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THE IMPACT OF SENSIBLE AND LATENT HEATING ON THE PREDICTION OF AN INTENSE EXTRATROPICAL CYCLONE -- SOME EXPERIMENTS WITH THE NESTED GRID MODEL ON THE PRESIDENTS' DAY SNOWSTORM OF 18-19 FEBRUARY 1979

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1. Introduction

The attention of many meteorologists has been directed to the Presidents' Day snowstorm of 18-19 February 1979. Not only was the storm very severe, but also the National Meteorological Center's (NMC's) operational model, the Limited-area Fine-mesh Model (LFM), failed to forecast the storm adequately.

On 18-19 February 1979, an intense cyclone developed along the mid-Atlantic coast and produced heavy snowfall there. The storm brought up to 24 inches of snow from Virginia to southern New Jersey. Snowfall rates of 1 inch per hour were common. Rates up to 4 inches per hour in the Washington D.C. area were the heaviest in over 50 years.

Using mesoscale synoptic analysis, Bosart (1981) described the features and processes contributing to cyclone intensification and heavy snowfall. The upper-level divergence associated with an amplifying subtropical jet streak (STJ) played an important role in lowering the surface pressure and increasing the magnitude of low-level winds. Also, an intense low-level jet (LLJ) transported enough moisture into the region of heavy snowfall and the increased thermal advection associated with the LLJ contributed to the development of the thermal ridge and surface pressure falls along the East Coast. The development of the coastal front and large-scale thermal ridge was the important factor in establishing conditions favorable for rapid cyclogenesis and in moving the cyclone north-northeastward parallel to the coast. Therefore phasing was favorable for deepening with respect to the vigorous short-wave trough moving eastward through the Ohio River Valley.

Uccellini et.al. (1983) made some numerical simulations of this snowstorm with a mesoscale model containing 14 layers and a grid spacing of 52 km. They found that the high-resolution boundary layer of the model, combined with the significant-level radiosonde data, contributed to a better forecast. Additionally, both dynamic and thermodynamic processes were needed for the development of the coastal inverted trough and the LLJ, which significantly influenced the development of the snowstorm.

Nappi and Warner's (1983) experiments on a mesoscale model (15 layers, 60-km grid spacing) supported the above conclusions, and emphasized that the greatest improvement resulted from an increase in model vertical resolution associated with the use of a high-resolution planetary boundary-layer parameterization.

Because of the great scientific interest and extensive documentation, the Presidents' Day storm was selected as a case to evaluate the performance of the Nested Grid Model (NGM) and to provide insight into the importance of the parameterization of various physical processes in accurately forecasting precipitation for this significant weather event. The results are shown and discussed in this paper.

2. Numerical Model -- the NGM

The NGM has been running on a daily basis at NMC since June 1984, with formal operational status beginning on 27 March 1985. The model forecasts on a polar-stereographic hemispheric grid and several interior rectangular grids, each of successively smaller area and finer horizontal resolution (Phillips, 1979). The number of grids, vertical resolution, and horizontal resolution are flexible. At the time of this study a 12-layer, three-grid version was in use. The horizontal grid increment of the finest grid was about 98 km at 45N. In contrast, the currently operational version has 16 layers with a grid increment of 84 km at 45N.

A relatively simple formulation of the boundary layer was used. The boundary layer, defined as the bottom layer of the model, had a thickness of 0.075 in the sigma coordinate system. Turbulent exchange of momentum, heat, and moisture was permitted between model layers. Surface momentum fluxes over land and water were calculated by a bulk aerodynamic formulation, as were heat and moisture fluxes to and from the ocean. The routine NMC analysis of ocean temperature was used, with the saturated specific humidity at the ocean surface derived from that.

The method of Phillips (1981) was used to determine grid-scale precipitation with associated latent heating. In this method, the specific humidity q around a grid point is assumed to be evenly distributed between the limits given by

$$\bar{q}\ (1-\Delta) < q < \bar{q}\ (1+\Delta),$$

where $\bar{q}$ is the value of specific humidity at the grid point, and Δ is a experimental coefficient, which was 0.05 for these experiments. The percentage of the area with supersaturation around the grid point, therefore, can be shown to be

$$f = \frac{\bar{q}\ (1+\Delta) - q_s}{2\ \bar{q}\ \Delta} \quad .$$

Clearly, condensation occurs completely ($f = 1$) when $q_s = \bar{q}\ (1-\Delta)$, and no condensation occurs ($f = 0$) when $q_s = \bar{q}\ (1+\Delta)$. All condensed water vapor fell immediately to the ground; neither evaporation of falling drops nor cloud storage were included.

A modified Kuo (1965) formulation of organized cumulus convection was applied for moist convective adjustment. Cloud temperatures were calculated from the warmest equivalent potential temperature in the lowest four layers for each grid point. The convective condensate was allowed to fall subject to the condition that it evaporated until each layer through which it fell had reached about 90% relative humidity.

3. Numerical Experiments

After making the control NGM forecast with all the physical processes mentioned above, forecasts (without moist convective adjustment, without latent heat release, without fluxes of heat and moisture from the sea surface) were run to test the impact of the sensible and latent heating on the development of the snowstorm. Each forecast began from the same initial conditions of 12 GMT 18 February 1979 just before the storm intensified rapidly.

a. Experiment 1: Forecast with all physical processes

Both the movement and intensification of the cyclone and the quantity of precipitation were forecast very well by the NGM. Fig. 1 illustrates 24-h forecasts of mean-sea-level pressure and 12-h accumulated precipitation. The corresponding observations are shown in Fig. 2. The forecast position of the cyclone was coincident with the observations. The deepening of the cyclone was close to the observed situation, with the forecast central pressure (1010 mb) 4 mb higher than that observed. In addition, with respect to the intensifying cyclone, there was a warm tongue at 850 mb that extended northward along the East Coast (Fig. 3). Most of the precipitation associated with this cyclone occurred over the ocean. Over land the forecast and observed areas of precipitation greater than 0.5 inches agree closely.

b. Experiment 2: Forecast without moist convective adjustment

In terms of the mean-sea-level pressure field there was very little difference between this forecast and the control forecast containing moist convective adjustment, with the most obvious difference being in the precipitation fields. The precipitation difference field shown in Fig. 4 indicates that cutting off the moist convective adjustment actually increased the amount of precipitation most places. The result was not unexpected. A function of the parameterization of moist convective adjustment is to remove moist convective instability. Without the parameterization, convective instabilities are alleviated through grid-scale precipitation, which in general releases latent heat at lower levels in the vertical than the moist convective adjustment. This lower release of latent heat is more conducive to development of more intense, smaller-scale systems.

c. Experiment 3: Forecast without latent heat release

The forecast in this case (Fig. 5) was significantly different from Experiment 1. The center of the cyclone at the earth's surface and the corresponding trough at 700 mb were forecast to the west of the positions in Experiment 1 by several degrees longitude. Central pressure at mean sea level was 10 mb higher than observed. The thermal ridge at 850 mb was correspondingly much weaker, and the temperature at the cyclone center was colder by 7°.

