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A STATISTICAL COMPARISON OF THE FORECASTS PRODUCED BY THE NGM AND LFM FOR THE COOL SEASON OF 1987-88

John S. Jensenius, Jr.

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1. INTRODUCTION

For the last several years, the Techniques Development Laboratory (TDL) has been evaluating the performance of the National Meteorological Center's (NMC's) numerical weather prediction models (Jensenius, 1988a; Jensenius, 1988b). Our goal in these efforts has been to determine the statistical behavior of the models' predictions of several important weather variables and to relay this information to field forecasters and to NMC. As a continuation of this effort, this Office Note describes results from the cool season (October - March) of 1987-88. We examined and compared the thermal, relative humidity, and precipitation forecasts from the Limited-area Fine-mesh Model (LFM) (National Weather Service, 1978; Newell and Deaven, 1981) and the Nested Grid Model (NGM) (National Weather Service, 1985a; National Weather Service, 1986; National Weather Service, 1987a). We did not, however, evaluate the Medium-Range Forecast (MRF) Model (National Weather Service, 1985b; National Weather Service, 1987b) since significant changes were made during the spring of 1988 to the surface evaporation scheme used in the model (National Weather Service, 1989a). This change significantly affected relative humidities and temperatures in the lower layers of the model. Consequently, any statistical results from the 1987-88 cool season would no longer be valid. In addition, the MRF model was changed during the fall of 1988 to include interactive clouds in the model's radiative calculations (National Weather Service, 1989b) and during the spring of 1989 to correct a post-processing error (Ballish, 1988) which resulted in erroneous temperatures below the model's terrain height. This error was the result of the wrong sign being given to the lapse rate and caused temperatures between the model's surface and sea level to cool with increasing pressure, rather than warm.

2. METHOD

To evaluate the models, we used a matched sample of model forecasts from the LFM and NGM for <u>0000 UTC only</u>. We interpolated the model predictions to about 230 stations across the contiguous United States. Data for the period of October 22, 1987 through March 31, 1988 were evaluated. Except where indicated otherwise, the results presented in this paper are for this evaluation period. Note that the period began after a hemispheric temperature correction scheme (National Weather Service, 1987a) was implemented in the NGM.

For each model, we combined the data for all stations and days and determined the average forecast values for each projection. By comparing the mean values for each projection, we determined the average "drift" in the model's predictions. Here, "drift" is defined as the tendency for the mean value of the forecast to increase or decrease with increasing forecast projection. Of course, the drift is best determined over 24- or 48-h periods to eliminate the effects of diurnal fluctuations in the data. In addition to determining the average drift for the country as a whole, we also calculated grid point values of the average 0- to 48-h drift for various fields. To do this, we simply subtracted the average 0-h field of a variable from the average 48-h field. In this office note, these results are presented in mapped form and should be useful in determining the local forecast bias of NMC's models.

3. RESULTS

A. Thermal Forecasts

Fig. 1 shows the average 1000-500 mb thicknesses for the 1987-88 cool season. Both the NGM and LFM warmed only slightly with time. However, due to a more realistic diurnal cycle, the NGM was cooler than the LFM at the 12- and 36-h projections from 0000 UTC. Fig. 2 gives the average 0- to 48-h temperature changes at the 1000-, 850-, 700-, and 500-mb levels in the models. Both the NGM and LFM appear to be very similar with only small changes in temperature at any of the levels. Figs. 3 and 4 show the 0- to 48-h change in 1000-500 mb thickness across the country for the NGM and LFM, respectively. Clearly, the NGM tended to warm with time in the eastern half of the country and tended to cool with time in the western half. In contrast, the LFM warmed most in the central part of the country and cooled most in the

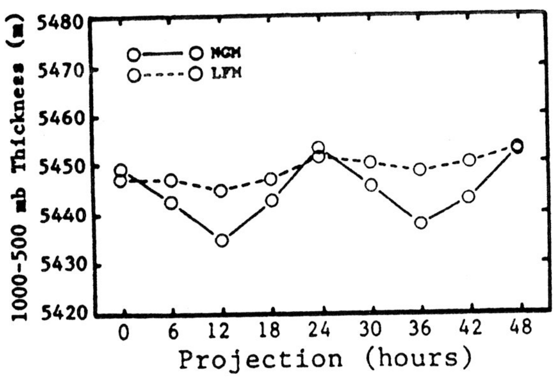

Figure 1. A comparison of the LFM and NGM average 1000-500 mb thickness forecasts.

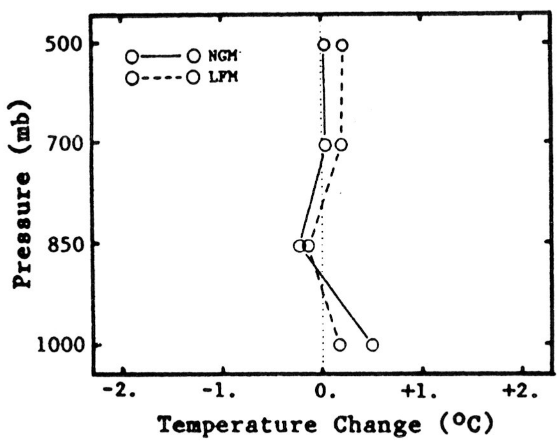

Figure 2. A comparison of the LFM and NGM average forecast 0- to 48-h temperature change.

