Preliminary Data Quality Analysis for May-June 1985 for Oklahoma and Kansas PRE-STORM PAM II MESONETWORK

By

Richard H. Johnson and James J. Toth

Department of Atmospheric Science
Colorado State University
Fort Collins, Colorado

Colorado State University

Department of Atmospheric Science

Paper No. 407

PRELIMINARY DATA QUALITY ANALYSIS FOR MAY-JUNE 1985 OKLAHOMA-KANSAS PRE-STORM PAM II MESONETWORK

by

Richard H. Johnson
and
James J. Toth

Research supported by the
National Science Foundation
under Grants ATM-8420328
and ATM-8507961

Department of Atmospheric Science
Colorado State University
Fort Collins, Colorado

November, 1986

Atmospheric Science Paper No. 407

1. Introduction

During May and June 1985 an 80-station surface network was established and operated over Kansas and Oklahoma as one component of the Oklahoma-Kansas Preliminary Regional Experiment for STORM-Central (OK PRE-STORM). The surface stations (Fig. 1) were centered over Kansas and Oklahoma in the midst of additional observing systems that included rawinsondes, profilers, Doppler radars, lightning detection equipment and research aircraft. The northernmost forty stations consisted of NCAR Portable Automated Mesonetwork (PAM II) instruments (Fig. 2). In addition, two PAM II stations (41 and 42 in Fig. 2) were colocated with two stations in the 40-station NSSL Surface Automated Mesonetwork (SAM) which made up the southern portion of the surface array.

This report summarizes results of preliminary analyses of the quality of the PRE-STORM PAM II observations. The analyses that we have carried out, while they have been clearly limited in scope, do provide several specific recommendations for users of the data that should be of immediate value. The in-field calibration checks of PAM II observing systems by NCAR Field Observing Facility personnel have proven to be vital in obtaining what we now conclude to be a high quality PRE-STORM PAM II data set (with some recommended corrections contained herein). Similar examination of NSSL SAM data quality has not yet been completed. One important step yet to be fully completed with both data sets is to carry out intercomparison studies using data from interior National Weather Service stations and employing data from the colocated sites (41 and 42). This work is now underway.

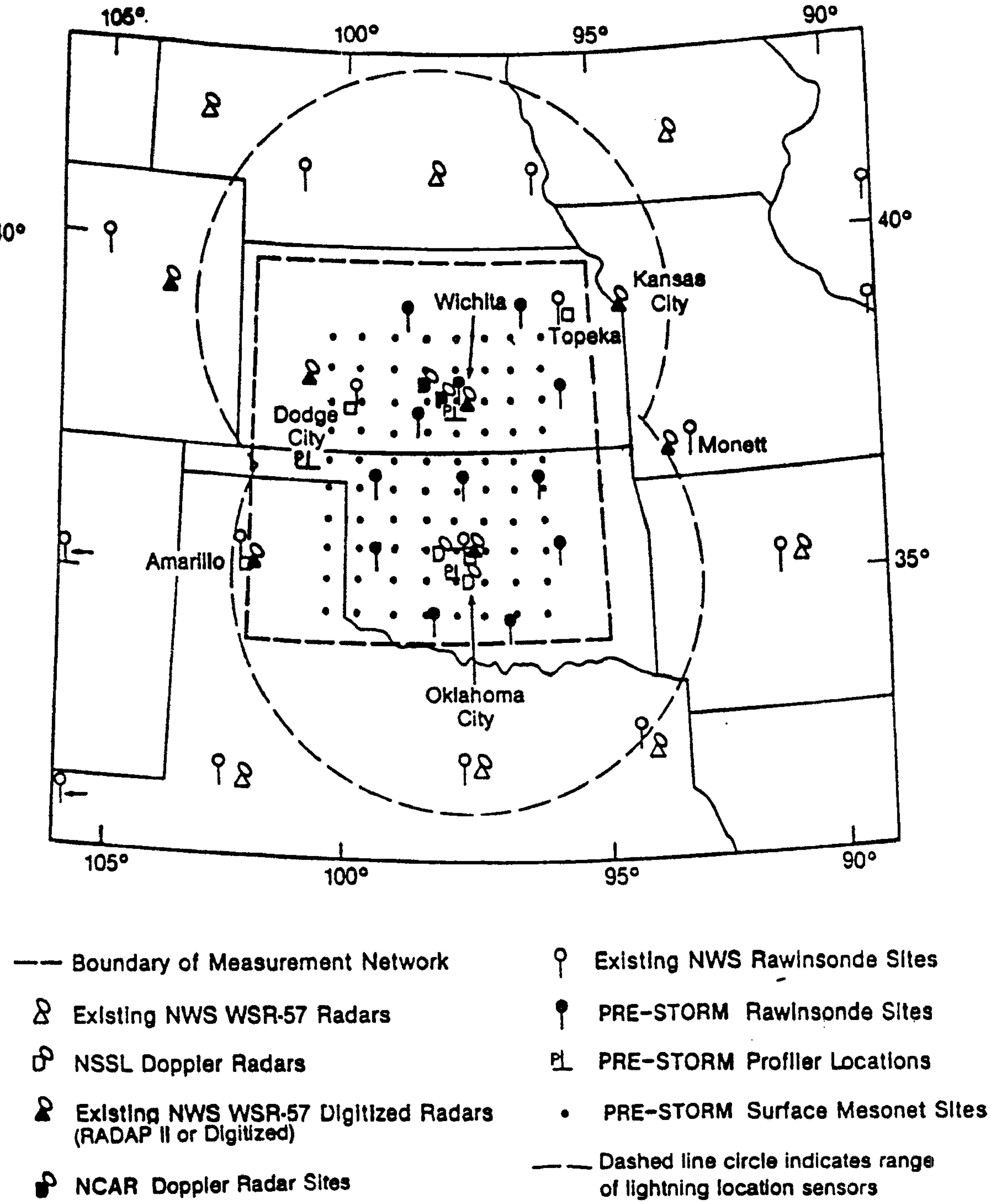

Fig. 1 May-June 1985 Oklahoma-Kansas PRE-STORM observational network.

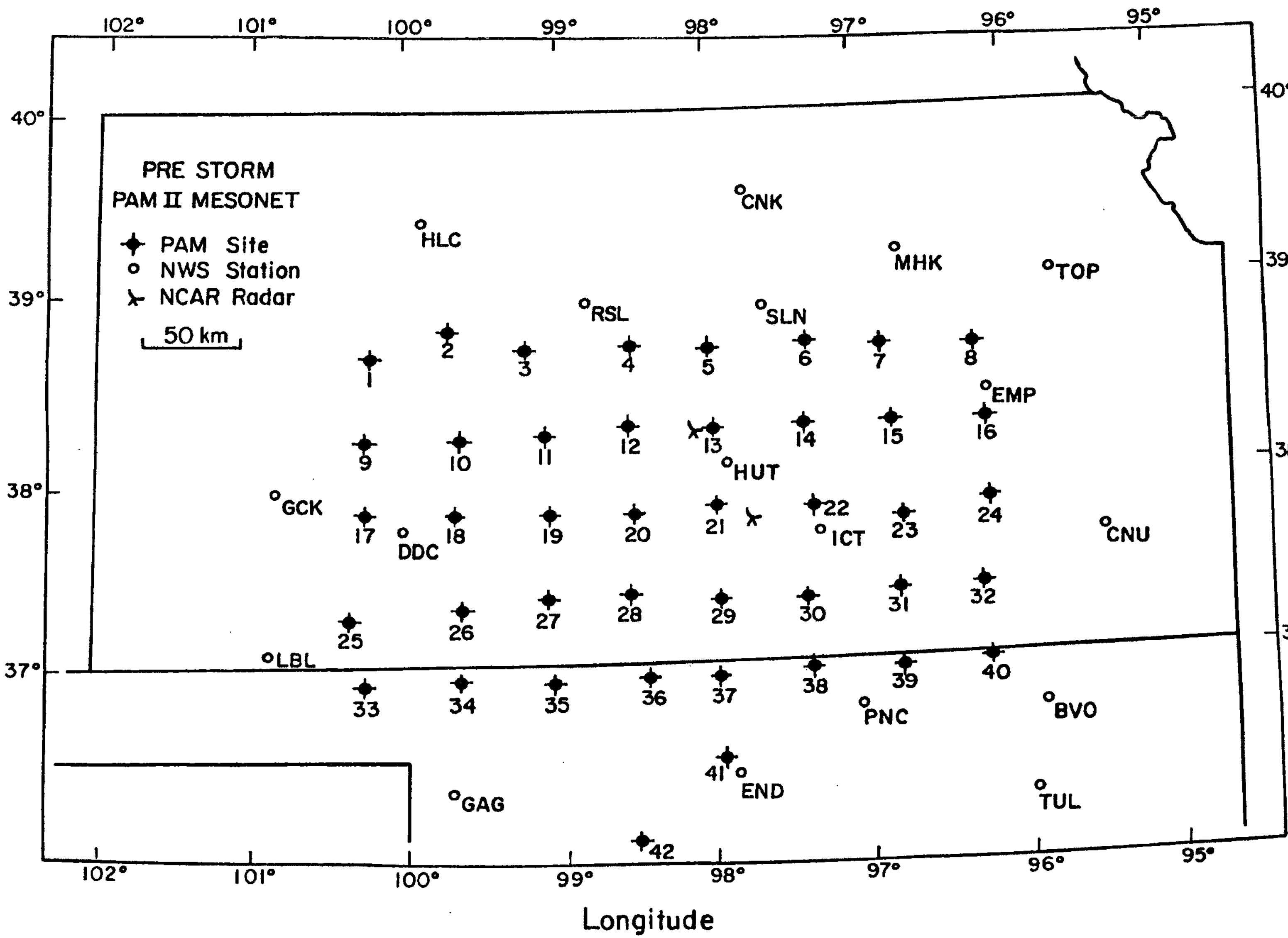

Fig. 2 Oklahoma-Kansas PRE-STORM PAM II surface mesonetwork.

2. PAM II Measurements in OK PRE-STORM

a. *Instruments*

Standard meteorological variable (u and v wind components, dry and wet bulb temperatures, pressure) and rainfall measurements were provided by the PAM stations during PRE-STORM. Characteristics of the instruments, measurement accuracies and recorded resolutions are shown in Table 1. A schematic showing positions of the sensors on the PAM II tower is provided in Fig. 3.

The stated accuracies in Table 1 are those anticipated for normal operation. During OK PRE-STORM a rather serious complication developed in connection with the PAM II psychrometers. Due an ineffective attempt to protect the temperature sensing elements against moisture by mounting them in a brass sleeve, cooling due to the wetted wick was not properly transmitted to the elements (Hjelmfelt *et al.*,1986). As a result, OK PRE-STORM wet bulb temperatures were generally too high, but the degree of error varied from station to station. Following recognition of this problem by the end of May 1985, in-field calibration of the sensors using an Assman psychrometer was carried out at all of the stations. These calibration checks permitted correction curves to be established for each station. It turned out that the wet bulb depression error was a function of both the size of the depression and the ambient temperatures. While data available for establishing the correction curves were quite limited at several sites, it is felt that the corrected wet bulb temperatures are accurate to within 1°C, with most values accurate to 0.5°C. Details of the correction procedure are in Hjelmfelt *et al.*,(1986).

The only other PAM II instrument problem of any significance (also identified while the experiment was in progress) was an occasional failure of the rain gauges. At some stations and at some times, dust would interfere with the proper functioning of the fulcrum on the

Table 1

PAM Parameters

Parameter	Sensors	Accuracy[1]	Resolution
Wind (u, v components)	Two orthogonal propeller anemomenters	+5% each for winds > 1 ms^{-1} [2]	0.1 ms^{-1}
Dry-bulb temperature	NCAR psychrometer	+0.25[3]	0.05°C
Wet-bulb temperature	NCAR psychrometer	+0.50[3,5]	0.05°C
Pressure	NCAR barometer	+1 mb	0.02 mb
Rain	Tipping bucket	+15%,[4]	0.25 mm

---

1. 2 σ bounds.
2. Stalling threshold is approximately 0.6 m/s. Speed and direction computation errors are maximized near the cardinal directions.
3. Plus radiation errors which may at times exceed 0.5°C depending on radiation levels and siting conditions.
4. Plus the 0.25 mm quantizing interval. These figures do not include wind caused errors.
5. Operates above 0°C.

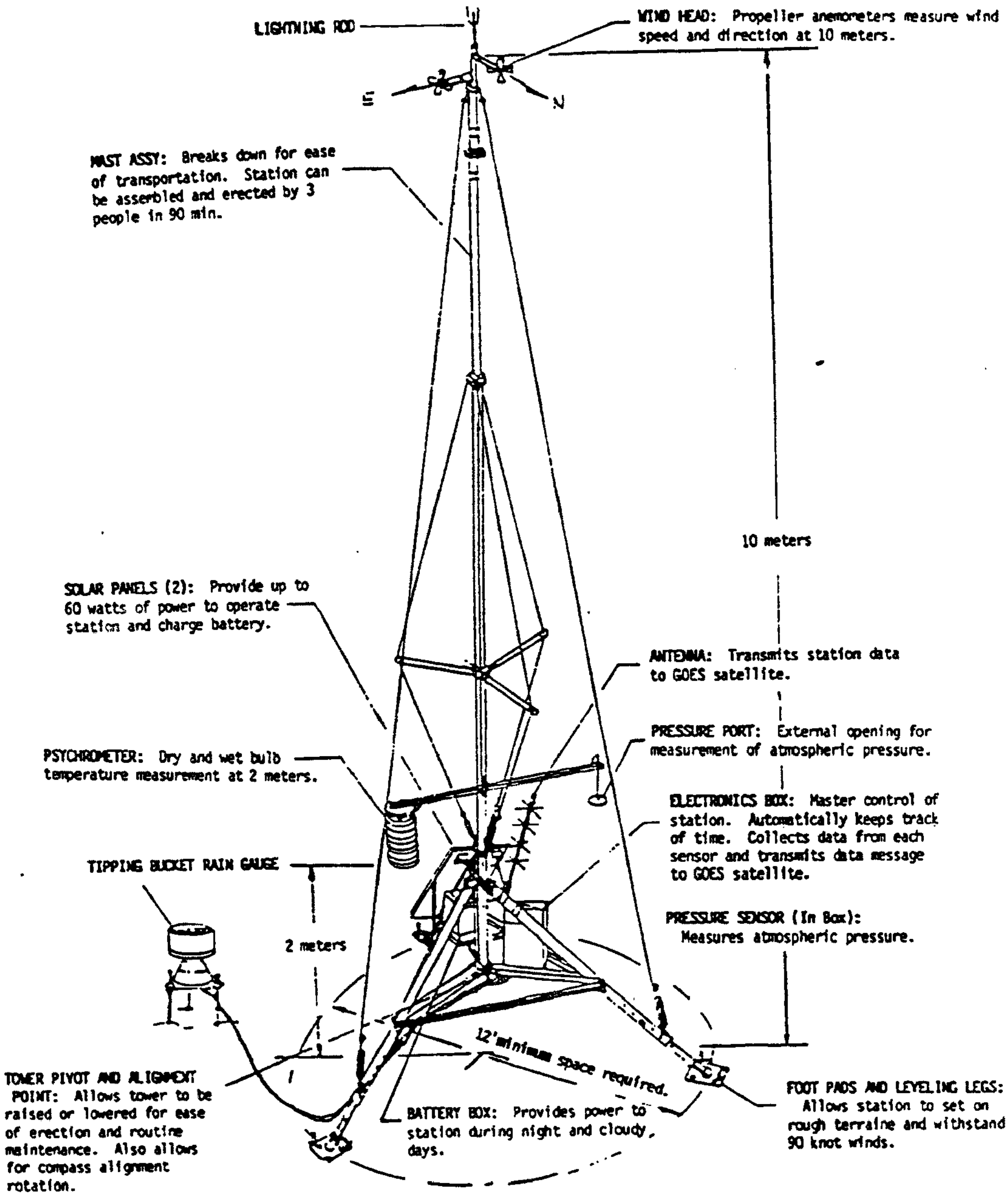

Fig. 3 NCAR Portable Automated Mesonetwork Station.

tipping bucket and rainfall measurements were seriously affected. These difficulties were documented when rain gauge calibration checks were made during site visits (every three to four weeks); however, the duration of the outages, if any, could not be easily determined. Users are cautioned to examine rain gauge data for possible errors on a case-by-case basis.

