NOAA TECHNICAL MEMORANDUM NWS CR-98

FEB 16 1990

Property of:
NOAA LIBRARY, E/OC43
7600 Sand Point Way N.E.
Seattle, WA 98115-0070

THE RECORD RAINFALL OF AUGUST 13-14, 1987 AT CHICAGO, ILLINOIS

Paul Merzock
National Weather Service Forecast Office
Chicago, Illinios

November 1989

UNITED STATES DEPARTMENT OF COMMERCE
Robert A. Mosbacher
Secretary

National Oceanic and Atmospheric Administration
John A. Knauss
Under Secretary

National Weather Service
Elbert W. Friday, Jr.
Assistant Administrator

TABLE OF CONTENTS

THE RECORD RAINFALL OF AUGUST 13-14, 1987 AT CHICAGO, ILLINOIS

Paul Merzlock
National Weather Service Forecast Office
Chicago, Illinois

ABSTRACT. On Friday, August 14, 1987, an unprecedented rainfall event occurred over northwest sections of Chicago. Resulting massive urban and street flooding as well as flash flooding of small streams claimed four lives. Property damage was widespread.

This paper examines the synoptic conditions that were responsible for relatively widespread heavy thunderstorm development. Analysis of rainfall patterns, both spatially and temporally, indicated that this flash flood event was due to a series of at least three mesoscale events which occurred over a 12 hour period. Detailed analysis of radar and satellite data confirm the mesoscale nature of the flash flood event.

Results indicate that although a good synoptic analysis of conventional weather data may alert the forecaster to the possibility of flash flooding, the actual warning of such an event before it occurs can be improved only by improved mesoanalysis emphasizing remote sensing data.

1. Introduction

During the evening of Thursday, August 13, 1987, a line of thunderstorms moved into the Chicago area from the southwest. Periods of torrential rain fell through the night, with over nine inches of precipitation having fallen by early the following morning.

The focus of this paper is to provide a synopsis of meteorological events prior to and during this record rainfall event. It is meant as a case study for interpreting conventional and remote sensing data for use in operational forecasting.

Analyses of sounding data and mandatory level charts from 1200 UTC Thursday, August 13, through 1200 UTC Friday, August 14, are discussed. In addition, satellite and radar data are also studied with reference to mesoscale features. These data are then compared to observed rainfall rates at O'Hare International Airport (a continuous observing site in the core of greatest rainfall).

2. Synoptic Conditions

Major surface features at 1200 UTC (Fig. 1) included a cold front that stretched from Lake Superior to northeast Iowa where it became quasi-stationary.

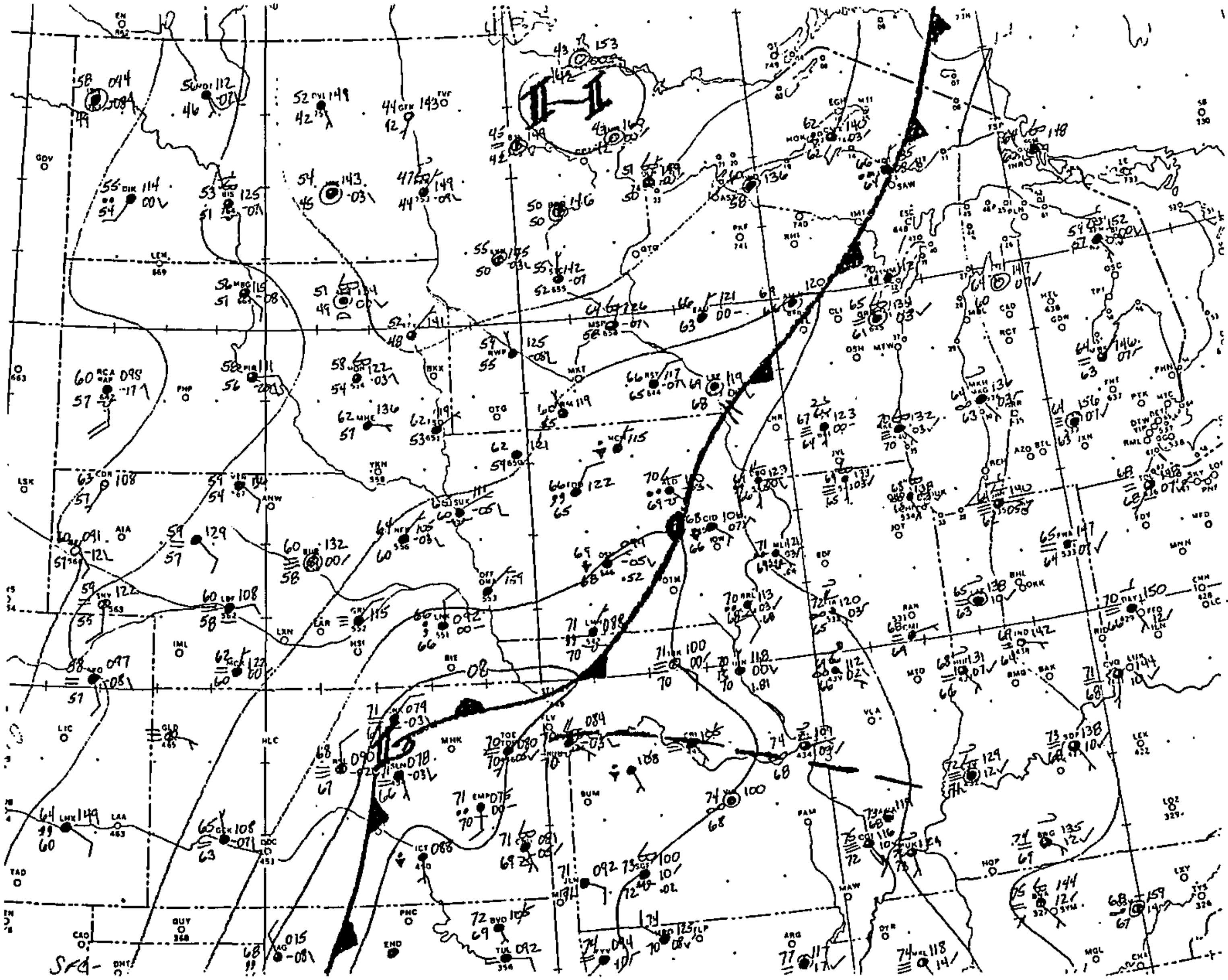


Fig. 1 Surface analysis from 12Z Thursday, August 13, 1987.

The front then continued southwest into western Oklahoma. A diffuse wave was evident on the front over north central Kansas with another trough extending east from the wave to east central Missouri. The front separated a continental high pressure center over northern Minnesota from a subtropical high anchored over the eastern United States. Surface dew points were generally in the 50s to the west of the boundary and were in the lower to middle 60s to the east. To the south of the trough, which displayed warm frontal characteristics, dew points were generally in the lower 70s. The focus of surface moisture convergence at this time was from central Kansas to northwest Missouri. Showers and thunderstorms were in progress from eastern Kansas, through most of Iowa and eastward into extreme western Illinois (see Fig. 2).

Inspection of the mandatory level package observed at 1200 UTC on Thursday, August 13, 1987, shows that conditions were indeed favorable for the development of deep convection across the central Great Plains states. This is apparent through the analysis of Figures 3 through 6 which display the 850, 700, 500, and 200 mb charts. The most striking feature at 850 mb is the nearly closed circulation centered over the Kansas/Nebraska border. A weak to moderate low level wind maximum extended ahead of the circulation and an associated trough which trailed southwestward through western Texas. Although the circulation was not very well developed, a significant (for mid-August) cyclonic shear zone extended east from the apparent low, across northern Missouri. This is the 850 mb reflection of the surface warm frontal trough previously discussed. Although the 850 mb chart showed the lower levels of the atmosphere to be rather homogeneous in the area both in terms of temperature and dew point, the moisture profile to the east of the low and trough was quite different with the air mass being nearly saturated through 500 mb. A thermal trough also extended from the Southern Plains into the lower Ohio Valley and inferred an axis of high total totals. Thus, an area of low level instability and very high precipitable water was available to this disturbance. In fact, heavy rainfall of five to six inches was reported across Kansas and extreme southern Nebraska in the 12 hours ending at 1200 UTC (Fig. 7).

At 700 and 500 mb a weak trough was analyzed behind which some mid-level drying and warming was evident. This may have enhanced the nocturnal convection over the Plains.

The mid-level drying becomes a little more evident by comparing the sounding from Omaha at 1200 UTC on the 13th and 0000 UTC on the 14th (Fig. 8). The wind profile also bears evidence to the low level trough/circulation passing to the south of the station during the day.

The 200 mb chart shows an area of speed divergence from western Oklahoma across northwest Missouri to northwest Illinois. This was mainly to the east of heavy nocturnal convection.

As the day progressed, the high dew point air (surface dew points reaching the middle and upper 70s by 2000 UTC) was advancing slowly northwest under the influence of the subtropical ridge to the east. By late afternoon, the warm frontal boundary had become easier to define by streamline analysis rather than

Fig. 2 GOES E visible imagery from 1231Z Thursday, August 13, 1987.

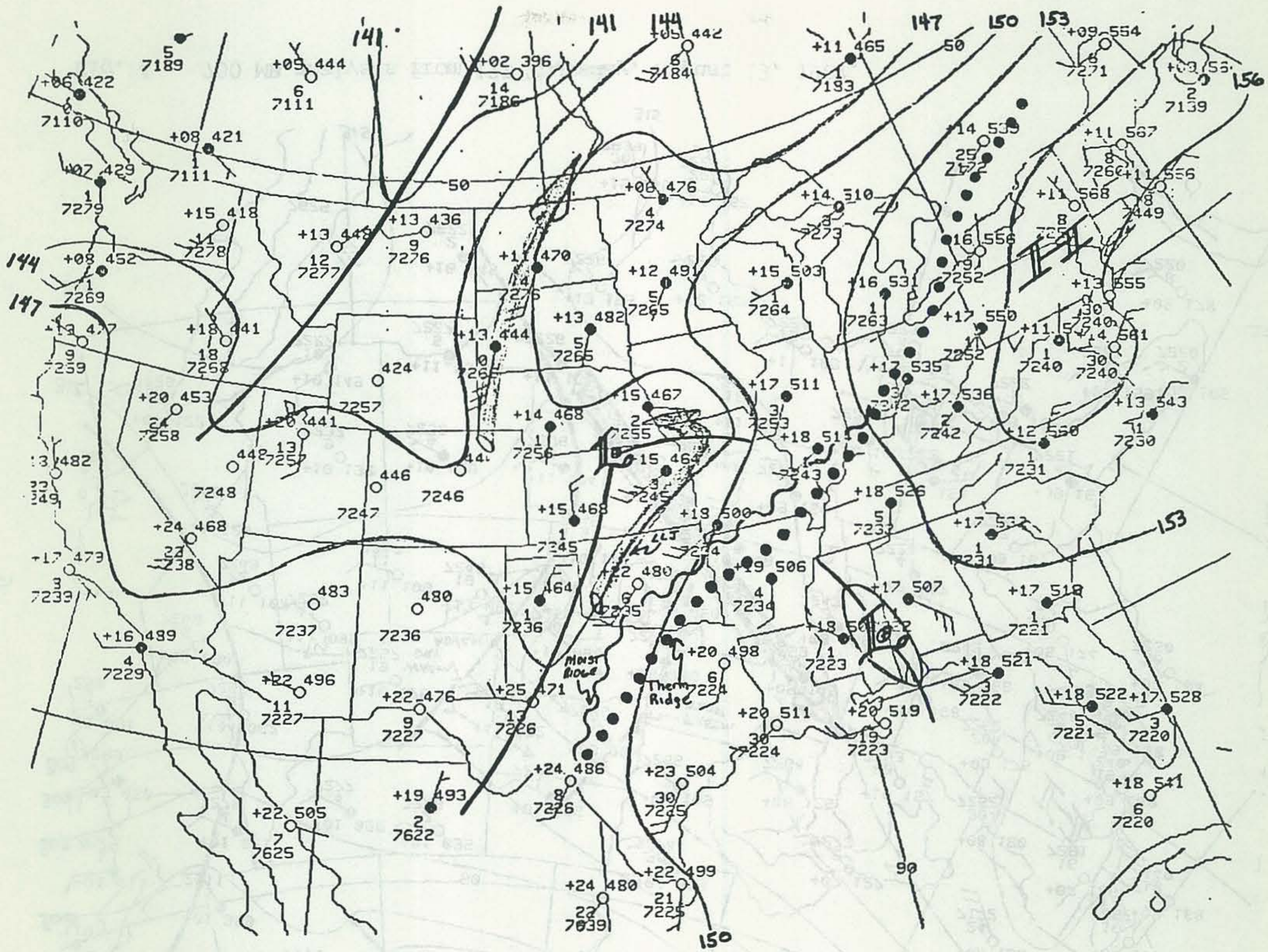


Fig. 3 850 MB analysis from 12Z Thursday, August 13, 1987.

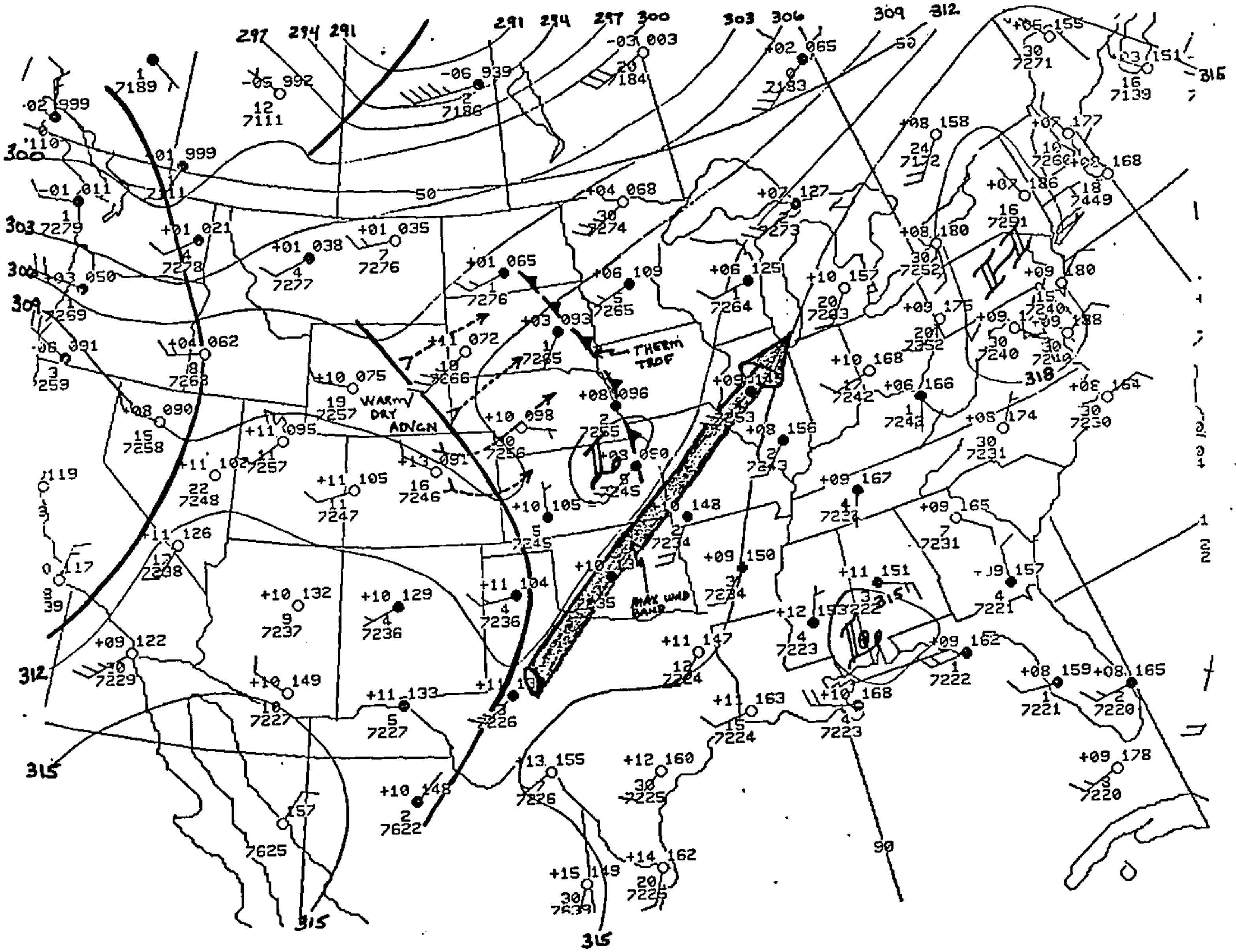


Fig. 4 700 MB analysis from 12Z Thursday, August 13, 1987.

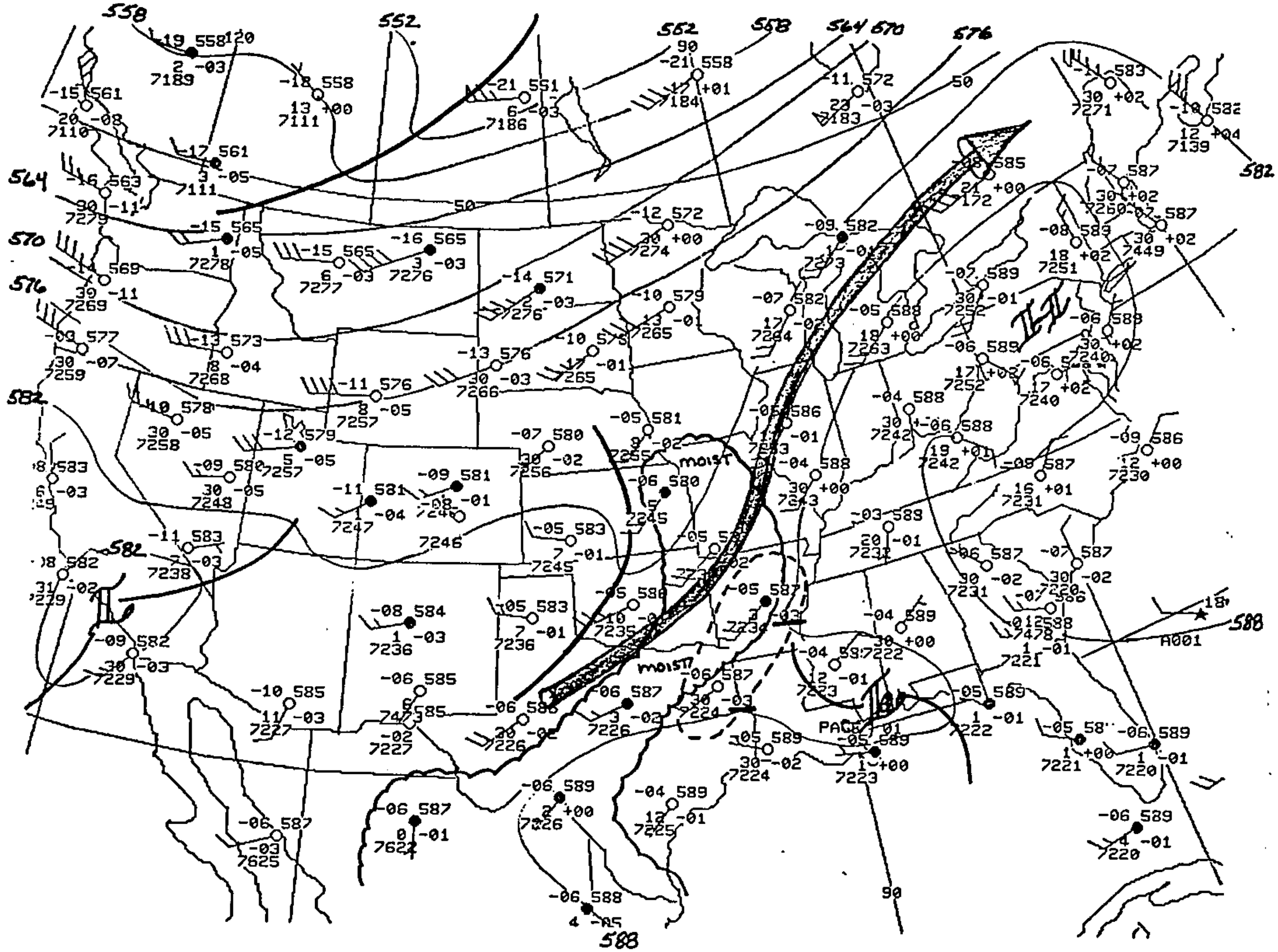


Fig. 5 500 MB analysis from 12Z Thursday, August 13, 1987.

