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PAPERS ON OPERATIONAL OBJECTIVE ANALYSIS SCHEMES AT THE NATIONAL SEVERE STORMS FORECAST CENTER

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PREFACE

The work reported here has been jointly supported by the National Severe Storms Laboratory, NOAA Environmental Research Laboratories, and the Techniques Development Laboratory, NOAA National Weather Service. It has involved facilities at the National Severe Storms Laboratory, Norman, Oklahoma, and at the National Severe Storms Forecast Center, Kansas City, Missouri, and personnel of these organizations working together to develop improved techniques for severe storm forecasting.

The author wishes to thank Mr. Wally Schroeter and the computer operators at the National Severe Storm Forecast Center for their valuable assistance in the use of the CDC 3100 computer at NSSFC. Gratitude is also expressed to Professor J. J. Stephens, Florida State University, and to Dr. Wayne Sangster, Central Region, National Weather Service, for their advice and assistance during the course of the work. Mr. William Bumgarner, NSSL, contributed a great deal to the development, coding and testing of the various computer programs.

The work reported here was substantially completed while the author was on the staff of the National Severe Storms Laboratory. He is presently affiliated with the Department of Meteorology, University of Oklahoma, Norman.

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Several objective analysis schemes have been developed for operational use at the National Severe Storm Forecast Center (NSSFC) from the basic analysis technique described by Cressman (1959). Modifications and additions that facilitate the use of Cressman's technique on the CDC 3100 computer at NSSFC are described, and several program listings are given.

Fundamentals of the polar stereographic map projection are discussed in Appendix A. A simple rectangular coordinate system on the map projection is described and formulae for computation of wind components along the grid axes are developed.

1. INTRODUCTION

Before good weather forecasts can be made, the current state of the atmosphere must be described to reveal the variability significant to the weather forecast. Numerical analysis techniques have been of great value at several large-scale weather forecast centers throughout the world, and they should also be very useful to operational groups with responsibility for forecasting small-scale weather phenomena. Perhaps the potential value of numerical methods is at least as great in the latter case because of the short time frame of small scale forecasts.

To obtain the full advantages of speed inherent in computers, objective methods of analysis and diagnosis suitable for application to the severe storm forecast problem must be developed; the problems involved are different in many ways from those encountered in analyses of large scale patterns. This paper describes various objective analysis schemes that have been made available for operational use at the National Severe Storms Forecast Center. These analysis methods are essentially those devised by Cressman (1959) and described in further detail by McDonell (1962). In Section 2 the basic scheme is described; modifications and additions that have been made to facilitate its use at NSSFC are discussed in later sections. In the last section a surface-fitting analysis scheme is described.

2. BASIC ANALYSIS PROCEDURE

We wish to interpolate from a set of data at irregularly distributed reporting points in order to assign estimates of the variable to points of regular net or grid. The "objective analysis" described below is provided by a series of corrections to initial estimates at grid points made during a series of passes or scans through the field.

Suppose that $[O_k]$ is a set of N observations (the data) for a group of stations. Also, for each grid point (i, j), the current estimate of the variable being analyzed is $Z^{\mu}_{i,j}$. Here μ is an integer indicating the scan number. Also, let D^{μ}_k be the difference between the observed value and the current analysis of the variable at the point of observation. As explained below, the estimate at the point of observation is interpolated from the current values at the four surrounding grid points. The correction C^{μ}, is evaluated by determining the contribution of each station which is within a distance R, the radius of influence. The correction to be made at the grid point (i, j) on scan μ is

$$C^{\mu}_{i,j} = \frac{\sum_{k=1}^{N} W_k D_k^{\mu-1}}{\sum_{k=1}^{N} W_k} . \tag{2.1}$$

Here W is a distance dependent weighting factor defined by

$$W = \frac{R^2 - d^2}{R^2 + d^2} , \tag{2.2}$$

where d is the distance between the grid point and the point of observation and R is the radius of influence. Only positive values of W are used, i.e., W = 0 for d > R. The new estimate at the grid point is then calculated according to

$$Z^{\mu}_{i,j} = Z^{\mu-1}_{i,j} + C^{\mu}_{i,j} .$$

Before the next scan can be made, the current estimate at the point of observation must be determined. For stations within the grid the new estimate is determined from values at the four surrounding grid points according to the bilinear interpolation formula given below. In the figure the reporting station is located at P and the surrounding grid points are numbered 1 through 4. The interpolation formula is

$$\begin{aligned} Z^{\mu}_{P} = {} & Z^{\mu}_{1} + (Z^{\mu}_{4} - Z^{\mu}_{1}) \frac{\Delta y}{b} + (Z^{\mu}_{2} - Z^{\mu}_{1}) \frac{\Delta x}{a} \\ & - (Z^{\mu}_{2} - Z^{\mu}_{3} + Z^{\mu}_{4} - Z^{\mu}_{1}) \frac{\Delta x}{a} \frac{\Delta y}{b} , \end{aligned} \tag{2.3}$$

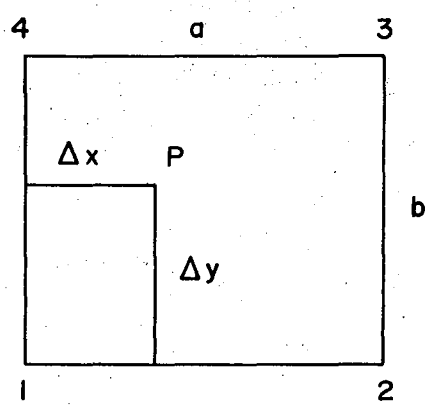

Illustration pertaining to the interpolation equation.

where the subscripts on the right hand side of the equation refer to the grid points, a is the distance between grid points along the x-axis and b is the corresponding distance along the y-axis.

The operational analysis scheme currently in use at the National Meteorological Center (NMC) utilizes first-guess fields as described by McDonell (1967). As McDonell points out, good first-guess fields are of great value in checking the data. They are not absolutely necessary, however, for successful application of this technique where sufficient data are available.

Gross errors in the observations usually can be detected by comparing them with the current analysis or the first-guess field in the case of the first pass. The data can be judged to be in error if

$$\left| D_k^{\mu} \right| > \epsilon^{\mu} ,$$

where ϵ is some predetermined maximum allowable difference; generally ϵ is decreased on successive passes. This effectively accomplishes what a human analyst does; that is, if a piece of data does not agree with neighboring observations, it usually is discarded.

For most purposes, up to four or five scans are made; the radius of influence, R, is decreased for each successive iteration. The maximum and minimum values of R that should be used depend on the initial guess field, the data density, and the scales of variation that one is trying to depict.

Experience indicates that some form of numerical filtering is required for best results. This is usually accomplished after each pass by employing one of the smoothing operators described by Shuman (1957).

3. MODIFICATIONS TO BASIC SCHEME

The basic analysis method briefly reviewed in the previous section is a versatile one. In this section a description is given of the revisions, modifications and additions which have been made in order to facilitate its use at NSSFC.

A CDC 3100 electronic computer is available for operational use at the forecast center; the NSSFC equipment does not include internal floating point hardware. Although floating point arithmetic is available in a software package, its relatively slow speed leads to use of fixed point arithmetic almost exclusively in the analysis programs; such programs can be operated in about 1/10 of the time needed for versions utilizing the software floating point arithmetic.

There are several approaches to the programming of this analysis technique for an electronic computer. For example, the calculation of the corrections to be applied to the previous analysis at a grid point can be accomplished by scanning the grid points and considering all data within the region of influence of each grid point. Alternatively, one can scan the data array and determine the contribution of each piece of data to the corrections to be made at surrounding grid points. We have chosen the former procedure for use at NSSFC. The two approaches differ little in their use of computing time, when the data is sorted so that all stations within a distance R of a particular grid point can be identified with a limited data scan. Because of the relatively large number of surface stations compared with upper air stations, surface data is usually sorted before being analyzed; it is also worthwhile to follow this procedure in the case of upper air data, although the time factor is not as critical.

3.1 First-Guess Fields

No fields of the quality available at NMC are available for use at NSSFC. Consequently, if no other initial estimate is available, a zero first-guess is employed along with a large radius of influence on the first pass with the successive approximation scheme. Effectively, this results in the computation of a local average of the variable that is being analyzed. Lack of first-guess fields is no handicap because of the relatively high data density over the United States.

Some of the analysis routines available at NSSFC have been programmed to use non-zero first-guess fields. Sometimes it is advantageous to use the mean value of all the observed data in the analysis as an initial estimate at each grid point. Also, Maine and Gauntlett (1968) have described a statistically-based first approximation which they applied to the difficult problem of rainfall analysis. Their technique could be applied easily to many problems at NSSFC.

3.2 Use of Data from Outside the Grid

When analyses are performed at NMC, usually all available data are from stations positioned within the grid. At NSSFC, however, analyses are usually made for grids which cover only a portion of the area for which data are available. Consequently, since valuable data are often available in the region surrounding the grid, the basic scheme has been modified to take advantage of these data. This allows the analysis near the boundary to have about the same quality as that at interior grid points (assuming that the same amount of data is available in the vicinity of the respective points).

If the station is outside the grid, the current estimate of the analysis may be calculated in essentially the same manner as the estimate at a grid point. That is,

$$D_k^{\mu} = D^{o} - Z_k^{\mu-1} , \qquad (3.1)$$

where $Z_k^o = 0$ and $Z_k^{\mu} = Z_k^{\mu-1} + C_k^{\mu}$. A slight variation of the above procedure usually works slightly better. Specifically, the latest estimate of the analysis at the station location is calculated according to

$$Z_k^{\mu} = \tfrac{1}{2} (Z_k^{\mu-1} + C_k^{\mu} + 0_k) , \qquad (3.2)$$

where 0_k is the observation.

3.3 A Modification of the Weight Function

Endlich and Mancuso (1968) devised an analysis method with a weighting function that gives greater weight to upwind-downwind observations than to those positioned in a crosswind direction. Isolines of the analyzed scalar produced by this weighting function tend to be elongated along the direction of the flow. In their procedure the analyzed values are obtained by fitting a plane surface to the five observations nearest the point at which the analysis is desired; a distance dependent weighting factor is applied to each item of data before the least squares fitting process.

At NSSFC we have found that the Cressman analysis scheme is most economical. Consequently, the distance dependent weight function defined by (2.2) has been modified so that upstream and/or downstream observations are given more weight than those positioned in a cross-stream direction. The new weight function is given by

$$W^* = \frac{R^{*2} - d^2}{R^{*2} + d^2} , \qquad (3.3)$$

where

$$R^{*2} = R^2 (1 + \beta \cos^2 \theta) , \qquad (3.4)$$

and θ is the angle between the position vector (locating an observation with respect to the grid point) and the wind velocity vector at the grid point. The influence of this modification is controlled through β. For example, in analyzing a wind field subjectively most analysts tend to elongate closed isotachs along the direction of the flow; furthermore, the stronger the flow the greater the tendency to construct the analysis in this manner. The value of β can be adjusted with wind speed to simulate this objectively. For example,

$$\beta = \frac{b\ C}{C^*}\ , \tag{3.5}$$

where C is the wind speed, C^* is some maximum wind speed and b is a constant, usually unity.

Experiments have been made with the weight function modified by the observed wind at the reporting station rather than by the analyzed wind at the grid point. This procedure usually results in inferior analyses, especially where the wind direction changes appreciably between the location of the grid point and the station.

3.4 Adjustments to Account for Variable Data Density

As indicated above, the Cressman method uses a radius of influence, R, which is decreased on successive passes. Effectively, this results in depiction or adjustment of larger scales of variation during the initial pass and successively smaller scales on later passes. However, corrections can be made only when data is available within the radius of influence. Experiments show that the best results are obtained when the radius of influence for the first pass (and perhaps the second) is chosen so that at least two or three stations are in the region of influence. However, this does not mean that R should be chosen so that two or three stations are within distance R of the grid point where the data density is least. When this is done, much time is wasted at grid points in regions of much data, calculating contributions by stations that simply cancel contributions computed for other stations. Thus, it is much more economical to specify a smaller radius of influence to be used over most of the grid and then increase R for grid points in regions of low data density. We have found that it usually is satisfactory to require the analysis at each grid point to be affected by at least two pieces of data on the first pass; slightly better results are obtained by imposing the same requirement on the second pass.

In applying the method to the analysis of surface data, where a large amount of data is available, it may be advantageous to multiply the weight function given by (2.2) or (3.3) by the parameter $\lambda_k = L/M$, where M is the number of stations within a distance R/2 of the kth station and L is the maximum number of stations within a distance R/2 or any of the k stations. Use of the factor λ prevents a few closely grouped stations from exerting undue influence in comparison with a relatively isolated station.

3.5 Height Analysis Routine

A subroutine which performs an objective analysis of the height of a constant pressure surface has been written for use on the CDC 3100 computer at NSSFC. The basic analysis method is the same as employed at NMC, as reported by McDonell (1962); however, there are some differences in details. In the following paragraphs, the technique is briefly reviewed.

The analysis is carried out in the manner described in Sections 2 and 3 except that the calculated corrections are a function of the observed winds as well as the observed heights. Three possibilities are considered; for each of these situations the difference, D_k, is calculated as shown below:

a. for a station with height report only,

$$D_{1k} = Z_k - Z_s \quad , \tag{3.6a}$$

where Z_k is the reported height and Z_s is the value of height (at the reporting station) interpolated from the current analysis;

b. for a station with wind only,

$$D_{2k} = Z_s + (\Delta x \frac{\partial Z}{\partial x} + \Delta y \frac{\partial Z}{\partial y}) - Z_{i,j} \quad , \tag{3.6b}$$

where Δx = x (grid point) - x (station),
Δy = y (grid point) - y (station),

and $\partial Z/\partial x$ and $\partial Z/\partial y$ are height gradients (determined from observed winds) in the x and y directions, respectively;

c. for a station with both height and wind

$$D_{3k} = Z_k + (\Delta x \frac{\partial Z}{\partial x} + \Delta y \frac{\partial Z}{\partial y}) - Z_{i,j} \quad . \tag{3.6c}$$

The height gradients are computed utilizing the geostrophic wind equations:

$$\frac{\partial Z}{\partial x} = \frac{1.08 \; f}{m \; \sigma \; g} \; v \quad , \tag{3.7a}$$

$$\frac{\partial Z}{\partial y} = - \frac{1.08\ f}{m\ \sigma\ g} u \quad , \tag{3.7b}$$

where f is the Coriolis parameter, σ is the image scale factor, m is the map scale, g is the acceleration of gravity and u and v are components of the observed wind along the x- and y-axes of the rectangular grid (see Appendix A). The constant 1.08 is the average ratio of geostrophic winds to actual winds as determined by Neiburger, et al, (1948).

The correction, C, to be applied at a grid point (i, j) is then calculated according to

$$C_{i,j} = \frac{\sum_{k=1}^{N_1} W_k D_{1k} + \alpha_2 \sum_{k=1}^{N_2} W_k D_{2k} + \alpha_3 \sum_{k=1}^{N_3} W_k D_{3k}}{\sum_{k=1}^{N_1} W_k + \alpha_2 \sum_{k=1}^{N_2} W_k + \alpha_3 \sum_{k=1}^{N_3} W_k} , \tag{3.8a}$$

where N_1, N_2 and N_3 are the number of stations with height reports only, wind reports only, and height and wind reports, respectively. The weighting factors α_2 and α_3 are varied depending on the pass as shown below.

Assignment of Weighting Factors

No. of Pass	α_2	α_3
1	0	0
2	1	8
3	2	8
4	4	8
5	8	8

Since a zero first-guess field is used, the first pass is accomplished using only reported heights. As the height analysis is adjusted and improved, greater weight is given to reports of wind only.

On the first pass at least two stations are required to be in the region of influence. On later passes, if only a single report is in the region, the correction is calculated according to

$$C_{i,j} = \frac{\sum_{k=1}^{N_1} W_k D_{1k} + \alpha_2 \sum_{k=1}^{N_2} W_k D_{2k} + \alpha_3 \sum_{k=1}^{N_3} W_k D_{3k}}{N_1 + \alpha_2 N_2 + \alpha_3 N_3} \quad . \tag{3.8b}$$

In determining the analysis at station locations outside the grid, only height reports are utilized in the present version of the analysis program. However, it is possible to use reports of wind as well.

4. APPLICATIONS

The analysis techniques described in preceding sections are employed in a simple FORTRAN computer program (PROGRAM SAMPLE) which analyzes the 500 mb height, wind, and temperature fields. Constants appearing in the program are appropriate for a rectangular grid on NSSFC Map No. 15, P93 (polar stereographic projection, true at 60°, map scale 1 : 15,000,000); the grid length of 190.5 km, one-half the NMC grid, is 1/2" on this map.

PROGRAM SAMPLE with several FORTRAN subroutines used for performing objective analyses on the CDC 3100 at NSSFC, is listed in Appendix B. The main program reads data from the NSSFC operational Raob data tape, prepares the data for analysis and calls the subroutines.

The Raob data tape contains the 500 mb height, temperature, and wind reports used in the analyses, checked for hydrostatic consistency at NSSFC (Inman, 1968). Data for a rawinsonde station on this tape is contained in an integer array of 150 pieces of information; the format is given in Appendix C.

The following paragraphs give additional remarks related to the analyses of wind, height, and temperature fields.

As discussed in Appendix A, the observed winds are transformed into velocity components along the x- and y-axes of the rectangular grid according to

$$\begin{aligned} u &= C \cos (\lambda - \alpha) \ , \\ v &= C \sin (\lambda - \alpha) \ , \end{aligned} \tag{4.1}$$

where α is the observed wind direction, C is the observed wind speed and λ is the deviation of longitude of the reporting station from 110 deg (reference longitude). Both components of the wind velocity are analyzed simultaneously utilizing subroutine TOBAN.

Since the analysis routines utilize fixed point arithmetic, it is necessary to have a restriction on the magnitude of the data analyzed. In the case of heights of constant pressure surfaces it is convenient to analyze the differences between observed heights and some standard value; here, 5500 m is subtracted from the heights of the 500-mb surface before the height analysis is performed. The observed winds are transformed into approximate height gradients as shown in Section 3.5. The analysis is then carried out in subroutine HOBAN.

The 500-mb temperature field is analyzed utilizing subroutine OBAN. In this analysis the analyzed winds at grid points are utilized to modify the weight function so that observations positioned downstream or upstream are given greater weight than those located in a crosswind direction. The weight function is described in Section 3.3.

5. A SURFACE-FITTING OBJECTIVE ANALYSIS TECHNIQUE

Endlich and Mancuso (1968) have devised an objective analysis technique which fits a first degree polynomial by the method of least squares to distance-weighted observations of a scalar quantity at the five stations nearest to a grid point. The weight function which they utilize is given by

$$W = C^2 / [(R + R^*)^2 + C^2] , \qquad (5.1)$$

where C^2 is a constant, R is the distance from the grid point to the observation and R^* is a factor that determines whether the observation is positioned in an upwind-downwind direction or in a crosswind direction from the grid point. The factor R^* is computed according to

$$R^* = \left| \hat{k} \cdot \hat{R} \times \hat{V}/V \right| , \qquad (5.2)$$

where $\hat{R}$ is the position vector locating the observation with respect to the grid point, $\hat{V}$ is the observed wind velocity, V is the observed wind speed and $\hat{k}$ is a vertically directed unit vector. They have successfully applied this technique to the objective analysis of various synoptic conditions associated with the development of severe thunderstorms. Also, Reap (1968) has applied this technique in his study of the prediction of temperature and dew point by means of the determination of three-dimensional trajectories.

This technique has the distinct advantage that it can be applied to the problem of interpolation of observations to one or more irregularly-spaced points; of course, it also can be applied to the problem of interpolating atmospheric variable values to a regular grid although it does require much more computer time than the previously discussed successive approximation technique.

One very important application of this technique at NSSFC is in the area of determination of erroneous data. That is, the method can be applied to estimate a variable at the site of the observation; if the resulting value differs greatly from the reported value, one can be sure that a data error has been found and necessary steps can be taken to insure that the bad data is eliminated or properly corrected.

A subroutine which determines the analysis of a variable at points of a rectangular grid has been written for the NSSFC CDC 3100 computer and is included in Appendix B (MOBAN).

APPENDIX A

The Polar Stereographic Map Projection

The nearly spherical surface of the earth may be mapped by means of projections which transpose points on the earth's surface into points of an image surface. The two most common types of maps employed in meteorology are the Lambert conformal and the polar stereographic. Saucier (1955) gives some of the details of these projections as well as others which are useful for special applications. Here we discuss the polar stereographic projection.

For our purposes the image surface is a plane which passes through the earth at 60 deg. N. latitude. Thus, we are concerned with a secant projection. The latitude at which the plane intersects the earth is normally referred to as the standard latitude or parallel of the projection and will be denoted as φ_o. Along the standard parallel, distance on the image surface is equal exactly to distance on a spherical earth.

The image scale, σ, is defined as the ratio of image surface distance to earth distance. Thus, σ has a value of one along the standard parallel and is greater or less than one at other latitudes as shown below.

The polar stereographic projection is a conformal map. That is, there is a one-to-one correspondence between angles on the map and angles on the earth's surface. Also, on a conformal map the image scale must be the same in all directions in the vicinity of a point.

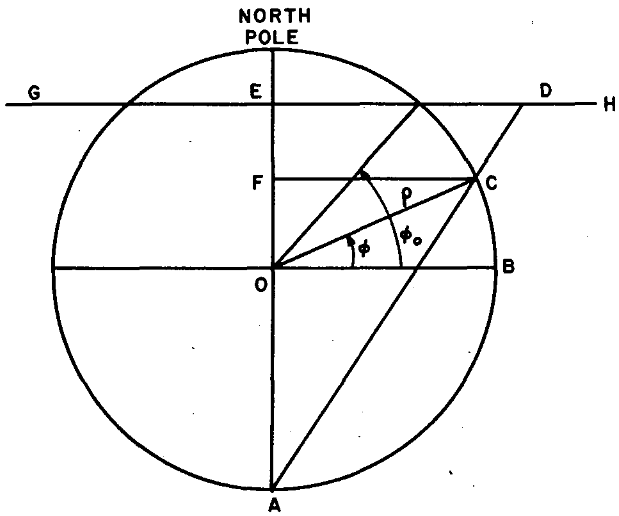

Figure A1. Scheme for polar stereographic map projection with standard parallel at latitude φ_o.

Figure A1 shows the scheme for the polar stereographic map projection. This is the simplest and most convenient of the projections in use in meteorology; it is a perspective projection for which the point of projection is the south pole (for a northern hemisphere map).

The image scale factor, σ, is given by the ratio of the radius of a latitude circle on the image surface to its corresponding radius on the earth. Point C on the earth at latitude φ is projected upon the secant plane GH at point D. Thus, the image scale σ is equal to the ratio of the lengths of the two line segments ED and FC. That is,

$$\sigma = \frac{ED}{FC} . \qquad (A.1)$$

The line segment FC is the radius of the latitude circle passing through C and is equal to $\rho \cos \varphi$, where ρ is the mean radius of the earth. It easily can be shown that the length of the line segment ED, which is the radius of the latitude circle on the image plane, is equal to $\rho(1 + \cos \Psi_o) \tan \frac{\Psi}{2}$, where Ψ is the co-latitude. Thus,

$$\sigma = \frac{\rho(1 + \cos \Psi_o) \tan (\frac{\Psi}{2})}{\rho \cos \varphi} = \frac{1 + \sin \varphi_o}{1 + \sin \varphi} . \qquad (A.2)$$

The variation of the image scale factor with latitude is shown in figure A2. The radius of any latitude circle on the image plane also may be expressed as

$$r = \rho \, \sigma \cos \varphi . \qquad (A.3)$$

A polar stereographic map can be constructed by introducing the map scale, m. This reduction scale is constant for the entire map and is usually printed on the chart (e.g., 1:10,000,000). It is defined by the ratio

$$m = \frac{\text{Distance on map}}{\text{Distance on image plane}} .$$

Thus the radius of a latitude circle on the map is given by

$$R = m \rho \sigma \cos \varphi . \tag{A.4}$$

On a polar stereographic map, lines of constant latitude are concentric circles about the pole, of radius R. Lines of constant longitude are straight lines radiating from the pole and are spaced at the same angular increment on the map as on the earth.

a. Space coordinates and finite-difference space coordinates

The simplest rectangular coordinate system on the image plane that one could choose is described below. It is convenient to put the origin of the coordinate system (x,y) at the north pole. Then, on the image plane,

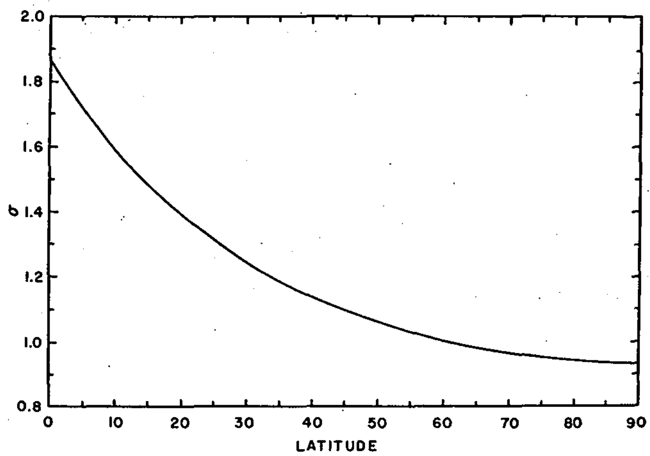

Figure A2. Image scale variation with latitude on the polar stereographic map projection with standard parallel at 60 deg.

$$x = r \cos \lambda = \rho \sigma \cos \varphi \cos \lambda ,$$
$$y = r \sin \lambda = \rho \sigma \cos \varphi \sin \lambda , \tag{A.5}$$

where λ is the deviation (λ_o - longitude of point) of longitude from the standard longitude, λ_o. The x-axis lies along the chosen standard longitude line onthe image plane and the y-axis is along the east-west direction at the point of intersection of the y-axis with the standard longitude line. The coordinate system is illustrated in figure A3.

