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USE OF LFM DATA IN PE-BASED MAX/MIN FORECAST EQUATIONS

J. Paul Dallavalle and Gordon A. Hammons

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I. INTRODUCTION

The National Weather Service (NWS) currently uses 3-month Model Output Statistics (MOS) equations (Hammons, Dallavalle, and Klein, 1976) twice daily to make objective forecasts of the calendar day maximum and minimum (max/min) temperatures at 228 stations in the conterminous United States. From 0000 GMT, the automated guidance is for today's max, tonight's min, tomorrow's max, and the min for the day after tomorrow. The 1200 GMT cycle is analagous, except that the first projection forecast is for a min, the second is for a max, and so forth. We developed these MOS linear regression equations from Primitive Equation (PE) model (Shuman and Hovermale, 1968) and Trajectory model (Reap, 1972) forecasts stratified into 3-month seasons. Station surface observations taken 6 hr after model time were also offered as potential predictors in the first two projections, while the first and second harmonics of the day of the year were used as climatic predictors in all four projections. Because of operational requirements we have backup equations for the first two projections that do not depend on surface observations.

To transmit the max/min forecasts to the field as soon as possible, we currently prepare an "early" teletype message (FOUS22 - see Technical Procedures Bulletin No. 150) that contains the objective temperature guidance based on PE-derived model output, the harmonic terms, and surface observations exclusive of the previous max or min. Later in the cycle, when 0600 GMT (1800 GMT) station observations are available, we produce a "final" FOUS22 which contains forecasts based on both model output and all available surface observations. The final guidance provides an update for the first two projections.

In the last several years, the NWS has increasingly emphasized the benefits of the Limited-Area Fine-Mesh (LFM) model (Howcroft, 1971). Since this model is run earlier in the operational environment than the PE, we decided to test LFM forecast fields as input to our PE-derived temperature forecast equations. This procedure was necessary because we do not as yet have enough LFM data to derive LFM-based max/min equations. This paper describes our experiments and gives our conclusion that we could use the LFM input in our early guidance forecasts despite some deterioration (particularly in the western United States) in skill.

II. EXPERIMENTAL DESIGN

The possible predictors contained in the MOS temperature equations are given in Table 1 of reference (a). To conduct our experiment, we simply substituted LFM fields for the corresponding PE fields in the operational equations. Since Trajectory model data were needed, we also ran a version of the Trajectory model off the LFM. This gave us LFM-based trajectory fields and meant that all model output fields were LFM-derived. We made two tests: from February 25 to March 16, 1976 and from April 1 to April 22, 1976 (Test I), and from April 28 to July 2, 1976 (Test II). During Test I, station surface observations were used as predictors, if required. In Test II, however, the actual operational environment was simulated by not allowing any surface observations as predictors. We then compared these Test II forecasts to guidance based solely on PE and Trajectory fields input to the PE-based equations.

III. RESULTS

The verification statistics are shown in Tables 1 and 2 for 126 stations in the United States. During Test I, the MOS equations using PE data had smaller mean absolute errors at all projections for the min and at the 36- and 48-hour projections for the max. The two systems were equal in mean absolute error for the 24- and 60-hour max although the correlation between the forecast and observed temperatures was larger for the PE-based forecasts. On a weighted average for all projections and both max and min, the PE-based forecasts were 0.11°F better in mean absolute error than those forecasts made by using LFM fields in the PE-derived equations.

During Test II, the PE-based forecasts had smaller mean absolute errors than the LFM-based forecasts at all projections for both the max and the min. In this case, the PE averaged 0.27°F mean absolute error better than the LFM forecasts. We also found that the final guidance based on both PE data and surface observations was 0.1°F better in mean absolute error than the early guidance for the 24- and 36-hour min and 0.2°F better for the 24- and 36-hour max. These figures corresponded reasonably well with our developmental data. Finally, there did not appear to be any distinct trend in the biases during either test period.

Table 3 is a distribution of the forecast errors for both tests. We have arbitrarily decided that an algebraic error of less than -10°F or greater than 9°F classified as a very poor forecast. During Test I, there was little difference in the number of cold bias ($T_{FCST} - T_{OBS} < -10°F$) forecasts between the PE- and LFM-based systems. However, for the min and, particularly, the max, the LFM data input to the PE-based temperature equations seemed to result in many more instances of warm bias ($T_{FCST} - T_{OBS} > 9°F$) than in the operational PE system. During Test II, the LFM-based forecasts occurred more frequently in the bias categories for both the max and the min, but they were still a relatively small percentage (approximately 5%) of the total forecasts made.