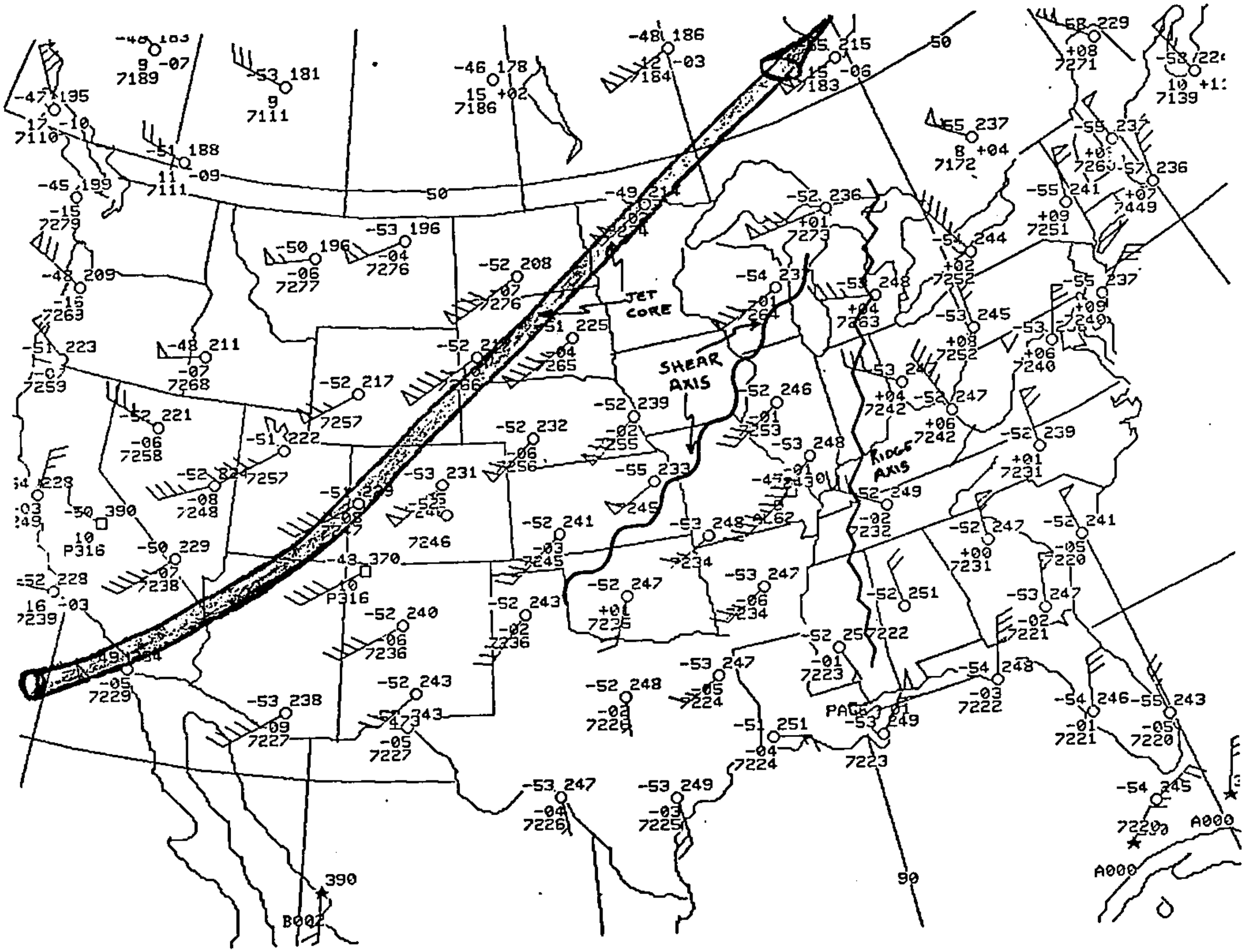


Fig. 6   200 MB analysis from 12Z Thursday, August 13, 1987.

Fig. 7 GOES E IR imagery with MB enhancement for 0431Z Thursday, August 13, 1987.

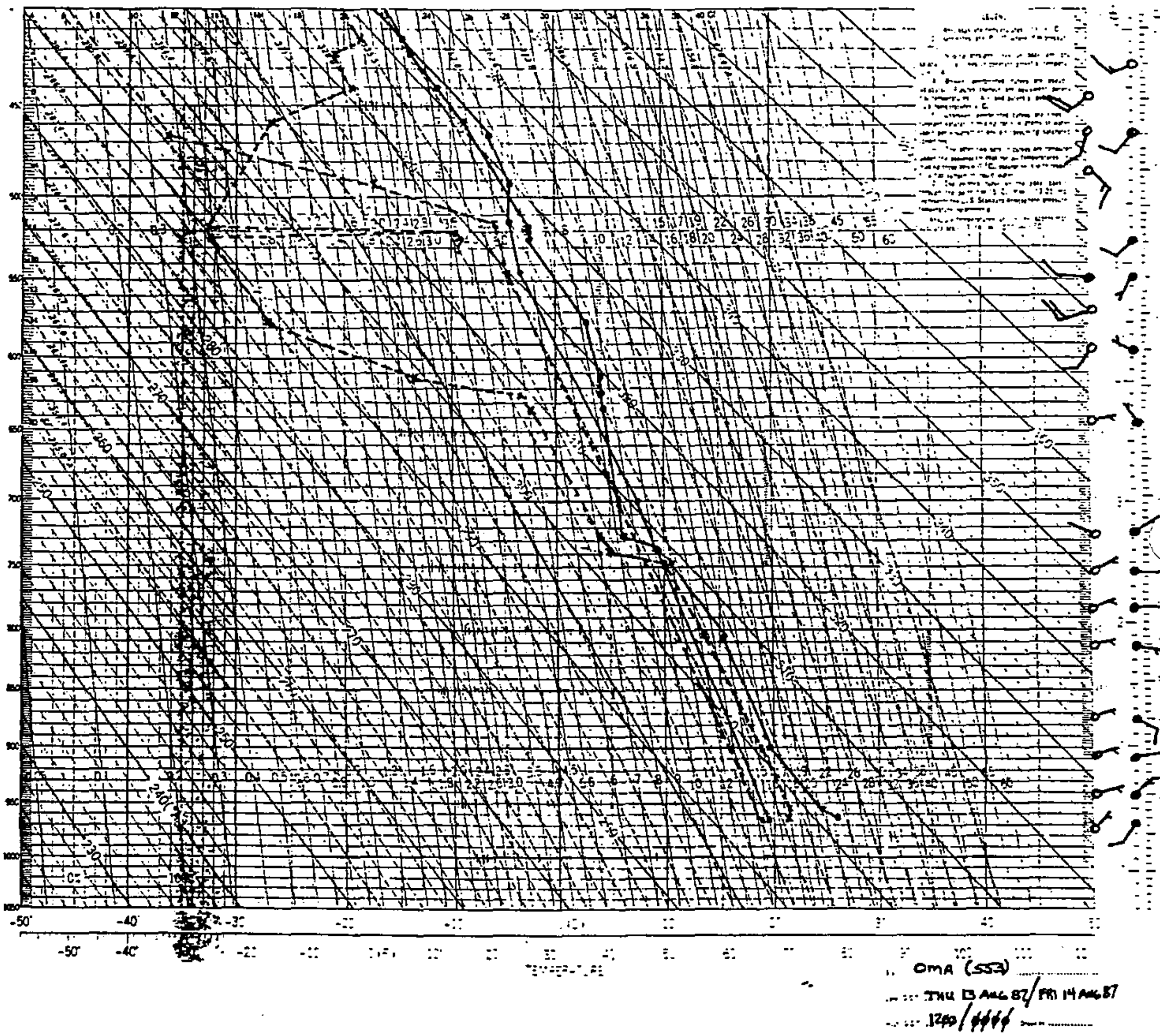


Fig. 8 Soundings from Omaha, Nebraska for 12Z Thursday, August 13, 1987 (dotted) and 00Z Friday, August 14, 1987 (solid).

temperature, dew point, or sea level pressure since the development of new convection made frontal analysis difficult.

At 0000 UTC on the 14th, a surface low was defined just south of Omaha with a warm or quasi-stationary front lying to the east across northern Illinois to southwest lower Michigan (see Fig. 9). At the same time, the cool high center had moved north of Lake Huron with somewhat cooler air from the high helping to define and reinforce the front over northern Illinois. By this time, strong convection had developed from southwestern Texas through Missouri to central and southern Illinois. A short squall line was in evidence moving northeastward out of central Illinois (see Figs. 10 through 13).

Comparison of the 1200 UTC August 13 and 0000 UTC August 14 soundings from Peoria, Illinois (Fig. 14) reveals that wind speeds in the low levels had increased about 10 knots. In addition, the entire lower portion of the sounding (below 700 mb) showed a marked increase in both temperature and dew point. The result was that destabilization had occurred under the influence of warm advection (see Table 1 below).

The atmosphere was now ripe for rapid convective growth and heavy rainfall. The sounding also indicated that the atmosphere was at or near saturation through 400 mb! A profile more likely to be found at Lake Charles, Louisiana than Peoria, Illinois. Winds aloft were rather light and will be shown shortly. Fields of greatest instability and upward vertical motion were basically parallel to the mid and upper tropospheric flow.

Table 1
Peoria, Illinois

	Morning Stability	Evening Stability
SSI	-0.3	-3.9
LI	+1.0	-7.6
K	32.7	43.0
SWEAT	276.5	362.7
CT	19.6	24.2
VT	22.1	24.7
TT	41.7	48.9

Analysis of the 0000 UTC 850 mb chart (Fig. 15) shows that the circulation that was over northeastern Kansas 12 hours earlier had weakened and become a barely discernable wave over southern Iowa, along a generally west-to-east boundary from Nebraska into northern Indiana. The low level maximum wind axis had become weak and diffuse due to diurnal heating. A broad thermal ridge extended from southwest Texas into the Ohio and middle Mississippi Valleys. Highest 850 mb dew points were generally in the same zone.

Weak perturbations were detected in the mid-levels (see Figs. 16 and 17) with maximum wind bands of 25 to 30 knots running along an axis from western Texas through northwest Missouri to Lake Huron. At 500 mb, thermal troughs were also indicated moving through the Central Plains and middle Mississippi Valley. For the most part, these features were having little influence on initiating or

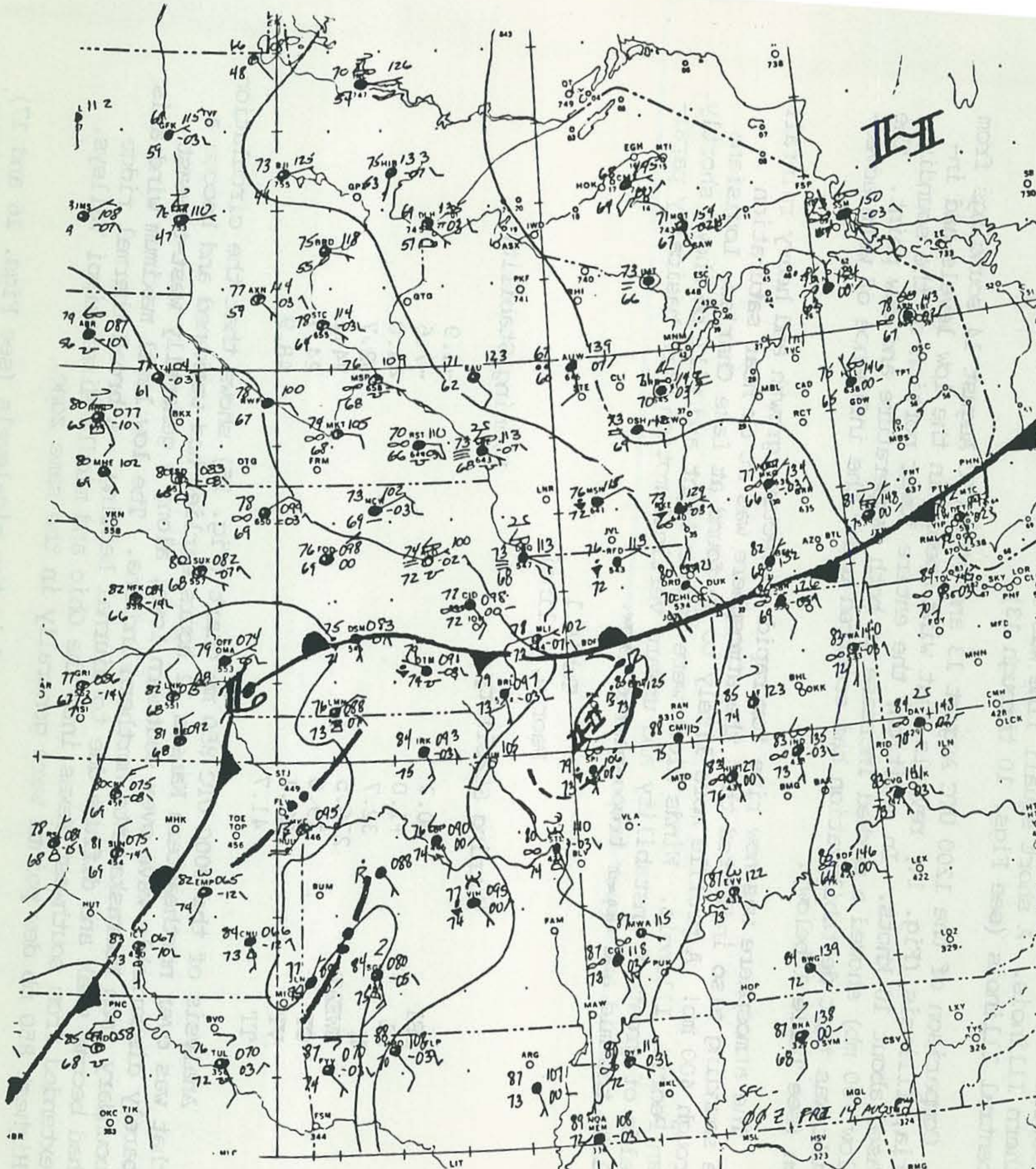


Fig. 9 Surface analysis from 00Z Friday, August 14, 1987.

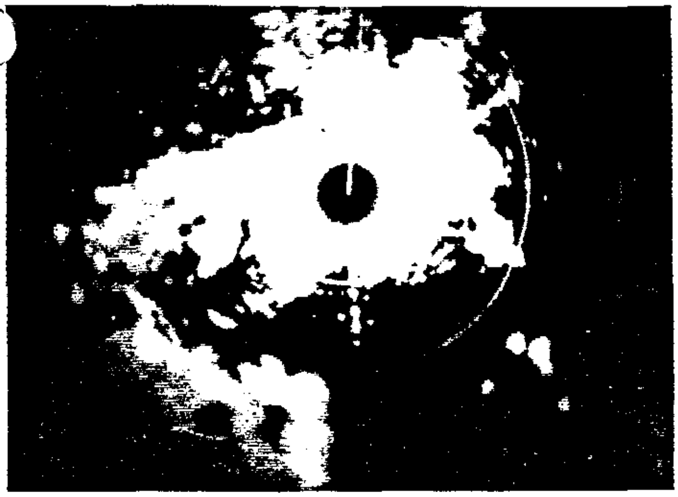


Fig. 10 Photo taken from WSR-57 at Marseilles, Illinois (MMO) at 2257Z.

Fig. 12 Photo taken from WSR-57 at MMO at 2330Z.

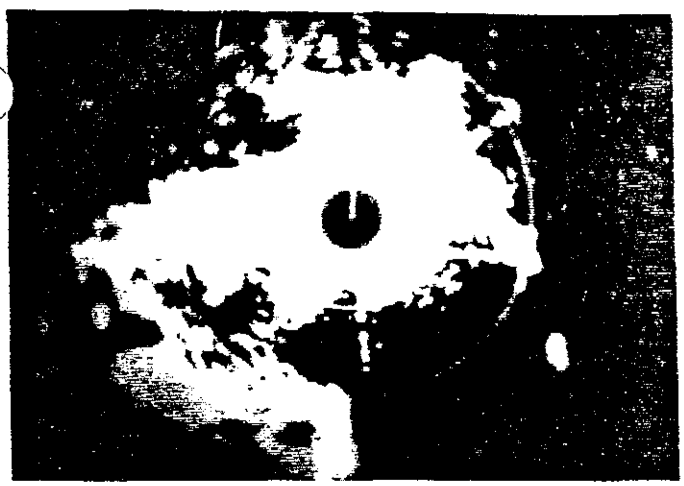


Fig. 11 Photo taken from WSR-57 at MMO at 2308Z.

Fig. 13 Photo taken from WSR-57 at MMO at 2345Z.

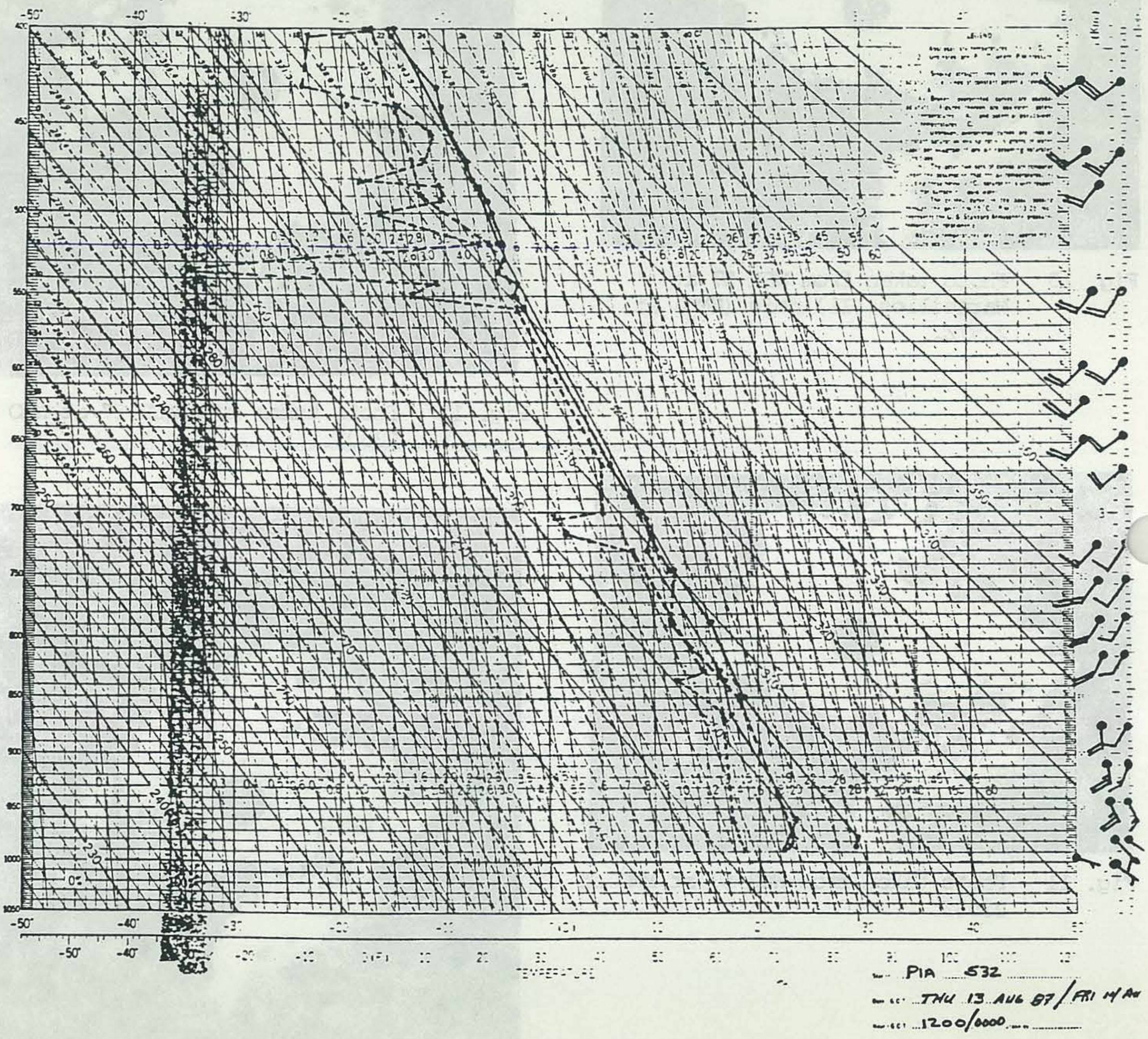


Fig. 14 Soundings from Peoria, Illinois for 12Z Thursday, August 13, 1987 (dotted) and 00Z Friday, August 14, 1987 (solid).

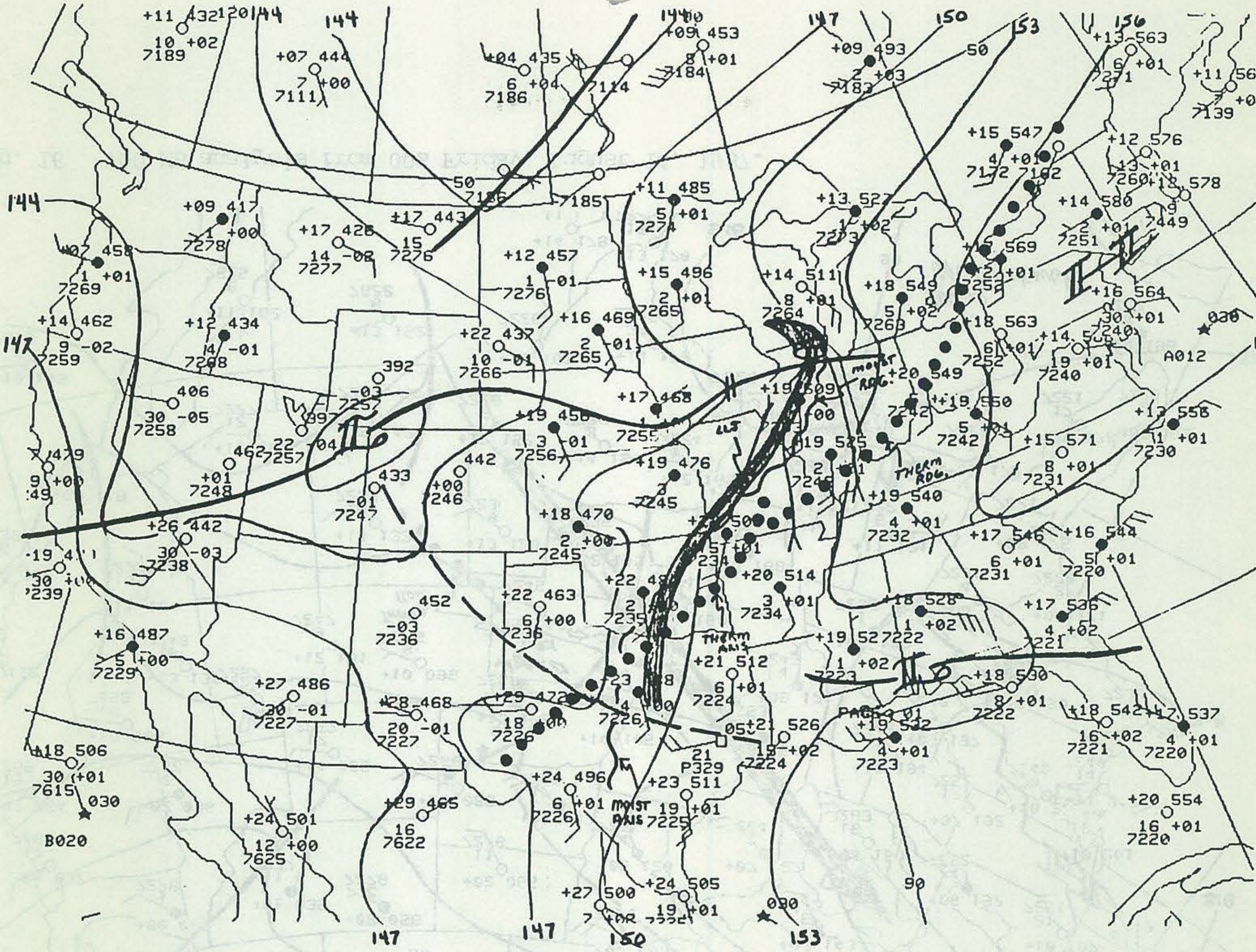


Fig. 15 850 MB analysis from 00Z Friday, August 14, 1987.