Fig. 6 shows that the mean-sea-level pressure was over 12 mb lower just east of the observed storm center in Experiment 1 than Experiment 3. The region of this major difference coincided closely with the area of heavy precipitation in Experiment 1, as shown in Fig. 6. Certainly in this case latent heating feedback was important.

d. Experiment 4: Forecast without heat flux from the ocean

The impact of neglecting the flux of heat from the sea surface was small. The region of rainfall over the ocean, however, was enlarged, although the amounts in this new perimeter area were light. Excluding the surface heat flux resulted in cooler temperatures in the bottom model layers above the ocean, so that the saturation specific humidity was less. Because evaporation from the ocean continued here, saturation in the low levels was more likely than in a forecast with the heat flux.

e. Experiment 5: Forecast without moisture flux from the ocean

In comparison to the forecast with full model physics, precipitation was markedly reduced by excluding the moisture flux from the sea. Decreases up to about 1.5 inches in 12-h accumulated precipitation off the Carolina coast are indicated in Fig. 7. In addition, the movement and intensification of the cyclone were different from Experiment 1. In the current experiment the cyclone track was more to the west over land with a central pressure 3 mb shallower (at 1013 mb) 24 h into the forecast (Fig. 8).

4. Discussion

A number of conclusions can be drawn from this set of experiments for this one data case for this specific forecast model, the NGM. Foremost might be the importance of the relationship between the evaporation from the ocean and the release of latent heat. Evaporation provided the energy essential for the forecast model to intensify the storm significantly. The storm was much weaker in terms of circulation and precipitation without the evaporation. Although evaporation was a necessary condition for forecasting significant intensification, it was not sufficient. The latent energy had to be released through the precipitation mechanisms of the model to get deepening similar to what was observed in nature.

The experiments illustrated the role of the moist convective adjustment in stabilizing the model atmosphere. We have seen this in other data cases with the NGM, as well as in forecasts with the LFM (Deaven, personal communication). More precipitation is normally forecasted by the model for organized weather systems when the moist convective parameterization is not included, in which cases the grid-scale precipitation process must take over the moist convective stabilization function. It does so in a less efficient manner than the moist convective parameterization through the thermodynamics available in the primitive equations.

Several other observations can be made from this study. For this limited study the flux of sensible heat from the ocean surface was insignificant in the model's ability to forecast intensification of the Presidents' Day storm. Also, if the Nested Grid Model had been providing operational guidance in February 1979, field forecasters would have been well alerted to the possibility of a significant East Coast snowstorm -- the Presidents' Day storm.

5. Acknowledgments

This paper benefited significantly from the support and assistance of Ronald McPherson and Norman Phillips. Expert administrative support was provided by Mary Chapman.

6. References

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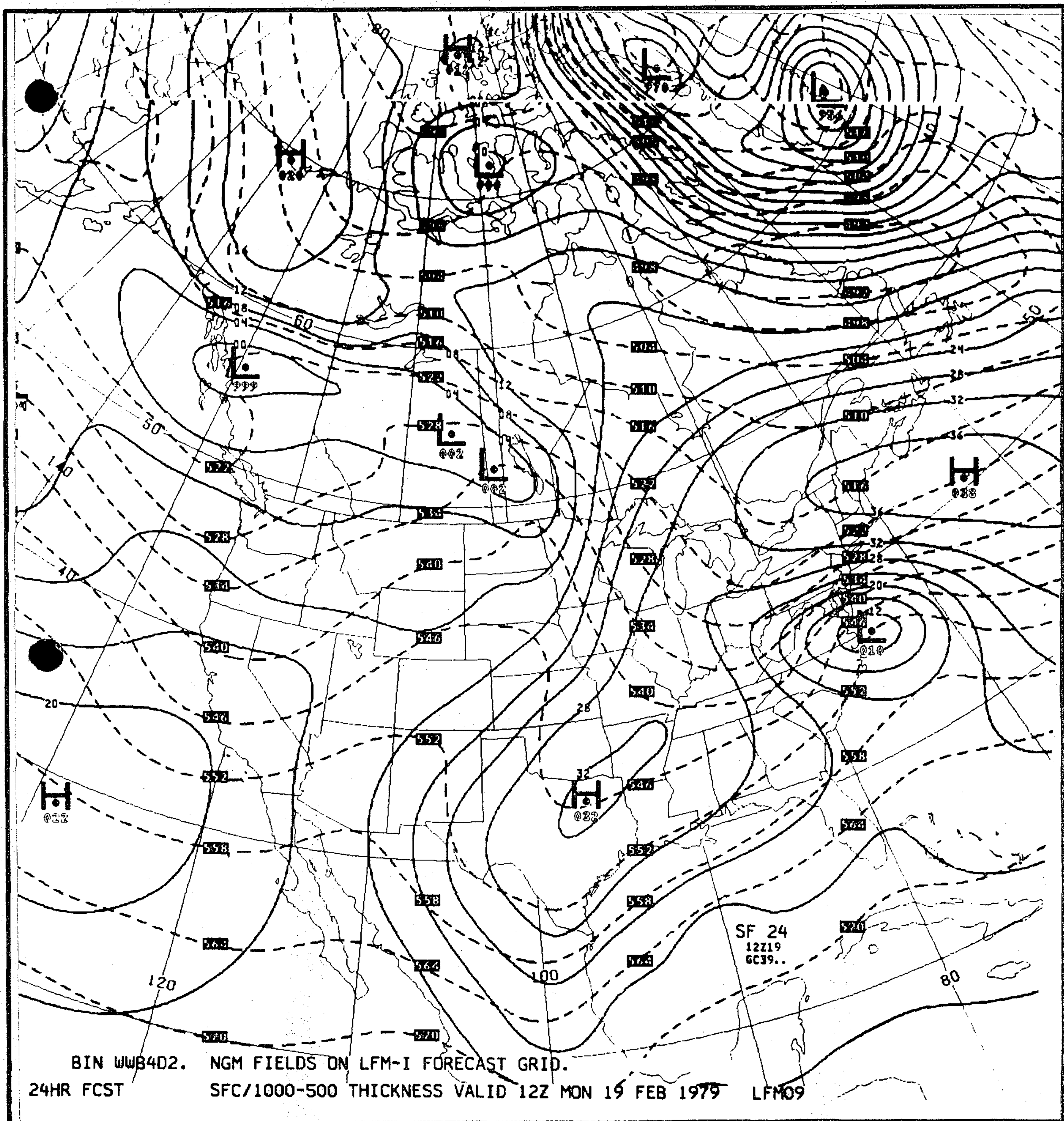