The latitude and deviation of longitude of a point (x,y) can be calculated according to

$$\varphi = \frac{\pi}{2} - 2 \tan^{-1} \left[\frac{(x^2 + y^2)^{\frac{1}{2}}}{\rho (1 + \sin \varphi_o)} \right]$$
$$\lambda = \tan^{-1} [y/x] . \tag{A.6}$$

The above expressions for the space coordinates can be evaluated at equally spaced points on a rectangular grid. A constant space increment Δ (i.e., constant on the image plane) is chosen so that the finite difference formulae for the cartesian coordinates may be written as

$$x = (i - 1)\,\Delta + x_o, \; i = 1, 2, \text{----}I \,,$$
$$y = (j - 1)\,\Delta + y_o, \; j = 1, 2, \text{----}J \,. \qquad (A.7)$$

Here we have allowed for the arbitrary translation of the origin of the coordinate system by including the numbers x_o and y_o in the formulas.

b. Velocity components on the image plane

The velocity components, U and V, are related to the observed wind velocity by

$$U = -\,C \sin \alpha \,,$$
$$V = -\,C \cos \alpha \,, \qquad (A.8)$$

where C is the magnitude of the horizontal wind velocity and α is the observed wind direction. This is illustrated in figure A4.

The velocity components along the x- and y-axes of the previously described rectangular coordinate system are u and v, respectively. Figure A5 reveals that these components are related to U and V by

$$u = -U \sin \lambda - V \cos \lambda \,,$$
$$v = U \cos \lambda - V \sin \lambda \,. \qquad (A.9)$$

Substitution for U and V in (A.9) from (A.8) yields

$$u = C \cos(\lambda - \alpha) = \sigma^{-1} \dot{x} \,, \qquad (A.10)$$
$$v = C \sin(\lambda - \alpha) = \sigma^{-1} \dot{y} \,,$$

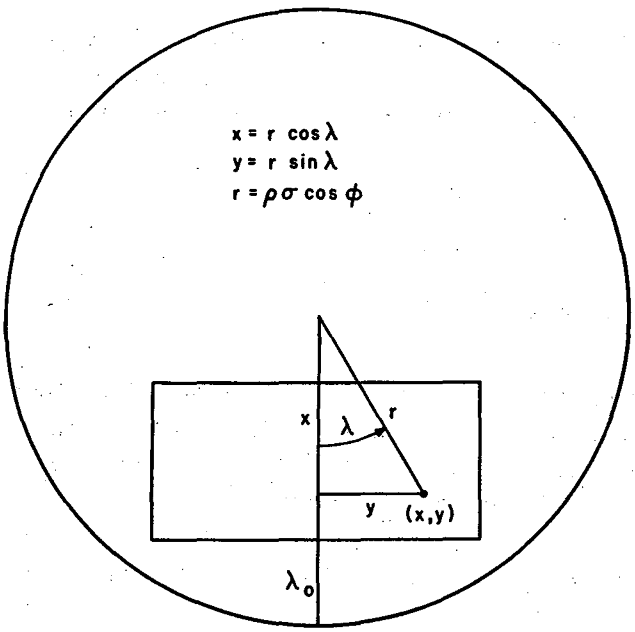

Figure A3. The image plane for the polar stereographic map projection. The computational grid is oriented so that the y-axis is perpendicular to the standard longitude, λ_o.

where $\dot{x}$ and $\dot{y}$ are velocity components along the x- and y-axes on the image plane, i.e., distance on the image plane per unit time.

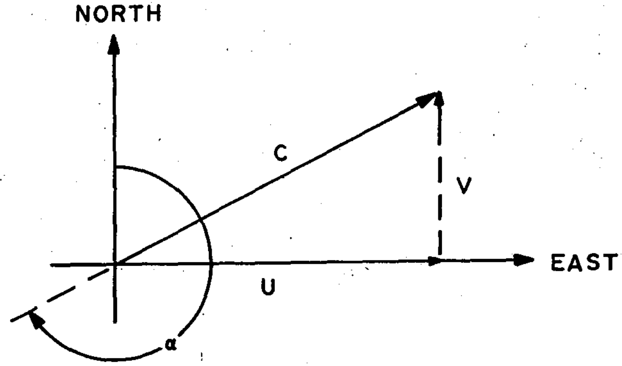

Figure A4. East-west and north-south components of the horizontal wind velocity.

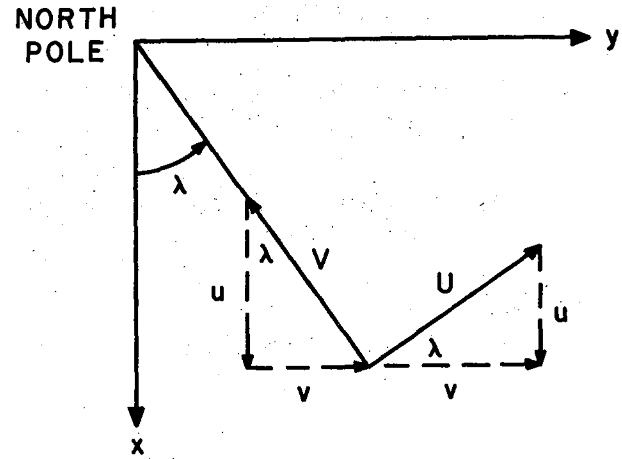

Figure A5. Relation of velocity components (u,v) to the east-west and north-south components of the horizontal wind.

APPENDIX B

Use of Objective Analysis Routines and Program Lists

This appendix contains listings of several FORTRAN subroutines utilized for various objective analyses on the CDC 3100 computer at NSSFC, Kansas City, Missouri. PROGRAM SAMPLE which utilizes some of the routines, is also included. All analysis routines do not have the same features; the user should add those he desires or delete those not needed. Subroutines included in this summary are:

OBAN - This is a general purpose routine to be used when the analysis of a single scalar field is desired.

TOBAN - This routine is similar to OBAN; it provides for economical analysis of two fields, simultaneously.

HOBAN - This routine should be used for constant pressure height analyses; observed heights and winds are used in the analysis.

BOBAN - This routine is similar to OBAN except that the data must be sorted; this routine should be used when surface data is to be analyzed because it is much more efficient than OBAN. A listing of BOBAN is given on pages 62 through 65 of this report.

SORTOB - This subroutine sorts data in the desired manner for use in BOBAN. A listing of this subroutine is given on pages 61 and 62 of this report.

SMOOTH - This is one of many smoothing operators that may be used with the analysis routines.

CONTUR - This is a sample output routine that prints analyzed values at grid points and contours the field (shading).

NAP2 - This is a sample program for printing station values on the U. S. map issued at NSSFC.

MOBAN - This objective analysis procedure fits a first degree polynomial to the five observations that are nearest to a grid point.

Parameters and Arrays Used in Objective Analysis Routines

Upon entry to most of the analysis routines the following must be in COMMON.

NOS	- number of observations
NI	- number of grid points along x-axis
NJ	- number of grid points along y-axis
NIMI	- NI - 1
NJMI	- NJ - 1
NOP	- number of scans employed in analysis (NOP.LE.6)

Distances on the map are measured in hundredths of an inch.

IDX	- distance between grid points along x-axis on map
IDY	- distance between grid points along y-axis on map
IXO	- value of x at upper left-hand corner grid point
IYO	- value of y at upper left-hand corner grid point
IXFO	- value of x for bottom row of grid points
IYFO	- value of y for right-hand side column of grid points
IR(NOP)	- radii of influence

IXGP(NI)	- values of x at grid points at successively higher values of x
IXGP(NJ)	- values of y at grid points at successively higher values of y
IX(NOS)	- values of x at locations of observations
IY(NOS)	- values of y at locations of observations
IU(NOS)	- x-component of observed wind
IV(NOS)	- y-component of observed wind
IM(NOS)	- magnitudes of observed wind squared
JX(NI, NJ)	- previously analyzed x-component of wind
JY(NI, NJ)	- previously analyzed y-component of wind

The following arrays contain the data and the results of the analysis and are usually not in COMMON.

1st field

IZX(NOS)	- contains observation
ICA(NOS)	- contains latest analysis at location of observation
IZH(NOS)	- deviation, i.e., IZX - ICA
IZGX(NI, NJ)	- analyzed field using data stored in IZX

