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OBJECTIVE MAP ANALYSIS FOR THE LOCAL AFOS MOS PROGRAM

Techniques Development Laboratory
Silver Spring, MD
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ABSTRACT

A computer program has been developed which can be used to analyze either spatially continuous or discontinuous hydrometeorological data. It is being used extensively in the development of a local MOS capability, and has been specifically tuned for the analysis of 13 meteorological variables. This paper describes the Cressman successive correction procedure, used for continuous fields, and the nearest neighbor procedure, used for discontinuous fields, and their implementation in this computer program. Control parameters and options are discussed, and several examples are presented.

1. INTRODUCTION

With the virtual explosion of computer technology in the last few years, it is now feasible to provide considerable computing power to all Weather Service Forecast Offices (WSFO's). This process is already well under way through the Automation of Field Operations and Services (AFOS) (AMS, 1978). Although the resources for running meteorological and hydrological applications programs on the AFOS computers are limited, minicomputers and microcomputers are being interfaced with them to provide additional capability. Also, a new generation of hardware and software for forecaster assistance is currently being planned --the Advanced Weather Interactive Processing System for the 1990's (AWIPS-90)--(NWS, 1984).

Many kinds of programs can be used by the forecaster to assist in his/her decision making. These programs may perform extremely simple tasks very rapidly and provide information in easily comprehensible formats. They may perform analyses of surface or upper air data and produce graphical representations of those data. Also, various models of atmospheric or hydrologic processes can be run to provide diagnostic or prognostic information which would be impossible to produce without a computer.

The Techniques Development Laboratory (TDL) has a project called the Local AFOS MOS Program (LAMP) (Glahn, 1980). The purpose of the project is to provide to a WSFO updated model output statistics (MOS) forecasts (Glahn and Lowry, 1972) for essentially all locations for which the WSFO makes routine forecasts. These forecasts will be for most weather elements and for projections of 1 to about 20 hours. Inputs will include centralized MOS forecasts, hourly observations, a few forecast fields from the National Meteorological Center's (NMC's) primary short-range guidance model, such as the Limited-Area Fine Mesh (LFM) model (Gerrity, 1977), and, when available, radar and satellite data.

Analyses of data, especially the hourly surface airway observations (SAO's), will be made objectively and will be input to simple numerical or advective models. Finally, the raw observations, analyses of them, the centralized MOS forecasts, and the output from the simple models will be input to statistical models to produce updated MOS guidance. Also, certain intermediate LAMP products can be used by the forecaster, such as analyses of sea level pressure, temperature, and dewpoint.

Objective map analysis is defined as the process of interpolation from unevenly spaced observations to a regularly spaced grid. Although the simplest application is analysis of a scalar at one level, the definition can include gridpoints in the vertical as well as the horizontal, use of observations other than the one being analyzed (such as use of wind in pressure or geopotential height analysis), and, possibly, the determination of spectral components. Even within a basic analysis scheme, some tailoring to the particular variable being analyzed is many times necessary, especially if one considers error checking of observations as part of the process. (Strictly speaking, error checking may not be part of an analysis technique, but the two need to be performed together for best results.)

This paper describes the methods used for analyzing weather elements in the SAO's for use in LAMP. Basically, two analysis techniques are used--one, a successive approximation scheme and the other the assignment of a value at a gridpoint equal to the nearest observation. These methods, the elements they are used for, and specifics of error checking and analysis parameters are explained in Sections 2 and 3. Both techniques are coded into one program M400 (Glahn and Chambers, 1985), which exists on TDL's library for use on NOAA's IBM 360/195's or NAS 9040's. The program has also been converted to run on the AFOS Eclipse minicomputer; this is explained in Section 4. All examples shown in this report are for 0800 GMT March 10, 1979.

2. THE BCD SUCCESSIVE APPROXIMATION TECHNIQUE

A. Background and General Discussion

One of the first objective map analysis techniques used operationally in meteorology was adapted by Cressman (1959) from Bergthorssen and Döös (1955). A first guess field (a value at each gridpoint) is somehow obtained, and in one or more passes (over the gridpoints and over the data) the observations are used to correct this field. Thus, the final analysis is found by successive approximation. In this paper, this is called the BCD technique for Bergthorssen, Cressman, and Döös.

In deciding on an analysis method, one must consider the inputs available and purpose of the analysis. For the initialization of primitive equation prediction models, a more sophisticated analysis-initialization technique which would produce dynamically consistent fields of several meteorological variables would be called for. But for the uses to be made of analyses for LAMP, the BCD successive approximation technique is quite sufficient. BCD has been rather widely used. The LAMP analysis program draws heavily on reports by Thomasell and Welsh (1962) and Glahn et al. (1969).

Even for a technique as basically simple as BCD, several decisions have to be made before applying it to a specific problem. The following sections address the options available and describe the application of BCD to the analysis of sea level pressure, surface drybulb temperature, surface dewpoint temperature, surface U- and V-wind components, surface wind speed, and saturation deficit.

B. First Guess Field

BCD requires an initial value at each gridpoint, which is called the first guess. This can be obtained in a variety of ways, depending on the particular situation, including: (1) a short-range forecast of the same field from a numerical prediction model valid at (nearly) the time of the observations being analyzed, (2) an analysis of the same field at some recent, earlier time, (3) estimation from some other variable or variables available on the same grid, (4) climatic values, (5) a suitable constant over the entire grid, (6) the value of the closest data point, and (7) the average of several nearby data points.

The quality of the first guess helps determine how BCD will be applied. Perhaps the crudest guess is (5), a constant field; if this is used, an extra corrective pass may be necessary. On the other hand, if one uses the closest observation as a first guess and that observation is in error, it may be very difficult to recognize the error later when performing the analysis. Also, the constant field is always available and does not require a time-consuming pass over the data as would (6) or (7) above. A forecast field or a recent analysis can provide a quality first guess.

In the development phase of LAMP, we use forecasts from the LFM model for first guess fields. The previous LFM run time we chose to use was determined by operational considerations. For instance, the 0000 (1200) GMT run time is used for the analysis times of 0800 and 1300 (2000) GMT. Note that forecasts from the 1200 GMT run are not available by 1300 GMT. The forecast projections to use were determined by the availability of archived LFM forecasts. When a forecast field is not available for the hour being analyzed, linear interpolation is made to the analysis hour from the forecasts that are available (see Appendix).

The gridlength of the LAMP grid is a quarter bedient,[1] oriented with the half bedient LFM grid. To get values on the LAMP grid at intermediate points, a bilinear interpolation is used after the time interpolation.

C. Influence Radius

A datum is used to correct a gridpoint value when its distance to the gridpoint is $\leq$ R, where R is a parameter called the influence radius. R is usually expressed in units of gridlengths. That is, R = 2 means that a datum will influence a gridpoint if it is within two gridlengths of the gridpoint.

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[1]A bedient is defined as the distance between adjacent points of a grid on a polar stereographic map which are 381 km apart at 60°N. One-quarter bedient at 40°N is approximately 84 km.

R will typically vary depending on the variable being analyzed, the density of data, the quality of the guess field, and the number of the pass being made.

Some analysis programs will compute the density of data surrounding each gridpoint and let R vary by gridpoint as a function of the data density. Another approach is to increase R for a particular gridpoint when the number of observations within the initial radius R is less than some predetermined constant, which can vary with pass number. Both of these variations are viable, but in many applications will increase computation time somewhat. This is not necessarily so. For instance, even though making R a function of data density requires a preanalysis pass to compute the density, it is possible one could use one less corrective pass.

D. Methods of Correction

Many methods could be used to correct a gridpoint, given the observations within the radius of influence. Three options are provided by M400. Let

$O_{x,y}$ = an observation at the point x,y and
$A_{x,y}$ = the value of the variable interpolated from the grid to the point x,y. When the point x,y is outside the grid, a linear extrapolation is made.

Then

$D = O_{x,y} - A_{x,y}$ = the difference between the observation and the value at that location implied by the gridpoint value.

Usually more than one observation will influence a gridpoint. The three options provided for correcting a gridpoint, given i = 1, n observations within the radius of influence, are

$$C_1 = \frac{1}{n}\sum_{i=1}^{n} D_i \qquad \text{Type 1}$$

$$C_2 = \frac{1}{n}\sum_{i=1}^{n} W_i D_i \qquad \text{Type 2}$$

$$C_3 = \frac{\frac{1}{n}\sum_{i=1}^{n} W_i D_i}{\frac{1}{n}\sum_{i=1}^{n} W_i} \qquad \text{Type 3}$$

where $W_i = \dfrac{R^2 - d_i^2}{R^2 + d_i^2} \qquad d_i < R$

and d_i = the distance in grid units between the observation location x,y and the gridpoint.

We call these three types of corrections, Type 1, Type 2, and Type 3, respectively. Type 1 correction is just the average difference between the observations and the interpolated values at the same locations. Type 2 weights the differences according to their distances from the gridpoint by W. A problem with this type of correction is that the gridpoint is modified very little if no observation is close to it. Type 3, by having the sum of the weights in the denominator, corrects the field more quickly than Type 2. This does not produce good results when n is very small and R is large. Therefore, in M400 when C_3 is being used on a particular pass, for those gridpoints at which $n = 1$ and $R \geq 3$, C_2 is used instead.

E. Smoothing

After any particular pass over the data in which the gridpoint values have been corrected, the analysis may be rather "rough." That is, if one were to contour the field (draw isolines of the values at the gridpoints), the lines would have small wiggles that a meteorologist would not consider appropriate, even though they might fit the observations very well. Therefore, a smoothing pass may be done after each corrective pass. The smoothing operator employed by M400 is that used by Thomasell and Welsh (1962) and is a generalization of the one given by Cressman (1959):

$$S_{i,j} = \frac{A_{i,j} + b\bar{A}_{i,j}}{1 + b} .$$

where $A_{i,j}$ = the gridpoint value at the point i,j,
$S_{i,j}$ = the smoothed value, and

$$\bar{A}_{i,j} = \frac{A_{i+1,j} + A_{i-1,j} + A_{i,j+1} + A_{i,j-1}}{4}$$

The value of b determines the degree of smoothing, a small value for light smoothing and a larger value for heavier smoothing. Even though large values of b can produce undesirable results for very short waves, on early passes when R is not small, the pattern will be predominantly large scale, and a large value of b can be used if desired.

F. Number of Passes

The number of corrective passes to make depends on several factors, including the quality of the first guess, the general density of data in relation to the density of gridpoints, the scale of the field being analyzed in terms of the gridpoint spacing, and whether or not there are abrupt changes in data density such as at a coastline.

Generally, the first pass is used with rather large R and serves to set each gridpoint to the general level of data within its vicinity. A Type 2 correction makes decreasingly small corrections away from data rich regions into data void regions and attempts to assure that discontinuities will not develop between the gridpoints where no correction is made (first guess remains) and where major corrections are made.

Characteristically, each pass will use a smaller R than the previous one and, perhaps, a lighter smoothing. Even for the most crude first guess, four passes are almost always sufficient. Also, unless an extremely good first guess is available, such as an analysis of the same variable one hour earlier, four passes are usually required; if no data void regions exist and data density is relatively homogeneous, two or three might suffice.

G. Error Detection

An essential aspect of real-time analysis of meteorological data is the detection of errors. In the BCD analysis, this can be done by interpolating into the currently available analysis (first guess when on the first pass) to the data point, comparing the results with the reported value, and not using the datum if the difference is greater than some predetermined value. M400 has a special feature that has proven quite effective. If a datum is about to be discarded for a particular pass, a check is made of its two closest neighbors. If either of the closest neighbors also disagrees with the analysis by more than the error criterion in the same direction, the datum is used (not judged to be in error) if it differs by less than 1.5 times the error criterion. The neighbor is also used if it meets 1.5 times the error criterion. This is a special "buddy check."

Some analysis programs employ a general buddy check before the first pass. The method is approximately the following. For each datum, the closest two neighbors are found. If the datum disagrees with both its neighbors by a predetermined amount, which may vary with distance between the data, it is permanently discarded. Limits can be set so that values are not checked against values an unreasonable distance away. (See Glahn, et al., 1969, for a variation of this.) A general buddy check is quite time consuming, since neighbors must be found for each datum. Also, we have found it to be unnecessary when four corrective passes are used and careful checking is done against the current analysis on each one.

Error detection when analyzing continuous fields of rather large scale patterns can be quite effective. For instance, sea level pressure errors of only 5 mb can many times be detected.

H. Sea Level Pressure Analysis

The sea level pressure (SLP) analysis for LAMP uses a first guess from the LFM model. Forecasts of 1000-mb geopotential height (H) in meters are converted to SLP in mb by the simple formula SLP = .12015 H + 1000. This is the same conversion formula used with the LAMP SLP prediction model (Unger, 1982).