Fig. 1 (a) 24-h forecasts for Experiment 1 valid at 12 GMT 19 February 1979: mean-sea-level pressure (solid line; contour interval: 4 mb) and 1000/500-mb thickness (dashed line; units: dekameters; contour interval: 6 dekameters).

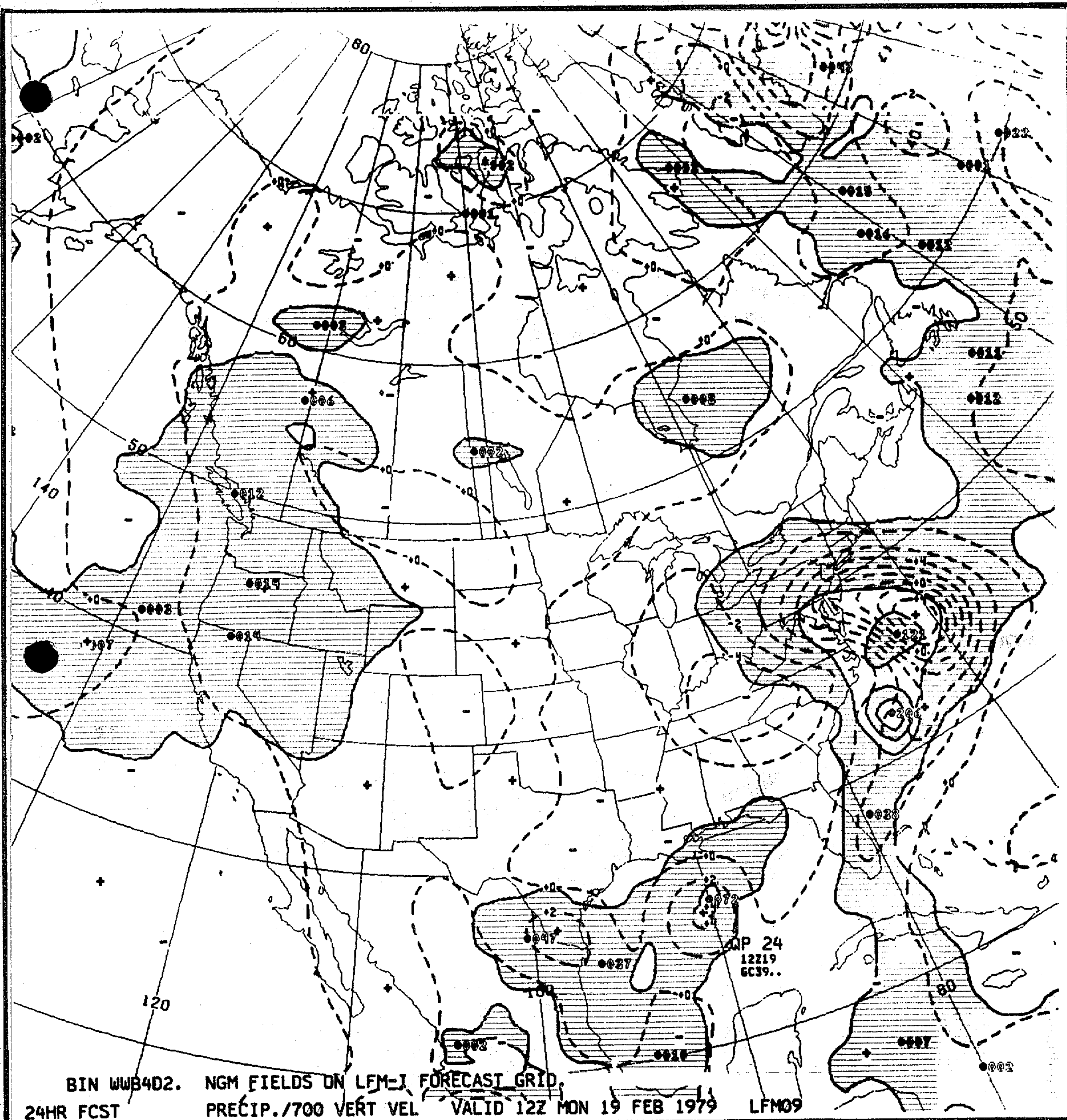

Fig. 1 (b) Accumulated precipitation from 12-24 h (solid line; units: 0.01 in; contour interval: 0.50 in) and vertical velocity (dashed line; contour interval: $2x10^{-3}$ mb/s, positive for upward motion) for Experiment 1 ending at 12 GMT 19 February 1979.

