ALARM RATIO:

	1ST PERIOD	2ND PERIOD	3RD PERIOD	OVERALL
MOS PoP	.188	.197	.235	.207
LGN PoP	.233	.286	.324	.281

PROBABILITY OF DETECTION:

	1ST PERIOD	2ND PERIOD	3RD PERIOD	OVERALL
MOS PoP	.765	.701	.591	.686
LGN PoP	.659	.690	.659	.669

CRITICAL SUCCESS INDEX:

	1ST PERIOD	2ND PERIOD	3RD PERIOD	OVERALL
MOS PoP	.650	.598	.500	.583
LGN PoP	.549	.541	.501	.530

PERCENT CORRECT:

	1ST PERIOD	2ND PERIOD	3RD PERIOD	OVERALL
MOS PoP	87.9%	85.8%	82.0%	85.2%
LGN PoP	83.4%	82.4%	79.9%	81.9%

BIAS:

	1ST PERIOD	2ND PERIOD	3RD PERIOD	OVERALL
MOS PoP	.941	.874	.773	.863
LGN PoP	.857	.966	.977	.933

TABLE 10. Statistical data derived from the independent data represented in Tables 6 through 8.

BRIER SCORES:

	1ST PERIOD	2ND PERIOD	3RD PERIOD	OVERALL
MOS PoP	.1028	.1043	.1273	.1115
LGN PoP	.1186	.1168	.1404	.1253
CLIMATOLOGY	.3354	.3354	.3354	.3354

% IMPROVEMENT ON CLIMATOLOGY:

	1ST PERIOD	2ND PERIOD	3RD PERIOD	OVERALL
MOS PoP	69.4%	68.9%	62.1%	66.8%
LGN PoP	64.6%	65.2%	58.1%	62.6%

FALSE ALARM RATIO:

	1ST PERIOD	2ND PERIOD	3RD PERIOD	OVERALL
MOS PoP	.298	.220	.364	.294
LGN PoP	.242	.310	.388	.313

PROBABILITY OF DETECTION:

	1ST PERIOD	2ND PERIOD	3RD PERIOD	OVERALL
MOS PoP	.688	.667	.583	.646
LGN PoP	.521	.604	.625	.583

CRITICAL SUCCESS INDEX:

	1ST PERIOD	2ND PERIOD	3RD PERIOD	OVERALL
MOS PoP	.533	.561	.437	.510
LGN PoP	.447	.475	.474	.465

PERCENT CORRECT:

	1ST PERIOD	2ND PERIOD	3RD PERIOD	OVERALL
MOS PoP	83.9%	86.1%	80.0%	83.3%
LGN PoP	82.8%	82.2%	79.4%	81.5%

BIAS:

	1ST PERIOD	2ND PERIOD	3RD PERIOD	OVERALL
MOS PoP	.979	.854	.917	.917
LGN PoP	.688	.875	1.021	.861

APPENDIX I

SMOOTHING

a. Averaging Method

Here, we present an example for vertical velocities and LGN PoPs of: 4 to 4.9 microbars/sec and 87%, 5 to 5.9 microbar/sec and 82%, and 6 or > microbar/sec and 97%. With increasing vertical velocities an increase in the LGN PoP is expected, therefore, the value of 82% for vertical velocities of 5 to 5.9 microbar/sec seems low. To adjust this, the following averaging technique is applied: the number of precipitation events ("yes" column) for this range of vertical velocities is added to those for the adjacent ranges of vertical velocities. The result is divided by the total number of events ("yes" and "no" columns) for the three vertical velocity ranges. Hence,

VERT. VEL. (microbar/sec)	SECOND PERIOD		
	Y	LGN PoP	N
4 to 4.9	13	87%	2
5 to 5.9	14	82%	3
6 or >	61	97%	2

$$(13+14+61)/(13+14+61+2+3+2) = 88/95 = 93\%$$

b. Graphical Methods

This example is based on LGN PoPs of 0%, 3%, 2%, 16%, 17%, 36%, 50%, 0%, and 100%. The averaging technique described above was used to smooth the LGN PoPs as needed for all but the last value (100%), which could not be smoothed by using this technique because it is the value for the last grouping of vertical velocities. To smooth this data point a graph was constructed by using smoothed LGN PoPs (Fig. 1) and extrapolation was used to obtain the value of 78% for vertical velocities of 6 or > microbar/sec. The two techniques resulted in smoothed PoPs of 0%, 3%, 7%, 16%, 17%, 36%, 50%, 64%, and 78%.

Graphical extrapolation can also be used for the first grouping of vertical velocity values. A similar graphical technique was occasionally needed to smooth data points which did not fall in either the first or the last grouping of vertical velocity values. This happened when combinations of R2+R3 and vertical velocity did not occur often enough in the data sample and, hence, the averaging technique could not be used. For these cases, graphical interpolation was used to smooth the data.