2nd field

IZY(NOS)	- contains observation
JCA(NOS)	- contains latest analysis at location of observation
IZJ(NOS)	- deviation, i.e., IZY - JCA
IZGY(NI, NJ)	- analyzed field using data stored in IZY

```
      PROGRAM SAMPLE
C     PROGRAM READS DATA FROM NSSFC RAOB DATA TA+E AND PERFORMS ANALYSIS
C     OF 500-MB WIND, HEIGHT AND TEMPERATURE FIELDS
C     OUTPUT ON NSSFC MAP NO. 15P93
      COMMON NI,NJ,NIM1,NJM1,IDX,IDY,IXO,IYO,IXFO,IYFO,IXGP(21),IYGP(27)
      COMMON NOS,NOP,IR(6)
      COMMON ICA(86),IZH(86),ICALL(86),JCALL(86),IZGE(21,27)
      COMMON IX(86),IY(86),IU(86),IV(86),IM(86),JX(21,27),JY(21,27)
      COMMON JCA(86),IZJ(86),LU(86),LV(86)
      DIMENSION IZX(86),IZGX(21,27),IZY(86),IZGY(21,27)
      DIMENSION DATE(4),DATA(150),SDATE(4)
      DIMENSION NSTN(86),ID(86),IS(86)
      DIMENSION ITH(6),ITT(6),ITV(6)
      DIMENSION LB(9),L1(9),L2(9),L3(9),L4(9),L5(9),L6(9),L7(9),L8(9),
     *  L9(9),LL(9)
      INTEGER DATE,DATA,SDATE
      COMMON/DATA/KALP(16)
      DATA((KALP(I),I=1,16)=1H ,1HA,1H ,1HA,1H ,1HA,1H ,1HA,1H ,1HA,1H ,
     *  1HA,1H ,1HA,1H ,1HA)
      READ 1001,NI,NJ,NOP,IXO,IYO,(IR(L),L=1,6),IDX,IDY,JJJ
 1001 FORMAT(16I5)
C     TOSS OUT CRITERIA FOR HEIGHT8 TEMPERATURE AND WIND ANALYSES
      READ 275,ITH,ITT,ITV
  275 FORMAT(6I5)
C     LABELS FOR OUTPUT
      READ 721,LB,L1,L2,L3,L4,L5,L6,L7,L8,L9,LL
  721 FORMAT (9A4)
      NIM1=NI-1
      NJM1=NJ-1
C     CALCULATION OF GRID COORDINATES
      DO 65 I=1,NI
   65 IXGP(I)=IXO+(I-1)*IDX
      DO 66 J=1,NJ
   66 IYGP(J)=IYO+(J-1)*IDY
      IXFO=IXGP(NI)
      IYFO=IYGP(NJ)
C     CONSTANTS FOR CONVERTING FROM DEGREES TO RADIANS
      DTR=.0174532925
      DDTR=.0174532925E-3
C     READ NSSFC RAOB DATA TAPE
      WRITE(59,723)
  723 FORMAT (26H MOUNT RAOB DATA TAPE, LU3    )
      PAUSE 777
      REWIND 3
  250 READ 1002,SDATE
 1002 FORMAT(4A4)
      IF(SDATE(1).EQ.4H9999)9999,200
C     SEARCH RAOB TAPE
  200 READ (3) DATE
      IF(DATE(1).EQ.9999) 202,204
  202 WRITE(59,206) SDATE
  206 FORMAT(4A4,50H NOT ON RAOB TAPE, MOUNT CORRECT TAPE ON 3, HIT GO )
      REWIND 3  $  PAUSE 111   $   REWIND 3   $   GO TO 200
  204 IF(DATE(1).NE.SDATE(1).OR.DATE(2).NE.SDATE(2).OR.DATE(3).NE.
     *  SDATE(3).OR.DATE(4).NE.SDATE(4)) 823,300
  823 READ(3)
      GO TO (200,823),EOFCKF(3)
C     DATA LOCATED, PROCEED TO PROCESS
```

```
  300 NOS=0
      GO TO(2070, 1) SSWTCHF(1)
 2070 PRINT 900,DATE
  900 FORMAT(1H1,4A4,/)
    1 READ (3) DATA
      GO TO (50,304),EOFCKF(3)
  304 JPP=DATA(150)
      NOS=NOS+1
      IF(DATA(150).LE.500)17000,306
  306 IZX(NOS)=32767
      IZY(NOS)=32767
      GO TO 17100
17000 IF(DATA(22).NE.32767) 501,507
  507 IZX(NOS)=32767
      GO TO 503
  501 IZX(NOS)=DATA(22)-5500
  503 IF(DATA(23).NE.32767) 505,509
  509 IZY(NOS)=32767
      GO TO 17100
  505 IZY(NOS)=DATA(23)
C     CALCULATION OF X- AND Y-COORDINATES FOR STATION
17100 PHI=DATA(145)*DDTR
C     DEVIATION OF LONGITUDE FROM 110 DEG
      E=(110000-DATA(146))*DDTR
C     IMAGE SCALE FACTOR
      SIGMA=1.8660254/(1.+SIN(PHI))
      RA=1672.282*SIGMA*COS(PHI)
C     X- AND Y-COORDINATES OF STATION
      IX(NOS)=RA*COS(E)
      IY(NOS)=RA*SIN(E)
      NSTN(NOS)=DATA(1)
      ID(NOS)=DATA(25)
      IS(NOS)=DATA(26)
      IF(DATA(25).EQ.32767.OR.DATA(26).EQ.32767) 10,310
C     CALCULATION OF X- AND Y-COMPONENTS OF WIND VELOCITY
  310 DR=E-DATA(25)*DTR
      MAG=10*DATA(26)
C     STATION WIND COMPONENTS
      IU(NOS)=MAG*COS(DR)
      IV(NOS)=MAG*SIN(DR)
      IM(NOS)=MAG*MAG
C    CALCULATION OF X- AND Y-COMPONENTS OF HEIGHT GRADIENT FROM OBSERVED
C     WIND
C     HEIGHT GRADIENTS CALCULATED FROM WINDS
      SP=(0.315/SIGMA)*SIN(PHI)
      LU(NOS)=-SP*IU(NOS)
      LV(NOS)=SP*IV(NOS)
      GO TO 1
   10 IU(NOS)=32767
      IV(NOS)=32767
      IM(NOS)=32767
      LU(NOS)=32767
      LV(NOS)=32767
      IF(NOS.EQ.86) 50,1
   50 GO TO(2050,2060) SSWTCHF(1)
 2050 PRINT 901,(K,NSTN(K),IX(K),IY(K),IZX(K),IZY(K),ID(K),IS(K),IU(K),
     *  IV(K),LU(K),LV(K), K=1,NOS)
  901 FORMAT(1H ,12I10)
```

```
2060 WRITE (59,650)
 650 FORMAT(25H MOUNT UXUS MAP, 10 LPI       )
     PAUSE 7
C     PLOT HEIGHTS AND TEMPERATURES
     CALL NAP2(IX,IY,NOS,IZX,IZY,LB,DATE)
C     PLOT WIND DIRECTION AND SPEED
     CALL NAP2(IX,IY,NOS,ID,IS,L1,DATE)
C     PLOT X- AND Y- WIND COMPONENTS
     CALL NAP2(IX,IY,NOS,IU,IV,L2,DATE)
     WRITE (59,653)
 653 FORMAT(7H 6 LPI    )
     PAUSE 7
C     WIND ANALYSIS (REGULAR WEIGHT FUNCTION)
     CALL TOBAN(IU,JX,IV,JY,0,ITV)
     CALL CONTUR(JX,NI,NJ,0,50,DATE,L3)
     CALL CONTUR(JY,NI,NJ,0,50,DATE,L4)
     DO 220 J=1,NJ
     DO 220 I=1,NI
 220 IZGE(I,J)=SQRT(FLOAT(JX(I,J)*JX(I,J)+JY(I,J)*JY(I,J)  )   )
     CALL CONTUR(IZGE,NI,NJ,0,50,DATE,L5)
C     WIND ANALYSIS (SPECIAL WEIGHT FUNCTION)
     CALL TOBAN(IU,IZGX,IV,IZGY,1,ITV)
     CALL CONTUR(IZGX,NI,NJ,0,50,DATE,L6)
     CALL CONTUR(IZGY,NI,NJ,0,50,DATE,L7)
     DO 230 J=1,NJ
     DO 230 I=1,NI
 230 IZGE(I,J)=SQRT(FLOAT(IZGX(I,J)*IZGX(I,J)+IZGY(I,J)*IZGY(I,J)  )   )
     CALL CONTUR(IZGE,NI,NJ,0,50,DATE,L8)
C     HEIGHT ANALYSIS
     CALL HOBAN(IZX,IZGX,ITH)
     CALL CONTUR(IZGX,NI,NJ,0,25,DATE,L9)
C     TEMPERATURE ANALYSIS
     CALL OBAN(IZY,IZGY,1,ITT)
     CALL CONTUR(IZGY,NI,NJ,0,50,DATE,LL)
     GO TO 250
9999 REWIND 3
     PAUSE 77
     END
```

```
      SUBROUTINE OBAN(IZX,IZGX,JJJ,IOUT)
C     ...ONE FIELD SCHEME WITH MISSING DATA PROVISION
C     ...JJJ=-1, STATION WIND VELOCITY USED
C     ...JJJ= 0, SKIP SPECIAL FORMULATION
C     ...JJJ= 1, ANALYZED WIND VELOCITY AT GRID POINTS USED
C     ...MISSING DATA INDICATED BY 32767 IN IZX,IU,IV,AND IM
C     ...IZX HOLDS OBS AND IS UNCHANGED
C     ...IZX SHOULD HAVE MAGNITUDE LESS THAN 1000
C     ...IZH HOLDS DEVIATION (OBSERVATION MINUS ANALYZED VALUE)
C     ...ICA HOLDS ANALYZED VALUE OF EACH STATION
C     ...IZGX HOLDS ANALYZED VALUE AT GRID POINTS
C     ...IX X-COORDINATE OF OBS STN (MEASURED IN UNITS OF 1/100 INCH)
C     ...IY Y-COORDINATE OF OBS STN (MEASURED IN UNITS OF 1/100 INCH)
C     ...IU HOLDS X-COMPONENT OF WIND VELOCITY
C     ...IV HOLDS Y-COMPONENT OF WIND VELOCITY
C     ...IM HOLDS SQUARE OF WIND SPEED
C     ...JX AND JY HOLD ANALYZED U,V COMP. OF WIND (NEEDED ONLY IFJJJ=1)
C     ...IOUT HOLDS TOSS-OUT CRITERIA
      COMMON NI,NJ,NIM1,NJM1,IDX,IDY,IXO,IYO,IXFO,IYFO,IXGP(21),IYGP(27)
      COMMON NOS,NOP,IR(6)
      COMMON ICA(86),IZH(86),ICALL(86),JCALL(86),IZGE(21,27)
      COMMON IX(86),IY(86),IU(86),IV(86),IM(86),JX(21,27),JY(21,27)
      COMMON JCA(86),IZJ(86),LU(86),LV(86)
      DIMENSION IZX(86),IZGX(21,27),IOUT(6)
      DO 2 I=1,NI
      DO 2 J=1,NJ
    2 IZGX(I,J)=0
      NNS=2
C  A CONSTANT RADIUS OF NR IS USED FOR STN OUTSIDE GRID ON ALL SCANS.
      NR=300
      NR2=NR*NR
C  LOCATES GRID SQUARE CONTAINING OBSERVATION STATION
      DO 50 K=1,NOS
      IF(IX(K)-IXO)16,17,18
   18 IF(IX(K)-IXFO)17,16,16
   17 IF(IY(K)-IYO)16,15,19
   19 IF(IY(K)-IYFO)15,16,16
C     ...STATION IS OUTSIDE GRID
   16 ICALL(K)=999
      GO TO 50
   15 ICALL(K)=1+(IX(K)-IXO)/IDX
      JCALL(K)=1+(IY(K)-IYO)/IDY
   50 CONTINUE
C  INITIALIZATION OF ARRAYS FOR GRID
      DO 4 K=1,NOS
      ICA(K)=0
    4 IZH(K)=IZX(K)
      DO 199 L=1,NOP
      KR=IR(L)
      IR2=KR*KR
C  ON SCAN 1 INITIAL GUESS IS PRODUCED
      IF(L-1) 123,23,123
C  INTERPOLATION OF ANALYSIS TO OBSERVATION LOCATION (SCANS 2,3, AND 4)
  123 DO 22 K=1,NOS
      IF(IZX(K)-32767)10022,22,22
10022 IXK=IX(K)
      IYK=IY(K)
      IF(ICALL(K)-999)52,516,52
```

```
C       CALCULATE DEVIATION AT STATION WHEN STATION IS OUTSIDE GRID
  516  IA1=0
       IA2=0
       DO 524  I= 1,NOS
       IF(IZX(I)-32767)10524,524,10524
10524  M1=IXK-IX(I)
       IF  (IABS(M1)-NR)  525,524,524
  525  M2=IYK-IY(I)
       IF  (IABS(M2)-NR)  526,524,524
  526  M3=M1*M1+M2*M2
       IB1=NR2-M3
       IF(IB1)524,524,536
C   SPECIAL FORMULATION (WEIGHT FUNCTION MODIFIED ACCORDING TO WIND VEL)
  536  IF(JJJ)636,736,836
  636  IF(M3)3736,736,3736
 3736  IF(IM(I)-32767)5736,736,1736
 5736  IF(IM(I))1736,736,1736
 1736  D=IU(I)*M1+IV(I)*M2
       LR2=   (1.+(D*D/(FLOAT(M3)*IM(I))))*NR2
       GO TO 438
  836  IF(M3)4736,736,4736
 4736  IF(IM(K)-32767)6736,736,2736
 6736  IF(IM(K))2736,736,2736
 2736  D=IU(K)*M1+IV(K)*M2
       LR2=   (1.+(D*D/(FLOAT(M3)*IM(K))))*NR2
  438  IB1=LR2-M3
       B2=LR2+M3
       GO TO 936
C      ...LAST OF SPECIAL FORMULATION
  736  B2=NR2+M3
  936  KW=(IB1/B2)*100
       IA1=IA1+KW*IZH(I)
       IA2=IA2+KW
  524  CONTINUE
       ICA(K)=(ICA(K)+IA1/IA2+IZX(K))/2
       GO TO 22
C   CALCULATION OF DEVIATION WHEN STATION IS WITHIN GRID
C   BILINEAR INTERPOLATION USING FOUR GRID POINTS SURROUNDING THE STN.
   52  M=ICALL(K)
       N=JCALL(K)
       M1=IXK-IXGP(M)
       M2=IYK-IYGP(N)
       IZ1=IZGX(M,N)
       IZ2=IZGX(M,N+1)
       IZ4=IZGX(M+1,N)
       ICA(K)=IZ1+((M1*(IZ4-IZ1))/IDX+(M2*(IZ2-IZ1))/IDY+
      1 (((M1*M2)/IDX)*(IZGX(M+1,N+1)-IZ4+IZ1-IZ2))/IDY)
   22  CONTINUE
       DO 950  K=1,NOS
       IZH(K)=IZX(K)-ICA(K)
       IF(IZH(K)-32767)10948,950,10948
10948  IF(IABS(IZH(K))-IOUT(L))950,950,10950
10950  WRITE(59,10946)  IX(K),IY(K),L,IZX(K),IZH(K),IOUT(L)
10946  FORMAT(1H-,8HDATA AT ,2I10,2X,17HREJECTED ON PASS ,I1,2X,
      *  4HIZX=I5,2X,4HIZH=I5,2X,5HIOUT=I5)
       IZX(K)=32767
       IZH(K)=32767
       ICA(K)=0
```

```
  950 CONTINUE
C   CALCULATION OF CORRECTION TO GRID POINT VALUE
   23 DO 198 J=1,NJ
      IYK=IYGP(J)
      DO 198 I=1,NI
      JR=KR
      JR2=IR2
      IXK=IXGP(I)
      IF (JJJ) 1136,1136,1336
 1336 JU=JX(I,J)
      JV=JY(I,J)
      V=JU*JU+JV*JV
 1136 IA1=0
      IA2=0
      NN=0
      DO 24 K=1,NOS
      IF(IZX(K)-32767)10024,24,10024
10024 M1=IX(K)-IXK
      IF(IABS(M1)-JR)25,24,24
   25 M2=IY(K)-IYK
      IF(IABS(M2)-JR)26,24,24
   26 M3=M1*M1+M2*M2
      IB1=JR2-M3
      IF(IB1)24,24,36
C   SPECIAL FORMULATION (WEIGHT FUNCTION MODIFIED ACCORDING TO WIND VEL)
   36 IF(JJJ)136,236,336
  336 IF(V)3236,236,3236
 3236 IF(M3)1236,236,1236
 1236 D=JU*M1+JV*M2
      LR2=  (1.+(D*D/(V*M3)))*JR2
  138 IB1=LR2-M3
      B2=LR2+M3
      GO TO 436
  136 IF(M3)4236,236,4236
 4236 IF(IM(K)-32767)5236,236,2236
 5236 IF(IM(K))2236,236,2236
 2236 D=IU(K)*M1+IV(K)*M2
      LR2=  (1.+(D*D/(FLOAT(M3)*IM(K))))*JR2
      GO TO 138
C     ...LAST OF SPECIAL FORMULATION CARDS
  236 B2=JR2+M3
  436 KW=(IB1/B2)*100
      IA1=IA1+KW*IZH(K)
      IA2=IA2+KW
      NN=NN+1
   24 CONTINUE
C   TWO STN ARE REQUIRED WITHIN JR ON THE FIRST SCAN ONLY
      IF(NN-NNS)398,201,201
  201 IF(NN-1)198,202,200
C     NO STATIONS WITHIN JR - INCREASE JR AND TRY AGAIN
  398 JR=JR+IDX
      JR2=JR*JR
      GO TO 1136
  200 IF(IA2)398,398,27
  202 IA2=100
   27 IZGX(I,J)=IZGX(I,J)+IA1/IA2
  198 CONTINUE
      NNS=0
```

```
      CALL SMOOTH(IZGX,IZGE)
  199 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE TOBAN(IZX,IZGX,IZY,IZGY,JJJ,IOUT)
C     ...DUE TO ERROR CHECKING PROCEDURES THIS VERSION SHOULD ONLY BE
C     ... USED FOR ANALYSIS OF THE WIND FIELD
C     ...TWO FIELD SCHEME WITH MISSING DATA PROVISION
C     ...JJJ=-1, STATION WIND VELOCITY USED
C     ...JJJ= 0, SKIP SPECIAL FORMULATION
C     ...JJJ= 1, ANALYZED WIND VELOCITY AT GRID POINTS USED
C     ...MISSING DATA INDICATED BY 32767 IN IZX,ZIY,IU,IV,AND IM
C     ...IZX,IZY HOLD OBS AND ARE UNCHANGED
C     ...IZX,IZY SHOULD HAVE MAGNITUDE LESS THAN 1000
C     ...IZH,IZJ HOLD DEVIATION (OBSERVATION MINUS ANALYZED VALUE)
C     ...ICA,JCA HOLD ANALYZED VALUES OF EACH STATION
C     ...IZGX,IZGY HOLD ANALYZED VALUES AT GRID POINTS
C     ...IX X-COORDINATE OF OBS STN (MEASURED IN UNITS OF 1/100 INCH)
C     ...IY Y-COORDINATE OF OBS STN (MEASURED IN UNITS OF 1/100 INCH)
C     ...IU HOLDS X-COMPONENT OF WIND VELOCITY
C     ...IV HOLDS Y-COMPONENT OF WIND VELOCITY
C     ...IM HOLDS SQUARE OF WIND SPEED
C     ...JX AND JY HOLD ANALYZED U,V COMP. OF WIND (NEEDED ONLY IFJJJ=1)
C     ...IOUT HOLDS TOSS OUT CRITERIA
      COMMON NI,NJ,NIM1,NJM1,IDX,IDY,IXO,IYO,IXFO,IYFO,IXGP(21),IYGP(27)
      COMMON NOS,NOP,IR(6)
      COMMON ICA(86),IZH(86),ICALL(86),JCALL(86),IZGE(21,27)
      COMMON IX(86),IY(86),IU(86),IV(86),IM(86),JX(21,27),JY(21,27)
      COMMON JCA(86),IZJ(86),LU(86),LV(86)
      DIMENSION IZX(86),IZGX(21,27),IZY(86),IZGY(21,27),IOUT(6)
      NNS=2
      DO 2 I=1,NI
      DO 2 J=1,NJ
      IZGX(I,J)=0
    2 IZGY(I,J)=0
C   A CONSTANT RADIUS OF NR IS USED FOR STN OUTSIDE GRID ON ALL SCANS.
      NR=300
      NR2=NR*NR
C   LOCATES GRID SQUARE CONTAINING OBSERVATION STATION
      KNT=0
      DO 50 K=1,NOS
      IF(IX(K)-IXO)16,17,18
   18 IF(IX(K)-IXFO)17,16,16
   17 IF(IY(K)-IYO)16,15,19
   19 IF(IY(K)-IYFO)15,16,16
C     ...STATION IS OUTSIDE GRID
   16 ICALL(K)=999
      KNT=KNT+1
      GO TO 50
   15 ICALL(K)=1+(IX(K)-IXO)/IDX
      JCALL(K)=1+(IY(K)-IYO)/IDY
   50 CONTINUE
      KNT=NOS-KNT
C   INITIALIZATION OF ARRAYS FOR GRID
      DO 4 K=1,NOS
      JCA(K)=0
      IZJ(K)=IZY(K)
      ICA(K)=0
    4 IZH(K)=IZX(K)
      DO 199 L=1,NOP
      KR=IR(L)
      IR2=KR*KR
```

```
C   ON SCAN 1 INITIAL GUESS IS PRODUCED
        IF(L-1) 123,23,123
C   INTERPOLATION OF ANALYSIS TO OBSERVATION LOCATION (SCANS 2,3, AND 4)
  123 DO 22 K=1,NOS
        IXK=IX(K)
        IYK=IY(K)
        IF(ICALL(K)-999)52,516,52
C       CALCULATE DEVIATION AT STATION WHEN STATION IS OUTSIDE GRID
  516 IA1=0
        ID1=0
        IA2=0
        ID2=0
        DO 524 I= 1,NOS
        M1=IXK-IX(I)
        IF(IABS(M1)-NR)525,524,524
  525 M2=IYK-IY(I)
        IF(IABS(M2)-NR)526,524,524
  526 M3=M1*M1+M2*M2
        IB1=NR2-M3
        IF(IB1)524,524,536
C   SPECIAL FORMULATION (WEIGHT FUNCTION MODIFIED ACCORDING TO WIND VEL)
  536 IF(JJJ)636,736,836
  636 IF(M3)3736,736,3736
 3736 IF(IM(I)-32767)5736,736,1736
 5736 IF(IM(I))1736,736,1736
 1736 D=IU(I)*M1+IV(I)*M2
      LR2=   (1.+(D*D/(FLOAT(M3)*IM(I))))*NR2
      GO TO 438
  836 IF(M3)4736,736,4736
 4736 IF(IM(K)-32767)6736,736,2736
 6736 IF(IM(K))2736,736,2736
 2736 D=IU(K)*M1+IV(K)*M2
      LR2=   (1.+(D*D/(FLOAT(M3)*IM(K))))*NR2
  438 IB1=LR2-M3
      B2=LR2+M3
      GO TO 936
C       ...LAST OF SPECIAL FORMULATION
  736 B2=NR2+M3
  936 KW=(IB1/B2)*100
      IF(IZX(I)-32767)610,608,610
  610 IA1=IA1+KW*IZH(I)
      IA2=IA2+KW
  608 IF(IZY(I)-32767)611,524,611
  611 ID1=ID1+KW*IZJ(I)
      ID2=ID2+KW
  524 CONTINUE
      IF(IZX(K)-32767)613,609,613
  613 ICA(K)=(ICA(K)+IA1/IA2+IZX(K))/2
  609 IF(IZY(K)-32767)614,22,614
  614 JCA(K)=(JCA(K)+ID1/ID2+IZY(K))/2
      GO TO 22
C   CALCULATION OF DEVIATION WHEN STATION IS WITHIN GRID
C   BILINEAR INTERPOLATION USING FOUR GRID POINTS SURROUNDING THE STN.
   52 M=ICALL(K)
      N=JCALL(K)
      M1=IXK-IXGP(M)
      M2=IYK-IYGP(N)
      IF(IZX(K)-32767)615,607,615
```

```
  615 IZ1=IZGX(M,N)
      IZ2=IZGX(M,N+1)
      IZ4=IZGX(M+1,N)
      ICA(K)=IZ1+((M1*(IZ4-IZ1))/IDX+(M2*(IZ2-IZ1))/IDY+
     1 (((M1*M2)/IDX)*(IZGX(M+1,N+1)-IZ4+IZ1-IZ2))/IDY)
  607 IF(IZY(K)-32767)616,22,616
  616 KZ1=IZGY(M,N)
      KZ2=IZGY(M,N+1)
      KZ4=IZGY(M+1,N)
      JCA(K)=KZ1+((M1*(KZ4-KZ1))/IDX+(M2*(KZ2-KZ1))/IDY+(((M1*M2)/IDX)*
     1(IZGY(M+1,N+1)-KZ4+KZ1-KZ2))/IDY)
   22 CONTINUE
      DO 950 K=1,NOS
      IZJ(K)=IZY(K)-JCA(K)
      IZH(K)=IZX(K)-ICA(K)
      IF(IZH(K)-32767)10948,950,10948
10948 IF(IABS(IZH(K))-IOUT(L))10944,10944,10950
10944 IF(IABS(IZJ(K))-IOUT(L))950,950,10950
10950 WRITE(59,10946)IX(K),IY(K),L,IZX(K),IZY(K),IZH(K),IZJ(K),IOUT(L)
10946 FORMAT(     8HDATA AT ,2I10,2X,17HREJECTED ON PASS ,I1, 2X,/5X,
     *  4HIZX=I5,2X,4HIZY=I5,   4HIZH=I5,2X,4HIZJ=I5,2X,5HIOUT=I5)
      IM(K)=32767
      IZX(K)=32767
      IZY(K)=32767
      IZH(K)=32767
      IZJ(K)=32767
      ICA(K)=0
      JCA(K)=0
  950 CONTINUE
C   CALCULATION OF CORRECTION TO GRID POINT VALUE
   23 DO 198 J=1,NJ
      IYK=IYGP(J)
      DO 198 I=1,NI
      IXK=IXGP(I)
      JR=KR
      JR2=IR2
      IF(JJJ)1136,1136,1336
 1336 JU=JX(I,J)
      JV=JY(I,J)
      V=JU*JU+JV*JV
 1136 IA1=0
      ID1=0
      IA2=0
      ID2=0
      MM=0
      NN=0
      DO 24 K=1,NOS
      M1=IX(K)-IXK
      IF(IABS(M1)-JR)25,24,24
   25 M2=IY(K)-IYK
      IF(IABS(M2)-JR)26,24,24
   26 M3=M1*M1+M2*M2
      IB1=JR2-M3
      IF(IB1)24,24,36
C   SPECIAL FORMULATION (WEIGHT FUNCTION MODIFIED ACCORDING TO WIND VEL)
   36 IF(JJJ)136,236,336
  336 IF(V)3236,236,3236
 3236 IF(M3)1236,236,1236
```

```
 1236 D=JU*M1+JV*M2
      LR2=   (1.+(D*D/(V*M3)))*JR2
  138 IB1=LR2-M3
      B2=LR2+M3
      GO TO 436
  136 IF(M3)4236,236,4236
 4236 IF(IM(K)-32767)5236,236,2236
 5236 IF(IM(K))2236,236,2236
 2236 D=IU(K)*M1+IV(K)*M2
      LR2=   (1.+(D*D/(FLOAT(M3)*IM(K))))*JR2
      GO TO 138
C    ...LAST OF SPECIAL FORMULATION CARDS
  236 B2=JR2+M3
  436 KW=(IB1/B2)*100
      IF(IZX(K)-32767)602,603,602
  602 IA1=IA1+KW*IZH(K)
      IA2=IA2+KW
      NN=NN+1
  603 IF(IZY(K)-32767)604,24,604
  604 ID1=ID1+KW*IZJ(K)
      ID2=ID2+KW
      MM=MM+1
   24 CONTINUE
      IF(NNS)300,200,300
C   NO STN. ARE REQUIRED WITHIN JR
  200 IF(NN-1)201,202,203
  203 IF(IA2)204,201,204
  202 IA2=100
  204 IZGX(I,J)=IZGX(I,J)+IA1/IA2
  201 IF(MM-1)198,212,213
  213 IF(ID2)214,198,214
  212 ID2=100
      GO TO 214
C   NNS STN. ARE REQUIRED WITHIN JR
  300 IF(NN-NNS)398,301,301
  301 IF(MM-NNS)398,302,302
C       NO STATIONS WITHIN JR - INCREASE JR AND TRY AGAIN
  398 JR=JR+IDX
      JR2=JR*JR
      GO TO 1136
  302 IF(IA2)303,398,303
  303 IF(ID2)304,398,304
  304 IZGX(I,J)=IZGX(I,J)+IA1/IA2
  214 IZGY(I,J)=IZGY(I,J)+ID1/ID2
  198 CONTINUE
      NNS=0
      CALL SMOOTH(IZGX,IZGE)
      CALL SMOOTH(IZGY,IZGE)
  199 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE HOBAN(IZX,IZGX,IOUT)
C     ...ONE FIELD SCHEME WITH MISSING DATA PROVISION
C     ...MISSING DATA INDICATED BY 32767 IN IZX,IU,IV
C     ...IZX HOLDS OBS AND IS UNCHANGED
C     ...IZX SHOULD HAVE MAGNITUDE LESS THAN 1000 (CDC 3100-FIXED POINT
C     ARITHMETIC)
C     ...IZH HOLDS DEVIATION (OBSERVATION MINUS ANALYZED VALUE)
C     ...ICA HOLDS ANALYZED VALUE OF EACH STATION
C     ...IZGX HOLDS ANALYZED VALUE AT GRID POINTS
C     ...IX X-COORDINATE OF OBS STN (MEASURED IN UNITS OF 1/100 INCH)
C     ...IY Y-COORDINATE OF OBS STN (MEASURED IN UNITS OF 1/100 INCH)
C     ...LU HOLDS X-COMPONENT OF HEIGHT GRADIENT
C     ...LV HOLDS Y-COMPONENT OF HEIGHT GRADIENT
C     ...IOUT HOLDS TOSS-OUT CRITERIA
      COMMON NI,NJ,NIM1,NJM1,IDX,IDY,IXO,IYO,IXFO,IYFO,IXGP(21),IYGP(27)
      COMMON NOS,NOP,IR(6)
      COMMON ICA(86),IZH(86),ICALL(86),JCALL(86),IZGE(21,27)
      COMMON IX(86),IY(86),IU(86),IV(86),IM(86),JX(21,27),JY(21,27)
      COMMON JCA(86),IZJ(86),LU(86),LV(86)
      DIMENSION MMB(4),IZX(86),IZGX(21,27),IOUT(6)
      MMB(1)=1
      MMB(2)=1
      MMB(3)=2
      MMB(4)=4
C     GRID POINTS ARE ASSIGNED VALUE OF ZERO INITIALLY
      DO 2 I=1,NI
      DO 2 J=1,NJ
    2 IZGX(I,J)=0
      NNS=2
C  A CONSTANT RADIUS OF NR IS USED FOR STN OUTSIDE GRID ON ALL SCANS.
      NR=300
      NR2=NR*NR
C  LOCATES GRID SQUARE CONTAINING OBSERVATION STATION
      DO 50 K=1,NOS
      IF(IX(K)-IXO)16,17,18
   18 IF(IX(K)-IXFO)17,16,16
   17 IF(IY(K)-IYO)16,15,19
   19 IF(IY(K)-IYFO)15,16,16
C     ...STATION IS OUTSIDE GRID
   16 ICALL(K)=999
      GO TO 50
   15 ICALL(K)=1+(IX(K)-IXO)/IDX
      JCALL(K)=1+(IY(K)-IYO)/IDY
   50 CONTINUE
C  INITIALIZATION OF ARRAYS FOR GRID
      DO 4 K=1,NOS
      ICA(K)=0
    4 IZH(K)=IZX(K)
      DO 199 L=1,NOP
      MB=MMB(L)
      KR=IR(L)
      IR2=KR*KR
C  ON SCAN 1 INITIAL GUESS IS PRODUCED
      IF(L-1) 123,23,123
C  INTERPOLATION OF ANALYSIS TO OBSERVATION LOCATION (SCANS 2,3, AND 4)
  123 DO 22 K=1,NOS
      IXK=IX(K)
      IYK=IY(K)
```

```
      IF(ICALL(K)-999)52,516,52
C     CALCULATE DEVIATION AT STATION WHEN STATION IS OUTSIDE GRID
  516 IF(IZX(K)-32767)10516,22,9999
10516 IA1=0
      IA2=0
      DO 524 I= 1,NOS
      IF(IZX(I)-32767)10524,524,10524
10524 M1=IXK-IX(I)
      IF (IABS(M1)-NR) 525,524,524
  525 M2=IYK-IY(I)
      IF (IABS(M2)-NR) 526,524,524
  526 M3=M1*M1+M2*M2
      IB1=NR2-M3
      IF(IB1)524,524,736
  736 B2=NR2+M3
      KW=(IB1/B2)*100
      IA1=IA1+KW*IZH(I)
      IA2=IA2+KW
  524 CONTINUE
      ICA(K)=(ICA(K)+IA1/IA2+IZX(K))/2
      GO TO 22
C  CALCULATION OF DEVIATION WHEN STATION IS WITHIN GRID
C  BILINEAR INTERPOLATION USING FOUR GRID POINTS SURROUNDING THE STN.
   52 M=ICALL(K)
      N=JCALL(K)
      M1=IXK-IXGP(M)
      M2=IYK-IYGP(N)
      IZ1=IZGX(M,N)
      IZ2=IZGX(M,N+1)
      IZ4=IZGX(M+1,N)
      ICA(K)=IZ1+((M1*(IZ4-IZ1))/IDX+(M2*(IZ2-IZ1))/IDY+
     1 (((M1*M2)/IDX)*(IZGX(M+1,N+1)-IZ4+IZ1-IZ2))/IDY)
   22 CONTINUE
      DO 950 K=1,NOS
      IF(IZX(K)-32767)1950,950,1950
 1950 IZH(K)=IZX(K)-ICA(K)
      IF(IABS(IZH(K))-IOUT(L))950,950,10950
10950 WRITE(59,10946) IX(K),IY(K),L,IZX(K),IZH(K),IOUT(L)
10946 FORMAT(1H-,8HDATA AT ,2I10,2X,17HREJECTED ON PASS ,I1,2X,4HIZX=I5,
     *  2X,4HIZH=I5,2X,5HIOUT=I1)
      IZX(K)=32767
      IZH(K)=32767
  950 CONTINUE
C  CALCULATION OF CORRECTION TO GRID POINT VALUE
   23 DO 198 J=1,NJ
      IYK=IYGP(J)
      DO 198 I=1,NI
      JR=KR
      JR2=IR2
      IXK=IXGP(I)
 1136 JA1=0
      JA2=0
      NNJ=0
      KA1=0
      KA2=0
      NNK=0
      IA1=0
      IA2=0
```

```
      NN=0
      DO 24 K=1,NOS
      IF(L-1)13001,13001,13002
13001 IF(IZX(K)-32767)10024,24,10024
13002 IF(IZX(K)-32767)10024,94,10024
   94 IF(LU(K)-32767)10024,24,10024
10024 M1=IX(K)-IXK
      IF(IABS(M1)-JR)25,24,24
   25 M2=IY(K)-IYK
      IF(IABS(M2)-JR)26,24,24
   26 M3=M1*M1+M2*M2
      IB1=JR2-M3
      IF(IB1)24,24,236
  236 B2=JR2+M3
      KW=(IB1/B2)*100
C     THREE POSSIBILITIES ARE CONSIDERED
C     STATION WITH HEIGHT ONLY          (I)
C     STATION WITH WIND ONLY            (J)
C     STATION WITH HEIGHT AND WIND      (K)
      IF(L-1)15008,15008,14999
14999 IF(IZX(K)-32767)15000,15002,15000
15000 IF(LU(K)-32767)15006,15008,15006
15002 IF(LU(K)-32767)15004,24,15004
C     STATION WITH WIND ONLY  (J)
15004 JA1=JA1+KW*(ICA(K)-(LV(K)*M1+LU(K)*M2)/100-IZGX(I,J))
      JA2=JA2+KW
      NNJ=NNJ+1
      GO TO 24
C     STATION WITH WIND AND HEIGHT  (K)
15006 KA1=KA1+KW*(IZX(K)-(LV(K)*M1+LU(K)*M2)/100-IZGX(I,J))
      KA2=KA2+KW
      NNK=NNK+1
      GO TO 24
C     STATION WITH HEIGHT ONLY  (I)
15008 IA1=IA1+KW*IZH(K)
      IA2=IA2+KW
      NN=NN+1
   24 CONTINUE
      IF(L-1)9999,10201,11201
11201 NN=NN+NNJ+NNK
C  TWO STN ARE REQUIRED WITHIN JR ON THE FIRST SCAN ONLY
10201 IF(NN-NNS)398,201,201
  201 IF(NN-1)198,202,200
C     NO STATIONS WITHIN JR - INCREASE JR AND TRY AGAIN
  398 JR=JR+IDX
      JR2=JR*JR
      GO TO 1136
  202 IA2=100
      IA1=IA1+JA1+KA1
      GO TO 27
  200 IA2=IA2+JA2*MB+8*KA2
      IF(IA2)398,398,17202
17202 IA1=IA1+JA1*MB+8*KA1
   27 IZGX(I,J)=IZGX(I,J)+IA1/IA2
  198 CONTINUE
      NNS=0
      CALL SMOOTH(IZGX,IZGE)
  199 CONTINUE
```

```
9999 RETURN
     END
```

```
      SUBROUTINE SMOOTH(JW,IUX)
      DIMENSION JW(21,27),IUX(21,27)
      COMMON NI,NJ,NIM1,NJM1,IDX,IDY,IXO,IYO,IXFO,IYFO,IXGP(21),IYGP(27)
      DO 10 J=2,NJM1
      DO 10 I=2,NIM1
   10 IUX(I,J)=(4*JW(I,J)+JW(I-1,J)+JW(I,J+1)+JW(I+1,J)+JW(I,J-1))/8
      DO 15 J=1,NJ,NJM1
      DO 15 I=2,NIM1
   15 IUX(I,J)=(2*JW(I,J)+JW(I-1,J)+JW(I+1,J))/4
      DO 20 I=1,NI,NIM1
      DO 20 J=2,NJM1
   20 IUX(I,J)=(2*JW(I,J)+JW(I,J-1)+JW(I,J+1))/4
      IUX(1,1)=JW(1,1)
      IUX(1,NJ)=JW(1,NJ)
      IUX(NI,1)=JW(NI,1)
      IUX(NI,NJ)=JW(NI,NJ)
      DO 25 J=1,NJ
      DO 25 I=1,NI
   25 JW(I,J)=IUX(I,J)
      RETURN
      END
```

```
      SUBROUTINE CONTUR(IZ,NI,NJ,MIN,INT,DATE,LB)
C     ...PRINTS STANDARD NI X NJ GRID WITH CONTOURING BETWEEN LINES
C     ...MIN IS THE MINIMUM VALUE, INT IS THE CONTOURING INTERVAL
C     ...NJ MUST BE.LE.26
      COMMON/DATA/KALP(16)
      DIMENSION IZ(21,27),DATE(4),LB(9)
      DIMENSION           LINE(126),LIN(26)
      INTEGER DATE
      LTOT=INT*16
      NJM=NJ-1
      DO 20 I=1,11
   20 PRINT 22
   22 FORMAT(1H )
      NJM=NJ-1
      NIM=NI-1
      NUM=5*NJ-4
      PRINT 900,(IZ(1,J),J=1,NJ)
  900 FORMAT(3X,26I5)
      DO 1 IR=2,NI
      DO 2 JD=1,2
      DO 3 L=1,NJ
    3 LIN(L)=((IZ(IR,L)-IZ(IR-1,L))*JD)/3+IZ(IR-1,L)
      K=1
      DO 4 J=1,NJM
      LINJ=LIN(J)
      LINE(K)=LINJ
      NDZ=LIN(J+1)-LINJ
      DO 5 L=1,4
      K=K+1
    5 LINE(K)=(NDZ*L)/5+LINJ
      K=K+1
    4 CONTINUE
      LINE(K)=LIN(NJM)
      DO 6 L=1,NUM
      JDF=LINE(L)-MIN
    7 IF(JDF)8,9,9
    8 JDF=JDF+LTOT
      GO TO 7
    9 J=JDF/INT
      IS=J-(J/16)*16+1
    6 LINE(L)=KALP(IS)
      PRINT 901,(LINE(L),L=1,NUM)
  901 FORMAT(7X,126A1)
    2 CONTINUE
      PRINT 900,(IZ(IR,J),J=1,NJ)
    1 CONTINUE
      PRINT 26,DATE,LB
   26 FORMAT(1H-,4A4,2X,9A4)
      DO 24 I=1,9
   24 PRINT 22
      RETURN
      END
```

```
      SUBROUTINE NAP2(IX,IY,NOS,IDR,ISP,LB,KATE)
C  PRINTS STATION VALUES ON US MAP
C  TO USE * ENTRY   POSITION MAP AT STANDARD POSITION. SET PRINTER AT
C                   10 LPI. AND CALL THIS SUBR.
C           EXIT    MAP IS LEFT AT STANDARD MAP POS
C  RESULTS * PRINTS 3 DIGITS AND SIGN OF IDR AND ISP TO THE LEFT AND
C                   RIGHT OF A STATION ASTERISK.  ALLOWED RANGE IS -999
C                   TO +999. S$$$ IS INSERTED IF OUTSIDE RANGE
C     FORM  SXXX*SXXX
C     MISSING DATA INDICATED BY 32767
      DIMENSION IX(86),IY(86),IDR(86),ISP(86),LINE(135)
      DIMENSION IT(86),IS(86)
      CHARACTER LINE
      DIMENSION LB(9),KATE(4)
      IXC=770  $  IYC=-380
      DO 1 L=1,NOS
      IS(L)=(IX(L)-IXC)/10
    1 IT(L)=(IY(L)-IYC)/10
      DO 4 IR=1,120
      DO 3 L=1,135
    3 LINE(L)=60B
      DO 5 I=1,NOS
      IF(IR.EQ.IS(I))6,5
    6 K=IT(I)
      IF(K.LT.1.OR.K.GT.135) 5,930
  930 IF(K.LT.5)30,31
   30 K=5 $ GO TO 32
   31 IF(K.GT.131)34,32
   34 K=131
   32 JJ=IABS(IDR(I))
      IF(JJ.GT.999)20,21
   20 IF(JJ.EQ.32767)7,420
  420 NH=NT=NU=53B $ GO TO 22
   21 NH=JJ/100 $ NX=JJ-NH*100 $ NT=NX/10 $ NU=NX-NT*10
   22 IF(NH.EQ.0)53,55
   53 IF(NT.EQ.0)54,56
   55 LINE(K-3)=NH
   56 LINE(K-2)=NT
   54 LINE(K-1)=NU
      IF(IDR(I))57,7,7
   57 KS=K
   58 KS=KS-1
      IF(LINE(KS).NE.60B)58,59
   59 LINE(KS)=40B
    7 JJ=IABS(ISP(I))
      IF(JJ.GT.999)23,24
   23 IF(JJ.EQ.32767)424,423
  424 IF(IDR(I).EQ.32767)5,425
  423 NH=NT=NU=53B $ GO TO 62
   24 NH=JJ/100 $ NX=JJ-NH*100 $ NT=NX/10 $ NU=NX-NT*10
   62 LINE(K)=54B
      IF(ISP(I))61,60,60
   61 LINE(K+1)=40B
      K=K+1
   60 IF(NH.EQ.0)9,10
    9 K=K-1
      IF(NT.EQ.0)11,12
   11 K=K-1
```

```
      GO TO 13
   10 LINE(K+1)=NH
   12 LINE(K+2)=NT
   13 LINE(K+3)=NU
      GO TO 5
  425 LINE(K)=54B
    5 CONTINUE
      PRINT 901,LINE
  901 FORMAT(1H ,135R1)
    4 CONTINUE
      PRINT 902,KATE,LB
  902 FORMAT(1H ,4A4,5X,9A4)
      DO 600 I=1,19
  600 PRINT 903
  903 FORMAT(1H )
      RETURN
      END
```

```
      SUBROUTINE MOBAN (IX,IY,IZX,IZGX,IU,IV,IM,NOS,JJJ)
C     MANCUSO METHOD - OBJECTIVE ANALYSIS
C     ONE FIELD VERSION
C     THE FIVE NEAREST STATIONS ARE USED
C     THE STARTING RADIUS IS INCREASED BY IDX UNTIL FIVE STNS ARE
C       FOUND
      COMMON NI,NJ,NIM1,NJM1,IDX,IDY,IXO,IYO,IXFO,IYFO,IXGP(21),IYGP(27)
      DIMENSION IX(86),IY(86),IZX(86),IZGX(21,27),IU(86),IV(86),IM(86)
      DIMENSION MD(20),MK(20)
C     REAP'S COEF.
      CSQ=16893.0
      IDXT=IDX+IDX
      DO 2 J=1,NJ
      IYK=IYGP(J)
      DO 2 I=1,NI
      IXK=IXGP(I)
C     NOTE ** A1 IS SET TO 0.05
      A1=0.05
      A2=0.0
      A3=0.0
      B2=0.0
      B3=0.0
      C3=0.0
      D1=0.0
      D2=0.0
      D3=0.0
      KR=200
   20 IR2=KR*KR
      N=0
      DO 4 K=1,NOS
      IF(IZX(K)-32767)5,4,5
    5 M1=IX(K)-IXK
      IF(IABS(M1)-KR)6,4,4
    6 M2=IY(K)-IYK
      IF(IABS(M2)-KR)8,4,4
    8 M3=M1*M1+M2*M2
      IF(M3-IR2)10,4,4
   10 N=N+1
      MD(N)=M3
      MK(N)=K
    4 CONTINUE
      IF(N-5)12,14,22
C     FEWER THAN FIVE STNS.
   12 IF(N)18,18,16
   18 KR=KR+IDXT
      GO TO 20
   16 KR=KR+IDX
      GO TO 20
C     MORE THAN FIVE STNS. FOUND.  SORT INTO INCREASING DIST (M3)
   22 DO 24 K=1,5
      LS=K+1
      MDX=MD(K)
      MDK=K
      DO 26 L=LS,N
      IF(MDX-MD(L))26,26,28
   28 MDX=MD(L)
      MDK=L
   26 CONTINUE
```

```
      IF(MDK-K)27,24,27
   27 MD(MDK)=MD(K)
      MD(K)=MDX
      NSV=MK(K)
      MK(K)=MK(MDK)
      MK(MDK)=NSV
   24 CONTINUE
   14 DO 30 KK=1,5
      K=MK(KK)
      M1=IX(K)-IXK
      M2=IY(K)-IYK
      M3=MD(KK)
      IOB=IZX(K)
      IF(JJJ)32,34,32
   34 W=CSQ/(M3+CSQ)
      GO TO 36
   32 IF(IM(K)-32767)38,34,40
   38 IF(IM(K))40,34,40
   40 RS=IABS(M1*IV(K)-M2*IU(K))
      CR=SQRT(FLOAT(M3))+RS/SQRT(FLOAT(IM(K)))
      W=CSQ/(CR*CR+CSQ)
   36 A1=A1+W
      WM1=M1*W
      WM2=M2*W
      A2=A2+WM1
      A3=A3+WM2
      B2=B2+M1*WM1
      B3=B3+M1*WM2
      C3=C3+M2*WM2
      D1=D1+W*IOB
      D2=D2+WM1*IOB
      D3=D3+WM2*IOB
   30 CONTINUE
C     ADD IN LOW WEIGHTED GRID PT. VALUE
      Z=D1/A1
      D1=D1+0.05*Z
      E1=B2*C3-B3*B3
      E2=A2*C3-B3*A3
      E3=A2*B3-B2*A3
      D=A1*E1-A2*E2+A3*E3
      IF(D)42,44,42
   44 IZGX(I,J)=Z
      GO TO 2
   42 IZGX(I,J)=(D1*E1-D2*E2+D3*E3)/D
    2 CONTINUE
      RETURN
      END
```

APPENDIX C

Location of Radiosonde and Upper Wind Data on NSSFC Magnetic Tape, February 1, 1968

This data is written on magnetic tape in binary mode. The data for each station is an integer array of 150 words and is one logical record. Upon completion of all stations for a given time, there is an end-of-file mark.