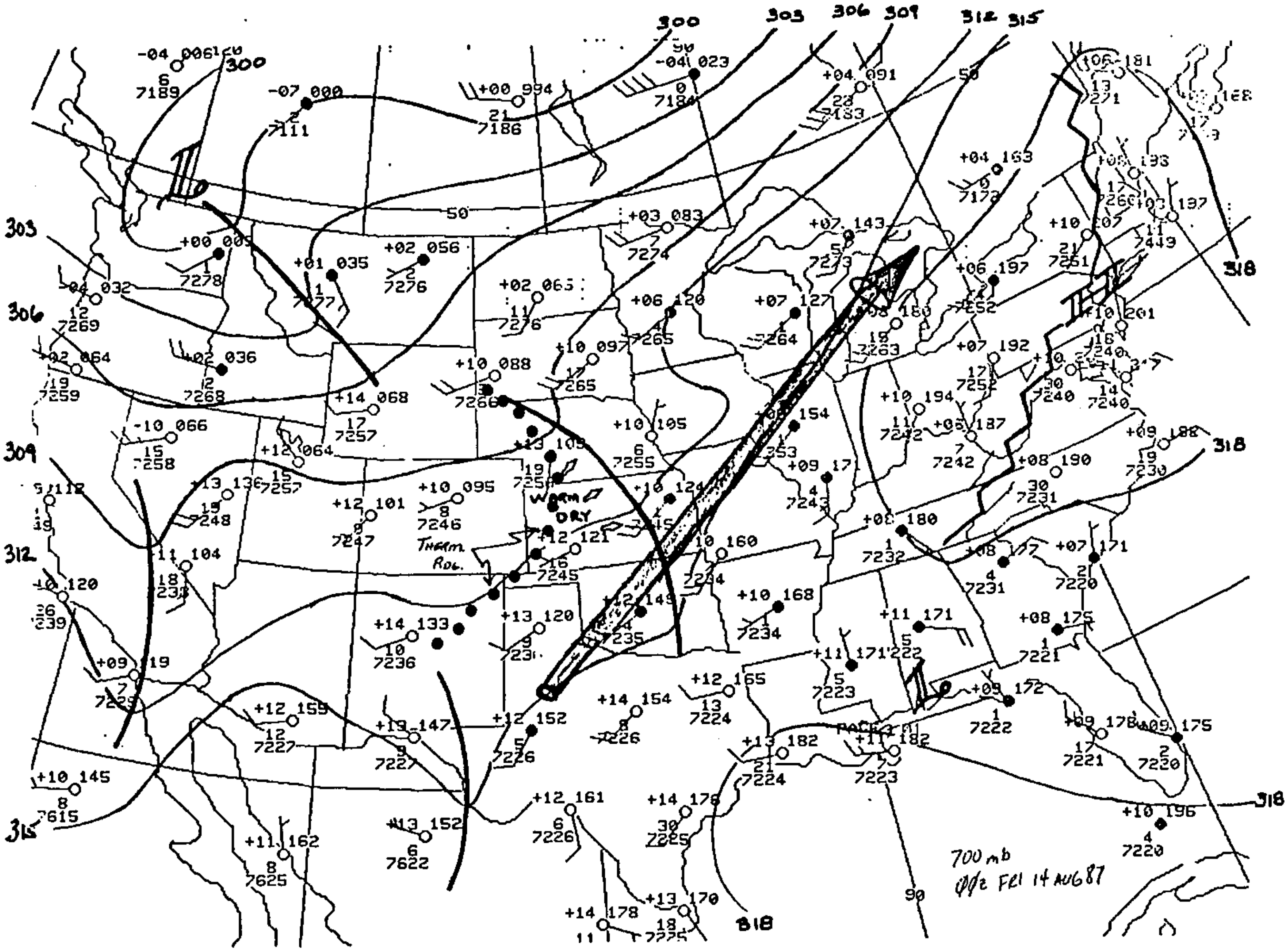


Fig. 16 700 MB analysis from 00Z Friday, August 14, 1987.

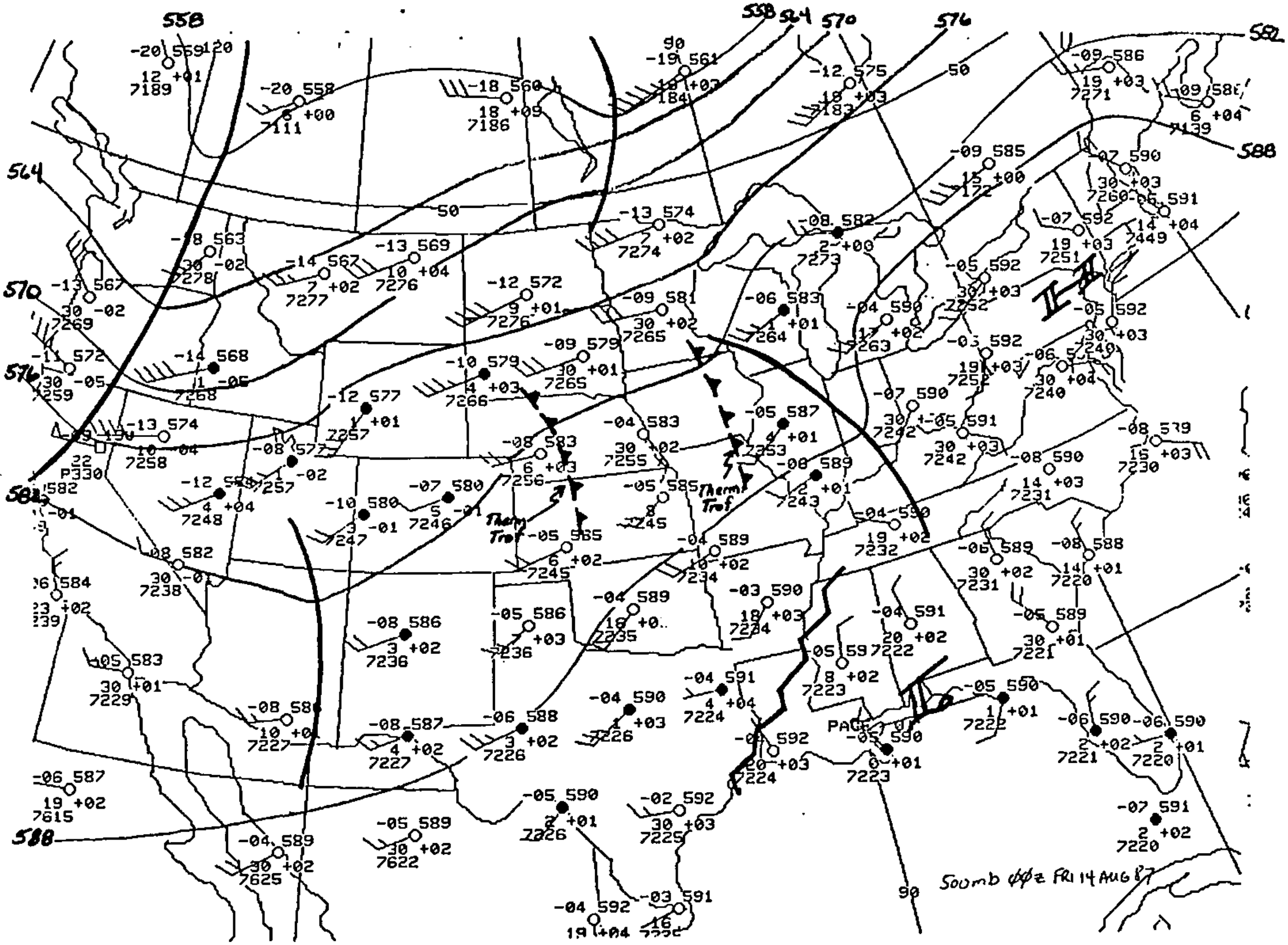


Fig. 17 500 MB analysis from 00Z Friday, August 14, 1987.

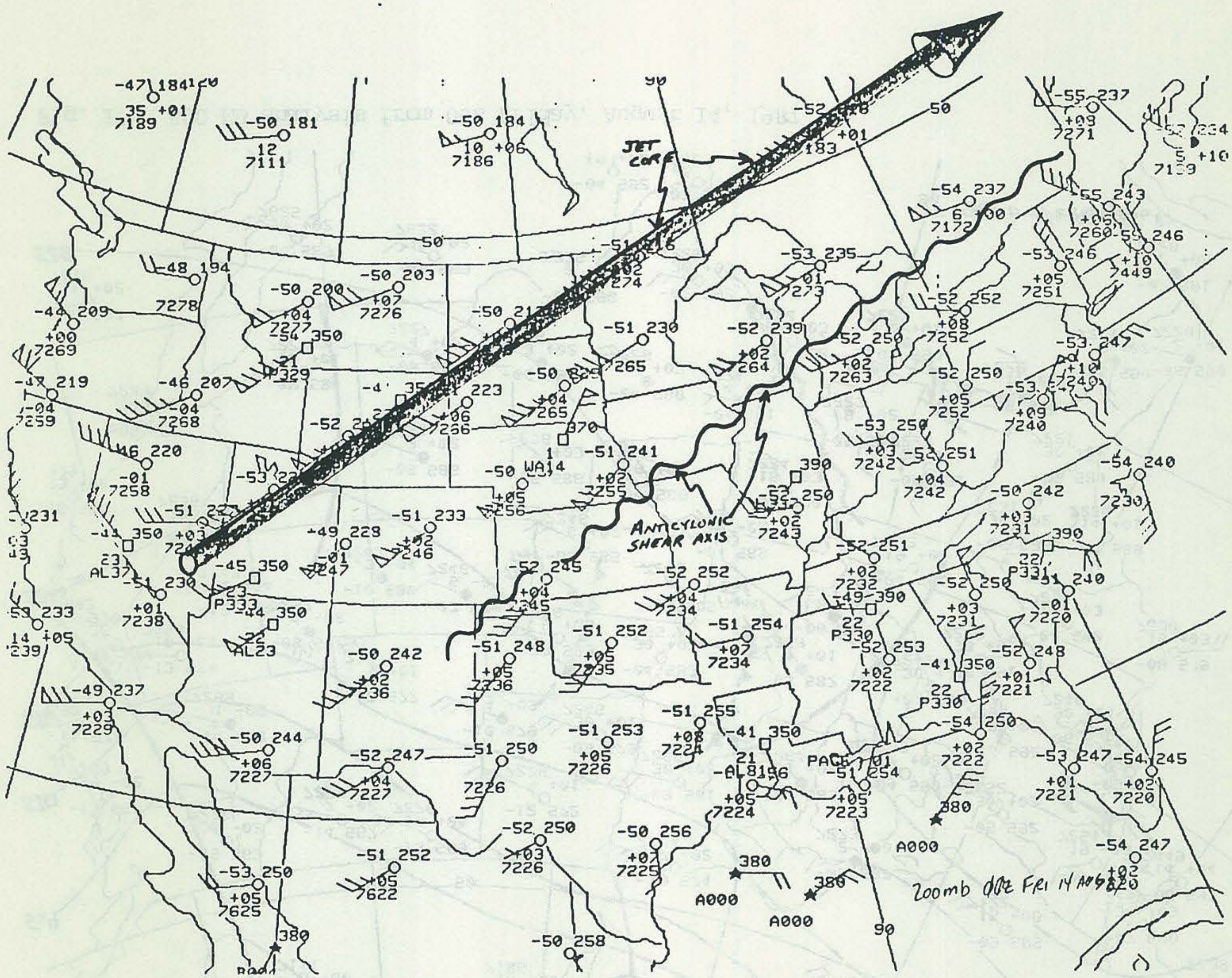


Fig. 18 200 MB analysis from 00Z Friday, August 14, 1987.

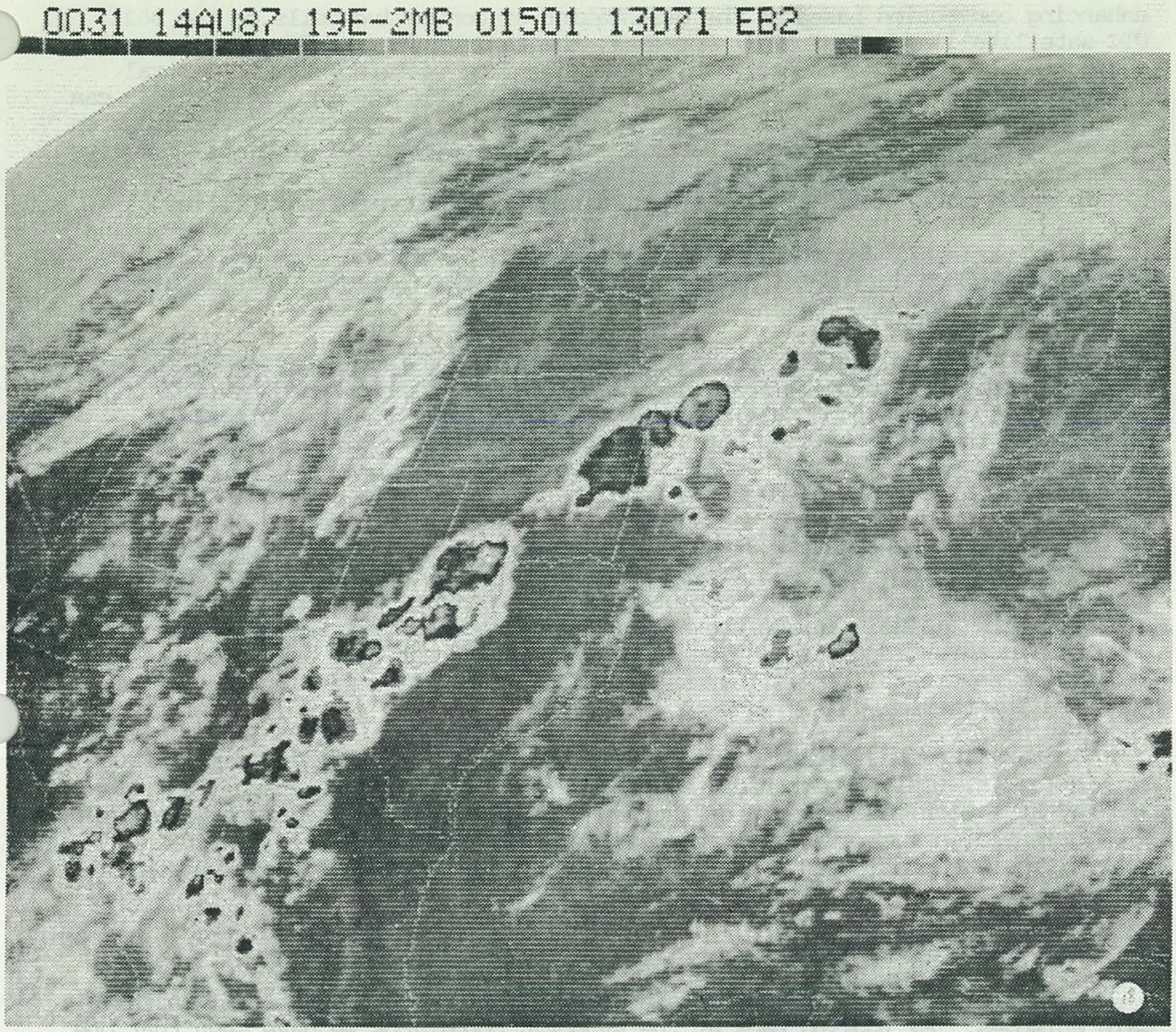


Fig. 19 GOES E IR imagery with MB enhancement for 0031Z Friday, August 14, 1987.

enhancing convection based on the orientation of convective cells on the 0021 UTC satellite image (Fig. 19). Moreover, the maximum wind bands (at all levels) seemed to fit the zone of organized convection from western Texas to central Illinois better than any disturbance in the geopotential height field. This can be interpreted as a statement on the relative lack of importance of PVA areas on summertime convection. However, analysis of the 200 mb level (Fig. 18) displays a striking fit between the zone of active convection and the pronounced anticyclonic speed shear axis from the Texas Panhandle, through northern Illinois.

Heavy rainfall began at O'Hare at about 9:15 p.m. local time and fell in two main episodes during the night. By 4:00 a.m. the following morning nearly six inches of rain had fallen.

At 1200 UTC on the 14th the third and final heavy precipitation episode was about to begin. Accounting for diurnal cooling, the Peoria sounding (Fig. 20) was basically identical to the one taken 12 hours earlier with one notable exception: the winds between the 2,000 and 6,000 foot levels had increased to 40 knots! At the same time, 850 mb winds at Neenah, Wisconsin were only five knots. This highlights a zone of strong low level moisture convergence over northern Illinois and southern Wisconsin. The morning surface and 850 mb charts (Figs. 21 and 22) showed a trough axis with strong cyclonic shear extending from Iowa through extreme northern Illinois to southeast Wisconsin. This feature may have been the primary reason for continued regeneration of thunderstorm activity over northern Illinois during the night as the low level jet re-intensified and intersected this trough axis. The low level jet had not only increased to 40 knots over northern Illinois, but was now in juxtaposition with a well defined moisture and thermal axis.

Instability was further maintained by the passage of a weak thermal trough at mid levels. This trough had a southwest-to-northeast orientation (Fig. 23) and may have been the trigger for the final round of heavy convection which was also oriented in such a fashion and displayed good organization. The 200 mb chart (Fig. 24) continued to show fairly decent speed divergence over northern Illinois.

3. Mesoscale Aspects

The more than nine inches of rain observed at O'Hare Airport fell in three main episodes. By looking back at the synoptic conditions we have seen that one can readily analyze large scale features with a history of producing heavy rainfall. In fact, the 9:00 p.m. CDT update of the Chicago local forecast included "locally heavy rainfall" for the duration of the first period forecast. But herein lies the root of the problem in forecasting and warning for unprecedented localized rainfall events. The rather obvious synoptic conditions favorable for flash flood events are inherently generalized. Questions such as why re-development of echoes occur in a particular area and why bands of convection suddenly change their translational movement and orientation need to be answered. Any answers to this problem would have to incorporate mesoscale remote sensing data.