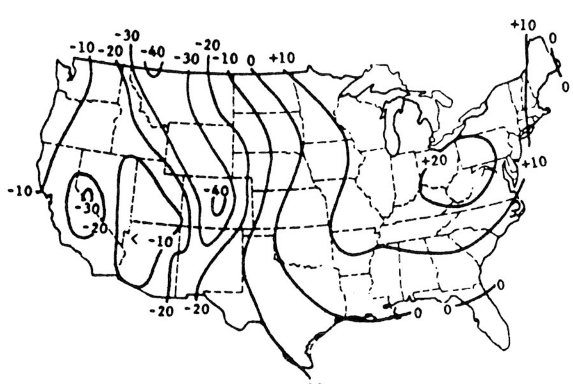

Figure 3. The average 0- to 48-h change (in meters) in the NGM 1000-500 mb thickness forecast.

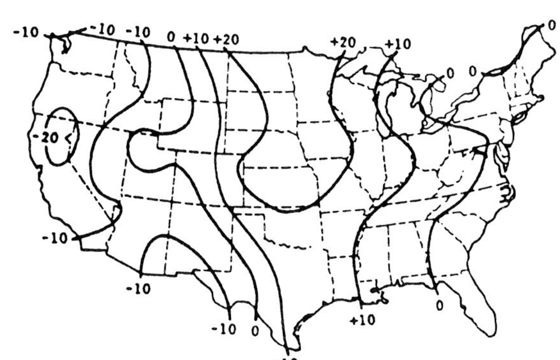

Figure 4. Same as Fig. 3 except that the results are for the LFM.

extreme western part. Along the eastern seaboard, temperatures also cooled slightly.

Fig. 5 gives the correlation between the observed surface temperature and forecasts of the 1000-850 mb thickness. Initially, both models' forecasts were about equally correlated with the observed temperatures. However, as the forecast projection increased, the NGM gradually had a higher correlation than the LFM.

B. Relative Humidity Forecasts

Before presenting results for the models' mean relative humidity forecasts, the differences between methods used to calculate this variable should be noted. For each model, the mean relative humidity is defined as an average for the layer between the model's surface and approximately 500 mb. For the LFM, this value is computed by determining the precipitable water and the saturated precipitable water for the surface to 500-mb layer. The precipitable water is then divided by the saturated precipitable water to obtain the mean relative humidity. Since the precipitable water tends to be greatest in the lower layers of the atmosphere, the method used to calculate mean relative humidity in the LFM tends to give the most weight to relative humidities near the surface. In contrast, the mean relative humidity in the NGM is determined by averaging the relative humidities for all model layers between the surface and approximately 500 mb. In the averaging, each layer is weighted only by the mass of the atmosphere the layer represents. Thus, the NGM's mean relative humidity is about equally influenced by all pressure levels between the surface and 500 mb.

Fig. 6 shows the average forecast values of mean relative humidity from the models. The LFM showed a very slight increase in mean relative humidity during the 48-h period. In contrast, the NGM, which was initially slightly drier than the LFM, had a gradual increase in mean relative humidity and was slightly more humid than the LFM at 48 hours. Fig. 7 gives the 0- to 48-h change in relative humidities at the 1000-, 850-, 700-, and 500-mb levels.

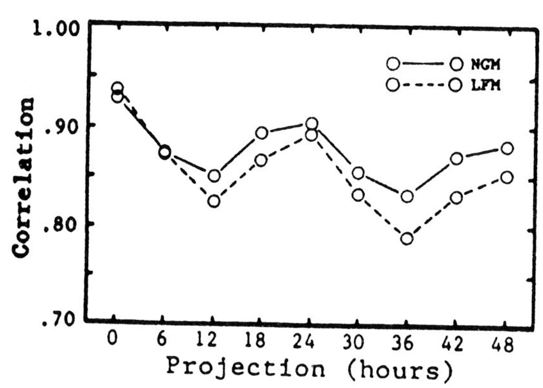

Figure 5. Correlation between the observed surface temperature and the forecast 1000-850 mb thicknesses.

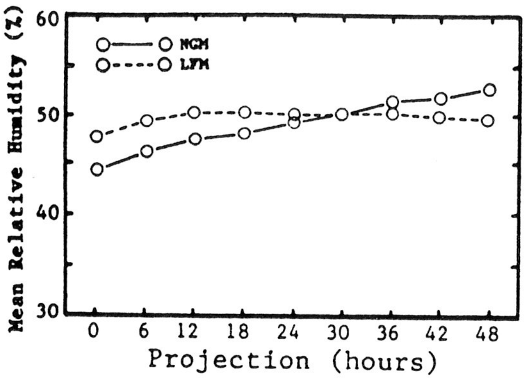

Figure 6. A comparison of the LFM and NGM average mean relative humidity forecasts.