The analysis parameters used are shown in Table 1. Note that there are four passes and R decreases from 8 gridlengths on pass No. 1 to 1 on pass No. 4. A C_2 type correction with R = 8 produces a very smooth field and no extra smoothing is needed. Rather heavy smoothing (b = 5) is used with a type C_3 correction with R = 5 on pass No. 2; thereafter, smoothing is not as heavy. Large discrepancies are allowed between the data and first guess on the first pass, but on the last pass differences > 4.1 mb are deemed to be due to data error.

Table 1. Analysis parameters for sea level pressure (SLP), surface drybulb temperature, and surface dewpoint temperature.

Pass No.	Radius of Influence R	Type of Correction	Smoothing Parameter b	Error Criterion SLP (mb)	Error Criterion Temperature (°F)
1	8.0	C_2	0	25.0	60
2	5.0	C_3	5	13.1	42
3	2.5	C_3	1	6.6	24
4	1.0	C_3	1	4.1	18

As an added error checking/correcting feature, if the observation is $>$ 1040 mb and $\geq$ 50 mb from the first guess, 100 mb is subtracted from the observation (i.e., 1070 would become 970 mb). Also, if the observation is $<$ 970 mb and $\geq$ 50 mb from the first guess, 100 mb is added to the observation. If the "corrected" observation is unreasonable, further checking will discard it.

Figs. 1 through 6 show analyses at various stages of completion for 0800 GMT March 10, 1979[2]. Fig. 1 shows a completed analysis over the entire 61 x 81 LAMP grid. Note that sharp data density discontinuities occur at coastlines, but the analysis (hand drawn lines on grid-printed maps) does not exhibit unreasonable discontinuities. All data available to the analysis program are shown in Fig. 1, including those within eight gridlengths north of the analysis area. The analysis over areas greater than eight gridlengths from the closest data point is due to the first guess. Only one station value was not accepted; a value of 999.1 mb in Canada just northeast of Lake Huron was about 9 mb lower than the analysis on both the 3rd and 4th passes and was not used on those passes.

It is worth noting that the data used in this analysis had already undergone a temporal automated checking procedure. The discarded 0800 GMT value of 999.1 mb was consistent with the 0700 GMT value of 999.8 mb and was not discarded by the automated check. However, values for several hours prior to 0700 GMT and for 0900 GMT and several hours thereafter were $\geq$ 1010 mb. Undoubtedly, the 0700 and 0800 GMT observations were 10 mb too low.

All analyses shown in this report were made on the 61 x 81 grid; however, only a portion of an analysis is shown in most figures. Fig. 2 shows plotted data over the eastern United States overlaid with the first guess. Note that the pattern of the 8-h LFM forecast (interpolated in time from 6- and 12-h forecasts and in space from the 1/2 bedient output to the 1/4 bedient LAMP grid) is quite good even though the field is rather smooth. Except for the bad observation northeast of Lake Huron, differences between the data and first guess are generally within 3 or 4 mb, the largest of about 5.5 mb being in Kansas.

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[2]This is the same case shown in Unger (1982).

Figs. 3 through 6 show the same plotted data overlaid with the analyses after passes 1 through 4, respectively. Note the increasingly close fit to the data without extreme wiggles. The frontal position is well done, except that a hand-drawn analysis would undoubtedly show a slightly different configuration with more "kinking" of isobars at the presumed position of the front.

These same data were analyzed starting with a constant first guess of 1013.25 mb. The final analysis was almost identical to the analysis made with the LFM as first guess for the area shown in Fig. 6. No significant differences in the two analyses occurred over any area where data were present. However, large gradients just off the coasts and south of Texas were unavoidable, since no attempt is made to infer the pressure distribution more than eight gridlengths from the data. With the constant first guess, no observations were thrown out on the first pass, three on the second, and only the 999.1 mb value mentioned previously on the third and fourth passes. This suggests the same analysis parameters shown in Table 1 can be used successfully for SLP starting from the constant 1013 mb first guess. However, if such a constant first guess were to be used routinely, a retuning of analysis parameters might be desirable.

I. Surface Temperature and Dewpoint Analyses

The first guess for surface drybulb (dewpoint) temperature is the LFM forecast of 1000-mb drybulb (dewpoint[3]) temperature. Conversion is made from °K to °F. Analysis parameters are also shown in Table 1, and are the same as for sea level pressure except for the error criteria. Note that the temperature observations are much more difficult to quality control; differences as large as 18°F between the observations and the third pass analysis are accepted on the last pass.

The example of surface temperature analysis shown in Fig. 7 shows the variable nature of the field and, therefore, the difficulty of detecting erroneous observations. The pattern of temperature associated with the front indicated in the SLP analyses is obvious.

In analyzing temperature and dewpoint for the 0800 GMT March 10, 1979 case, only two temperature observations and four dewpoint observations were thrown out on the last pass. All were within the 61 x 81 analysis grid, but only one temperature observation was within the area shown in Fig. 7. Note the observation of 86°F in the extreme northeastern part of the area that is obviously incorrect. It was thrown out on all four passes.

J. Surface Wind Analysis

Analysis of surface wind presents special problems since it is a vector. In order to be as consistent as possible in accepting or rejecting observations, U- and V-components and speed are analyzed concurrently. The component analyses are used to represent the individual components and direction. A speed analysis is made rather than using the speed computed from the U- and

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[3]Actually, the 1000-mb dewpoint forecasts are obtained by postprocessing LFM 1000-mb drybulb temperature forecasts and relative humidity forecasts.

V-component analyses because the latter would be biased toward low values. To get a qualitative appreciation for this bias, consider an area where winds are light and variable. Component analyses may show both components to be near zero, while the average speed may be on the order of 5 to 10 kt.

Analysis parameters used for wind are shown in Table 2. They are the same as for SLP and temperature except for the error criteria. Note that the acceptance criteria are in terms of direction and speed. The direction criterion is not used (that is, any wind can be accepted) if the speed is less than 10 kt; this allows light and variable winds to be retained. Note, also, that the direction criteria are not very stringent.

The first guess fields for the wind analyses are obtained from the LFM boundary layer winds. This first guess has very little effect on the final analysis except in data void areas. Figs. 8 and 9 show the wind analysis for the same case as the other analyses. Fig. 8 shows the complete 61 x 81 area, while Fig. 9 affords a closer look at the data and analysis over the eastern United States. In Fig. 8, all data within 4 gridlengths of the analysis area are plotted. It can be seen that the analyzed winds (plotted at alternate gridpoints) are a reasonable fit to the data, especially where the observations show consistency in space. Note that the analyzed direction shift along the frontal boundary in the eastern United States is quite good.

The buddy check explained in Section 2.G is used with both wind speed and direction, except that for wind direction a neighboring station can "agree" without regard to whether the direction "error" (difference between analysis and observation) is clockwise or counterclockwise for both stations.

Only two observations were thrown out on the last pass. One is in Mexico just west of Brownsville, Texas. Both the direction and speed were inconsistent with the pass 3 analysis. The other observation along the southern border of New Mexico (70 degrees at 30 kt) did not meet the speed criterion. Both of these observations were also thrown out on pass 3 and the latter on pass 2; both were accepted on pass 1.

As a final adjustment to the wind speed analysis, each gridpoint is set to the maximum of (a) its analyzed value, or (b) the speed computed from the analyzed component values. This correction is used mainly to eliminate possible negative values in the speed analysis. Significant corrections can occur in data sparse regions.

Table 2. Analysis parameters for U- and V-wind components and wind speed.

Pass No.	Radius of Influence R	Type of Correction	Smoothing Parameter b	Direction Error Criterion (deg)	Speed Error Criterion (kt)
1	8.0	C_2	0	180	20
2	5.0	C_3	5	160	15
3	2.5	C_3	1	150	9
4	1.0	C_3	1	140	7

As an additional example, Figs. 10 and 11 show, respectively, the first guess and analysis of winds associated with Hurricane Allen for 1200 GMT August 10, 1980. Note that the 12-h LFM boundary layer wind forecast used as the first guess does not fit the observations well in some areas.

During the analysis, all reports were accepted on pass 1, Brownsville was not accepted on pass 2, Corpus Christi was not accepted on pass 3, and all reports were accepted on pass 4. The actual hurricane center at this time, according to a detailed postanalysis (Ho and Miller, 1983), was somewhat east of what would be inferred from this analysis alone.

K. Saturation Deficit Analysis

Saturation deficit, S_d, is the moisture variable used in the LAMP moisture model. It is defined as the amount the 1000-500 mb thickness would have to decrease in order for precipitation to occur for a given amount of moisture in that 1000-500 mb layer. The thickness at which precipitation would occur, given the moisture between 1000 and 500 mb, is known as the saturation thickness, h_s. Therefore, S_d is the difference between the actual 1000-500 mb thickness, h_5, and the saturation thickness,

$$S_d = h_5 - h_s. \quad (1)$$

The method by which S_d is estimated from LFM forecasts and current surface observations is explained in detail by Lewis, et al. (1984). Briefly, data from 54 radiosonde stations over the United States for the 8-yr period 1973 to 1980 were used to define the estimation equation.

$$h_s = 5296 + 267 \ln(W) + .1056 E, \quad (2)$$

where h_s = saturation thickness in meters,
W = precipitable water in cm, and
E = LFM model elevation in meters interpolated biquadratically to station location.

Then, regression equations to estimate ln(W) from the LFM forecast of W and the surface dewpoint were developed:

$$\ln(W) = -.2970 + .6293 \ln(\hat{W}) + .01121 T_d \quad \text{(for 0000 GMT)} \quad (3a)$$

$$\ln(W) = -.3612 + .5920 \ln(\hat{W}) + .01388 T_d \quad \text{(for 1200 GMT)} \quad (3b)$$

where $\hat{W}$ = the LFM forecast interpolated to the station location, and
T_d = the observed surface dewpoint in degrees Fahrenheit.

Estimates of ln(W) can be made for any hour by using T_d for that hour and Eq. (3a) if the most recent LFM run was at 0000 GMT and Eq. (3b) if the most recent LFM run was at 1200 GMT. These estimates of ln(W) are then used in Eq. (2) to get h_s. S_d is then obtained from Eq. (1) in which h_5 is determined from the 500-mb LFM forecast and the 1000-mb forecast from the LAMP SLP model.

By definition, $S_d = 0$ at locations where precipitation is occurring, so estimates provided by Eq. (1) are ignored and S_d is set equal to zero at those locations where precipitation is observed.

Analysis of S_d presents special problems because there are large areas of zero values, then values may increase to several hundred meters in only a few gridlengths. Without special procedures, the large values will swamp the zeros.

In order to give more weight to the smaller values, the first guess, FG, and S_d estimates at stations are input to the analysis program following the procedure given in Fig. 12. The regression estimates S_d at stations are provided by Eqs. (3), (2), and (1), and the first guess estimates FG are provided at gridpoints by Eqs. (4), (2), and (1), where Eq. (4) is

$$\ln(W) = .3042 + .9024 \ln(\hat{W}) \quad \text{(for 0000 GMT)} \tag{4a}$$

$$\ln(W) = .3262 + .9197 \ln(\hat{W}) \quad \text{(for 1200 GMT)} \tag{4b}$$

Note that Eq. (4) is a regression estimate similar to Eq. (3) except for the dewpoint term.

The scaled saturation S_d', is analyzed, and then transformed back to its original scale according to:

when $S_d' > 6$ $\quad S_d = 6S_s' - 30$

when $S_d' < 0$ $\quad S_d = 0$

when $0 \leq S_d' \leq 6$ $\quad S_d = S_d'$

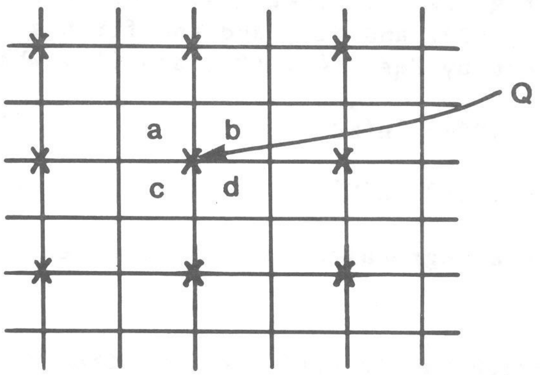
Analysis parameters for S_d' are given in Table 3.

Table 3. Analysis parameters for scaled saturation deficit, S_d'.