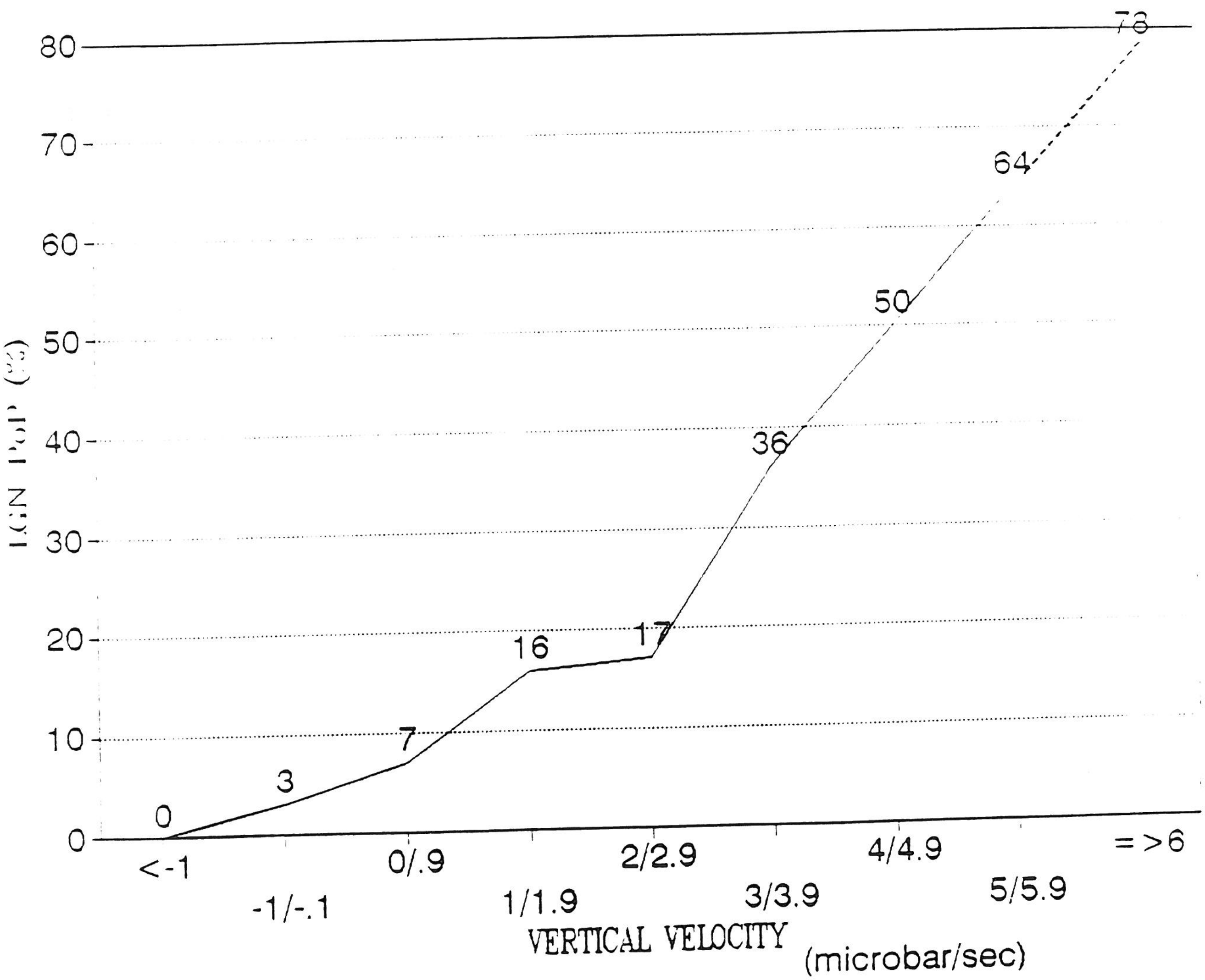

Figure 1. Graphical extrapolation from 64% to 78%.

APPENDIX II

STATISTICAL EQUATIONS USED IN THIS PAPER

The statistical scores were calculated using the equations given below. Note that in computing the statistics a PoP of 50% or greater was considered a forecast of precipitation.

Brier Skill Score

$$1/N * [\sum_{1}^{N}(F-O)^2]$$

where: F=forecast probability
O=1 measurable precipitation
or 0 no measurable precipitation
N=total number of forecasts

percent improvement on climatology

$$\frac{Brier_{climat.} - Brier_{MOS\ or\ LGN}}{Brier_{climat.}} *100\%$$

FAR

$$\frac{\text{number of incorrect precipitation forecasts}}{\text{number of precipitation forecasts}}$$

POD

$$\frac{\text{number of precipitation cases correctly forecast}}{\text{total number of precipitation cases}}$$

CSI

$$\frac{1}{1/POD + 1/(1-FAR) - 1}$$

BIAS

$$\frac{\text{number of precipitation forecasts}}{\text{number of precipitation events}}$$