MAC
137
GOVT COPIES

NWS-CR-TA-89-21

CRH SSD
JULY 1989

AWS TECHNICAL LIBRARY
FL 4414
SCOTT AFB IL 62225
17 JUL 1989

CENTRAL REGION TECHNICAL ATTACHMENT 89-21

CONVERGENCE COMPUTATIONS USING A LIMITED DATA SET FROM THE MILWAUKEE, WISCONSIN FLASH FLOOD

Jeffrey K. Last
National Weather Service Office
Peoria, Illinois

1. Introduction

The lack of data over large bodies of water is an obvious problem in weather data analysis and prediction. The problem is magnified when analyses of mesoscale features are attempted. Even though weather buoys, Coast Guard stations and ships transmitting weather data may be available to the forecaster, calculations of dynamic and thermodynamic variables may not include these important data sources. Even in regions where these data are usually available, there are occasions when it is not reported. These problems often preclude the use of a fine scale objective analysis of meteorological fields important to mesoscale analysis and nowcasting.

This paper examines a relatively simple and fast approach to computing surface convergence using a limited data set from the August 6, 1986 flash flood that occurred at Milwaukee, Wisconsin. Ulanski and Garstang (1978) described the relationship between low level convergence and the occurrence of rainfall but operational application of the concept requires extensive computer use to perform objective analysis. A brief description of the flood and the weather pattern associated with it are given first. The convergence calculation technique is then described and applied to the data set. Finally, the results of the computations are compared and discussed.

2. Overview of the Milwaukee Flash Flood

During the late morning and early afternoon hours of August 6, 1986, over 15 cm (nearly six inches) of rain fell in Milwaukee, Wisconsin causing severe flash flooding over the metropolitan area. Ten thousand homes in Milwaukee suffered damage and the total cost to personal property reached well into the millions of dollars. Two deaths were attributed to the flood.

The heavy rain fell in a southeast to northwest strip extending from northeast Racine County to northwest Milwaukee County (Fig. 1). The heaviest rain in this corridor fell about 3 km south of Milwaukee Mitchell International Airport (MKE). Between 1700 and 1900 UTC (1200 and 1400 CDT), 13.3 cm (5.24 inches) of

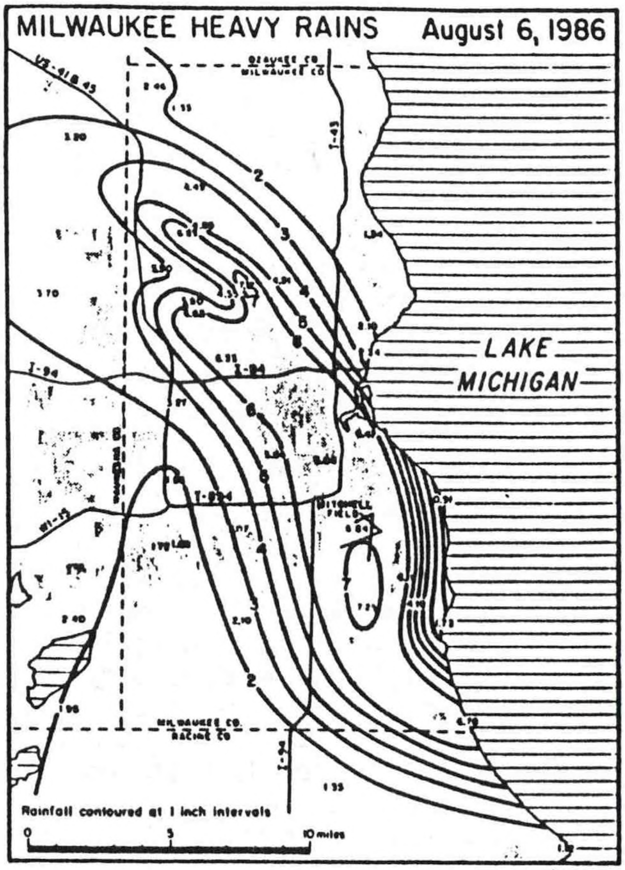


Fig. 1 Isohyet analysis for August 6, 1986 over Milwaukee County, Wisconsin from Storm Data. Amounts are in inches. Milwaukee Mitchell International Airport (MKE) is located south of downtown.