Pass No.	Radius of Influence R	Type of Correction	Smoothing Parameter b	Error Criterion (m)
1	8.0	2	0	30
2	4.0	2	1	25
3	2.0	3	1	25
4	1.0	3	0	25

Fig. 13 shows a saturation deficit analysis completed according to the procedure explained above for the 0800 GMT March 10, 1979, case. Note that the zero line lies generally between areas of precipitation (indicated by S_d = 0 at station locations) and no precipitation.

A final modification based on radar data is made to the saturation deficit analysis. Manually Digitized Radar (MDR) values are available on a grid with one-half the LAMP gridlength (Foster and Reap, 1978). The relationship between MDR and LAMP grids is shown in the diagram below:



The boxes represent areas over which MDR values pertain; the X's are LAMP gridpoints. After the S_d analysis is completed, a gridpoint value is reduced by the fraction N/4 where N is the number of boxes surrounding the gridpoint with radar echos. For instance, gridpoint Q is reduced by 1/4 if only one of the neighboring boxes a, b, c, and d has a radar echo. However, because radar reports can result from precipitation not reaching the ground and the coverage in the boxes can be less than 100 percent, the S_d value is never set less than 5 m on the basis of MDR reports alone. A gridpoint with reports in all four adjacent boxes will be set to 5 m. If the analyzed S_d is already less than 5 m, no adjustment based on MDR data will be made.

The effect of the MDR data is to decrease the S_d values in some areas, especially near areas where the S_d values are already rather low. Fig. 14 shows the S_d analysis of Fig. 13 after these MDR modifications have been made; instead of station S_d values being plotted, the number of MDR boxes (quadrants) indicating precipitation is plotted at each LAMP gridpoint. The absence of a plotted value indicates no precipitation reported by radar; however, this could be due to missing data. The largest change to the S_d analysis for the case shown is near the left edge of the map in southern Oklahoma. Values were reduced from about 100 m to below 40 m (5 m at one gridpoint). This adjusted analysis better delineates the frontal boundary extending through eastern and southern Arkansas and southern Oklahoma.

3. THE NEAREST NEIGHBOR TECHNIQUE

A. Background and General Discussion

While a successive approximation technique works well in the analysis of continuous fields, there is some question as to whether it is appropriate for fields which are characterized by discontinuities, such as ceiling height, visibility, and yes/no precipitation occurrence. For instance, should a gridpoint one-third the way between an observation of ceiling of 200 ft and one of ceiling of 5000 ft be about 2000 ft? Or would the 200 ft value just as appropriately apply? Also in the analysis of a binary (zero-one) field, for many purposes one would want all gridpoints to take on either a value of zero or one, not intermediate values.

For the analysis of sky cover, ceiling height, visibility, and precipitation type in LAMP, we use a nearest neighbor technique. This consists basically of three steps. First, we assign each gridpoint a constant value appropriate to the variable being analyzed. Then, we set each gridpoint to the value of the closest observation of the element being analyzed taken 1 hour previous to the hour for which the analysis is being performed, provided the closest observation is $\leq$ 5 gridlengths from the gridpoint. Then, if the on-time observation is no more than one gridlength farther away, we reset the gridpoint value to the on-time value. The use of observations from the previous hour helps especially when on-time observations are missing for an area the size of a few states. In no case is an observation more than 5 gridlengths away used at a gridpoint.

Error detection is limited to assuring that the observation is a reportable value. No first guess is used in the analysis procedure, except that gridpoints more than 5 gridlengths from the nearest observation retain their assigned constant value. Analyses are not smoothed.

B. Sky Cover Analysis

Opaque sky cover is analyzed in tenths of coverage. Fig. 15 shows an example of such an analysis for the same case presented in previous figures. The observations plotted are taken from the surface hourly reports which are in the form of clear, scattered, broken, and overcast. These four categories are plotted as 0, 4, 8, and 10 tenths coverage. Contours are labeled 2, 5, 7, and 10; the contouring program actually drew them at 2.0, 4.4, 6.8, and 9.2. Note that there is one contour between "reported" values of 0 and 4, two contours between 4 and 8, and one contour between 8 and 10.

Note the overcast conditions (10 tenths coverage) along the front and in the low pressure center. Sharp gradients exist on both sides of the frontal zone; cloud cover may change from zero to 10 tenths coverage from one station to the next and from one gridpoint to the next.

Although a first guess is not necessary for the nearest neighbor analysis process, the field is initialized to a constant value which will be retained if no datum is within 5 gridlengths of the gridpoint. For sky cover, the field is initialized to .5 and this value is retained in the Atlantic at the eastern edge of the map. The analysis over any data void region must be viewed with extreme caution.

C. Ceiling Height Analysis

Fig. 16 shows the ceiling height analysis for the same case shown in previous figures. Values are plotted in hundreds of ft. An unlimited ceiling, or any value over 40,000 ft, is shown as 400. Contours are at 50 (5000 ft), 150, 250, and 350.

Low ceilings prevail along the front and into the low pressure area. Most reported values are accommodated by the analysis, but a few exceptions can be noted. The 2000 ft ceiling in the Mississippi Delta region of Louisiana near values of unlimited appears to be not "drawn for." Gridpoints to the south and east of the 2000 ft value were given values of 2000 ft, but the interpolation performed by the contouring routine could not recover the 2000 ft value at the station. This brings up the point that contouring is also an interpolation process and therefore not exact. That is, even if every gridpoint had the correct value (suppose reports were available at gridpoints), the interpolation performed by a contouring routine would not always produce correct (reported) intermediate values.

The field is initialized to 400; this value is retained in data void regions. Projecting isolated reports into data void regions (such as the two reports of zero in the midst of many reports of unlimited in eastern South Carolina) does not produce useful results in these regions.

D. Liquid Precipitation Analysis

For the same case discussed above, Fig. 17 shows each observation of liquid precipitation plotted as a "1" and each observation of no liquid precipitation as a "0", with a contour provided by the analysis program at a value of 0.5. Generally, liquid precipitation is occurring along the front. All precipitation areas are indicated by the analysis, except the two reports near New York City cannot be depicted with the grid spacing used for these analyses.

The other types of precipitation--frozen and freezing--are analyzed in the same way. For mixed types, each type is treated as 0.5 rather than both being treated as 1.0.

E. Visibility Analysis

No example of visibility analysis is shown. It would be much like ceiling height or cloud cover in appearance. In M400, the field is initialized to 15 mi.

4. AFOS ECLIPSE VERSION

The successive approximation and nearest neighbor techniques were coded for the AFOS Eclipse minicomputer. With floating point hardware and the FORTRAN V compiler, sea level pressure at 400 stations can be analyzed on a 30 x 35 grid in 1 minute. This includes producing one gridprint map which actually accounts for half of the running time. This test indicates the feasibility of running a four-pass BCD analysis program with an augmentation to present AFOS equipment of floating point hardware. Without this hardware, the FORTRAN IV compiler must be used and the analysis requires 10 to 15 times as long, making it impractical. The area could be reduced and with a good first guess the number of passes could be reduced; however, the time required for several analyses would probably not make it attractive for routine operational use.

5. SUMMARY

The successive correction objective map analysis defined by Cressman (1959) and a nearest neighbor technique have been described. The former technique has been applied to sea level pressure; saturation deficit; and surface drybulb temperature, dewpoint temperature, U- and V-wind components, and wind speed. The nearest neighbor technique has been applied to sky cover, ceiling height, visibility, and precipitation type.

Examples of several analyses have been presented and discussed. It is concluded that such analyses are quite adequate for purposes such as input to simple models like LAMP. Only for quite sophisticated models (e.g., primitive equation models) would more complicated schemes such as optimum interpolation be required.

AFOS Eclipse minicomputer versions of these techniques show their feasibility for routine on-station use, but only with the addition of floating point hardware to the Eclipse.

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APPENDIX

First Guess Fields from LFM Forecasts

LFM forecasts from the 0000 and 1200 GMT cycles are used as first guess fields for LAMP analyses. The cycle and forecast projections to use for each analysis time are determined by what would be the most recent guidance available to field stations at that time. When an LFM forecast is valid at an analysis time, only that forecast is needed for the first guess. When there is no LFM forecast available that verifies at the analysis time, a linear interpolation is made at each gridpoint from two appropriate LFM forecasts. For instance, for an analysis time of 0100 GMT, the 1200 GMT cycle of the previous day is used with each gridpoint receiving 5/6 of the LFM 12-h forecast value and 1/6 of the 18-h value. LFM fields used for each analysis hour appear in Table 1.

Table 1. LAMP analysis hours and corresponding LFM cycle and projection(s) used in preparing first guess fields.

LAMP Analysis Time (GMT)	LFM Day	LFM Cycle (GMT)	LFM Forecast Projection(s) (h)
0	previous	12	12
1	previous	12	12, 18
2	previous	12	12, 18
3	previous	12	12, 18
4	previous	12	12, 18
5	previous	12	12, 18
6	same	0	6
7	same	0	6, 12
8	same	0	6, 12
9	same	0	6, 12
10	same	0	6, 12
11	same	0	6, 12
12	same	0	12
13	same	0	12, 18
14	same	0	12, 18
15	same	0	12, 18
16	same	0	12, 18
17	same	0	12, 18
18	same	12	6
19	same	12	6, 12
20	same	12	6, 12
21	same	12	6, 12
22	same	12	6, 12
22	same	12	6, 12

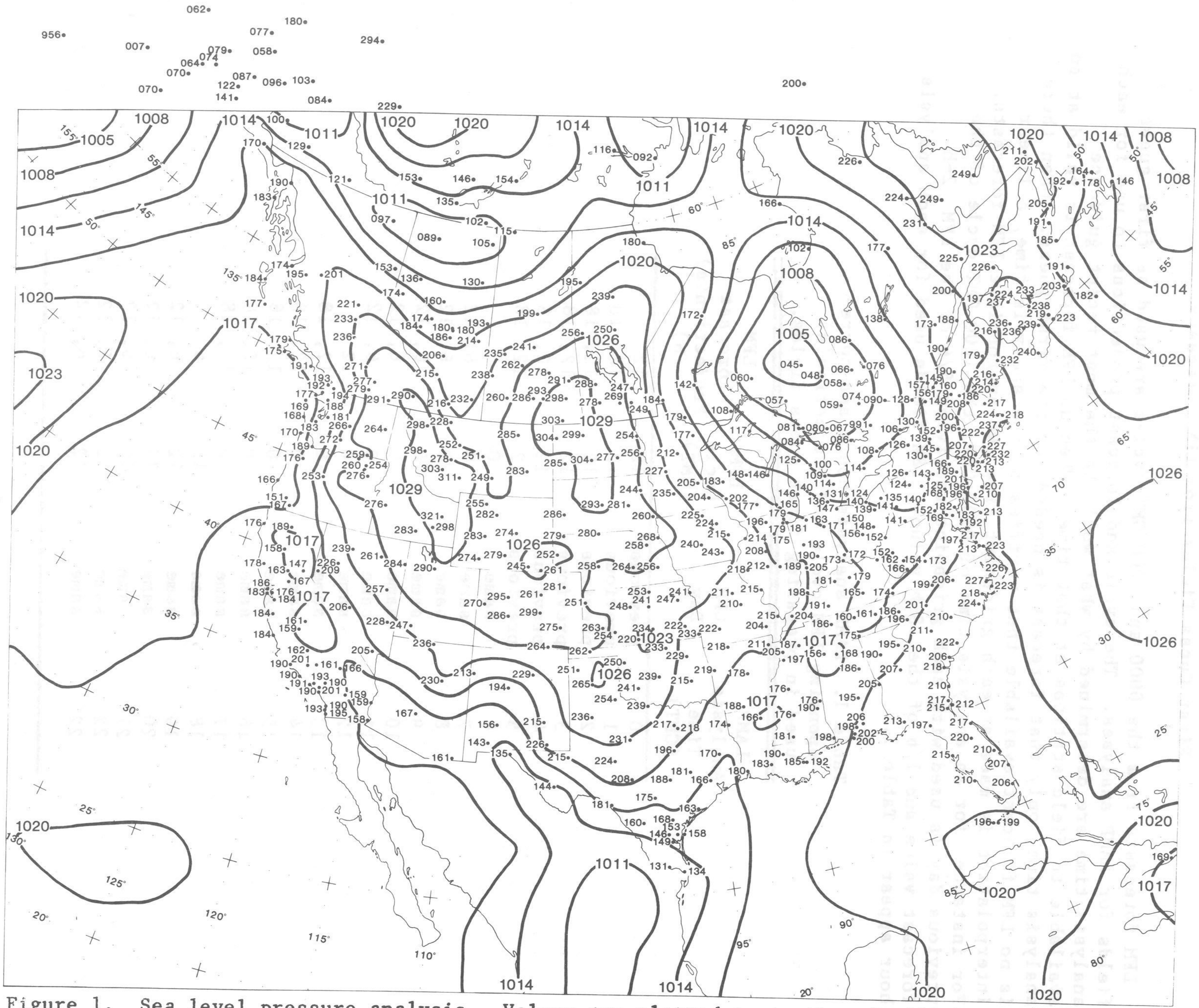

Figure 1. Sea level pressure analysis. Values are plotted to tenths of millibars with the hundreds digits omitted. Contours are labeled in millibars.

