Performance of NMC in Forecasting a Record-Breaking Winter Storm, 6-7 February 1978

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Abstract

An intense winter storm deepened rapidly to maturity off the Mid-Atlantic coast and brought record amounts of snow to southeastern New England. The development, which was not the typical development of a Cape Hatteras storm into a "northeaster," was predicted 3½ days in advance by the National Meteorological Center's seven-layer primitive equation (7LPE) model. The NMC's limited area fine mesh (LFM) model consistently forecast details of the cyclogenesis 24 h ahead. The success of the models in forecasting the cyclogenesis resulted in excellent forecasts of precipitation amounts and heavy snow. The total performance of NMC was probably the very best possible with the current models.

1. Introduction

The record-breaking winter storm in the northeastern United States of 6–7 February 1978 first appeared at sea level as a weak extratropical cyclone off the South Carolina coast on the afternoon of 5 February (Fig. 1). At that time, the potential for a sneak storm existed as the low was not the typical Cape Hatteras low with an earlier track through the southeastern states. The low had formed deep in the cold air mass as the polar front lay west to east through the Bahamas and the arctic front was along the Appalachians (Fig. 2a). The low and several lows on the arctic front were associated with a 500 mb trough that extended from the Great Lakes to the Bahamas (Fig. 4a). In the trough a cold low was positioned over northern Lake Huron.

During the night and the following day (6 February) the 500 mb low plunged southeastward to the Virginia Capes and the sea level low concomitantly moved rapidly northward and deepened 28 mb to its minimum pressure of 984 mb (Fig. 1). Early on 6 February the sea level low had developed as a frontal wave (Fig. 2b) that occluded rapidly thereafter to maturity (Fig. 2c). Careful examination of the track of the surface low (Fig. 1) will reveal that the position for 1200 GMT, 6 February, is ~100 n mi west-northwest of the operational analysis (Fig. 2b). This was based on reanalysis of later data, and the possibility exists that the low was even closer to the coast.

Editor's note: Because this article discusses a group of operationally produced maps and charts, it was decided to retain the original units that are used operationally at NMC instead of converting to SI units ordinarily required in BULLETIN articles (see August 1974 BULLETIN). It is hoped that this will facilitate any comparisons that readers may want to make with their operational charts.

The intense storm decelerated greatly as the sea level center came under the 500 mb low (Fig. 1). The sea level center appears to have made a small complete loop to its left as it came under the low aloft. Thereafter, the sea level and 500 mb low centers moved east-northeastward together. The mature storm moved very slowly while south of New England on the night of 6–7 February and the sea level central pressure filled to 989 mb.

Strong winds and heavy snow accompanied this major storm development and the slow movement of the storm. On the morning of 7 February, winds in excess of hurricane force with peak wind gusts of 83 mph at Boston and 92 mph at Cape Cod were observed. One to three feet of snow fell from Delaware to Massachusetts. A total of 27 inches of snowfall was recorded at Providence and at Boston. The Boston amount was the greatest since the beginning of records in 1870. The

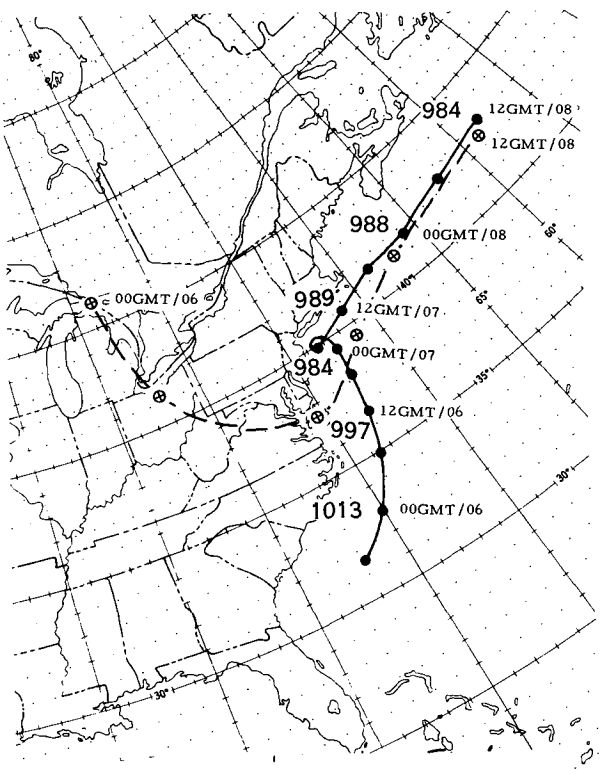

FIG. 1. Observed 500 mb low positions (circles) at 12 h intervals beginning 0000 GMT, 6 February 1978; observed sea level low positions (dots) at 6 h intervals beginning 1800 GMT, 5 February 1978; and observed central pressure (in millibars).

snow blown by the strong winds lowered visibility to near zero and produced blizzard conditions for much of New England. The gale force and greater easterly winds produced a strong storm surge, which resulted in serious coastal flooding and beach erosion in New Jersey and from Rhode Island to Maine. Troops from the U.S. Army and from the National Guard were sent to help find victims stranded in 9 ft drifts and to otherwise help in the recovery operations.

2. Short-range prognoses

a. Sample of the limited area fine mesh (LFM) prognoses

The current version of the National Meteorological Center's (NMC) LFM model (denoted as LFM2 on the figures) became operational on 31 August 1977. Its grid spacing is two-thirds that of the old LFM, which it replaced (Howcroft *et al.*, 1971). Prognoses from the new LFM valid throughout the 2-day storm period consistently predicted details of the development. The prognoses made from initial data for 1200 GMT, 5 February 1978, constitute a representative sample, as will be shown.

The sea level prognoses projected through 48 h are shown in Fig. 3, and the analyses for verification, in Fig. 2. The 12 h prognosis (Fig. 3a) did forecast the initial cyclogenesis off the South Carolina coast but the position was south of the observed on Fig. 2a. Although the forecast pressures were generally low in the eastern United States, except for the central value of the low, three isobars were forecast and observed between North Carolina and New England. The 24 h and 36 h prognoses (Figs. 3b and 3c) forecast both the northward movement of the sea level low and its intensification. Between 24 and 36 h the model forecast a steepening of the pressure gradient in New England. However, the predicted development lagged behind that of the atmosphere. The 36 h forecast low position was ~120 n mi south of the observed position on Fig. 2c and the forecast central pressure of 991 mb was 7 mb higher than observed. At 48 h the LFM no longer lagged behind as the forecast low position was ahead of the observed; i.e., the position on Fig. 3d was ~120 n mi east-northeast of the observed position on Fig. 2d. Over the entire northeastern United States the forecast sea level circulation closely resembled the observed.

The 500 mb prognoses extended through 48 h (Fig. 5) and successfully forecast the plunge of the cold low to eastern Virginia and the subsequent turn toward the east-northeast. The 36 h 500 mb low position in Virginia (Fig. 5c) was only 60 n mi west of the observed position on Fig. 4c. The predicted vorticity maximum of $>26 \times 10^{-5}\ s^{-1}$, although less than the observed value of $32 \times 10^{-5}\ s^{-1}$, did indicate a large increase for the 36 h period. The forecast 48 h low position (Fig. 5d) was within the limits of accuracy of the analysis (Fig. 4d).

The LFM forecasts for occurrence of measurable precipitation for 12 h periods (Fig. 7) were as successful as the circulation prognoses. Forecasts of both the break out of precipitation in the Mid-Atlantic states and the spread of precipitation into New England were timely. The 12–24 h area of forecast precipitation valid 1200 GMT, 6 February (Fig. 7b), indicates an increase in the Mid-Atlantic region from the 0–12 h forecast (Fig. 7a). However, the model was slow at this time in indicating the spread of precipitation into New England as observed (Fig. 6b) and as might be expected from the lag noted in the sea level prognoses. The northern limit of precipitation was accurately indicated by the 24–36 h forecast (Fig. 7c). At 48 h (Fig. 7d) and throughout the 2-day period the LFM forecast a premature ending of precipitation in the lee of the Great Lakes and on the western slopes of the Appalachians (Fig. 6d). The prognoses in the sample were not better than LFM prognoses made from different initial times. For example, the 48 h sea level prognoses valid at the same time (0000 GMT, 6 February; not shown) as the 12 h in the sample also forecast the new low formation off the South Carolina coast.

b. Consistency of LFM prognoses

LFM prognoses made from successive initial analyses and valid for the days of the storm were consistent throughout. Forecast positions of the sea level low from successive 24 h prognoses and the analyzed positions are plotted together in Fig. 8a. As can be seen, the difference between forecast and observed positions was ~90 n mi for all four forecasts. The directions of the differences changed with the evolution of the storm; while the storm intensified, the forecast position was south of the observed and when the storm matured, the forecast positions were east of the observed. Corresponding forecasts and analyzed positions of the 500 mb low are shown in Fig. 8b. The differences between forecast and observed positions were greater than at sea level and varied from 60 to 120 n mi. The 24 h forecast from the sample is the first forecast in Fig. 8 and valid for 1200 GMT, 6 February. Thus, the sample is representative of all four successive prognoses.