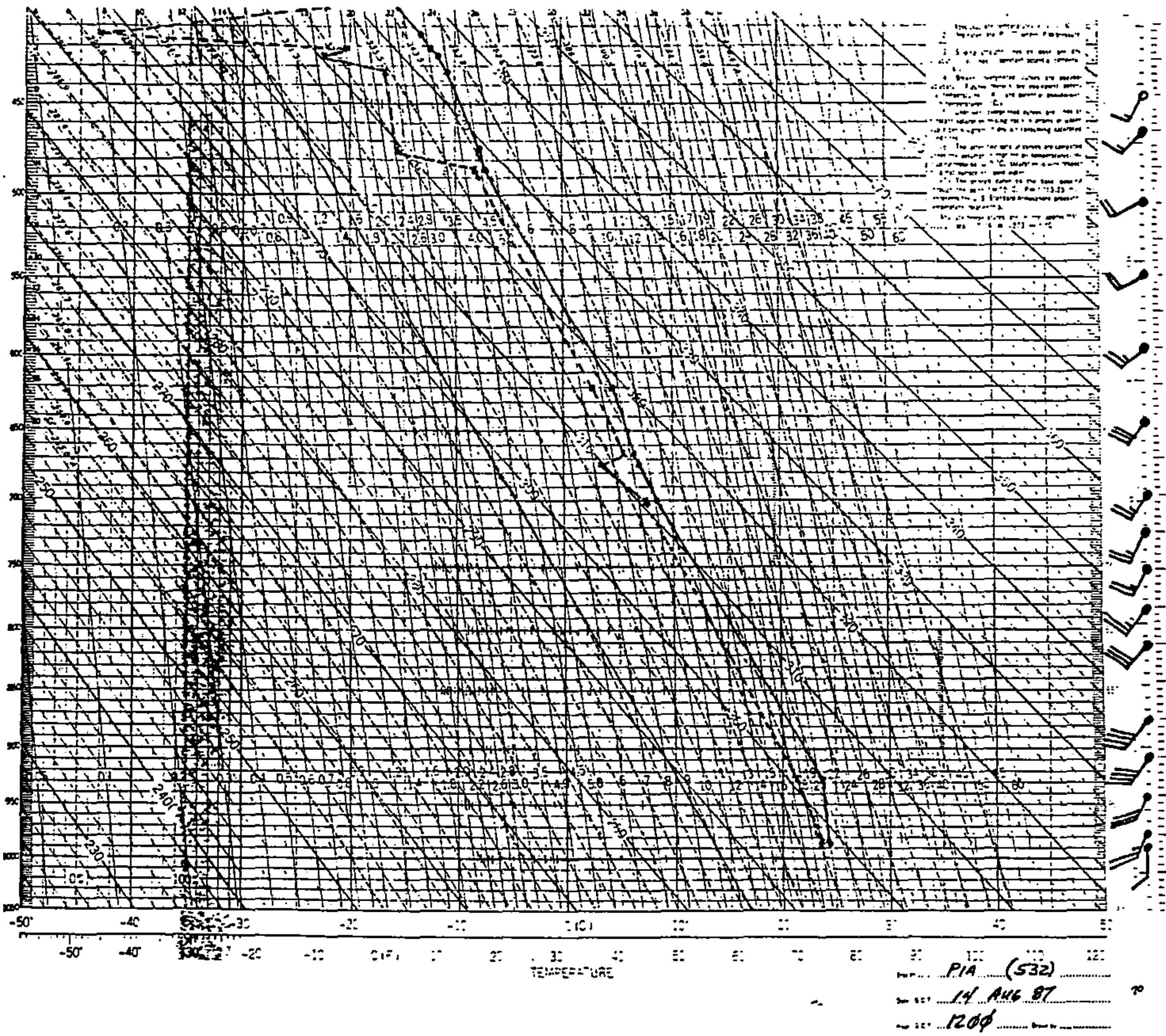


Fig. 20 Sounding from Peoria, Illinois for 12Z Friday, August 14, 1987.

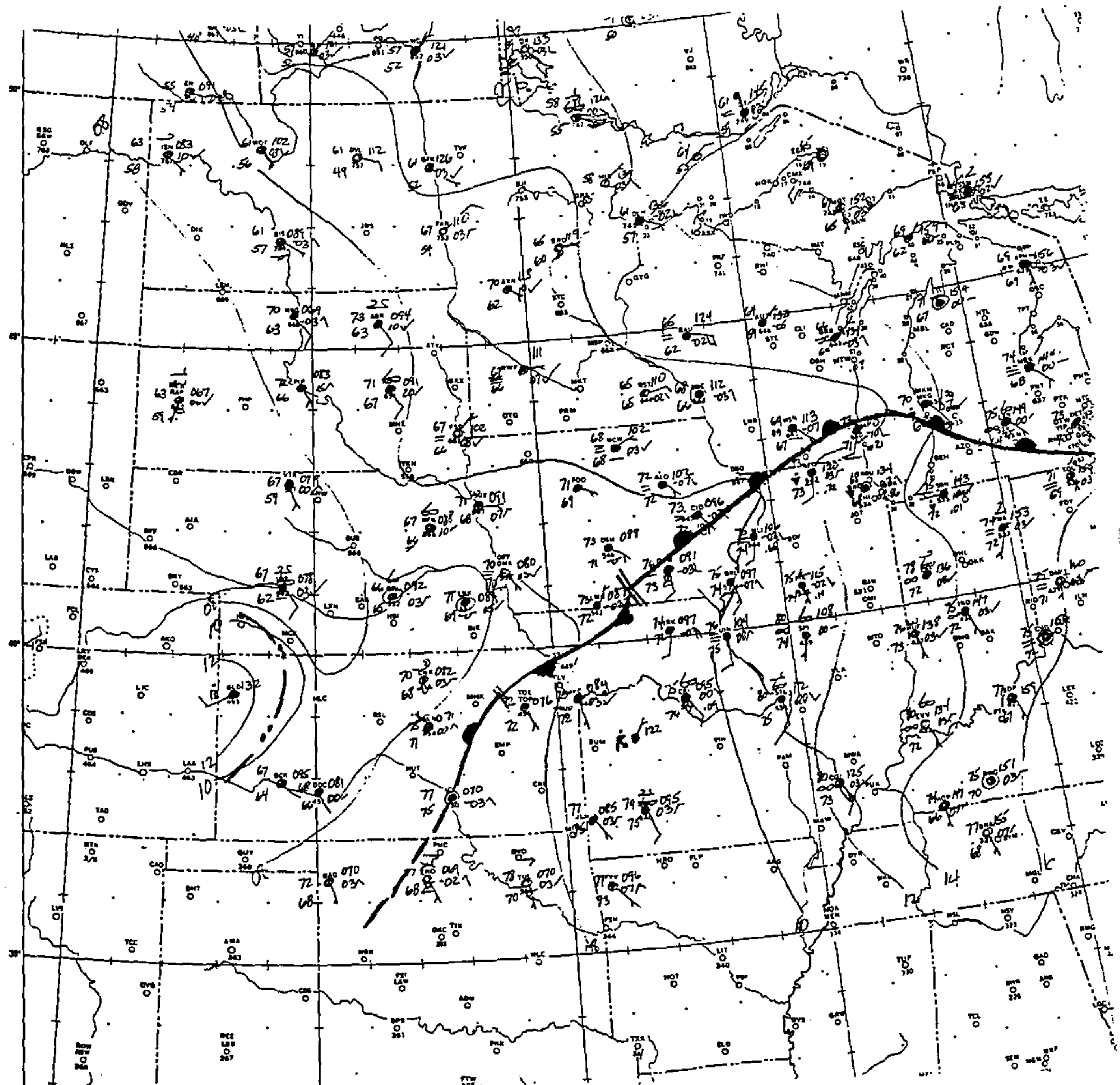


Fig. 21 Surface analysis from 12Z Friday, August 14, 1987.

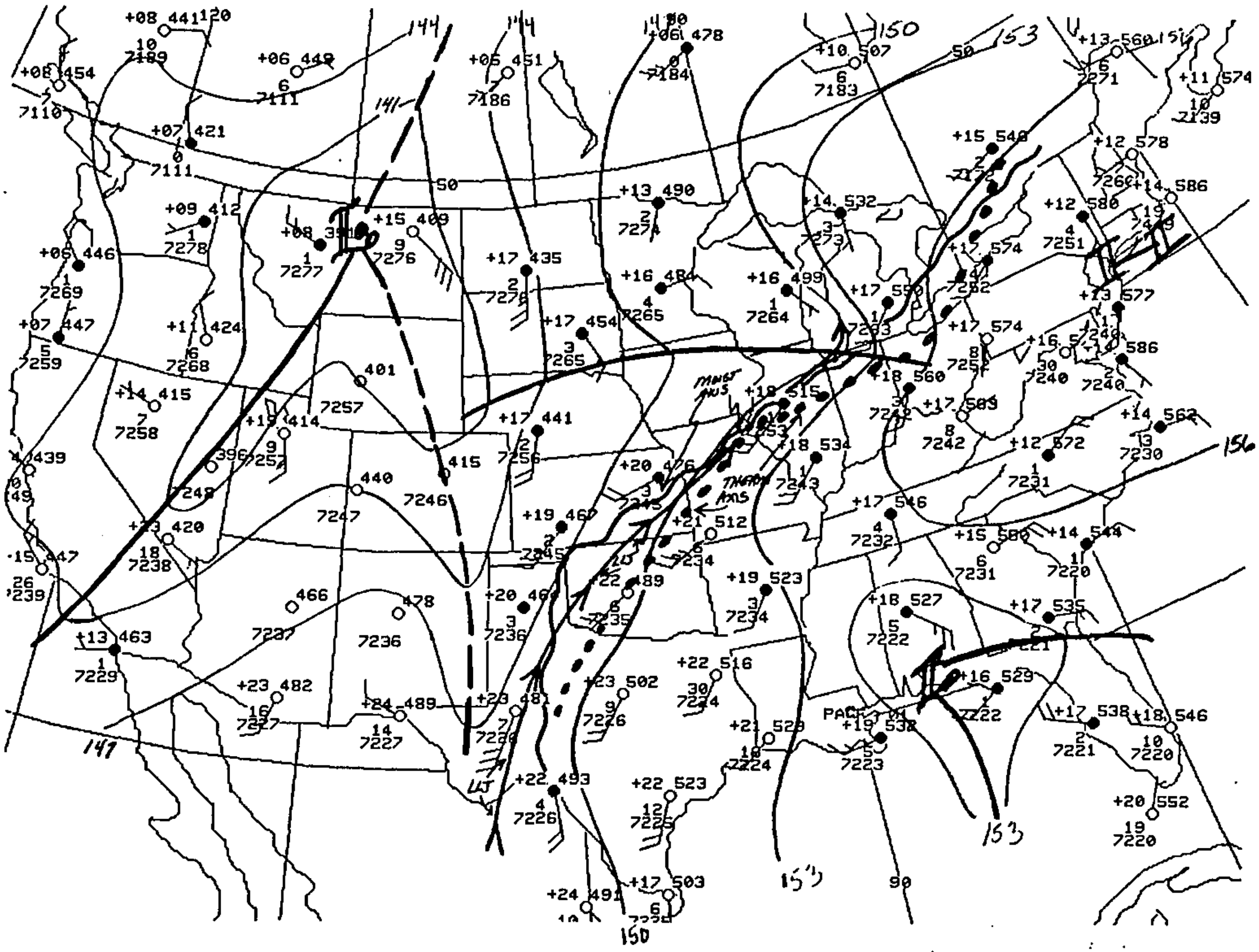


Fig. 22 850 MB analysis from 12Z Friday, August 14, 1987.

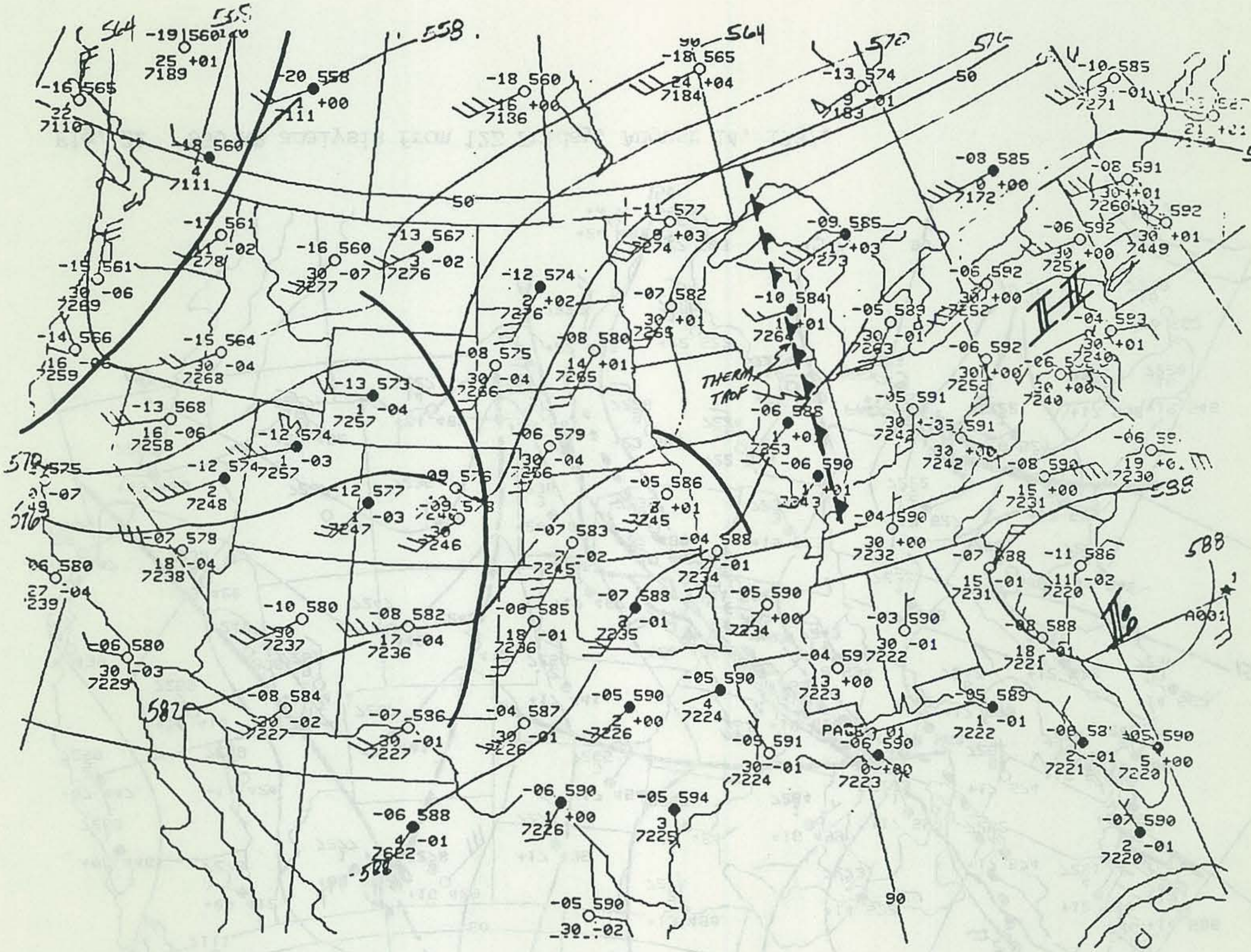


Fig. 23 500 MB analysis from 12Z Friday, August 14, 1987.

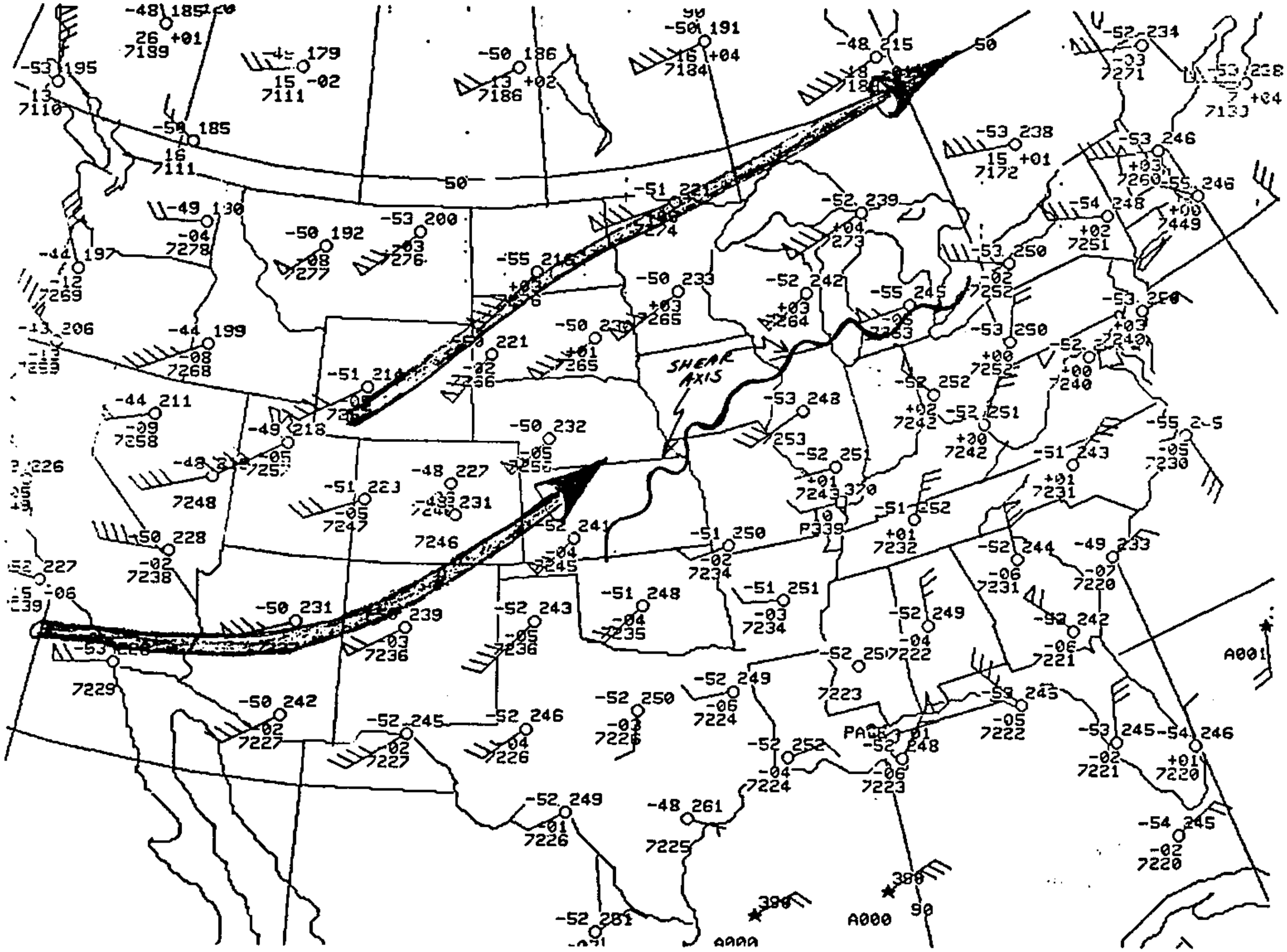


Fig. 24 200 MB analysis from 12Z Friday, August 14, 1987.

As an example, let's begin with the 0031 UTC satellite picture from August 14, 1987 (Fig. 19). By this time, convection had already become quite active in a well defined band extending from the Big Bend area of Texas northeast in an arc through southwest Missouri to central Illinois. Small convective clusters were embedded in this area with the northernmost cluster approaching northeast Illinois. Satellite continuity up to this time indicated that the arc of convection had been quasi-stationary and was formed by synoptic conditions discussed in the previous section. Most notable, however, was the apparent influence of the developing 850 mb jet and associated high thermodynamic values. Note the inflow tails on many of the clusters over the Southern Plains. Given the large scale set up portrayed by the 0031 UTC imagery and the fact that the vertical motion field in this zone of convection was primarily triggered by low level advective processes, it should come as no surprise that nocturnal convection would be quite active during the next 12 hours resulting in locally heavy rainfall amounts.

The steady northeast progress of individual thunderstorm cells during the evening of August 13 could easily by traced by both satellite imagery and radar (see Figs. 25 and 26).

At roughly 2115 CDT, the leading cluster of thunderstorms hit O'Hare Airport, as the rainfall trace in Figure 27 indicates. The trace graphically illustrates that the 12 hour rainfall event was actually broken up into three distinct phases or episodes. Phase one commenced with the onset of the heavy thunderstorm cluster that had moved up from central Illinois.

Take particular note, at this time, of the apparent passage of the strongest cell to the west and north of the Chicago Metropolitan area (see Fig. 28).

Based on the methodical northeast movement and longevity of this initial thunderstorm feature, it is safe to say that it was synoptically triggered and forecastable in the short term. True, 2.51 inches of rain, most of which fell in a little over an hour, is impressive. But this is not awe-inspiring considering the type of air mass involved, not is it an exceptional amount for an area receiving a direct hit by a summertime thunderstorm.

The passage of the phase one thunderstorm caused only very temporary urban and street flooding. Rainfall tapered off by 2230 CDT for what would have appeared to be the start of a lull in the thunderstorm activity of at least six hours duration based on extrapolation of thunderstorm activity over central and northern Missouri (Fig. 29). But, as fate would have it, this was not to be the case.