Detailed recommendations concerning each of the measured variables follows in Section 4, 5 and 6.

b. Siting information

The locations and elevations of the forty-two PAM II stations are given in Appendix 1. The elevations, which have been determined from 7.5 ft. quadrangle maps and also include revisions based on analysis of pressure data (to be discussed later), have an estimated accuracy of $\pm$ 3 m.

As might be expected in Kansas, there were no significant difficulties in obtaining meteorologically-sound site locations for the PAM II stations. A few instances of minor contamination by local effects were unavoidable; however, and it is one purpose of this analysis to attempt to identify the magnitude of such difficulties. A listing of the primary terrain and man-made features in the vicinity of each station is provided in Appendix 2.

3. Analysis procedures

A variety of procedures have been devised to remove systematic errors or biases in data from mesometeorological networks. Fujita (1963) has suggested some simple procedures which involve analyses of data from neighboring, well-calibrated stations such as National Weather Service first-order stations. A host of alternative approaches have been suggested in subsequent years, with some of the more recent schemes permitting a rather detailed determination of error patterns and/or deficiencies in station siting (e.g., Wade and Engel, 1985).

A unique feature of the PRE-STORM PAM mesonetwork was the capability of realtime display of the surface observations. This capability permitted continual scrutiny of mesonet data for errors, inconsistencies or disagreements with neighboring NWS reports. In fact, it was this realtime examination of the data that first led to the recognition of the earlier-discussed problem with PAM wet-bulb temperatures. Therefore, both scheduled and nonscheduled maintenance and calibration could be accomplished to minimize periods of poor quality data collection.

Our approach to the analysis of PAM data quality has been influenced by three primary considerations: (1) reasonably frequent instrument calibration was carried out so that error behavior is reasonably well known from maintenance logs, etc.; (2) other than the wet-bulb problem, quality and representativeness of the data appears to be exceptionally good; (3) insufficient resources exist to conduct a comprehensive data quality analysis such as that recently completed for CCOPE (Wade, 1986, personal communication). As a result, our efforts have been primarily concentrated in two directions: (a) the preparation and analysis of ten-day, twenty-day and monthly mean charts to use with calibration records to examine error patterns and data inconsistencies and (b) comparison of PAM observations with NWS station data.

To produce mean charts, five-minute observations have been averaged for the periods of interest, following removal of data gaps and, to the best of our ability, data glitches. Data gaps were filled by linear interpolation for outages less than one hour. Periods of missing data longer than one hour were excluded from the averages. Results are insensitive to the gap treatment since outages were rare (only 2 to 3% of the PAM II data were missing during PRE STORM). Data glitches were treated by setting reasonable limits for the various meteorological variables.

4. Precipitation

Rain gauges at PAM II sites functioned rather well throughout PRE-STORM; however, there were occasional periods when errors and outages did exist. Because calibration checks could not be carried out with great frequency and precipitation is, by its nature, highly intermittent, the determination of errors with each rainfall episode can often be difficult. In those instances where widespread, relatively uniform rainfall occurred, the determination of problems with raingages is somewhat simplified.

a. Monthly totals

In principle, it should be possible to use the PAM raingage data to construct maps of total monthly rainfall. It should then be appropriate to compare and merge these data with data from other sources to obtain a best estimate of the rainfall distribution. In practice, however, this goal has not been achievable due to problems with the archived PAM rainfall data.

Difficulties in the interpretation of PAM raingage records arise because of spurious noise in the time series of accumulated rainfall. This noise is primarily a consequence of three factors: random glitches in the data stream (which are particularly difficult to remove when convective rainfall is occurring in the network), false amounts entered into the data during raingage calibration exercises and aperiodic resetting of the accumulated rain totals to zero.

Since accurate analyses of monthly rainfall amounts from the PAM data are not possible, we present here (to assist in the interpretation of other PAM measurements) monthly totals based on National Weather Service Cooperative Observing Station reports.

The network of Cooperative Observing Stations in the region is illustrated in Fig. 4. The density of stations is sufficient to obtain a reasonable analysis on a 30-40 km scale in

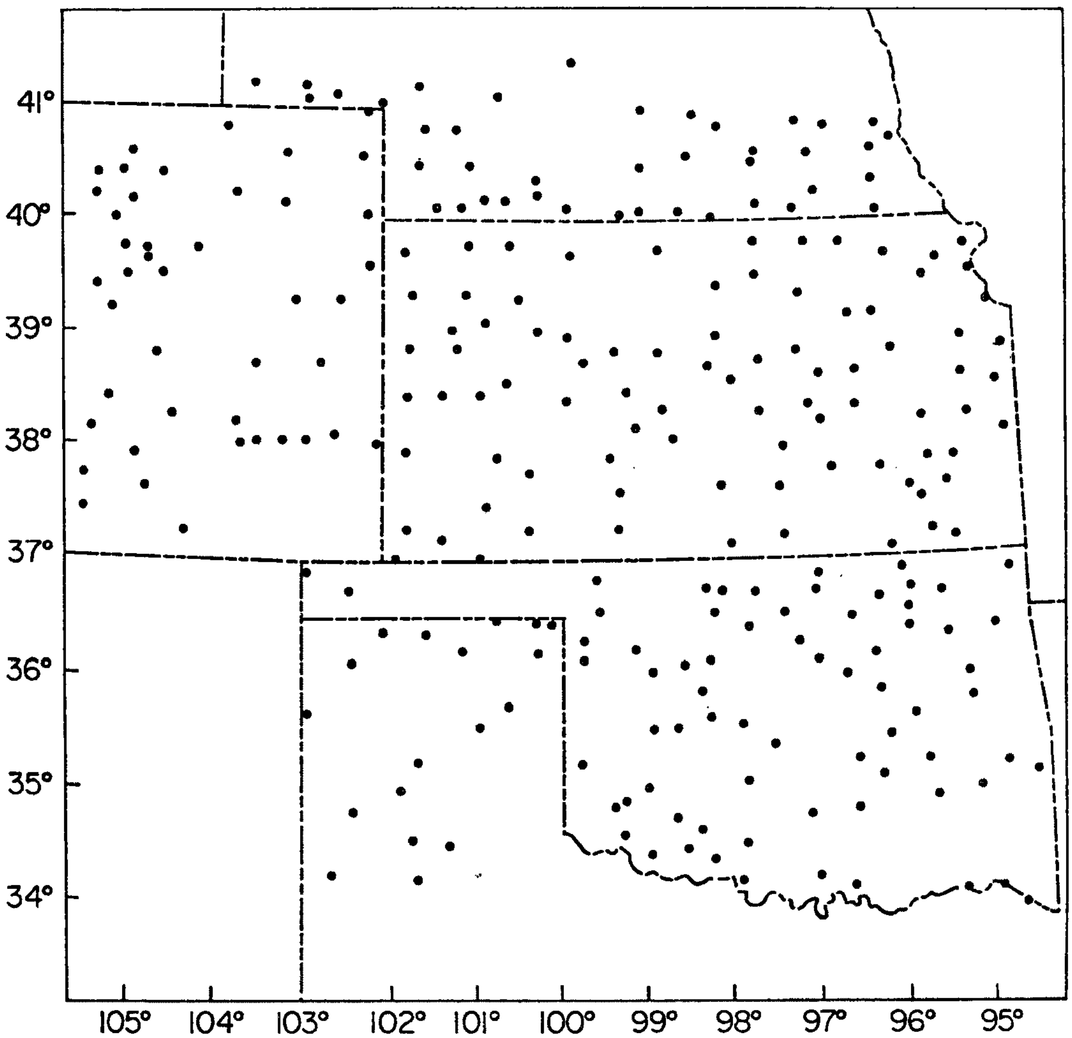

Fig. 4 NOAA/NWS Cooperative Observing Station Locations (1985).

Kansas and Oklahoma, although it is recognized that such analyses are problematic owing to the erratic behavior of convective rainfall. Using long-term precipitation records for the region (NOAA, 1982), we first present 30-year (1951-1980) mean precipitation maps for May and June in Figs. 5 and 6. Rainfall generally increases from west to east with maximum amounts in Oklahoma during May (Fig. 5) and in Kansas during June (Fig. 6). During May 1985, however, the region of maximum rainfall (Fig. 7) was shifted north of its normal position. This pattern is consistent with the observation during PRE-STORM of the passage of numerous mesoscale convective systems (MCSs) across the northern and eastern portions of Kansas. The greater-than-normal rainfall in this region and below-normal rainfall over most of Oklahoma are illustrated in Fig. 8.

During June the rainfall maximum shifted south (Fig. 9), along with the primary track of MCSs. This shift led to significant positive rainfall anomalies over southeast Kansas and most of Oklahoma (Fig. 10).

5. Thermodynamic Variables

Interpretation of a number of the long-term mean results presented in this section is assisted by reference to topographic features, despite their small amplitude in Kansas. The topography of the region is therefore presented in Fig. 11. Elevation generally decreases from west to east with the slope greatest in western Kansas and Oklahoma. The river basins are quite broad and very shallow.

a. Pressure

Pressure is measured with the NCAR aneroid barometer at 2 m above the ground. The construction of charts of long-term mean pressure (with suitable reduction to a standard altitude) should, in the absence of errors, result in a smooth horizontal pressure field since transient effects such as storms, cyclones and atmospheric tides are effectively filtered out.

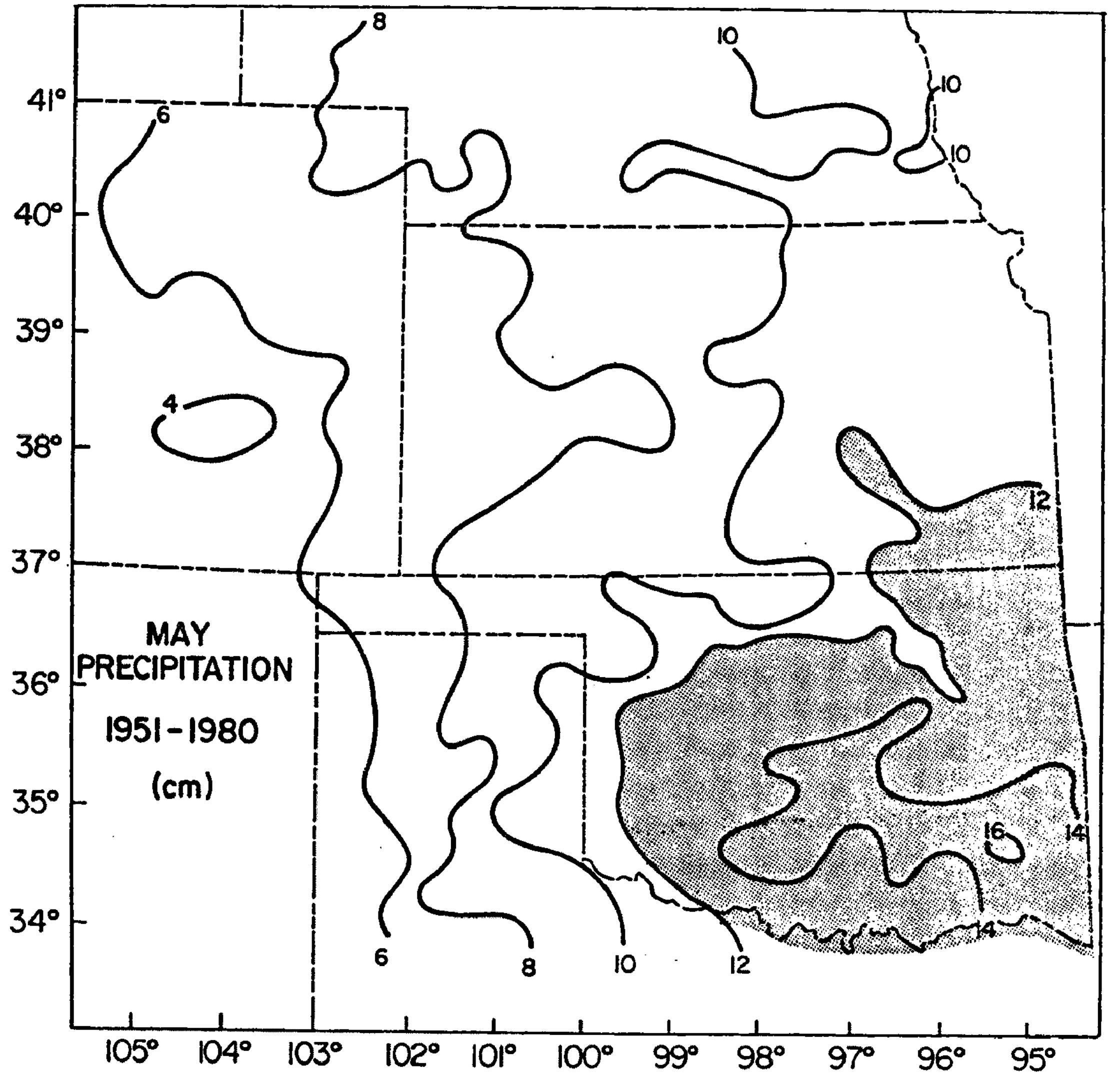

Fig. 5 Thirty-year mean precipitation (1951-1980) for May (cm).

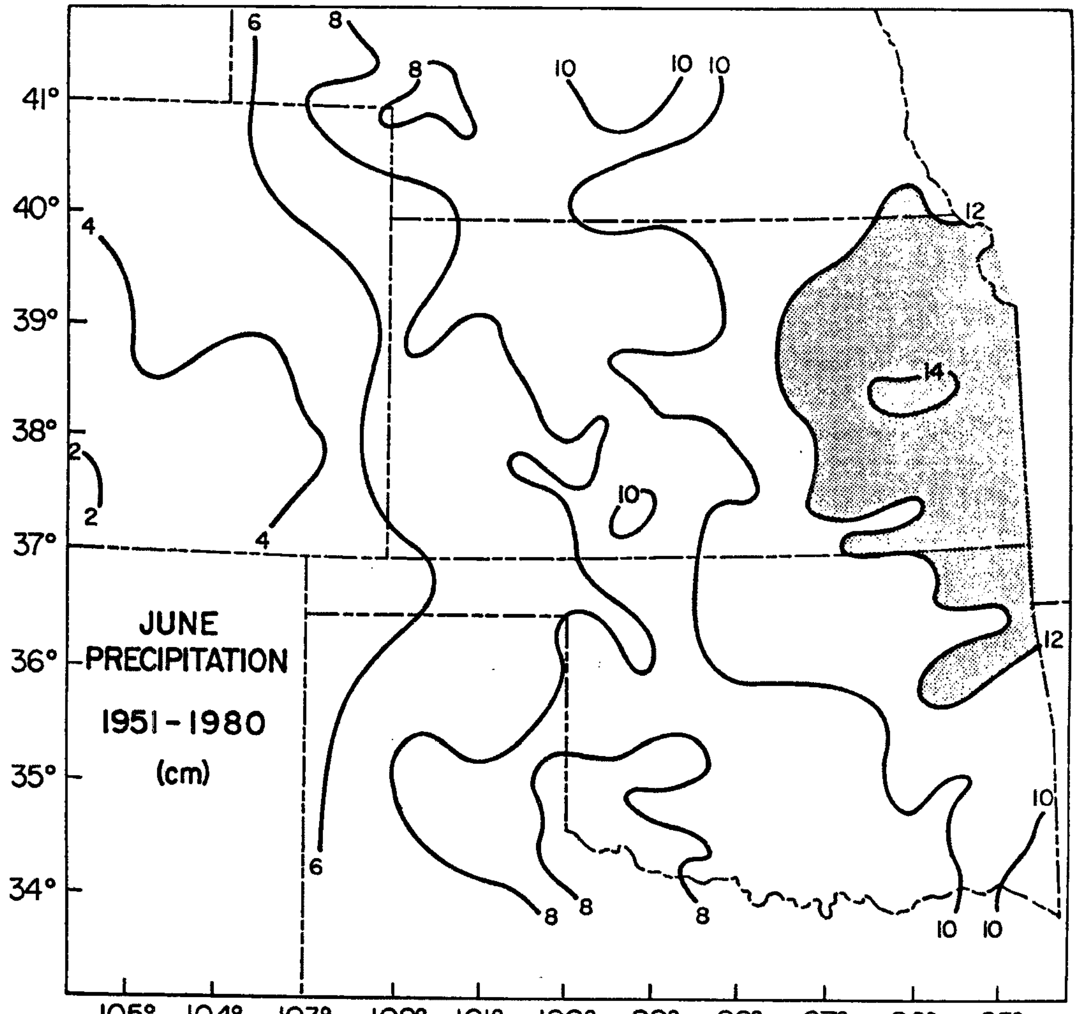

Fig. 6 Thirty-year mean precipitation (1951-1980) for June (cm).