The consistency of the LFM series for the storm and also the little improvement that occurred with decreasing forecast projection are illustrated in Table 1. The sea level pressure at 45°N, 70°W, minus that at 41°N, 70°W, is a measure of the easterly flow. The forecast strength

TABLE 1. Sea level pressure (in millibars) at 45°N, 70°W, minus sea level pressure at 41°N, 70°W.

Valid Time	Observed	LFM Forecast 12 h	24 h	36 h	48 h
0000 GMT, 6 Feb.	2	4	NA	3	3
1200 GMT, 6 Feb.	10	8	11	NA	12
0000 GMT, 7 Feb.	29	24	24	23	NA
1200 GMT, 7 Feb.	16	21	18	14	13
0000 GMT, 8 Feb.	12	13	8	8	3

NA, not available.

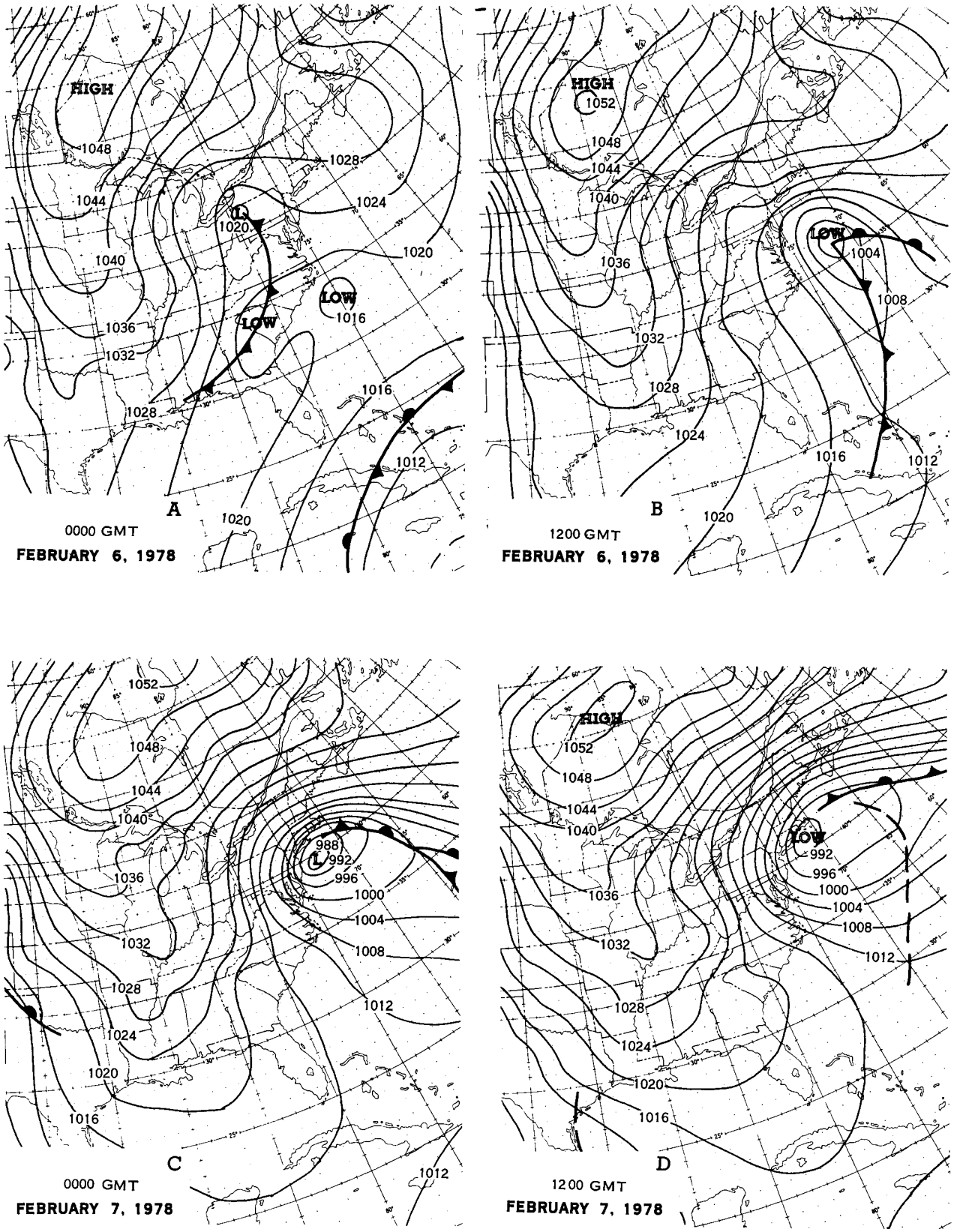

FIG. 2. Observed sea level isobars (in millibars) and fronts at 12 h intervals (a–d) beginning 0000 GMT, 6 February 1978.