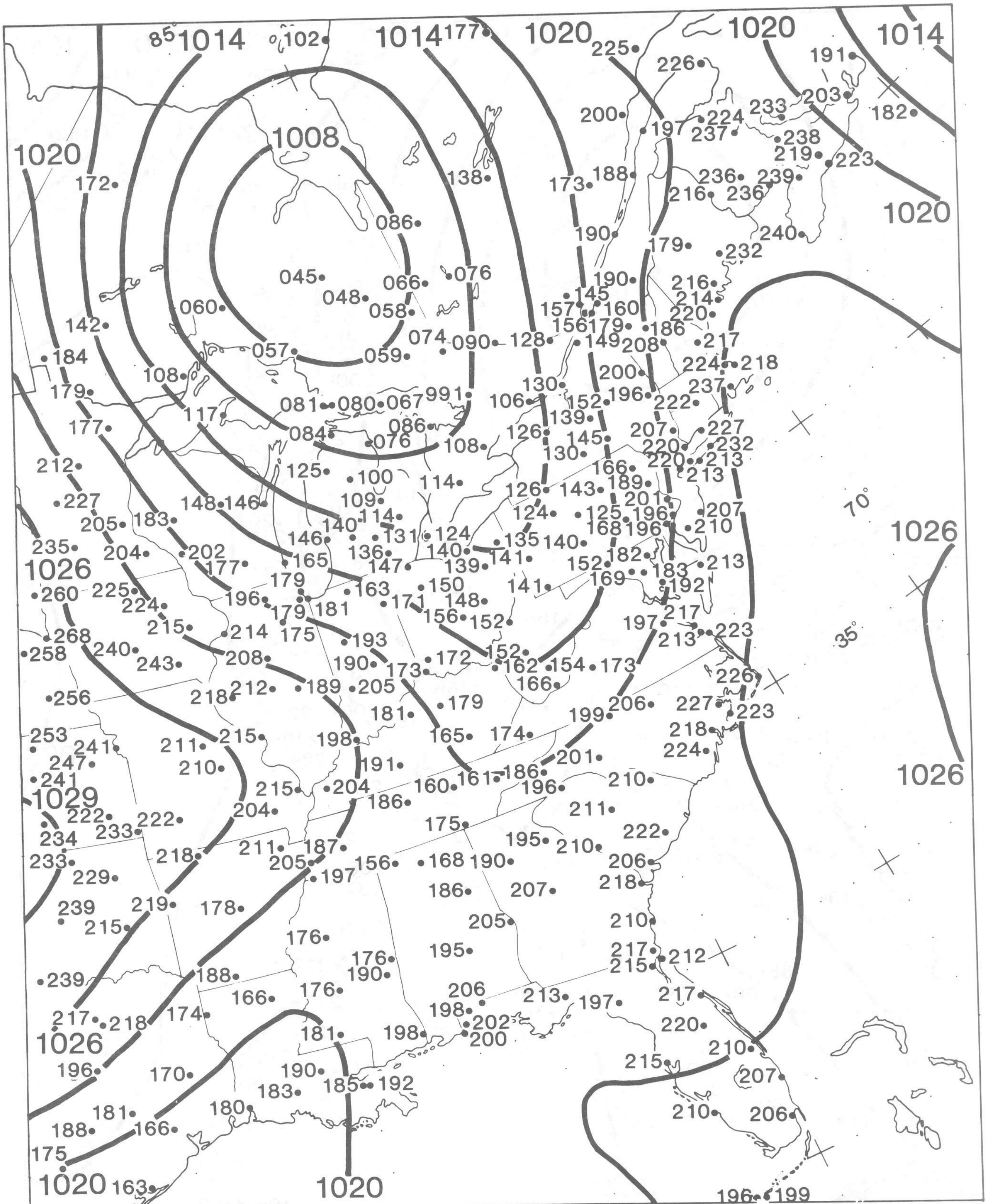

Figure 2. A portion of the area shown in Fig. 1 with plotted data and the first guess used for the sea level pressure analysis. On this scale, 1 inch equals 4.75 gridlengths.

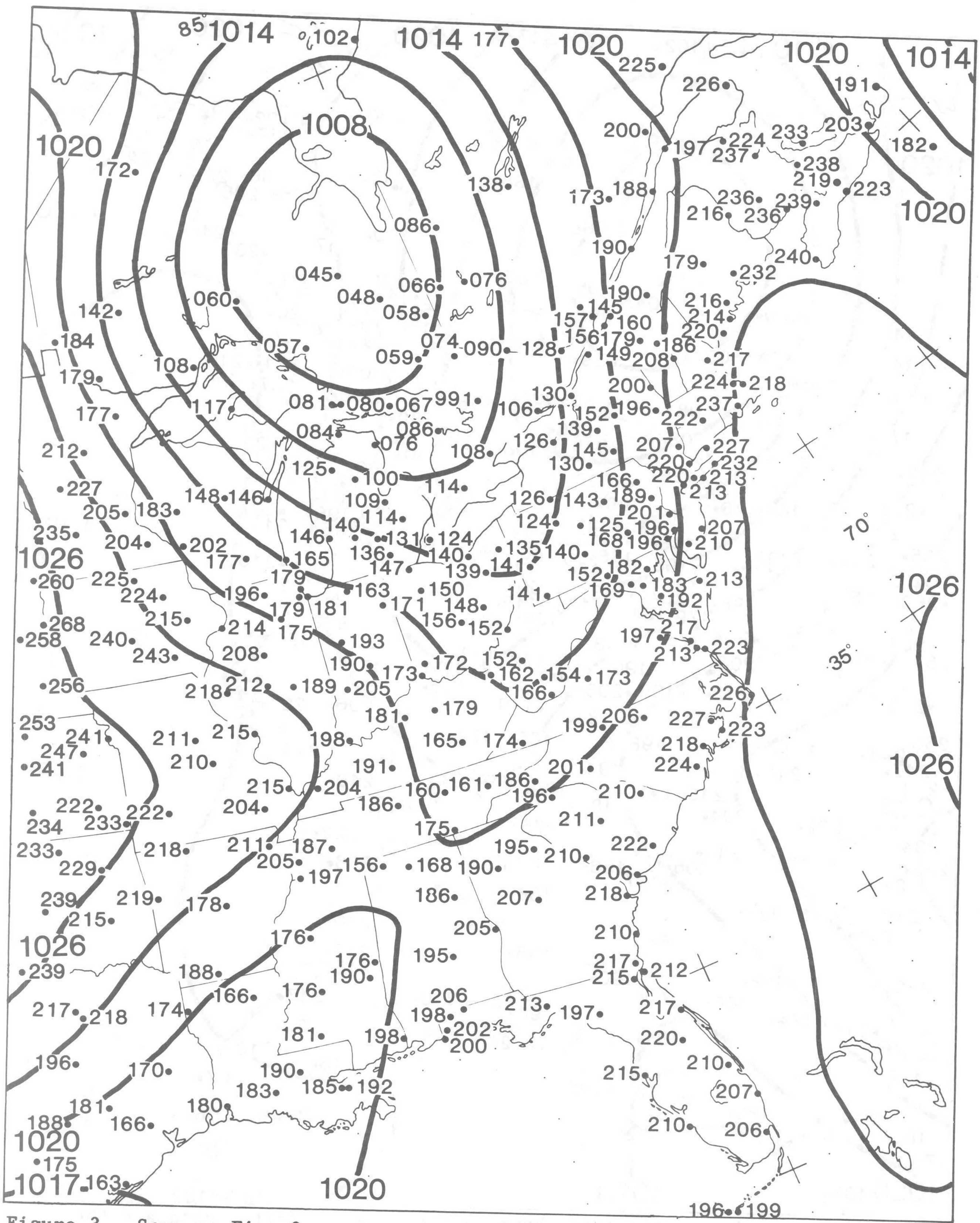

Figure 3. Same as Fig. 2 except with analysis after the first pass.

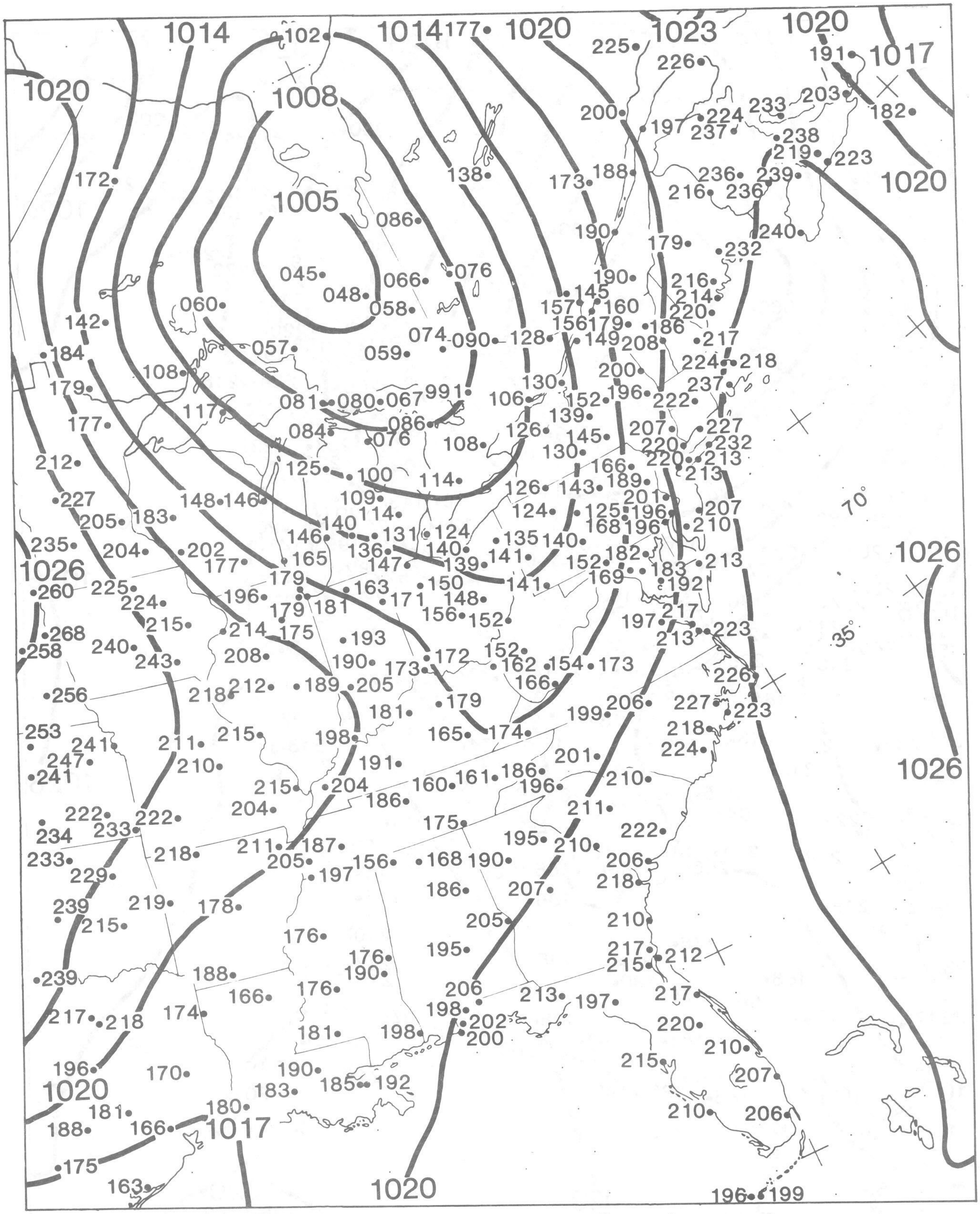

Figure 4. Same as Fig. 2 except with analysis after the second pass.