In addition to the overall summary, we verified the 126 stations by region (see Figure 1). In this way we attempted to determine whether there were any systematic geographical biases in the accuracy of the LFM temperature forecasts.

The input of LFM data to the PE-derived equations seemed to cause the greatest forecast deterioration in the Southwest. For Test I, the PE-based forecasts ranged from 0.1°F to 0.4°F mean absolute error better than the LFM-based forecasts for all projections and both max and min. During Test II, the differences between the two systems became larger, ranging from 0.2°F to 1.0°F. The PE-based forecasts were consistently superior.

In the Northwest, the MOS PE forecasts were also better than those based on the LFM, but the differences were smaller than those in the Southwest. This improvement with the PE was true for both the max and the min at all projections except the 48-hr min during Test I. The differences in mean absolute errors between the two systems were small for the min but ranged up to 0.5°F for the max.

The smallest deterioration occurred in the Northeast. Generally, the improvement with the PE-based forecasts did not exceed 0.1° or 0.2°F mean absolute error over the LFM forecasts. The only exception was that the 60-hr forecasts from the LFM were 0.3° to 0.4°F better than the PE-based forecasts during Test I.

Finally, in the Southeast, the comparative results show a small (0.1°-0.3°F) degradation of the MOS min forecasts when LFM data were used. For the max forecasts, the statistics were inconclusive; the superiority of one model over the other depended on both the projection and the test period. Hence, for forecasts of the maximum in the Southeast, the small differences in the two systems may be seasonally dependent.

IV. DISCUSSION

Generally, we felt that the improved timeliness of the early guidance, particularly in the eastern United States, compensates for the overall deterioration in the temperature forecasts (in our two samples combined, 0.21°F for all projections and both max and min). Thus, it was decided to produce the early temperature guidance (FOUS22) by using LFM forecast fields as input to the PE-based max/min equations. No surface observations will be used as predictors. When we make this operational change, hopefully during the summer of 1976, the early guidance should be available an hour or more sooner than at present. The final guidance will remain based on the PE and Trajectory models and station surface observations. The facsimile maps will contain the final guidance; however, if the final should fail, the backup fax chart will contain the early guidance based on LFM data.

From our limited verification, it appears that these LFM-based temperature forecasts are most reliable in the Northeast and least in the West--particularly the Southwest. At this point, we feel that forecasters in the West should be very careful about using the early guidance. We encourage the field forecasters to monitor this guidance closely because there will often be differences between the two systems at all four projections. In most cases these discrepancies will be small, but there may be occasions when they are quite large. With careful study, the forecasters may be able to determine synoptic situations when either the early or the final guidance is superior.

In addition, the above conclusions may well be seasonally dependent; this possibility gives the user even more reason to inspect these early forecasts closely. This type of early guidance is, of course, only an interim step until we have sufficient LFM data to derive LFM-based MOS temperature equations.

V. CONCLUSIONS

We have shown that, by using LFM forecasts in place of the corresponding PE forecasts as input to our current MOS temperature equations, we can produce acceptable early max/min guidance. At 126 U.S. stations for both max and min and for all projections, the LFM-based guidance averaged only 0.21°F mean absolute error worse than the PE-based guidance. Beginning in the late summer of 1976, we intend to produce the early FOUS22 teletype message based on LFM and LFM-derived Trajectory fields. This should make the guidance available an hour or so earlier than at present.