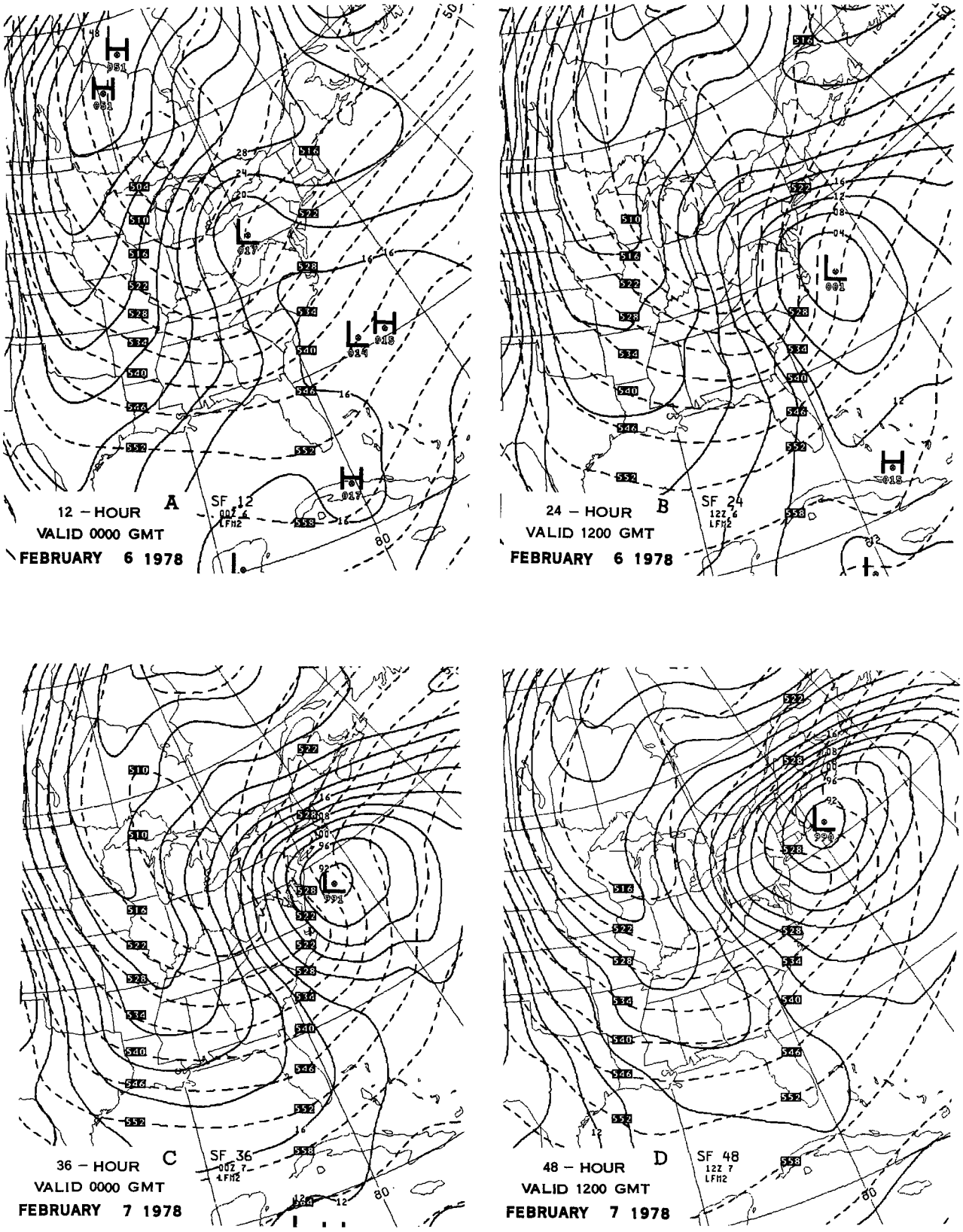

FIG. 3. LFM prognostic (from 1200 GMT, 5 February 1978) sea level isobars (in millibars) and 1000–500 mb thickness contours (in dekameters) at 12 h intervals (a–d). Verification charts in Fig. 2 are identified by corresponding letters.

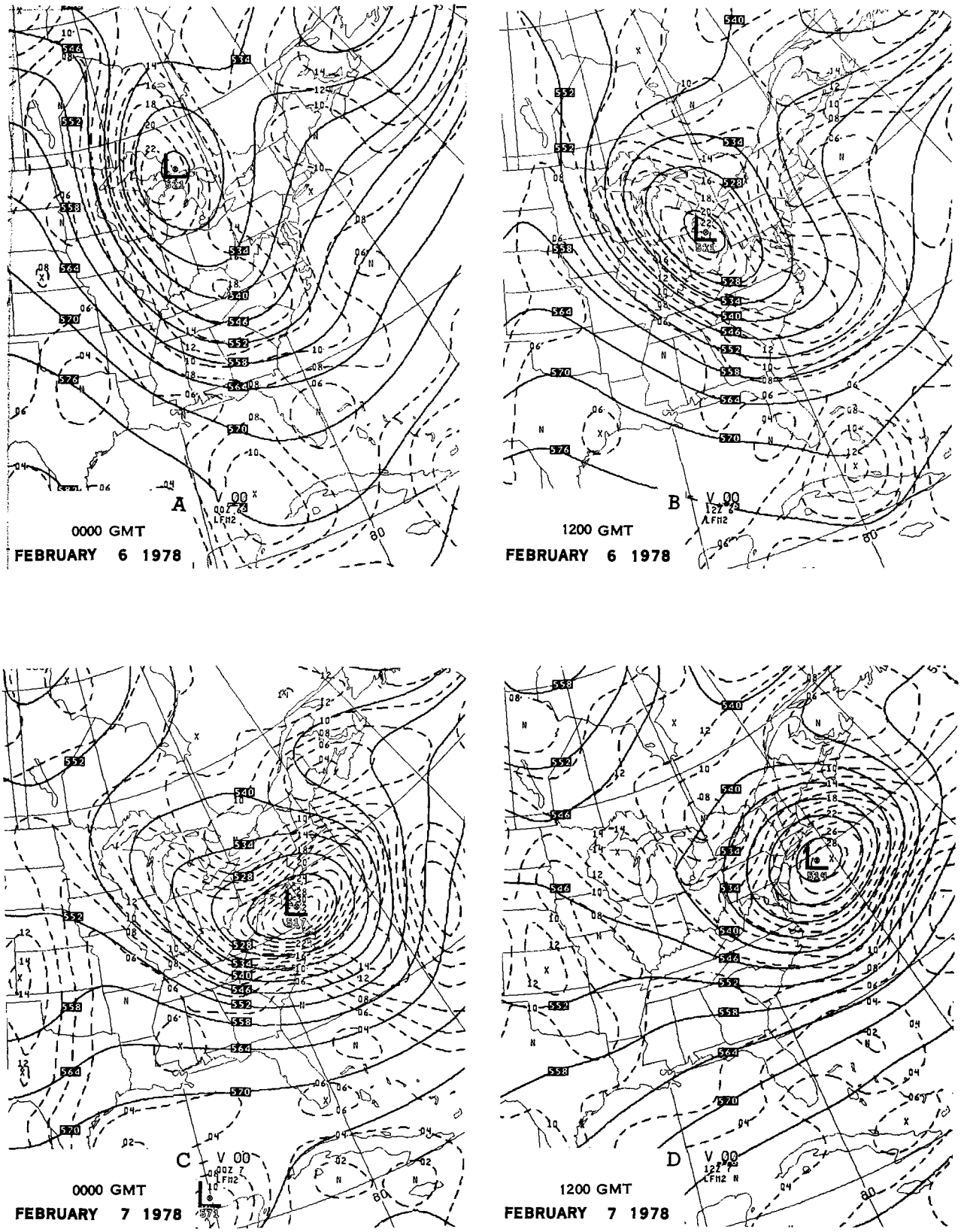

FIG. 4. Observed 500 mb contours (in dekameters) at 12 h intervals (a–d) beginning 0000 GMT, 6 February 1978, and vorticity (10^{-5} s^{-1}).

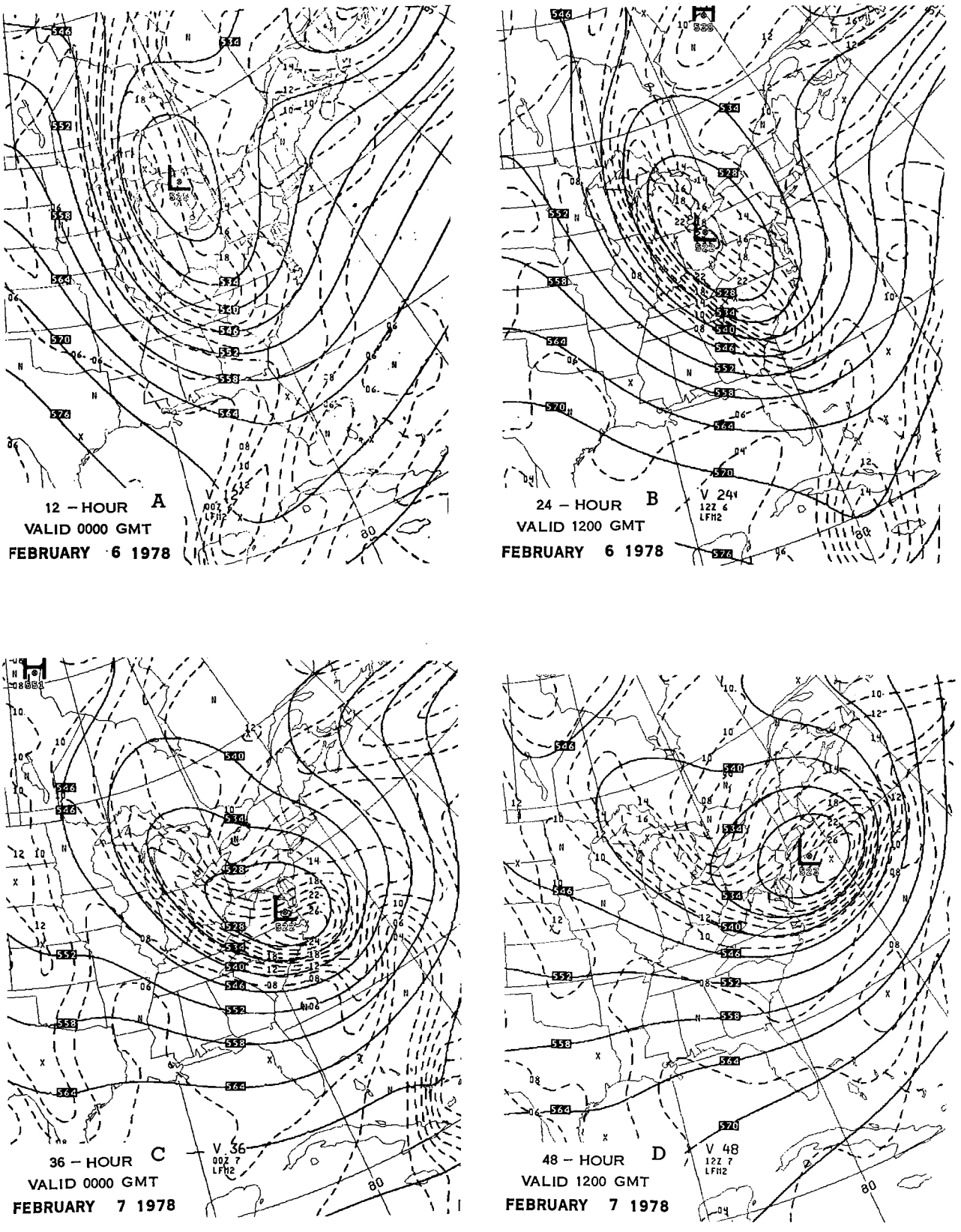

FIG. 5. LFM prognostic (from 1200 GMT, 5 February 1978) 500 mb contours (in dekameters) and vorticity (10^{-5} s^{-1}) at 12 h intervals (a–d). Verification charts in Fig. 4 are identified by corresponding letters.