The following applies:

Missing data	77777B = 32767
Temperature	Tenths of degrees
Dew point	Same as temperature
Pressure	Whole millibars
Height	Mandatory level heights in meters. There is one exception; the height of maximum wind is in feet
Wind direction	Meteorological angles to nearest 5 degrees, e.g., 290 or 295
Wind velocity	Knots

The date-time group is 4 words long, each word containing 4 BCD characters. This date-time group is written on magnetic tape in binary mode and it constitutes one logical record. It precedes the entry of the first station and its format is

06Z 15 Dec 1967

with the hour given in Greenwich time. If Date (4) is an integer array, then

Date (1) = 00067160B
Date (2) = 01056024B
Date (3) = 25236001B
Date (4) = 11060760B

9999 in Date (1) indicates end of information on that tape.

The contents of the integer array Data (150) is as follows:

Data (1)---Station identifier, 72456
Data (2)---Surface pressure
Data (3)---Surface temperature
Data (4)---Surface dew point
Data (5)---Surface wind direction
Data (6)---Surface wind speed
Data (7)---1000 mb height
Data (8)---1000 mb temperature
Data (9)---1000 mb dew point
Data (10)---1000 mb wind direction
Data (11)---1000 mb wind speed
Data (12)---850 mb height
Data (13)---850 mb temperature
Data (14)---850 mb dew point
Data (15)---850 mb wind direction
Data (16)---850 mb wind speed
Data (17)---700 mb height
Data (18)---700 mb temperature
Data (19)---700 mb dew point
Data (20)---700 mb wind direction
Data (21)---700 mb wind speed
Data (22)---500 mb height
Data (23)---500 mb temperature
Data (24)---500 mb dew point
Data (25)---500 mb wind direction
Data (26)---500 mb wind speed
Data (27)---400 mb height
Data (28)---400 mb temperature
Data (29)---400 mb dew point
Data (30)---400 mb wind direction
Data (31)---400 mb wind speed
Data (32)---300 mb height
Data (33)---300 mb temperature
Data (34)---300 mb dew point
Data (35)---300 mb wind direction
Data (36)---300 mb wind speed
Data (37)---250 mb height
Data (38)---250 mb temperature
Data (39)---250 mb dew point
Data (40)---250 mb wind direction
Data (41)---250 mb wind speed
Data (42)---200 mb height
Data (43)---200 mb temperature
Data (44)---200 mb dew point
Data (45)---200 mb wind direction
Data (46)---200 mb wind speed
Data (47)---150 mb height
Data (48)---150 mb temperature
Data (49)---150 mb dew point
Data (50)---150 mb wind direction
Data (51)---150 mb wind speed
Data (52)---100 mb height
Data (53)---100 mb temperature
Data (54)---100 mb dew point
Data (55)---100 mb wind direction
Data (56)---100 mb wind speed
Data (57)---Pressure at tropopause
Data (58)---Temperature at tropopause
Data (59)---Print coordinates for NSSFC upper air map
Data (60)---Wind direction at tropopause
Data (61)---Wind speed at tropopause
Data (62)---Height of maximum wind (in feet)
Data (63)---Wind direction of maximum wind
Data (64)---Wind speed of maximum wind
Data (65)---Top indicator for max wind (=60B if not top, otherwise = 63B)
Data (66)---Significant level no. 1
Data (67)---Temperature
Data (68)---Dew point
Data (69)---Significant level no. 2
Data (70)---Temperature
Data (71)---Dew point
Data (72)---Significant level no. 3
Data (73)---Temperature
Data (74)---Dew point
Data (75)---Significant level no. 4
Data (76)---Temperature
Data (77)---Dew point
Data (78)---Significant level no. 5
Data (79)---Temperature

Data (80)---Dew point
Data (81)---Significant level no. 6
Data (82)---Temperature
Data (83)---Dew point
Data (84)---Significant level no. 7
Data (85)---Temperature
Data (86)---Dew point
Data (87)---Significant level no. 8
Data (88)---Temperature
Data (89)---Dew point
Data (90)---Significant level no. 9
Data (91)---Temperature
Data (92)---Dew point
Data (93)---Significant level no. 10
Data (94)---Temperature
Data (95)---Dew point
Data (96)---Significant level no. 11
Data (97)---Temperature
Data (98)---Dew point
Data (99)---Significant level no. 12
Data (100)---Temperature
Data (101)---Dew point
Data (102)---Significant level no. 13
Data (103)---Temperature
Data (104)---Dew point
Data (105)---Significant level no. 14
Data (106)---Temperature
Data (107)---Dew point
Data (108)---Significant level no. 15
Data (109)---Temperature
Data (110)---Dew point
Data (111)---Surface wind direction
Data (112)---Surface wind speed
Data (113)---1000 foot wind direction
Data (114)---1000 foot wind speed
Data (115)---2000 foot wind direction
Data (116)---2000 foot wind speed
Data (117)---3000 foot wind direction
Data (118)---3000 foot wind speed
Data (119)---4000 foot wind direction
Data (120)---4000 foot wind speed
Data (121)---6000 foot wind direction
Data (122)---6000 foot wind speed
Data (123)---7000 foot wind direction
Data (124)---7000 foot wind speed
Data (125)---8000 foot wind direction
Data (126)---8000 foot wind speed
Data (127)---9000 foot wind direction
Data (128)---9000 foot wind speed
Data (129)---12000 foot wind direction
Data (130)---12000 foot wind speed
Data (131)---14000 foot wind direction
Data (132)---14000 foot wind speed
Data (133)---16000 foot wind direction
Data (134)---16000 foot wind speed
Data (135)---20000 foot wind direction
Data (136)---20000 foot wind speed
Data (137)---25000 foot wind direction
Data (138)---25000 foot wind speed
Data (139)---30000 foot wind direction
Data (140)---30000 foot wind speed
Data (141)---35000 foot wind direction
Data (142)---35000 foot wind speed
Data (143)---50000 foot wind direction
Data (144)---50000 foot wind speed
Data (145)---Latitude x 1000
Data (146)---Longitude x 1000
Data (147)---Station height in meters
Data (148)---Deviation from longitude 100 deg. in radians x 10E5
Data (149)---Image scale factor x 10E4
Data (150)---Top of hydrostatic check in mbs

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OBJECTIVE ANALYSIS OF MEAN MOISTURE ALOFT UTILIZING RADIOSONDE AND SURFACE DATA

A procedure of objective analysis for the mean mixing ratio in the 100 mb layer adjacent to the earth's surface utilizes radiosonde data and surface observations of humidity. An estimation, based on the observed data, of the relationship between the surface mixing ratio and the mean mixing ratio in the 100 mb layer provides a bogus value of mean mixing ratio at the location of each surface station. These values are then used with the mean mixing ratios determined at each upper air station to produce the final objective analysis of the mean low-level moisture. The method incorporates procedures for the detection of errors in both surface and upper air data and is presently being used operationally at the National Severe Storm Forecast Center (NSSFC), Kansas City, Missouri.

1. INTRODUCTION

Determination of the three dimensional distribution of moisture in the atmosphere is of prime importance in the prediction of precipitation. The problem is extremely acute in the forecasting of areas where severe thunderstorms are most likely to occur. An effort must be made to predict thunderstorm events on a smaller scale than is normally possible with upper air data alone. Since the precipitable water in a column in the atmosphere is highly correlated with the surface dew-point, temperature severe thunderstorm forecasters have long used the surface dew point to aid in the delineation of areas where severe convective activity is likely to develop.

This note describes a simple method of utilizing surface humidity observations to better define the field of mean mixing ratio in the lowest 100 mb layer of the atmosphere. The objective analysis utilizes both surface data and radiosonde data.

2. RELATIONSHIPS BETWEEN SURFACE HUMIDITY AND VERTICALLY INTEGRATED MOISTURE

In the past few years several investigators have attempted to find linear relationships between the natural logarithm of precipitable water in a column and the surface dew-point temperature. Reitan (1963) determined a linear correlation of 0.98 between the logarithm of mean monthly total precipitable water and mean monthly surface dew point from a total of 540 observations. Bolsenga (1965) found correlation coefficients of 0.85 and 0.80 for mean daily and hourly observations, respectively. Lowry and Glahn (1969) collected a total of 33,134 1200 GMT observations, made at 56 U. S. stations east of the Rocky Mountains for the period December 1965 through November 1967. They determined multiple regression equations which relate the natural logarithm of precipitable water in the column between the surface and 500 mb, to surface dew-point temperature and 10 other variables. They found that when the data were stratified by month and dew point used as a specifier, a total of 83.9 per cent of the variance of the natural logarithm of precipitable water was explained. Another 2.7 per cent was explained by two additional variables, surface weather and total sky cover. The remaining predictors were shown to be of little additional value.

It is hardly surprising that the precipitable water in a column is highly correlated to surface dew-point temperatures since it is well known that an approximate expression of the form

$$\ln w_o = A + Bt_d \quad ,$$

can easily be derived by combining Tetens' (1930) empirical formula for vapor pressure with the definition of water vapor mixing ratio. Here w_o is surface mixing ratio and t_d is surface dew point. Thus, one can always expect the surface dew point and the mean mixing ratio, $\bar{w}$, in an atmospheric column to be highly correlated because (for almost any grouping of the data) there will be a dominant range of values of the ratio, $\bar{w}/w_o$. Stratification of the data should be accomplished to separate cases characterized by similar values of the ratio $k = \bar{w}/w_o$. Other investigators (Lowry and Glahn, 1969) have done this by stratifying the data by month, season, geographical location, etc., or by averaging the data over a period of time so that at least a portion of the variability of $\bar{w}/w_o$ is removed.

Smith (1966) derived a theoretical relationship between total precipitable water and surface dew-point temperature by assuming that the average decrease of moisture with height through the atmospheric column may be described by the power law

$$w = w_o \left(\frac{p}{p_o}\right)^{\lambda} \quad , \tag{1}$$

where w is mixing ratio, w_o is the mixing ratio at $p = p_o$, p is pressure and λ is a parameter. The mean mixing ratio in a vertical column in the atmosphere is

$$\bar{w} = \frac{1}{p_o} \int_0^{p_o} w_o \left(\frac{p}{p_o}\right)^{\lambda} dp = \frac{w_o}{\lambda + 1} \quad . \tag{2}$$

Since the total precipitable water in the column is related to the mean mixing ratio by

$$U = \frac{p_o}{g} \bar{w} \quad , \tag{3}$$

where g is the acceleration of gravity, Smith wrote the equation in the form

$$\begin{aligned} \ln U &= \ln\left(\frac{p_o}{g}\right) + \ln \bar{w} \\ &= \ln\left(\frac{p_o}{g}\right) - \ln(\lambda + 1) + \ln w_o . \end{aligned} \tag{4}$$

Of course w_o can be related to the surface dew-point temperature by use of Tetens' empirical formula (1930) for saturation vapor pressure and the definition of mixing ratio.

A better understanding of Smith's relationship can be obtained by transforming the equation to a slightly different form. Remembering that

$$(\lambda + 1)^{-1} = \frac{\bar{w}}{w_o} , \tag{5}$$

we see that the term $\ln(\lambda+1)$ in (4), the only one which depends on the vertical distribution of moisture in Smith's equation may be written simply as $\ln(\bar{w}/w_o)$. That is, if one desires to estimate mean moisture aloft from surface data, he simply should have information concerning the variability of $\bar{w}/w_o$. There is no need to be concerned with the parameter λ. If we write

$$\bar{w} = k\, w_o , \tag{6}$$

where k is an independent estimate of $\bar{w}/w_o$, we have a more sensible type of assumed relationship; note that this is equivalent to the type of relationship sought by the previously mentioned investigators. Here, however, we characterize the actual moisture profile with the realistic ratio k $(=\bar{w}/w_o)$ instead of a parameter associated with an assumed power law. Naturally we can expect that this ratio will vary considerably spatially as well as with time. It will also depend greatly on the synoptic situation, i.e., the type of air mass involved.

The variability of mean values of k can be illustrated by reexamining some of the previous work in this area. Here k is the ratio of the mean mixing ratio in the column between p_o and $p = 0$, to the mixing ratio at the surface. Smith (1966) presented a table showing the seasonal latitudinal mean values of the parameter λ defined in (1). Since $k = \bar{w}/w_o = (\lambda+1)^{-1}$, we can easily transform Smith's results to show variations of the mean values of k with season and latitude. Smith utilized mean Northern Hemisphere soundings tabulated by London (1957) in his evaluations of λ. The Northern Hemisphere averages were derived by weighting each latitude band equally.

Table 1. Seasonal and latitudinal mean values of $k = \overline{w}/w_o$ (after Smith, 1966).

Latitudinal Zone (deg N)	Winter	Spring	Summer	Fall	Annual Average
0–10	.23	.26	.26	.27	.26
10–20	.25	.25	.27	.25	.26
20–30	.22	.25	.25	.25	.24
30–40	.25	.24	.26	.25	.25
40–50	.27	.25	.27	.27	.26
50–60	.28	.25	.27	.25	.26
60–70	.36	.27	.28	.28	.29
70–80	.38	.37	.31	.28	.33
80–90	.47	.41	.34	.33	.38
Northern Hemisphere Average	.28	.27	.28	.27	.28

Table 1 shows that the seasonal and latitudinal variations of the mean values of k are rather insignificant in the low and middle latitudes. Very significant variations occur, however, in the latitude band, 60–90 deg N.

During the past several years NSSL has operated a mesonetwork of rawinsonde stations, usually during portions of the months of April, May and June. Most of these soundings were made during the period 1100 – 0300 CST. From data collected during 1966 and 1967, a total of 776 soundings have been processed for the purpose of investigating the variability of the ratio, $\overline{w}/w_o$, where $\overline{w}$ is the mean mixing ratio in the 100 mb layer adjacent to the surface of the earth, and w_o is the surface mixing ratio. Table 2 shows the frequency distribution of $\overline{w}/w_o$. Note that in over half of the soundings $\overline{w}/w_o$ has a value between 0.90 and 1.03 and in almost 80 per cent of the cases has a value between 0.83 and 1.10. In about 69 per cent of the soundings $\overline{w}$ is less than or equal to the surface value, w_o.

Table 2. Frequency distribution of $\overline{w}/w_o$ based on 1966–1967 data from NSSL rawinsonde network.

Class Interval, $\overline{w}/w_o$	f	%	Cum. Freq. (%)
.55 - .61	1	.13	.13
.62 - .68	7	.90	1.03
.69 - .75	17	2.19	3.22
.76 - .82	42	5.41	8.63
.83 - .89	114	14.69	23.32
.90 - .96	213	27.44	50.76
.97 - 1.03	196	25.26	76.02
1.04 - 1.10	96	12.37	88.39
1.11 - 1.17	48	6.19	94.58
1.18 - 1.24	30	3.87	98.45
1.25 - 1.31	6	.77	99.22
1.32 - 1.38	5	.64	99.86
1.39 - 1.45	0	.00	99.86
1.46 - 1.52	1	.13	100.00
	776		

3. ANALYSIS PROCEDURE

The analysis procedure is summarized as follows and detailed in following paragraphs:

a. Consistent values of surface mixing ratio, w_o, at radiosonde stations, are determined.

b. The mean mixing ratio in the lowest 100 mb layer at each radiosonde station is calculated and R ($=\overline{w}/w_o$) is computed, where w_o is the surface mixing ratio evaluated in the first step rather than the reported surface mixing ratio.

c. The distribution of R is defined objectively so that R may be estimated at each surface station.

d. A bogus value of $\overline{w}$ ($=Rw_o$) is computed for each surface station.

e. An objective analysis of $\overline{w}$ is performed utilizing the two sets of data, i.e., the observed values of $\overline{w}$ at radiosonde stations and the bogus values of $\overline{w}$ at surface stations.

The basic objective analysis method employed in this study is similar to that devised by Cressman (1959); the particular scheme, as well as others available for operational use at NSSFC, is described on pages 1 through 41. One modification has been added to facilitate its use for the analysis of moisture, i.e., the routine has been redesigned to use two sets of data of different reliability in a single analysis. Reports from the two sets are given different weights depending on their relative accuracy. Specifically, in the application of the successive approximations technique the correction made at the grid point (i, j) is

$$C_{i,j} = \frac{\sum_{k=1}^{K} W_k D_k + \alpha \sum_{m=1}^{M} W_m D_m}{\sum_{k=1}^{K} W_k + \alpha \sum_{m=1}^{M} W_m} , \qquad (7)$$

where W is the Cressman distance-dependent weight function, D is the deviation between the observation and the current analysis at the location of the report (interpolated) and α is the relative reliability factor of the second set of data.

An objective analysis of the field of surface mixing ratio, w_o, is first accomplished with observations of surface humidity from both surface stations and radiosonde stations. On each pass through the data, as the analysis is successively corrected, each piece of data, $\hat{Z}$, is compared with the current analysis, Z, at the location of the observing station. If $|Z - \hat{Z}|$ is greater than some predetermined number (different from each pass) the datum is assumed to be bad and is discarded. This technique requires a first approximation available at all grid points; in the analysis of the surface mixing ratio the first-guess field is assumed to be zero.

The analyzed values of surface mixing ratio are then utilized in the calculation of $R = \bar{w}/w_o$, where w_o is the interpolated surface mixing ratio at the upper air station and $\bar{w}$ is the mean mixing ratio in the lowest 100 mb layer at the upper air station. The calculation of $\bar{w}$ is defined by

$$\bar{w} = \frac{1}{100} \int_{P_s-100}^{P_s} w dp , \qquad (8)$$

where P_s is the surface pressure. The integral is evaluated with the trapezoidal rule utilizing significant level data from rawinsonde reports. If the value of R determined at a radiosonde station is greater than 1.25, R is set equal to 1.25; also, if the value is less than 0.5, R is set equal to 0.5. These arbitrary limits were placed on R to insure that the analysis would not be spoiled by an unrepresentative surface dew-point temperature. It is seldom necessary to make this adjustment.

Next an objective analysis of R is performed to provide estimates of R at each surface station. An initial guess of 0.9 at all grid points is used in this analysis. After this is completed, one could produce a final analysis of the mean mixing ratio by simply multiplying R at each grid point by the corresponding previously analyzed values of surface mixing ratio. In practice, however, it has been found to be desirable to control the influence of the surface data; thus, we have proceeded by first interpolating a value of R for each surface station. Then a bogus value of $\overline{w}$ ($=R\overline{w}_o$) is calculated for each surface station. At this point two sets of data are available; (1) the mean mixing ratios determined at each radiosonde station, and (2) the bogus values of $\overline{w}$ estimated for each surface station. Certainly the former set of data should be considered to be the most reliable. Consequently, the analysis scheme is designed so that the upper air data is given greater weight than the bogus values of mean mixing ratio. By proper adjustment of the relative weights assigned to the two sets of data, one can obtain a final analysis of the mean mixing ratio that reflects, to the degree desired, the smaller scale variations present in the surface data. For operational analysis at NSSFC the upper air data is given a weight three times that given to the bogus data.

4. APPLICATION OF THE ANALYSIS PROCEDURE

The area of analysis, shown in figure 1, is covered by a 21 x 27 grid which has a gridlength of approximately 68.5 n mi. Radiosonde stations in the United States also are shown in figure 1; the average distance between stations is about three times the gridlength. Roughly ten times as many surface stations as upper air reporting stations are positioned within the grid.

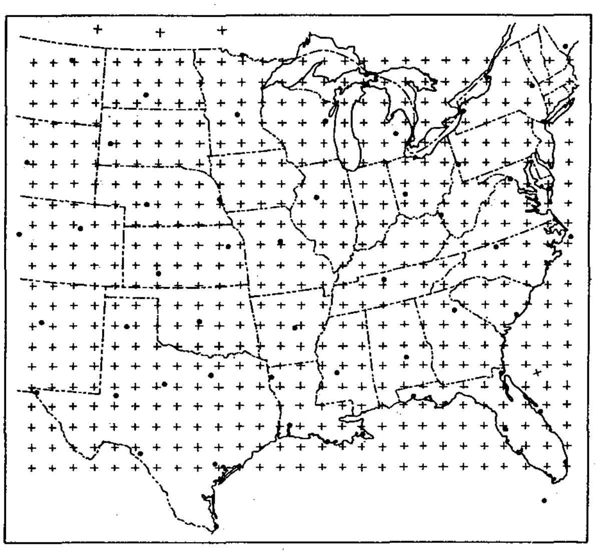

Figure 1. The area of analysis of the 21 x 27 grid. United States rawinsonde stations are shown by black dots.

The data employed include the radiosonde reports processed at the National Severe Storm Forecast Center; these data are checked for hydrostatic consistency (Inman, 1968) before they are stored on magnetic tape. Surface data from the surface observation network are placed on a separate magnetic tape.

An example of the analysis of R, the ratio of $\overline{w}$ to w_o, is shown in figure 2 for 00 GMT, April 4, 1968. Important features include a minimum in the field of R located in eastern Kansas to the west of the surface position of a cold front. (The surface map is shown in figure 3.) Also, a maximum in the field of R is located in southeastern Missouri east of the surface position of the cold front. The continuity of dominant features such as these is usually rather good as frontal systems move across the United States.

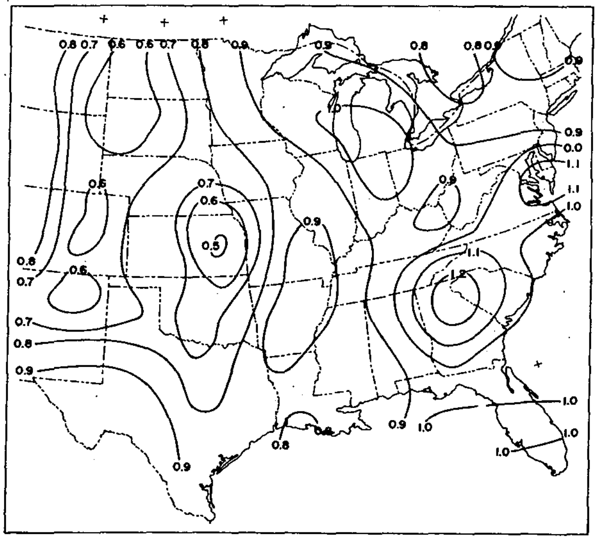

Figure 2. An example of the analysis of R, the ratio of mean mixing ratio, $\overline{w}$, to the surface mixing ratio, w_o. Data are for 00 GMT, April 4, 1968.

An example of the analysis of $\overline{w}$ obtained by the techniques described in the previous sections is shown in figure 4. A moist tongue extends from the Texas Gulf coast region northeastward through northern Louisiana and eastern Arkansas and then northward to southeastern Iowa. Similar configurations of the moisture field often develop as a low-level low-pressure system develops in the central United States. That is, a tongue of low-level moisture develops east of the surface front and usually extends northward and then northwestward around the surface position of the low-level Low.

Accurate determination of the position of the axis of such moist tongues is extremely important in severe thunderstorm forecasting. If an analysis of low-level moisture is attempted utilizing only radiosonde data, often the analysis is constructed so that the axis of the moist tongue passes through the location of one or more radiosonde stations. However, there is a strong probability that the axis should be located up to a hundred miles from the radiosonde station(s). Such errors may be particularly large when a radiosonde report happens to be missing in a critical location, i.e., in the vicinity of the true position of the moist axis. Obviously, by utilizing the surface observations as described in this report, one has a better change of accurately describing the low-level moisture field.