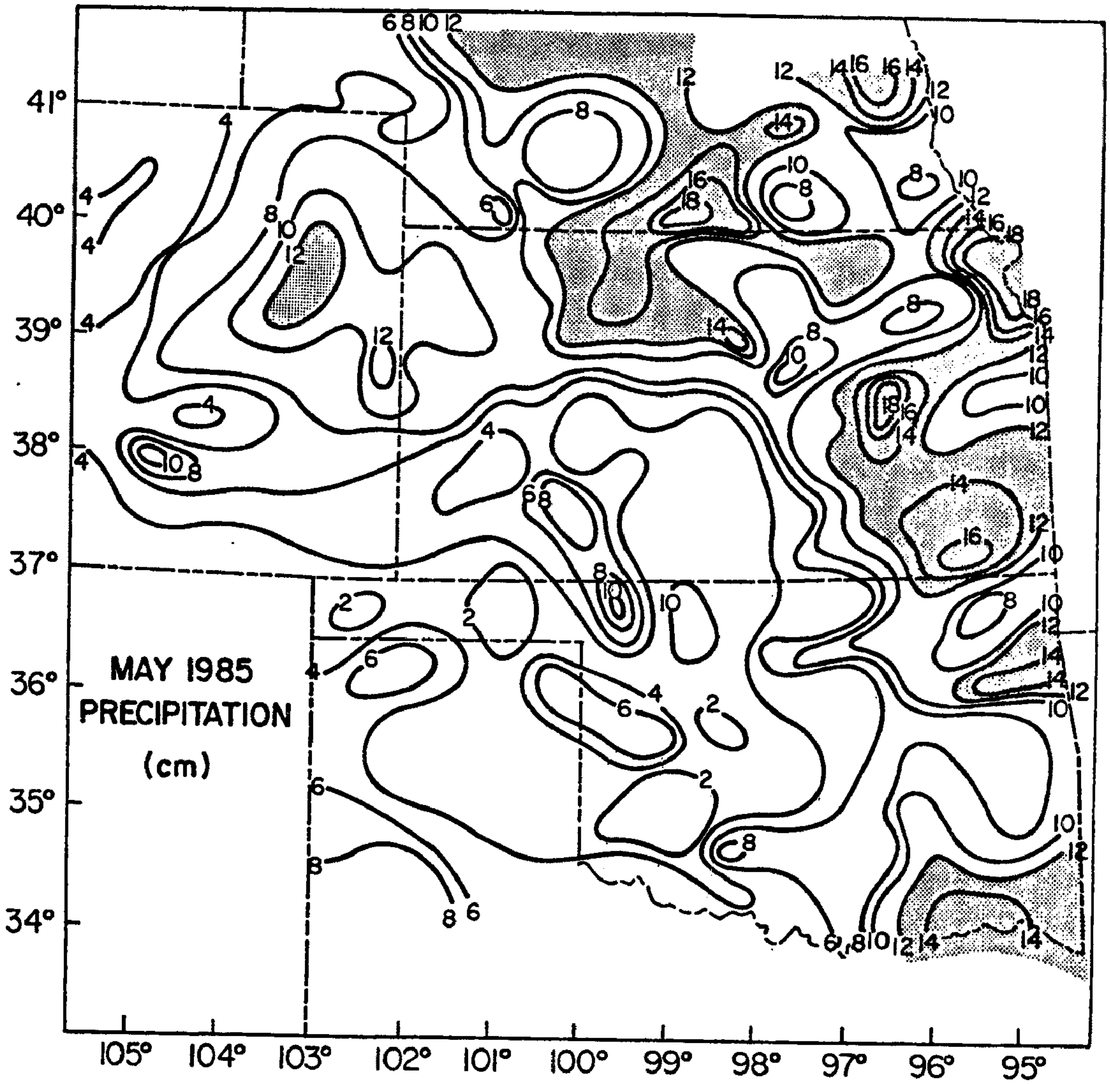

Fig. 7 May 1985 precipitation (cm).

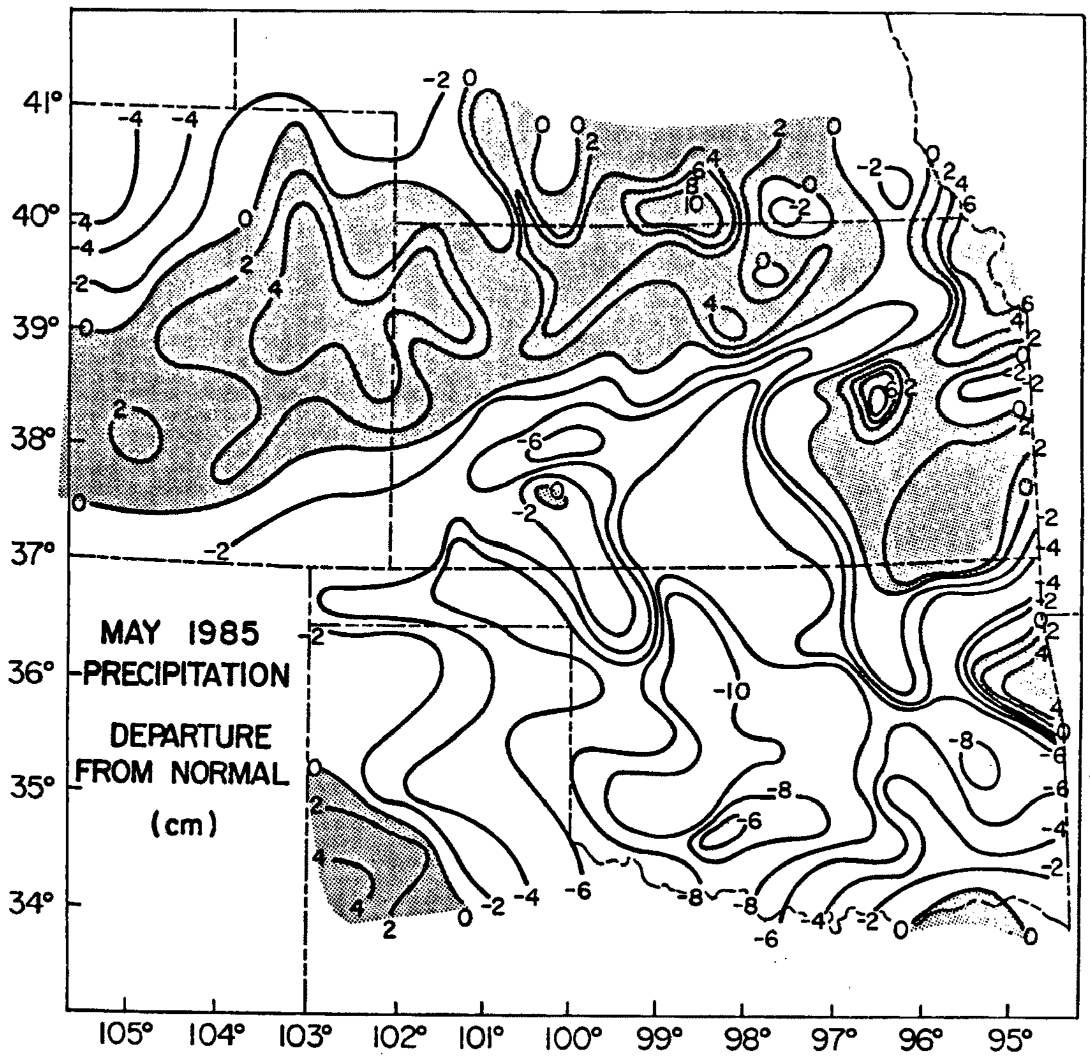

Fig. 8 May 1985 departure from normal precipitation (cm).

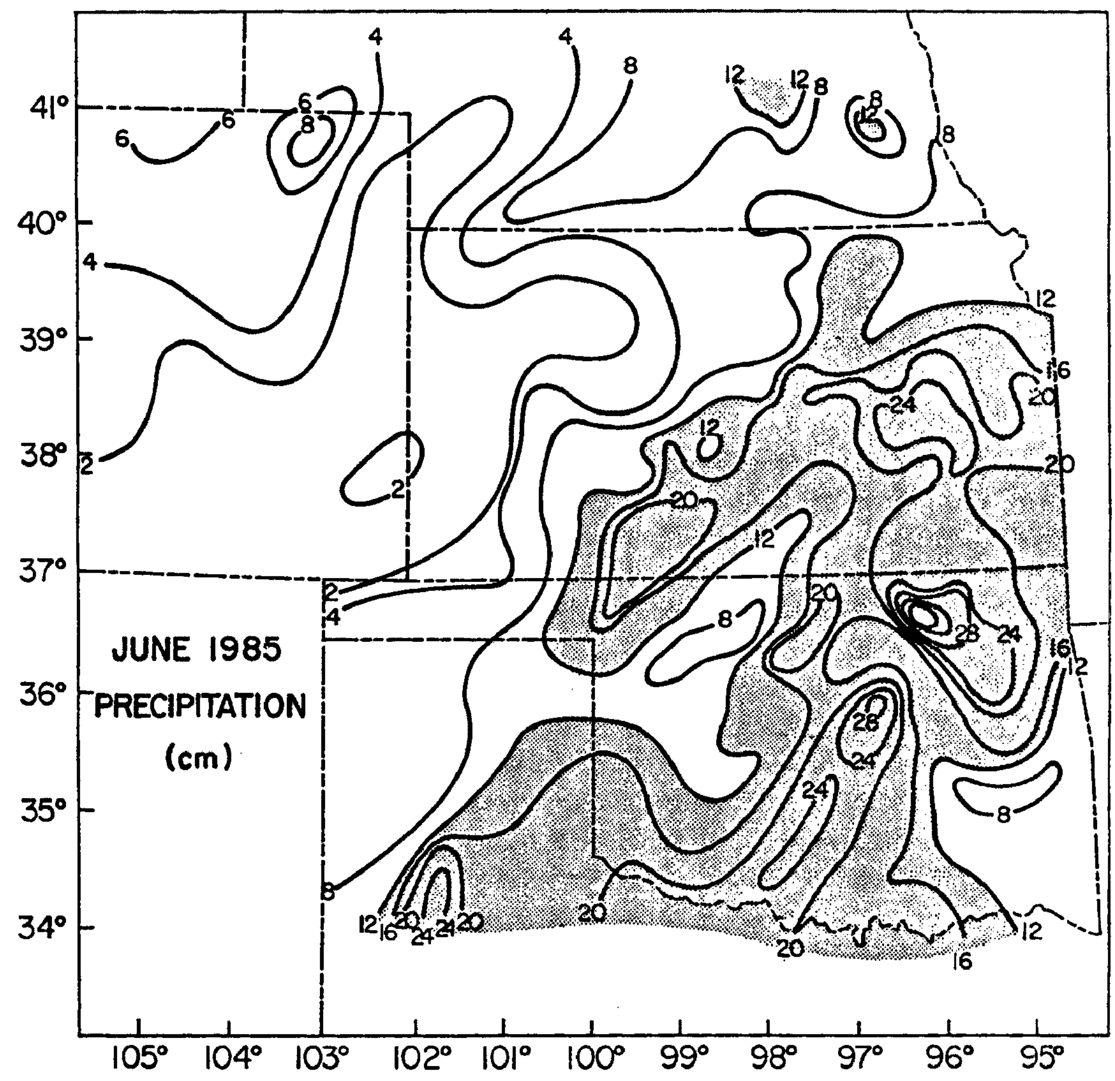

Fig. 9 June 1985 precipitation (cm).

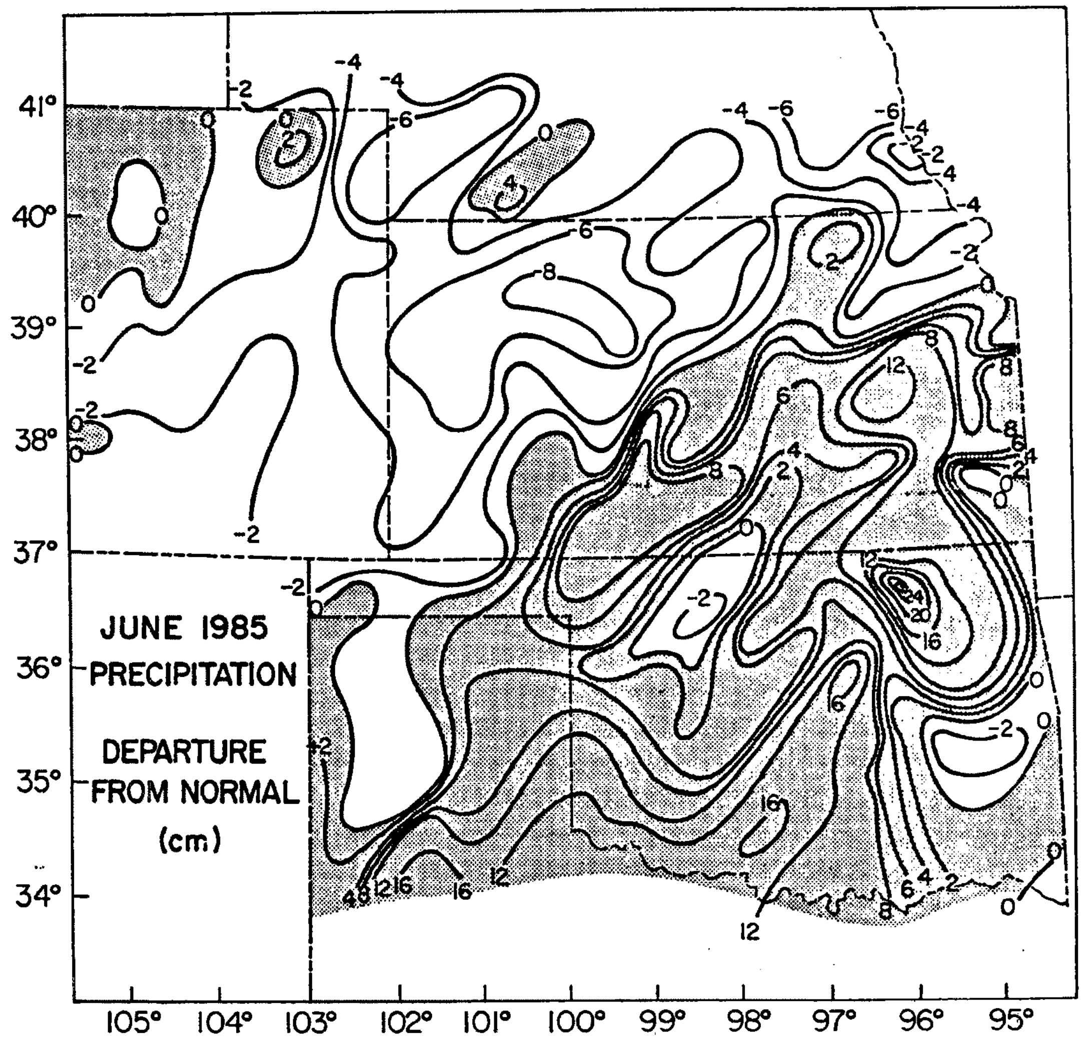

Fig. 10 June 1985 departure from normal precipitation (cm).