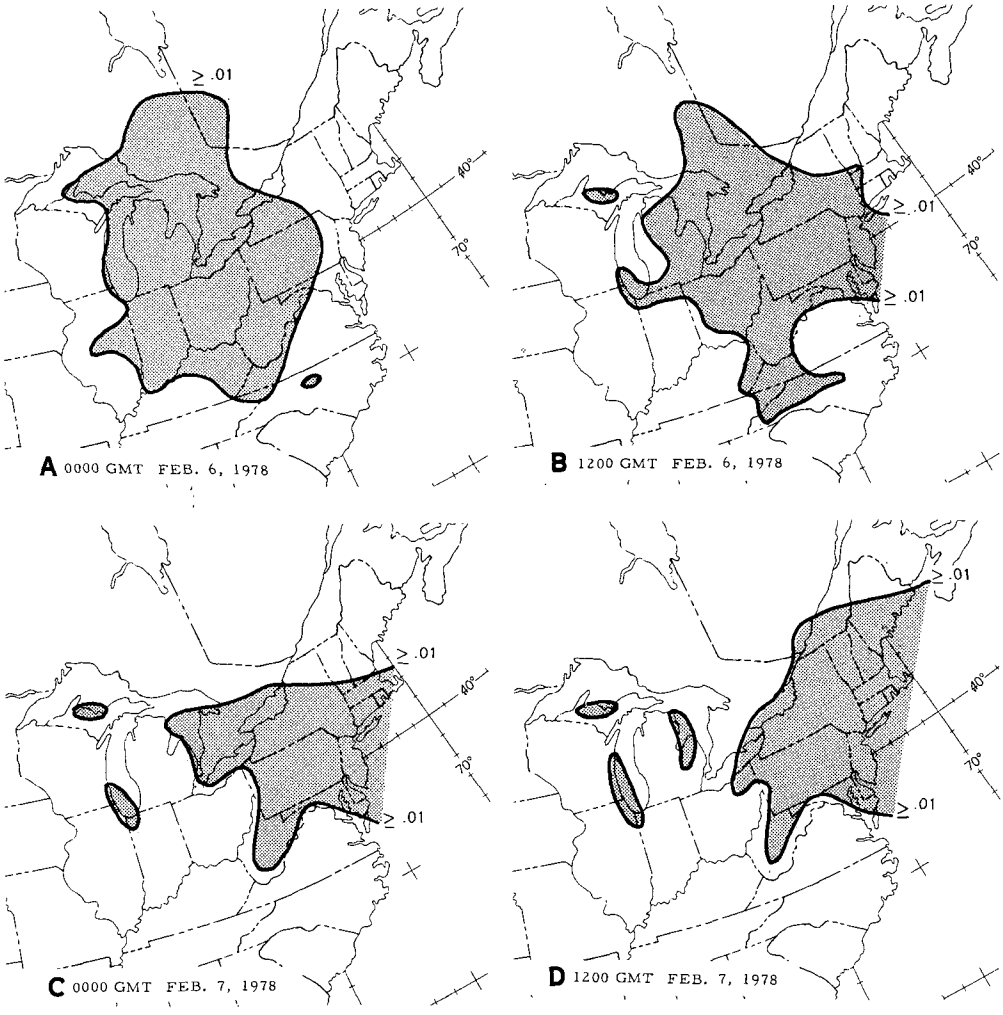

FIG. 6. Occurrence of measurable precipitation (≥0.01 inch) for 12 h periods at 12 h intervals (a–d).

of the easterly flow was important because of the coastal flooding that occurred as a result of the observed strong easterly winds. The sample LFM is the one with 12 h valid 0000 GMT, 6 February. The LFM made 12 h later with 24 h valid 0000 GMT, 7 February, had a difference of 24 mb, whereas, the 36 h for same valid time from the sample had a difference of 23 mb. The LFM never forecast the magnitude of the observed pressure difference of 29 mb. Thus, model output, extrapolated to the observational site at Boston, underestimated the strength of the easterly component of the boundary layer winds.

3. Extended-range prognoses

a. Seven-layer primitive equation (7LPE) model prognoses

The 7LPE, which became operational on 19 January 1978, is a version of the 6LPE (Shuman and Hovermale, 1968). The greatest difference between the two versions is that the current grid spacing is half of that in the replaced 6LPE.

The 7LPE made excellent 84 h prognoses valid during the 2-day storm period. Starting from the initial 500 mb analysis of 0000 GMT, 4 February (Fig. 9a), the model made the prognosis in Fig. 9b, which corresponds to the 500 mb analysis in Fig. 4d. Very large 84 h changes were successfully predicted. The elongated 500 mb low forecast in Ontario and New England developed from the weak short wave trough extending from south central Canada to northwestern Wyoming on the initial analysis.

The sea level prognosis also valid 1200 GMT, 7 February (Fig. 10a), was equally successful as can be seen by comparison with the analysis in Fig. 2d. The forecast low position was only 180 n mi east-northeast of the observed position and the central pressure error was 13 mb. The circulation forecast inland has many similarities with that observed. The 108 h sea level prognosis valid 1200 GMT, 8 February (not shown), was also excellent. It forecast the sea level low ~150 n mi northwest of the observed position shown in Fig. 1.

The 7LPE is the NMC hemispheric fine mesh model, which Brown and Younkin (1973, p. 535, §5) said, ". . . will eliminate the LFM's areal restrictions and is ex-