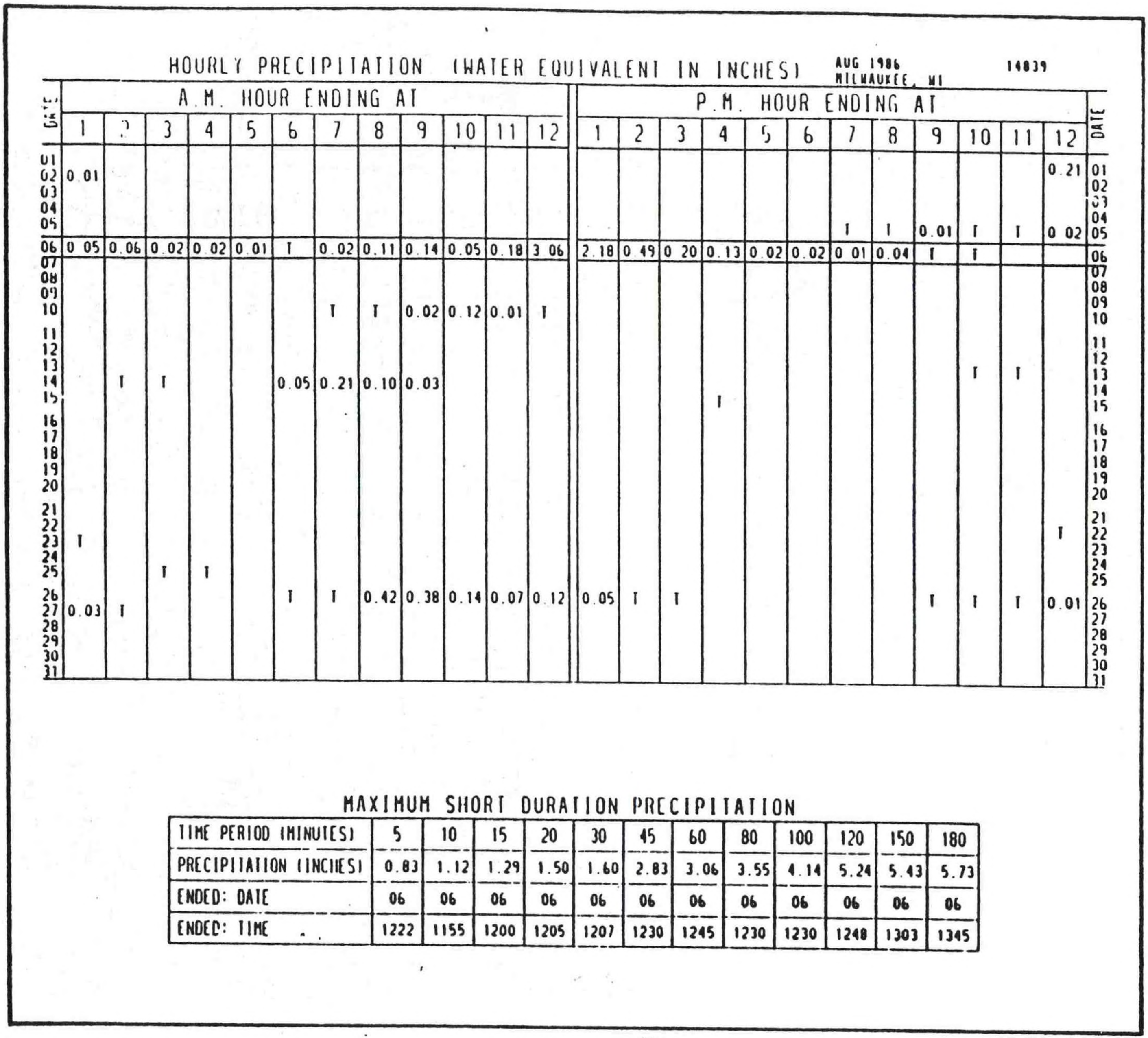
rain spilled on MKE. Table 1 shows the hourly rainfall totals and maximum short duration rainfall records set by the storm, as documented by the National Weather Service in Milwaukee and the National Climatic Data Center.

3. Weather Pattern on August 6, 1986

Elsner et al. (1989), detailed the synoptic pattern associated with this flood. Briefly, a well defined short wave trough was evident at 1200 UTC August 6 from 850 mb through 500 mb over the Midwest. A 500 mb vorticity maximum was located near Peoria, Illinois (PIA). An associated weak surface low moved from Moline, Illinois (MLI) at 1200 UTC to near Marseilles, Illinois (MMO) at 0000 August 7. The cyclonic circulation system (CCS) that produced the rain was evident on satellite imagery and contained warm top convection (cloud top temperatures over MKE were approximately -43°C at the time of the heaviest rain).