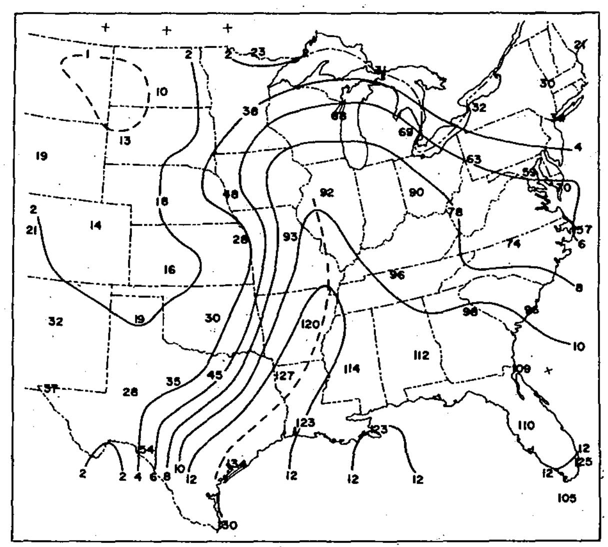

Figure 3. An example of the analysis of mean mixing ratio, $\overline{w}$, in the 100-mb thick surface layer. Values of $\overline{w}$ (10^{-1} gm kg^{-1}) are plotted at radiosonde stations. Data are for 00 GMT, April 4, 1968.

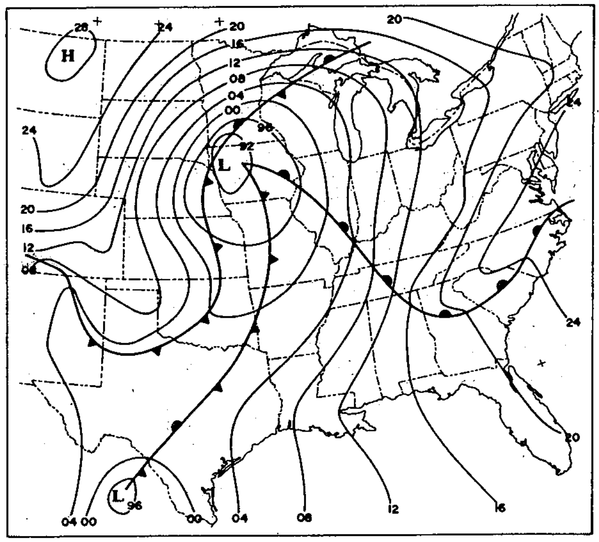

Figure 4. Surface map for 00 GMT, April 4, 1968.

APPENDIX

The listings of the FORTRAN programs which perform the described analyses are contained in this appendix. The programs are in the form necessary for use with the operating system on the CDC 3100 computer at NSSFC, Kansas City, Missouri. Because of the limited storage of the CDC 3100 it was necessary to separate the program into a main program and three overlays. Program MOIST is the main program; its purpose is simply to transfer control to one of the three overlay programs.

Program SFCDAT (OVERLAY 1) is called by MOIST to read surface data from the NSSFC data tape and to accomplish some preliminary processing of these data. No FORTRAN subroutine is called by this program.

Program UPDAT (OVERLAY 2) is called to read radiosonde data from the NSSFC Raob data tape and to analyze the surface mixing ratio, w_o. FORTRAN subroutines SORTOB and BOBAN are called by this program to analyze w_o.