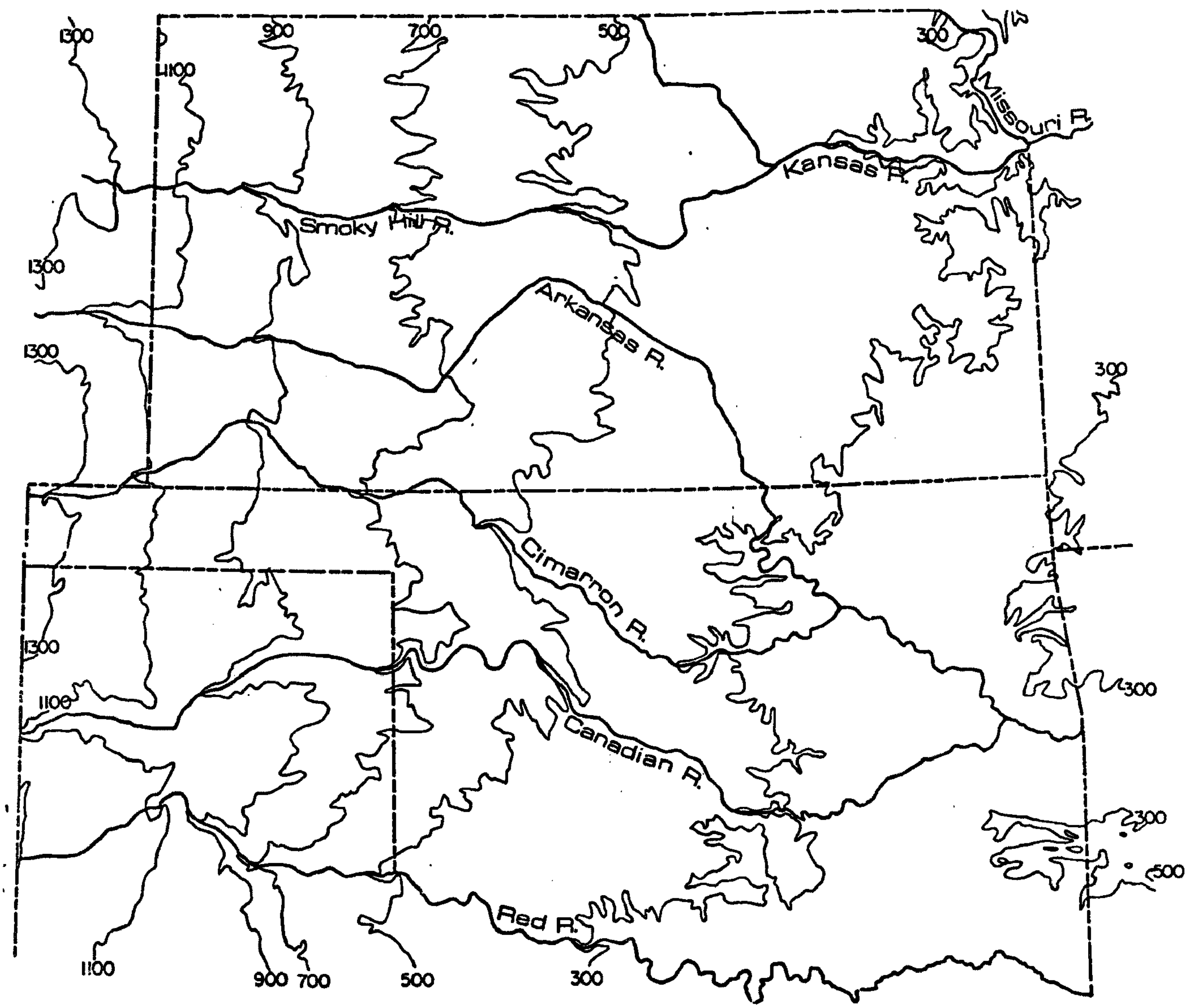

Fig. 11 Topography of May-June 1985 Oklahoma-Kansas PRE-STORM area (contours in m).

Maps of mean pressure at 500 m (the approximate mean elevation of all stations) for four different time periods are displayed in Figs. 12-15. In the computations, layer mean virtual temperatures at all stations of 293 K for 1-21 May and 297 K for 21 May-31 June were used. Note that there is a change in the geostrophic wind direction throughout the period: southwesterly flow from 1 to 21 May, southerly from 21 to 31 May, southeasterly from 1 to 11 June and a return to southwesterly (with a stronger gradient) from 11 to 30 June. Based on these smooth subjective analyses and sensor calibrations, a tabulation of suggested corrections to PAM II PRE-STORM pressure data has been prepared and is shown in Table 2. To determine the recommended adjustment at a station, users should add or subtract numbers in the pressure adjustment column (for the time period of interest) from the reported pressure in the PAM data archive. The adjusted pressure should be treated as a first guess; additional adjustments by a few tenths of a millibar may be required for individual cases especially, e.g., when extreme temperatures occur (the relationship of the transducer reading to the actual pressure varies as a function of temperature). The procedure we have used has also led to slight revisions in elevations at stations 5, 15 and 28 from those estimates based on topographic chart analysis. The revised elevations are included in Appendix 1 and Table 2. In all other cases the agreement between the analysis-determined and calibration-determined pressure corrections was excellent, indicating the elevation estimates from the topographic chart data were quite accurate (within ± 3 m). Subsequent comparison of the calibration-determined pressure corrections with the DDC and ICT station pressures revealed a mean bias of -0.7 mb. This additional correction has been incorporated into Table 2.

For completeness, we show the May and June 500 m mean pressure maps in Figs. 16 and 17. General south to southwesterly geostrophic flow is indicated over the region except

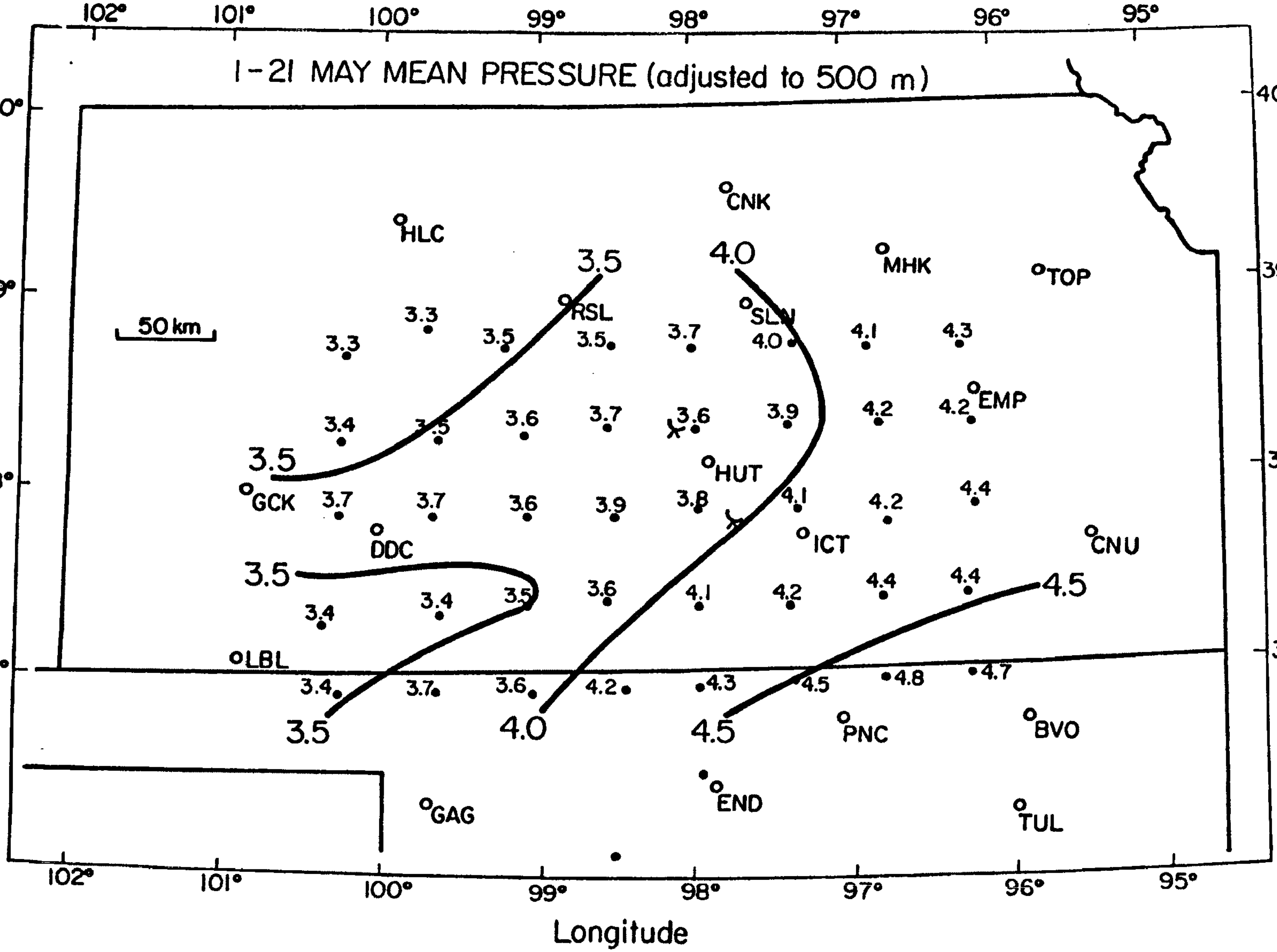

Fig. 12 Mean pressure for 1-21 May (adjusted to 500 m). Contours are actual pressure (mb) minus 950 mb.

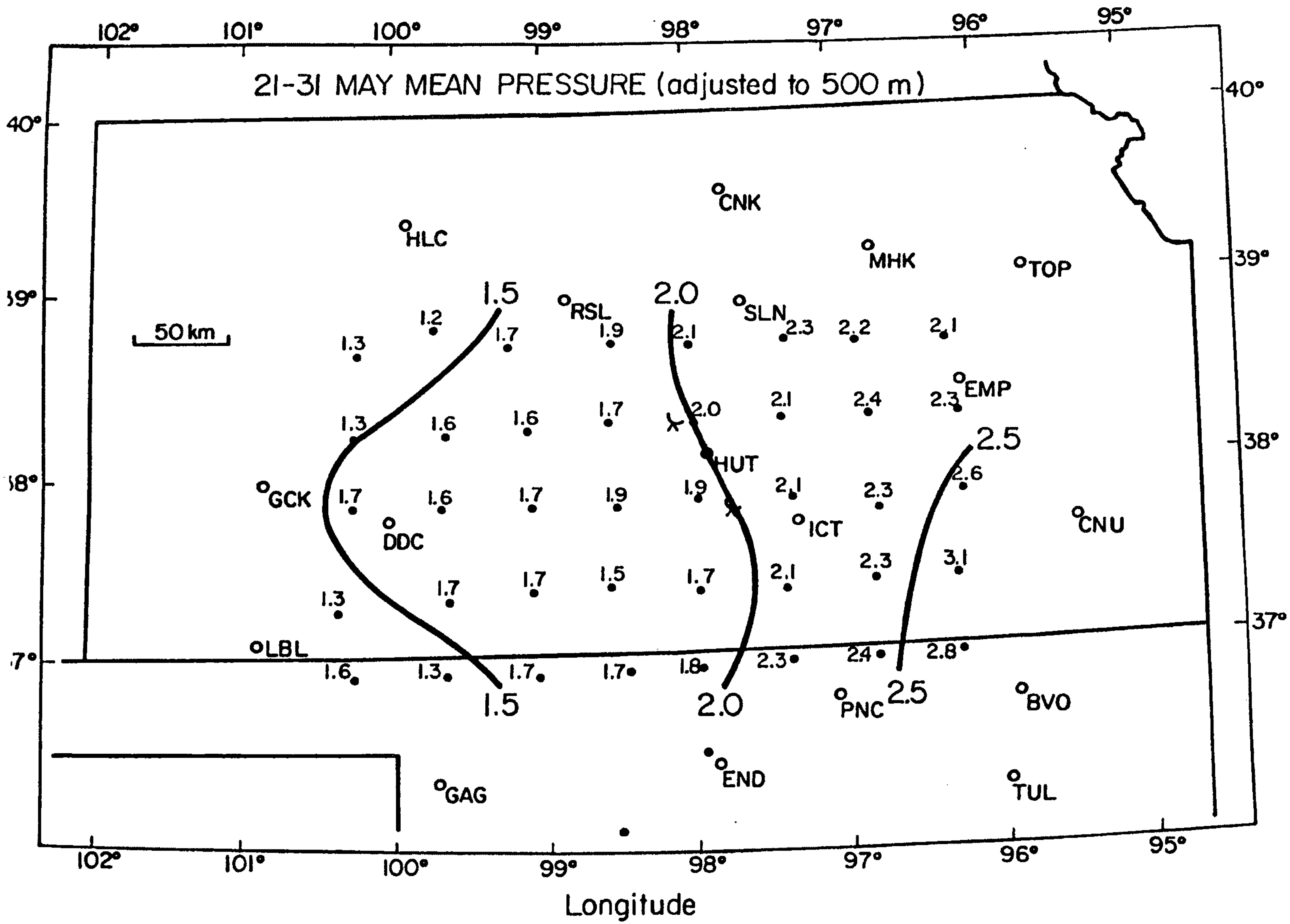

Fig. 13 Same as Fig. 12, except for 21-31 May.

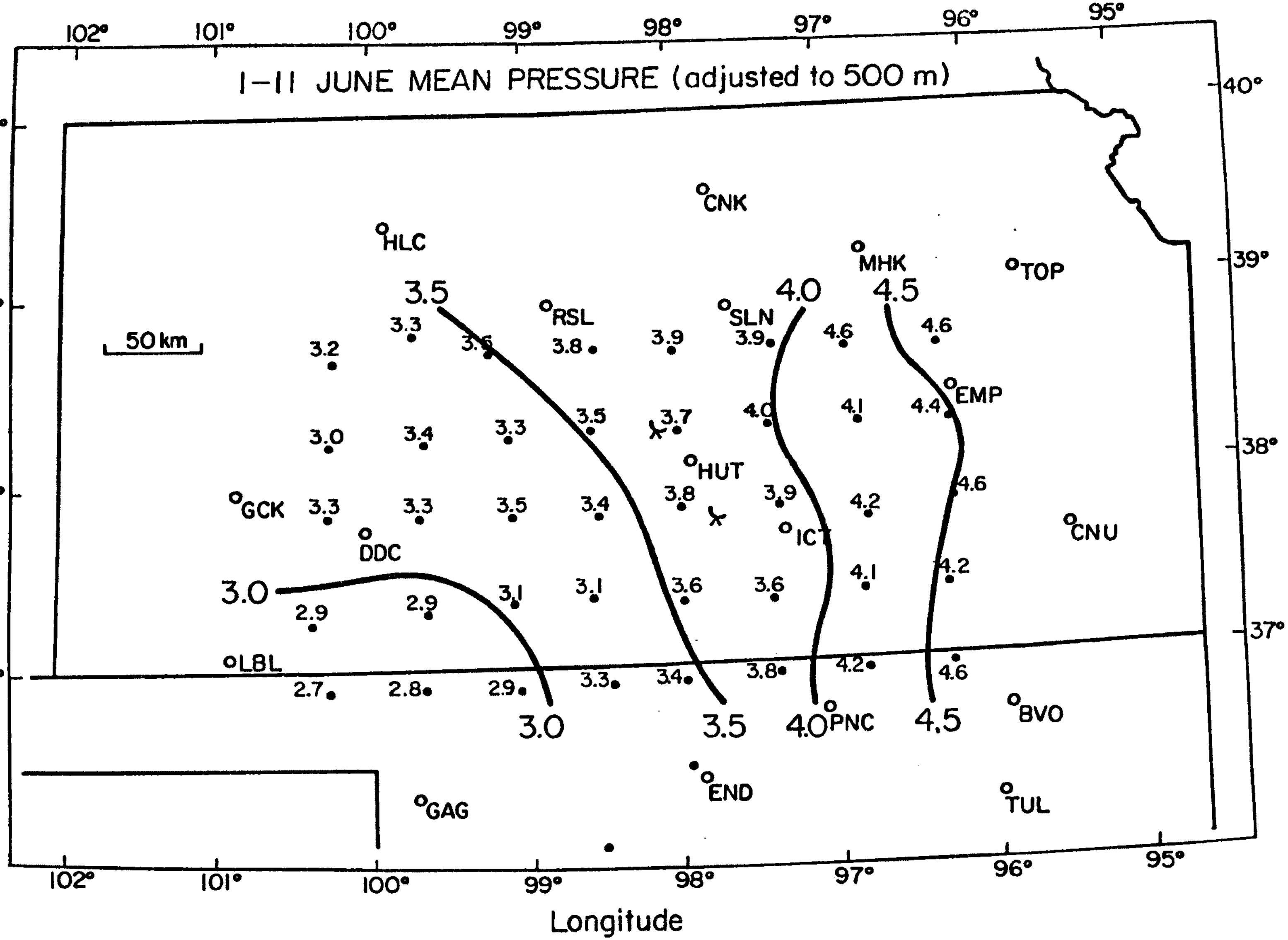

Fig. 14 Sames as Fig. 12, except for 1-11 June.