Figure 2 details the surface weather conditions at 1800 UTC, near the peak of the heavy rainfall at MKE. A weak surface low (1011 mb) was located near Bradford, Illinois (BDF) with a trough extending northeastward into southeast

Table 1
Hourly and maximum short duration precipitation at MKE for August 1986 from Local Climatological Data. Time is CST (+ 6 = UTC).



HOURLY PRECIPITATION (WATER EQUIVALENT IN INCHES) AUG 1986 MILWAUKEE, WI 14839

DATE	A.M. HOUR ENDING AT												P.M. HOUR ENDING AT												DATE
	1	2	3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	
01																								0.21	01
02	0.01																								02
03																									03
04																									04
05																			T	T	0.01	T	T	0.02	05
06	0.05	0.06	0.02	0.02	0.01	T	0.02	0.11	0.14	0.05	0.18	3.06	2.18	0.49	0.20	0.13	0.02	0.02	0.01	0.04	T	T			06
07																									07
08																									08
09																									09
10							T	T	0.02	0.12	0.01	T													10
11																									11
12																									12
13																						T	T		13
14		T	T			0.05	0.21	0.10	0.03																14
15																T									15
16																									16
17																									17
18																									18
19																									19
20																									20
21																									21
22																								T	22
23	T																								23
24																									24
25			T	T																					25
26						T	T	0.42	0.38	0.14	0.07	0.12	0.05	T	T						T	T	T	0.01	26
27	0.03	T																							27
28																									28
29																									29
30																									30
31																									31

MAXIMUM SHORT DURATION PRECIPITATION

TIME PERIOD (MINUTES)	5	10	15	20	30	45	60	80	100	120	150	180
PRECIPITATION (INCHES)	0.83	1.12	1.29	1.50	1.60	2.83	3.06	3.55	4.14	5.24	5.43	5.73
ENDED: DATE	06	06	06	06	06	06	06	06	06	06	06	06
ENDED: TIME	1222	1155	1200	1205	1207	1230	1245	1230	1230	1248	1303	1345