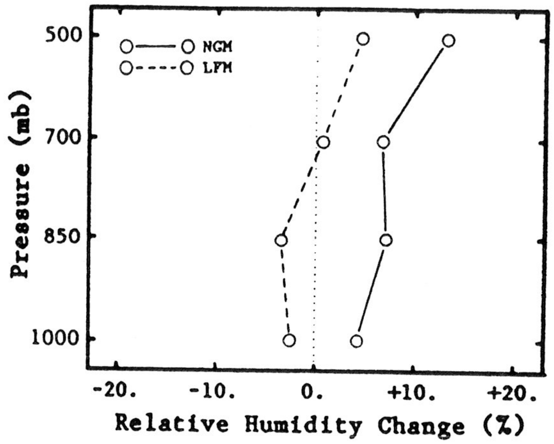

Figure 7. A comparison of the LFM and NGM average forecast 0-48 h relative humidity change.

The NGM's relative humidities increased at all four levels, most noticeably near 500 mb where the increase was more than 13%. The LFM's humidity decreased slightly at the 1000- and 850-mb levels and increased slightly at the 500-mb level. Figs. 8 and 9, respectively, show the NGM's and LFM's 0- to 48-h change in mean relative humidity across the country. The NGM's mean relative humidity increased over almost the entire country with the largest increases occurring in mountainous areas. The LFM's mean relative humidity also increased over much of the country, although the increases were generally less than those of the NGM.

Fig. 10 shows the correlation between the observed opaque cloud cover and the models' forecasts of mean relative humidity. The correlations for both models were similar throughout the 48-h forecast period.

C. Precipitation Forecasts

Fig. 11 is a comparison of the average 6-h precipitation amounts predicted by the models. The NGM was initially very dry, but gradually became wetter

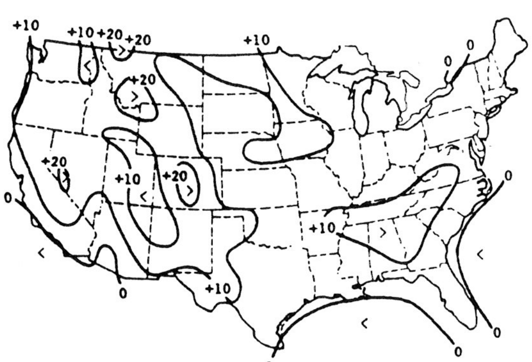

Figure 8. The average 0- to 48-h change (in %) in the NGM mean relative humidity forecast.

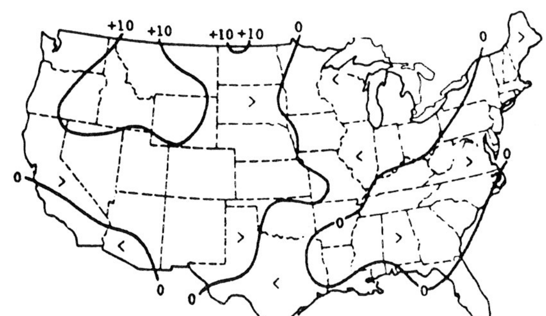

Figure 9. Same as Fig. 8 except that the results are for the LFM.

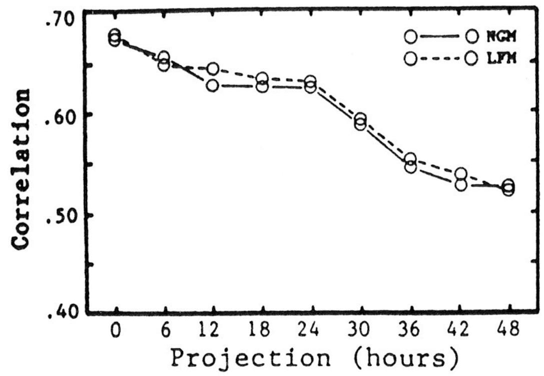

Figure 10. Correlation between the observed opaque cloud cover and the forecast mean relative humidity.

with increasing forecast projection. During the first 6 hours of the forecast period, the NGM predicted only about 40 percent of the total observed precipitation. In contrast, during the 42- to 48-h period, the NGM predicted about 98 percent of the observed precipitation. The LFM forecast only about 20 percent of the observed precipitation during the first 6 hours of the forecast period and then overforecast precipitation during all 6-h periods beyond 6 hours. During the periods between 18 and 42 hours, the LFM consistently forecast about 55 percent more precipitation than was actually observed.

Fig. 12 shows the correlation between the observed and forecast 6-h precipitation amounts from the NGM and LFM. The NGM forecasts were generally better correlated with the observed precipitation than were those from the LFM, especially during the first 6 hours of the forecast period. Note that the correlation between two continuous variables is not affected by bias. Hence, the NGM correlation during the first 6 hours was high, despite the tendency to greatly underforecast the total precipitation.