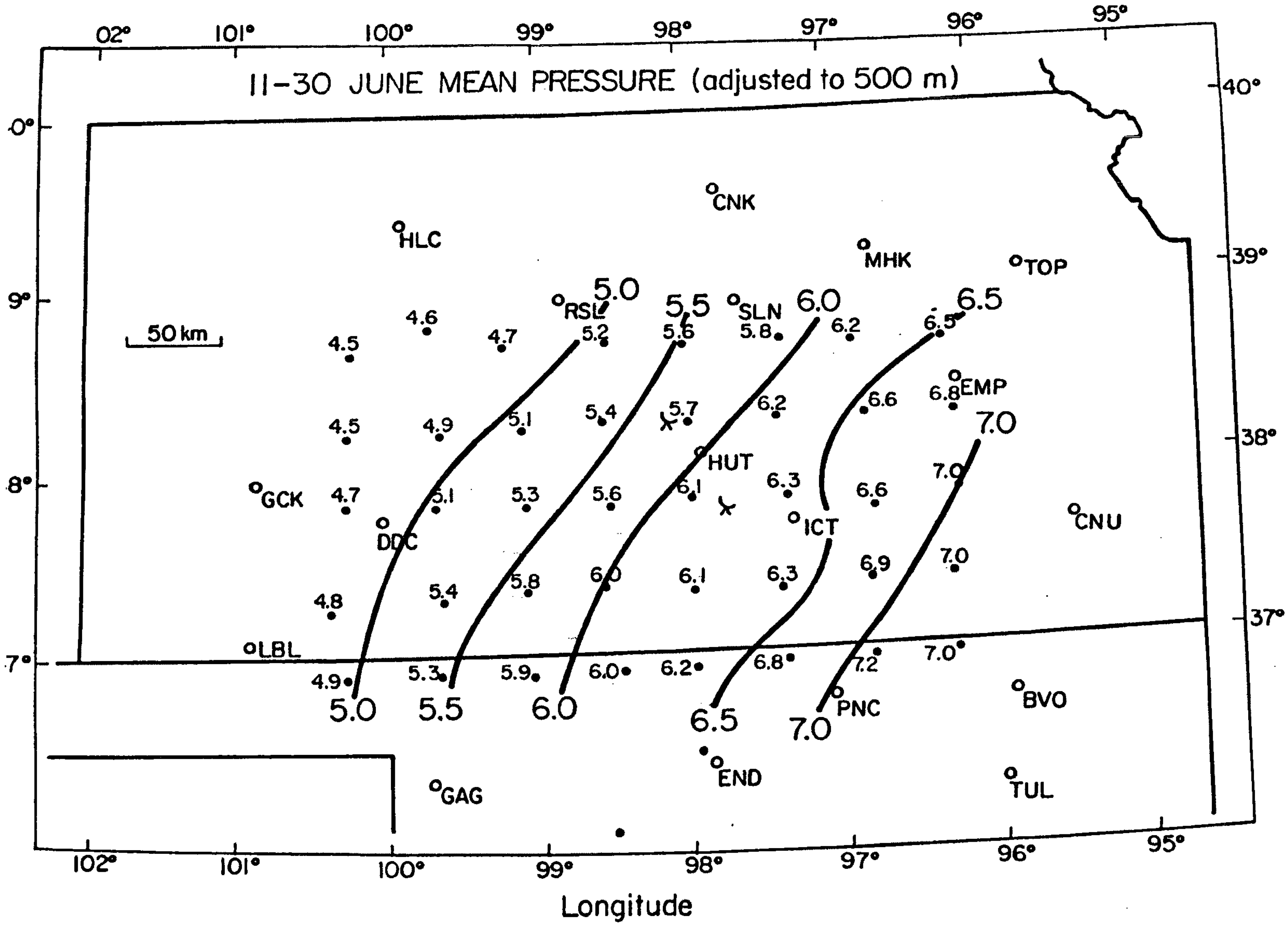

Fig. 15 Same as Fig. 12, except for 11-30 June.

Table 2

Estimated PRE-STORM PAM Station Elevations and Pressure Adjustments

SITE	ELEV(m)	Pressure Adjustment	SITE	ELEV(m)	Pressure Adjustment
1	799	+1.3	22	407	-0.7
2	651	May-12 June: +0.9	23	418	+0.3
		12-30 June: +1.2	24	336	-0.4
3	575	-0.5	25	769	May: +0.4
4	540	May: -0.7			June: +0.1
		1-11 June: -1.2	26	625	1-21 May: +0.3
		11-30 June: -1.6			21-31 May: -0.4
5	484	0.0			June: 0.0
6	404	-0.1	27	625	-0.1
7	452	May-7 June: +0.5	28	530	May: -1.5
		7-30 June: +0.8			June: -1.8
8	461	May: +0.6	29	434	+1.4
		June: -0.6	30	387	1-21 May: +0.5
9	791	-0.2			21 May-June: +0.8
10	653	-0.3	31	407	+1.4
11	613	-0.2	32	320	????
12	545	+1.1	33	786	1-21 May: +0.3
13	479	+0.7			21 May-June: -0.1
14	467	1-21 May: -1.2	34	628	+0.3
		21-31 May: -1.7	35	546	1-21 May: +0.5
		1-11 June: -2.2			21 May-June: 0.0
		11-30 June: -2.0	36	379	1-23 May: -1.1
15	403	May: +0.7			23 May-June: +0.2
		June: +1.0	37	356	+0.5
16	371	+0.2	38	330	+0.2
17	821	-0.1	39	374	+2.0
18	725	May: +0.2	40	300	May: E 0.0
		June: -0.1			June: E+1.1
19	632	May: +0.1	41	414	May-16 June: E-0.7
		June: +0.4			16-30 June: E+2.0
20	561	-0.2	42	480	May: ????
21	472	+0.4			June: E+0.2

E = estimated

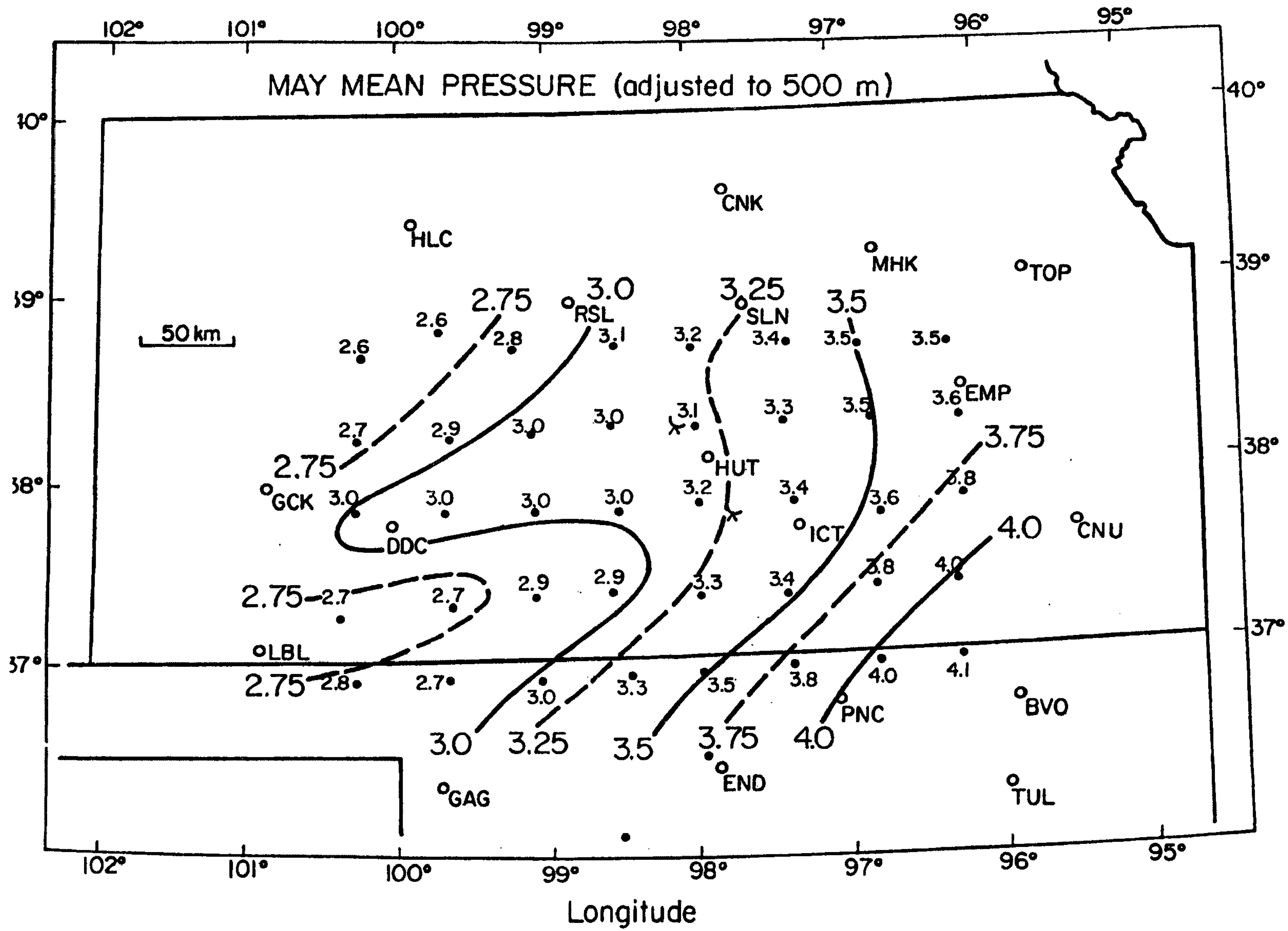

Fig. 16 Same as Fig. 12, except for all of May 1985.

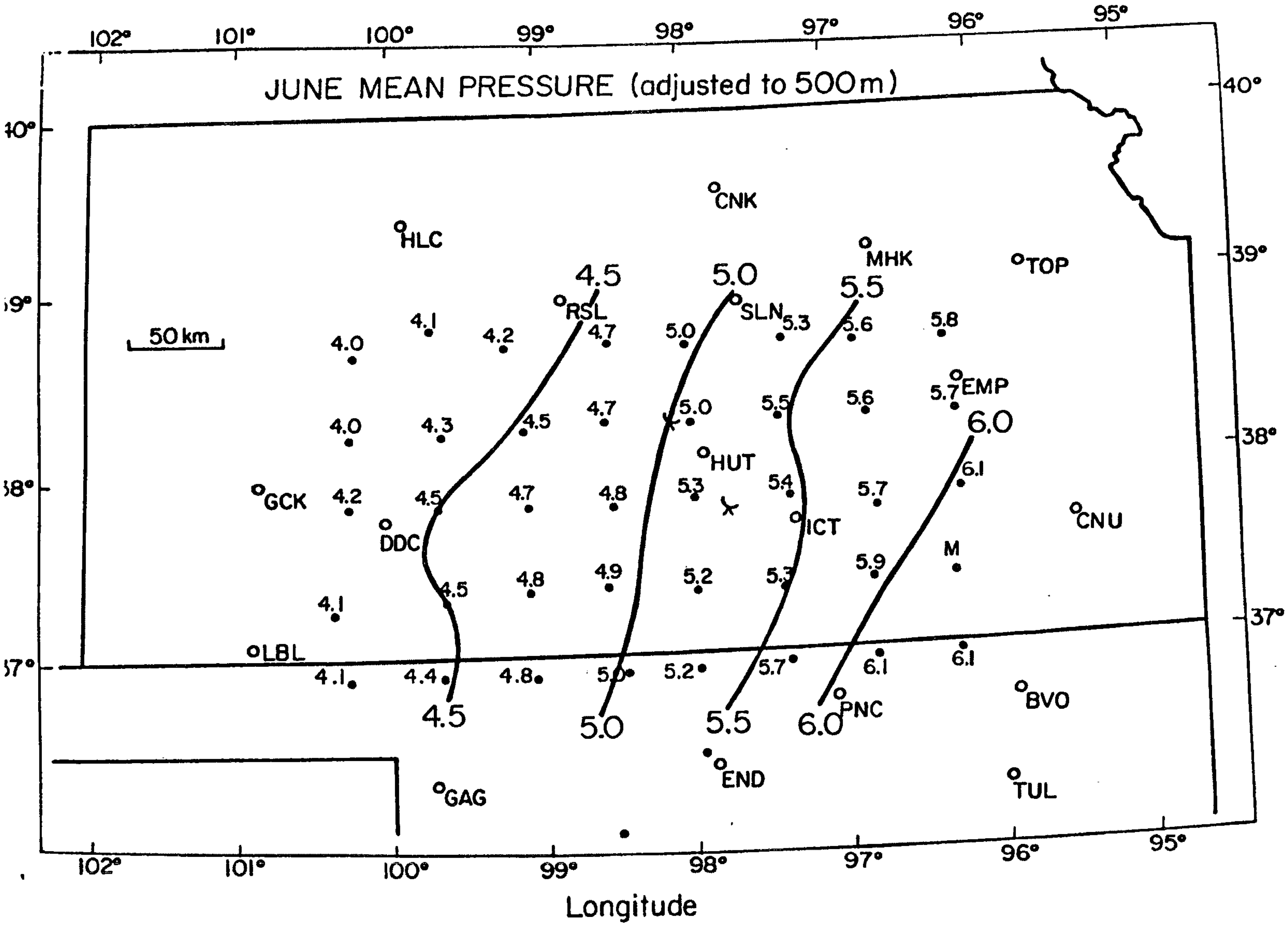

Fig. 17 Same as Fig. 12, except for all of June 1985.

in the western portion of the domain where some irregularities exist. These features can most likely be attributed to the greater topographic variability in this region.

b. Temperature

Instrument calibration checks conducted during PRE-STORM indicate that temperatures from the PAM sites are probably accurate to within 0.5°C. Nonrepresentativeness of sites probably contributes errors of comparable size. Analyses of monthly mean temperatures should remove most effects of transient phenomena and reveal bias that may exist at certain stations.

In Fig. 18 an analysis of mean temperature for May is presented. Temperature generally increases from north to south over the region as expected, with some minor irregularities in the field. Average temperatures for May at National Weather Service first order Stations Dodge City (DDC) and Wichita (ICT) are both 0.7°C greater than estimates at those positions based on the PAM data analysis. This small difference could be a reflection of slight urban heat island effects at both locations. Irregularities due to topographic effects can be eliminated (in principle) by repeating the analysis using potential temperature. These results are shown in Fig. 19. The irregularities are indeed diminished somewhat and there is a generally smooth west to east gradient of θ. Highest values in the west are a reflection of elevated heat source effects (day is longer than night in May). It is possible that there is some contribution to lower values of θ in the east and north due to the excessive rainfall there (Fig. 7).

The mean temperature analysis for June is shown in Fig. 20. A north- south gradient exists, but for June there are larger perturbations in the field. The perturbations still exist in the analysis of potential temperature (Fig. 21). Superimposed on the θ analysis is the field of precipitation. It is quite clear that lower values of temperature are well

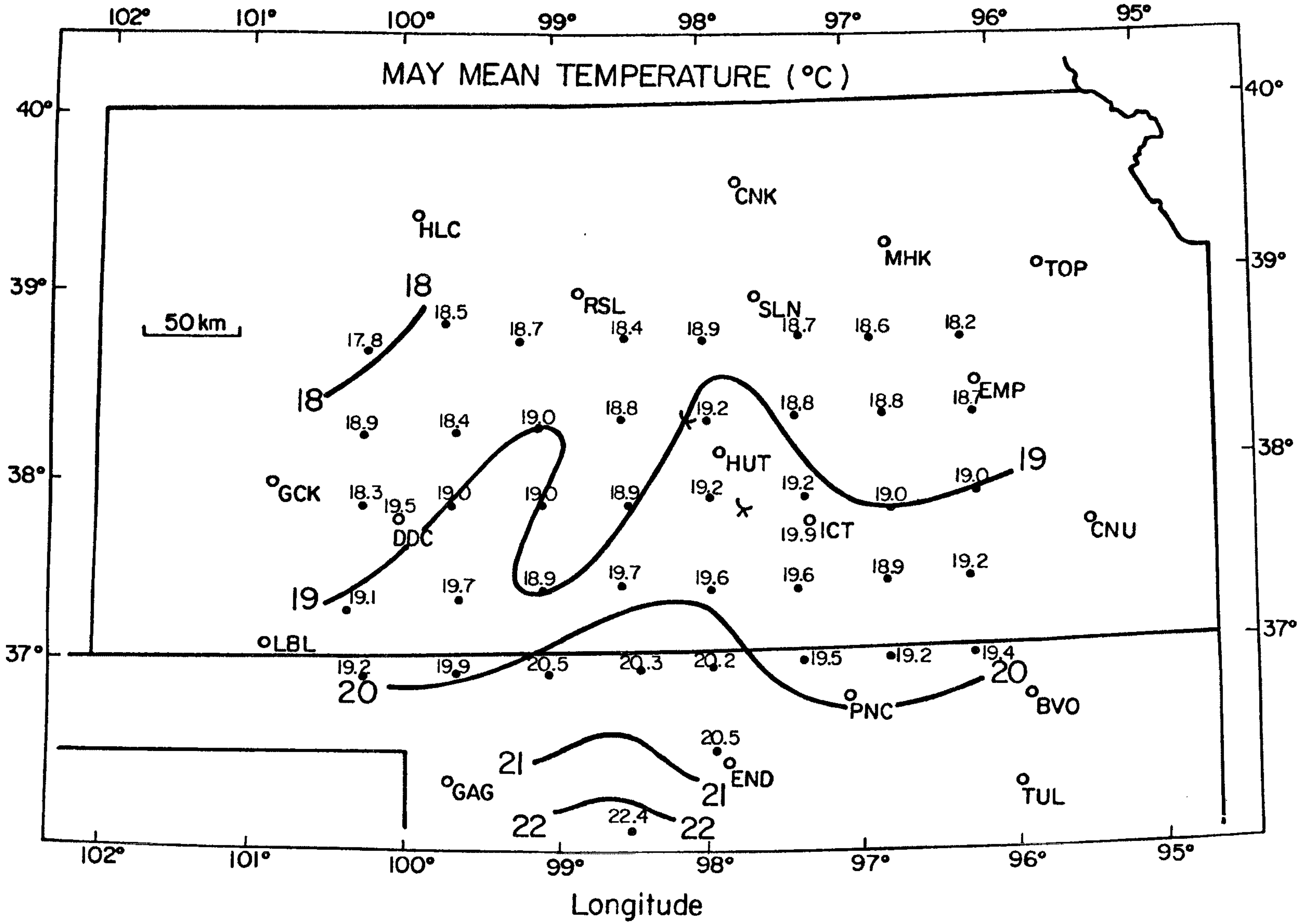

Fig. 18 Mean temperature for May (°C).