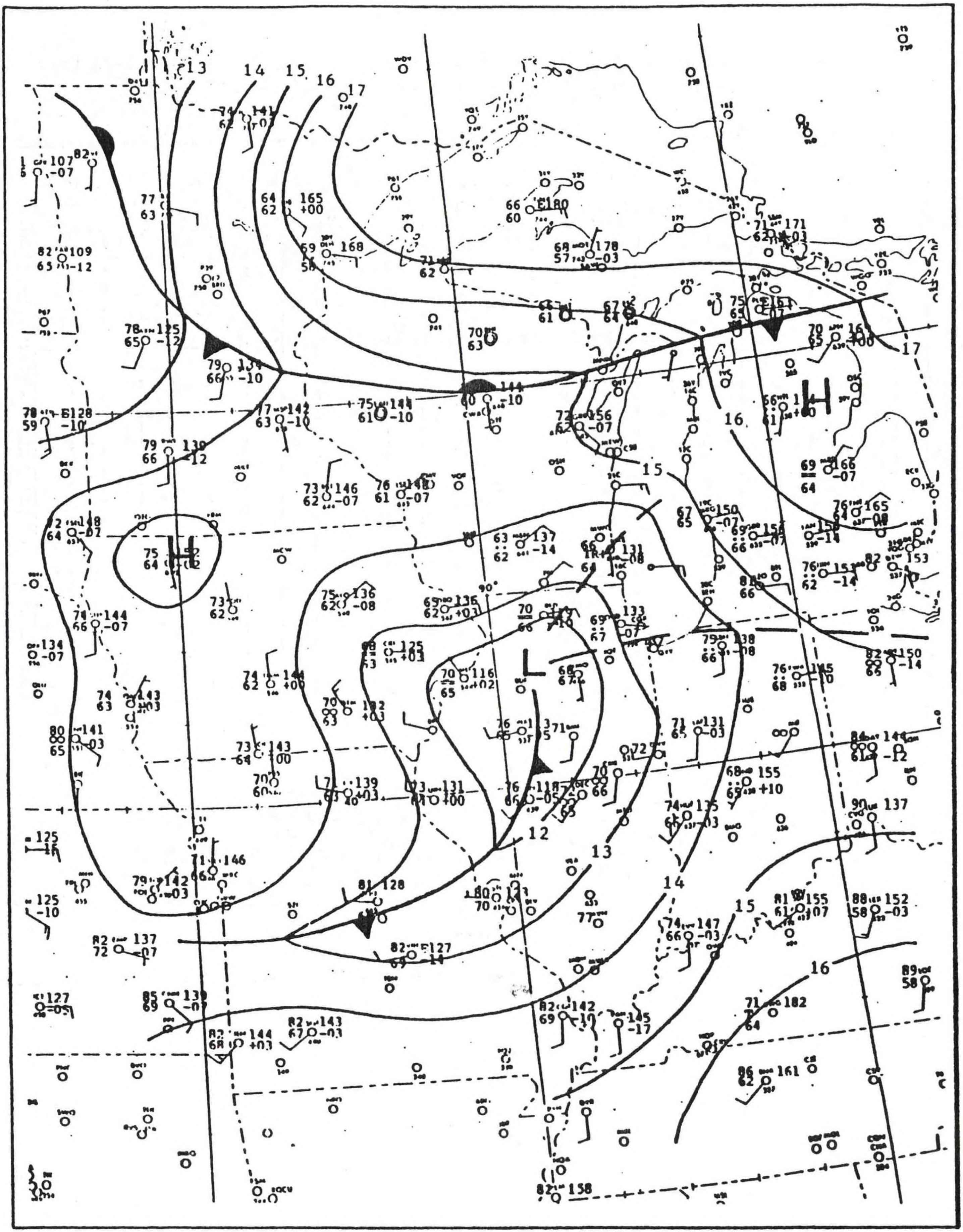


Fig. 2 Surface analysis for 1800 UTC, August 6, 1986. Solid lines are isobars.

Wisconsin and a wind shift line extending eastward to northern Ohio. A weak cold front stretched southwestward from the low into Missouri. Surface winds over Lake Michigan and at shore line observation stations in eastern Wisconsin averaged 15 to 20 knots from the east, while winds at MKE (about 5 km inland) were under five knots from the south. Obviously, strong surface convergence was occurring at or near to the southeastern Wisconsin shore line.

4. Areal Convergence Calculations

Recently, Heimbach and Engel (1987) demonstrated a method of computing surface meteorological kinematic quantities using data from small groups of stations. This technique is referred to as limited station analysis (LSA). Convergence, for example, can be computed from an area bounded by at least three non-linearly spaced data points. In the case study presented here, three areas, each bounded by three stations, are used to make areal convergence calculations. Sensitivity testing indicated little accuracy is gained by inclusion of more than three data points in the LSA analysis.

Areal convergence is defined as the fractional decrease of area per time. In this study, it is evaluated by measuring the percentage decrease or increase in an area of a triangle per unit time. After the initial triangle bounded by wind observation points is identified, the winds are allowed to displace the vertices for a time interval δt. The difference in area between the two triangles is then used to compute the convergence. This quantity is calculated following Saucier (1962),

$$-(A_1-A_0)/A_0\ \delta t = \mathrm{CON} \tag{1}$$

where, A_0 is the area of the triangle at time 0, and A_1 is the area after time δt (Fig. 3).

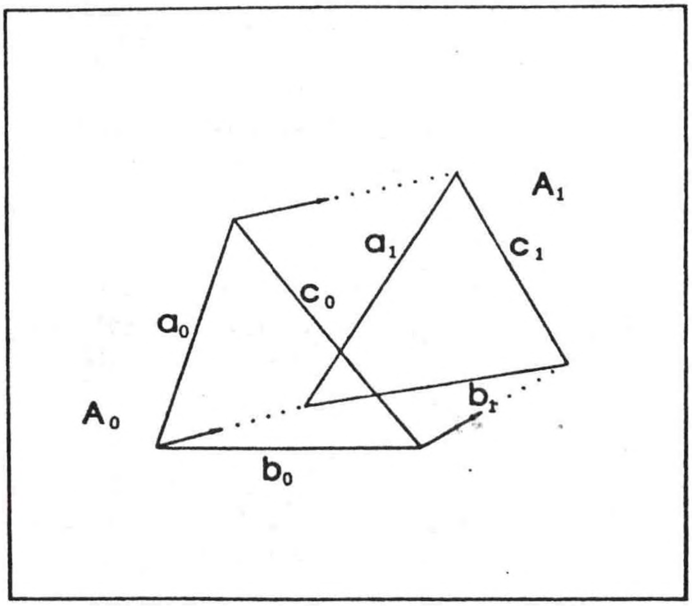


Fig. 3 Geometry of computing areal convergence for three stations.