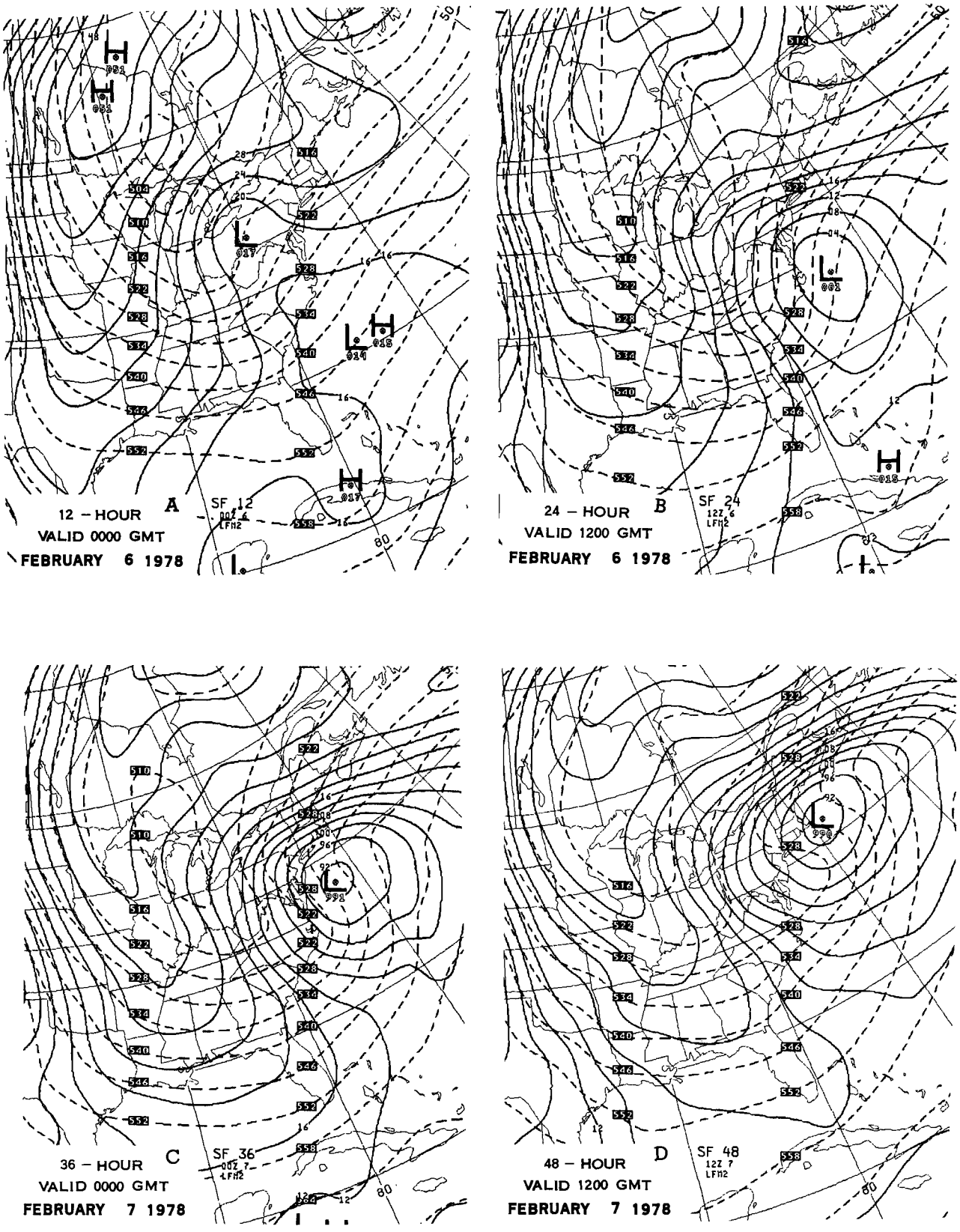

FIG. 3. LFM prognostic (from 1200 GMT, 5 February 1978) sea level isobars (in millibars) and 1000–500 mb thickness contours (in dekameters) at 12 h intervals (a–d). Verification charts in Fig. 2 are identified by corresponding letters.

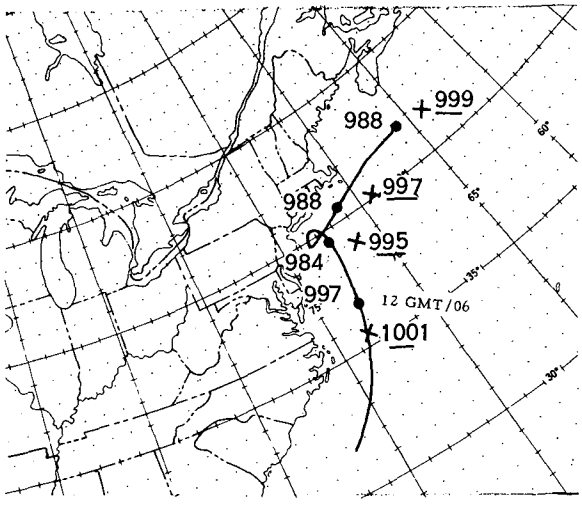

FIG. 8a. Observed sea level low positions (dots) at 6 h intervals beginning 1200 GMT, 6 February 1978, and observed central pressure (in millibars); corresponding 24 h LFM prognostic sea level low positions (crosses) and forecast central pressure (in millibars underlined).

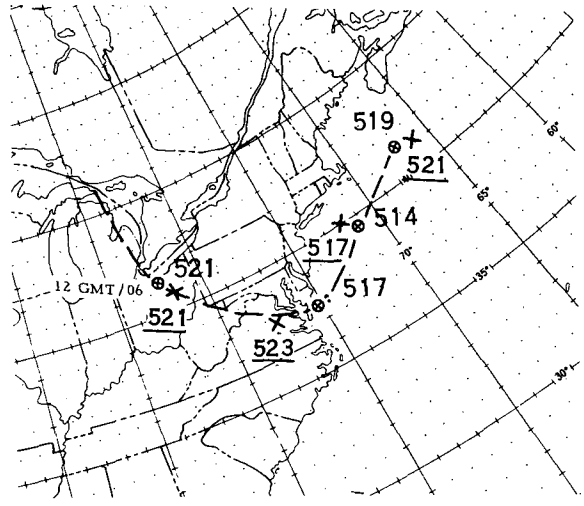

FIG. 8b. Observed 500 mb low positions (circles) at 12 h intervals beginning 1200 GMT, 6 February 1978, and observed central height (in dekameters); corresponding 24 h LFM prognostic 500 mb low positions (crosses) and forecast central height (in dekameters underlined).

pected to make prognoses beyond 24 h with the accuracy of the [1972] LFM." At least for this storm the expectation has been realized.

b. Manual prognoses

The 84 h, 500 mb prognoses were available to field forecasters, but the sea level prognoses were not because they are not regularly transmitted on facsimile. But the field did receive 72 h manual prognoses, which are modifications of the 7LPE 84 h; e.g., the 72 h (Fig. 10b) is a modification of the 84 h (Fig. 10a). The successful modifications decreased the magnitude of the position error by half and lowered the forecast central pressure by a minimum of 12 mb, so that the 72 h forecast central pressure was within the limits of accuracy of the analysis (Fig. 2d). The manual prognoses made a day earlier than the above example were not as spectacular but were good enough to enable the forecaster on 3 February to issue a prognostic discussion [1] that included the following statement: "Associated surface development near New Jersey shore in 60 hours should be rapid and strong enough to give moderate to heavy precipitation in the northeastern states."

4. Snowfall predictions

Three vital parameters combined to cause the total devastation wreaked by this storm. These are precipitation amount and type (here, snowfall), wind, and temperature. Of these, NMC's contribution for temperature is completely automated (MOS temperature guidance (Model Output Statistics)) for the first 60 h (Days 3–5 temperatures are subjective, however). For wind, NMC's contribution is in the form of predicted sea level circulation patterns (from which wind may be inferred) and the fully automated MOS surface wind guidance. In the case of snowfall guidance predictions, the NMC end product is a subjective issuance from the Quantitative Precipitation Branch (QPB) that is a judicious blend of the numerical model predictions, MOS products, and indications from latest data as well as the individual forecaster's expertise and knowledge. Virtually all of the information used by the QPB forecaster is available to the field forecaster.

a. QPB discussions

Daily at 1200 GMT the QPB forecaster prepares and releases over teletypewriter a technical discussion of amounts of precipitation and snow anticipated during the next 2 days—or longer, if appropriate! Well before the attack of this vicious storm, a couple of these discussions were especially pertinent. On Saturday morning, 4 February, ~48 h prior to the onset of the intense portion of the storm, the QPB, 1200 GMT, discussion read in part,

> Digging short wave southern Canada holds threat of major snowstorm for New England and possibly northern portions of mid-Atlantic states beginning Day 2 as cutoff upper low forms Great Lakes.[1]

On Sunday morning this scheduled discussion stated, also in part,

> Major surface development East Coast seems assured, however, location and timing uncertain. . . . This will be a slow moving system as upper trof forms a cutoff. Severe snowstorm likely New Jersey and eastern Pennsylvania northeastward through southern and central New England.[1]

[1] Original discussions are attachment 15 to National Weather Service report, "NMC's Prognoses and Precipitation Forecasts for the Winter Storm in Northeastern United States," February 6–8, 1978, unpublished.