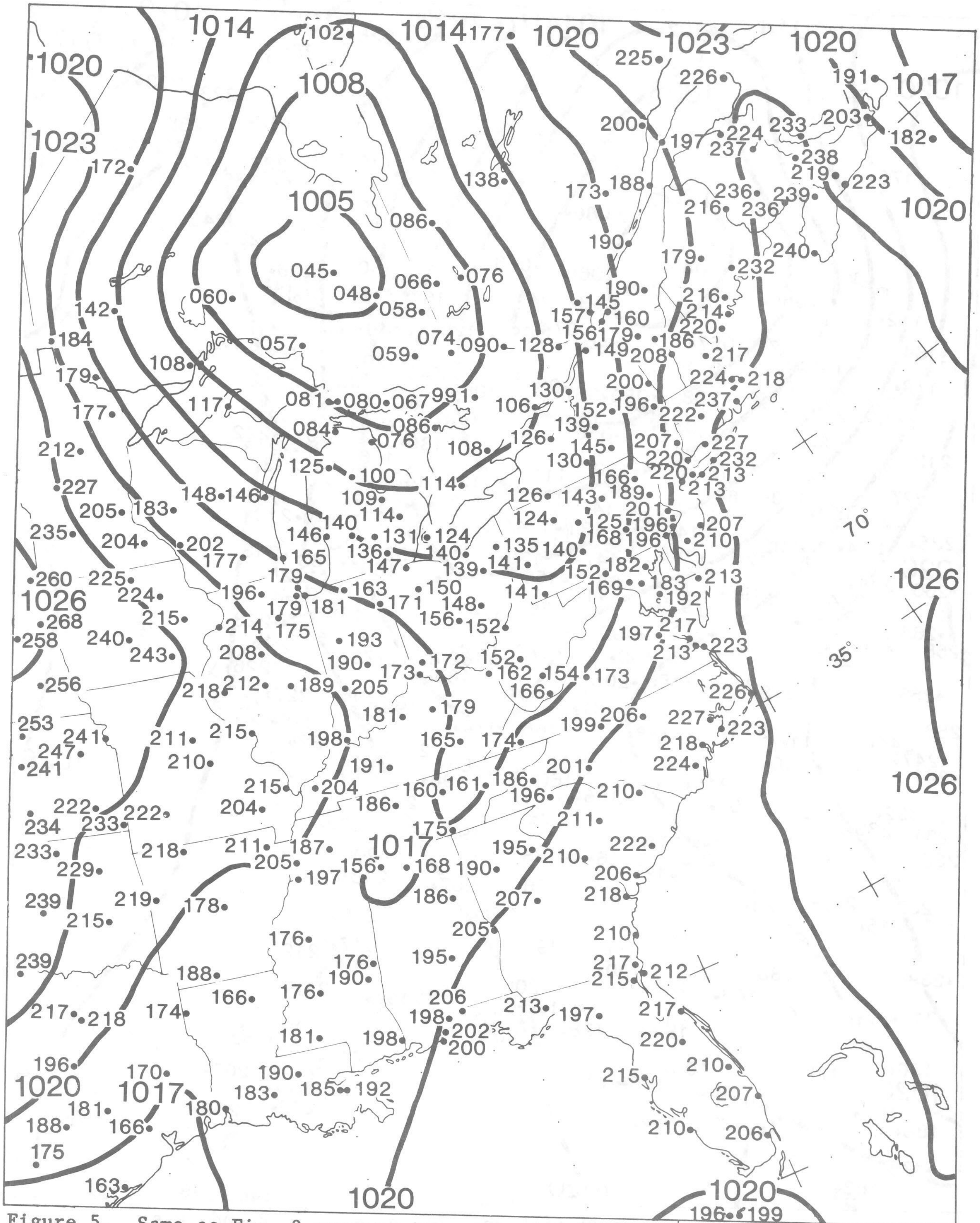

Figure 5. Same as Fig. 2 except with analysis after the third pass.

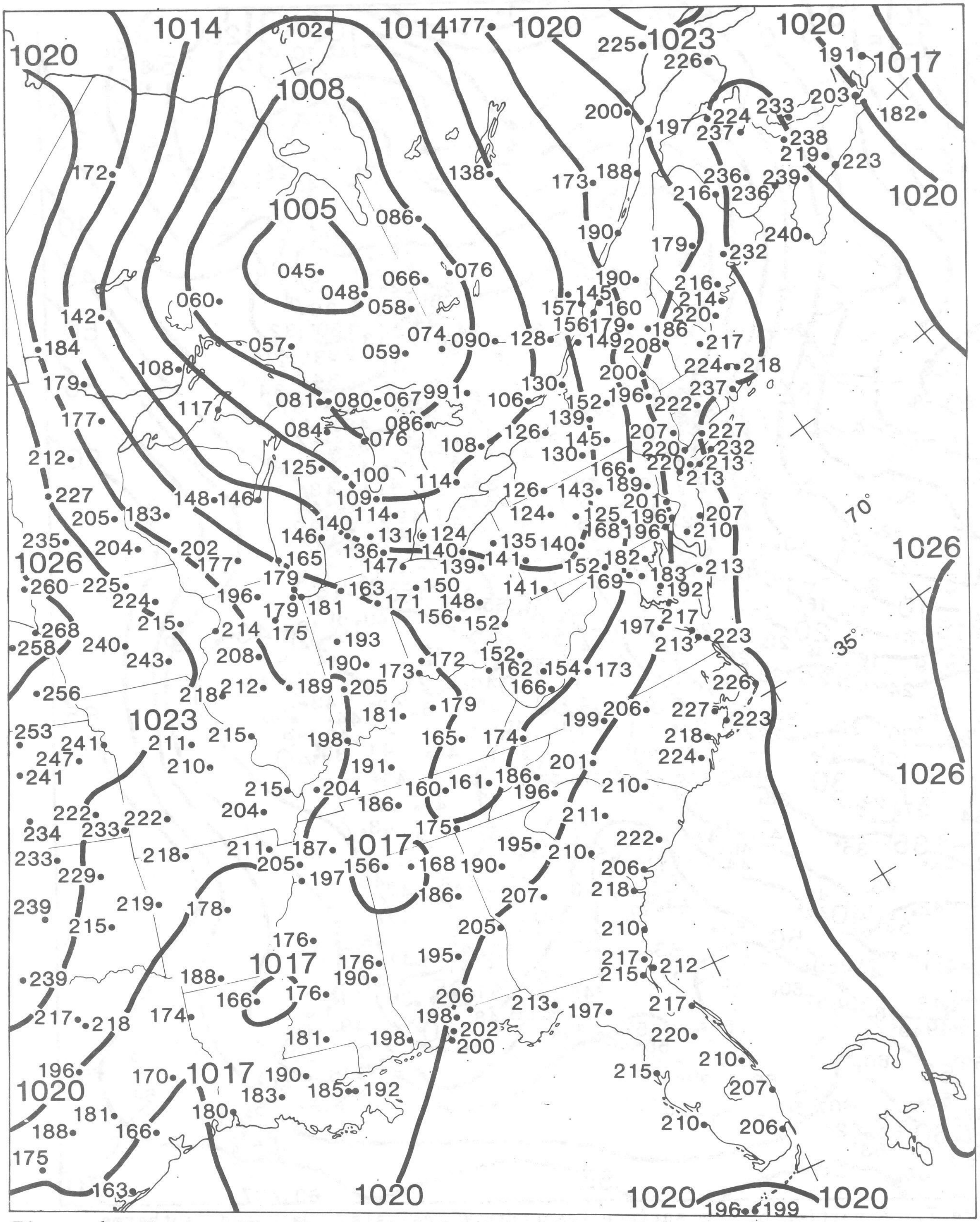

Figure 6. Same as Fig. 2 except with analysis after the fourth pass. This analysis is the same as that shown in Fig. 1.

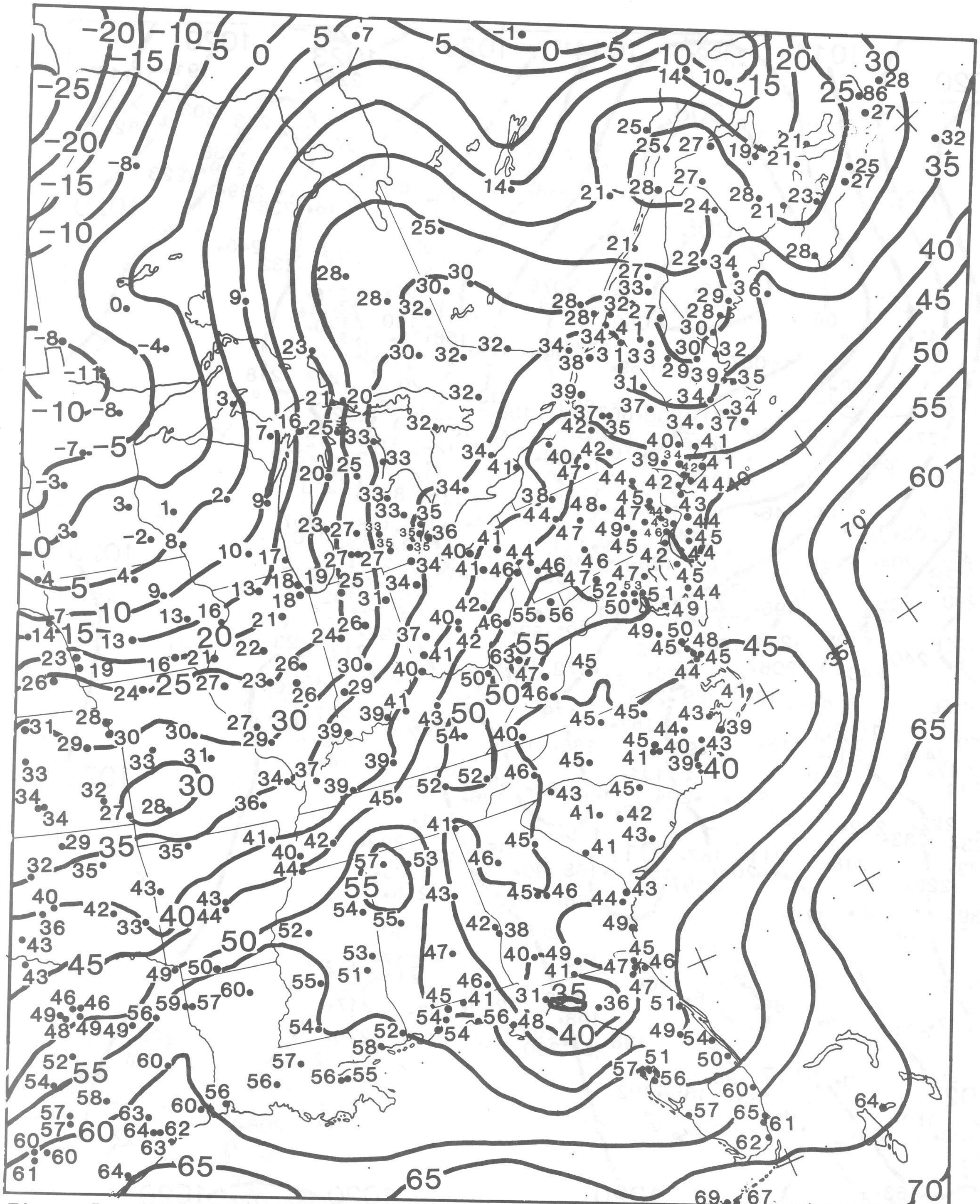

Figure 7. A portion of the surface temperature analysis. Data and isotherms are in degrees Farenheit.