The area of a triangle can be found by using Heron's Formula, which states that for any triangle, the area K is given by,

$$K = [s(s-a)(s-b)(s-c)]^{1/2} \qquad (2)$$

where, a, b, and c are the lengths of the triangle's legs, and

$$s = (a + b + c)/2.$$

At time 0, the area of the triangle bounded by three stations (A_0), having legs a_0, b_0, c_0 is computed using (2). Lengths of the legs are calculated from the station's latitude and longitude. After time δt, a second area is produced by advecting the apices with the wind at each station. The new area, A_1, with legs a_1, b_1, c_1 is computed in the same manner. Areal convergence is then calculated using (1). Saucier states that any convenient interval of time δt may be used. In the study presented here, a one hour interval was used. As shown by Schaefer and Doswell (1979), in the limit, this computed areal convergence is mathematically the same as the convergence computed by differentiation of the wind field. Day (1953) applied this method to upper air data, but because of the infrequency of observations in both space and time the computed convergence field was not well correlated with the observed weather.

5. Data

Data used in this study include weather observations from the National Weather Service, the Federal Aviation Administration, and the United States Coast Guard. Analyses of surface and upper air weather data were done to facilitate the discussion of the general weather pattern.

Figure 4 shows the region where convergence was computed. Three triangles were identified, and calculations were performed using seven stations. Triangle 1 consists of MKE, Chicago, Illinois O'Hare International Airport (ORD), and weather buoy 45007. Triangle 2 includes Madison, Wisconsin Airport (MSN), Rockford, Illinois Airport (RFD), and MKE. Triangle 3 consists of Muskegon, Michigan Airport (MKG), Benton Harbor, Michigan (BEH), and buoy 45007. Two-hourly data were available for all stations. Data from BEH were only obtainable from 1000 to 2200 UTC August 6, 1986.

Heimbach and Engel state that LSA calculations are sensitive to area size; therefore, care was taken in choosing the areas used in this study. The three triangles are approximately equal in area at time 0. This allowed for a meaningful comparison of the convergence in the three triangles.

6. Results

Two-hourly convergence calculations were made for August 6 fro 0600 UTC until 2200 UTC for the three triangles in Fig. 4. The results are shown in Fig. 5. The graph shows surface convergence versus time for the three regions.

A dramatic increase is seen in convergence in the region over the southeast Wisconsin shore line (triangle 1). Convergence values began to significantly increase between 0800 and 1000 UTC, reaching a peak at 1400 UTC, about