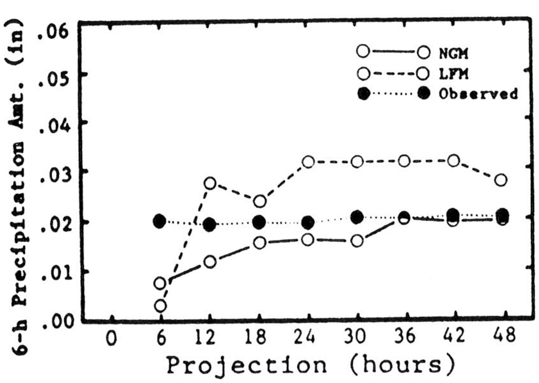

Figure 11. A comparison of the average observed and forecast 6-h precipitation amounts.

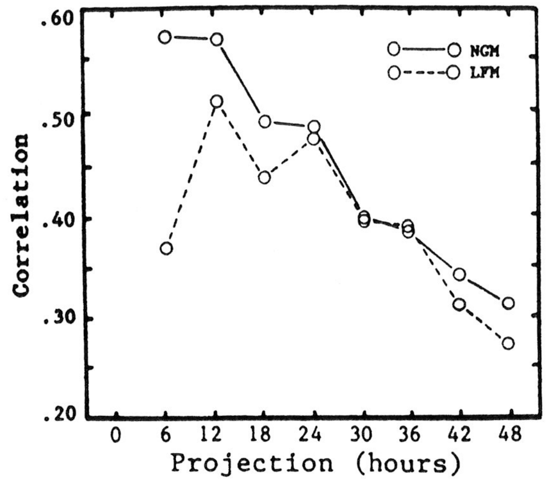

Figure 12. Correlation between the observed and forecast 6-h amounts.

Fig. 13 shows the total precipitation observed during the December 1987 to February 1988 period (Joint Agricultural Weather Facility, 1988). The largest total precipitation amounts occurred in western Washington and Oregon, northern California, the lower Mississippi Valley, northern New Hampshire to western Maine, extreme eastern North Carolina, and extreme eastern Massachusetts. Figs. 14 and 15 give the total precipitation predicted by the NGM and LFM, respectively, during the first 24 hours of their forecast periods. Note that the NGM total did not include forecasts for two days that were unavailable. On one of those days, significant precipitation occurred along the Gulf Coast. The LFM total did not include one day; however, no significant precipitation occurred on that day. The NGM clearly underforecast the amounts in areas of greatest precipitation. In comparison, the LFM 0-24 h forecasts did much better predicting the total winter precipitation. However, the LFM results show some significant biases over certain parts of the country. In particular, the LFM brought too much precipitation into eastern Washington and Oregon, western Montana, Idaho, and western Nevada. Also, the LFM underforecast the precipitation in southern Florida where convection is responsible for much of the rainfall. The generally good correspondence between the LFM predictions and the observed precipitation amounts, however, may have been somewhat fortuitous since each of the 6-h periods in the 0-24 h period had significant biases. For the LFM, the extreme dry bias during the first 6 hours was balanced by a wet bias during the period between 6 and 24 hours. In contrast, the dry bias in the first 24 hours of the NGM was the result of a dry bias in each of the 6-h periods between 0 and 24 hours.

Figs. 16 and 17 give the total precipitation predicted by the NGM and LFM, respectively, for the 24- to 48-h period. The NGM's forecasts were generally too dry in most areas of the country that received more than 12 inches of precipitation. Otherwise, the NGM's precipitation predictions matched the observed precipitation fairly well. In contrast, the LFM greatly overforecast the total precipitation over most of the country, except in southern Florida where convection caused most of the precipitation.

Fig. 18 gives a comparison of the observed and forecast frequencies of $\geq$ .01 inches of precipitation. Because we've combined the data for stations

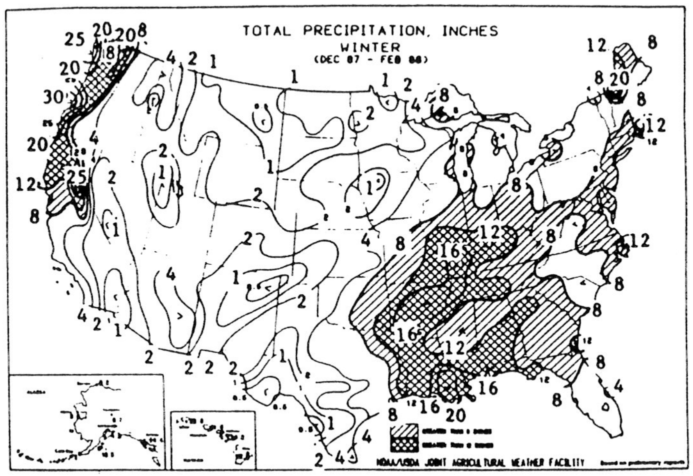

Figure 13. Observed precipitation amounts for the December 1, 1987 - February 29, 1988 period [modified from the Weekly Weather and Crop Bulletin (Joint Agricultural Weather Facility, 1988)].