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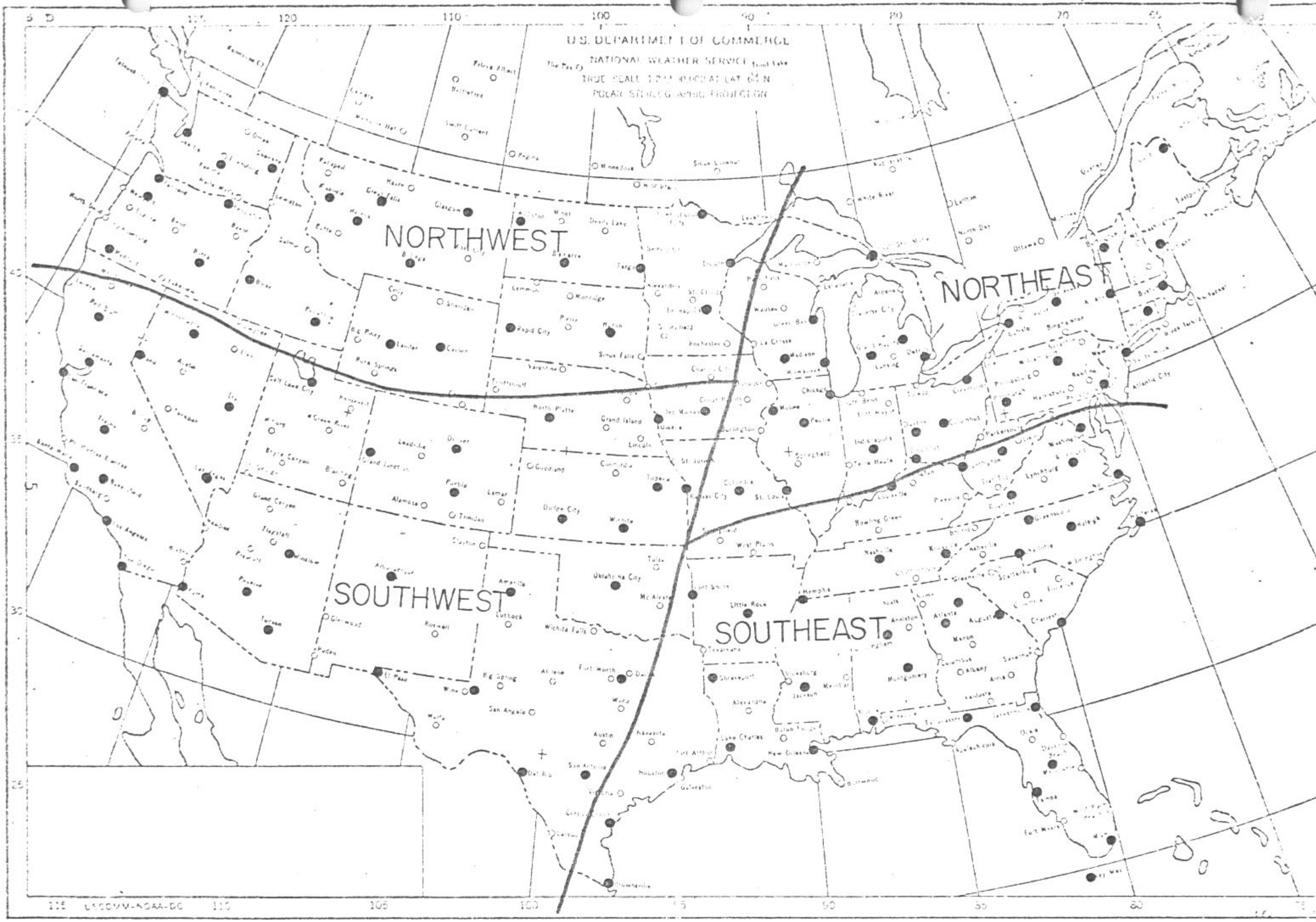

Figure 1. Four regions into which the United States was divided for verification purposes. MOS max/min temperature forecasts were verified for the 126 U.S. stations marked by dots.

Table 1. Verification statistics (Test I) for MOS max/min temperature forecasts at 126 stations in the conterminous United States. These test forecasts were made during the period February 25 to March 16, 1976 and from April 1 to April 16, 1976. The forecast equations were derived from PE model and Trajectory model data. PE refers to forecasts made by using PE data and PE-based Trajectory output in the PE-developed equations. LFM denotes forecasts made by using LFM data and LFM-based Trajectory forecasts as input to the PE-derived equations. Observations were used in the 24-hr and 36-hr projections, if required and available. The mean algebraic error is defined as Forecast Temp. minus Observed Temp.