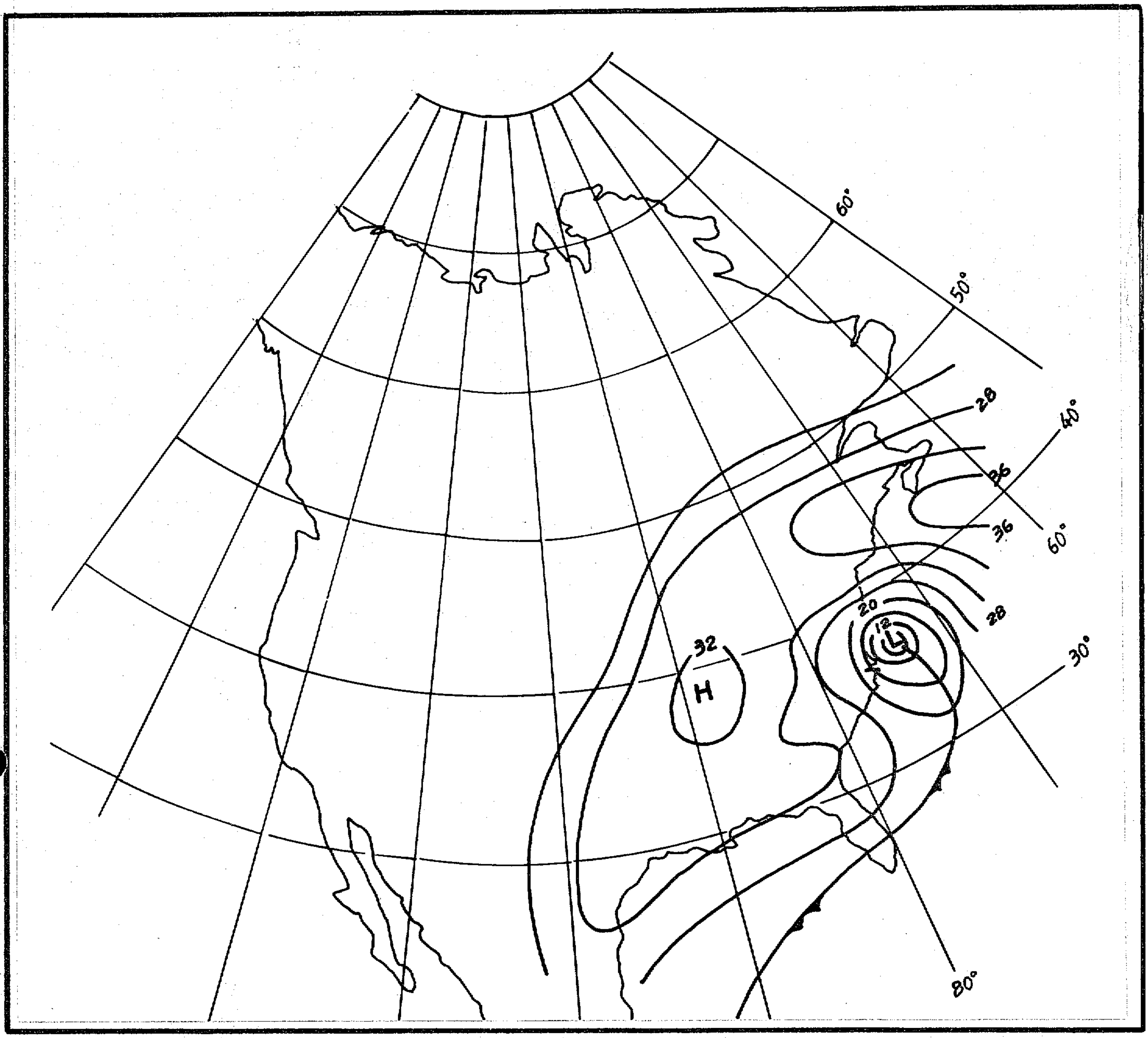

Fig. 2 (a) Mean-sea-level pressure analysis for 12 GMT 19 Feb 1979 (contour interval: 4 mb).

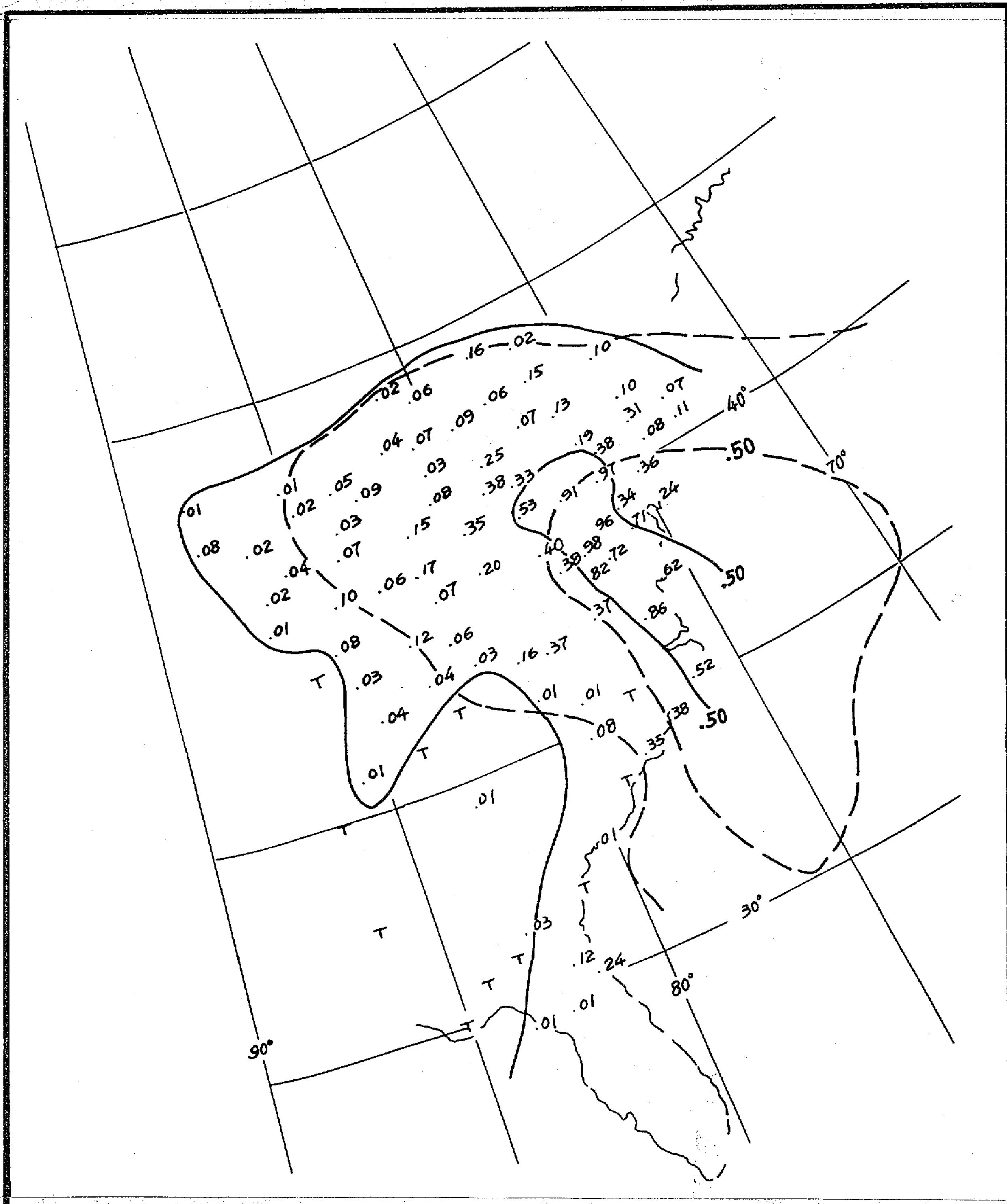

Fig. 2 (b) Observed accumulated 12-h precipitation (solid line; units: inches; contour interval: 0.50 inches) ending 12 GMT 19 Feb 1979, and corresponding forecast from Experiment 1 (dashed line; contour interval: 0.50 inches).