Referring to the 0601 UTC satellite photo (Fig. 30), some development is noted over extreme southeast Iowa and northwest Illinois, but still nothing to effect the Chicago area for several hours. By 0631 UTC (Fig. 31), thunderstorms began to develop back over northwest sections of Chicago. Referring once again to the O'Hare rainfall trace, we see that phase two began about 0115 CDT and continued until 0230. During this time, rainfall amounted to another 3.27 inches for a total of 5.94 inches in just under six hours. It is phase two which is of particular interest since the forecaster had little or no indication

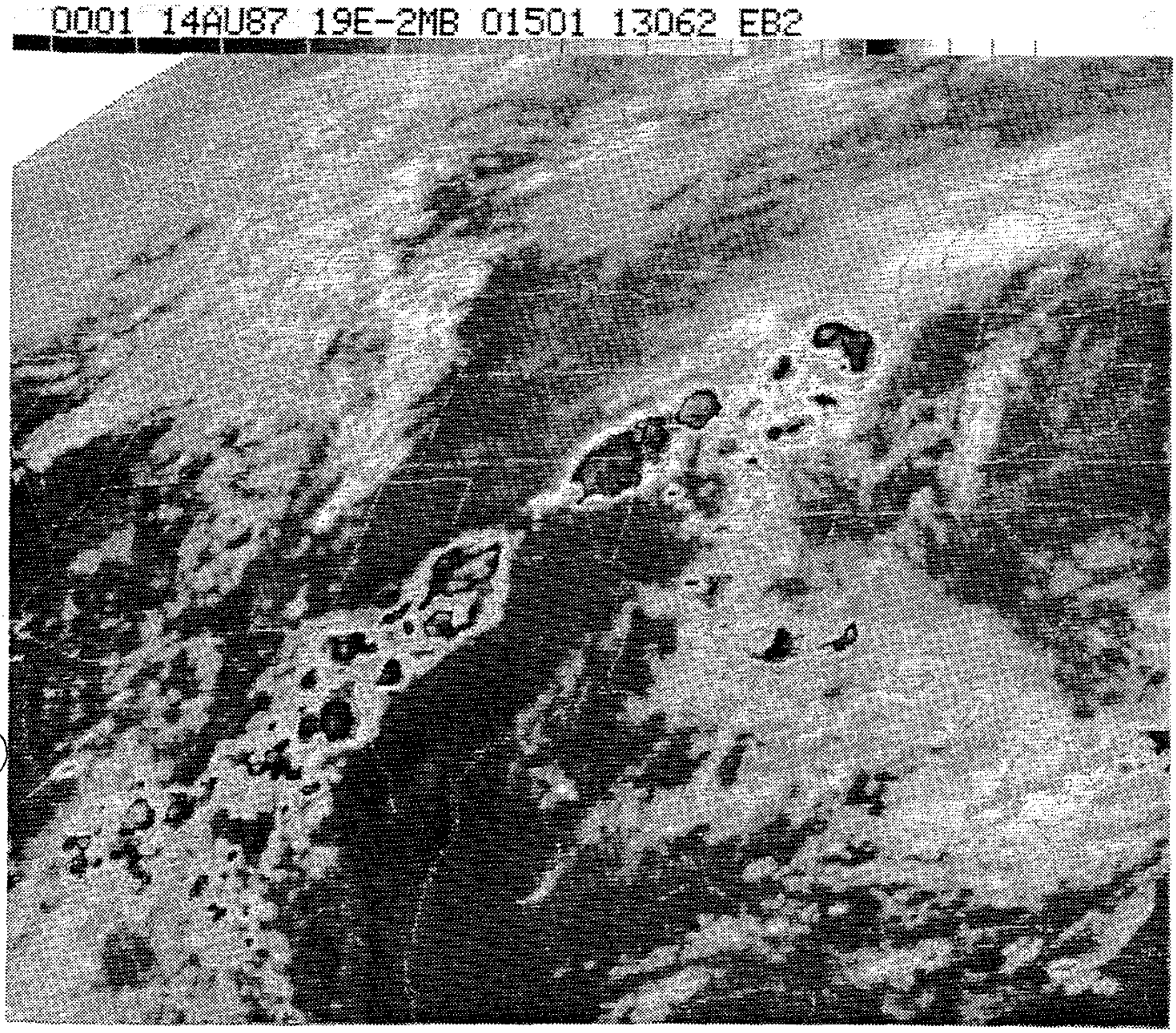


Fig. 25a GOES E IR imagery with MB enhancement Friday, August 14, 1987 from 0001Z.

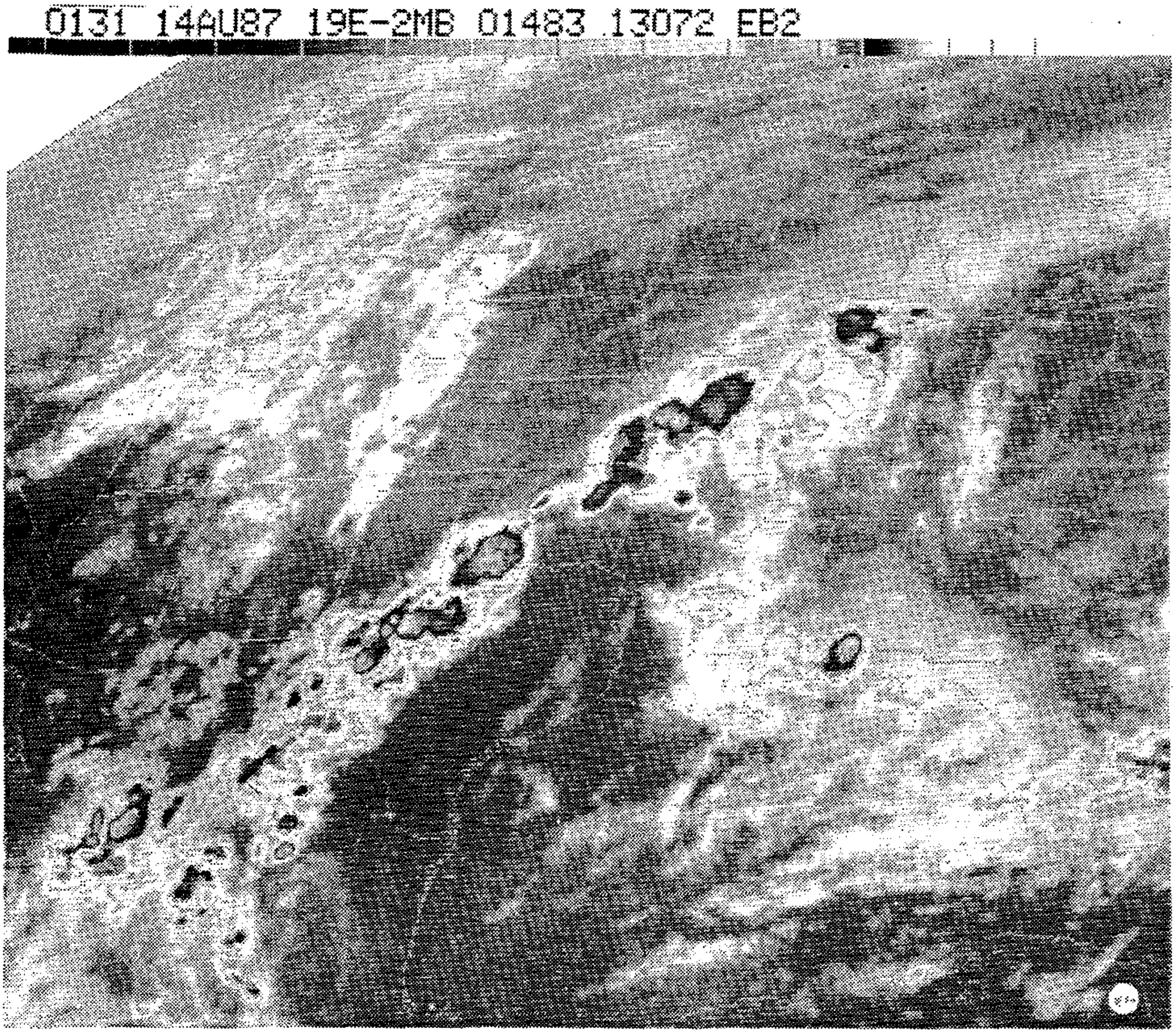


Fig. 25b GOES E IR imagery with MB enhancement Friday, August 14, 1987 from 0131Z.

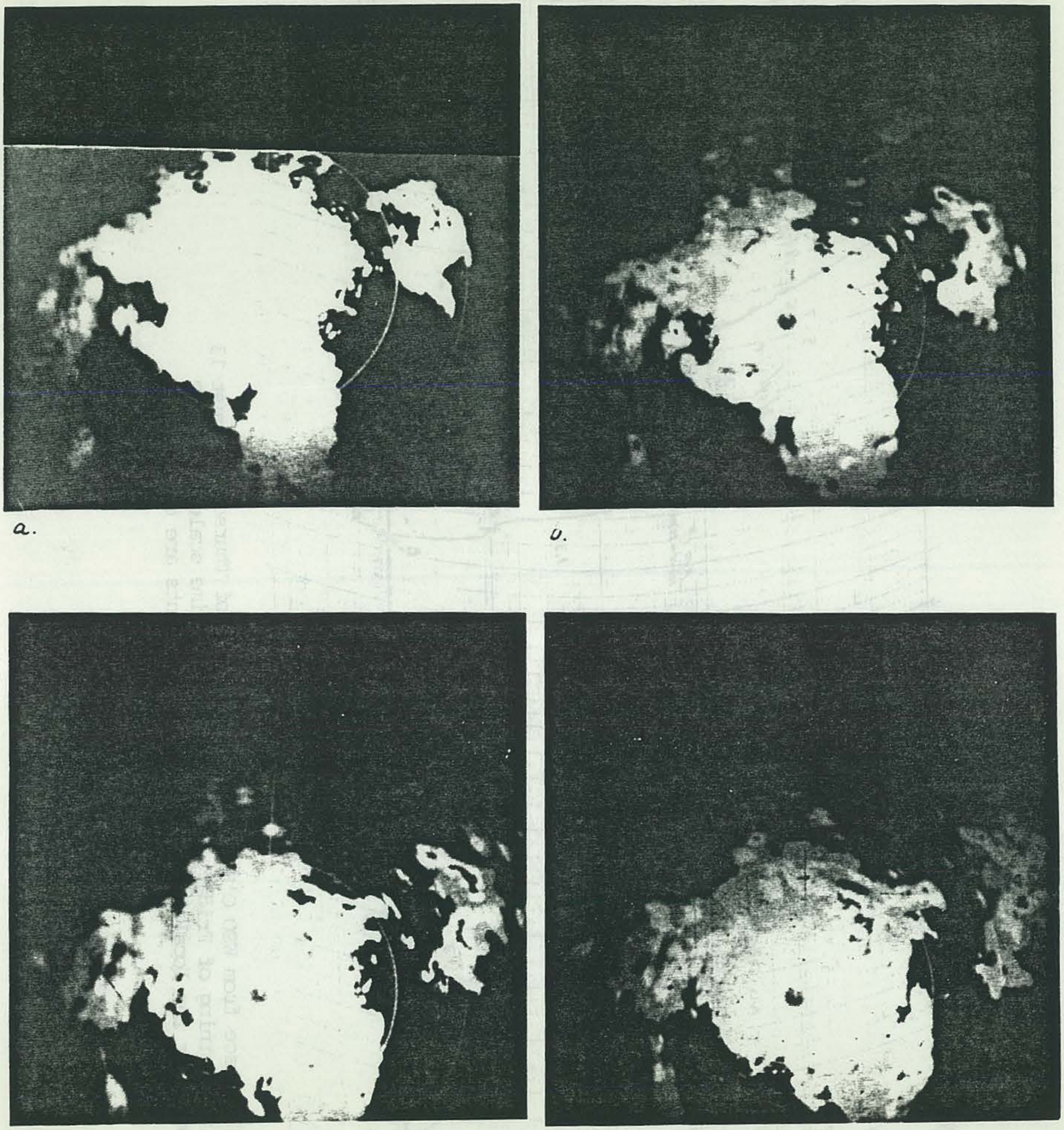


Fig. 26 Photos taken from WSR-57 at MMO Friday, August 14, 1987 at: (a) 0014Z, (b) 0047Z, (c) 0117Z, and (d) 0147Z.

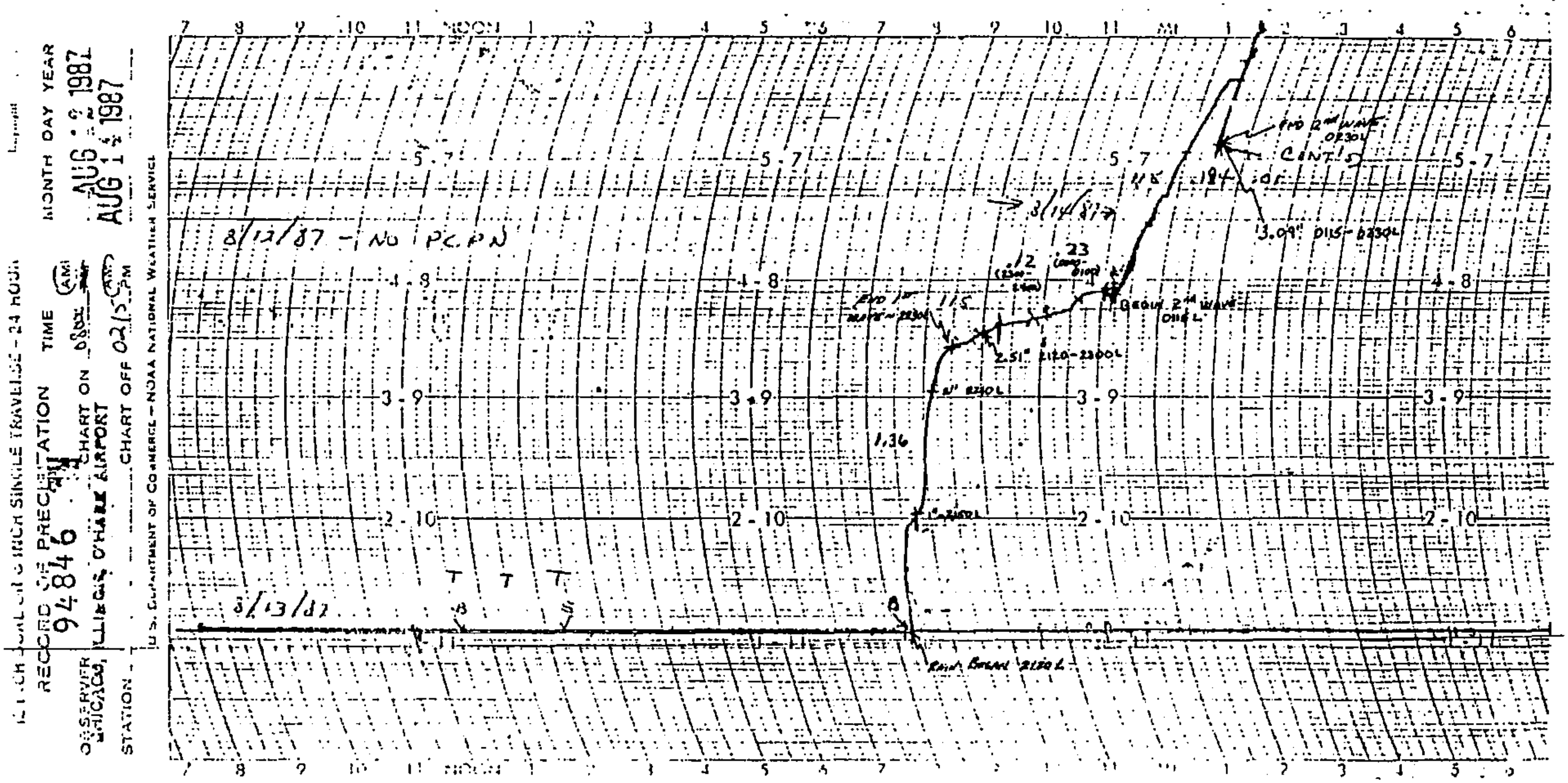
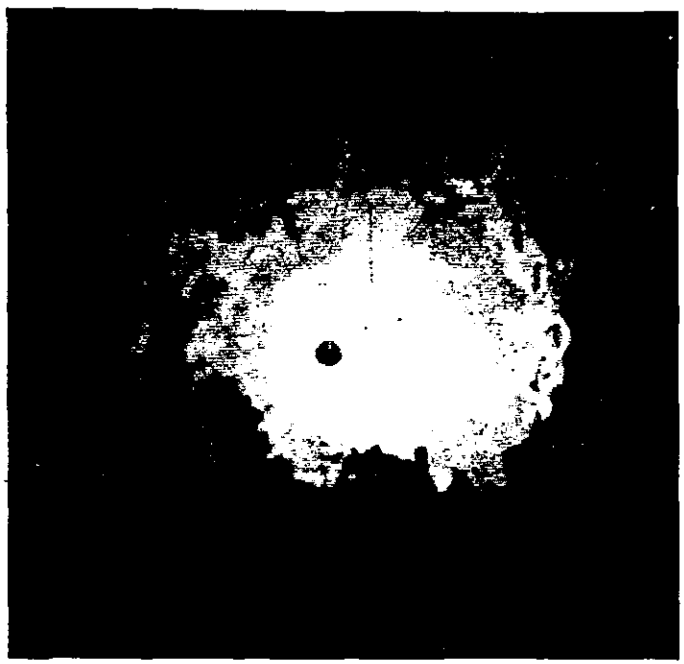


Fig. 27 Rainfall trace from WSO O'Hare from the evening of Thursday, August 13 and early morning of Friday, August 14, 1987. Time scale is in CST (add one hour for local time). Rainfall increments are every .05 inch.

a.

b.



c.

d.

Fig. 28 Photos taken from WSR-57 at MMO Friday, August 14, 1987 at: (a) 0216Z, (b) 0231Z, (c) 0243Z, and (d) 0250Z.

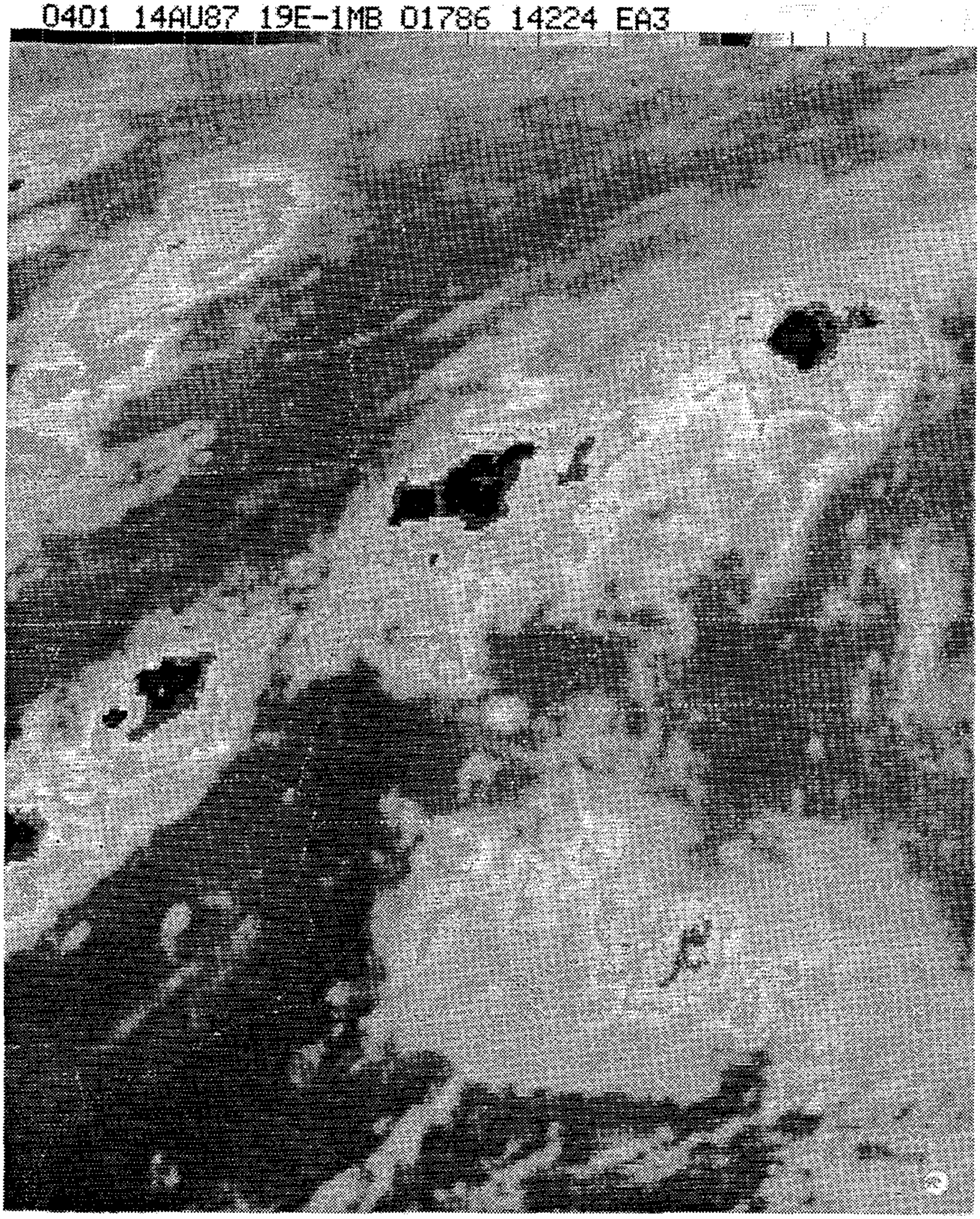


Fig. 29 GOES E IR imagery with MB curve from 0401Z Friday, August 14, 1987.

Fig. 30 GOES E IR imagery with MB curve from 0601Z Friday, August 14, 1987.