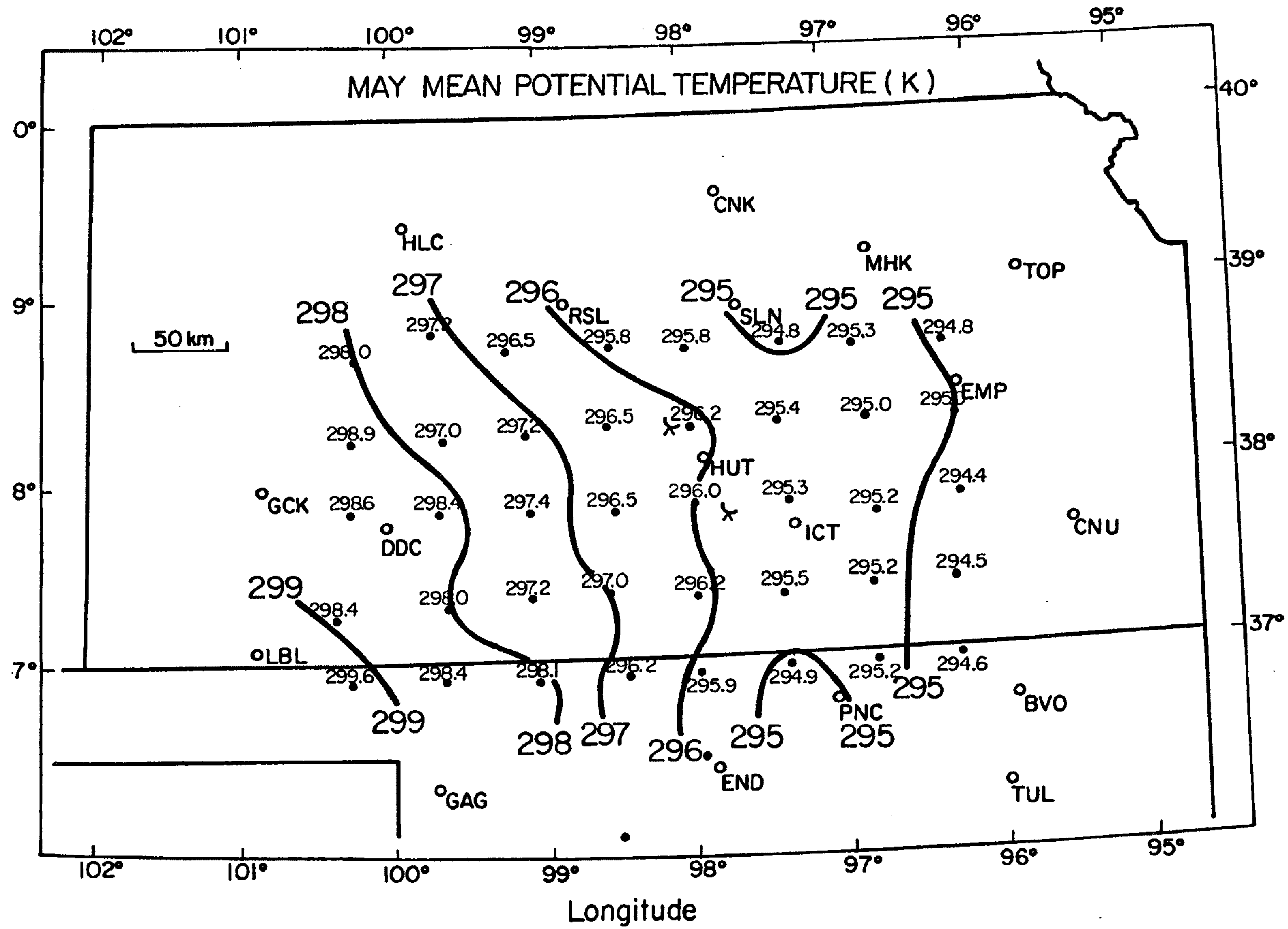

Fig. 19 Mean potential temperature for May (° K).

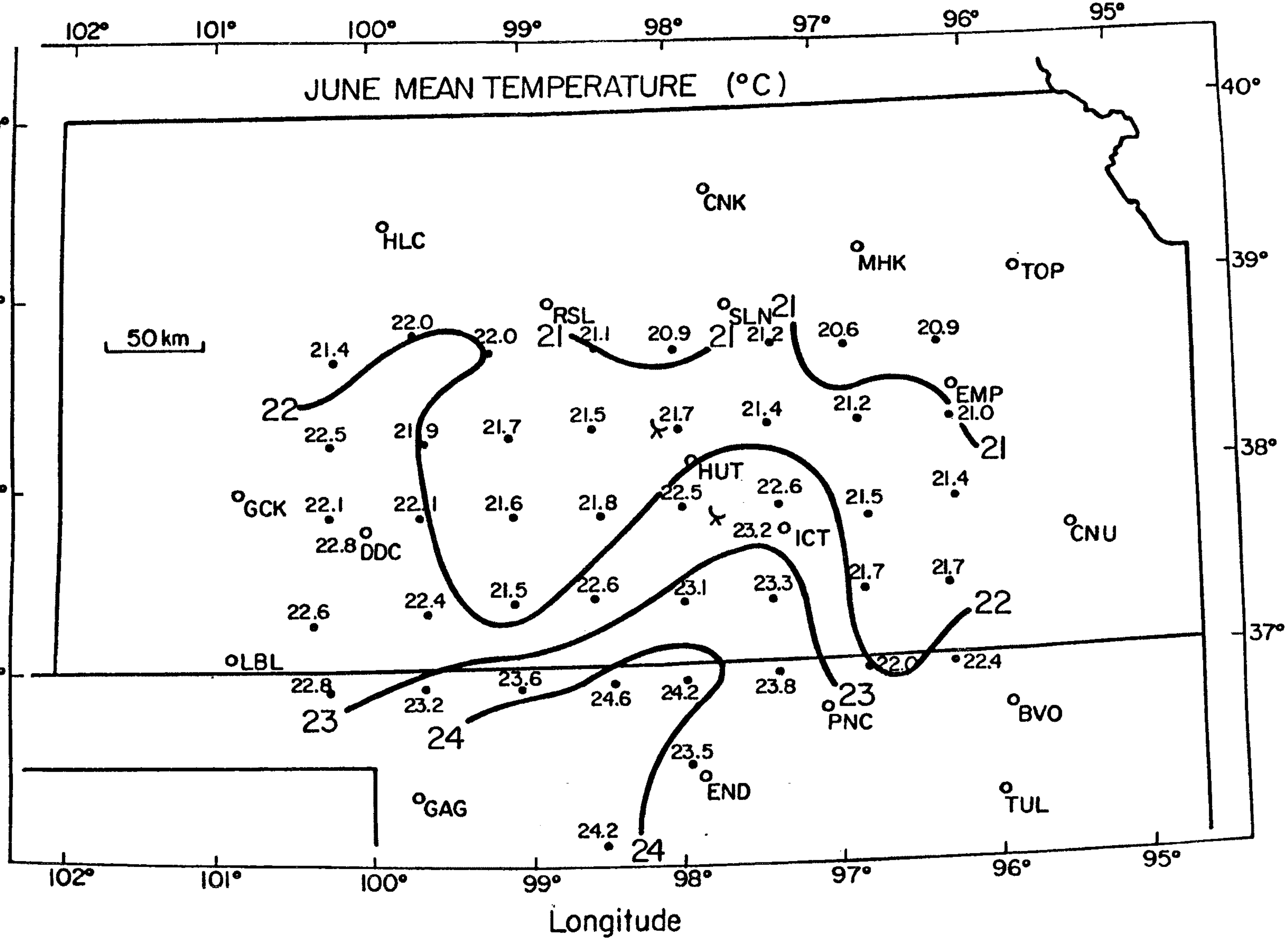

Fig. 20 Mean temperature for June (°C).

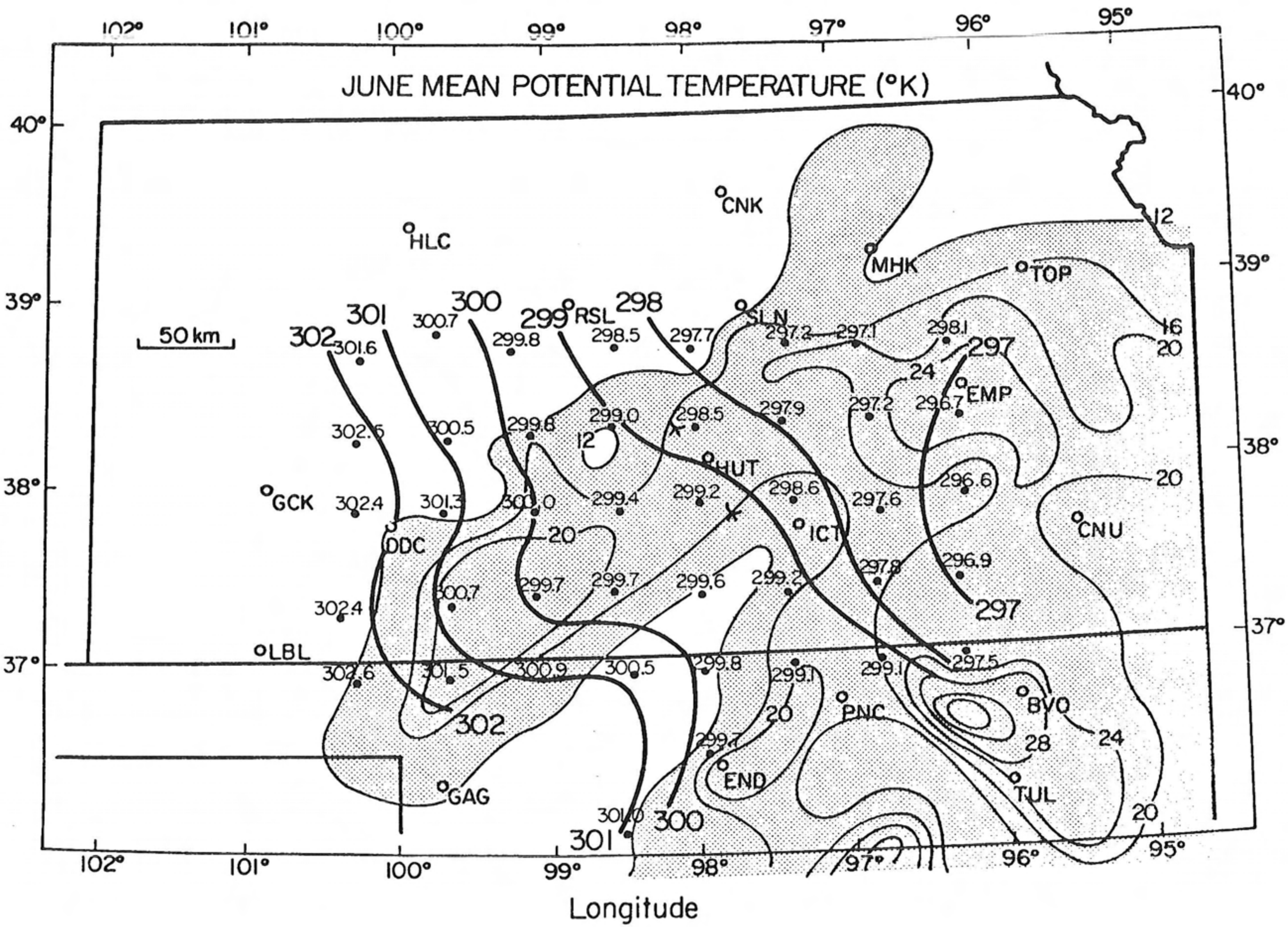

Fig. 21 Mean potential temperature for June (°*K*) and June precipitation (shaded; mm).

correlated with areas of heavy rainfall. Surface wetting, enhanced evaporation and possibly greater cloudiness in these areas are probably creating localized cool anomalies that are dramatically evident in the monthly mean fields.

For June (Fig. 20) the monthly mean temperatures at DDC and ICT are 0.5°C greater than the analysis would indicate, again suggesting a slight urban heat island effect.

c. Wet bulb temperature

Difficulties with the wet-bulb instrumentation have already been discussed in Section 2a. Using wet-bulb temperatures corrected according to procedures described by Hjelmfelt *et al.*, (1986), May and June mean maps of this quantity have been prepared (Figs. 22 and 23).

During May (Fig. 22), wet-bulb temperatures are seen to be highest in the southeast portion of the network and lowest in the west at the highest elevations. Monthly mean values at the National Weather Service stations (Dodge City, Wichita and Topeka) agree with the PAM analysis to within 0.5°C. A similar pattern is evident for June (Fig. 23) and, again, agreement with neighboring National Weather Service stations is very good. We are, therefore, quite confident that the correction procedures applied by Hjelmfelt *et al., (1986)* have yielded a quite reliable wet-bulb temperature record for PRE-STORM.

6. Winds

Maps of vector-averaged winds have been prepared following the removal of unusually large five-minute average winds (where a component exceeds 30 m s^{-1}) that may have been associated with severe weather or glitches in the data stream. Mean vector fields for six different periods are presented in Figs. 24 and 25.

During 1-11 May (Fig. 24a) a strong southerly flow existed across the Kansas- Oklahoma region and at this time there was considerable convective activity over Kansas.