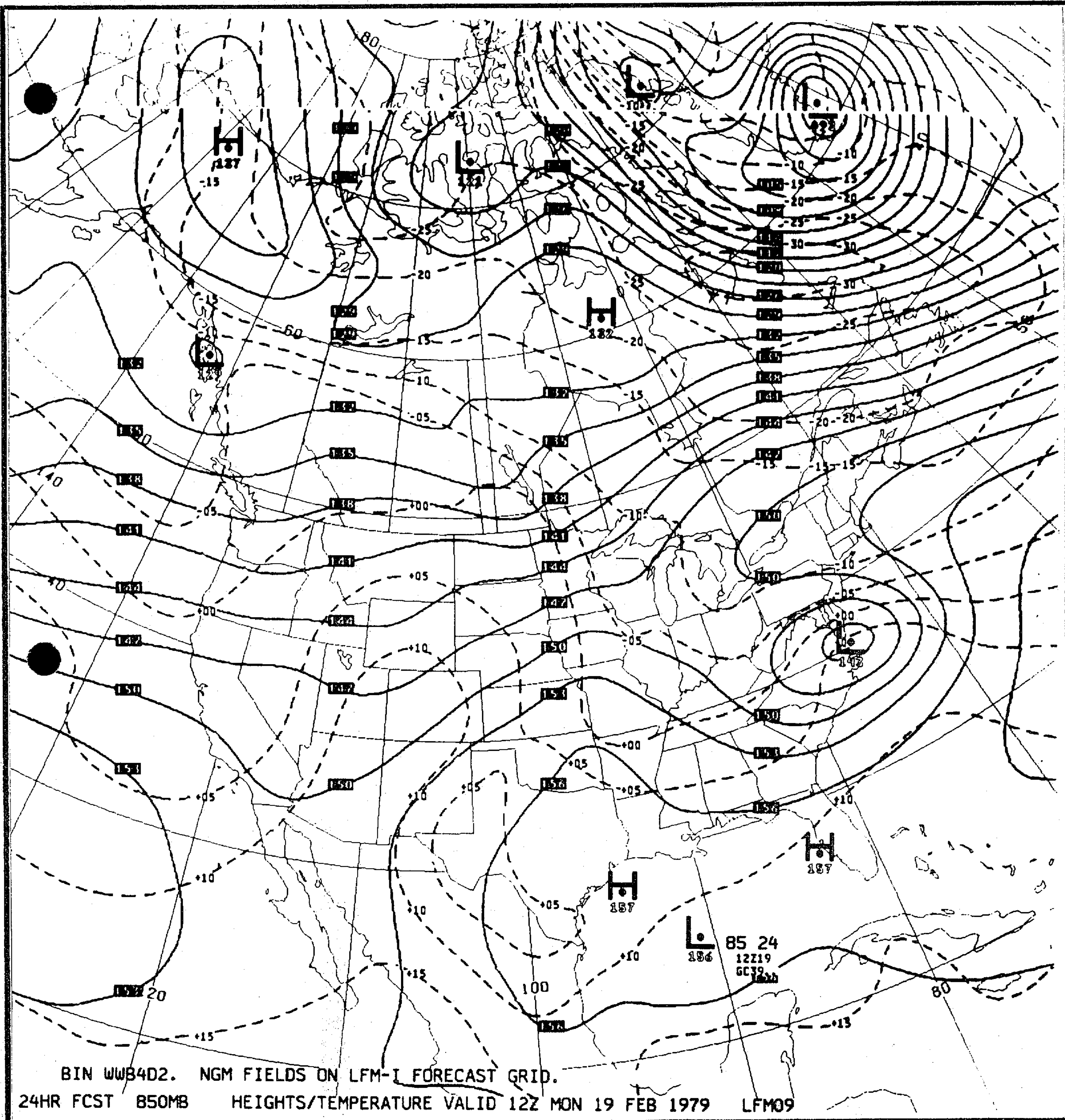

Fig. 3 24-h forecasts for Experiment 1 valid at 12 GMT 19 February 1979: 850-mb height (solid line; units: dekameters; contour interval: 3 dekameters) and 850-mb temperature (dashed line; units: °C; contour interval: 5°C).