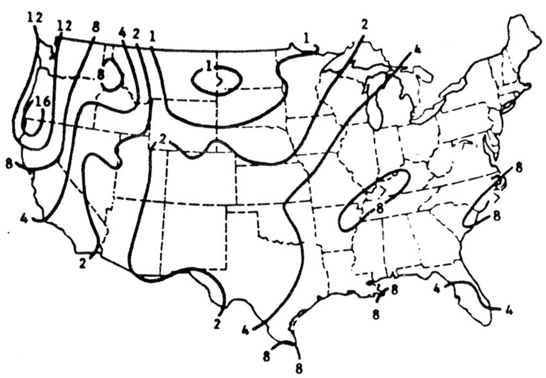

Figure 14. Total NGM 0-24 h precipitation amount (inches) forecast for the December 1, 1987 - February 29, 1988 period.

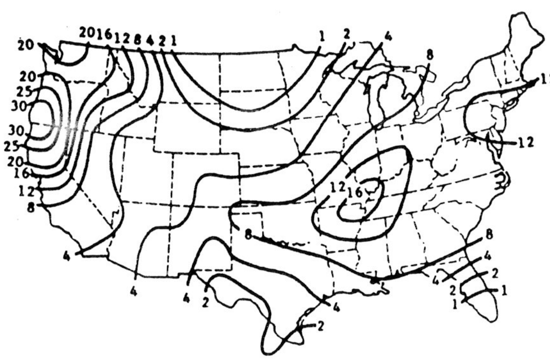

Figure 15. Same as Fig. 14 except that the results are for the LFM.

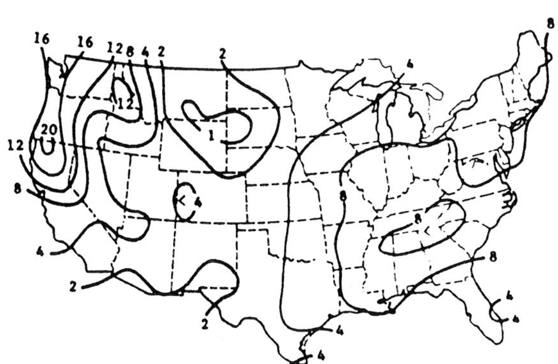

Figure 16. Total NGM 24-48 h precipitation amount (inches) forecast for the December 1, 1987 - February 29, 1988 period.

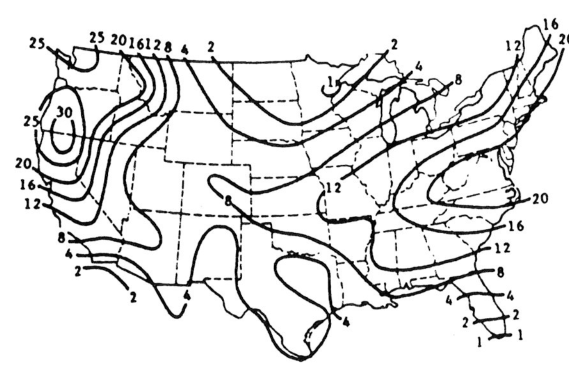

Figure 17. Same as Fig. 16 except that the results are for the LFM.

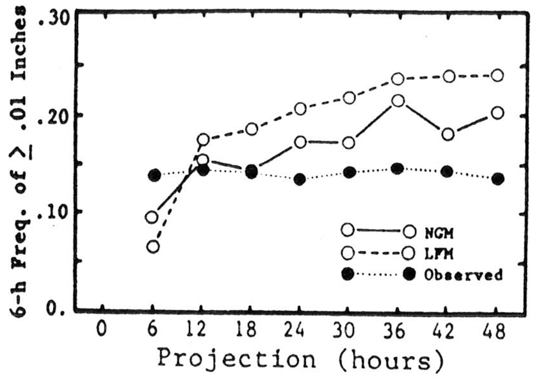

Figure 18. Comparison of the observed and forecast frequency of ≥ .01 inches of precipitation during 6-h periods

throughout the contiguous United States, this diagram can also be interpreted as a comparison of the average areal coverage of ≥ .01 inches of precipitation. Both the NGM and LFM underforecast the areal coverage of ≥ .01 inches of precipitation during the first 6 hours of the forecast period and overforecast the areal coverage beyond the 6-h projection. In general, the NGM had about half the bias of the LFM. Note the relative maxima in the NGM's precipitation that occurred during the 6-12 and 30-36 h periods. The combination of low temperatures and radiational cooling in the model during these periods may have caused precipitation to fall from a saturated boundary layer in an otherwise unsaturated model atmosphere. Note, however, that these maxima are considerably smaller than those seen during the 1986-87 cool season (Jensenius, 1988a). Fig. 19 gives the correlation between the observed and forecast occurrences of ≥ .01 inches of precipitation. The NGM forecasts of ≥ .01 were better correlated with the observed occurrences of ≥ .01 than were forecasts produced by the LFM.