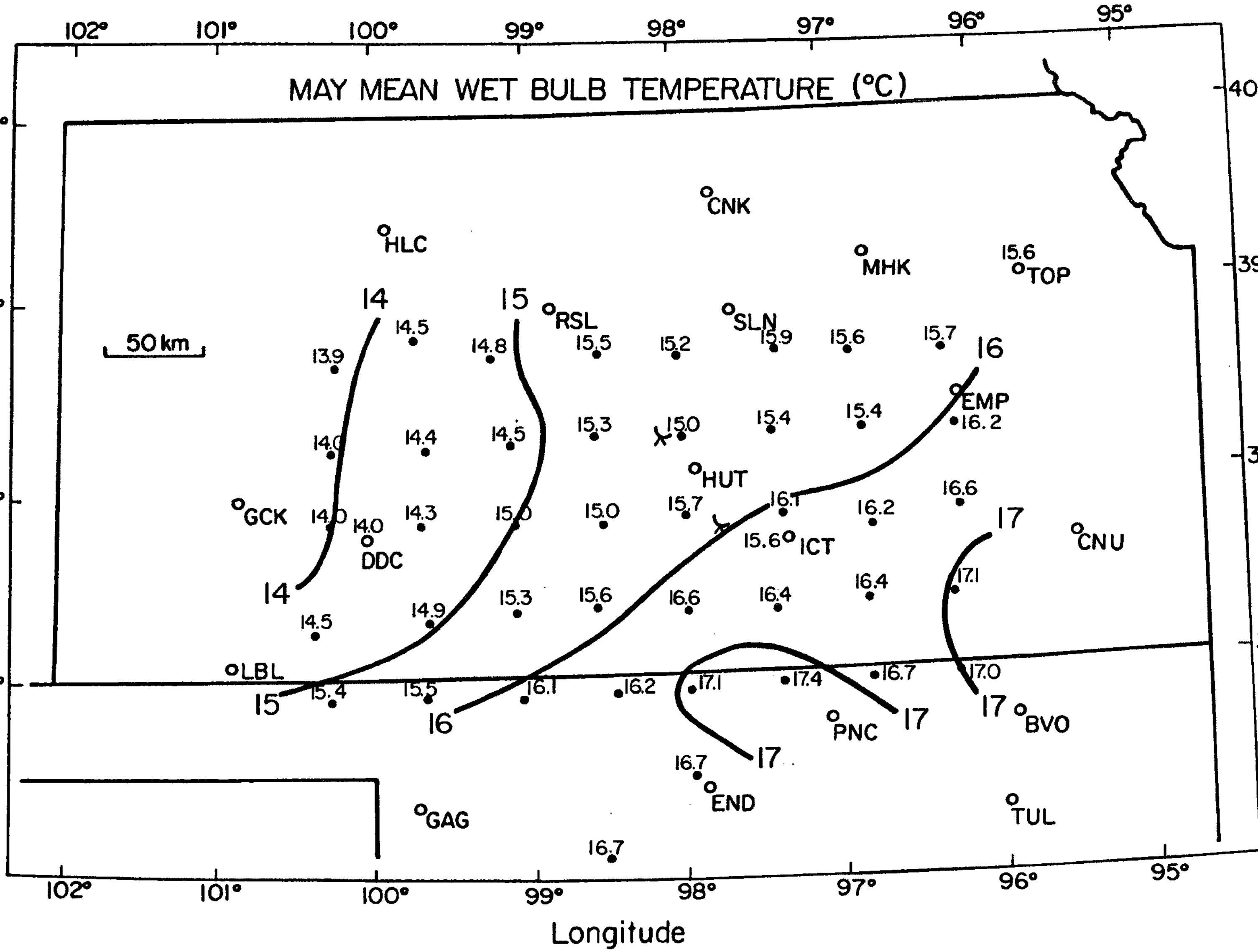

Fig. 22 Mean wet-bulb temperature for May (°C).

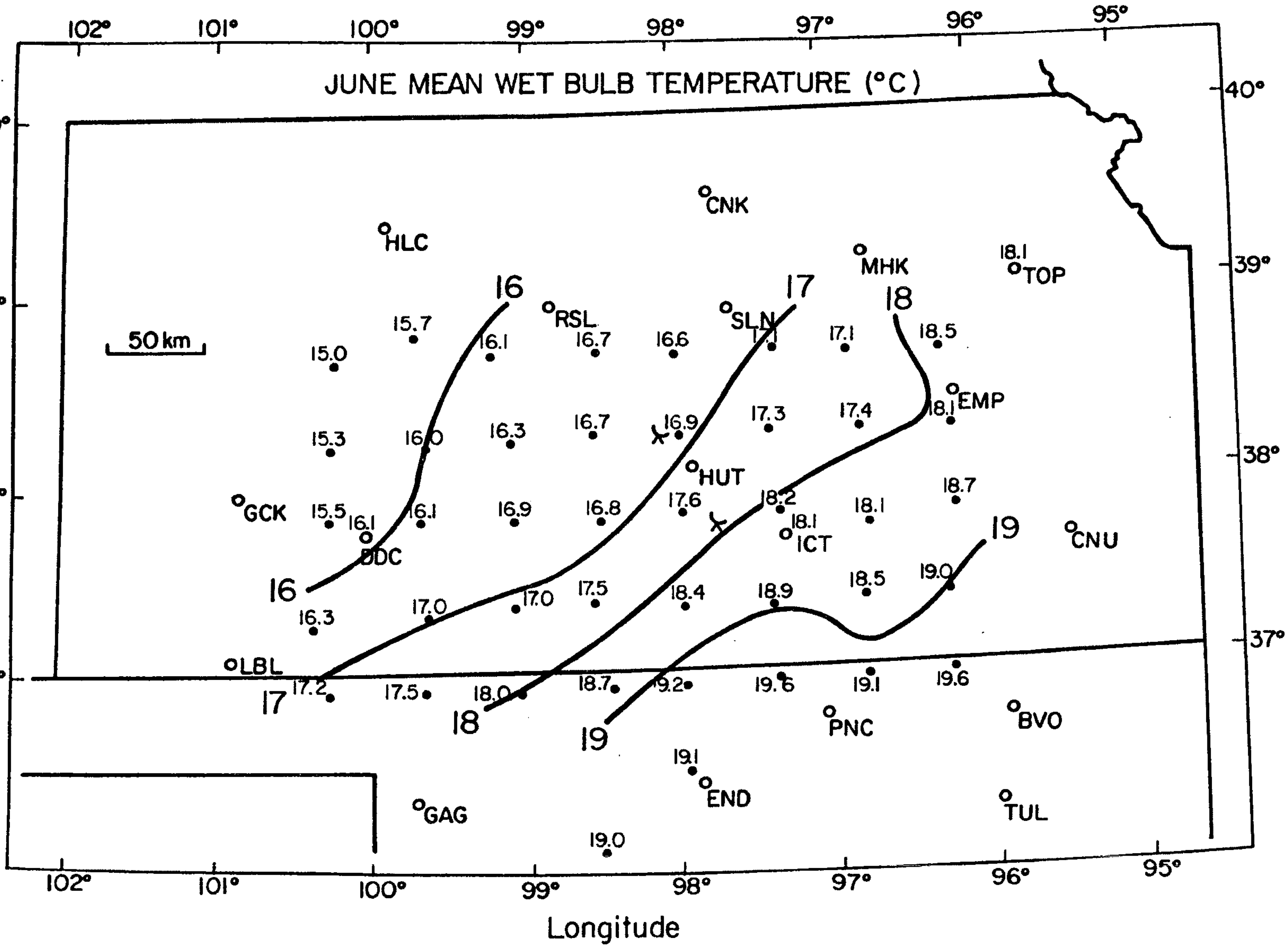

Fig. 23 Mean wet-bulb temperature for June (°C).

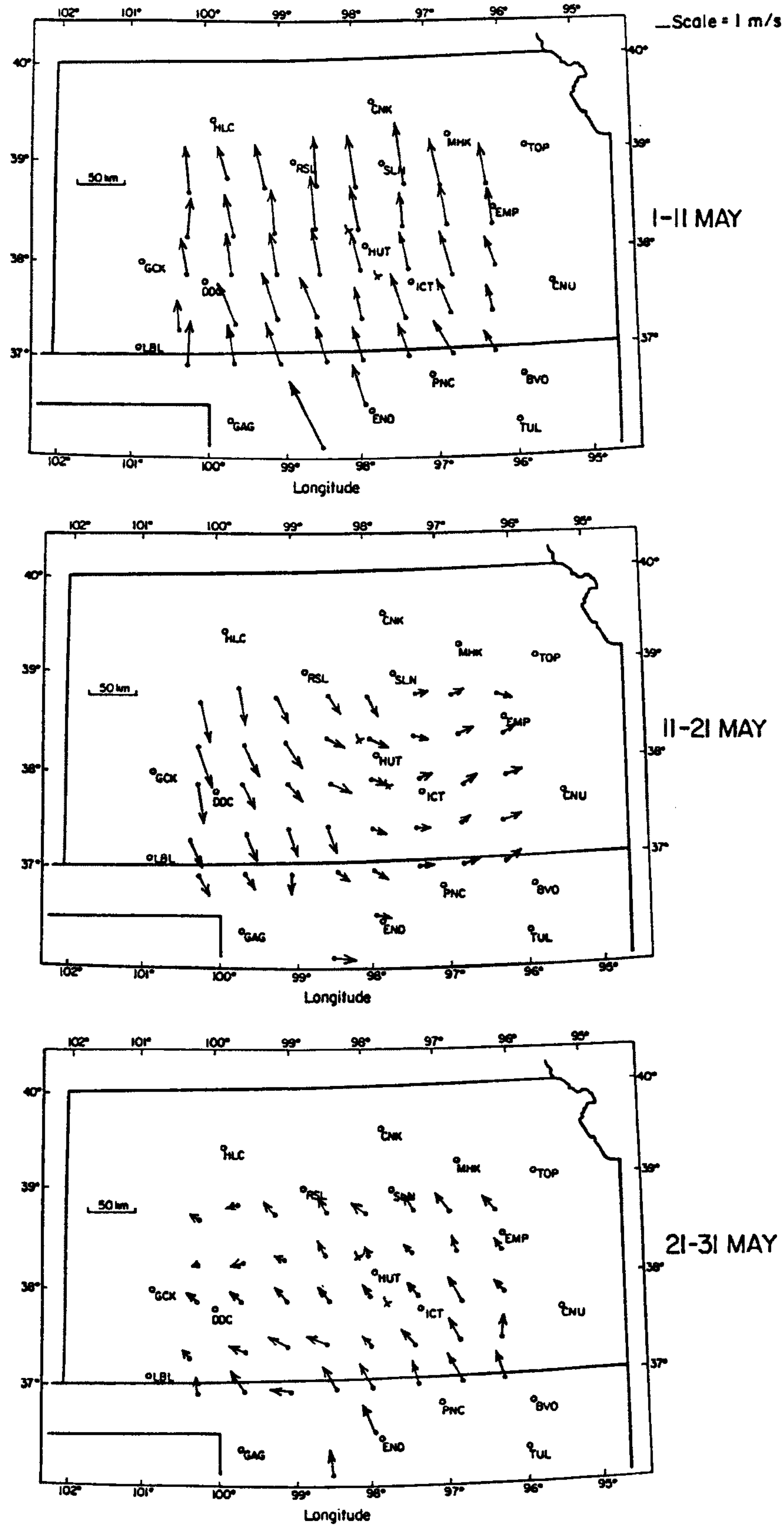

Fig. 24 Vector-averaged winds in PAM II mesonetwork for (a) 1-11 May, (b) 11-21 May and (c) 21-31 May. Scale is shown at upper right.

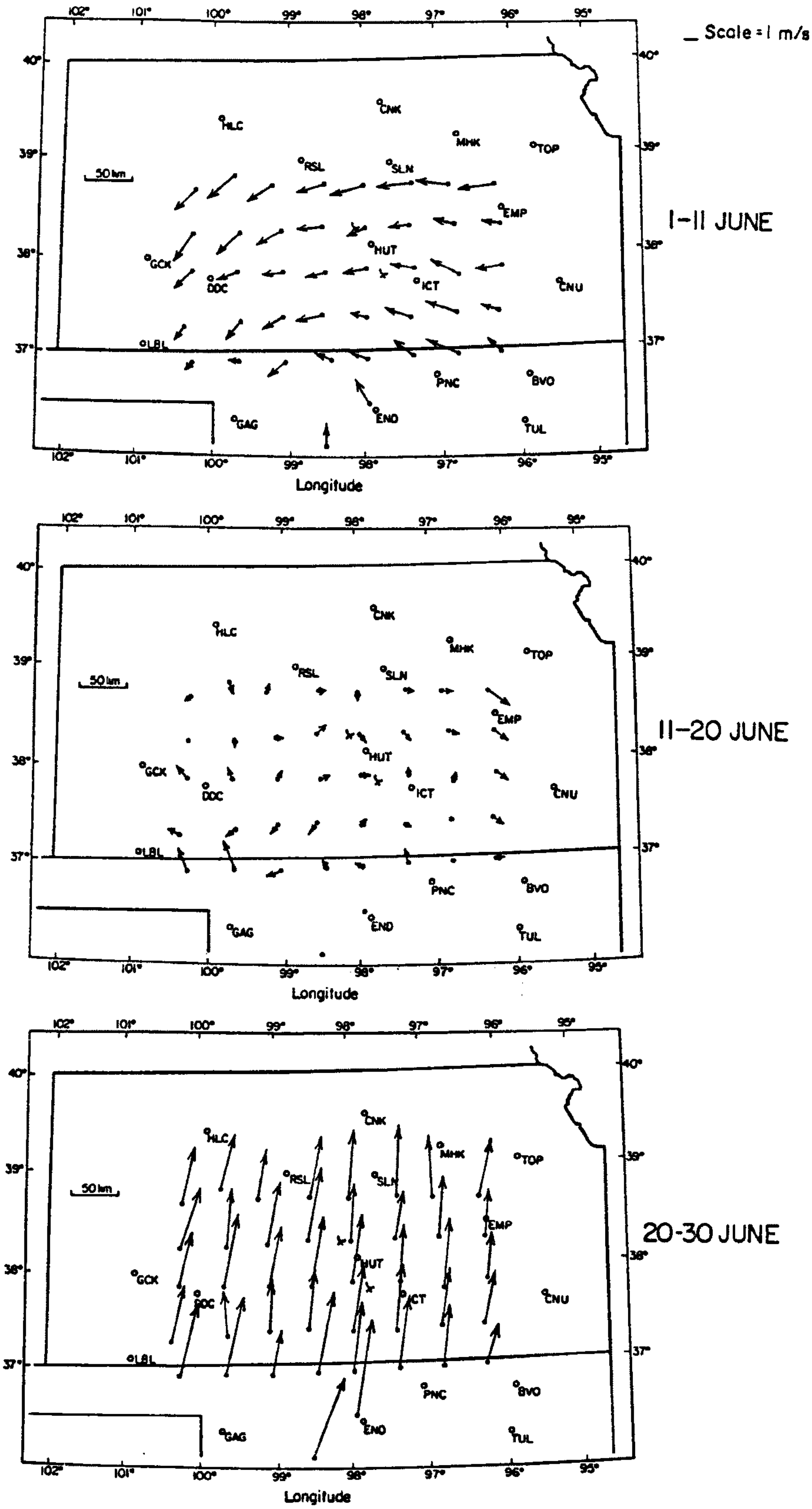

Fig. 25 Same as Fig. 25, except for (a) 1-11 June, (b) 11-20 June and (c) 20-30 June.

Rather suppressed conditions occurred during the 11-21 May period (Fig. 24b) when a mean west to northwesterly flow prevailed. A southerly component returned during 21-31 May (Fig. 24c), along with a resurgence in convective activity.

One of the most active periods during PRE-STORM was the 1-11 June period (Fig. 25a) when a mean easterly flow occurred over the network. The synoptic situation was frequently characterized by an east-west surface front existing to the south of Kansas. The mean flow during the 11-20 June period was somewhat nondescript (Fig. 25b) and there was a reduction in convection during this period. During the final ten days of June (Fig. 25c), there was a strong south-southwesterly flow over the region.

The mean surface flow for all of May and all of June is presented in Figs. 26 and 27. During both months the mean flow was southerly at 1 to 2 m s^{-1} and generally strongest in the eastern half of the network. The flow field is quite uniform (though some irregularities exist), reinforcing our opinion that no serious siting problems existed. The slight irregularities that did exist, particularly in the western portion of the network, may be attributable to topographic effects. Note, for example, in both Figs. 26 and 27 that winds at stations 26, 27 and 28 are deflected in an upslope direction where higher terrain juts eastward. The deflection may be a consequence of the dominant effects of upslope flow (day is longer than night) in these monthly mean fields for May and June.

A detailed analysis of possible wind errors as a function of time of day, stability conditions and wind direction has not been carried out. Nevertheless, based on the analysis completed here and visual inspection of the mesonet winds throughout the experiment, we are quite confident that there are no serious difficulties with the PRE-STORM PAM II wind fields, particularly for the types of analyses for mesoscale convective systems for which they were deployed.