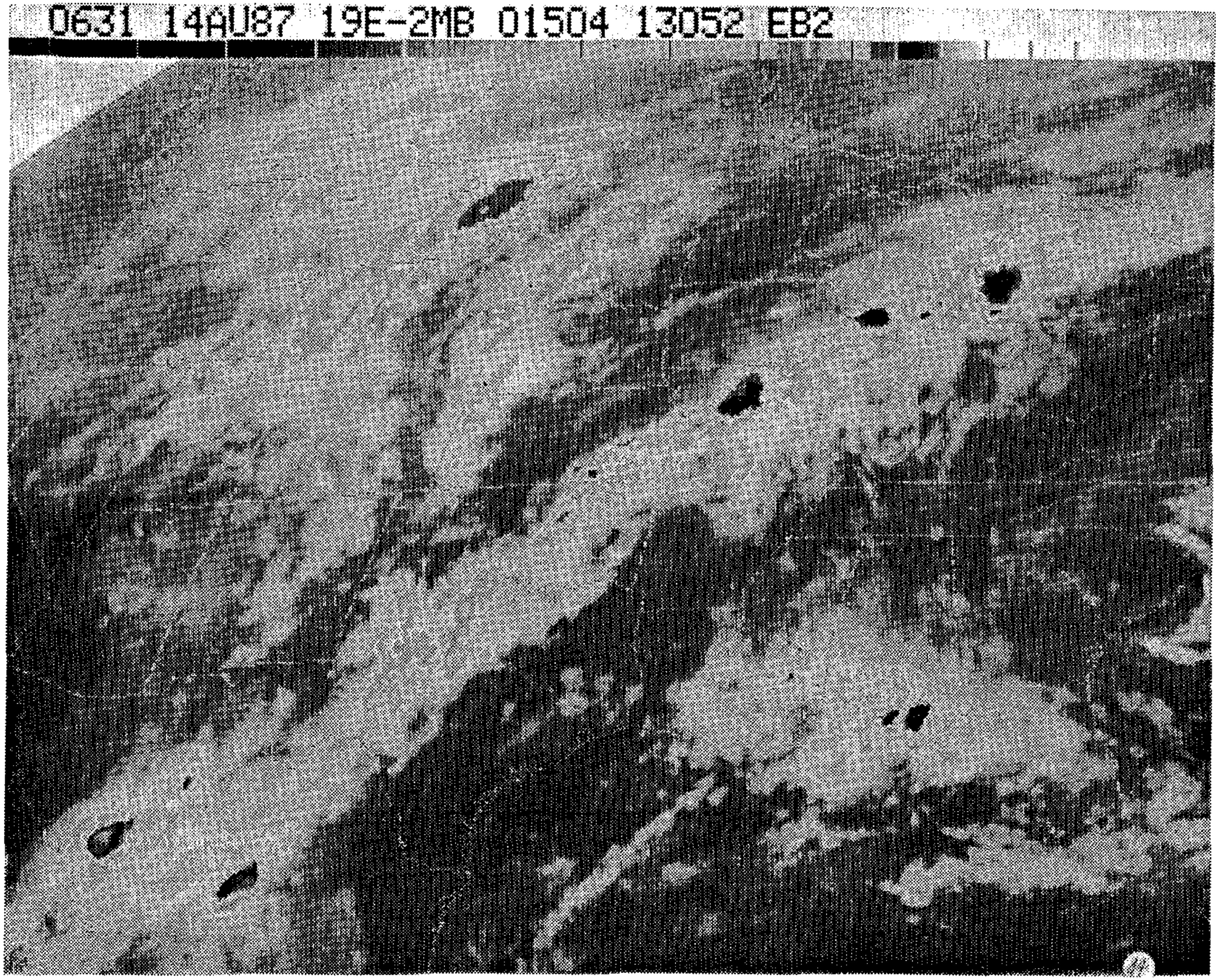


Fig. 31 GOES E IR imagery with MB enhancement from 0631Z Friday, August 14, 1987.

that a second excessive rainfall episode was about to occur. Furthermore, radar echo tops and reflectivities, as well as IR imagery, did not look impressive considering the intensity of rainfall. This again displays the tropical nature of these storms. Also, development was sudden and movement unrepresentative of the synoptic scale flow field. By following satellite and radar pictures from 0631 UTC through 1000 UTC (Figs. 32 through 36), it becomes apparent that this second precipitation episode was meso-induced. Radar displayed especially well the quasi-stationary precipitation "plume" feature responsible for the excessive rainfall.

One possible explanation for this point source is that the low level inflow and subsequent lift was enhanced by a boundary left in the wake of the strong thunderstorm cell associated with phase one, the core of which passed just to the west and north of where the plume echo was to develop. More specifically, the low level jet was intersecting a convergence line set up by the rear flank of the initial thunderstorm cluster. This explains the tendency for development back into the moist low level flow and the position of the point of plume generation. Another possible explanation would simply be that this was the point of intersection between the low level jet and the 850 mb front (trough). The latter scenario seems a little less plausible though since such a feature would be bordering on the synoptic size scale, whereas in reality, radar pictures show the point of plume generation to the south-southeast of O'Hare to be about five nautical miles wide! Furthermore, the primary channel of new convective growth was taking place over northwest and west-central Illinois.

From 0300 to 0700 CDT, only trace amounts of rain fell at the O'Hare observation site. Also indicated by the satellite photos and corresponding radar pictures through 1000 UTC was heavy thunderstorm activity tracking northeast through north central Illinois and extreme southeastern Wisconsin. This activity was associated with the main channel of low level warm advection. It appeared that the area already deluged by two heavy precipitation episodes would be spared long enough to allow for an appreciable amount of runoff. Flash flood guidance for the affected areas of northwest Cook and Du Page counties gave a critical rate of six inches in 12 hours. In fact, widespread urban and street flooding was now in progress and a number of small streams and creeks were running at bankfull. By 0500 CDT, satellite and radar data had begun to hint at imminent disaster for the area around O'Hare Airport. The line of heavy convection to the west and north of the metropolitan area which had been moving northeast was beginning to lay over into a west-to-east orientation, thus closing in on the northwest suburbs of Chicago and the upper reaches of the Des Plaines and Fox River drainage basins (Fig. 37).

This was probably a reflection of the anticyclonic curvature of the mid and upper tropospheric flow around the subtropical high circulation. At 0530 CDT a flash flood warning was issued and at 0715 CDT the third and final precipitation phase began (Figs. 38 and 39).

This, as expected, was the proverbial straw that broke the camel's back. In the ensuing 1 1/2 to two hours another 3.01 inches of rain fell at O'Hare. The heavy rain sent creeks and rivers in the area gushing out of their banks.

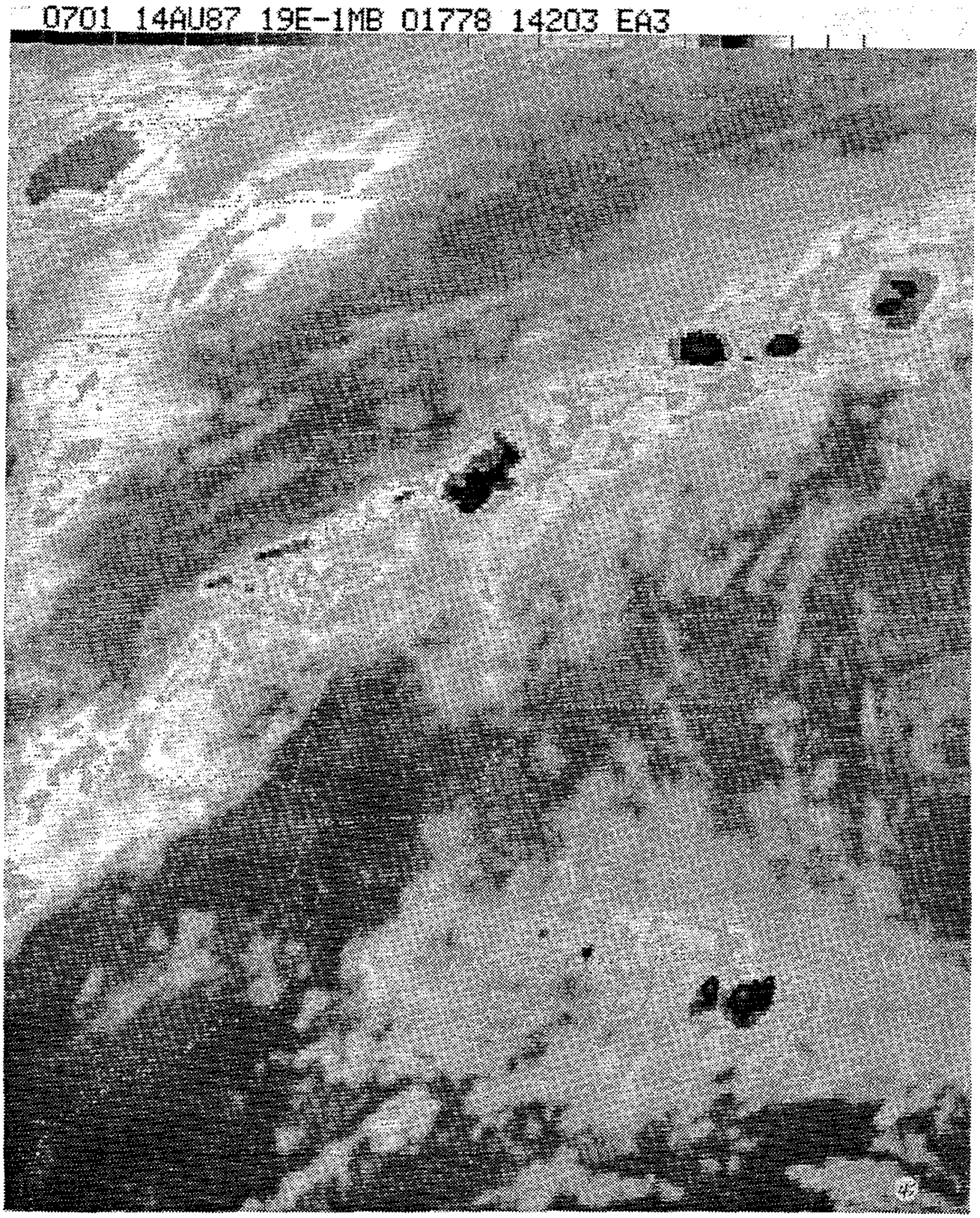


Fig. 32a GOES E IR imagery with MB enhancement Friday, August 14, 1987 from 0701Z.

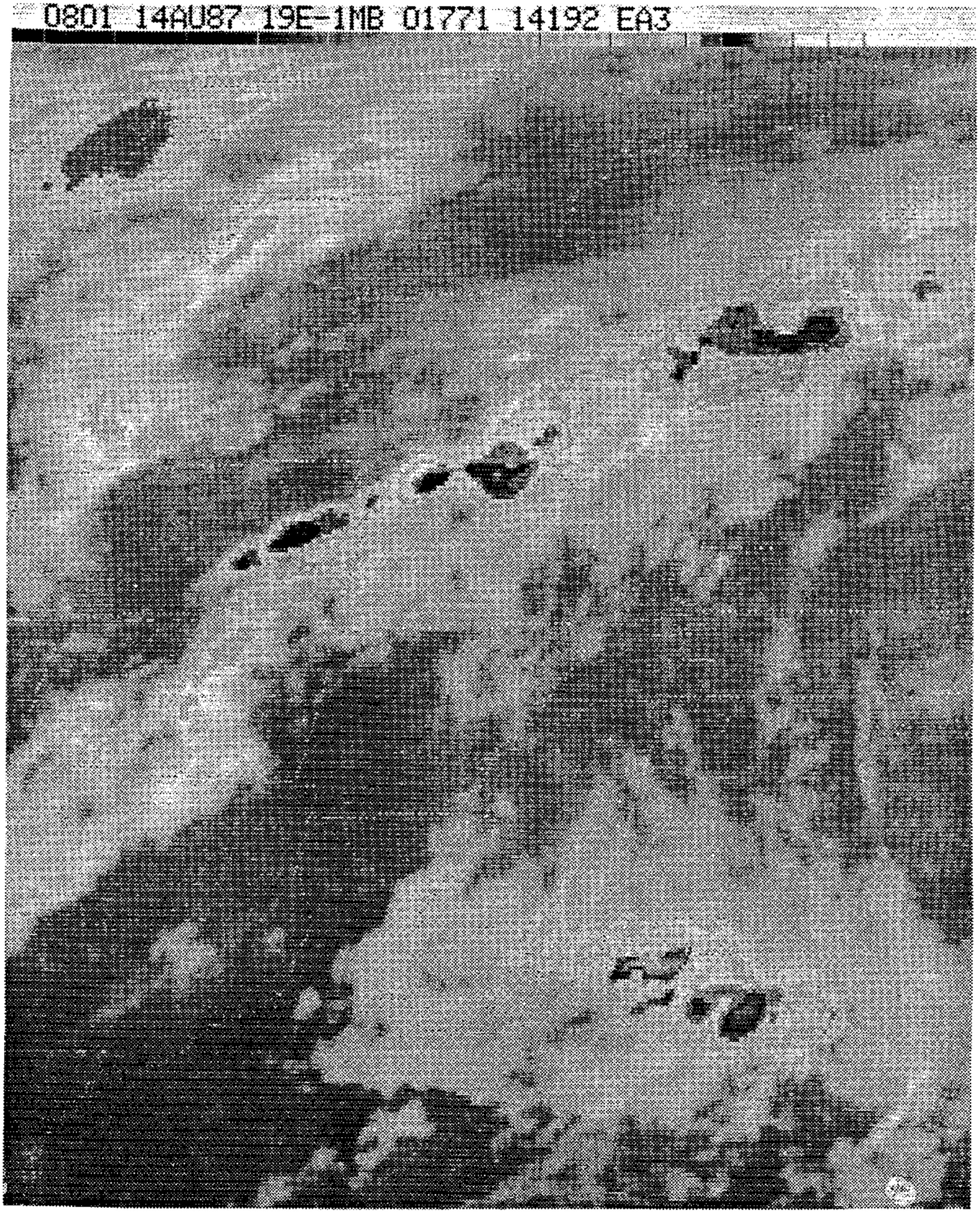


Fig. 32b GOES E IR imagery with MB enhancement Friday, August 14, 1987 from 0801Z.

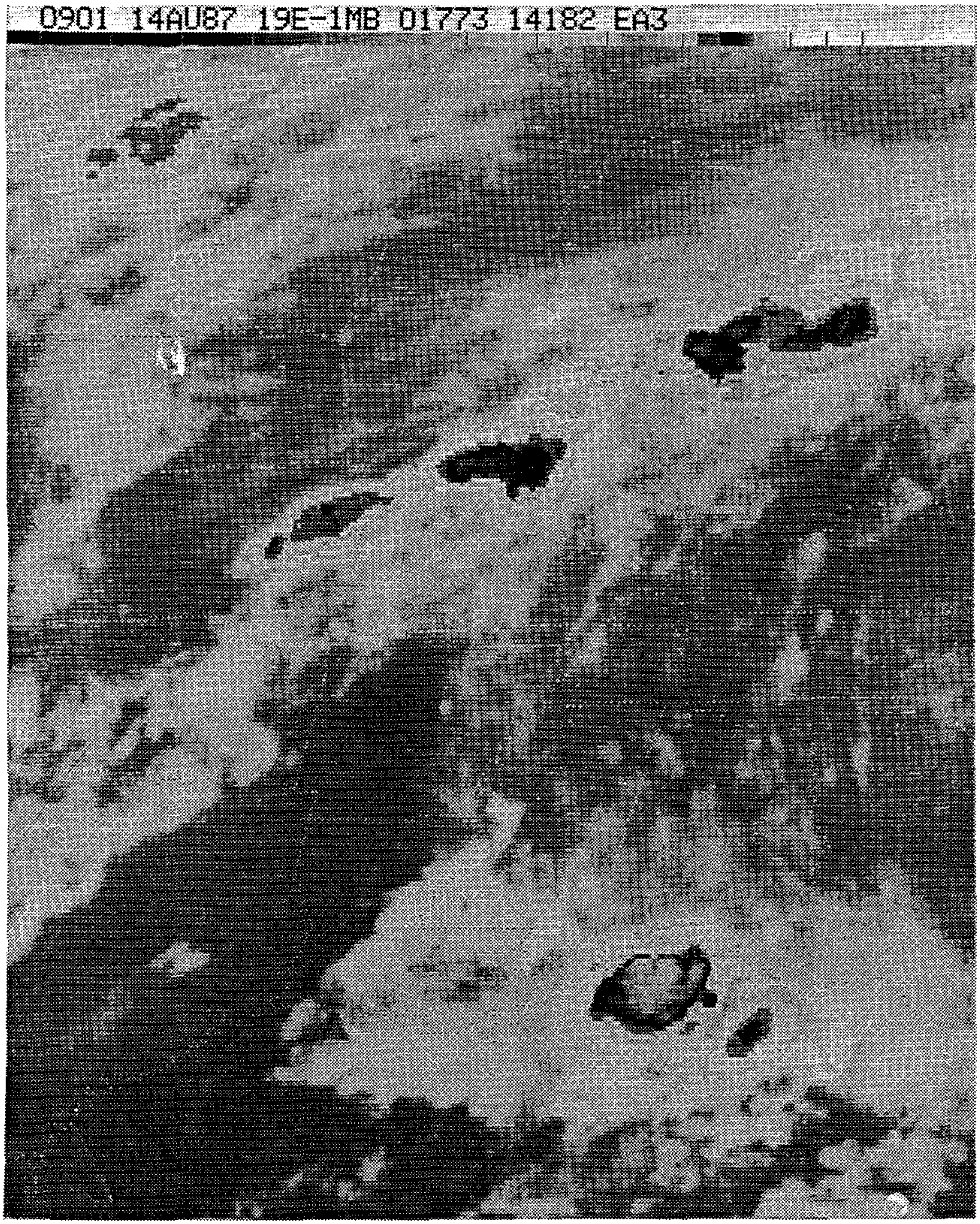


Fig. 32c GOES E IR imagery with MB enhancement Friday, August 14, 1987 from 0901Z.

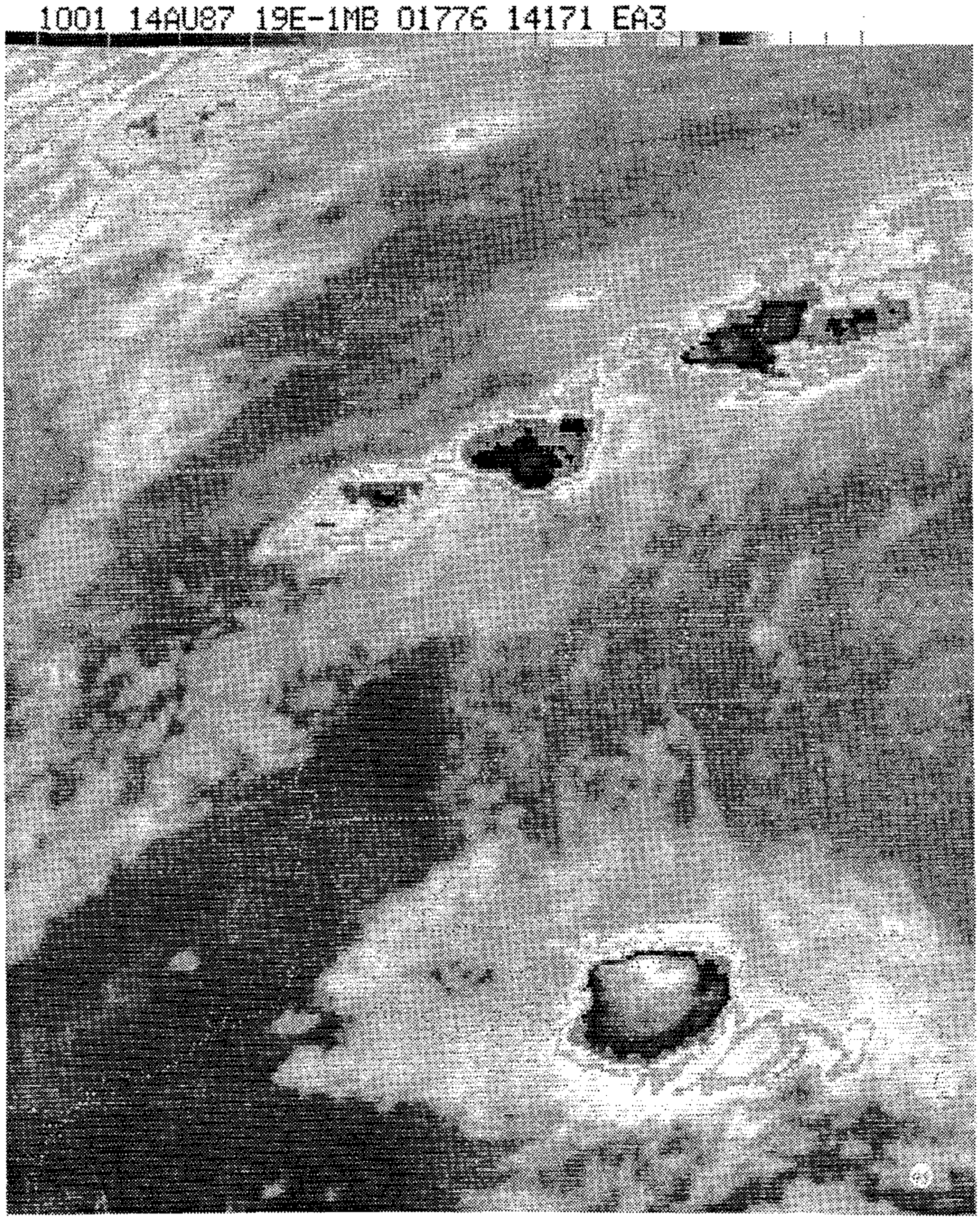


Fig. 32d GOES E IR imagery with MB enhancement Friday, August 14, 1987 from 1001Z.