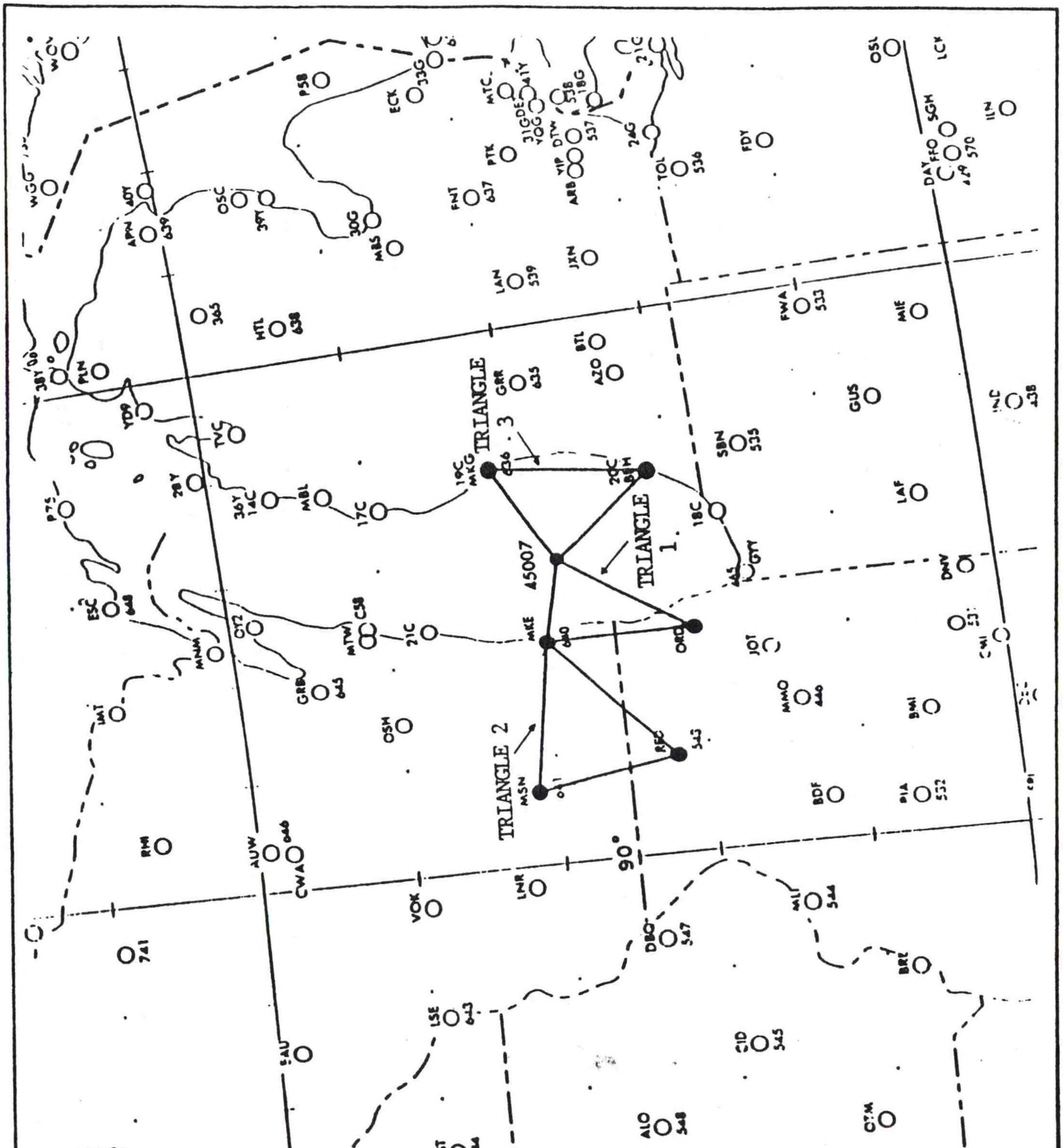


Fig. 4 Areas and station locations used for calculations of areal convergence.