Figs. 20 and 21 show a comparison of the observed and forecast frequencies of ≥ .10 and ≥ .25 inches of precipitation, respectively. For both amounts,

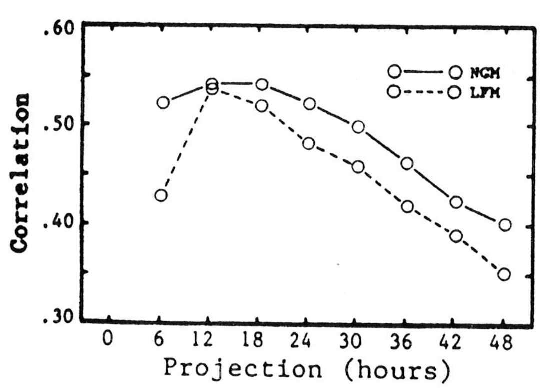

Figure 19. Correlation between the observed and forecast occurrences of ≥ .01 inches of precipitation during 6-h periods.

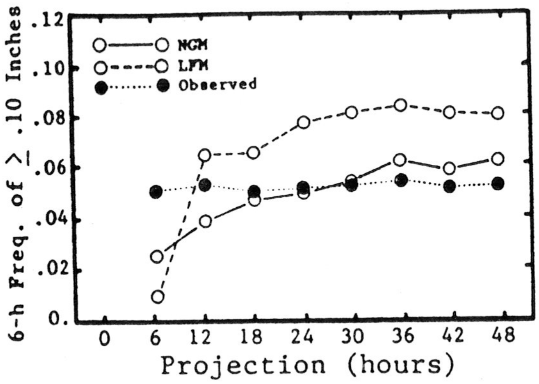

Figure 20. Same as Fig. 18 except that the results are for the observed and forecast frequency of ≥ .10 inches of precipitation.

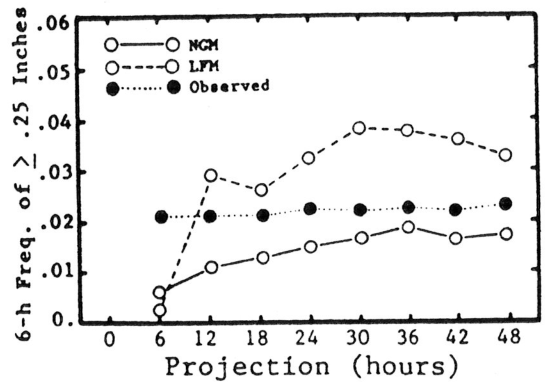

Figure 21. Same as Fig. 18 except that the results are for the observed and forecast frequency of ≥ .25 inches of precipitation.

the LFM underestimated the areal coverage during the first 6 hours and overforecast the areal coverage for periods beyond 6 hours. For the occurrence of ≥ .10 inches of precipitation, the NGM underforecast the frequency during the first 12 hours and overforecast the frequency beyond 30 hours. For the occurrence of ≥ .25 inches, the NGM underforecast the frequency throughout the entire 48-h forecast period. The correlation between the observed and forecast occurrences of ≥ .25 inches of precipitation is shown in Fig. 22. During the first 6 hours of the forecast period, the NGM was distinctly better than the LFM. However, beyond 30 hours, the LFM forecasts correlated better with the observed occurrence of ≥ .25 inches than did the forecasts from the NGM. Note that statistically the correlation between the observed and forecast occurrence of a binary event behaves similarly to a threat score between such forecasts and observations. To maximize either the threat score or correlation for a rare event, it is generally more advantageous to overforecast the number of occurrences of the event than to underforecast the number of occurrences. The NGM bias in underforecasting the number of occurrences of ≥ .25 inches of precipitation and the LFM bias in overforecasting the number of occurrences gave the LFM an advantage on the basis of correlation.

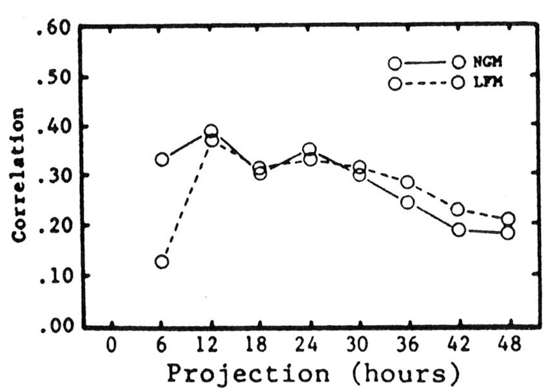

Figure 22. Same as Fig. 19 except that the results are for ≥ .25 inches of precipitation.

Figs. 23 and 24 compare the observed and forecast frequencies of ≥ .50 and ≥ 1.00 inches of precipitation, respectively. As before, the LFM was too dry during the first 6 hours of the forecast period. Beyond 6 hours, the LFM forecast too many occurrences of ≥ .50 inches and, on the average, about the right number of cases of ≥ 1.00 inches of precipitation. In contrast, the NGM underforecast the number of cases of ≥ .50 inches of precipitation and greatly underforecast the number of cases of ≥ 1.00 inches of precipitation.