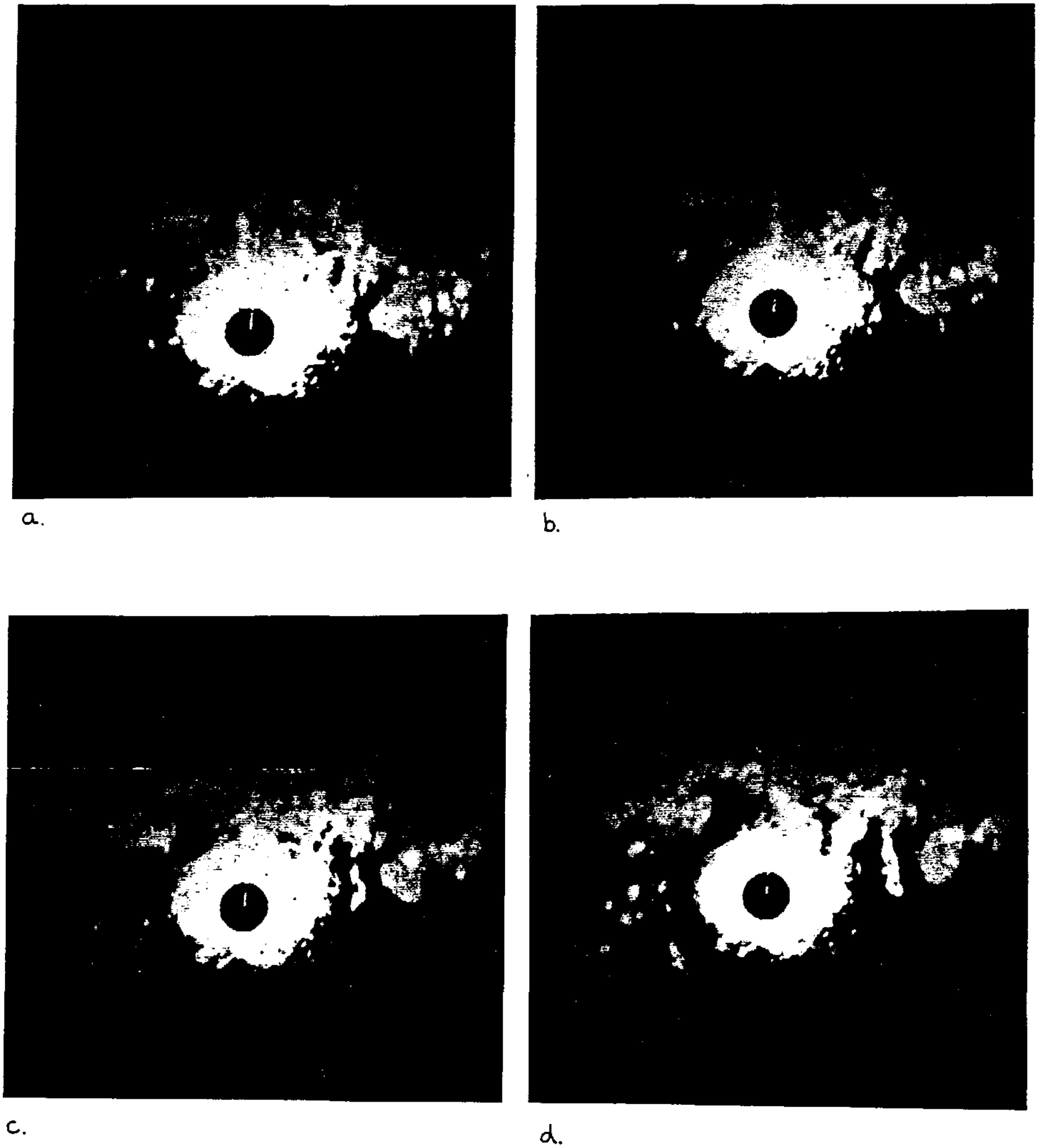
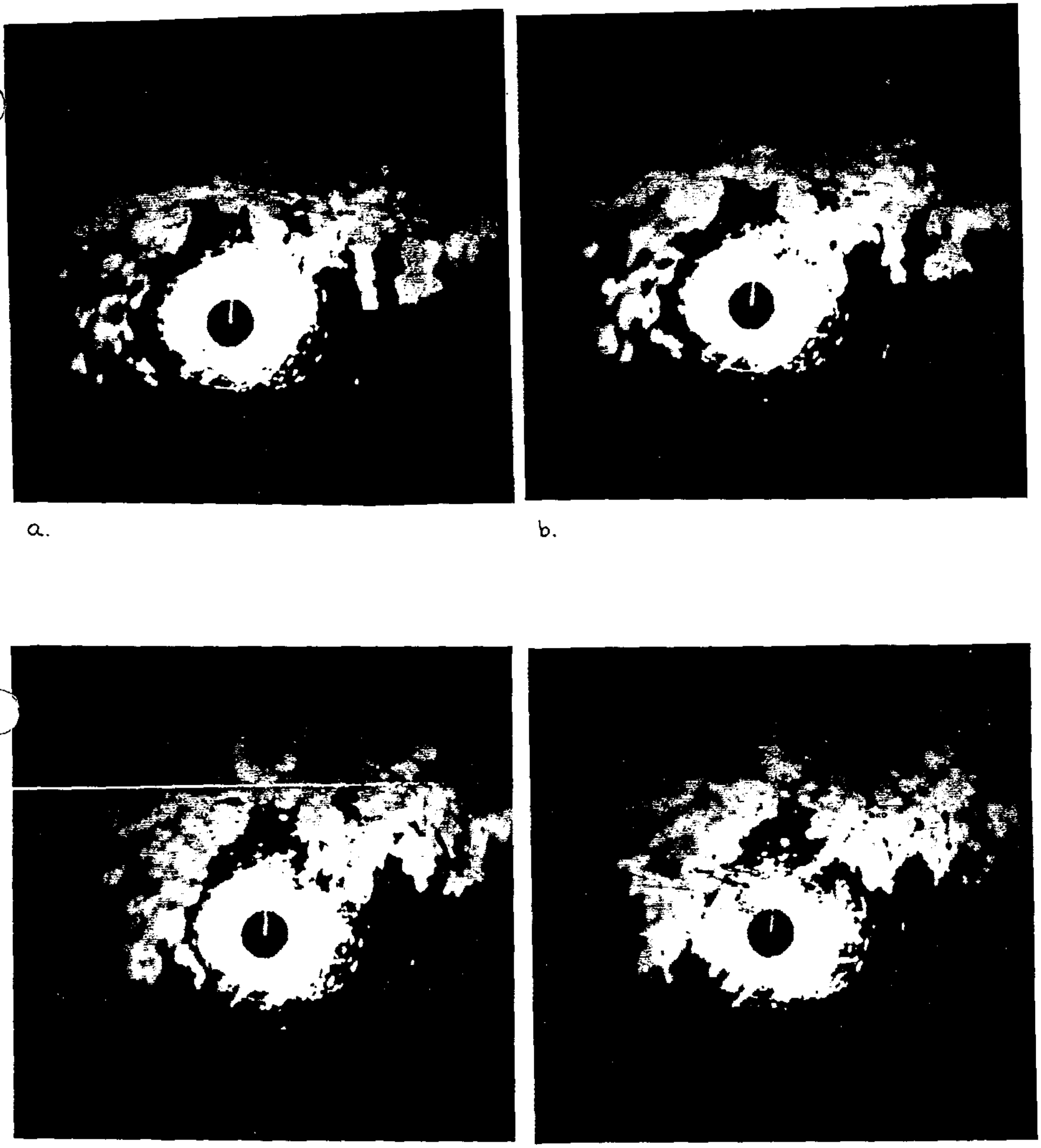
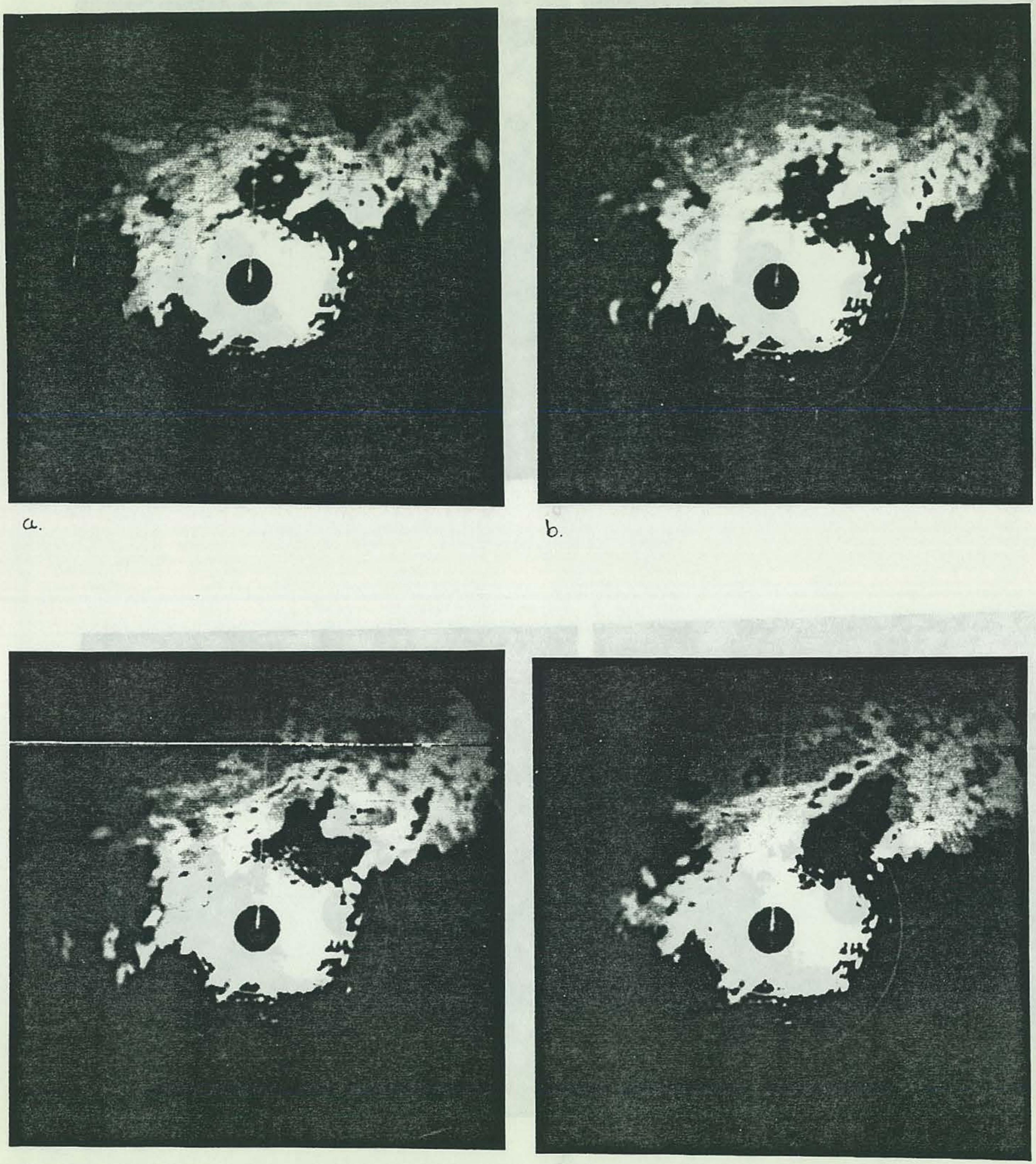


Fig. 33 Photos taken from WSR-57 at MMO Friday, August 14, 1987 at: (a) 0546Z, (b) 0556Z, (c) 0616Z, and (d) 0631Z.



a. b. c. d.

Fig. 34 Photos taken from WSR-57 at MMO Friday, August 14, 1987 at: (a) 0646Z, (b) 0657Z, (c) 0714Z, and (d) 0732Z.



a. b. c. d.

Fig. 35 Photos taken from WSR-57 at MMO Friday, August 14, 1987 at: (a) 0747Z, (b) 0802Z, (c) 0818Z, and (d) 0844Z.

a.

b.

Fig. 36 Photos taken from WSR-57 at MMO Friday, August 14, 1987 at: (a) 0915Z, and (b) 0945Z.

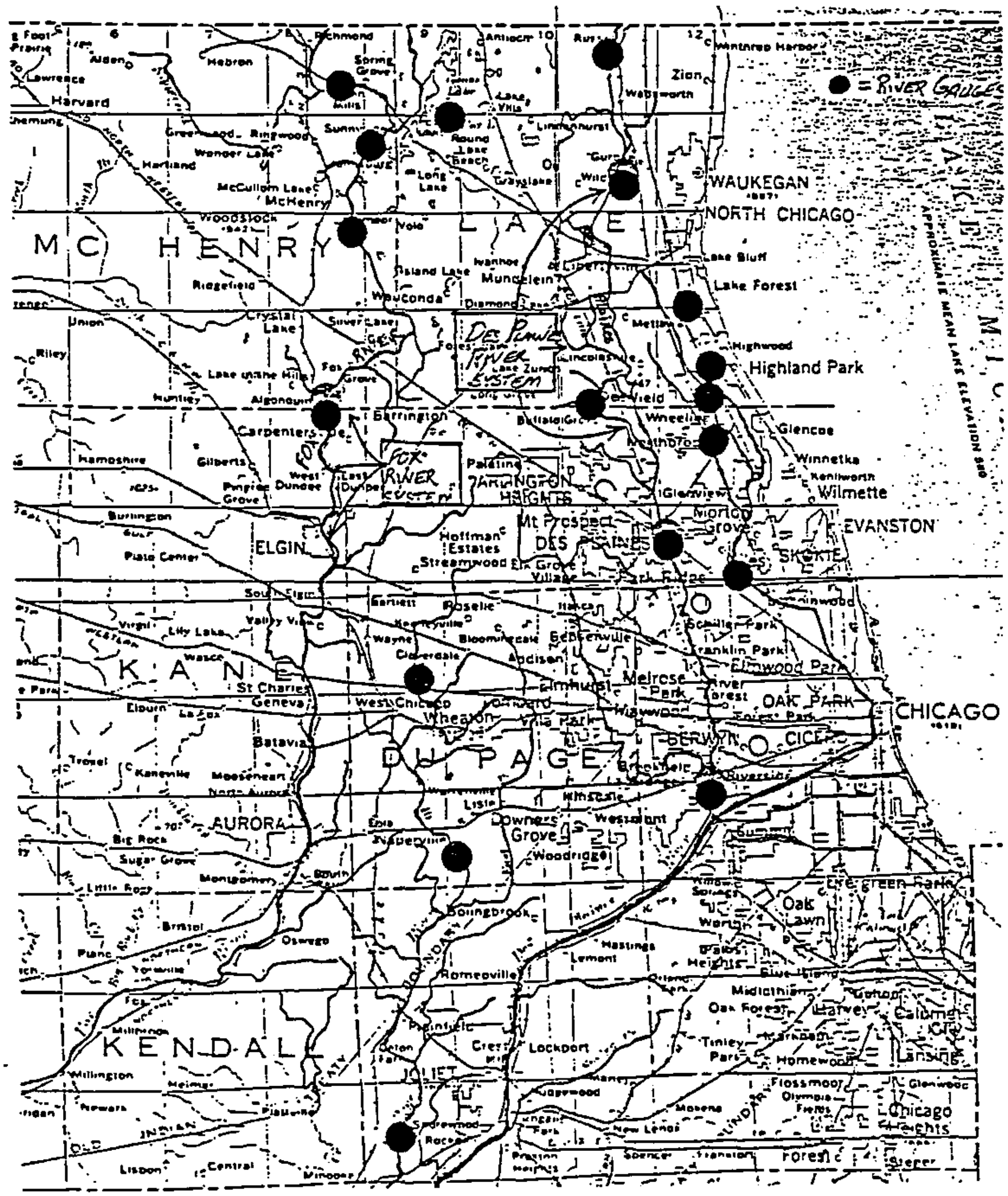


Fig. 37 Map depicting the drainage basins of northeast Illinois.

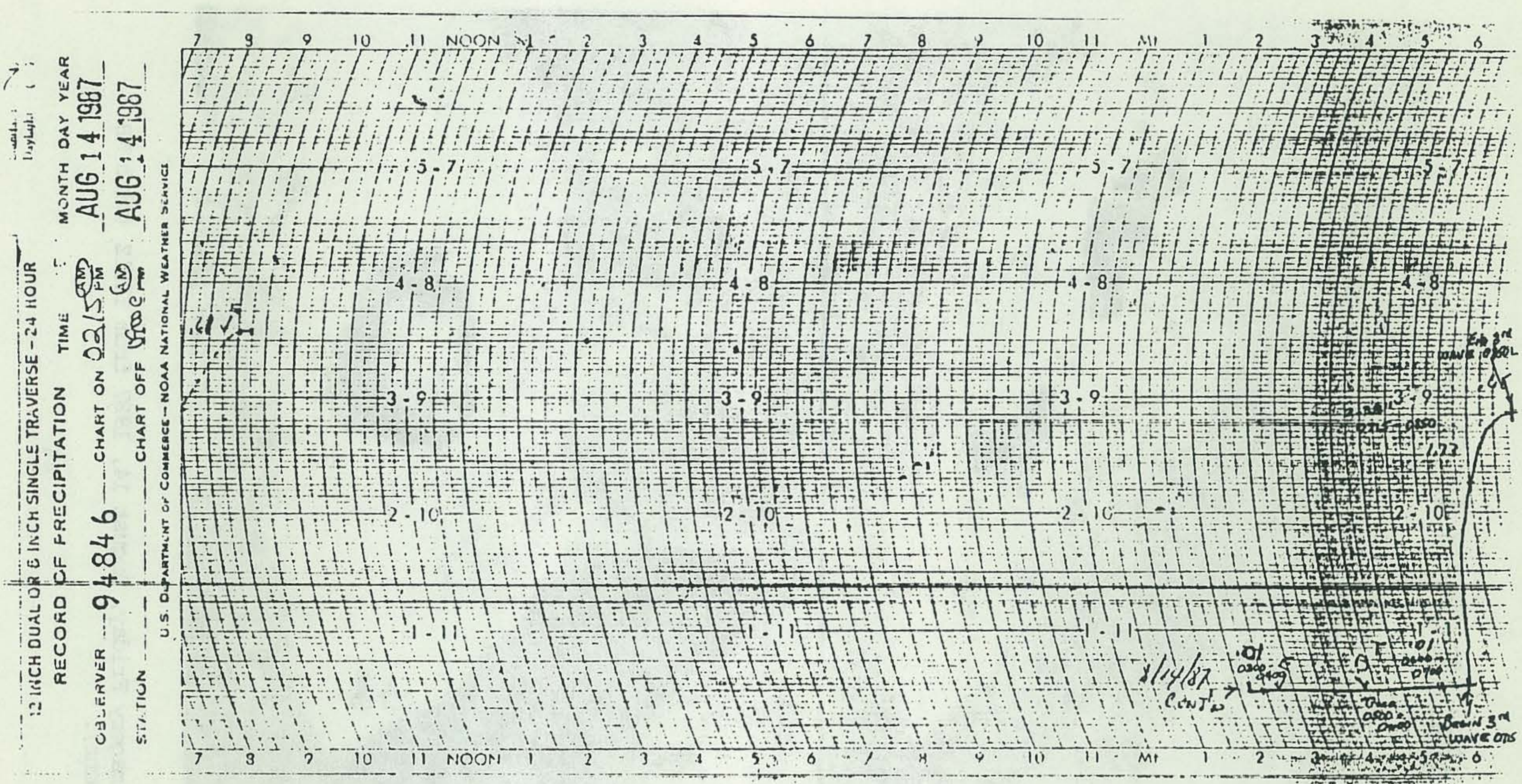


Fig. 38 Segment of the rainfall trace from O'Hare Airport showing the rainfall rate during the third heavy precipitation episode.

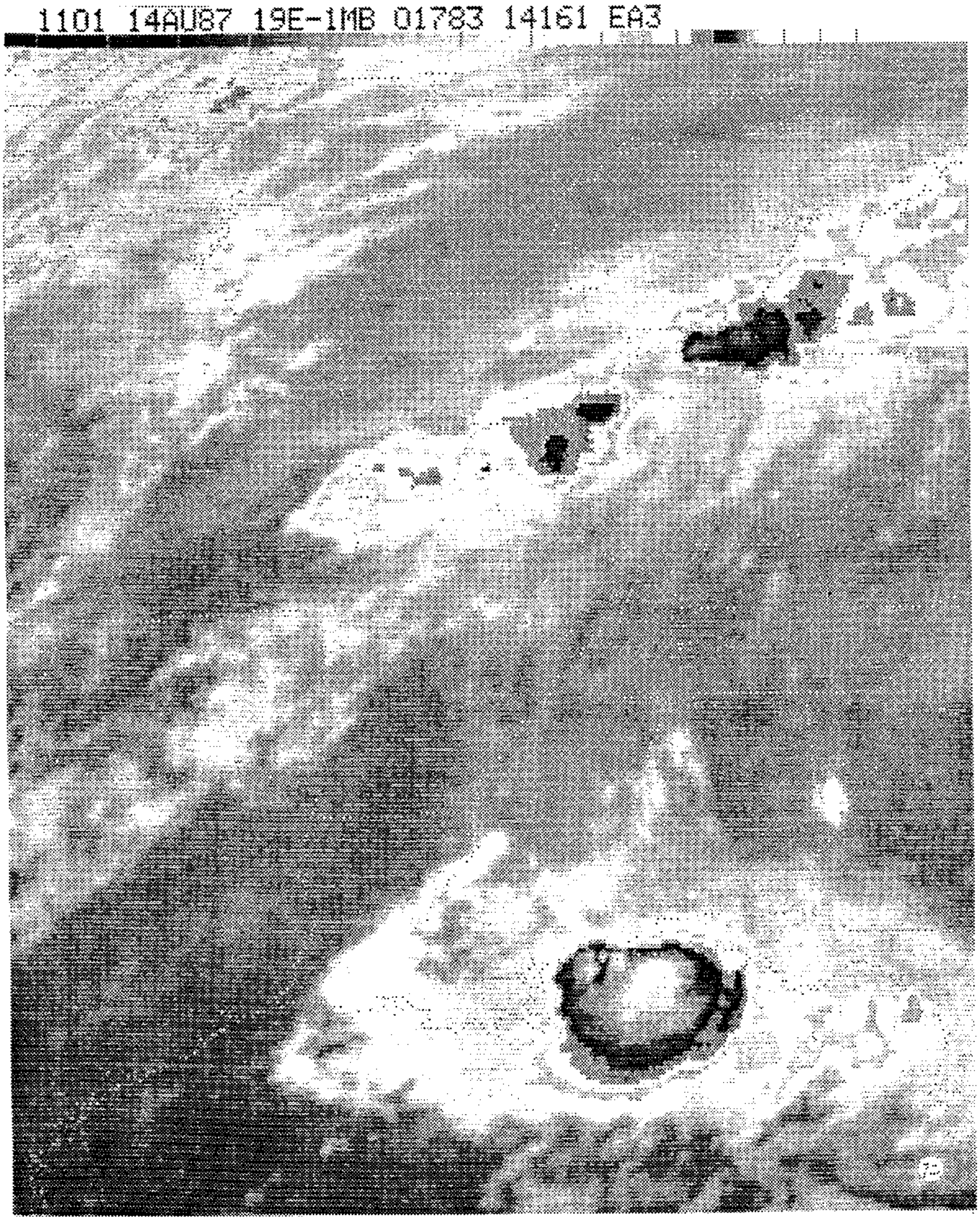


Fig. 39a GOES E imagery Friday, August 14, 1987 from 1101Z (with MB enhancement).