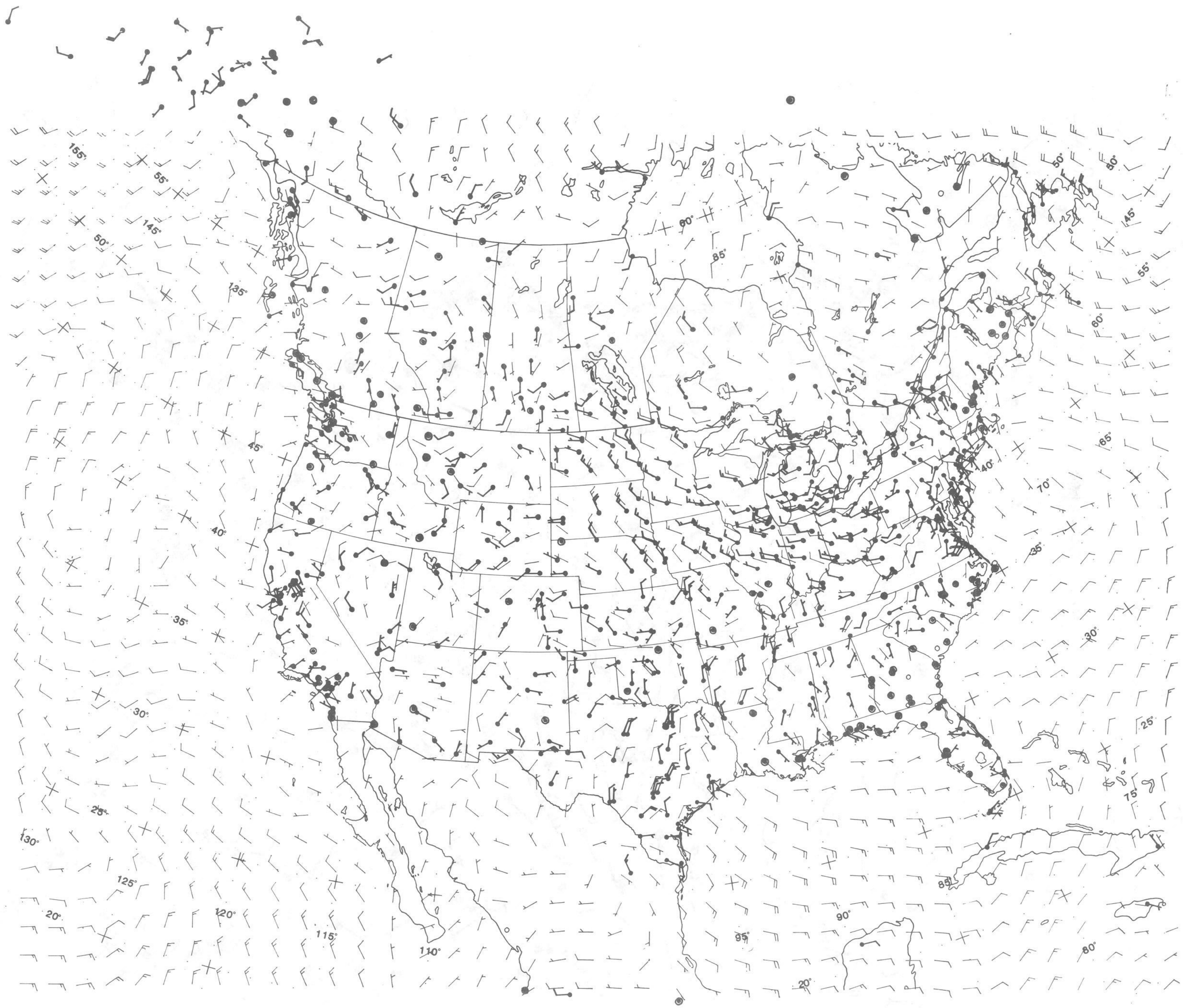

Figure 8. Surface wind analysis. Observations are plotted with the usual plotting model. One full barb = 10 kt; a half barb = 5 kt; a staff with no barb = 2 kt; and a circle = calm. Analyzed values are plotted with thinner lines at alternate gridpoints. The direction is taken from the U- and V-component analyses and the speed from the speed analysis.

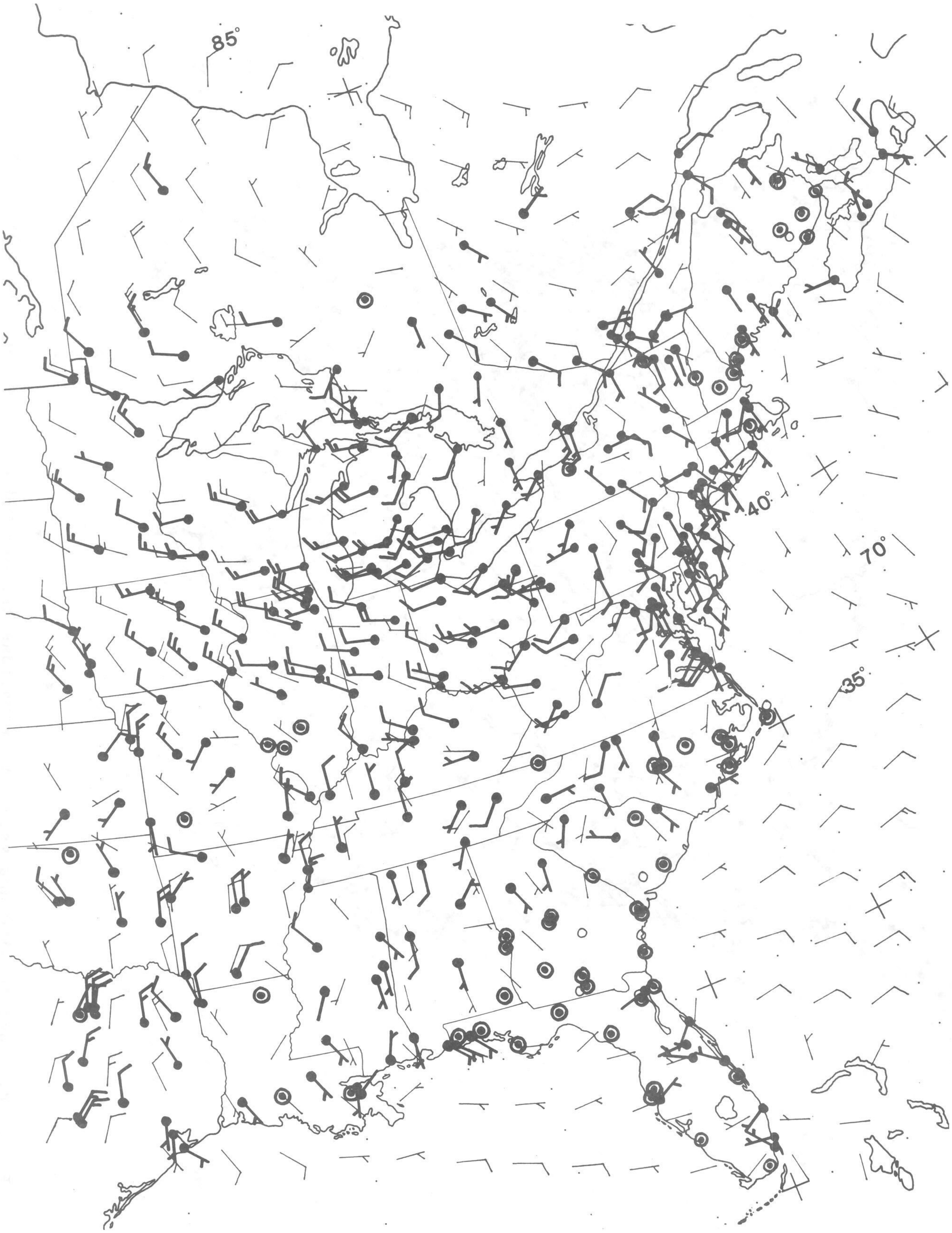

Figure 9. A portion of the analysis shown in Fig. 8.

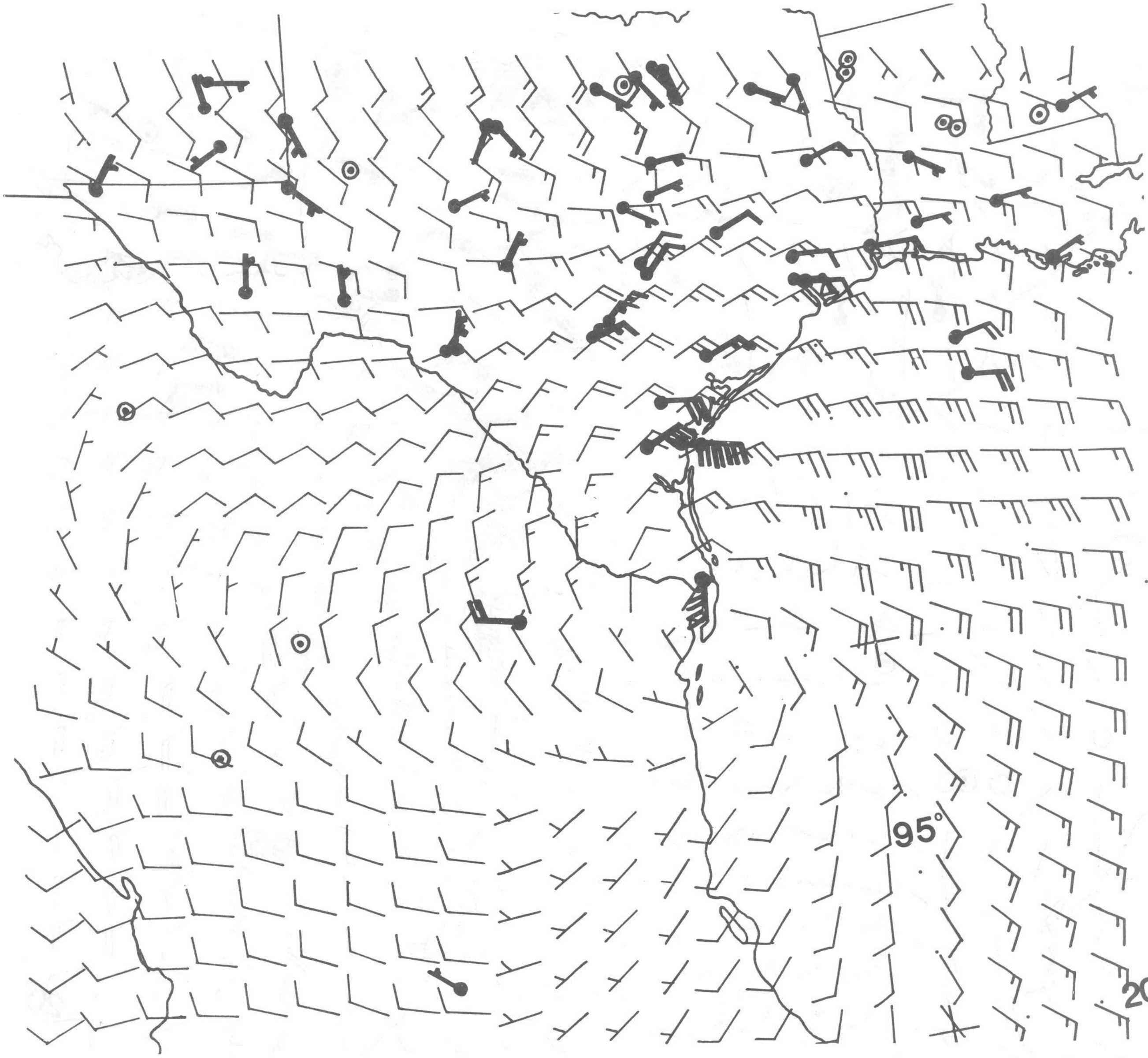

Figure 10. First guess winds plotted at alternate gridpoints and observations associated with Hurricane Allen for 1200 GMT August 10, 1980.

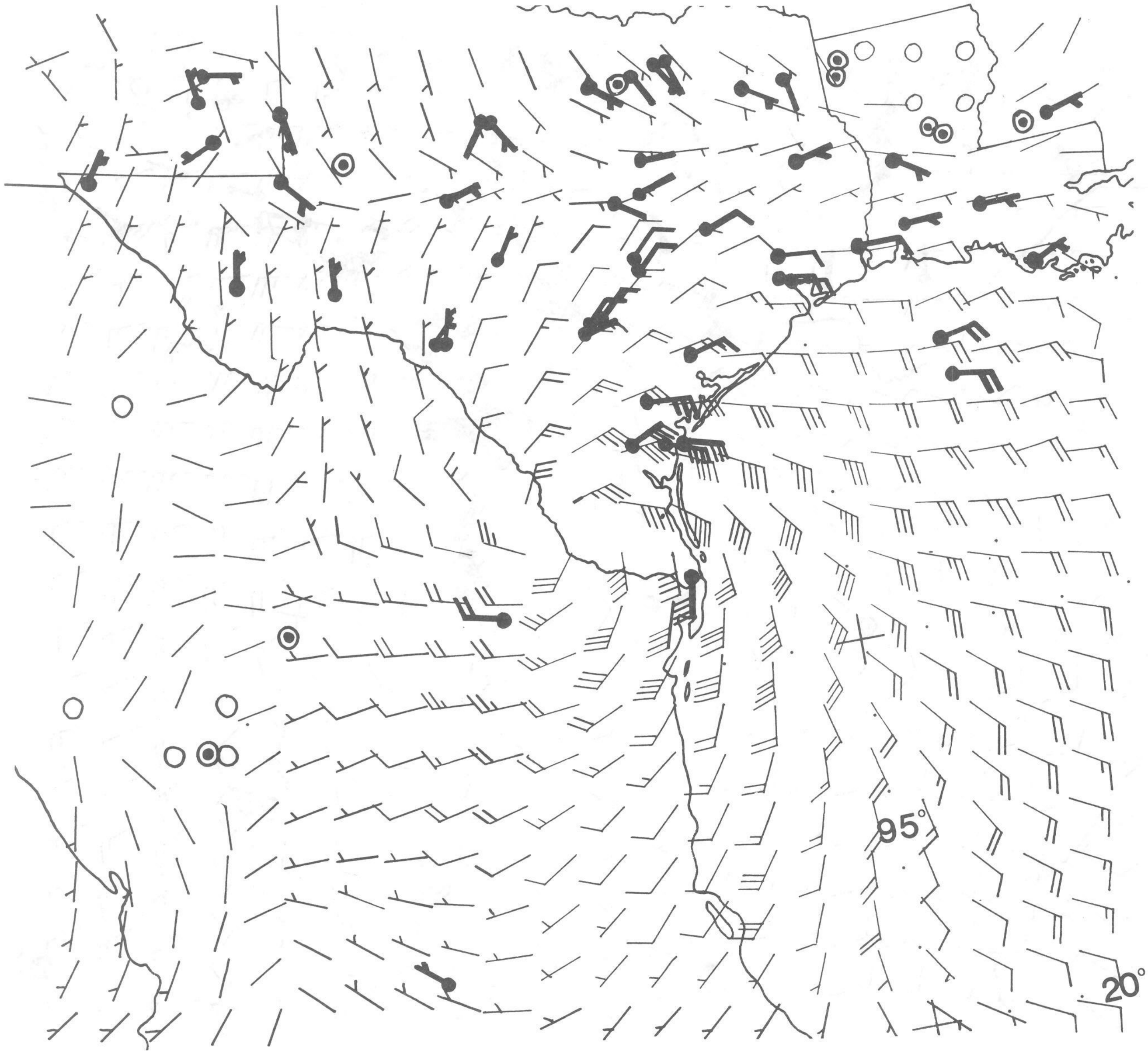

Figure 11. Analysis winds plotted at alternate gridpoints and observations associated with Hurricane Allen for 1200 GMT August 10, 1980.