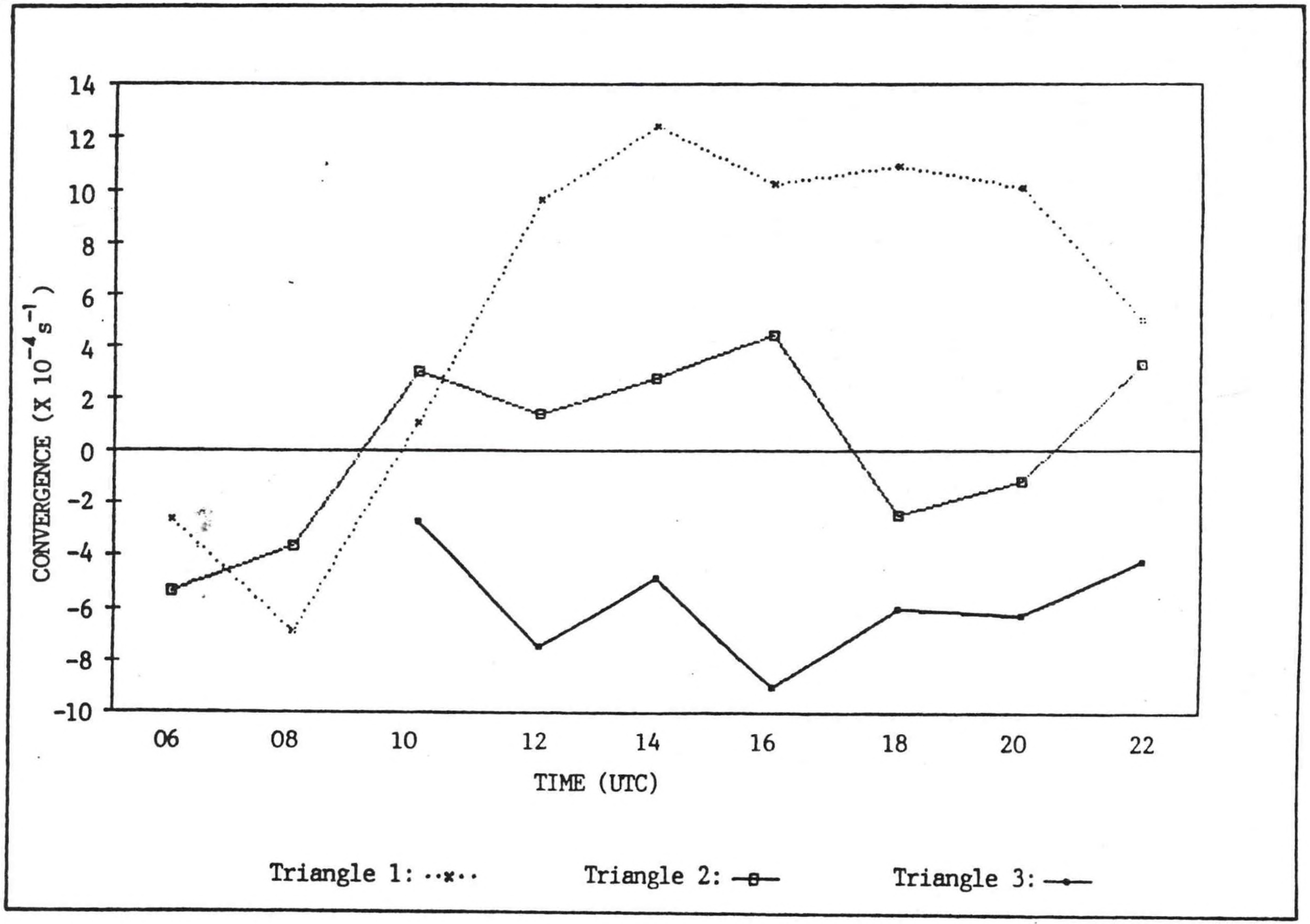


Fig. 5 Surface convergence versus time for the three triangles in Fig. 4. Convergence scaled by 10^{-4} s^{-1}.

two hours before heavy rain began falling over southeast Wisconsin. During the period of flooding rains at MKE (1700-1900 UTC), convergence values remained above $10 \times 10^{-4}\ s^{-1}$. Convergence over the shore line decreased after 1800 UTC; the heavy rain at MKE had all but ended by 2000 UTC.

Areal convergence calculations over the inland Wisconsin triangle (no. 2) show weak convergence or slight divergence throughout most of the morning of August 6. Rainfall at MSN for the 24 hour period ending at 1200 UTC August 7 was 2.1 cm (0.83 inches); RFD reported 0.6 cm (0.22 inches) for the same period.

Divergence prevailed over the area covering eastern Lake Michigan (triangle 3). Total rainfall at MKG for the 24 hours ending at 1200 UTC August 7 was 0.5 cm (0.21 inches).

7. Discussion and Summary

The weather system that produced the flooding rains in southeast Wisconsin had a history of producing moderate rainfall over the Midwest. Figure 6a shows rainfall totals from 1200 UTC August 5 through 1200 UTC August 6. A swath of one inch (2.5 cm) rainfall is seen from eastern Iowa to central Missouri. In contrast, rainfall totals for 1200 UTC August 6 through 1200 UTC August 7 are shown in Figure 6b. An area of moderate to heavy rainfall extended from southeast Wisconsin to southern Michigan. Note that no total from observing stations in the Midwest were anywhere near MKE's total. Further, a review of Storm Data (NOAA, 1986) indicated that the only major flooding from this weather system occurred in southeast Wisconsin.

Strong east winds off of Lake Michigan caused intense surface convergence near the southeast Wisconsin shore line on August 6, 1986. Areal convergence calculations, using buoy data on Lake Michigan, reveal a sharp increase in convergence several hours before the onset of very heavy rainfall at MKE, while areas to the east and west of the Wisconsin shore line showed only weak convergence or divergence. A decrease in shore line convergence is seen after 1800 UTC, and rain intensity at MKE diminished about an hour later.

The addition of buoy, ship, and Coast Guard data in the analyses and computations reveal the importance of such data in gaining insight in the subsynoptic scale features of this rain event. Without the wind data from buoy 45007, areal convergence calculations would not have shown the sharp increase in surface convergence prior to the flooding rain.

Certainly, more research can be done to look into whether the low level convergence produced the heavy rain, or was a by-product of the convection. Regardless of whether the convergence was a cause or effect, it preceded the heavy rain event and could be an important forecast tool. As shown here, the use of limited station analysis using these data may aid the forecaster in analyzing mesoscale features caused by the complex interaction between land and water.