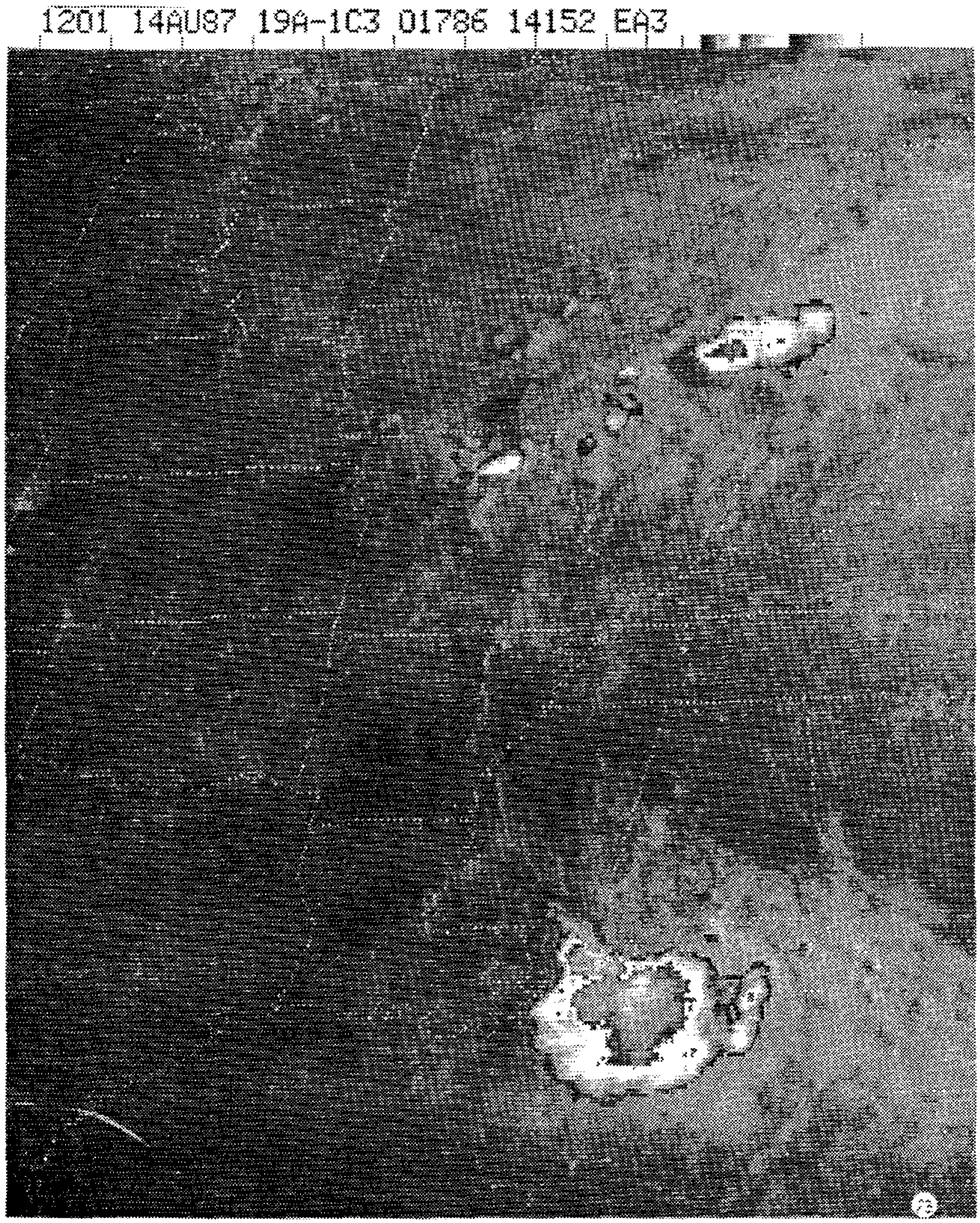


Fig. 39b GOES E imagery Friday, August 14, 1987 from 1201Z with C3 threshold IR enhancement.

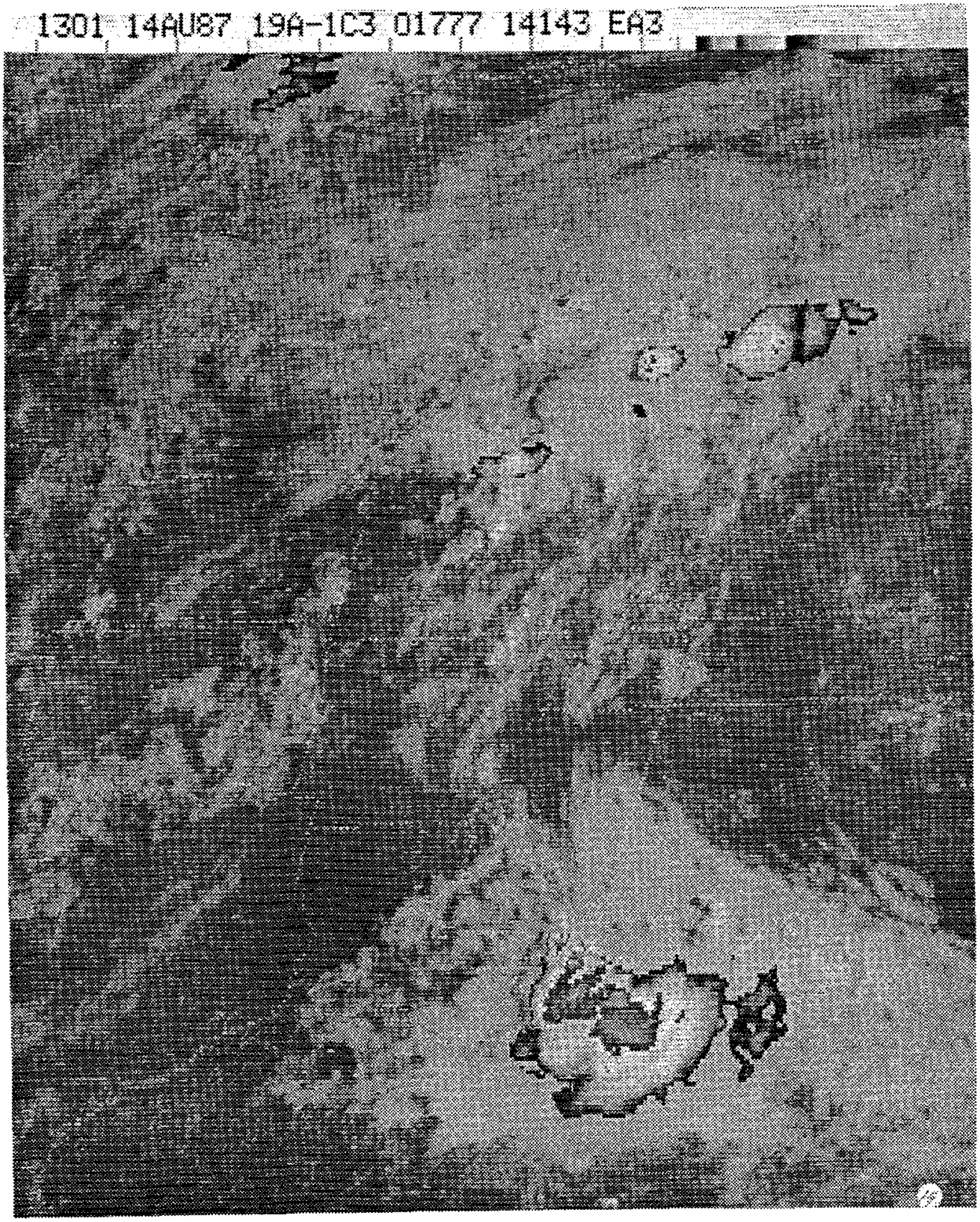


Fig. 39c GOES E imagery Friday, August 14, 1987 from 1301Z with C3 threshold IR enhancement.

Major thoroughfares became life-threatening currents and one of the world's busiest airports became an isolated island.

By late morning, convection had begun its diurnal decay. Only light rainfall amounts were reported the remainder of the day (Fig. 40).

The following map and series of photographs are provided to illustrate the location and extent of the flooding (Figs. 41 and 42).

4. Concluding Remarks

The data compiled for this study provide a good example of how synoptic scale trigger mechanisms may be readily detectable while small scale development of intense convection remains an obscure phenomena in terms of real time forecasting. That is, such events may actually be made up of two or more very localized storms resulting from a myriad of causes undetectable by conventional means. In dealing with events of this nature, one must not only consider the basic synoptic set up but also take into consideration the type of air mass involved. This may indicate an enhanced potential for an extreme precipitation event that could be reflected in a local forecast despite unrepresentative rainfall rates as indicated by radar or satellite.

During extreme weather events, surface observations are important. Fortunately, the O'Hare WSO was in one of the core areas of precipitation with the observer on duty relaying rainfall amounts to the forecast office. Such observations help the forecaster make critical assessments of a flood situation when non-meteorological variables such as soil permeability, runoff capability, etc., are unfamiliar or not readily known.

I would like to note, also, that the SWIS unit was an extremely valuable tool. Because of its looping capability, convective intensity and organization could be followed through the synoptic flow pattern. This capability aided in the issuance of a flash flood warning with a nearly two hour lead time.

In the future, it is quite obvious that the availability of VAS data to the field sites will also aid in the flash flood problem, although to what extent remains to be proven.

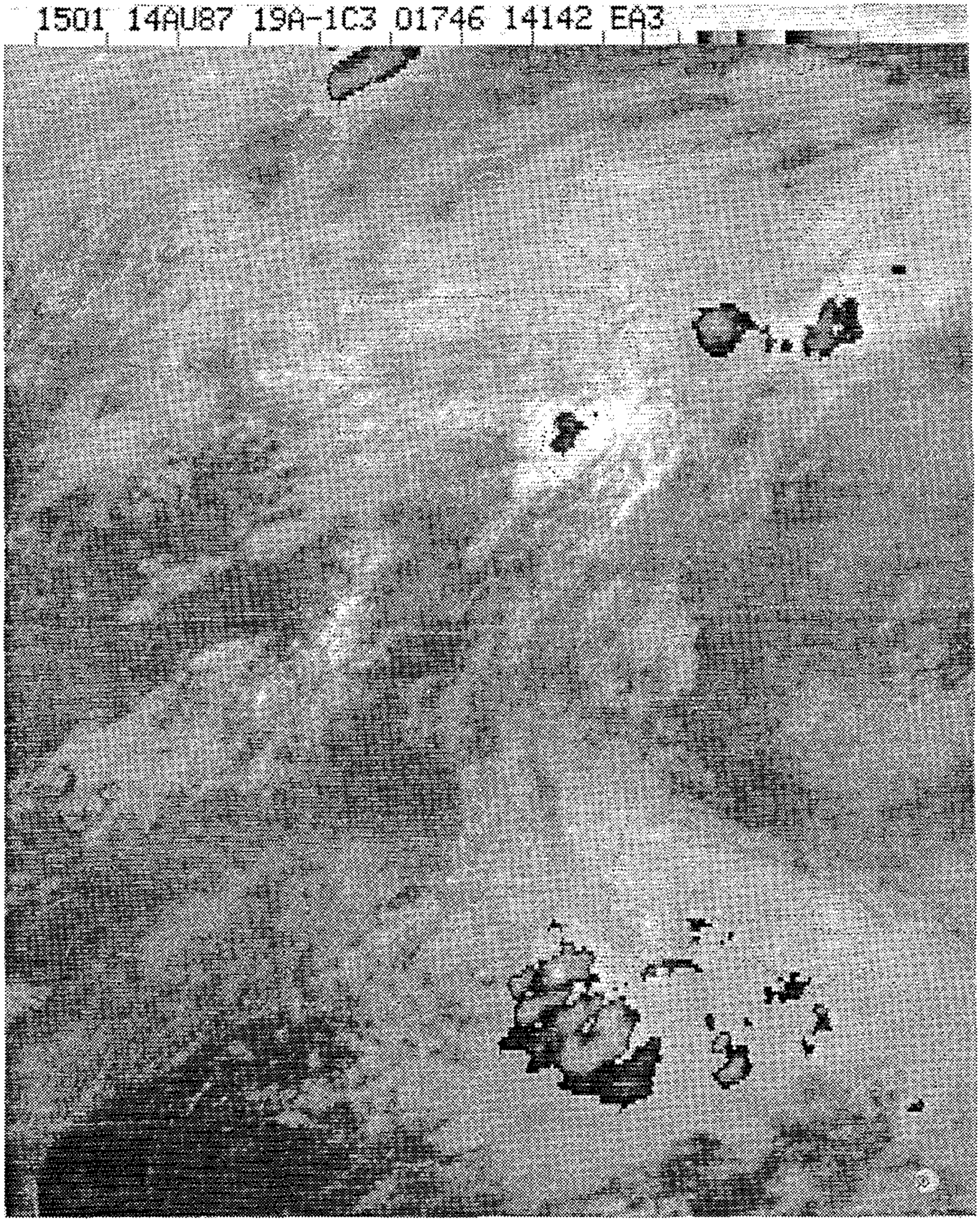


Fig. 40a GOES E imagery Friday, August 14, 1987 with C3 threshold IR enhancement for 1501Z.

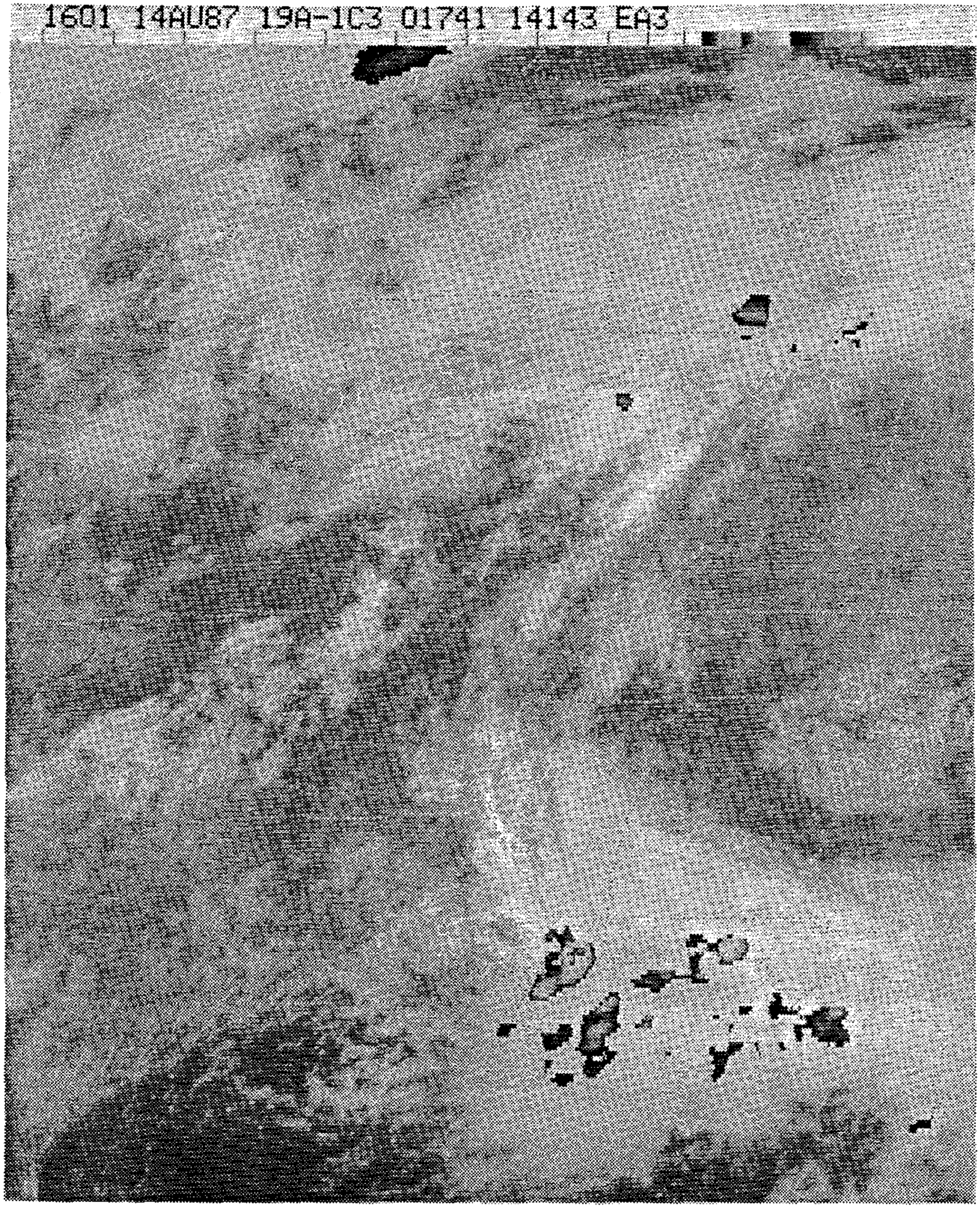


Fig. 40b GOES E imagery Friday, August 14, 1987 with C3 threshold IR enhancement for 1601Z.

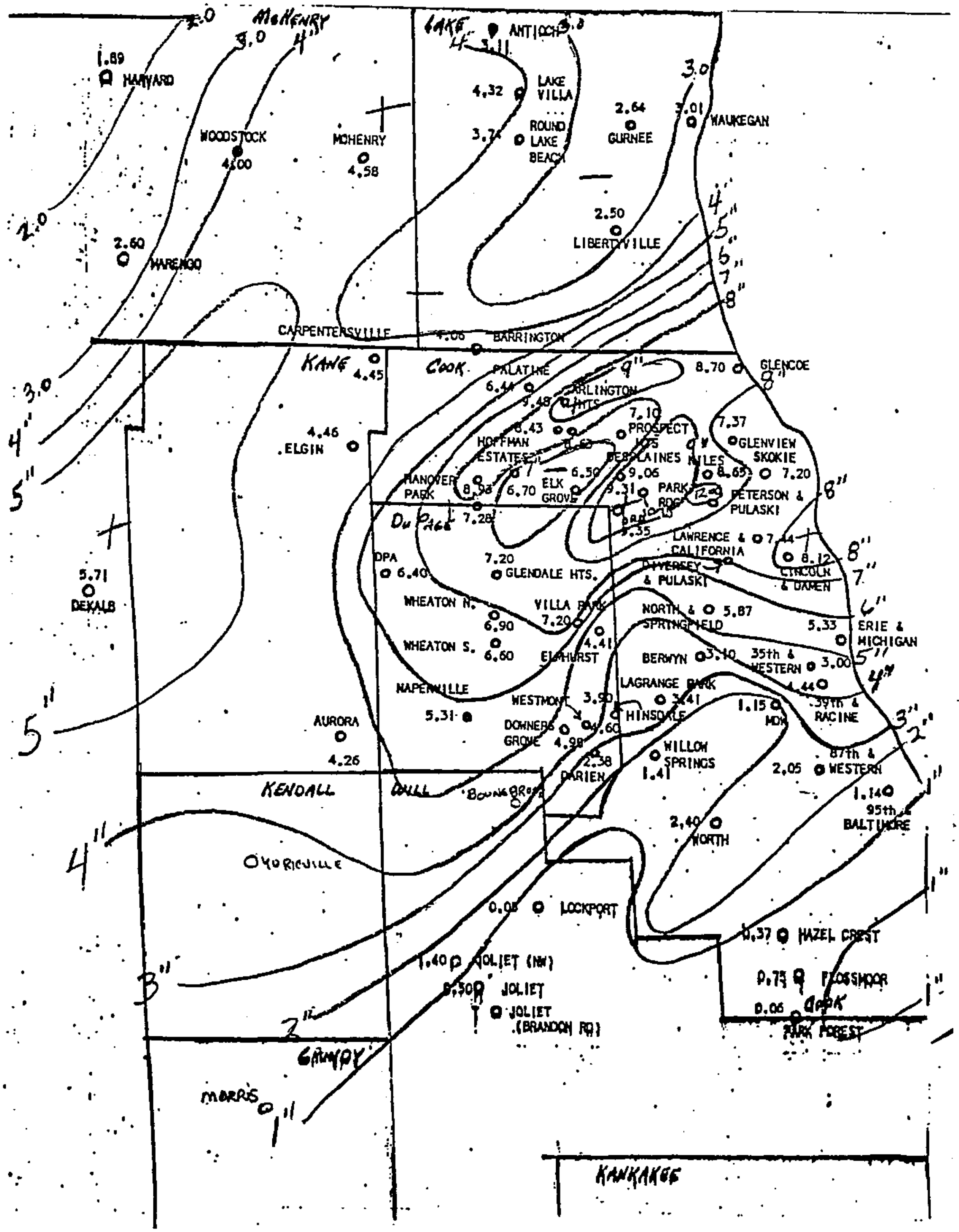


Fig. 41 Map of northeast Illinois showing the distribution of observed rainfall for the 12 hour period at 0900 CDT Friday, August 14, 1987.

Fig. 42 Photographs taken at the WSFO in Chicago (immediately northeast of O'Hare) showing the extent of the flooding on the morning of August 14, 1987.