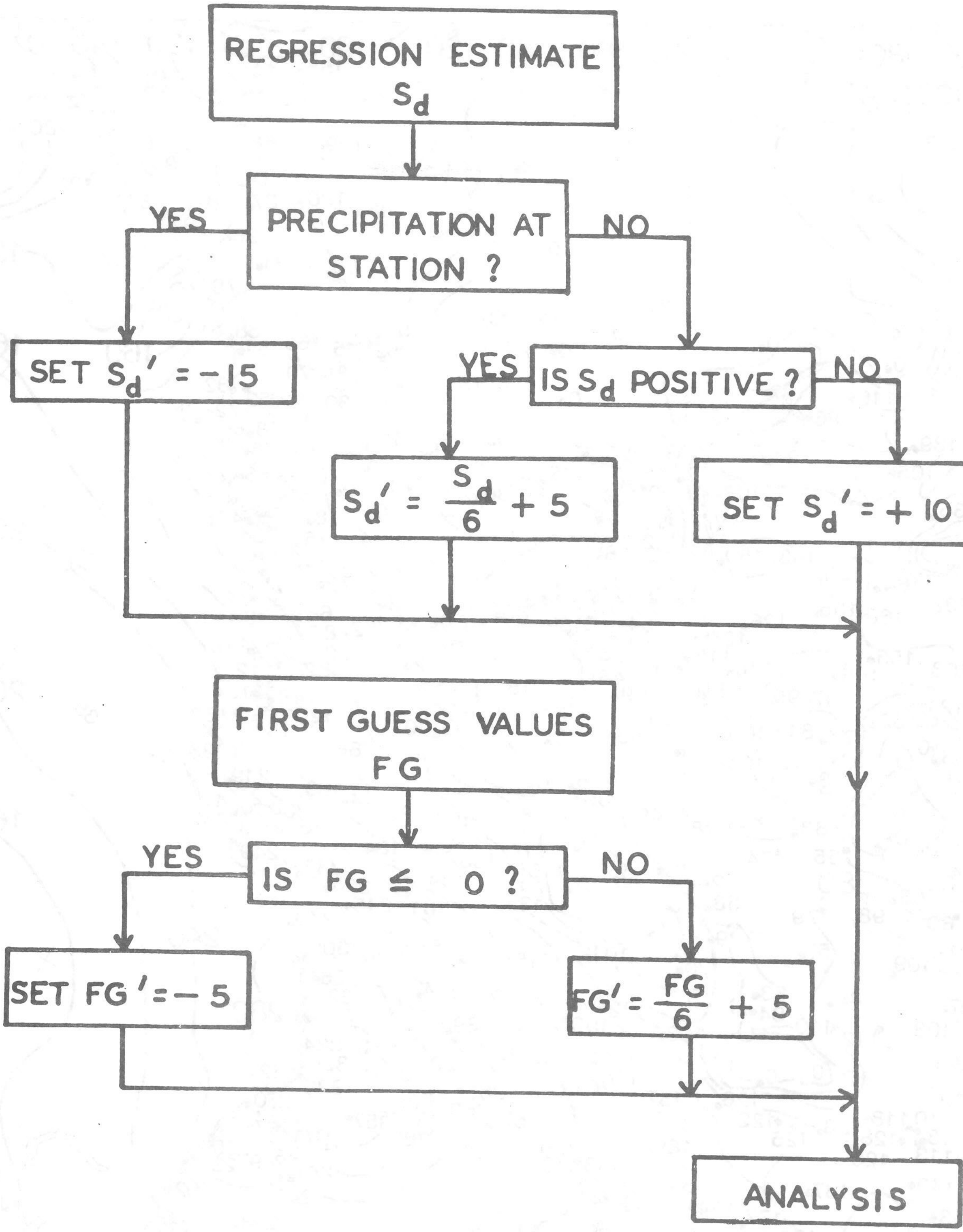

Figure 12. The transformations used in modifying the regression estimates of saturation deficit S_d and first guess values FG before analysis (slightly modified from Glahn et al., 1969).

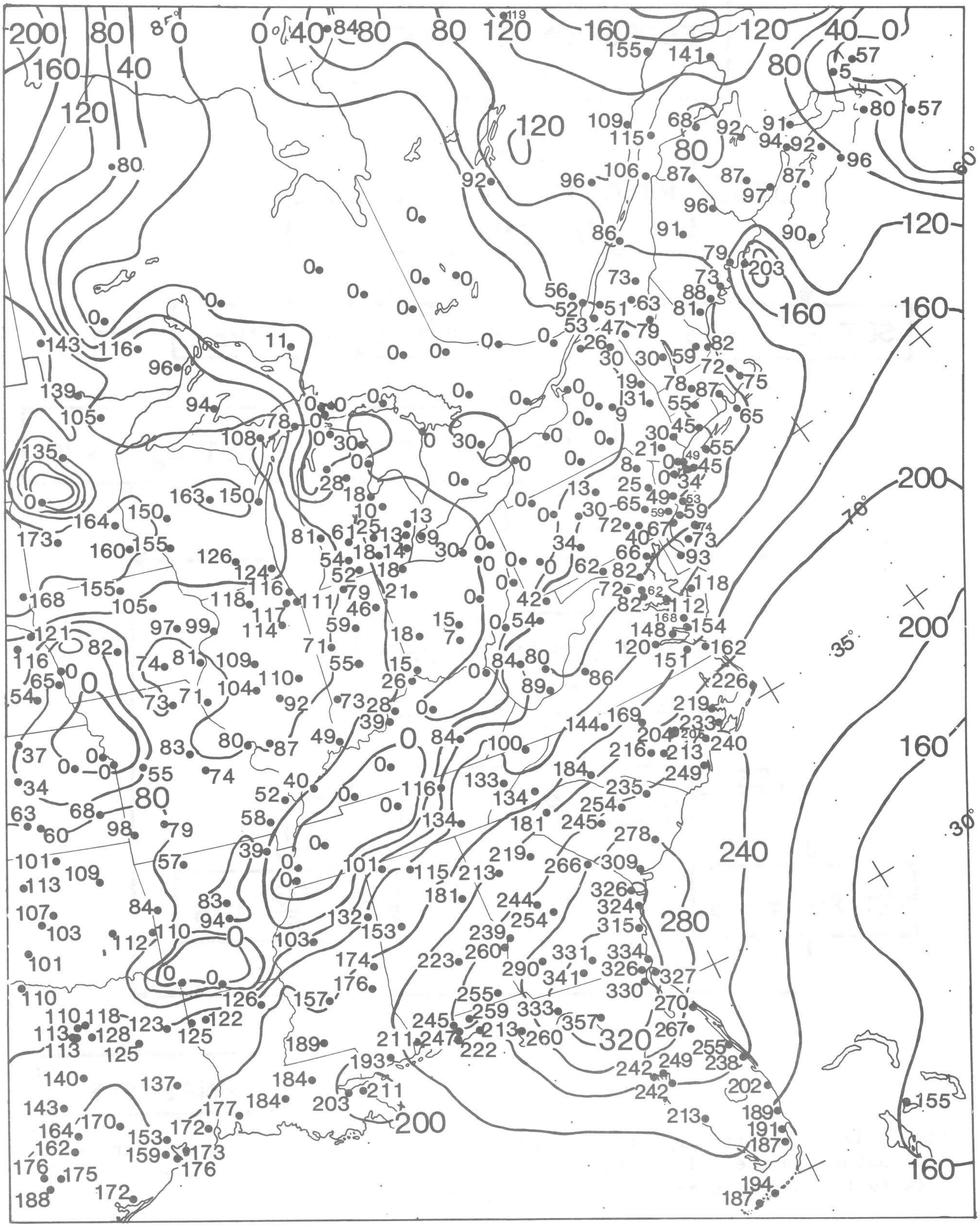

Figure 13. A portion of the saturation deficit analysis before modification by MDR data. Data and contour lables are in meters.

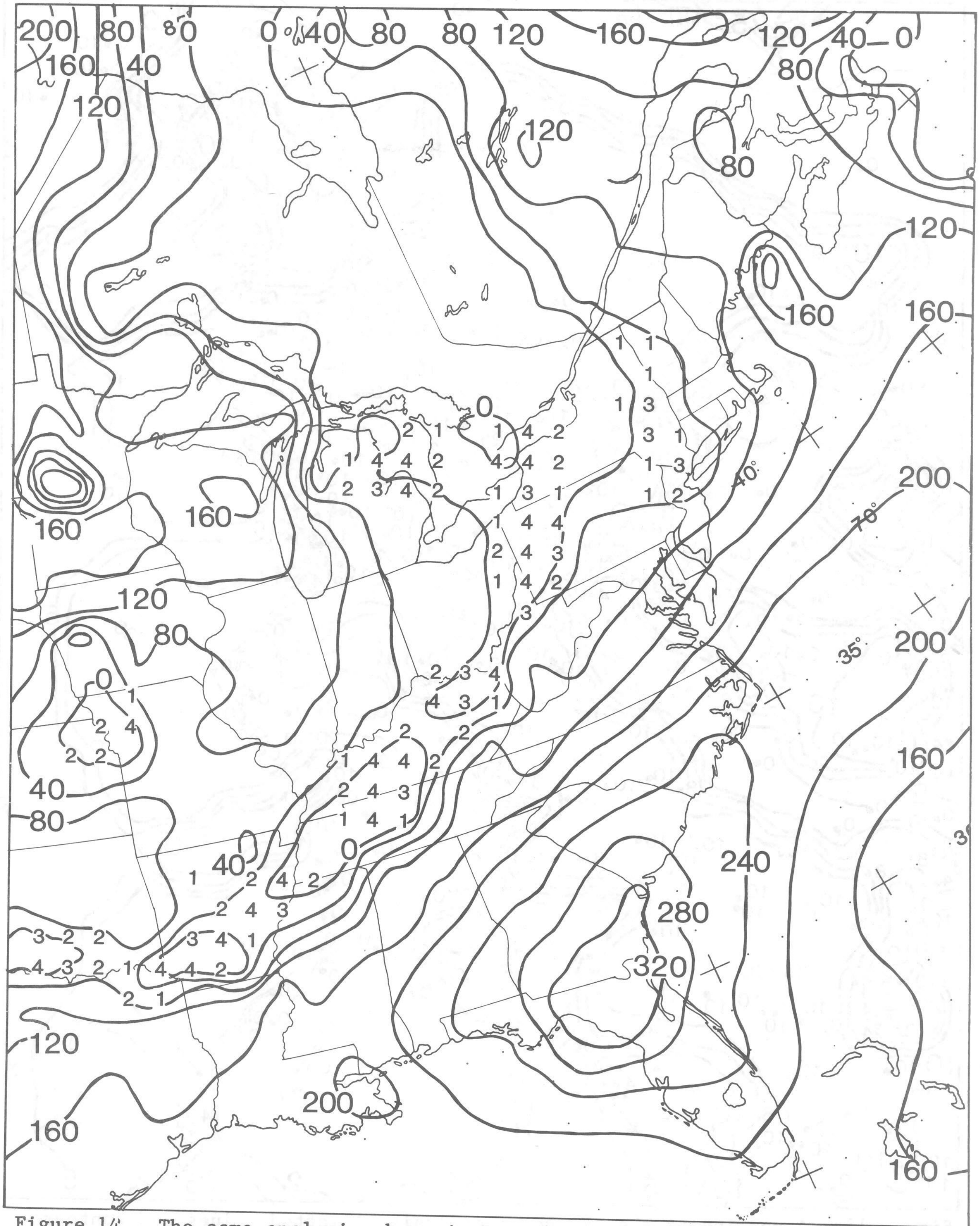

Figure 14. The same analysis shown in Fig. 11 except after modification by MDR data. Plotted values at gridpoints are the number of boxes adjacent to the gridpoint with radar echoes.