Program FINAL (OVERLAY 3) is called to analyze the field of R ($=\overline{w}/w_o$), interpolate a value of R for each surface station, calculate a bogus value of $\overline{w}$ at each surface station and perform the objective analysis of $\overline{w}$ using the two sets of data, i.e., the observed $\overline{w}$'s and the bogus values. Several FORTRAN subroutines are called by this program. SORTOB and BOBAN are called to accomplish the objective analyses. PRTFLD is a simple output routine utilized to print analyzed values at grid points; no contouring is done. Subroutine MAPONE is called to print station values of $\overline{w}$ on the NSSFC sectional map. Subroutine CONTUR is called to print analyzed values at grid points and to contour the analyzed field. A listing of CONTUR is given on page 33 of this report.

```
      PROGRAM MOIST
C     ...CALCULATES AND OBJECTIVELY ANALYZES THE MEAN MIXING RATIO IN
C        THE LOWEST 100MB USING A COMBINATION OF UPPER AIR AND SFC
C        STATIONS
C     (1)  WBAR/WSFC IS CALCULATED AND ANALYZED USING UPPER AIR DATA
C     (2)  A VALUE OF THE RATIO IS INTERPOLATED FOR EACH SFC
C          STATION WITHIN THE GRID
C     (3)  WSFC IS CALCULATED FOR EACH SFC STATION
C     (4)  WBOGUS(BOGUS MEAN MIXING RATIO) = RATIO*WSFC
C     (5)  BOTH WBAR AND WBOGUS ARE ANALYZED
C     ...SENSE SWITCH 1 ON - PRINTS ANALYZED RATIO FIELD
C     ...SENSE SWITCH 2 ON - PRINTS INTERMEDIATE MIXING RATIOS,ETC FOR
C                            UPPER AIR STATIONS
C     ...SENSE SWITCH 3 ON - PRINTS INTERMEDIATE MIXING RATIOS,ETC
C                            FOR SFC STATIONS
C     ...SENSE SWITCH 4 ON - PRINTS WBAR USING RAOB DATA ONLY
C     ...SENSE SWITCH 5 ON - COMPUTES (WBAR)=(WZERO)(RATIO) PRINTS FLD
C     ...ORDER OF OVERLAYS * SFCDAT, UPDAT, FINAL
C     ...TAPES **** RAOB ON 2,  SFC ON 3
      COMMON NI,NJ,IDX,IDY,IXFO,IYFO,IXO,IYO,IXGP(21),IYGP(27)
      COMMON NWEG,NSFC,NRAOB,NOPSF,NOPUA,KOUT(4)
      COMMON DATE(4),SDATE(4),IRSF(4),IRUA(4),IX(485),IY(485),IZX(485)
      COMMON IZGY(21,27),IXS(86),IYS(86),IZXT(86),IXQ(86),IYQ(86),
     *  IZXQ(86)
      INTEGER DATE,SDATE
  100 CALL OVERLAY(1,0,55)
      CALL OVERLAY(2,0,55)
      CALL OVERLAY(3,0,55)
      PAUSE 7
      GO TO 100
      END
```

```
      PROGRAM SFCDAT
      DIMENSION DATA(2680),CDATA(10720)
      CHARACTER CDATA
      EQUIVALENCE(DATA,CDATA)
      INTEGER DATE,SDATE
      COMMON NI,NJ,IDX,IDY,IXFO,IYFO,IXO,IYO,IXGP(21),IYGP(27)
      COMMON NWEG,NSFC,NRAOB,NOPSF,NOPUA,KOUT(4)
      COMMON DATE(4),SDATE(4),IRSF(4),IRUA(4),IX(485),IY(485),IZX(485)
      COMMON/DATA/NLAT(536),NLONG(536),NALTC(536)
      DATA(( NLAT(I),I=  1, 86)=       55183, 54917, 55117, 53883, 54417,   NLAT  1
     *   54133, 53967, 53033, 53583, 53667, 52883, 53350, 53217, 51983,   NLAT  2
     *   52183, 52767, 52383, 50683, 52167, 52100, 50000, 51267, 51100,   NLAT  3
     *   50700, 50633, 51100, 49383, 49800, 49817, 54617, 49900, 50250,   NLAT  4
     *   50017, 49083, 49967, 50333, 49183, 50283, 49383, 50017, 49467,   NLAT  5
     *   49450, 49533, 48800, 49500, 49633, 49067, 47950, 48133, 48267,   NLAT  6
     *   47950, 48600, 48550, 47450, 48300, 48217, 48167, 46967, 47400,   NLAT  7
     *   47633, 46900, 47467, 46917, 47483, 46150, 46567, 47050, 46783,   NLAT  8
     *   46767, 46917, 46100, 46383, 45600, 46600, 46433, 45617, 45450,   NLAT  9
     *   45683, 44917, 45950, 45800, 44917, 45700, 44117, 44833, 45250)   NLAT 10
      DATA(( NLAT(I),I= 87,172)=       44383, 44267, 44767, 44383, 43417,   NLAT 11
     *   44517, 44050, 43567, 44050, 43583, 43967, 43567, 43517, 42367,   NLAT 12
     *   43050, 41783, 42917, 42833, 42583, 42150, 42917, 41983, 42917,   NLAT 13
     *   42817, 41783, 42533, 42050, 41433, 40983, 41317, 42167, 41867,   NLAT 14
     *   40967, 41800, 41133, 41317, 41600, 41100, 40600, 40900, 41183,   NLAT 15
     *   40150, 40833, 41300, 41150, 40517, 40617, 40733, 40217, 40767,   NLAT 16
     *   40067, 40167, 39133, 39500, 40183, 39100, 39950, 39383, 39767,   NLAT 17
     *   39367, 39650, 38867, 38517, 39283, 39383, 39600, 39117, 38817,   NLAT 18
     *   37733, 38283, 37767, 37367, 38067, 38433, 38417, 37933, 38050,   NLAT 19
     *   37367, 37367, 36583, 37700, 37700, 37450, 37250, 36767, 36683)   NLAT 20
      DATA(( NLAT(I),I=173,258)=       36300, 36333, 36750, 36750, 36017,   NLAT 21
     *   36083, 35350, 35683, 35417, 34900, 35617, 35650, 35233, 35000,   NLAT 22
     *   35183, 34583, 34567, 34750, 34650, 34867, 35133, 35167, 35050,   NLAT 23
     *   34433, 35017, 35100, 34433, 34767, 34200, 34650, 34383, 33933,   NLAT 24
     *   33933, 33650, 33617, 33617, 33400, 33433, 33233, 32433, 32733,   NLAT 25
     *   32833, 32683, 32850, 32667, 32300, 32633, 32333, 31933, 32250,   NLAT 26
     *   32117, 31783, 31367, 31800, 31833, 31350, 31583, 31450, 30967,   NLAT 27
     *   29367, 27850, 46867, 48333, 46133, 45650, 53833, 46800, 44950,   NLAT 28
     *   52233, 44317, 48050, 49417, 45467, 51467, 43650, 48567, 50183,   NLAT 29
     *   47700, 50283, 44467, 44933, 43200, 43633, 46367, 42367, 50117)   NLAT 30
      DATA(( NLAT(I),I=259,344)=       48583, 45567, 43350, 41250, 46617,   NLAT 31
     *   49267, 42200, 41733, 44000, 42750, 41933, 41167, 44967, 43150,   NLAT 32
     *   48367, 44117, 45883, 41267, 46467, 43117, 48567, 41633, 47167,   NLAT 33
     *   44750, 43117, 42217, 40450, 43683, 46533, 45567, 45067, 43983,   NLAT 34
     *   40700, 47383, 42933, 42167, 41333, 47500, 46833, 40650, 40033,   NLAT 35
     *   44733, 42850, 41250, 44367, 43300, 41800, 39883, 39450, 42083,   NLAT 36
     *   43533, 40883, 39667, 40217, 44917, 44483, 45867, 42967, 39133,   NLAT 37
     *   45583, 44867, 41267, 40300, 44000, 41400, 43167, 42217, 39183,   NLAT 38
     *   44883, 42267, 43933, 40500, 39400, 38333, 40917, 43867, 42950,   NLAT 39
     *   42233, 41600, 38950, 44550, 43133, 40183, 43917, 40817, 43200)   NLAT 40
      DATA(( NLAT(I),I=345,430)=       41017, 39650, 41700, 39950, 41983,   NLAT 41
     *   41000, 38883, 43150, 42200, 40000, 38133, 37500, 42400, 39350,   NLAT 42
     *   36900, 41500, 42550, 39900, 37083, 36267, 41883, 41450, 40417,   NLAT 43
     *   39433, 38367, 35267, 40300, 37317, 42400, 39733, 38367, 37783,   NLAT 44
     *   40667, 39067, 41533, 40050, 36567, 35967, 41100, 40783, 39267,   NLAT 45
     *   37300, 39450, 35867, 35083, 41300, 39833, 36083, 38183, 38033,   NLAT 46
     *   40617, 39933, 40100, 40850, 35000, 38983, 36483, 37083, 35733,   NLAT 47
     *   34267, 38050, 40317, 38750, 39767, 35217, 38967, 35433, 39550,   NLAT 48
     *   39117, 36967, 34183, 33683, 38733, 35817, 39067, 38133, 39150,   NLAT 49
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*    37067, 36667, 35950, 34900, 37233, 36117, 33950, 38817, 37800)  NLAT 50
  DATA(( NLAT(I),I=431,516)=         34500, 38333, 35033, 32900, 38067,  NLAT 51
*    37667, 36017, 37233, 33950, 33367, 37650, 37167, 35600, 34700,  NLAT 52
*    34350, 36133, 36267, 35350, 34750, 33650, 32133, 36733, 35050,  NLAT 53
*    33583, 32700, 36000, 36183, 34267, 36333, 33567, 31150, 35333,  NLAT 54
*    34733, 32517, 31533, 33233, 33633, 35400, 34483, 34167, 32300,  NLAT 55
*    31533, 30417, 34883, 33500, 30783, 30233, 31317, 34650, 32333,  NLAT 56
*    29183, 34300, 29700, 33217, 30383, 33450, 32317, 33717, 30783,  NLAT 57
*    29633, 33967, 28550, 28100, 32517, 30067, 32467, 27650, 30467,  NLAT 58
*    31267, 30683, 32833, 32783, 32350, 27967, 31400, 30400, 26683,  NLAT 59
*    31050, 30533, 26067, 31233, 31617, 29983, 26583, 25800, 30200)  NLAT 60
  DATA(( NLAT(I),I=517,536)=         29333, 31067, 30117, 30583, 29950,  NLAT 61
*    30300, 30500, 29650, 24550, 29300, 29533, 28717, 28850, 28367,  NLAT 62
*     28450, 27683, 27733, 27500, 26183, 25900)                      NLAT 63
  DATA((NLONG(I),I=  1, 86)=     118883, 98633,105300,122683,110283, NLONG  1
*  115667,101100,122517,116417,113467,118067,110833,105683,124933, NLONG  2
*  122050,108250,114917,127367,106683,111450,127417,102467,100050, NLONG  3
*  121317, 97050,114017,126533, 94367,124500,101350, 97233,102533, NLONG  4
*  100317,125767,119383,105550,123167,107683,121433,110717,119600, NLONG  5
*  117567,115767,122533,113950,112800,103000,124550,123400,101283, NLONG  6
*   97183,112367,109767,122300,114267,106617,103633,123933,120200, NLONG  7
*  117533, 96800,115767, 98683,111350,123883,120533,109450,102800, NLONG  8
*  100750,114083,118283,117017,122600,112000,105867,121150, 98433, NLONG  9
*  118850,123017,112500,108533, 97150,110433,123217,117817,112550) NLONG 10
  DATA((NLONG(I),I= 87,172)=         98217,121150,106967,100283,124250, NLONG 11
*  109017,101600, 96733,103067,119050,107950,116217,112067,122867, NLONG 12
*  115850,124233,114767,103083, 99983,121733,106467, 97433,112600, NLONG 13
*  108733,122467,113767,102800, 97350,124100,122317,112317,103600, NLONG 14
*   98317,107200,100683,105683,109067,102983, 98433,117800,112017, NLONG 15
*  122250,115783,110983,104817,101617,116867,114033,100583,111967, NLONG 16
*  118550,103217,123200,119783,112933,121567,105833, 99833,104883, NLONG 17
*  101700,106917, 98817,121500,114850,112517,110750,108533,104700, NLONG 18
*  122200,104517, 99967,121917,117083,113017,110683,100717,103517, NLONG 19
*  120567,118367,121850,113100,112150,105867,104333,119717,121767) NLONG 20
  DATA((NLONG(I),I=173,258)=         99767,119950,104500,108250,102550, NLONG 21
*  115167, 99200,117683,119050,120450,106083,105150,101700, 99050, NLONG 22
*  103600,117900,120667,118733, 99267,116783,111667,107900,106617, NLONG 23
*  100283,110733,108783,119833,114617,118367,112433,103317,118383, NLONG 24
*  116950,101817,116167,114717,104533,112017,107267, 99683,117167, NLONG 25
*  115567,103200,106083,114600,101450,108167,104267,102200,107700, NLONG 26
*  110933,103200,100500,106400,104800,113667,110333,109600,110300, NLONG 27
*  100917,110917, 68017, 71000, 67783, 68683, 89867, 71383, 68667, NLONG 28
*   87883, 69800, 77783, 82467, 73750, 90250, 70317, 81367, 86700, NLONG 29
*   79850, 88900, 73150, 74833, 71500, 72317, 79417, 71033, 91900) NLONG 30
  DATA((NLONG(I),I=259,344)=         85283, 77417, 73617, 70067, 80800, NLONG 31
*   90583, 72533, 71433, 76017, 73800, 72683, 71583, 79300, 75383, NLONG 32
*   89317, 77533, 82567, 72883, 84367, 76117, 93383, 73883, 83017, NLONG 33
*   81100, 77667, 75983, 73117, 79650, 87567, 84800, 83567, 80750, NLONG 34
*   74167, 92850, 78733, 76900, 75733, 94933, 92183, 75433, 74350, NLONG 35
*   85583, 80267, 76917, 84683, 81517, 78633, 75250, 74583, 80183, NLONG 36
*   84083, 78083, 75600, 76850, 89617, 88133, 95383, 83733, 75467, NLONG 37
*   94183, 91483, 80667, 78317, 88567, 81850, 86233, 83350, 76667, NLONG 38
*   93217, 84467, 90267, 80217, 77983, 75500, 81433, 91250, 87900, NLONG 39
*   85550, 83800, 77450, 95083, 89333, 80650, 92500, 82517, 90183) NLONG 40
  DATA((NLONG(I),I=345,430)=         83667, 79917, 86317, 81900, 87900, NLONG 41
*   85200, 79850, 93333, 89100, 82883, 78450, 77333, 90700, 81433, NLONG 42
*   76200, 88167, 92400, 84217, 77950, 76183, 91700, 90517, 86933, NLONG 43
*   83800, 81600, 75550, 88150, 79967, 96383, 86283, 82550, 81117, NLONG 44
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*     89683, 84667, 93650, 88267, 79333, 77800, 92450, 91117, 85900, NLONG 45
*     81217, 87300, 78783, 77033, 95900, 89667, 79950, 85733, 84600, NLONG 46
*     93933, 91200, 92550, 96750, 78883, 89167, 82400, 84083, 81383, NLONG 47
*     77917, 87533, 96750, 90383, 94917, 80933, 92367, 82533, 97650, NLONG 48
*     94583, 86433, 79717, 78933, 93567, 83983, 95633, 91767, 96667, NLONG 49
*     88767, 87500, 85083, 82217, 89583, 86683, 81117, 97567, 92100) NLONG 50
  DATA((NLONG(I),I=431,516)=        82717, 96200, 85200, 80033, 97867, NLONG 51
*     95483, 89400, 93383, 83317, 81967, 97417, 94500, 88917, 86583, NLONG 52
*     85167, 90933, 93150, 89867, 87617, 84433, 81200, 97100, 89983, NLONG 53
*     85850, 83650, 94167, 95900, 88767, 97900, 86750, 81383, 94367, NLONG 54
*     92233, 84933, 82517, 87617, 88450, 97600, 93100, 91933, 86400, NLONG 55
*     84183, 81650, 95783, 90200, 83283, 81667, 85450, 98400, 88750, NLONG 56
*     81050, 97017, 82267, 92800, 84367, 94000, 90083, 96667, 86517, NLONG 57
*     83100, 98483, 81333, 80633, 92050, 85583, 93817, 80417, 87200, NLONG 58
*     90467, 88250, 97050, 98067, 95400, 82533, 92300, 88917, 80100, NLONG 59
*     93183, 91150, 80150, 94750, 97217, 90250, 81867, 80267, 91983) NLONG 60
  DATA((NLONG(I),I=517,536)=        89400, 97833, 93217, 96350, 94017, NLONG 61
*     97700, 99767, 95283, 81750, 94800, 98467, 96250, 96917, 97667, NLONG 62
*     99217, 97283, 98033, 99500, 98233, 97433)                       NLONG 63
  DATA((NALTC(I),I=  1, 86)=         2293,   817,  1286,  2322,  1879, NALTC  1
*      2536,   954,  1882,  3137,  2398,  3576,  2138,  1498,  3055, NALTC  2
*      3192,  1892,  3430,    80,  1736,  2724,     0,  1745,  1065, NALTC  3
*      1690,   776,  3635,     0,  1426,   457,  1070,   840,  2134, NALTC  4
*      1642,     0,  1492,  1954,     0,  2783,   164,  2470,  1192, NALTC  5
*      2100,  3117,   172,  3877,  3122,  1982,   221,    31,  1807, NALTC  6
*       889,  3924,  2705,   483,  3078,  2403,  2003,    16,  1332, NALTC  7
*      2470,   959,  3690,  1581,  3748,    24,  1135,  4219,  2689, NALTC  8
*      1752,  3291,  1282,  1520,    42,  3981,  2740,   226,  1379, NALTC  9
*      1582,   217,  5518,  3664,  1834,  4667,   401,  3472,  5219) NALTC 10
  DATA((NALTC(I),I= 87,172)=         1368,  3188,  4049,  1820,    18, NALTC 11
*      5124,  2316,  1511,  3270,  4242,  4280,  2964,  4786,  1409, NALTC 12
*      3118,    62,  3759,  3415,  2686,  4160,  5294,  1639,  4535, NALTC 13
*      5541,  2761,  4230,  4012,  1524,   242,  3680,  4551,  4039, NALTC 14
*      1953,  6607,  2893,  7071,  6609,  4372,  2043,  4403,  4513, NALTC 15
*       380,  5097,  6829,  6070,  3384,  4586,  4308,  2676,  4297, NALTC 16
*      3987,  4670,   664,  4461,  4422,    79,  8168,  2325,  5333, NALTC 17
*      3778,  6403,  1966,    27,  6179,  4802,  5853,  4875,  6096, NALTC 18
*         8,  4763,  2698,    60,  5427,  5056,  4520,  2988,  4285, NALTC 19
*       212,  4218,   237,  5596,  7345,  7303,  5710,   352,   155) NALTC 20
  DATA((NALTC(I),I=173,258)=         2306,   256,  6281,  5490,  4077, NALTC 21
*      2283,  2032,  2342,   528,   256,  6220,  6723,  3697,  1659, NALTC 22
*      4117,  2417,    82,  4578,  1460,  2028,  6849,  6413,  5317, NALTC 23
*      2051,  4916,  6344,    22,   947,   776,  5046,  4370,   112, NALTC 24
*      2706,  3342,  -120,   421,  3711,  1178,  4893,  1848,    30, NALTC 25
*       -51,  3757,  4179,   222,  2670,  5374,  3362,  2968,  4389, NALTC 26
*      2661,  2926,  2006,  3999,  5451,    54,  4731,  4182,  5211, NALTC 27
*      1094,    29,   673,   575,   511,   444,   770,   264,   145, NALTC 28
*       897,   387,  1179,   804,   106,  1285,    68,  1029,  1134, NALTC 29
*       860,  1134,   366,   224,   372,   611,  1285,    31,  1303) NALTC 30
  DATA((NALTC(I),I=259,344)=         1320,   612,   358,    13,  1192, NALTC 31
*      1743,   266,    67,   358,   314,   193,   127,   988,   796, NALTC 32
*       690,   286,   669,    14,   775,   439,  1257,   175,   844, NALTC 33
*       770,   595,  1729,   117,   620,  1509,   765,   742,  1442, NALTC 34
*        32,  1438,   756,  1017,  1011,  1459,  1501,   414,   119, NALTC 35
*       675,   843,   563,  1233,   887,  2253,    30,    72,   788, NALTC 36
*       717,  2012,    86,   378,  1271,   751,  1515,   819,    41, NALTC 37
*      1111,   955,  1260,  1555,   850,   860,   678,   711,   167, NALTC 38
*       895,  1087,   976,  1301,   573,    65,  1313,   720,   742, NALTC 39
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     *      933,     741,     348,    1097,     925,    1270,    1400,    1392,     771) NALTC 40
      DATA((NALTC(I),I=345,430)=                858,    1330,     826,     963,     722, NALTC 41
     *      885,    2106,    1197,     795,     890,     690,     177,    1149,     922, NALTC 42
     *       32,     630,     937,    1069,     471,      14,     930,     637,     682, NALTC 43
     *     1141,    1014,      12,     799,    1250,    1174,     863,     895,    2620, NALTC 44
     *      709,     936,    1027,     816,     632,     132,     908,     751,     712, NALTC 45
     *     2973,     636,     474,      26,    1047,     657,     946,     524,    1054, NALTC 46
     *     1193,     819,    1029,    1263,     211,     579,    1613,    1286,    1262, NALTC 47
     *       41,     417,    1398,     605,     874,     822,     839,    2273,    1570, NALTC 48
     *      802,     575,     163,      38,     938,    1045,     945,    1209,    1139, NALTC 49
     *      444,     623,    1967,    1035,     379,     648,     242,    1332,    1170) NALTC 50
      DATA((NALTC(I),I=431,516)=                826,    1287,     736,      52,    1612, NALTC 51
     *     1046,     371,    1348,     867,     160,    1421,    1050,     453,     690, NALTC 52
     *      689,     305,    1468,     318,     603,    1101,      55,    1063,     306, NALTC 53
     *      662,     389,    1336,     724,     388,    1397,     675,      26,     497, NALTC 54
     *      285,     424,     222,     201,     241,    1383,     595,     231,     218, NALTC 55
     *      208,      33,     796,     144,     240,      62,     380,    1272,     334, NALTC 56
     *       44,     825,     178,     307,      73,     396,     356,     816,     199, NALTC 57
     *       48,    1097,     128,      29,      87,      30,     279,      30,     127, NALTC 58
     *      503,     238,     618,    1036,     591,      12,     127,      39,      23, NALTC 59
     *      355,      82,      11,     340,     545,      32,      13,      13,      45) NALTC 60
      DATA((NALTC(I),I=517,536)=                  1,    1081,      35,     353,      24, NALTC 61
     *      665,    1806,      67,      23,      58,     849,      16,     126,     211, NALTC 62
     *      514,      21,     194,     447,     121,      22)                            NALTC 63
      NOS=0
      DIST=2508.263*1.8660254
      CINTMB=(1013.25/29.92119696)/1000.
      DDTR=.0174532925E-3
      WRITE(59,750)
  750 FORMAT(30HMOUNT RAOB DATA TAPE ON UNIT 2,/34HAND SFC HOURLY DATA T
     1APE ON UNIT 3)
      PAUSE 1111
    2 CONTINUE
C     ...READ OBAN PARAMETERS
      READ 701,NI,NJ,NOPUA,IXO,IYO,IRUA,IDX,IDY,NWEG,KOUT
      READ 701,NI,NJ,NOPSF,IXO,IYO,IRSF,IDX,IDY
  701 FORMAT(16I5)
      DO 65 I=1,NI
   65 IXGP(I)=IXO+(I-1)*IDX
      DO 66 J=1,NJ
   66 IYGP(J)=IYO+(J-1)*IDY
      IXFO=IXGP(NI)
      IYFO=IYGP(NJ)
      READ 700,SDATE
  700 FORMAT(4A4)
      IF(SDATE(1).EQ.4H9999)50,5
   50 WRITE(59,751)
  751 FORMAT(40HLAST DATE PROCESSED,HIT GO TO START OVER)
      PAUSE 5555
      GO TO 2
C     ...SEARCH SFC TAPE
    5 BUFFER IN(2,1) (DATE(1),DATE(4))
    6 GO TO (6,7,5) ,UNITSTF(2)
    7 IF(DATE(1).EQ.9999)52,8
   52 WRITE(59,753) SDATE
  753 FORMAT(4A4,47H NOT ON SFC TAPE,MOUNT CORRECT TAPE ON 2,HIT GO)
      REWIND 2 $ PAUSE 3333 $ REWIND 2 $ GO TO 5
    8 IF(DATE(1).NE.SDATE(1).OR.DATE(2).NE.SDATE(2).OR.DATE(3).NE.
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     *  SDATE(3).OR.DATE(4).NE.SDATE(4))9,11
    9 BUFFER IN(2,1) (DATA(1),DATA(2680))
   10 GO TO (10,9,5),UNITSTF(2)
C       ...BOTH DATES FOUND AND READ
   11 BUFFER IN(2,1) (DATA(1),DATA(2680))
C       ...SCAN SFC DATA
 8105 GO TO (8105,8106),UNITSTF(2)
 8106 ITWC=1
  124 DO 105 K=1,10681,40
      IF(CDATA(K+3).EQ.60B.OR.CDATA(K+34).EQ.60B.OR.CDATA(K+27).EQ.60B)
     *  105,106
C       ...REJECT IF Y COORD. IS LE 075
  106 IF(CDATA(K+7).GT.00B)109,107
  107 IF(CDATA(K+8)-07B)105,108,109
  108 IF(CDATA(K+9).LE.05B)105,109
C       ...DATA IS NOT MISSING AND IS EAST OF 110 DEGREES
  109 LSUB=(K-1)/40+ITWC
      A=DDTR*(100000-NLONG(LSUB))
      PHI=DDTR*NLAT(LSUB)
      RA=DIST*COS(PHI)/(1.+SIN(PHI))
      IXT=RA*COS(A)
      IF(IXT.LT.IXO.OR.IXT.GT.IXFO)105,110
  110 IYT=RA*SIN(A)
      IF(IYT.LT.IYO.OR.IYT.GT.IYFO)105,111
C       ...STATION IS INSIDE GRID
C       ...FORM STATION PRESSURE
  111 N1=CDATA(K+32) $ N2=CDATA(K+33) $ N3=CDATA(K+34)
      IF(N1.LT.4)112,113
  112 N1=N1+30 $ GO TO 114
  113 N1=N1+20
  114 SPRES=CINTMB*(N1*1000+N2*100+N3*10-NALTC(LSUB))
      N2=CDATA(K+27)
      IF(CDATA(K+26).EQ.60B)115,116
  115 STEMP=N2 $ GO TO 117
  116 N1=CDATA(K+26)
      STEMP=N1*10+N2
  117 IF(CDATA(K+25).EQ.40B)118,119
  118 STEMP=-STEMP
C       ...CALCULATE SFC MIXING RATIO
  119 CTEMP=(STEMP-32.0)*.55555556
      VAP=6.108*EXP((17.269388*CTEMP)/(237.3+CTEMP))
      WZERO=(622.*VAP)/(SPRES-VAP)
      IF(WZERO.GT.35.0.OR.WZERO.LE.0.0)105,130
  130 NOS=NOS+1
      IX(NOS)=IXT
      IY(NOS)=IYT
C       SURFACE MIXING RATIO (SURFACE DATA)
      IZX(NOS)=WZERO*100.+.5
      GO TO (120,105),SSWTCHF(3)
  120 PRINT 905,DATE
  905 FORMAT(1H1,4A4 //)
      PRINT 903,CDATA(K),CDATA(K+1),CDATA(K+2),IX(NOS),IY(NOS),IZX(NOS),
     1  SPRES,STEMP
  903 FORMAT(1H ,3R1,2X,3I6,F7.0,F6.0)
  105 CONTINUE
      IF(ITWC.EQ.1)122,121
  122 BUFFER IN(2,1) (DATA(1),DATA(2680))
      ITWC=269
```

```
123 GO TO (123,124),UNITSTF(2)
121 CONTINUE
    NSFC=NOS
    END
```

```
      PROGRAM UPDAT
      COMMON NI,NJ,IDX,IDY,IXFO,IYFO,IXO,IYO,IXGP(21),IYGP(27)
      COMMON NWEG,NSFC,NRAOB,NOPSF,NOPUA,KOUT(4)
      COMMON DATE(4),SDATE(4),IRSF(4),IRUA(4),IX(485),IY(485),IZX(485)
      COMMON IZGY(21,27),IXS(86),IYS(86),IZXT(86),IXQ(86),IYQ(86),
     *  IZXQ(86)
      INTEGER DATE,SDATE,T,D,P
      DIMENSION NH(11),T(22),D(22),ND(28),NS(28),MMM(9),P(22),W(22)
      DDTR=.0174532925E-3
  905 FORMAT(1H )
  754 FORMAT(44HMOUNT SECTIONAL MAP, SET AT 6 LINES PER INCH    )
C     ...SEARCH RAOB TAPE
    3 READ(1) DATE
      IF(DATE(1).EQ.9999)51,4
   51 WRITE(59,752) SDATE
  752 FORMAT(4A4,48H NOT ON RAOB TAPE,MOUNT CORRECT TAPE ON 1,HIT GO)
      REWIND 1 $ PAUSE 2222 $ REWIND 1 $ GO TO 3
    4 IF(DATE(1).NE.SDATE(1).OR.DATE(2).NE.SDATE(2).OR.DATE(3).NE.
     2  SDATE(3).OR.DATE(4).NE.SDATE(4))823,5
  823 READ(1)
      GO TO (3,823),EOFCKF(1)
C     ...READ RAOB DATA
    5 NOS=0
   12 DO 812 L=1,6
  812 P(L)=0
  813 READ(1) ISTN,(NH(I),T(I),D(I),ND(I),NS(I),I=1,11),(MMM(J),
     1  J=1,9),(P(K),T(K),D(K),K=7,21),(ND(L),NS(L),L=12,28),LAD,LOD,
     2  IHS,LAMBDA,LBETA,I150
      GO TO (100,13),EOFCKF(1)
   13 IF(I150.EQ.47B)813,10013
10013 IF(NH(1).EQ.32767.OR.D(1).EQ.32767)813,14
   14 P(1)=NH(1)
      LX=P(22)=P(1)-100
      MLEV=850
      IF(LX.LT.850)817,816
  817 MLEV=700
      IF(LX.LT.700) 818,816
  818 MLEV=500
  816 IF(I150.LE.MLEV)333,813
  333 D(22)=32767
      IF(P(1).LE.850)15,16
   16 IF(P(1).LE.1000)17,18
   18 P(2)=1000
   17 P(3)=850
```

```
   15 P(4)=700
      P(5)=500
      DO 19 I=1,21
      IF(P(I).EQ.32767.OR.D(I).EQ.32767)20,21
   20 P(I)=0
      GO TO 19
   21 IF(P(I).EQ.0)19,22
   22 IF(P(I).EQ.P(22))23,19
   23 P(22)=0
   19 CONTINUE
C     ...ARRAY PRESSURES IN DESCENDING ORDER
   24 DO 25 I=1,21
      K=22-I
      DO 25 N=1,K
      IF(P(N).GT.0)26,27
   26 IF(P(N+1)-P(N))25,28,27
   28 P(N+1)=0
      GO TO 24
   27 NSV=P(N+1) $ P(N+1)=P(N) $ P(N)=NSV
      NSV=D(N+1) $ D(N+1)=D(N) $ D(N)=NSV
   25 CONTINUE
      DO 29 K=1,22
      IF(P(K).EQ.0) 30,31
   31 IF(P(K).LT.500)30,29
   29 CONTINUE
      NL=22 $ GO TO 32
   30 NL=K-1
   32 DO 33 IPA=1,NL
      IF(P(IPA).EQ.LX)34,33
   33 CONTINUE
   34 IF(D(IPA).NE.32767)36,37
   37 DLP=P(IPA-1)
      D(IPA)=D(IPA-1)+(D(IPA+1)-D(IPA-1))*(ALOG(DLP/P(IPA))/
     *  ALOG(DLP/P(IPA+1)))
   36 DO 35 K=1,IPA
      VAP=6.108*EXP((17.269388*D(K))/(2373+D(K)))
   35 W(K)=(622.*VAP)/(P(K)-VAP)
C     ...INTEGRATE TO FIND WBAR
      WBAR=0.0
      DO 38 K=2,IPA
   38 WBAR=WBAR+(W(K-1)+W(K))*(P(K-1)-P(K))
      WBAR=.005*WBAR
      IF(WBAR.GT.35..OR.WBAR.LE.0.)12,2780
 2780 CONTINUE
C     ...COMPUTE STATION COORDINATES
      RA=.2508263*LBETA*COS(LAD*DDTR)
      DLO=1.E-5*LAMBDA
      NOS=NOS+1
      IXQ(NOS)=IXS(NOS)=RA*COS(DLO)
      IYQ(NOS)=IYS(NOS)=RA*SIN(DLO)
      IZXT(NOS)=WBAR*100.+.5
      IZXQ(NOS)=W(1)*100.+.5
      GO TO (39,12),SSWTCHF(2)
```

```
   39 RRR=WBAR/W(1)
      PRINT 900,ISTN,IXQ(NOS),IYQ(NOS),P(1),D(1),WBAR,W(1),RRR
  900 FORMAT(1H ,I5,3I6,I5,3F8.2)
      GO TO 12
C     RAOB COMPUTATIONS COMPLETE
  100 NRAOB=NOS
      NACT=NSFC+NRAOB
      CALL SORTOB(IXS,IYS,IZXT,NRAOB,IXO,IDX)
      CALL SORTOB(IXQ,IYQ,IZXQ,NRAOB,IXO,IDX)
      NWEGS=NWEG $ NWEG=100
      DO 150 L=1,NRAOB
      LSUB=NSFC+L
      IX(LSUB)=IXQ(L) $ IY(LSUB)=IYQ(L)
  150 IZX(LSUB)=-IZXQ(L)
      CALL SORTOB(IX,IY,IZX,NACT,IXO,IDX)
      CALL BOBAN(IX,IY,IZX,IZGY,NACT,IRSF,NOPSF,0)
      NWEG=NWEGS
      GO TO(10150,10152),SSWTCHF(1)
C     ...PRINT ANALYZED SFC MIXING RATIOS
10150 WRITE(59,754)
      PAUSE 1234
      DO 8101 L=1,5
 8101 PRINT 905
      PRINT 906,(IZGY(1,L),L=1,NJ)
  906 FORMAT(1H ,I4,26I5)
      DO 102 I=2,NI
  102 PRINT 902,(IZGY(I,L),L=1,NJ)
  902 FORMAT(/1H0,I4,26I5)
      PRINT 911,DATE,(IRSF(L),L=1,NOPSF)
  911 FORMAT(/1H0,19H SFC MIXING RATIOS ,4A4,5X,4I5)
      DO 8102 L=1,15
 8102 PRINT 905
10152 CONTINUE
      END
```

```
      SUBROUTINE SORTOB(IX,IY,IZX,NOS,IXO,IDX)
C     ...PREPARES DATA IN BANDS OF IDX FOR BOBAN
C     ...SORTS ON IX, THEN IY IN BANDS OF IDX
      DIMENSION IX(1),IY(1),IZX(1)
      NOSM=NOS-1
      DO 1 I=1,NOSM
      IS=I
      IMX=IX(I)
      K=I+1
      DO 2 J=K,NOS
      IF(IMX-IX(J))2,2,3
    3 IS=J
      IMX=IX(J)
    2 CONTINUE
      IF(IS-I)4,1,4
    4 IX(IS)=IX(I)
      IX(I)=IMX
      IMX=IY(IS)
      IY(IS)=IY(I)
      IY(I)=IMX
      IMX=IZX(IS)
      IZX(IS)=IZX(I)
      IZX(I)=IMX
    1 CONTINUE
C     ...SORT ON IY IN BANDS OF IDX
      IF(IX(1)-IXO)5,6,6
    5 IXI=IXO-IDX*(1+(IXO-IX(1)-1)/IDX)
      GO TO 7
    6 IXI=IXO+IDX*((IX(1)-IXO)/IDX)
    7 IS=1
      N=0
      IXB=IXI+IDX
   10 IE=IS
   11 IF(IX(IE)-IXB)12,13,13
   12 IE=IE+1
      IF(IE-NOS)11,11,13
   13 IE=IE-1
      IF(IS-IE)14,15,15
   14 IEE=IE-1
C     ...SORT ON IY
      DO 20 I=IS,IEE
      IQ=I
      IMX=IY(I)
      K=I+1
      DO 21 J=K,IE
      IF(IMX-IY(J))21,21,22
   22 IQ=J
      IMX=IY(J)
   21 CONTINUE
      IF(IQ-I)23,20,23
   23 IY(IQ)=IY(I)
      IY(I)=IMX
      IMX=IX(IQ)
      IX(IQ)=IX(I)
      IX(I)=IMX
      IMX=IZX(IQ)
      IZX(IQ)=IZX(I)
```

```
   IZX(I)=IMX
20 CONTINUE
15 IS=IE+1
   IXB=IXB+IDX
   IF(IS-NOS)10,10,30
30 CONTINUE
   RETURN
   END
```

```
      SUBROUTINE BOBAN(IX,IY,IZX,IZGX,NOS,IR,NOP,LLL)
C     INMAN  4/28/69
C     ...BANDED OBAN VERSION...MISSING DATA PROVISION
C     ...LLL=0, IZGX ZEROED
C     ...LLL=1, INITIAL VALUES FOR IZGX PROVIDED OUTSIDE SUBROUTINE
C     ...VERSION FOR POSITIVE VALUES ONLY
C     ...IZX HOLDS OBS AND IS UNCHANGED
C     ...IZH HOLDS DEVIATION
C     ...ICA HOLDS ANALYZED VALUE OF EACH STATION
C     ...NEG. IZX ARE GIVEN A WEIGHT OF NWEG AND IABS(IZX) IS USED
      DIMENSION IX(485),IY(485),IZX(485),IZGX(21,27),
     *IR(4),IZH(485),ICA(485),ICALL(485),JCALL(485),IPOS(55),IPOE(55)
      COMMON NI,NJ,IDX,IDY,IXFO,IYFO,IXO,IYO,IXGP(21),IYGP(27)
      COMMON NWEG,NSFC,NRAOB,NOPSF,NOPUA,KOUT(4)
      IF(LLL)2000,1000,2000
 1000 DO 1010 J=1,NJ
      DO 1010 I=1,NI
 1010 IZGX(I,J)=0
 2000 NNS=2
      IF(IX(1)-IXO)1,2,2
    1 IXI=IXO-IDX*(1+(IXO-IX(1)-1)/IDX)
      GO TO 3
    2 IXI=IXO+IDX*((IX(1)-IXO)/IDX)
    3 ICONST=(IXO-IX(1))/IDX+1
      NBAN=0
      IS=1
      IXB=IXI+IDX
      IE=IS
    5 IF(IX(IE)-IXB)6,7,7
    6 IE=IE+1
      IF(IE-NOS)5,5,10
    7 IF(IS-IE)8,9,9
    9 IS=0
    8 NBAN=NBAN+1
      IPOS(NBAN)=IS
      IPOE(NBAN)=IE-1
      IS=IE
      IXB=IXB+IDX
      GO TO 5
   10 NBAN=NBAN+1
      IPOS(NBAN)=IS
      IPOE(NBAN)=IE-1
C     ...NR IS THE RADIUS FOR STATIONS OUTSIDE THE GIRD
      NR=300
      NR2=NR*NR
```

```
C  LOCATES GRID SQUARE CONTAINING OBSERVATION STATION
      DO 50 K=1,NOS
      IF(IX(K)-IXO)16,17,18
   18 IF(IX(K)-IXFO)17,16,16
   17 IF(IY(K)-IYO)16,15,19
   19 IF(IY(K)-IYFO)15,16,16
C     ...STATION IS OUTSIDE GRID
   16 ICALL(K)=999
      GO TO 50
   15 ICALL(K)=1+(IX(K)-IXO)/IDX
      JCALL(K)=1+(IY(K)-IYO)/IDY
   50 CONTINUE
C  INITIALIZATION OF ARRAYS FOR GRID
      DO 14 K=1,NOS
      ICA(K)=0
   14 IZH(K)=IABS(IZX(K))
      DO 199 L=1,NOP
      KR=IR(L)
      IR2=KR*KR
      JGRDL=KR/IDX
      IF(LLL)1030,1020,1030
 1020 IF(L-1)1030,23,1030
C  INTERPOLATION
 1030 DO 22 K=1,NOS
      IF(IZX(K)-32767)10022,22,22
10022 IXK=IX(K)
      IYK=IY(K)
      IF(ICALL(K)-999)52,516,52
C     CALCULATE DEVIATION AT STATION WHEN STATION IS OUTSIDE GRID
  516 IA1=0
      IA2=0
      DO 524 I= 1,NOS
      IF(IZX(I)-32767)10524,524,10524
10524 M1=IABS(IXK-IX(I))
      IF(M1-NR)525,524,524
  525 M2=IABS(IYK-IY(I))
      IF(M2-NR)526,524,524
  526 M3=M1*M1+M2*M2
      IB1=NR2-M3
      IF(IB1)524,524,536
  536 B2=NR2+M3
      IF(IZX(I))637,636,636
  637 KW=(IB1/B2)*NWEG
      GO TO 638
  636 KW=(IB1/B2)*100.
  638 IA1=IA1+KW*IZH(I)
      IA2=IA2+KW
  524 CONTINUE
      ICA(K)=(ICA(K)+IA1/IA2+IABS(IZX(K)))/2
      GO TO 22
C  CALCULATION OF DEVIATION WHEN STATION IS WITHIN GRID
   52 M=ICALL(K)
      N=JCALL(K)
```

```
      M1=IXK-IXGP(M)
      M2=IYK-IYGP(N)
      IZ1=IZGX(M,N)
      IZ2=IZGX(M,N+1)
      IZ4=IZGX(M+1,N)
      ICA(K)=IZ1+((M1*(IZ4-IZ1))/IDX+(M2*(IZ2-IZ1))/IDY+
     1 (((M1*M2)/IDX)*(IZGX(M+1,N+1)-IZ4+IZ1-IZ2))/IDY)
   22 CONTINUE
      DO 950 K=1,NOS
      IZH(K)=IABS(IZX(K))-ICA(K)
      IF(IZH(K)-32767)10948,950,10948
10948 IF(IABS(IZH(K))-KOUT(L))950,950,10950
10950 WRITE(59,75)IX(K),IY(K),L,IZX(K)
      IZX(K)=32767
      IZH(K)=32767
      ICA(K)=0
   75 FORMAT(1X,8HDATA AT ,2I10,2X,17HREJECTED ON PASS ,I1,2X,9HVALUE IS
     * ,I5)
  950 CONTINUE
C     ...BAND VERSION FOR ANALYZED VALUE AT GRID POINTS
   23 DO 198 J=1,NJ
      IYK=IYGP(J)
      DO 198 I=1,NI
      JR=KR
      JR2=IR2
      IGRDL=JGRDL
      IXK=IXGP(I)
 1136 IA1=0
      IA2=0
      NN=0
      IONE=100
      IBGRD=I+ICONST
      IBT=IBGRD-IGRDL
      IBB=IBGRD+IGRDL-1
      IF(IBT)400,400,401
  400 IF(IBB)198,198,402
  402 IBT=1
  401 IF(IBB-NBAN)405,405,404
  404 IBB=NBAN
  405 DO 410 KB=IBT,IBB
      IS=IPOS(KB)
      IF(IS)410,410,411
  411 IE=IPOE(KB)
      NB=0
      DO 424 K=IS,IE
      IF(IZX(K)-32767)10024,424,10024
10024 M1=IABS(IX(K)-IXK)
      IF(M1-JR)425,430,430
  425 M2=IABS(IY(K)-IYK)
      IF(M2-JR)426,430,430
  426 M3=M1*M1+M2*M2
      IB1=JR2-M3
      IF(IB1)424,424,436
```

```
  436 B2=JR2+M3
      IF(IZX(K))737,736,736
  737 KW=(IB1/B2)*NWEG
      IONE=NWEG
      GO TO 738
  736 KW=(IB1/B2)*100.
  738 IA1=IA1+KW*IZH(K)
      IA2=IA2+KW
      NN=NN+1
      NB=1
      GO TO 424
  430 IF(NB)424,424,410
  424 CONTINUE
  410 CONTINUE
C     TWO STATIONS ARE REQUIRED WITHIN JR ON FIRST SCAN ONLY
      IF(NN-NNS)398,201,201
  201 IF(NN-1)198,202,200
C     NO STATIONS WITHIN JR-INCREASE JR AND TRY AGAIN
  398 JR=JR+IDX
      JR2=JR*JR
      IGRDL=IGRDL+1
      GO TO 1136
  200 IF(IA2)398,398,27
  202 IA2=IONE
   27 IZGX(I,J)=IZGX(I,J)+IA1/IA2
  198 CONTINUE
      NNS=0
  199 CONTINUE
      RETURN
      END
```

```
      PROGRAM FINAL
      INTEGER DATE,SDATE
      DIMENSION IZGX(21,27)
      COMMON NI,NJ,IDX,IDY,IXFO,IYFO,IXO,IYO,IXGP(21),IYGP(27)
      COMMON NWEG,NSFC,NRAOB,NOPSF,NOPUA,KOUT(4)
      COMMON DATE(4),SDATE(4),IRSF(4),IRUA(4),IX(485),IY(485),IZX(485)
      COMMON IZGY(21,27),IXS(86),IYS(86),IZXT(86),IXQ(86),IYQ(86),
     *  IZXQ(86)
C     ...SET CONTOURING SYMBOLS
      COMMON/DATA/KALP(16)
      DATA(KALP=1HA,1H ,1HB,13(1H ))
C     ...INTERPOLATE A VALUE OF WZERO FOR EACH UA STAT I/S GRID
      NACT=NSFC+NRAOB
      DO 120 L=1,NRAOB
      IXT=IXQ(L)  $  IYT=IYQ(L)
      IF(IXT.LT.IXO.OR.IXT.GT.IXFO)121,122
  122 IF(IYT.LT.IYO.OR.IYT.GT.IYFO)121,123
  123 M=(IXT-IXO)/IDX+1 $ N=(IYT-IYO)/IDY+1
      M1=IXT-IXGP(M) $ M2=IYT-IYGP(N)
      IZ1=IZGY(M,N) $ IZ2=IZGY(M,N+1) $ IZ4=IZGY(M+1,N)
      NZERO=IZ1+((M1*(IZ4-IZ1))/IDX+(M2*(IZ2-IZ1))/IDY+
     *  (((M1*M2)/IDX)*(IZGY(M+1,N+1)-IZ4+IZ1-IZ2))/IDY)
      IZXQ(L)=(IZXT(L)*1000)/NZERO
      GO TO (125,170),SSWTCHF(2)
  125 PRINT 901,IXQ(L),IYQ(L),IZXQ(L),NZERO
  901 FORMAT(6H WZERO,4I7)
      GO TO 170
  121 IZXQ(L)=(IZXT(L)*1000)/IZXQ(L)
  170 IF(IZXQ(L).GT.1250)171,172
  171 IZXQ(L)=1250 $ GO TO 120
  172 IF(IZXQ(L).LT.500)173,120
  173 IZXQ(L)=500
  120 CONTINUE
C     ...ANALYZE THE RATIOS (IZXQ)
      DO 10120 J=1,NJ
      DO 10120 I=1,NI
10120 IZGX(I,J)=900
      CALL BOBAN(IXQ,IYQ,IZXQ,IZGX,NRAOB,IRUA,NOPUA,1)
      DO 10125 J=1,NJ
      DO 10125 I=1,NI
      IF(IZGX(I,J)-500)10123,10125,10125
10123 IZGX(I,J)=500
10125 CONTINUE
      GO TO (126,127),SSWTCHF(1)
  126 WRITE(59,754)
      PAUSE 1234
  754 FORMAT(44HMOUNT SECTIONAL MAP, SET AT 6 LINES PER INCH    )
      CALL PRTFLD(IZGX,NI,NJ)
      PRINT 902,DATE,(IRUA(L),L=1,NOPUA)
  902 FORMAT(/1H0,36HRATIO OF MEAN AND SFC MIXING RATIOS ,4A4,5X,4I5)
      DO 128 L=1,15
  128 PRINT 903
  903 FORMAT(1H )
  127 CONTINUE
C     ...INTERPOLATE A RATIO FOR THE SFC STATIONS
      LS=0
      DO 136 L=1,NACT
      IF(IZX(L).LT.0 .OR.IZX(L).EQ.32767)136,137
```

```
  137 LS=LS+1
      IXT=IX(L) $ IYT=IY(L)
      M=(IXT-IXO)/IDX+1 $ N=(IYT-IYO)/IDY+1
      M1=IXT-IXGP(M) $ M2=IYT-IYGP(N)
      IZ1=IZGX(M,N) $ IZ2=IZGX(M,N+1) $ IZ4=IZGX(M+1,N)
      NRAT=IZ1+((M1*(IZ4-IZ1))/IDX+(M2*(IZ2-IZ1))/IDY+
     *  (((M1*M2)/IDX)*(IZGX(M+1,N+1)-IZ4+IZ1-IZ2))/IDY)
      IZX(LS)=(IZX(L)*NRAT+500)/1000
      IX(LS)=IX(L) $ IY(LS)=IY(L)
  136 CONTINUE
C     ...MOVE (WBAR)UA INTO LIST
      DO 138 L=1,NRAOB
      LSUB=NSFC+L
      IX(LSUB)=IXS(L)
      IY(LSUB)=IYS(L)
  138 IZX(LSUB)=-IZXT(L)
      GO TO (400,401)SSWTCHF(2)
  400 PRINT 920,(IX(L),IY(L),IZX(L),L=1,NACT)
  920 FORMAT(4H ***,3I10)
  401 CONTINUE
C     ...COMPUTE WBAR FIELD BY MULT OF GRID PTS OF WZERO AND RATIO
  129 DO 130 I=1,NI
      DO 130 J=1,NJ
  130 IZGX(I,J)=(IZGY(I,J)*IZGX(I,J)+500)/1000
      GO TO(10129,141),SSWTCHF(5)
10129 CALL PRTFLD(IZGX,NI,NJ)
      PRINT 904,DATE
  904 FORMAT(/1H0,18HMEAN MIXING RATIO ,4A4)
      DO 131 L=1,15
  131 PRINT 903
  141 CALL SORTOB(IX,IY,IZX,NACT,IXO,IDX)
C     MEAN MIXING RATIO
      CALL BOBAN(IX,IY,IZX,IZGX,NACT,IRSF,NOPSF,1)
      DO 2000 I=1,NI
      DO 2000 J=1,NJ
 2000 IZGX(I,J)=(IZGX(I,J)+5)/10
      DO 2001 K=1,5
 2001 PRINT 903
      CALL CONTUR(IZGX,NI,NJ,60,40,KALP)
      PRINT 910,DATE,NWEG,(IRSF(L),L=1,NOPSF)
  910 FORMAT(/1H0,47HMEAN MIXING RATIO IN 100MB THICK SURFACE LAYER ,
     *4A4,5X,5HNWEG=,I5,5X,4I5)
      DO 142 L=1,18
  142 PRINT 903
      GO TO(160,150)SSWTCHF(4)
  160 NWEG=100
      CALL BOBAN(IXS,IYS,IZXT,IZGY,NRAOB,IRUA,NOPUA,0)
      DO 9923 J=1,NJ
      DO 9923 I=1,NI
 9923 IZGY(I,J) =(IZGY(I,J)+5)/10
      CALL PRTFLD(IZGY,NI,NJ)
      PRINT 913,DATE,(IRUA(L),L=1,NOPUA),NRAOB
  913 FORMAT(/1H0,21HMEAN USING RAOB ONLY    ,5X,4A4,5X,4I5,2X,I5)
      DO 162 L=1,15
  162 PRINT 903
      DO 163 I=1,NI
      DO 163 J=1,NJ
  163 IZGX(I,J)=IZGX(I,J)-IZGY(I,J)
```

```
      CALL PRTFLD(IZGX,NI,NJ)
      PRINT 914 ,DATE
  914 FORMAT(/1H0,10HMEAN-RAOB    ,5X,4A4)
      DO 164 L=1,15
  164 PRINT 903
  150 WRITE(59,912)
  912 FORMAT(32HSET PRINTER AT 10 LINES PER INCH)
      PAUSE 4321
      DO 3000 I=1,NRAOB
 3000 IZXT(I)=(IZXT(I)+5)/10
      PRINT 915,DATE
  915 FORMAT(37X,47HMEAN MIXING RATIO IN 100MB THICK SURFACE LAYER ,4A4)
      CALL MAPONE(IXS,IYS,NRAOB,IZXT)
      CONTINUE
      END
```

```
      SUBROUTINE PRTFLD(IAR,NI,NJ)
C     ...PRINTS OBAN FIELD - PROVIDES SPACING AT TOP ONLY
      DIMENSION IAR(21,27)
      DO 1 L=1,5
    1 PRINT 901
  901 FORMAT(1H )
      PRINT 902,(IAR(1,L),L=1,NJ)
  902 FORMAT(1H ,3X,26I5)
      DO 2 I=2,18
    2 PRINT 903,(IAR(I,L),L=1,NJ)
  903 FORMAT(/1H0,3X,26I5)
      PRINT 10,(IAR(19,L),L=1,17),(IAR(19,L),L=23,26)
   10 FORMAT(/1H0,3X,17I5,25X,4I5)
      PRINT 12,(IAR(20,L),L=1,12),(IAR(20,L),L=23,26)
   12 FORMAT(/1H0,3X,12I5,50X,4I5)
      PRINT 14,(IAR(21,L),L=1,11),(IAR(21,L),L=24,26)
   14 FORMAT(/1H0,3X,11I5,60X,3I5)
      RETURN
      END
```

```
      SUBROUTINE MAPONE(IX,IY,NOS,IZX)
C   PRINTS STATION VALUES ON SECTIONAL MAP
C   TO USE * ENTRY    POSITION MAP AT STANDARD POSITION, SET PRINTER AT
C                     10 LPI, PRINT A ONE LINE HEADER, AND CALL THIS SUB
C              EXIT   MAP IS LEFT AT STANDARD MAP POS
C   RESULTS * 4 DIGITS OF IZX ARE PRINTED TO THE LEFT OF THE STATION
C               ASTERISK. IF THE NUMBER EXCEEDS 4 CHARACTERS, $$$$ IS INSERTED
C   IX,IY,IZX,NOS ARE NOT MODIFIED IN ANY WAY
C     FORM  XXXX*  OR  -XXX*
      CHARACTER LINE
      DIMENSION IZX(1),IX(1),IY(1),IS(86),IT(86),LINE(135)
      IXC=1689 $ IYC=-342
      DO 1 L=1,NOS
      IS(L)=(IX(L)-IXC)/10
    1 IT(L)=(IY(L)-IYC)/10
      DO 4 IR=1,126
      DO 3 L=1,135
    3 LINE(L)=60B
      DO 5 I=1,NOS
      IF(IR.EQ.IS(I))6,5
    6 K=IT(I)
      IF(K.LT.1.OR.K.GT.135) 5,930
  930 IF(K.LT.5)30,31
   30 K=5
   31 KK=IZX(I)
      IF(KK.GT.9999.OR.KK.LT.-999)25,21
   25 NS=NH=NT=NU=53B
      GO TO 518
   21 JJ=IABS(KK)
      NS=JJ/1000 $ NX=JJ-NS*1000 $ NH=NX/100 $ NX=NX-NH*100 $ NT=NX/10
      NU=NX-NT*10
      IF(NS.EQ.0)517,518
  517 NS=60B
      IF(KK.LT.0)521,522
  521 NS=40B
  522 IF(NH.EQ.0)519,518
  519 NH=NS
      IF(NT.EQ.0)523,524
  523 NT=NH $ GO TO 525
  518 LINE(K-4)=NS
  524 LINE(K-3)=NH
  525 LINE(K-2)=NT
      LINE(K-1)=NU
      LINE(K)=54B
    5 CONTINUE
      PRINT 901,LINE
  901 FORMAT(1H ,135R1)
    4 CONTINUE
      PRINT 902
  902 FORMAT(12(/))
      RETURN
      END
```