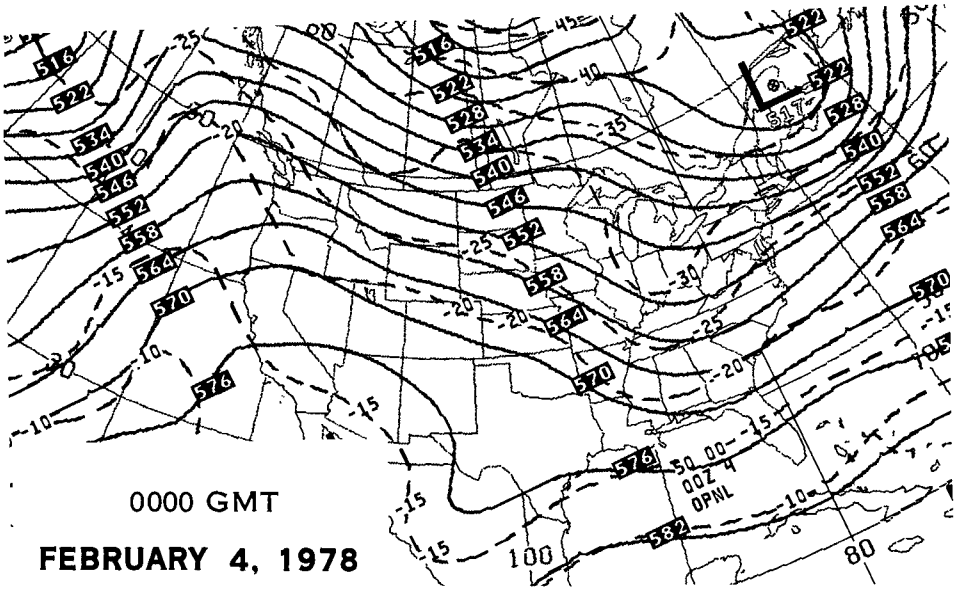

FIG. 9a. Observed 500 mb contours (in dekameters) and isotherms (in degrees Celsius), 0000 GMT, 4 February 1978.

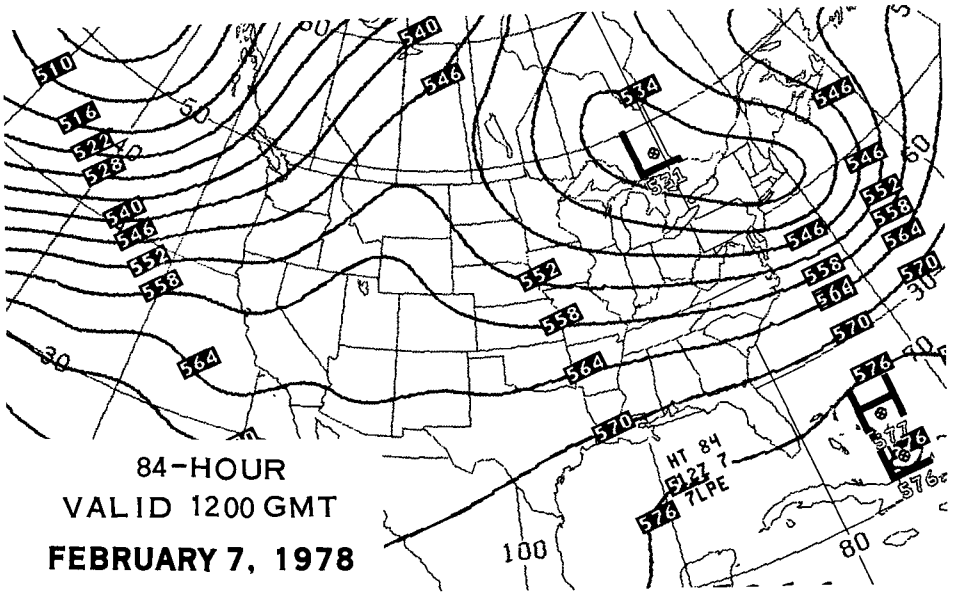

FIG. 9b. 7LPE, 84 h prognostic (from 0000 GMT, 4 February 1978) 500 mb contours (in dekameters). Verification chart is Fig. 4d.

The statement on uncertainty reflected nonavailability of the LFM from 0000 GMT, 5 February, and considerable delay of 7LPE from the same initial time due to computer difficulties, both of which are primary numerical guidance for this issuance.

b. 24 h quantitative precipitation forecasts (QPFs)

The 24 h QPFs issued by the QPB include an implied snowfall guidance forecast. During the cold season these isohyetal predictions include a dashed line delineating that portion of the QPF that is expected to be nearly all in frozen form. Daily at 1149 GMT, forecasts are issued covering a 48 h period in 24 h increments. These are appropriately termed "Day 1" and "Day 2" and are based on the 0000 GMT numerically predicted parameters, as well as other forms of data available up to an hour or so before issuance. Each afternoon at 1930 GMT an "Update" of the morning's Day 2 is issued but is now based on the 1200 GMT numerical calculations. Thus, for each 24 h period ending at 1200 GMT, three QPFs will have been made (Day 2, Update, Day 1, in order). The series of these forecasts for the 24 h period ending 1200 GMT, 6 and 7 February, are shown in Figs. 11 and 12. Since these are being discussed in terms of snowfall guidance only, the total storm snowfall (shown in Fig. 13) and snowfall in 12 h increments (Fig. 15 and Section 4.c) shall represent the verification.

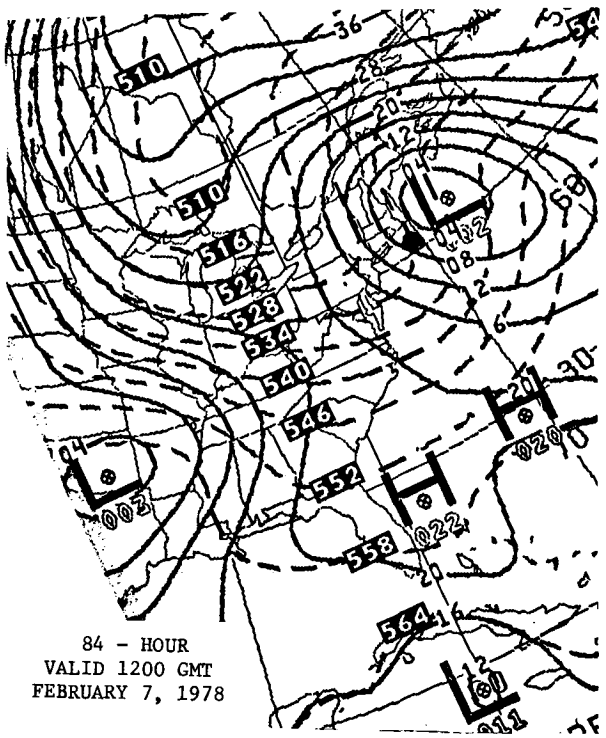

FIG. 10a. 7LPE, 84 h prognostic (from 0000 GMT, 4 February 1978) sea level isobars (in millibars) and 1000–500 mb thickness contours (in dekameters). Verification chart is Fig. 2d.

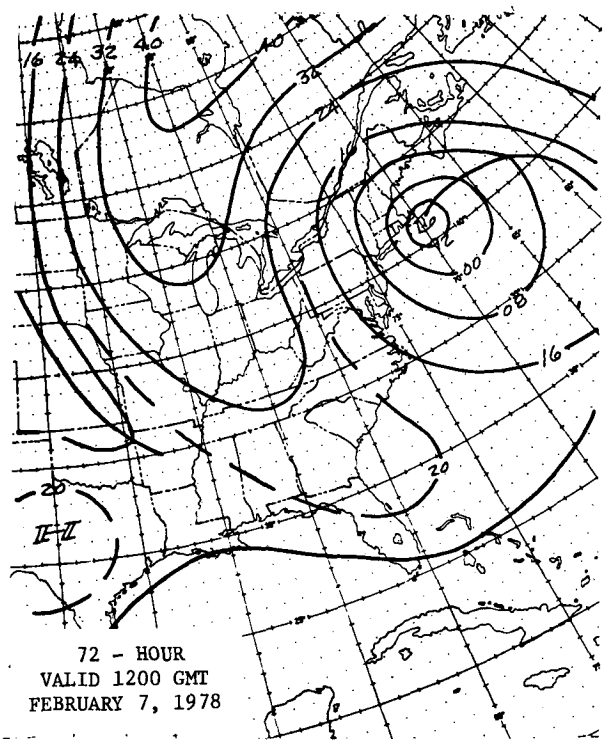

FIG. 10b. Manual 72 h prognostic (from 1200 GMT, 4 February 1978) sea level isobars (in millibars). Verification chart is Fig. 2d.