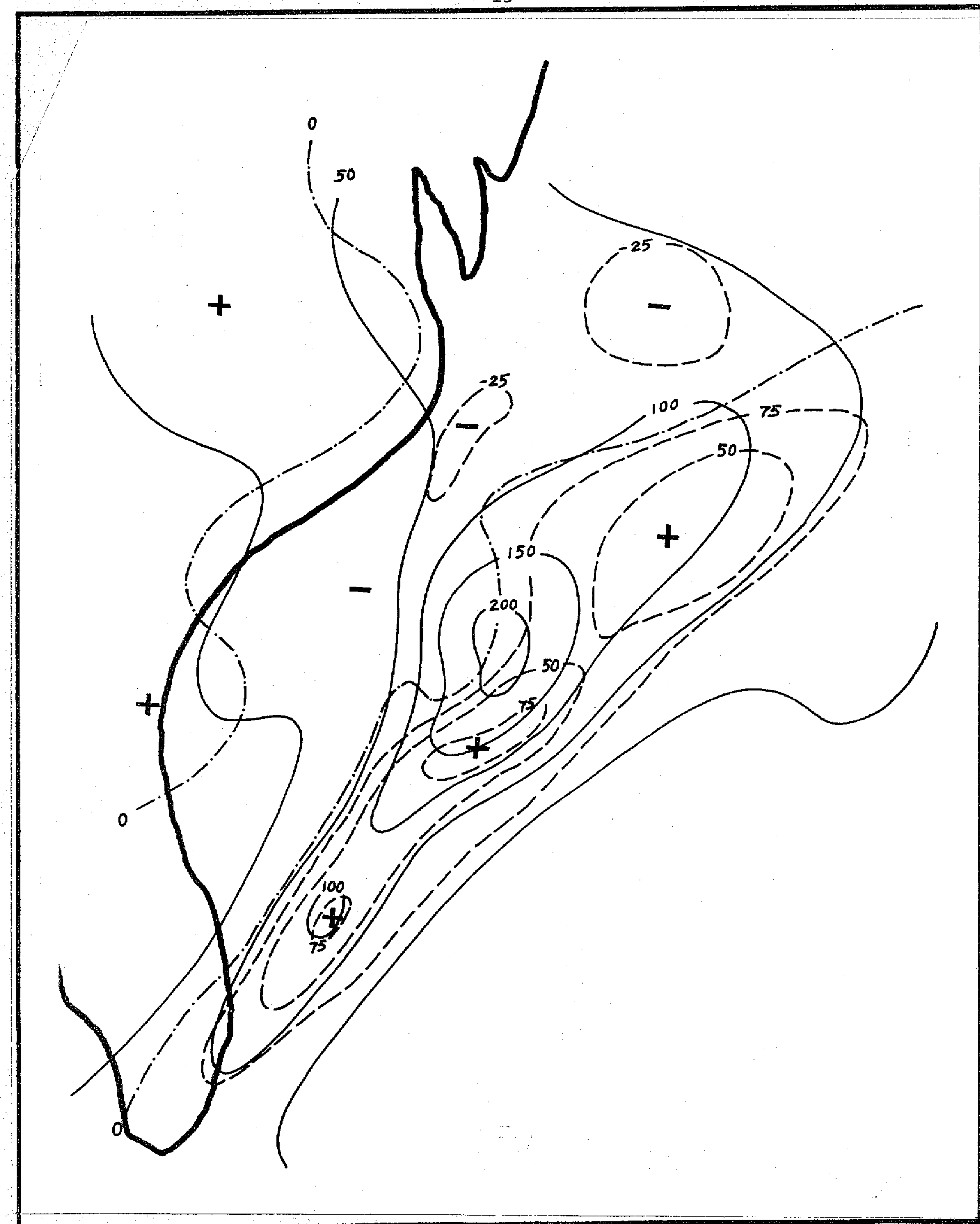

Fig. 4 The influence of moist convective adjustment: accumulated precipitation from 12-24 h (solid line; units: 0.01 inches; contour interval: 0.50 inches) for Experiment 2 ending at 12 GMT 19 February 1979, and the difference (Experiment 2 minus Experiment 1; dashed line; units: 0.01 inches; contour interval: 0.25 inches) for 12-24 h accumulated precipitation ending at 12 GMT 19 February 1979.

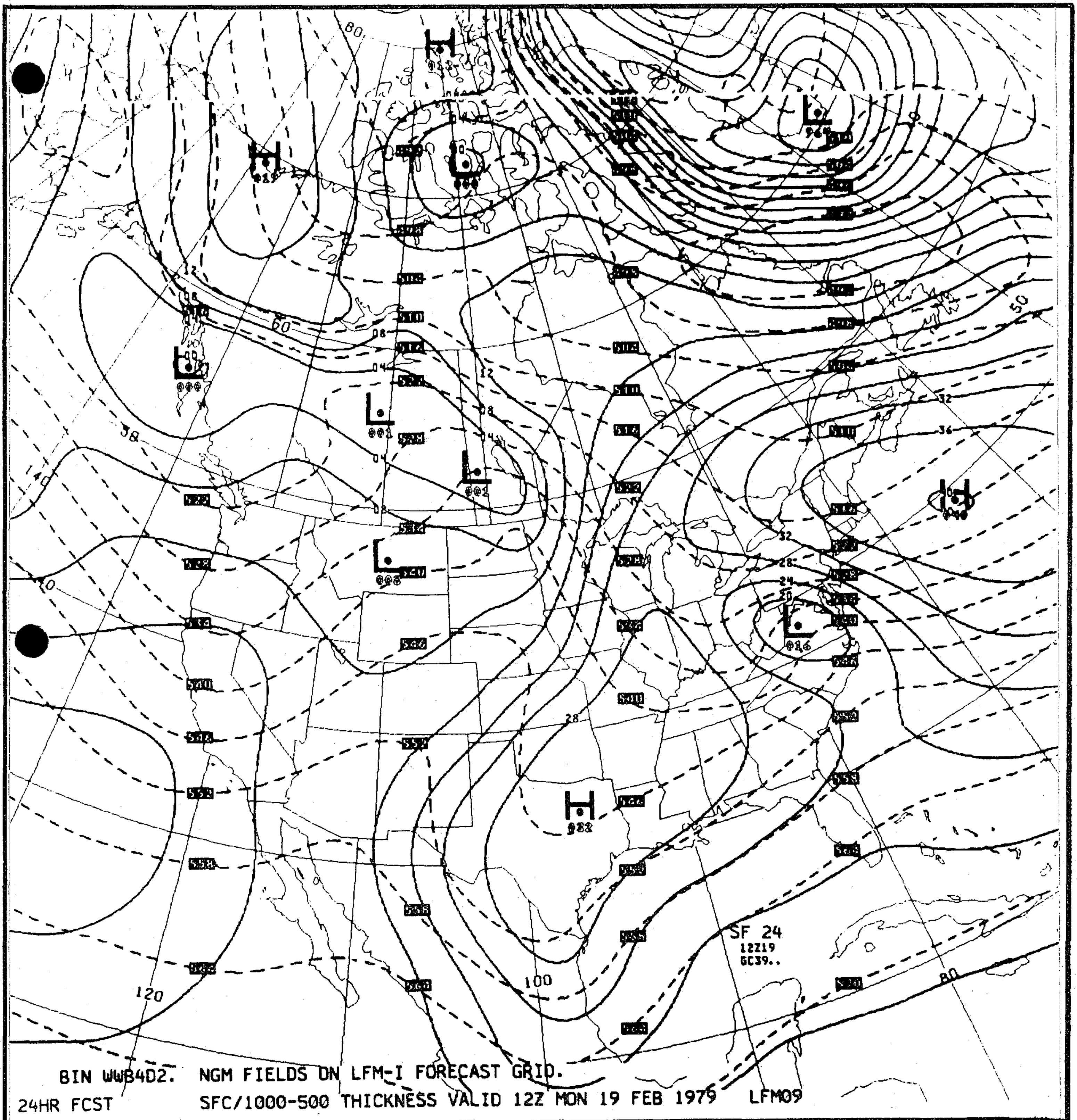

Fig. 5 The influence of the feedback of latent heating: 24-h forecasts for Experiment 3 valid at 12 GMT 19 February 1979 for mean-sea-level pressure (solid line; contour interval: 4 mb), and 1000/500-mb thickness (dashed line; units: dekameters; contour interval: 6 dekameters).