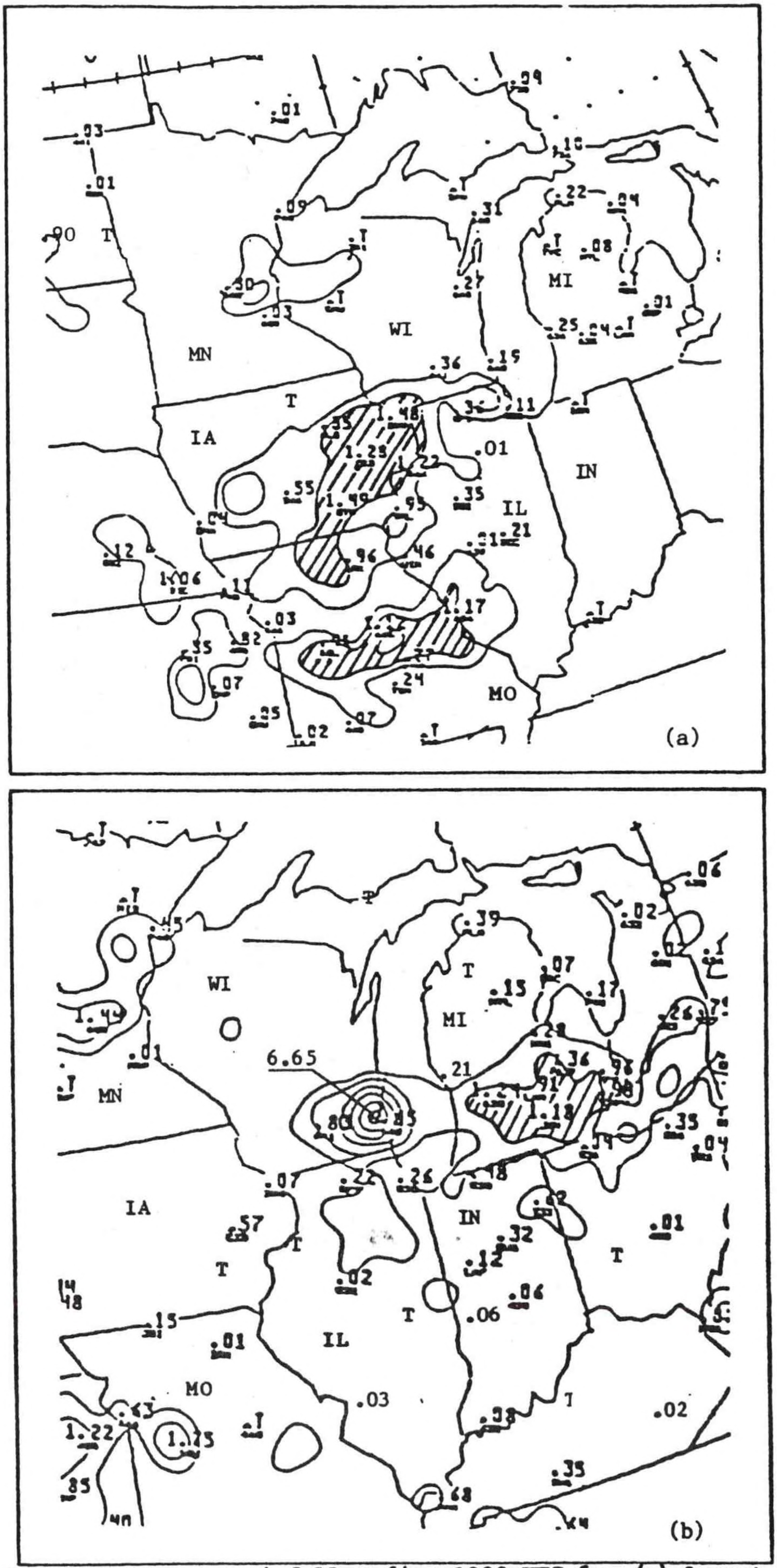


Fig. 6 Autoanalysis of 24 hour rainfall ending 1200 UTC for (a) August 6, 1986, and (b) August 7, 1986 over the Midwest United States. Hatched area is rainfall in excess of one inch (2.54 cm).

8. Acknowledgements

The author wishes to thank James Skowronski, Dr. James Elsner, and Chris Miller for their helpful comments.

9. References

Day, S., 1953: Horizontal convergence and the occurrence of summer precipitation at Miami, Florida. Mon. Wea. Rev., 81, 155-161.

Elsner, J. B., Drag, W. H., and J. K. Last, 1989: Synoptic weather patterns associated with the Milwaukee, Wisconsin flash flood. Weather and Forecasting, in press.

Heimbach, J. A., Jr., and T. M. Engel, 1987: The use of limited surface networks to measure mesoscale phenomena. Mon. Wea. Rev., 115, 118-129.

National Oceanic and Atmospheric Administration, 1986: Local Climatological Data - Milwaukee, Wisconsin. Available from National Climatic Data Center, Asheville, NC.

National Oceanic and Atmospheric Administration, 1986: Storm Data. Available from National Climatic Data Center, Asheville, NC.

Saucier, W. J., 1962: Principles of Meteorological Analysis. Univ. of Chicago Press, 438 pp.

Schaefer, J. T., and C. A. Doswell III, 1979: On the interpolation of a vector field. Mon. Wea. Rev., 107, 458-476.

Ulanski, S. L., and M. Garstang, 1978: The role of surface divergence and vorticity in the life cycle of convective rainfall. Part I: Observation and analysis. J. Atmos. Sci., 35, 1047-1062.