Forecast	Mean Absolute Error (°F)		Mean Algebraic Error (°F)		Root Mean Square Error (°F)		Correlation of Fcst with Obs. Temp.		No. of Cases
	PE	LFM	PE	LFM	PE	LFM	PE	LFM	
24-hr Min	4.1	4.2	.1	-.4	5.3	5.5	.78	.77	3917
36-hr Min	4.2	4.3	-.2	-.1	5.4	5.6	.76	.76	4530
48-hr Min	4.7	4.8	-.2	-.2	6.1	6.2	.73	.72	3914
60-hr Min	4.9	5.1	-.2	.3	6.3	6.5	.69	.69	4520
24-hr Max	3.7	3.7	-.5	-.5	5.0	5.0	.85	.84	4515
36-hr Max	4.5	4.7	-1.1	-.9	5.9	6.2	.80	.79	3904
48-hr Max	4.6	4.8	-1.2	-.8	6.1	6.4	.78	.76	4515
60-hr Max	5.6	5.6	-1.6	-.5	7.3	7.3	.72	.69	3900

Table 2. Same as Table 1 except for Test II (April 28–July 2, 1976). No observations, however, were used in any of the projections. In the PE columns, the numbers in parentheses refer to the verification of the operational forecasts that may use surface observations as predictors in the first two projections.

Forecast	Mean Absolute Error (°F)		Mean Algebraic Error (°F)		Root Mean Square Error (°F)		Correlation of Fcst with Obs. Temp.		No. of Cases
	PE	LFM	PE	LFM	PE	LFM	PE	LFM	
24-hr Min	3.1 (3.0)	3.3	-.2 (-.2)	-.7	4.1 (4.1)	4.4	.78 (.78)	.76	6249
36-hr Min	3.3 (3.2)	3.4	.2 (.1)	.3	4.4 (4.3)	4.5	.76 (.77)	.75	6495
48-hr Min	3.4	3.7	-.1	-.2	4.5	4.8	.70	.70	6235
60-hr Min	3.7	4.0	.1	.5	4.8	5.2	.68	.66	6487
24-hr Max	3.2 (3.0)	3.5	-.5 (-.2)	-.6	4.3 (4.2)	4.7	.80 (.81)	.80	6491
36-hr Max	3.7 (3.5)	4.0	-.8 (-.8)	-1.1	4.8 (4.7)	5.4	.75 (.76)	.73	6241
48-hr Max	3.9	4.2	-.3	-.2	5.1	5.6	.71	.69	6494
60-hr Max	4.5	4.9	-.9	-.7	5.8	6.5	.63	.61	6114

Table 3. Error distribution of the temperature forecasts made for 126 stations in the United States during Test I (February 25-March 16, 1976 and April 1 to April 16, 1976) and Test II (April 28-July 2, 1976).

Category 1: $T_{FCST} - T_{OBS} < -10° F$;

Category 2: $-10^{o}F \leq T_{FCST} - T_{OBS} \leq 9^{o}F$

Category 3: $T_{FCST} - T_{OBS} > 9° F$

Test	Forecast	Model	Error Category		
			1	2	3
Test I	Minimum	PE	617	15505	759
		LFM	648	15400	833
	Maximum	PE	880	15259	695
		LFM	817	15160	857
	Min/Max	PE	1497	30764	1454
		LFM	1465	30560	1690
Test II	Minimum	PE	286	24767	413
		LFM	391	24472	603
	Maximum	PE	580	24019	741
		LFM	914	23557	869
	Min/Max	PE	866	48786	1154
		LFM	1305	48029	1472

Table 4. Mean Absolute errors (^{o}F) and correlations between forecast and observed temperatures for 4 regions (Figure 1) in the U.S. (Test I). The column headings are similar to those found in Table 1.