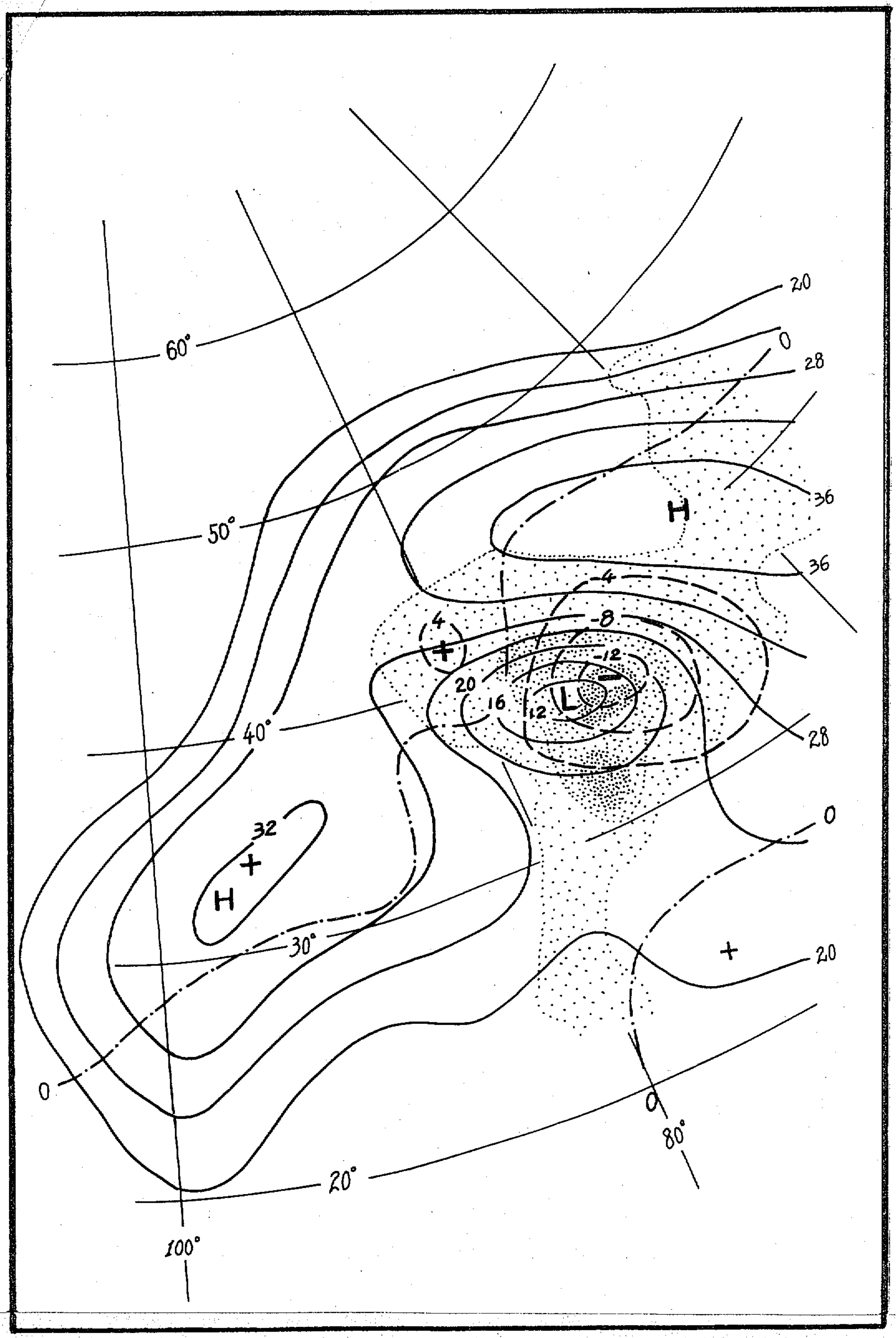

Fig. 6 The influence of the feedback of latent heating on mean-sea-level pressure: 24-h forecast of mean-sea-level pressure (solid line; contour interval: 4 mb) valid at 12 GMT 19 February 1979; difference of the 24-h forecast of mean-sea-level pressure (Experiment 1 minus Experiment 3; dashed line; units: mb; contour interval: 4 mb); and 12-24 h precipitation area (stippled) as forecast in Experiment 1.