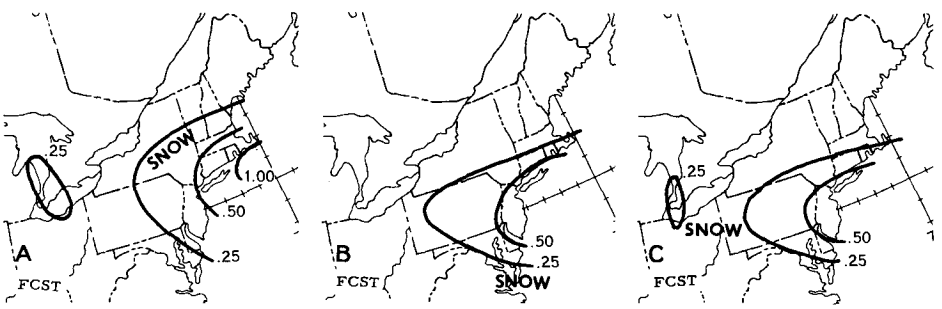

FIG. 11. Subjective QPFs (in inches) for the 24 h ending 1200 GMT, 6 February 1978: (a) Day 2, issued 1149 GMT, 4 February 1978; (b) Update, issued 1930 GMT, 4 February 1978; and (c) Day 1, issued 1149 GMT, 5 February 1978.

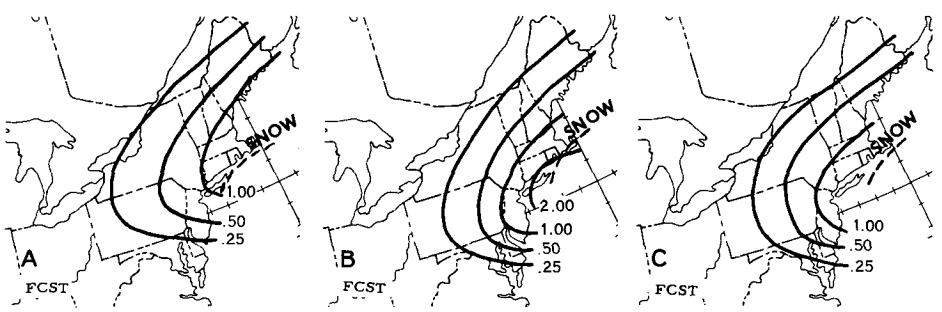

FIG. 12. Subjective QPFs (in inches) for the 24 h ending 1200 GMT, 7 February 1978: (a) Day 2, issued 1149 GMT, 5 February 1978; (b) Update, issued 1930 GMT, 5 February 1978; and (c) Day 1, issued 1149 GMT, 6 February 1978.

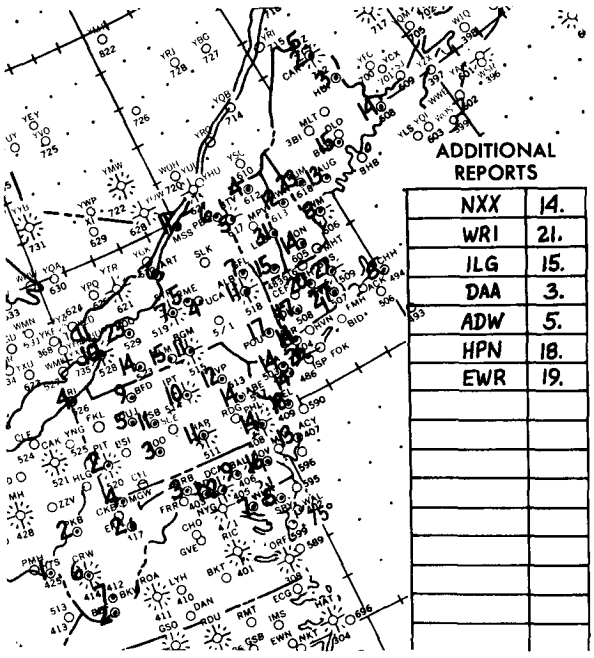

FIG. 13. Total observed snowfall in inches, 6–8 February 1978.

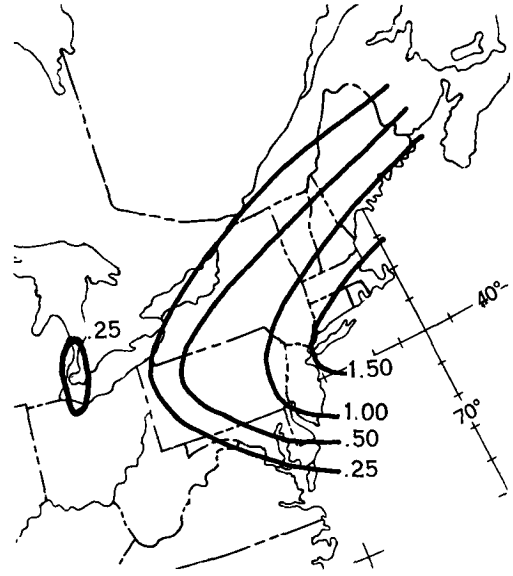

FIG. 14. The 48 h combined QPF (in inches) from 1200 GMT, 5 February, through 1200 GMT, 7 February and issued 1149 GMT, 5 February.

The 24 h forecasts ending 1200 GMT, 6 February, all erred on the side of premature development of the snowfall by several hours. However, Fig. 15a shows that 3 inches of snow had fallen over southeastern Pennsylvania and New Jersey, with some locations (not shown) reporting at least 5 inches by 1200 GMT. The snowfall was increasing rapidly and dramatically in intensity at this time; thus the forecasters erred slightly in timing, but not in the event itself! As guidance for Fig. 11a, the LFM and 7LPE from 0000 GMT, 4 February, were of minimal help, being much too slow with indications of developing precipitation. Due to computer difficulties, the 7LPE was not available as guidance for Fig. 11b, while the most the 24–48 h LFM could predict was 0.17 inch near Elmira, N.Y. (Note that the intense precipitation was occurring in southern New Jersey at the end of this period.) The LFM was unavailable as guidance for Fig. 11c due to computer difficulties, while the 7LPE indicated the development of very light precipitation only into western Pennsylvania and prognostic output had been completely processed by time of issuance.

Figs. 11c and 12a are forecasts issued at the same time and jointly cover the important 48 h period; they were the first predictions of precipitation amount that could be converted into important snowfall by application of a rain/snow conversion ratio. Up to this point, NMC's numerical models had certainly indicated the potential for an intense surface development as well as an intense 500 mb system. Although the numerical models had not explicitly indicated the precipitation potential of this storm, the QPB forecasters had injected this into the system and predicted a lot of snow. The man-machine mix worked quite well! Note that >1.00 inch was predicted in Fig. 12a and it was expected to be all snow. Fig. 14 is the sum of Figs. 11c and 12a and shows >1.50 inches of liquid equivalent predicted for much of southern New England! The LFM and 7LPE explicit precipitation prognoses used as guidance for Figs. 11a–11c and Fig. 12a have not been shown because they show very little precipitation or were not available.

Consideration of the very cold air, indicated by very low 1000–500 mb predicted thickness values (as low as 516–522 dam, see Fig. 3), as well as the initially very low surface temperatures over interior southern New England (daytime temperatures, Sunday, 6 February, were in the mid-teens) in conjunction with the subjective QPF of Fig. 14, led to some important implications regarding potential anticipated snowfall. A traditional snowfall to rainfall conversion ratio is 10:1. Over the northcentral United States, where the air is typically very cold during snowstorms, it is not at all uncommon to experience ratios >20:1. With the very cold air well entrenched over all of New England, it would probably thus not be overly unreasonable to expect a conversion >10:1. It might be pointed out that an assumed 15:1 ratio would imply ~23 inches along the 1.50-inch isohyet of Fig. 14, and higher amounts south of the 1.50-inch isohyet. This is admittedly a crude approximation. Examples of storm totals for three cities were:

	Rainfall	Snowfall	Ratio
Providence	1.37	27	19.7
Boston	2.86	27	9.4
Hartford	1.30	17	13.1

These observed ratios do indeed support the assumption of a ratio >10:1. Some of this precipitation fell