Region of U.S.	Forecast	Mean Abs. Error (°F)		Corr. of Fcst, Obs.		No. of Cases
		PE	LFM	PE	LFM	
Northwest	24-hr Min	4.6	4.8	.75	.74	767
	36-hr Min	4.6	4.6	.72	.71	887
	48-hr Min	5.4	5.3	.69	.66	768
	60-hr Min	5.0	5.2	.69	.65	888
	24-hr Max	3.8	3.9	.86	.85	885
	36-hr Max	4.7	4.9	.81	.79	766
	48-hr Max	5.1	5.4	.74	.69	885
	60-hr Max	5.9	6.4	.64	.58	766
Southwest	24-hr Min	3.8	4.0	.75	.72	1083
	36-hr Min	4.0	4.3	.69	.67	1251
	48-hr Min	4.3	4.6	.63	.62	1077
	60-hr Min	4.7	5.1	.58	.54	1242
	24-hr Max	3.9	4.0	.81	.82	1245
	36-hr Max	4.6	4.9	.78	.77	1075
	48-hr Max	4.8	5.2	.75	.72	1244
	60-hr Max	5.6	5.8	.71	.66	1072
Northeast	24-hr Min	4.4	4.4	.82	.82	923
	36-hr Min	4.3	4.6	.84	.85	1069
	48-hr Min	5.0	5.0	.80	.81	924
	60-hr Min	5.4	5.0	.75	.82	1068
	24-hr Max	4.3	4.3	.88	.88	1067
	36-hr Max	5.2	5.3	.84	.83	923
	48-hr Max	5.2	5.2	.83	.83	1067
	60-hr Max	6.4	6.1	.78	.76	922
Southeast	24-hr Min	3.7	3.9	.81	.80	1144
	36-hr Min	3.9	4.0	.81	.81	1323
	48-hr Min	4.4	4.4	.77	.77	1145
	60-hr Min	4.7	4.9	.74	.75	1322
	24-hr Max	2.9	2.9	.84	.83	1318
	36-hr Max	3.6	3.7	.78	.76	1140
	48-hr Max	3.8	3.7	.79	.81	1319
	60-hr Max	4.8	4.4	.74	.76	1140

Table 5. Same as Table 4 except for the Test II period. In the PE columns, the number in parentheses refers to verification of the operational forecasts that may use surface observations as predictors in the first two projections.

Region of U.S.	Forecast	Mean Abs. Error (°F) PE	Mean Abs. Error (°F) LFM	Corr. of Fcst, Obs. PE	Corr. of Fcst, Obs. LFM	No. of Cases
Northwest	24-hr Min	3.4 (3.4)	3.6	.77 (.74)	.77	1221
	36-hr Min	3.7 (3.7)	3.8	.71 (.71)	.73	1269
	48-hr Min	3.9	4.1	.66	.65	1220
	60-hr Min	4.1	4.5	.60	.57	1269
	24-hr Max	3.9 (3.6)	4.0	.86 (.86)	.85	1269
	36-hr Max	4.3 (4.2)	4.6	.80 (.79)	.78	1220
	48-hr Max	5.0	5.0	.70	.70	1270
	60-hr Max	5.7	6.2	.60	.59	1195
Southwest	24-hr Min	3.2 (3.1)	3.5	.75 (.74)	.71	1724
	36-hr Min	3.3 (3.2)	3.5	.73 (.74)	.71	1791
	48-hr Min	3.5	3.8	.70	.68	1716
	60-hr Min	3.6	4.0	.64	.61	1788
	24-hr Max	3.3 (3.0)	4.0	.83 (.83)	.82	1792
	36-hr Max	3.7 (3.5)	4.7	.79 (.81)	.78	1720
	48-hr Max	3.8	4.8	.76	.72	1794
	60-hr Max	4.7	5.3	.68	.67	1684
Northeast	24-hr Min	3.1 (3.1)	3.3	.86 (.83)	.83	1472
	36-hr Min	3.3 (3.3)	3.5	.83 (.83)	.81	1530
	48-hr Min	3.6	3.7	.80	.77	1467
	60-hr Min	4.0	4.1	.72	.73	1526
	24-hr Max	3.2 (3.2)	3.3	.85 (.84)	.85	1529
	36-hr Max	3.9 (3.8)	4.0	.77 (.77)	.75	1471
	48-hr Max	4.0	4.0	.75	.75	1529
	60-hr Max	4.6	4.8	.66	.68	1442
Southeast	24-hr Min	2.8 (2.6)	3.0	.76 (.78)	.74	1832
	36-hr Min	3.0 (2.9)	3.0	.77 (.78)	.76	1905
	48-hr Min	3.1	3.2	.72	.69	1832
	60-hr Min	3.2	3.5	.74	.70	1904
	24-hr Max	2.8 (2.6)	2.7	.70 (.72)	.71	1901
	36-hr Max	3.2 (3.0)	3.2	.65 (.66)	.62	1830
	48-hr Max	3.1	3.3	.65	.64	1901
	60-hr Max	3.4	3.8	.58	.53	1793