The correlation between the observed and forecast occurrence of a certain precipitation amount is an indication of how well a particular model is forecasting the location of the event. However, as discussed earlier, the correlation between the observed and forecast occurrences of a rare event is somewhat affected by the forecast bias. To maximize the correlation, it is generally better to overforecast, rather than underforecast, the occurrence of the event. To obtain a better comparison between two sets of forecasts, both forecasts should have the same bias characteristics. To do this, we decided to normalize the precipitation amount forecasts from the NGM and the LFM so that each model forecast as many occurrences of an event as were observed. First, we determined the observed relative frequencies for a given amount of precipitation for each of the 6-h forecast periods. Then we found the model forecast amount (to the nearest hundredth) that was predicted with about the same frequency. Finally, we found the correlation between the observed occurrence of the selected amount and the forecast occurrence of the normalized amount. For example, the observed frequency of ≥ .50 inches of precipitation during the 6-12 h period was .0072. During the 6-12 h period, the forecast frequency of ≥ .64 inches of precipitation from the LFM was .0072 while the forecast frequency of ≥ .30 inches of precipitation from the NGM was .0072. In other words, there were about the same number of cases of LFM forecasts of ≥ .64, NGM forecasts of ≥ .30, and observed occurrences of ≥ .50. The correlation between the occurrences of these normalized amounts and the observed occurrence of ≥ .50 inches of precipitation was then determined. For the NGM normalized amount, the correlation was 0.28; for the LFM normalized amount, the correlation was 0.22. The correlation values for the raw model forecasts of ≥ .50 inches were 0.17 for the NGM and 0.25 for

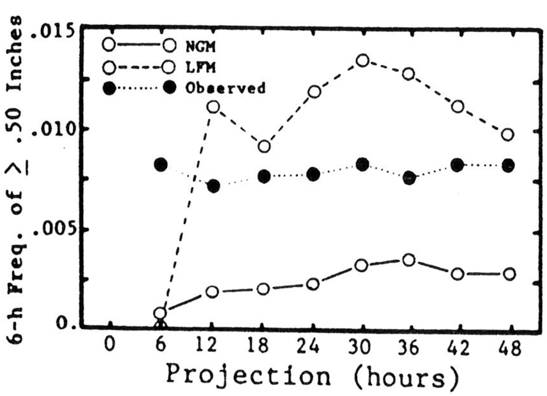

Figure 23. Same as Fig. 18 except that the results are for the observed and forecast frequency of ≥ .50 inches of precipitation.

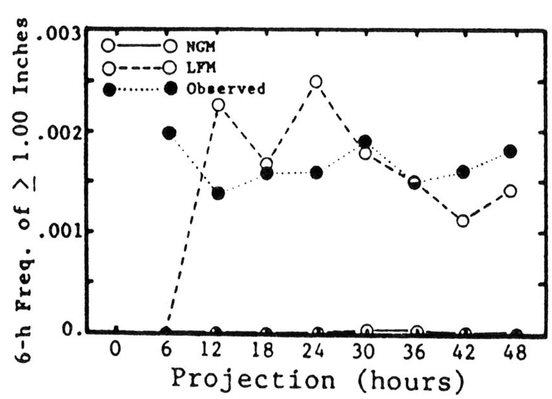

Figure 24. Same as Fig. 18 except that the results are for the observed and forecast frequency of ≥ 1.00 inches of precipitation.

the LFM. Clearly, the overforecasting bias helped the LFM's raw correlation scores and the underforecasting bias hurt the NGM's raw correlation scores.

Tables 1, 2, and 3 are normalization tables for the occurrences of ≥ .10, ≥ .25, and ≥ .50 inches of precipitation, respectively. For each amount and model projection, these tables contain the observed frequency, the normalized amount and associated frequency corresponding to the amount, and the correlation (r) between the observed occurrence of the amount and forecast occurrence of the normalized amount. These correlations are also shown in Figs. 25, 26, and 27 for ≥ .10, ≥ .25, and ≥ .50 inches of precipitation, respectively. For forecasting ≥ .10 and ≥ .25 inches of precipitation, the normalized NGM was slightly better than the LFM for most projections. For forecasting ≥ .50 inches of precipitation, the NGM is better than the LFM during the first 6 hours of the forecast period, with little overall difference between the models beyond the 6-h projection.

Table 1. Normalization table for the occurrence of ≥ .10 inches of precipitation.

Proj.	Observed Freq.	LFM			NGM		
		Freq.	Amt.	r	Freq.	Amt.	r
06	.0516	.0467	.02	.43	.0535	.04	.52
12	.0525	.0527	.14	.49	.0545	.07	.53
18	.0507	.0506	.14	.43	.0483	.09	.45
24	.0513	.0510	.17	.43	.0508	.10	.48
30	.0532	.0537	.18	.39	.0542	.10	.42
36	.0542	.0538	.18	.35	.0520	.12	.36
42	.0523	.0512	.18	.30	.0537	.11	.32
48	.0525	.0517	.17	.28	.0522	.12	.31

Table 2. Same as Table 1 except for the occurrence of ≥ .25 inches of precipitation.