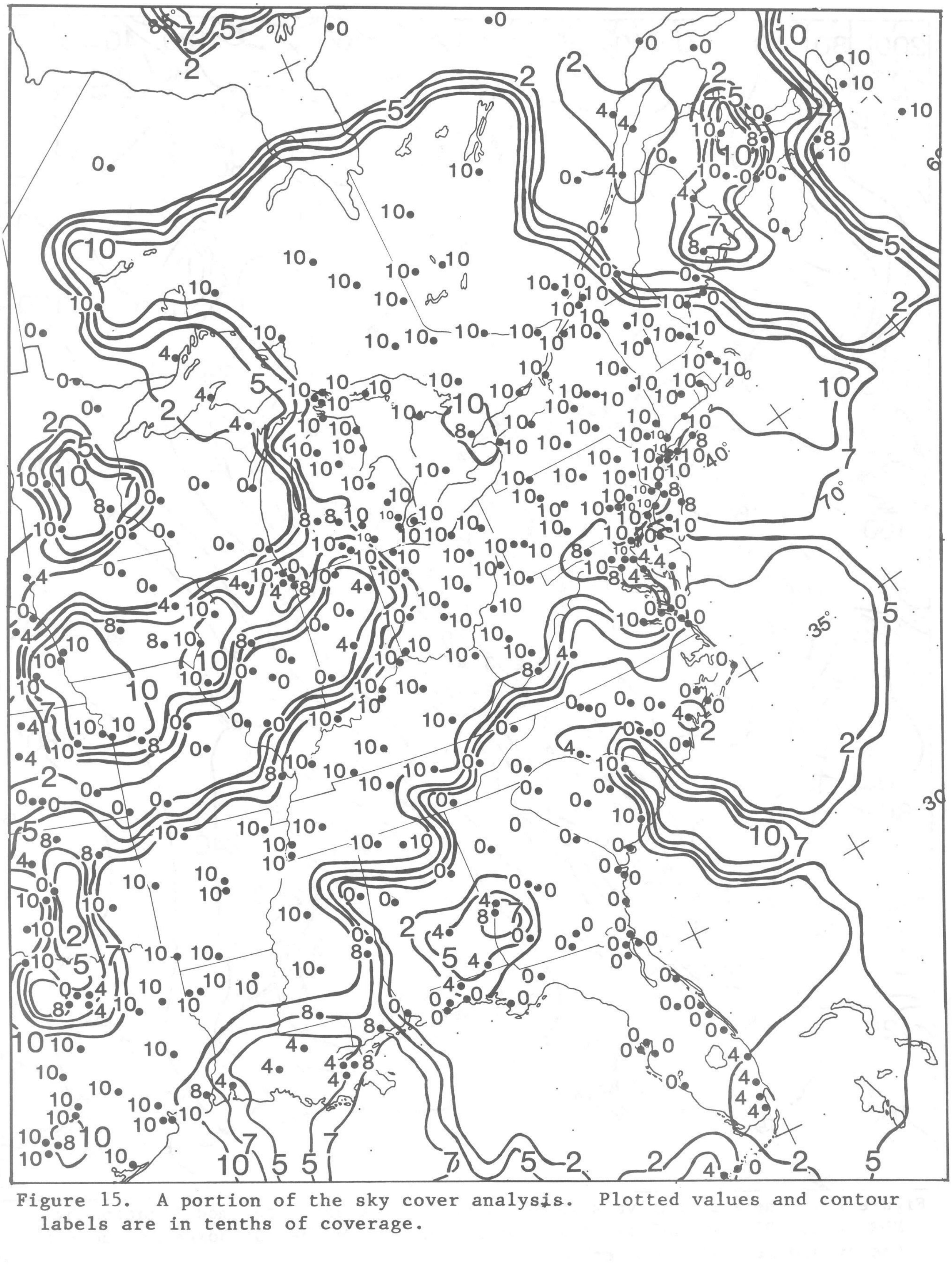

Figure 15. A portion of the sky cover analysis. Plotted values and contour labels are in tenths of coverage.

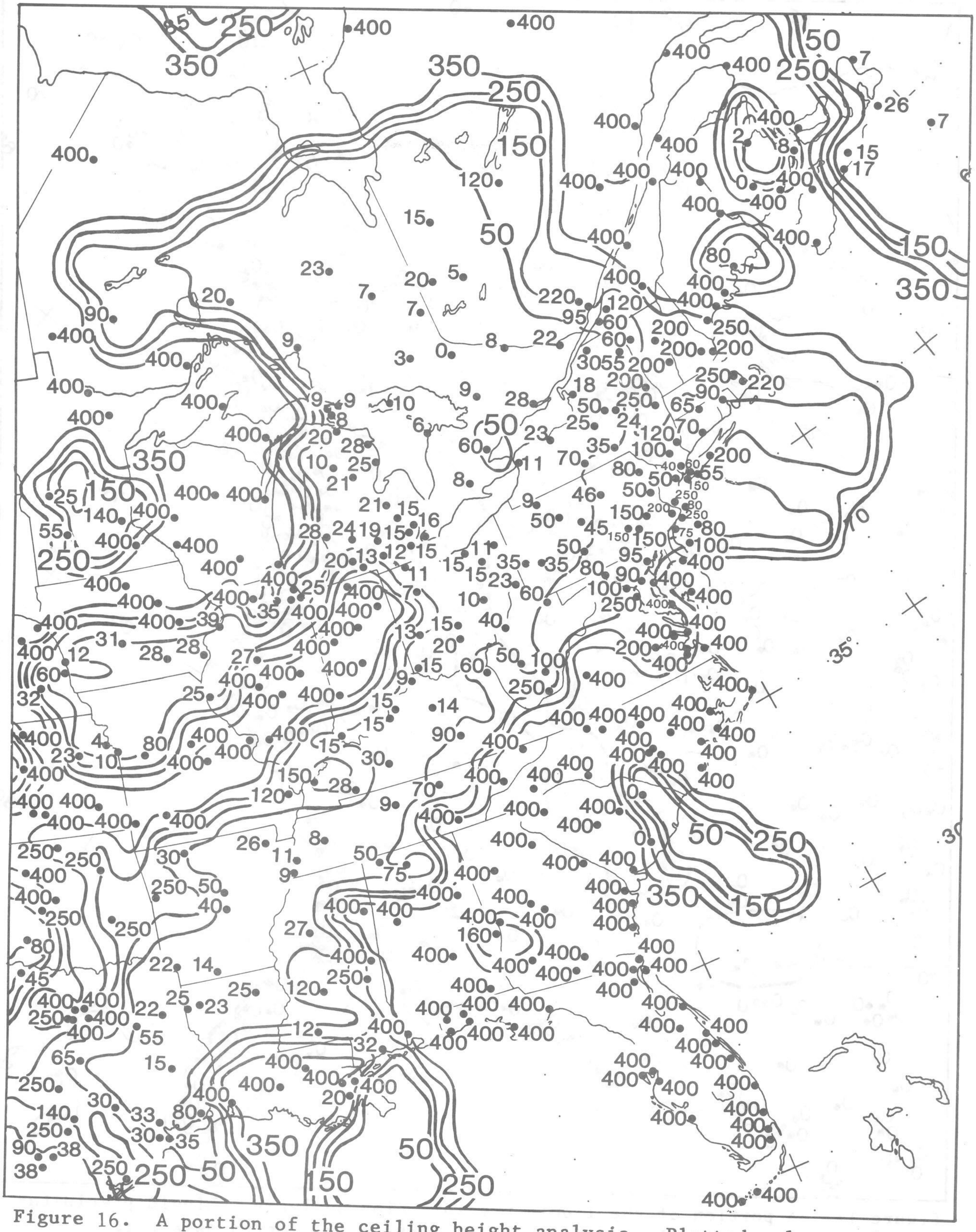

Figure 16. A portion of the ceiling height analysis. Plotted values and contour labels are in hundreds of feet.

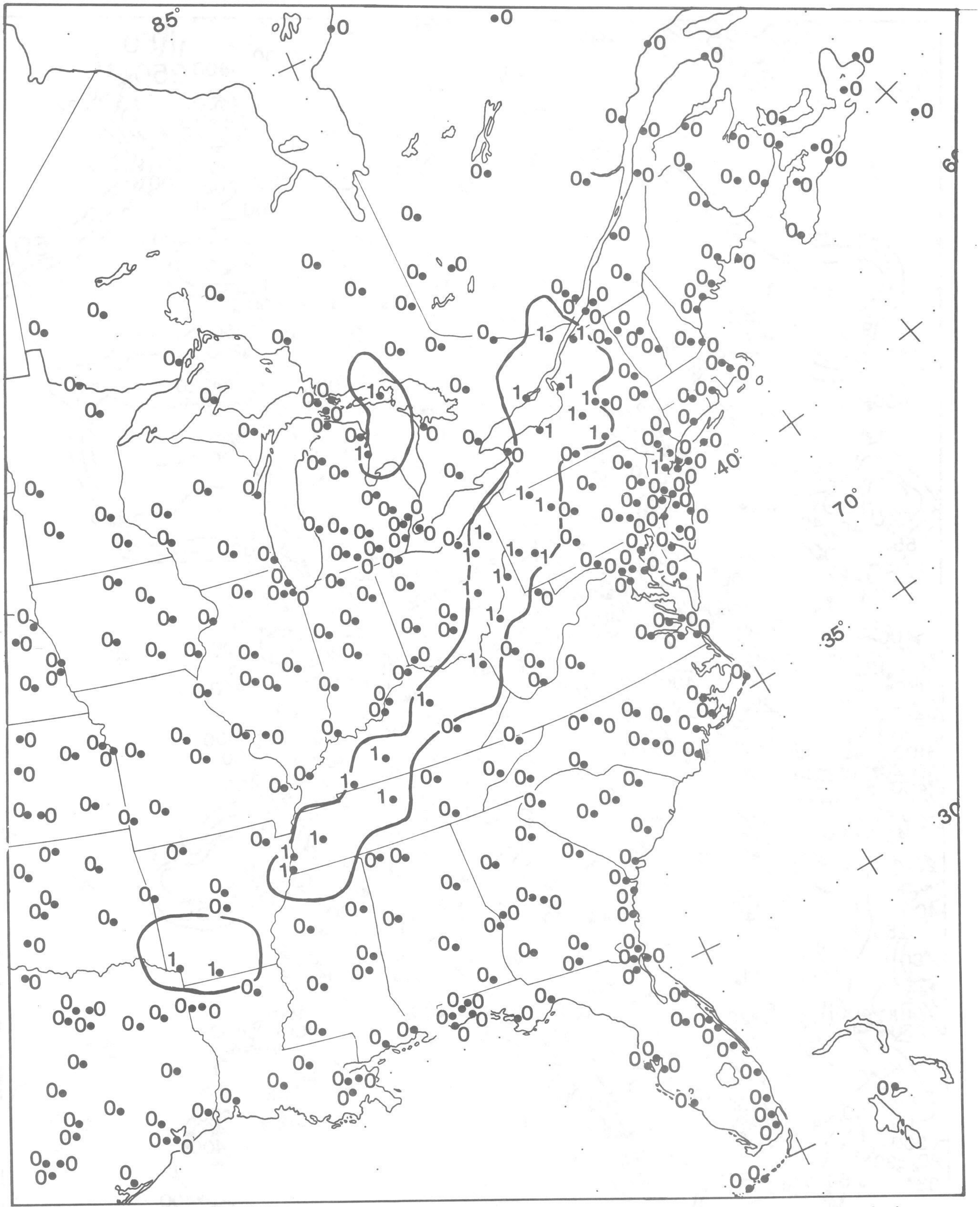

Figure 17. A portion of the liquid precipitation analysis. Liquid precipitation is plotted as a 1; no liquid precipitation is plotted as a zero.

(Continued from inside front cover)

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