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KINEMATIC VERTICAL VELOCITY COMPUTED FROM UXUS MEAN LOW-LEVEL WINDS

A computer program which performs computations of kinematic vertical velocity at 5,000 and 10,000 ft for the region of the United States east of the Rocky Mountains is described. The low-level mean winds reported on the early raob transmission (UXUS) are analyzed objectively by means of the method of successive approximations; however, the distance-dependent weight function has been modified so that upstream and/or down-stream observations within an elliptical region are given greater weight then those positions in a cross-stream direction. Wind error-detecting procedures are included in the objective and analysis routine.

The divergence of the field of vertically integrated winds is calculated in order to obtain the vertical velocity at the top of the layer. A listing of the program is included.

1. INTRODUCTION

In order to achieve success in low-level forecasting and prediction of baroclinic development, correct determination of the field of vertical motion is of paramount importance. For the purposes of numerical weather prediction the initial vertical motion field should be determined by means of a diagnostic model which is consistent with the prediction model to be employed. Calculation of vertical motion by kinematical methods for this purpose is not possible because of the relatively large errors contained in the wind observations. However, for qualitative evaluation of baroclinic development and many other diagnostic purposes, the relatively simple kinematic methods can be employed to great advantage.

A prime consideration which had to be made in developing a program for calculating vertical motion on the CDC 3100 is the computer time available for the computation. In order to take advantage of all available wind data one could analyze the wind field at the surface and aloft at 1,000 ft intervals (up to 10,000 ft) above mean sea level. The horizontal velocity divergence could then be evaluated and integrated from the surface up to the desired height to obtain the vertical motion at the top of the layer. The following sections present a less time consuming computation, mathematically equivalent to the above procedure, and similar to that described by Panofsky (1946). Bonner (1966) also utilized a similar method to calculate vertical velocities in the vicinity of the low-level jet in his study of the relationships of thunderstorm activity to the low-level jet.

2. METHOD OF CALCULATION

2.1 Equation for Vertical Velocity

The equation of mass continuity for an incompressible atmosphere in spherical polar coordinates may be written as

$$\frac{2w}{\rho} + \frac{\partial w}{\partial Z} + \frac{\partial U}{\partial X} + \frac{\partial V}{\partial Y} - \frac{V}{\rho}\tan\varphi = 0 \tag{1}$$

where w is the vertical component of motion, ρ is the mean radius of the earth, Z is the vertical coordinate, U and V are the east-west and north-south components of the horizontal wind, respectively, φ is latitude, and X and Y are curvilinear distances along latitude and longitude circles, respectively. We may consider the lower portion of the atmosphere to be incompressible to a very good degree of approximation; also, the first term on the left-hand side of (1) is very small compared to the remaining terms. Thus, we may write the approximate form of the equation of continuity as

$$\frac{\partial w}{\partial Z} = -\left(\frac{\partial U}{\partial X} + \frac{\partial V}{\partial Y} - \frac{V}{\rho}\tan\varphi\right), \tag{2}$$

where the quantity in parentheses on the right-hand side of (2) is the horizontal velocity divergence. The vertical motion at Z = H is obtained by integrating (2) from the surface of the earth, h, to the level H. Thus,

$$\int_h^H \frac{\partial w}{\partial Z}\, dZ = -\int_h^H \left[\frac{\partial U}{\partial X} + \frac{\partial V}{\partial Y} - \frac{V}{\rho}\tan\varphi\right] dZ,$$

By employing the formula of Leibnitz for differentiation under the integral the above expression may be written as

$$w_H - w_h = -\left[\frac{\partial U^*}{\partial X} + \frac{\partial V^*}{\partial Y} - \frac{V^*}{\rho}\tan\varphi\right] - U_h\frac{\partial h}{\partial X} - V_h\frac{\partial h}{\partial Y},$$

where any variable labeled with an asterisk is defined by

$$(\ )^* = \int_h^H (\ )\, dz,$$

and U_h and V_h are the east-west and north-south components of the horizontal wind at the surface where Z = h. Here it is assumed that h is a function of X and Y and that H is constant. By applying the kinematic boundary condition[1] at the surface of the earth it follows that

$$w_h = u_h \frac{\partial h}{\partial X} + v_h \frac{\partial h}{\partial Y} .$$

Consequently the above expression may be written as

$$w_H = - \left[\frac{\partial u^*}{\partial X} + \frac{\partial v^*}{\partial Y} - \frac{v^*}{\rho} \tan \varphi \right] . \tag{3}$$

That is, the vertical motion at the top of a column is equal to the horizontal convergence of the vertically integrated horizontal wind. The right-hand side of (3) may be written as

$$w_H = - \sigma^2 \left[\frac{\partial}{\partial x} \left(\frac{u^*}{\sigma}\right) + \frac{\partial}{\partial y} \left(\frac{v^*}{\sigma}\right) \right] , \tag{4}$$

if the polar stereographic map projection is to be employed. On the map x and y are distances along the rectangular coordinate axes; u and v are components of the horizontal velocity along the x- and y-axes of the cartesian grid chosen for computational purposes.

2.2 Space Coordinates and Velocity Components on the Map Projection

A convenient rectangular coordinate system on the polar stereographic map projection is described below. If the origin of the coordinate system (x,y) is located at the north pole, then, on the map

$$\begin{aligned} x &= R \cos \lambda = m\rho\, \sigma \cos \varphi \cos \lambda , \\ y &= R \sin \lambda = m\rho\, \sigma \cos \varphi \sin \lambda , \end{aligned} \tag{5}$$

where R is the radius of any latitude circle on the polar stereographic map λ is the deviation of longitude from the reference longitude, λ_o, m is the map scale, σ is the image plane scale factor defined by

$$\sigma = \frac{1 + \sin \varphi_\sigma}{1 + \sin \varphi} ,$$

---

1 The kinematic boundary condition requires that the component of motion perpendicular to a rigid boundary must vanish at this surface.

where φ_o is the standard latitude of the polar stereographic map projection and φ is the latitude of the point under consideration. The x-axis lies along the chosen standard longitude line on the map, and the y-axis is along the east-west direction at the point of intersection of the y-axis with the standard longitude line.

The wind velocity components along the x- and y-axes of the previously described rectangular coordinate system are u and v, respectively. These components are related to the observed wind direction, α, and wind speed, C, according to

$$u = C \cos (\lambda - \alpha)$$
$$v = C \sin (\lambda - \alpha) \quad (6)$$

2.3 The Finite-Difference Space Coordinates and Equations and Computational Procedure

The vertical motion at the level H is to be calculated according to (4). We shall evaluate this expression at equally spaced points on a rectangular grid. A constant space increment Δ (i.e., constant on the map) is chosen so that we may write the finite difference formulae for the rectangular coordinates as

$$x = (i - 1)\,\Delta + x_o, \; i = 1, 2, ---I$$
$$y = (j - 1)\,\Delta + y_o, \; j = 1, 2, ---J \; .$$

The numbers x_o and y_o in the formulae are the x- and y-coordinates of the upper left-hand corner grid point.

Various parameters, which define the grid employed in the calculation of vertical motion in the FORTRAN program WUXUS[2], are listed below:

λ_o = 100 deg W longitude

Δ = 0.5 in on map (68.5 n mi on image plane)

φ_o = 60 deg N latitude

I = 21

J = 27

x_o = 17.83 in on map

y_o = -3.0 in on map

2 A listing of this program is shown in the Appendix; directions for running the program on the CDC 3100 are included.

The wind data utilized in this computation are stored on the NSSFC UXUS Data Tape which is a product of the UXUS Filter program operated twice daily at NSSFC. First the mean wind data are read from the tape and checked for gross errors. Next $\bar{u}$ and $\bar{v}$ are calculated according to (6) and the vertically integrated components (u^*, v^*), are determined according to

$$u^* = \bar{u}\,(H - h) \ ,$$

$$v^* = \bar{v}\,(H - h) \ .$$

Objective analyses of the fields of

$$\frac{u^*}{\sigma} \text{ and } \frac{v^*}{\sigma} \text{ are}$$

then performed utilizing a revised version (described in Section 3) of the successive approximation scheme described on pages 1 through 11. Finally, the field of vertical motion is calculated by evaluating the following finite-difference equation at each interior grid point:

$$(w_H)_{i,j} = -\frac{\sigma^2_{i,j}}{2\Delta}\left[\left(\frac{u^*}{\sigma}\right)_{i+1,j} - \left(\frac{u^*}{\sigma}\right)_{i-1,j} + \left(\frac{v^*}{\sigma}\right)_{i,j+1} - \left(\frac{v^*}{\sigma}\right)_{i,j-1}\right] \ .$$

The printed output from the computer program WUXUS consists of three maps as described below:

a) The mean winds at each station for each of the layers are plotted on a map in the following format:

```
dd      ff      5,000 - 10,000 ft
     0
dd      ff      Surface - 5,000 ft .
```

b) Grid point values of w at 5,000 and 10,000 ft are displayed on separate charts.

2.4 Data and Analysis Area

Beginning June 1, 1968, rawinsonde stations within the U. S. began routine computation and transmission of low-level mean winds for all 00 and 12 GMT rawinsonde observations. The mean winds are computed for two layers: 1) surface to 5,000 ft MSL, and 2) 5,000 to 10,000 ft MSL. These data are transmitted on the early raob transmission (UXUS) and are employed in the determination of kinematic vertical motion at 5,000 and 10,000 ft.

The analysis area, shown in figure 1, is covered by a 21 x 27 grid which has a grid length of 68.5 n mi. Radiosonde stations in the United States also are shown in figure 1; the average distance between stations is about three times the grid length.

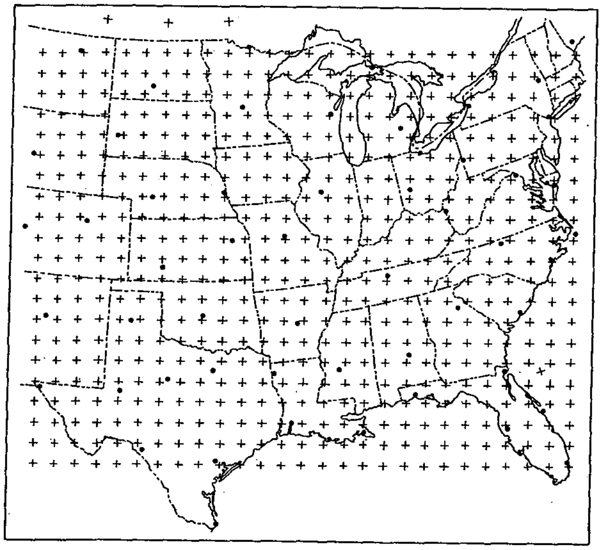

Figure 1. The area of analysis of the 21 x 27 grid. United States rawinsonde stations are shown by black dots.

3. THE MODIFIED OBJECTIVE ANALYSIS SCHEME

The successive approximations objective analysis scheme (pages 1-11) has been modified so that observations within an elliptical region are utilized to correct previously determined estimates of the analysis at grid points. The major axis of the elliptical region is oriented along the wind vector at the grid point. The weight, W, applied to any observation within this region is determined by

$$W = \beta^2 \frac{D^2 - d^2}{D^2 + d^2},$$

where d is the distance between the grid point and the observation point, D is the distance from the grid point to the boundary of the elliptical region along the direction of the position vector locating the station with respect to the grid point, and β is the cosine of the angle between the wind velocity vector at the grid point, and the wind velocity vector at the observation point. W is set to zero if β is less than zero. D^2 is calculated according to

$$D^2 = \frac{b^2}{1 - \left(\frac{\alpha^2 - 1}{\alpha^2}\right) \cos^2 \theta},$$

where b is one half the length of the minor axis of the elliptical region, α is the ratio of the length of the major axis to that of the minor axes, and θ in the angle between the position vector locating the observation and the wind velocity vector at the grid point.

The analyses of the integrated wind fields, utilized in the computation of the vertical motion fields described in Section 4, were determined using the following values of b and α on four successive scans through the data.

Scan	b (grid increments)	α
1	6	2
2	5	2
3	4	2
4	$2\frac{1}{2}$	2

4. EXAMPLES OF THE COMPUTATION

The vertical velocity at 10,000 ft MSL has been computed for three consecutive observation times for the severe thunderstorm situation of 3-4 April 1968. These vertical velocity patterns are shown in figures 2a, 3a, and 4a. The surface positions of the frontal systems and the radar reports for the respective observation times are shown in figures 2b, 3b, and 4b. The integrated winds utilized in these computations were determined from rawinsonde data.

In general, the vertical velocity patterns agree quite well with the radar reports and are consistent with the observed frontal positions. Also, the continuity displayed between the vertical velocity patterns at the three consecutive observation times appears to be very good. Magnitudes of the vertical motion computed for the three cases are quite reasonable.

The field of vertical velocity for 0600 CST, 4 April 1968, shown in figure 5 should be compared with the vertical motion field shown in figure 4a. In calculating the vertical velocities for figure 5 analyses of the wind components were obtained utilizing a circular region of influence; that is, the ordinary successive approximations technique

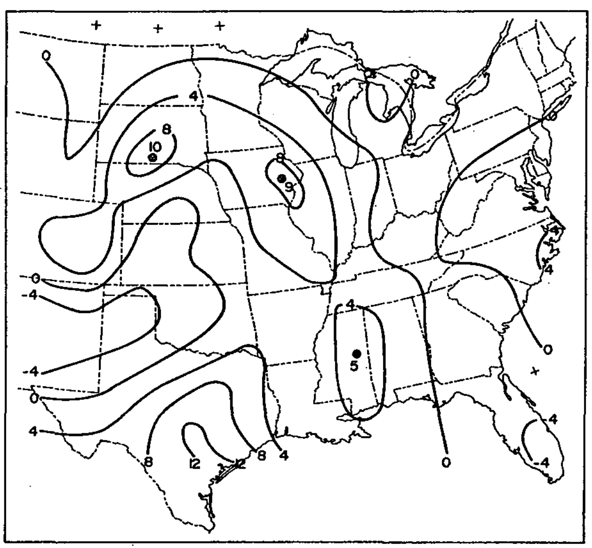

Figure 2a. Vertical velocities in cm sec^{-1} at 10,000 ft MSL for 0600 CST, 3 April 1968.

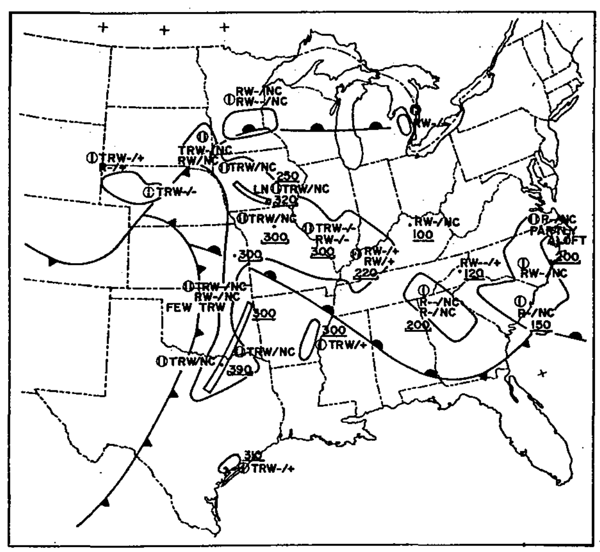

Figure 2b. Radar echo patterns at 0545 CST, 3 April 1968. Surface frontal positions are also shown in figures 2b, 3b, and 4b.

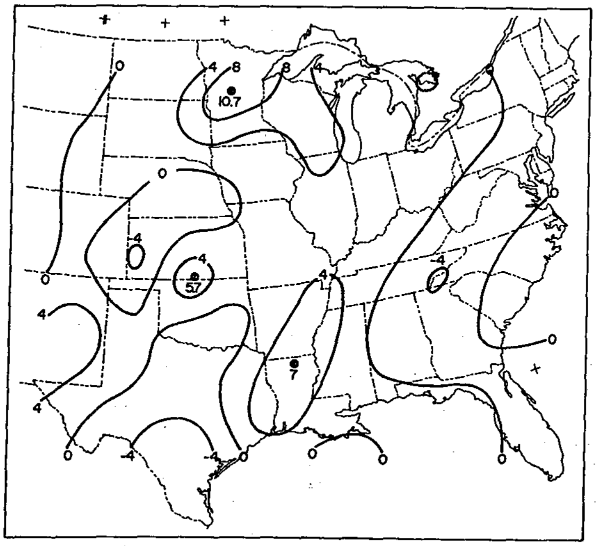

Figure 3a. Vertical velocities in cm sec^{-1} at 10,000 ft MSL for 1800 CST, 3 April 1968.

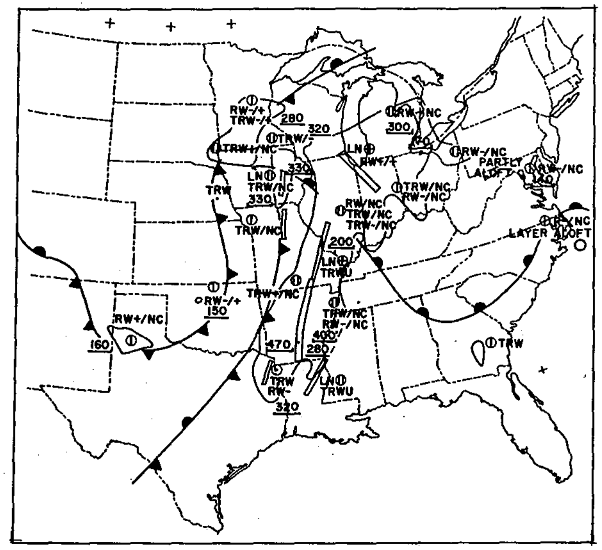

Figure 3b. Radar echo patterns at 1745 CST, 3 April 1968.

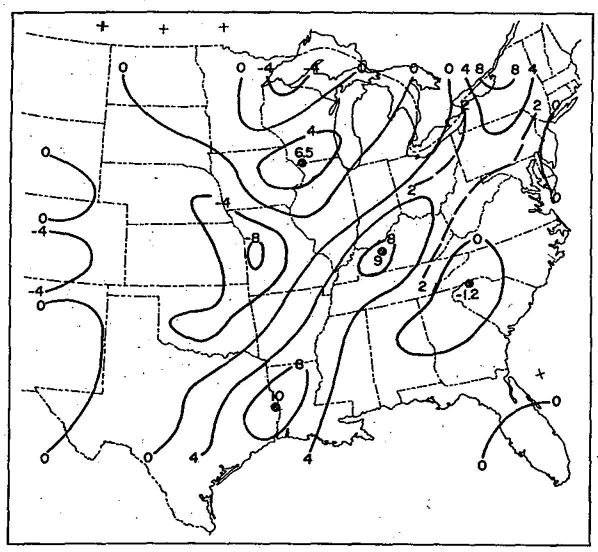

Figure 4a. Vertical velocities in cm sec^{-1} at 10,000 ft MSL for 0600 CST, 4 April 1968.