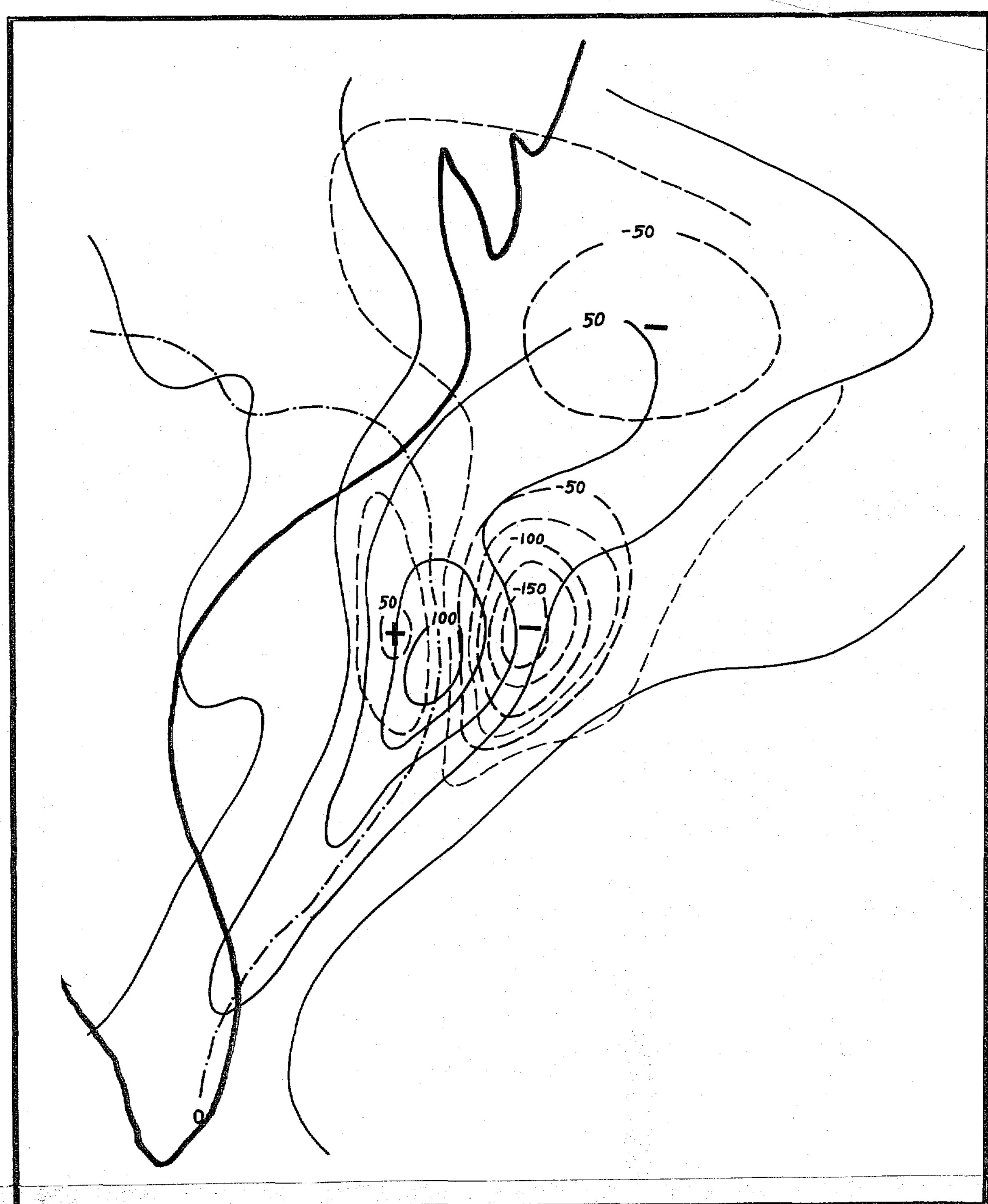

Fig. 7 The influence of moisture flux from the ocean: accumulated precipitation from 12-24 h (solid line; units: 0.01 inches; contour interval: 0.25 inches) from Experiment 5 ending at 12 GMT 19 February 1979 and the difference (Experiment 5 minus Experiment 1; dashed line; units: 0.01 inches; contour interval: 0.25 inches) for 12-24 h accumulated precipitation ending at 12 GMT 19 February 1979.

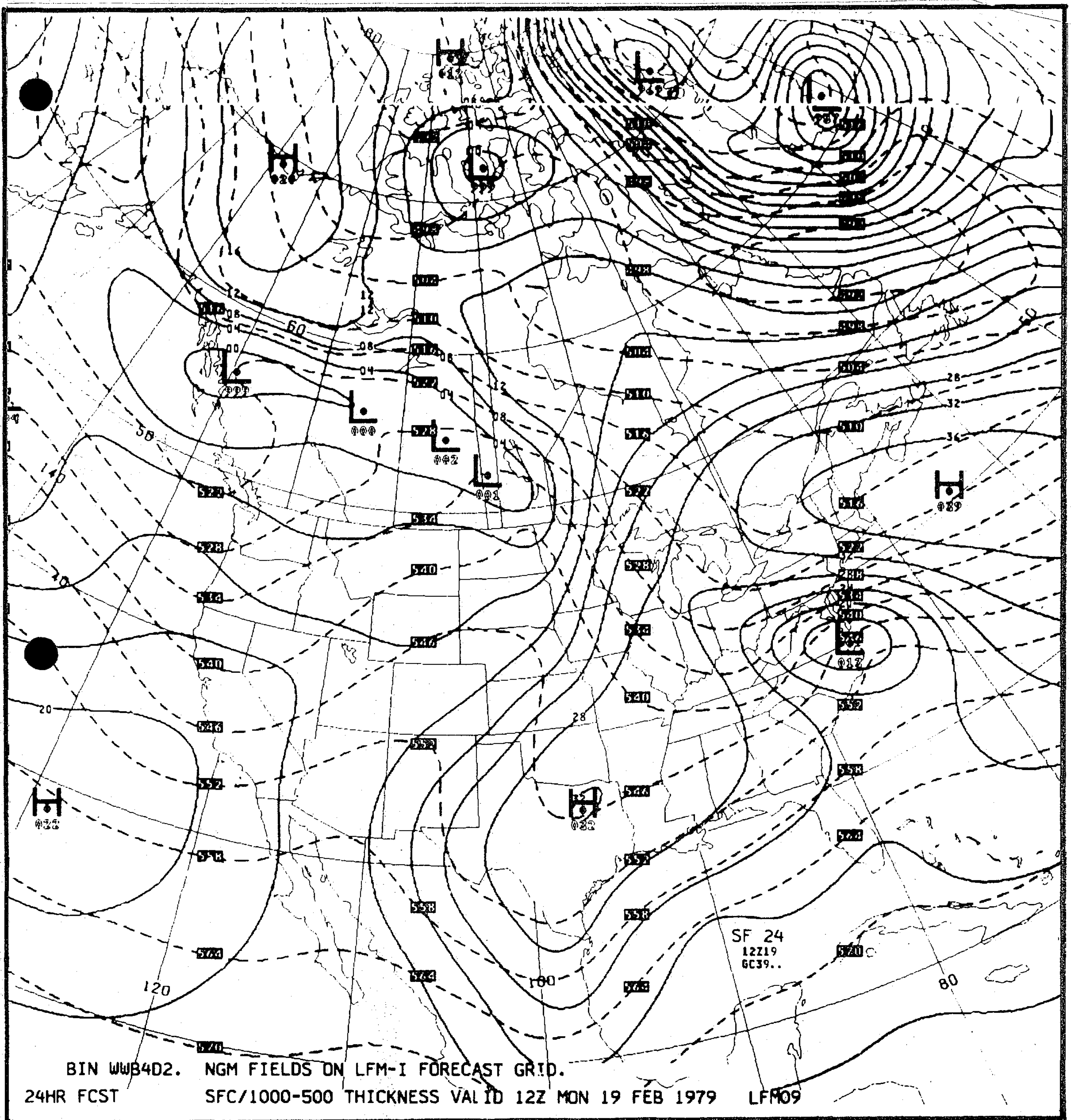

Fig. 8 The influence of moisture flux from the ocean: 24-h forecasts of mean-sea-level pressure (solid line; contour interval: 4 mb) and 1000/500-mb thickness (dashed line; units: dekameters; contour interval: 6 dekameters) for Experiment 5 valid at 12 GMT 19 February 1979.