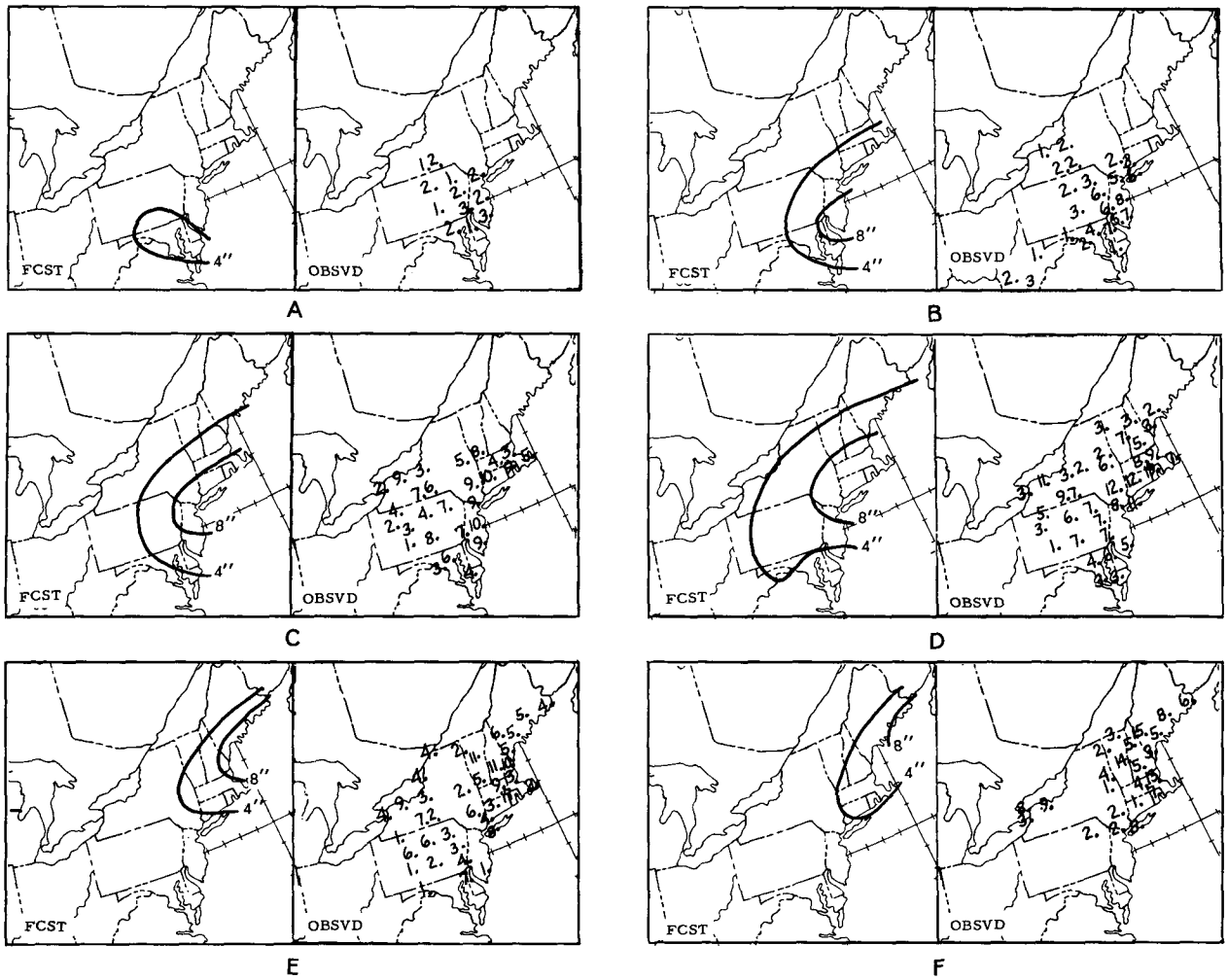

FIG. 15. 12 h heavy snowfall (in inches) forecasts and corresponding snowfall observations: (a) valid for the 12 h ending 1200 GMT, 6 February 1978; (b) valid for the 12 h ending 1800 GMT, 6 February 1978; (c) valid for the 12 h ending 0000 GMT, 7 February 1978; (d) valid for the 12 h ending 0600 GMT, 7 February 1978; (e) valid for the 12 h ending 1200 GMT, 7 February 1978; (f) valid for the 12 h ending 1800 GMT, 7 February 1978.

after 1200 GMT, 7 February. The subjective QPFs consistently showed an additional ¼–½ inch from eastern Massachusetts through southern Maine after this time. The forecasts shown in Figs. 12b and 12c are virtual reproductions of the explicit LFM and 7LPE precipitation forecasts. Figs. 7c and 7d contain LFM explicit precipitation guidance as guidance for Fig. 12b.

c. *Specific 12 h snowfall predictions*

These are issued via facsimile 4 times per day ~4–5 h prior to the start of the valid period and depict the QPB predicted snowfall amounts in increments of 4 inches per 12 h. The series of these 12 h forecasts issued during the major part of this storm are shown in Fig. 15(a–f) along with a representative sampling of the observed snowfall amounts during the corresponding 12 h periods. These figures largely speak for themselves. Perhaps the most important portion of these forecasts is not the extent of the 4-inch lines, but rather the location and timing of the 8-inch areas. Although we have stated that explicit LFM precipitation prognoses were of minimal help with the longer-range forecasts discussed earlier, it may be stated without further discussion that the LFM precipitation guidance was excellent (better than the 7LPE) as it related to the 12 h snowfall forecasts in Fig. 15(b–e) for southern New England. It did not, however, provide for sufficient northward spread of significant snowfall into Maine, a matter that was easily corrected subjectively (Fig. 15(d–f)). MOS heavy snow guidance, available this season for the first time, largely duplicated the LFM2 forecasts and does not contain any provision for forecasting amounts >4 inches.

d. *Verification of subjective forecasts*

There is little question that the statements in the NMC discussion were highly significant. The comparison of Figs. 13 and 14 has shown that the 24 h QPFs issued Sunday, 5 February, were quite good in indicating a

major snowstorm for southern New England. Some of the snowfall in Fig. 13 fell after 1200 GMT, 7 February, particularly in Maine. Subsequent forecasts maintained excellent continuity. None of the forecasts indicated the intensity or magnitude of the snow that occurred in western New York. The lines delineating the frozen precipitation areas on the 24 h QPFs are not verified formally; however, visual inspection indicates that for this storm they were very accurately placed.

Since inception of the heavy snow forecast program in the 1962–63 season, QPB can claim only a modest degree of success. Verification of 12 h, 4-inch forecast areas has been accomplished by measuring the forecast area (A_f), analyzing and measuring the observed area (A_o), and measuring the correct area (A_c) manually with a planimeter and converting the measurements into square degrees by appropriate map scale factors. These quantities may then be combined to calculate threat score ($A_c/(A_f + A_o - A_c)$) and postagreement (A_c/A_f). Seasonal averages of threat scores have a range of 13–22% with a postagreement range of 18–31%. During some storms, particularly those associated with deepening or occluding cyclones (Goree and Younkin, 1966; Browne and Younkin, 1970), QPB forecasts have been quite successful (see Brown and Younkin, 1973). During this storm, the following quantities (in square degrees) were measured: $A_f = 79.2$, $A_o = 77.3$, and $A_c = 54.8$. The threat score is calculated to be 53.9%, and the postagreement (percent correct) is 69.2%. As is readily seen, the bias (A_f/A_o) is very close to 1, the ideal.

Although 8 inches in 12 h occurs with some regularity, the areas are typically quite small. Errors in analysis, transposition, and measurement could have a more profound influence on the computed score for very small areas than they do when we are dealing with much larger ones, such as for 4 inches. Thus, although these areas are predicted, no areal verification of them is attempted. A subjective comparison of the 8-inch prediction to the observed 12 h amounts (Fig. 15(b–f)) shall have to suffice for verification. This shows excellent timing and coverage of the 8-inch area through the developing stage. As was stated earlier, the western New York maximums were not predicted. The forecasts were also somewhat deficient in early termination of the 8-inch area, as in Fig. 15e over central New England. These deficiencies are related to similar deficiencies in the numerical guidance in the latter stages of the storm.

5. Concluding remarks

1) The potential for a sneak storm for the northeastern United States existed on 5 February 1978 because the initial cyclogenesis was far off the coast and had had no history as a typical Cape Hatteras low.
2) The combination of NMC's LFM prognoses for short range, the 7LPE and manual prognoses for extended range, and manual modification of the models' precipitation forecasts resulted in field forecasters being warned 2½ days in advance and being guided consistently thereafter.
3) The numerical prognoses were consistent from successive initial analyses. The nonavailability of some of these products on 4 February had no adverse effect on NMC's total performance.
4) Forecasts from the short-range LFM were superior to those from the short-range 7LPE.
5) Although longer-range (36–60 h) explicit numerical QPFs were deficient, circulation prognoses were sufficient for preparation of timely and accurate subjective QPFs, which when converted to snowfall gave warning of a major snowstorm.

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