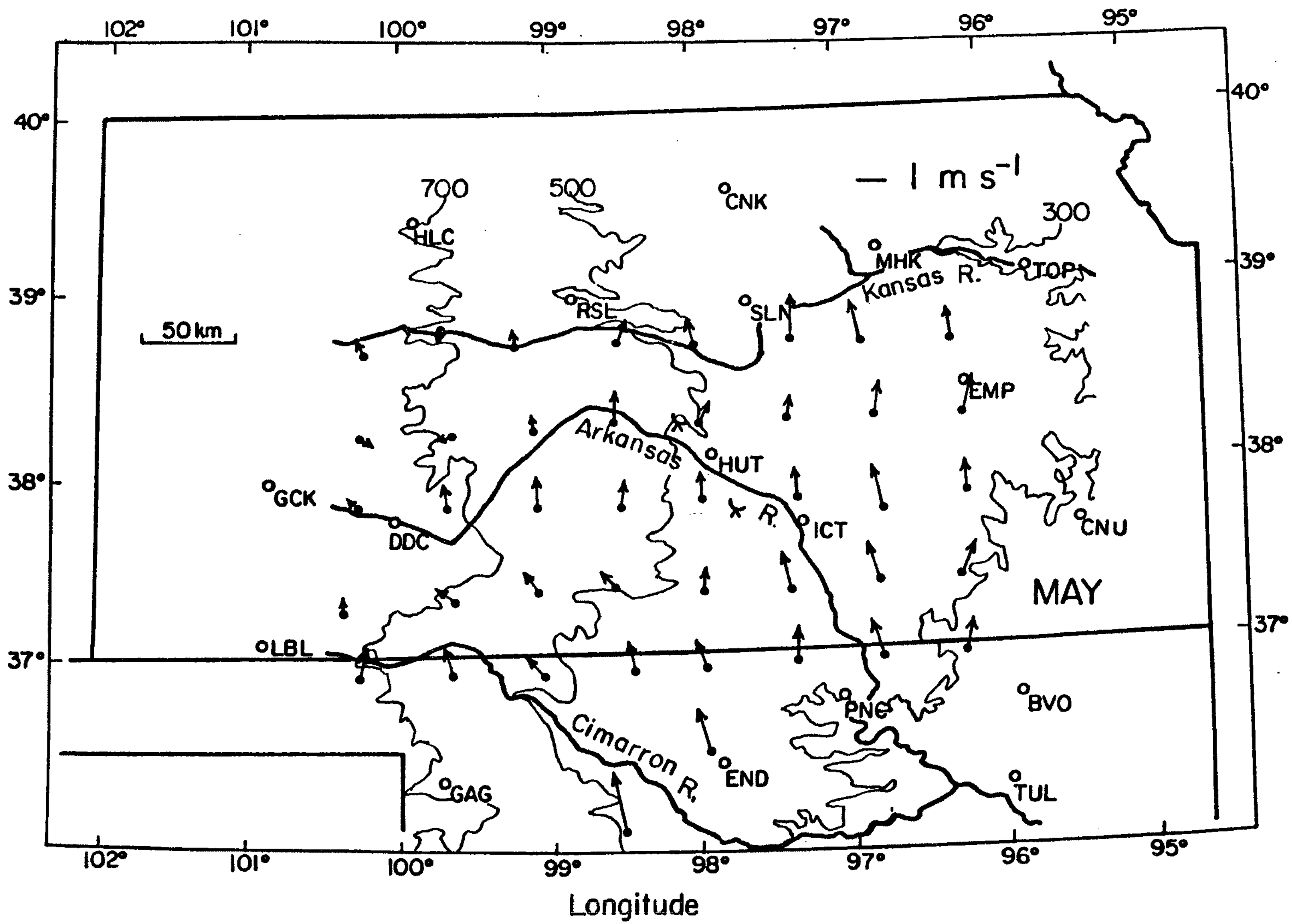

Fig. 26 Vector-averaged winds for all of May, superimposed on terrain features from Fig. 11.

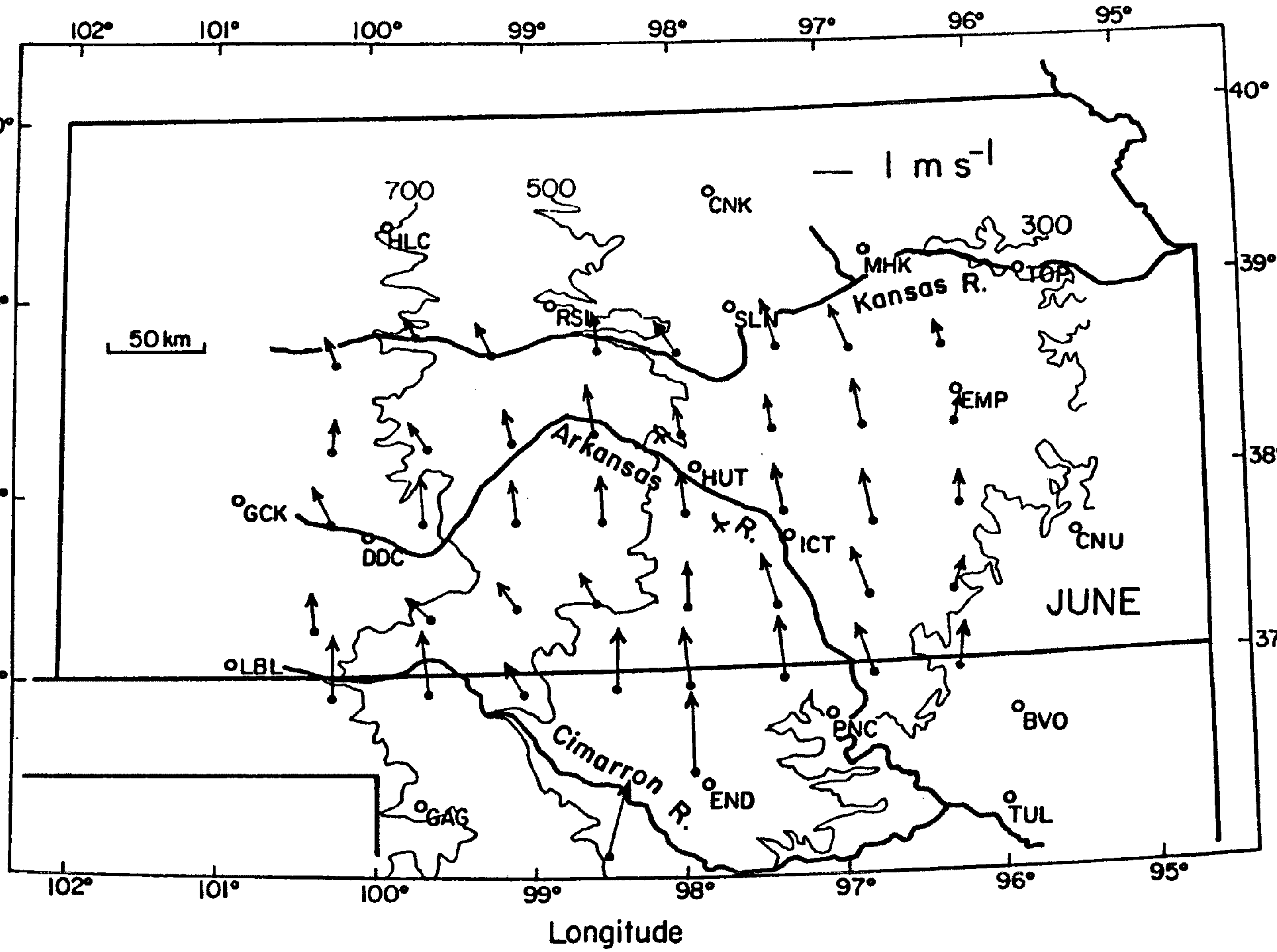

Fig. 27 Same as Fig. 26, except for June.

7. Discussion and Summary

This report summarizes the results of a preliminary analysis of the quality of data from the Oklahoma-Kansas PRE-STORM PAM II Mesonetwork. Our approach has been to examine field calibration logs, monthly mean fields and comparisons with neighboring National Weather Service stations to assess the quality of pressure, temperature, moisture, wind and precipitation measurements from the PAM II instrumentation. More detailed analysis of errors, e.g., using techniques such as those employed for CCOPE by Wade and Engel (1985), would clearly be of value; nevertheless, it is felt that with the realtime data aquisition, meteorologically-sound siting and field calibration of sensors that a high level of accuracy has been achieved by the PRE-STORM PAM II instrumentation.

Several recommendations regarding the use of this data set, based on our preliminary analyses, are contained in this report. The most significant of these recommendations concern the pressure data, where corrections of up to 1 to 2 mb are suggested (Table 2).

Analyses similar to those reported here for the PAM II data are presently planned for NSSL SAM data, although modifications may be required due to rather significant gaps in the SAM data set. This problem is currently under study.

8. Acknowledgments

We extend our sincere appreciation to the entire NCAR Field Observing Facility staff for their extremely dedicated and highly professional assistance and guidance during all stages of the PAM II operation in OK PRE-STORM. Thanks also go to Don Cobb (CSU), Irv Watson (NOAA/WRP) and C.G. Lindsey (Battelle) for their efforts in PAM site selection. The assistance of Jeff Zimmerman, Tracy Malara, Tammy Taylor, Pam Tabor, George Young and Gail Watson in data reduction and manuscript preparation is also gratefully acknowledged. This research has been supported by the Atmospheric Sciences Division of the National Science Foundation under Grants ATM-8420328 and ATM-8507961.

References

Fujita, T., 1963: Analytical mesometeorology. A review. *Met. Monogr., 5*, 77- 125.

Hjelmfelt, M., J. Pike, S. Semmer, G. Wardell and C. Burghart, 1986: Corrections to PAM psychrometer wet-bulb data in PRE-STORM. Informal Report, Field Observing Facility, Atmospheric Technology Division, National Center for Atmospheric Research, Boulder, CO.

National Oceanic and Atmospheric Administration, 1982: *Monthly Normals of Temperature, Precipitation, and Heating and Cooling Degree Days 1951-80.* Climatography of the United States No. 81. National Climatic Center, Asheville, NC.

Wade, C.G., and T.M. Engel, 1985: A technique for correcting humidity errors in mesometeorological data. Reprints, Proc. 1985 International Symposium on Moisture and Humidity, Washington, DC.

Appendix 1

PRE STORM PAM STATIONS

May - June 1985

Location	Latitude	Longitude	Elevation*(m)
1. Carson Farm Utica, KS	38°39'44"	100°12'51"	799
2. Cedar Bluff Dam Bureau of Land Management Cedar Bluff Dam, KS	38°48'20"	99°42'56"	651
3. Eugene Jacobs Farm Pfeifer, KS	38°42'50"	99°12'25"	575
4. Harry Swart Ranch Wilson, KS	38°43'06"	98°33'30"	540
5. Kanopolis State Park Marquette, KS	38°39'52"	97°59'08"	484
6. Neil Carlson Ranch Gypsum, KS	38°42'34"	97°22'04"	404
7. Herington Runway Herington, KS	38°41'58"	96°48'37"	452
8. Lyon County Property Allen, KS	38°41'37"	96°13'17"	461
9. Byrd Ranch Kalvesta, KS	38°12'34"	100°15'41"	791
10. Bauer Farm Burdett, KS	38°13'59"	99°37'43"	653
11. Larned-Pawnee County Airport Larned, KS	38°12'26"	99°05'09"	613
12. Doll Property Ellinwood, KS	38°16'37"	98°31'23"	545
13. Keith Lafferty Property Inman, KS	38°15'40"	97°56'50"	479
14. Voth Field Goessel, KS	38°14'44"	97°21'11"	467
15. Pinkston Farm Cedar Point, KS	38°15'32"	96°49'27"	403 ± 4m

* ± 3m unless otherwise indicated

PAM Stations (cont.)

Location	Latitude	Longitude	Elevation*(m)
16. Wendling Field Olpe, KS	38°15'41"	96°11'32"	371
17. Phelps Farm Cimarron, KS	37°48'47"	100°16'22"	821
18. Naab Farm Spearville, KS	37°49'03"	99°40'50"	725
19. Cudney Farm Haviland, KS	37°49'55"	99°04'40"	632
20. Max Bauman Turon, KS	37°48'23"	98°31'12"	561
21. Waltner Farm Pretty Prairie, KS	37°49'03"	97°58'48"	472
22. Benefield Farm Valley Center, KS	37°48'18"	97°20'58"	407
23. Patty Airport El Dorado, KS	37°48'19"	96°47'41"	418
24. Olson Field Eureka, KS	37°49'20"	96°14'00"	336
25. Meade Municipal Airport Meade, KS	37°16'45"	100°21'29"	769
26. Seacat Farm Ashland, KS	37°18'55"	99°38'47"	625 ± 8m
27. Trummel Farm Wilmore, KS	37°21'45"	99°07'15"	625
28. Chain Ranch Isabel, KS	37°21'45"	98°33'04"	530
29. Easter Home Harper, KS	37°19'19"	97°58'49"	434
30. Wellington Municipal Airport Wellington, KS	37°19'19"	97°23'26"	387
31. Craig Ranch Burden, KS	37°22'36"	96°49'35"	407

* ± 3m unless otherwise indicated

PAM Stations (cont.)

Location	Latitude	Longitude	Elevation*(m)
32. Elk County Airport Moline, KS	37°22'42"	96°16'11"	320
33. Shepherd Farm Knowles, OK	36°53'07"	100°14'40"	786
34. Jordon Farm Buffalo, OK	36°55'00"	99°40'07"	628
35. Tinker Farm Freedom, OK	36°52'18"	99°05'44"	546
36. Stauffer Farm Burlington, OK	36°54'36"	98°28'59"	379
37. Feist Farm Manchester, OK	36°54'44"	98°02'06"	356
38. Partee Farm Braman, OK	36°55'03"	97°24'41"	330
39. Frank Ranch Newkirk, OK	36°56'13"	96°50'53"	374
40. Ross Ranch Elgin, KS	36°58'11"	96°15'51"	300

* ± 3m unless otherwise indicated

(Add 2m to get elevation of pressure sensor)

Appendix 2

Abbrevieated PAM Site Descriptions

PAM Site	PAM Site Descriptions
PAM 1	- between two telephone poles on high ground - fence around it - 1.0 mi E of residence - less than 0.5 mi from old homestead
PAM 2	- dam to S
PAM 3	
PAM 4	- fence around it - 1.5 mi from house
PAM 5	- fence around it
PAM 6	- on small hilltop - 200 yd N of house
PAM 7	- between two hangars to the N and S
PAM 8	
PAM 9	- fence around it
PAM 10	- fence around it - trees 0.2 mi to W - residence 0.4 mi SW
PAM 11	- distant farmhouse to S (approx. 1.0 mi)
PAM 12	- fence around it - 200 yds S of house and buildings
PAM 13	- NW of house approx. 0.5 mi
PAM 14	- factory some distance NE - next to a fence

PAM Site	PAM Site Descriptions
PAM 15	- in backyard of house against a fence - house is to the N - garage to E - two alternate sites were specified - small trees
PAM 16	- fence near it - house to the N
PAM 17	- corner of fence - residence NW less than 0.5 mi
PAM 18	- house to the SE
PAM 19	- house to the E less than 0.5 mi - two oil wells to the S 15 yds
PAM 20	- fence around it - house and buildings 0.25 mi N of site
PAM 21	- fence around it - house 0.2 mi to the N - farm with trees some distance to the S - telephone poles to the S approx. 15 yds - Cheney Reservoir from due E at 4 mi to SE at 12.8 mi
PAM 22	- house 100 meters to the W - maybe fenced
PAM 23	- 100 ft from runway - house and hangar to the N (slightly E) approx. 100 ft - hangar to the S approx. 100 ft - large wood pile to N (slightly W)
PAM 24	- house to the NE (approx. 700 ft away) - 350 ft tower located 150 ft SE - barn N NE (approx. 600 ft away)
PAM 25	- buildings to the E less than 0.5 mi away - runway on other side of buildings
PAM 26	- fence around it - house to E approx. 0.2 mi - in a slight valley hills to SW, W and N

PAM Site	PAM Site Descriptions
PAM 27	- on a rise - next to fence - residence to SW approx. 0.5 mi
PAM 28	- atop a small rise - fence around it - house to the NW approx. 3 mi
PAM 29	- house 50 meters N - bottom of a small rise - maybe fenced
PAM 30	- runway 100 m to E - radio antenna 100 m to S - ground was muddy
PAM 31	- trees to the N
PAM 32	- small pond to the S - runway to the W approx. 1 mi - large tree stump to SW
PAM 33	- inside fence
PAM 34	- in corner of fence - residence to NW approx. 0.2 mi
PAM 35	- in corner of fence - residence to N approx. 0.3 mi - in corner of intersectionof roads that form a T
PAM 36	- hangar 60 m to W - Great Salt Plains Lake 20.8 mi SE (lake is 4 mi across) - runway SW approx. 30 m
PAM 37	- fence around it - metal barn 150 m to W - airport 2 mi N (slightly E) - Great Salt Plains Lake 14.4 mi Sw - house and trees beyond the barn
PAM 38	- maybe fenced - house to NE in distance
PAM 39	- in a wooden corral - house 1.25 mi to S and slightly W
PAM 40	- in a corral - small trees in the area