Proj.	Observed Freq.	LFM			NGM		
		Freq.	Amt.	r	Freq.	Amt.	r
06	.0214	.0217	.05	.35	.0216	.11	.47
12	.0217	.0221	.32	.38	.0214	.16	.42
18	.0213	.0215	.30	.31	.0219	.18	.36
24	.0227	.0225	.34	.33	.0234	.19	.38
30	.0222	.0220	.38	.29	.0217	.21	.32
36	.0226	.0228	.36	.27	.0237	.22	.26
42	.0227	.0224	.35	.20	.0225	.21	.22
48	.0234	.0233	.32	.20	.0236	.21	.21

Table 3. Same as Table 1 except for the occurrence of ≥ .50 inches of precipitation.

Proj.	Observed Freq.	LFM			NGM		
		Freq.	Amt.	r	Freq.	Amt.	r
06	.0083	.0087	.10	.19	.0087	.20	.39
12	.0072	.0072	.64	.22	.0072	.30	.28
18	.0078	.0078	.54	.21	.0076	.32	.19
24	.0078	.0078	.64	.24	.0076	.35	.20
30	.0084	.0085	.61	.17	.0082	.35	.20
36	.0076	.0077	.63	.18	.0075	.37	.12
42	.0084	.0085	.56	.10	.0084	.34	.13
48	.0083	.0082	.54	.07	.0083	.34	.11

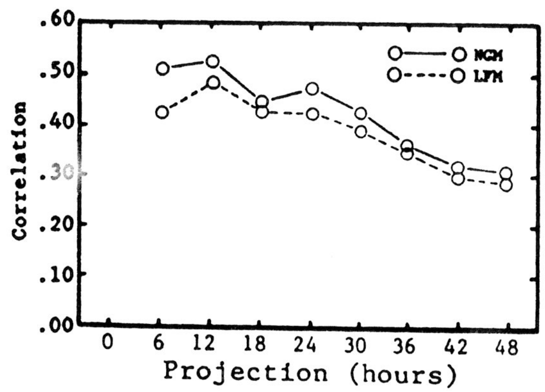

Figure 25. Correlation between the observed occurrence of ≥ .10 inches of precipitation and the forecast occurrence of an equivalent normalized amount.

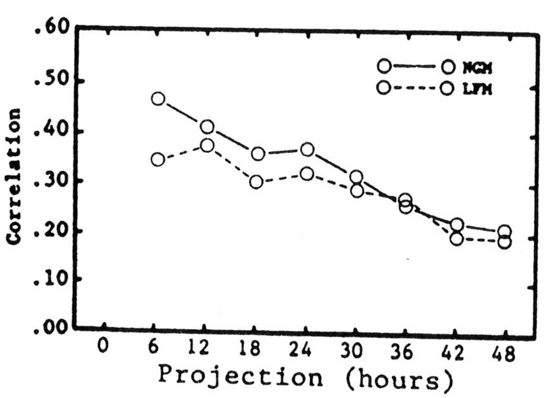

Figure 26. Same as Fig. 25 except that the results are for ≥ .25 inches of precipitation.

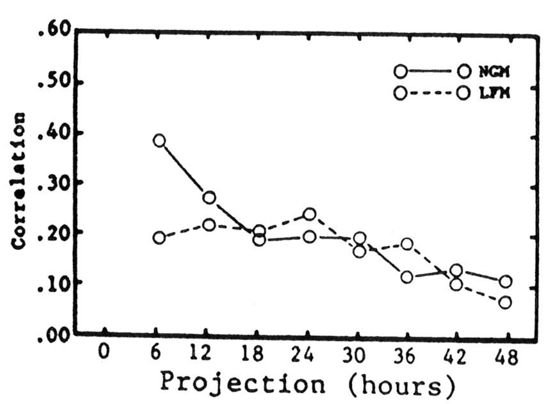

Figure 27. Same as Fig. 25 except that the results are for ≥ .50 inches of precipitation.

4. SUMMARY

Due to the hemispheric temperature correction scheme, the NGM produced relatively unbiased forecasts of temperature for the country as a whole. However, significant regional temperature biases were still present in the model. In particular, the NGM tended to warm with time in the eastern United States and to cool with time in the western United States. The NGM also had an overall increase of about 8% in the model's average mean relative humidity for the country as a whole, with the greatest increase occurring near 500 mb. The humidity increased most in the western United States where model temperatures were cooling. With regard to precipitation, the NGM produced too little precipitation during the first 30 hours of the forecast period. Beyond the first 18 hours, the areal coverage of the 0.01 inches contour was too large. The areal coverage of the large amount contours was too small throughout the entire forecast period.

The LFM also produced relatively unbiased forecasts for the country as a whole. However, the model warmed with time in the central United States and cooled with time in the western United States. There was little overall drift in the LFM relative humidity forecasts, although the model humidity increased somewhat over the western United States. With regard to precipitation, during the first 6 hours, the LFM predicted far too little precipitation, both in terms of amount and areal coverage. Beyond the 6-h projection, the model predicted too much precipitation, both in terms of areal coverage and amount.

On the average, the NGM forecasts appeared to be slightly better related to the observed weather than did the forecasts from the LFM. The differences between models in terms of correlation scores were generally small. Consequently, on a day-to-day basis, either model could provide the better guidance.

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