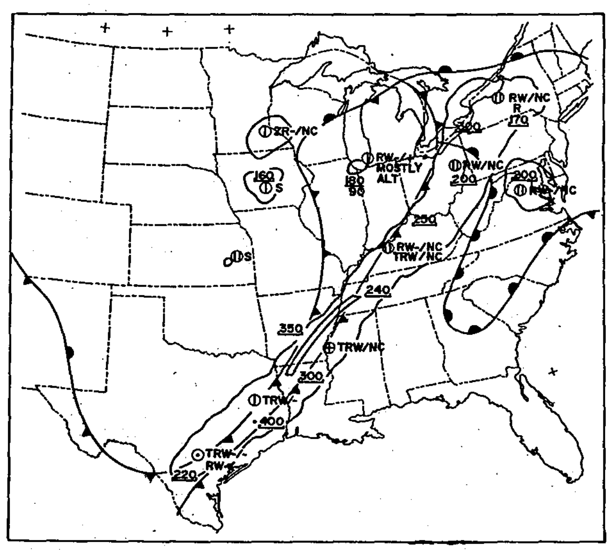

Figure 4b. Radar echo patterns at 0545 CST, 4 April 1968.

was employed. By comparing the two vertical motion fields it is easy to see that the field in figure 4a is much smoother; also, the magnitudes of the vertical velocities are only slightly smaller. The differences between the two fields are especially noticeable in the elongated region along and in advance of the cold front extending northeastward from Louisiana. In figure 5 there are three separated centers of strong upward motion with small positive or even negative values in between the centers. In contrast, the field of vertical motion shown in figure 4a appears to be more regular and in better agreement with the radar reports which show echoes along the entire elongated region. One may conclude that the use of the elliptical region of influence in the objective analysis procedure has resulted in a desirable selective smoothing of the fields along the direction of the flow.

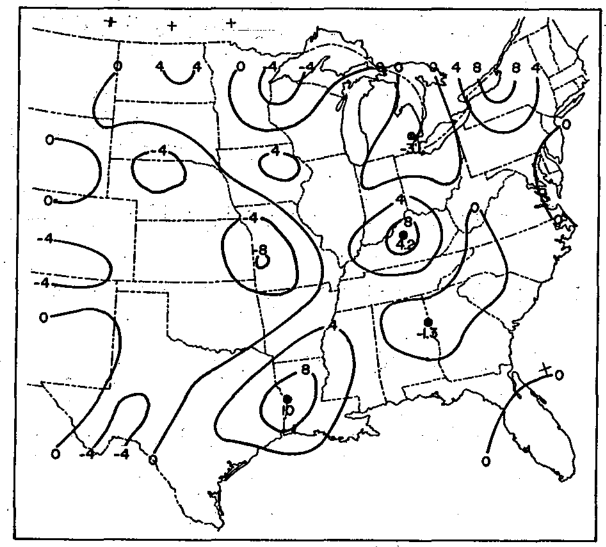

Figure 5. Vertical velocities in cm sec^{-1} at 10,000 ft MSL for 0600 CST, 4 April 1968. Analyses of the wind components were obtained utilizing a circular region of influence.

APPENDIX

This appendix contains the FORTRAN listings of the main program, WUXUS, and subroutines necessary for the vertical velocity calculation. These programs are in the form for use on the CDC 3100 at the National Severe Storms Forecast Center.

Subroutine EOBAN performs the objective analyses of the fields of mean wind; the x- and y-components are analyzed simultaneously. Subroutine MAPFOU plots the observed mean wind data on a map. Subroutine CONTUR is used for printing the calculated fields of vertical velocity. The divergence of the integrated winds is calculated in subroutine DIV. Subroutine SMOOTH is used by EOBAN to smooth the analyses after each pass. Listings of SMOOTH and CONTUR are given on pages 32 and 33, respectively.

Provisions have been made for inserting extra wind data by punch cards. Each time the program is run the program instructs the computer operator to turn Sense Switch (5) on if additional data are to be read from cards. The latitude, longitude, surface to 5,000 ft mean wind, 5,000 - 10,000 ft mean wind, and the surface elevation are punched on cards according to the following format:

FORMAT (2F10.2, 3I10).

The latitude and longitude are in degrees; the winds are in the regular UXUS format, i.e., a wind of 215/25 is coded as 215025, and the surface elevation is in meters.

Data Cards for WUXUS

The present version of WUXUS requires several data cards as explained below.

Card 1. Objective analysis parameters

NI = 21 (number of grid points along x-axis)

NJ = 27 (number of grid points along y-axis)

NOP = 4 (number of passes)

Distances are expressed in hundredths of inches

IXO = 1783 (x_o)

IYO = -300 (y_o)

IR = 300, 250, 200, 125 (radii of influence on successive passes)

IDX = 50 (Δx)

IDY = 50 (Δy)

ZFAC = 10.0 (scaling factor for w)

MIN = 0 (base value for contouring routine)

INT = 40 (contour interval for w)

Card 2. Contour symbols

Card 3. Toss-out criteria for detecting wind errors in objective analysis routine

IOUT = 1000, 650, 400, 275

Card 4. Time-date group, e.g., 12Z 04 AUG 1969
Needed only when program is run with Sense Switch (6) on

Card 5. Bogus wind data; see previous explanation of format

```
      PROGRAM WUXUS
C*****SENSE SWITCH (1) ON--PRINT TEST RESULTS
C*****SENSE SWITCH (6) ON--READ DATE,SEARCH TAPE
C     THIS PROGRAM COMPUTES VERTICAL MOTION AT 5000 AND 10000 FT MSL
C     UTILIZING MEAN WIND DATA REPORTED ON THE EARLY RAOB TRANSMISSION (UXUS)
C   IXO,IYO,IDX,IDY, ARE MULTIPLIED BY 100
      COMMON ZFAC,NOS,KNT,NI,NJ,NIM1,NJM1,NOP,IDX,IDY,IXO,IYO,IXFO,IYFO
      COMMON IR(4),IR2(4),IXGP(21),IYGP(27),ICALL(90),JCALL(90)
      COMMON IZGX(21,27),ICA(90),IZH(90),IZGY(21,27),JCA(90),IZJ(90),
     1 JX(21,27),JY(21,27),IU(90),IV(90),IZGE(21,27),IM(90),JM(90)
      COMMON NREC
      INTEGER BATE
      DIMENSION BATE(4),IOUT(4)
      INTEGER STADA ,DATE
      COMMON  DATE(4),STADA(10,33),LD5(90),LF5(90),LD1(90),LF1(90),
     1 IX5(90),IY5(90),IX(90),IY(90),IX1(90),IY1(90),KX(90),KY(90),
     2 KSTN(90),JSTN(90)
      DIMENSION KALP(16)
      DIMENSION L1(21,27),L5(21,27)
      EQUIVALENCE(L1,IZGE)
      NLAST=0
      READ 1001,NI,NJ,NOP,IXO,IYO,(IR(L),L=1,4),IDX,IDY,ZFAC,MIN,INT
 1001 FORMAT(11I5,F10.3,2I5)
      READ 6500,KALP
 6500 FORMAT(16A1)
      READ 550,IOUT
  550 FORMAT(4I5)
      ZFAC=ZFAC/137.
      NIM1=NI-1
      NJM1=NJ-1
      DO 65 I=1,NI
   65 IXGP(I)=IXO+(I-1)*IDX
      DO 66 J=1,NJ
   66 IYGP(J)=IYO+(J-1)*IDY
      IXFO=IDX*NIM1+IXO
      IYFO=IDY*NJM1+IYO
      DTR=0.017453292
      DDTR=0.017453292E-3
      WRITE(59,19)
   19 FORMAT(28H LOAD UXUS DATA TAPE ON LU 3 )
      PAUSE 7
      REWIND 3
 6000 N1=0
      N5=0
  888 FORMAT(4A4)
      GO TO (1000,2)SSWTCHF(6)
 1000 READ 888,(BATE(I),I=1,4)
      IF(BATE(1).EQ.4H9999)6004,2
 6004 PAUSE 77777
      GO TO 1000
C     READ MEAN WIND DATA
C    LD1=MEAN WIND DIRECTION(DEG) IN 5000-10000 FT LAYER
C     LF1=MEAN WIND SPEED(NM/HR) IN 5000-10000 FT LAYER
C     LD5=MEAN WIND DIRECTION (DEG) IN SURFACE-5000 FT LAYER
C    LF5= MEAN WIND SPEED (NM/HR) IN SURFACE-5000 FT LAYER
    2 BUFFER IN(3,1)(DATE(1),DATE(4))
    1 GO TO(1,3,2),UNITSTF(3)
    3 IF(DATE(1).EQ.9999)9999,410
```

```
  410 GO TO(411,4)SSWTCHF(6)
  411 DO 412 I=1,4
      IF(DATE(I).NE.BATE(I))414,412
  412 CONTINUE
      GO TO 4
  414 BUFFER IN(3,1)(NREC,NREC)
  416 GO TO(416,418),UNITSTF(3)
  418 DO 420 N=1,NREC
      BUFFER IN(3,1)(STADA(1,1),STADA(10,33))
  422 GO TO(422,420),UNITSTF(3)
  420 CONTINUE
      GO TO 2
    4 BUFFER IN(3,1)(NREC,NREC)
    5 GO TO(5,6),UNITSTF(3)
    6 DO 10 NN=1,NREC
      IF(NREC.EQ.1) 512,22512
22512 BUFFER IN(3,1)(STADA(1,1),STADA(10,33))
    7 GO TO(7,8),UNITSTF(3)
C     PROCESS DATA
    8 CONTINUE
  512 DO 90 L=1,10
      IF(STADA(L,1).EQ.9999)91,11
   11 PHI=DDTR*STADA(L,29)
      A=(100000-STADA(L,30))*DDTR
      B=1.8660254/(1.+SIN(PHI))
      RA=2508.263*B*COS(PHI)
      B=B*36.
      LLL=STADA(L,23)
      IF(LLL.EQ.9999)20,12
   12 N5=N5+1
   74 LD5(N5)=LLL/1000
      LF5(N5)=LLL-LD5(N5)*1000
      IF(LD5(N5).GT.360.OR.LF5(N5).GT.100)84,861
  860 N5=N5-1    $    GO TO 20
  861 LS=9999
      LD8=STADA(L,8)
      IF(LD8.EQ.9999)88,86
   86 LD=LD8/1000
      LS=LD8-LD*1000
      IF(IABS(LF5(N5)-LS).GT.35)84,88
   84 WRITE(59,80)STADA(L,1),LD5(N5),LF5(N5)
      WRITE(59,81)
   80 FORMAT(I10,I5,1H/,I3,2X,22H LOWER WIND MAY BE BAD)
   81 FORMAT(31H TYPE 999999 TO REJECT, 0 IF OK /29H TO CORRECT USE FORM
     1AT 270015)
      READ(58,78) LLL
   78 FORMAT(I6)
      IF(LLL.EQ.999999)860,76
   76 IF(LLL.EQ.0)88,74
   88 DR5=A-LD5(N5)*DTR
      C=(1524-STADA(L,31))/B
      CC=C*LF5(N5)
      IU(N5)=IX5(N5)=CC*COS(DR5)
      IX(N5)=RA*COS(A)
      IV(N5)=IY5(N5)=CC*SIN(DR5)
      IY(N5)=RA*SIN(A)
      KSTN(N5)=STADA(L,1)
      IM(N5)=IU(N5)*IU(N5)+IV(N5)*IV(N5)
```

```
   20 IF(STADA(L,31).LE.1524)22,24
   24 C=(3048-STADA(L,31))/B
      GO TO 26
   22 C=1524/B
   26 LLL=STADA(L,24)
      IF(LLL.EQ.9999)90,28
   28 N1=N1+1
  174 LD1(N1)=LLL/1000
      LF1(N1)=LLL-LD1(N1)*1000
      IF(LD1(N1).GT.360.OR.LF1(N1).GT.100)184,840
  830 N1=N1-1    $    GO TO 90
  840 LD7=STADA(L,15)
      IF(LD7.EQ.9999)188,186
  186 LD=LD7/1000
      LS7=LD7-LD*1000
      IF(LS.NE.9999)155,157
  155 LS7=(LS+LS7)/2
  157 IF(IABS(LF1(N1)-LS7).GT.35)184,188
  184 WRITE(59,180) STADA(L,1),LD1(N1),LF1(N1)
  180 FORMAT(I10,I5,1H/,I3,2X,22H UPPER WIND MAY BE BAD )
      WRITE(59,81)
      READ(58,78) LLL
      IF(LLL.EQ.999999)830,176
  176 IF(LLL.EQ.0)188,174
  188 DR1=A-LD1(N1)*DTR
      CC=C*LF1(N1)
      IX1(N1)=CC*COS(DR1)
      KX(N1)=RA*COS(A)
      IY1(N1)=CC*SIN(DR1)
      KY(N1)=RA*SIN(A)
      JSTN(N1)=STADA(L,1)
      JM(N1)=IX1(N1)*IX1(N1)+IY1(N1)*IY1(N1)
   90 CONTINUE
   10 CONTINUE
   91 CONTINUE
      IF(NLAST-9) 514,504,502
  514 WRITE(59,506)
  506 FORMAT(39HTO ENTER BOGUS WIND DATA TURN SS(5) ON     )
      PAUSE 22
      GO TO (502,504) SSWTCHF(5)
  502 KBS=0   $   NREC=1   $   NLAST=10
  511 READ 508,BLAT,BLONG,IW5,IW10,ISFCHT
  508 FORMAT(2F10.2,4X,I6,4X,I6,I10)
      IF(BLAT.EQ.99.99)510,22510
22510 KBS=KBS+1
      STADA(KBS,1)=KBS
      STADA(KBS,29)=1000*BLAT
      STADA(KBS,30)=1000*BLONG
      STADA(KBS,23)=IW5
      STADA(KBS,8)=9999
      STADA(KBS,31)=ISFCHT
      STADA(KBS,24)=IW10
      STADA(KBS,15)=9999
      IF(KBS-10)511,6,9999
  510 STADA(L,1)=9999
      NLAST=9
      GO TO 6
  504 NOS=N5
```

```
      GO TO(300,400)SSWTCHF(1)
  300 PRINT 250, (KSTN(I),IX(I),IY(I),IX5(I),IY5(I),IM(I),I=1,N5)
  250 FORMAT(1X,6I10)
  400 CALL EOBAN (IX5,JX,IY5,JY,0,IX,IY,IOUT)
      CALL EOBAN (IX5,IZGX,IY5,IZGY,1,IX,IY,IOUT)
      GO TO(700,805)SSWTCHF(1)
  700 CALL POUT(IZGX)
      CALL POUT(IZGY)
  805 CALL DIV(L5,IZGX,IZGY)
      WRITE(59,800)
  800 FORMAT(45H MOUNT SECTIONAL MAP, PRINT 6 LINES PER INCH      )
      PAUSE 77
      DO 118 I=1,8
  118 PRINT 1300
 1300 FORMAT(1H )
      CALL CONTUR(L5,NI,NJ,MIN,INT,KALP)
      IH5=5000
      PRINT 70,IH5,(DATE(I),I=1,4),(IR(J),J=1,4),N5,KNT
      DO 710 I=1,26
  710 PRINT 1300
      NOS=N1
      DO 150 K=1,NOS
      IM(K)=JM(K)
      IU(K)=IX1(K)
  150 IV(K)=IY1(K)
      GO TO(500,600)SSWTCHF(1)
  500 PRINT 250,(JSTN(I),KX(I),KY(I),IX1(I),IY1(I),JM(I),I=1,N1)
  600 CALL EOBAN(IX1,JX,IY1,JY,0,KX,KY,IOUT)
      CALL EOBAN (IX1,IZGX,IY1,IZGY,1,KX,KY,IOUT)
      GO TO (1700,1805)SSWTCHF(1)
 1700 CALL POUT(IZGX)
      CALL POUT(IZGY)
 1805 CALL DIV(L1,IZGX,IZGY)
      DO 200 I=2,NIM1
      DO 200 J=2,NIM1
  200  L1(I,J)=L5(I,J)+L1(I,J)
      CALL CONTUR( L1,NI,NJ,MIN,INT,KALP)
      IH1=10000
      PRINT 70,IH1,(DATE(I),I=1,4),(IR(J),J=1,4),N1,KNT
   70 FORMAT(/1H0,39H VERTICAL MOTION IN TENTHS OF CM/SEC AT,I7,10X,4A4,
     *5X,4I5,10X,2I5)
      DO 910 I=1,18
  910 PRINT 1300
      WRITE(59,8000)
 8000 FORMAT(1X,25H SET PRINTER 10 LINES             )
      PAUSE 77
      PRINT 940,DATE
  940 FORMAT(1H ,54X,11H MEAN WINDS ,4A4)
      CALL MAPFOU(KX,KY,IX,IY,N1,N5,LD1,LF1,LD5,LF5)
      GO TO(6000,9999)SSWTCHF(6)
 9999 PAUSE 777
      END
```

```
      SUBROUTINE EOBAN(IZX,IZGX,IZY,IZGY,JJJ,IX,IY,IOUT)
C     ...TWO FIELD SCHEME FOR ANALYZING WIND COMPONENTS ONLY
C     ...JJJ= 0, SKIP SPECIAL FORMULATION
C     ...JJJ= 1, ANALYZED WIND VELOCITY AT GRID POINTS USED
C     ...IZX,IZY HOLD OBS AND ARE UNCHANGED
C     ...IZH,IZJ HOLD DEVIATIONS
C     ...ICA,JCA HOLD ANALYZED VALUES AT EACH STATION
C     ...IZGX,IZGY HOLD ANALYZED VALUES AT GRID POINTS
C     ...IM HOLDS SQUARE OF WIND SPEED
      COMMON ZFAC,NOS,KNT,NI,NJ,NIM1,NJM1,NOP,IDX,IDY,IXO,IYO,IXFO,IYFO
      COMMON IR(4),MR2(4),IXGP(21),IYGP(27),ICALL(90),JCALL(90)
      COMMON MZGX(21,27),ICA(90),IZH(90),MZGY(21,27),JCA(90),IZJ(90),
     1 JX(21,27),JY(21,27),IU(90),IV(90),IZGE(21,27),IM(90),JM(90)
      DIMENSION IZX(90),IZGX(21,27),IZY(90),IZGY(21,27),IX(90),IY(90)
     * ,IOUT(4),JL2(4)
      JL2(1)=JL2(2)=JL2(3)=JL2(4)=2
      NNS=2
      DO 2 I=1,NI
      DO 2 J=1,NJ
      IZGX(I,J)=0
    2 IZGY(I,J)=0
C   A CONSTANT RADIUS OF NR IS USED FOR STN OUTSIDE GRID ON ALL SCANS.
      NR=300
      NR2=NR*NR
C   LOCATES GRID SQUARE CONTAINING OBSERVATION STATION
      KNT=0
      DO 50 K=1,NOS
      IF(IX(K)-IXO)16,17,18
   18 IF(IX(K)-IXFO)17,16,16
   17 IF(IY(K)-IYO)16,15,19
   19 IF(IY(K)-IYFO)15,16,16
C     ...STATION IS OUTSIDE GRID
   16 ICALL(K)=999
      KNT=KNT+1
      GO TO 50
   15 ICALL(K)=1+(IX(K)-IXO)/IDX
      JCALL(K)=1+(IY(K)-IYO)/IDY
   50 CONTINUE
      KNT=NOS-KNT
C   INITIALIZATION OF ARRAYS FOR GRID
      DO 4 K=1,NOS
      JCA(K)=0
      IZJ(K)=IZY(K)
      ICA(K)=0
    4 IZH(K)=IZX(K)
      DO 199 L=1,NOP
      JLL=JL2(L)
      KR=IR(L)
      IR2=KR*KR
      JA=JLL*KR
      CC=JLL*JLL
      CC=(CC-1.0)/CC
C   ON SCAN 1 INITIAL GUESS IS PRODUCED
      IF(L-1) 123,23,123
C   INTERPOLATION OF ANALYSIS TO OBSERVATION LOCATION (SCANS 2,3, AND 4)
  123 DO 22 K=1,NOS
      IF(IZX(K)-32767)813,22,813
  813 IXK=IX(K)
```

```
      IYK=IY(K)
      IF(ICALL(K)-999)52,516,52
C     CALCULATE DEVIATION AT STATION WHEN STATION IS OUTSIDE GRID
  516 IA1=0
      ID1=0
      IA2=0
      DO 524 I= 1,NOS
      IF(IZX(I)-32767)811,524,811
  811 M1=IXK-IX(I)
      IF(IABS(M1)-NR)525,524,524
  525 M2=IYK-IY(I)
      IF(IABS(M2)-NR)526,524,524
  526 M3=M1*M1+M2*M2
      IB1=NR2-M3
      IF(IB1)524,524,536
C  SPECIAL FORMULATION (WEIGHT FUNCTION MODIFIED ACCORDING TO WIND VEL)
C     CIRCULAR REGION OF INFLUENCE
  536 IF(JJJ)836,736,836
  836 IF(M3)4736,736,4736
 4736 IF(IM(K)-32767)6736,736,2736
 6736 IF(IM(K))2736,736,2736
 2736 D=IU(K)*M1+IV(K)*M2
  438 LR2=NR2*(1.0+(D*D/(FLOAT(M3)*IM(K))))
      IB1=LR2-M3
      B2=LR2+M3
      GO TO 936
C     ...LAST OF SPECIAL FORMULATION
  736 B2=NR2+M3
  936 KW=(IB1/B2)*100
  610 IA1=IA1+KW*IZH(I)
      IA2=IA2+KW
  611 ID1=ID1+KW*IZJ(I)
  524 CONTINUE
  613 ICA(K)=(ICA(K)+IA1/IA2+IZX(K))/2
  614 JCA(K)=(JCA(K)+ID1/IA2+IZY(K))/2
      GO TO 22
C  CALCULATION OF DEVIATION WHEN STATION IS WITHIN GRID
C  BILINEAR INTERPOLATION USING FOUR GRID POINTS SURROUNDING THE STN.
   52 M=ICALL(K)
      N=JCALL(K)
      M1=IXK-IXGP(M)
      M2=IYK-IYGP(N)
  615 IZ1=IZGX(M,N)
      IZ2=IZGX(M,N+1)
      IZ4=IZGX(M+1,N)
      ICA(K)=IZ1+((M1*(IZ4-IZ1))/IDX+(M2*(IZ2-IZ1))/IDY+
     1 (((M1*M2)/IDX)*(IZGX(M+1,N+1)-IZ4+IZ1-IZ2))/IDY)
  616 KZ1=IZGY(M,N)
      KZ2=IZGY(M,N+1)
      KZ4=IZGY(M+1,N)
      JCA(K)=KZ1+((M1*(KZ4-KZ1))/IDX+(M2*(KZ2-KZ1))/IDY+(((M1*M2)/IDX)*
     1(IZGY(M+1,N+1)-KZ4+KZ1-KZ2))/IDY)
   22 CONTINUE
      DO 950 K=1,NOS
      IZJ(K)=IZY(K)-JCA(K)
      IZH(K)=IZX(K)-ICA(K)
      IF(IZH(K)-32767)10948,950,10948
10948 IF(IABS(IZH(K))-IOUT(L))10944,10944,10950
```

```
10944 IF(IABS(IZJ(K))-IOUT(L))950,950,10950
10950 WRITE(59,10946)IX(K),IY(K),L,IZX(K),IZY(K),IZH(K),IZJ(K),IOUT(L)
10946 FORMAT(     8HDATA AT ,2I10,2X,17HREJECTED ON PASS ,I1, 2X,/5X,
     *  4HIZX=I5,2X,4HIZY=I5,2X,4HIZH=I5,2X,4HIZJ=I5,2X,5HIOUT=I5)
      IM(K)=32767
      IZX(K)=32767
      IZY(K)=32767
      IZH(K)=32767
      IZJ(K)=32767
      ICA(K)=0
      JCA(K)=0
  950 CONTINUE
C   CALCULATION OF CORRECTION TO GRID POINT VALUE
   23 DO 198 J=1,NJ
      IYK=IYGP(J)
      DO 198 I=1,NI
      IXK=IXGP(I)
      JR=KR
      JR2=IR2
      IF(JJJ)1136,1136,1336
 1336 JU=JX(I,J)
      JV=JY(I,J)
      V=JU*JU+JV*JV
 1136 IA1=0
      ID1=0
      IA2=0
      NN=0
      DO 24 K=1,NOS
      IF(IZX(K)-32767)807,24,807
  807 CAA=1.0
      M1=IX(K)-IXK
      IF(IABS(M1)-JA)25,24,24
   25 M2=IY(K)-IYK
      IF(IABS(M2)-JA)26,24,24
   26 M3=M1*M1+M2*M2
C   SPECIAL FORMULATION (WEIGHT FUNCTION MODIFIED ACCORDING TO WIND VEL)
   36 IF(JJJ)336,236,336
  336 IF(V)236,236,1236
 1236 D=JU*M1+JV*M2
      D=D*D/(V*M3)
      IF(IM(K))803,803,801
  801 VV=JV
      UU=JU
      VG=UU*IZX(K)+VV*IZY(K)
      IF(VG)24,24,805
  805 CAA=(VG*VG)/(V*IM(K))
  803 LR2=BS/(1.0-CC*D)
      IB1=CAA*(LR2-M3)
      GO TO 436
      B2=LR2+M3
  236 B2=JR2+M3
      IB1=JR2-M3
C     ...LAST OF SPECIAL FORMULATION CARDS
  436 IF(IB1)24,24,809
  809 KW=(IB1/B2)*100
  602 IA1=IA1+KW*IZH(K)
      IA2=IA2+KW
      NN=NN+1
```

```
  604 ID1=ID1+KW*IZJ(K)
   24 CONTINUE
      IF(NNS)300,200,300
C  NO STN. ARE REQUIRED WITHIN JR
  200 IF(NN-1)198,202,304
  202 IA2=100
      GO TO 304
C  NNS STN. ARE REQUIRED WITHIN JR
  300 IF(NN-NNS)398,304,304
C     NO STATIONS WITHIN JR - INCREASE JR AND TRY AGAIN
  398 JR=JR+IDX
      JR2=JR*JR
      JA=JLL*JR
      GO TO 1136
  304 IZGX(I,J)=IZGX(I,J)+IA1/IA2
  214 IZGY(I,J)=IZGY(I,J)+ID1/IA2
  198 CONTINUE
      NNS=0
      CALL SMOOTH(IZGX,IZGE)
      CALL SMOOTH(IZGY,IZGE)
  199 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE MAPFOU(IX1,IY1,IX5,IY5,N1,N5,ID1,IS1,ID5,IS5)
C  PRINTS STATION VALUES ON SECTIONAL MAP
C  TO USE * ENTRY    POSITION MAP AT STANDARD POSITION, SET PRINTER AT
C                    10 LPI, PRINT A ONE LINE HEADER, AND CALL THIS SUB
C            EXIT    MAP IS LEFT AT STANDARD MAP POS
C  RESULTS * PRINTS TWO SETS OF WINDS, DIR AND SPEED ONE LINE ABOVE AND
C              ONE LINE BELOW THE STATION LINE
C     FORM   XXX XX
C               *
C            XXX XX
      CHARACTER LINE1,LINE2,LINE3
      DIMENSION IX1(1),IY1(1),IX5(1),IY5(1),ID1(1),IS1(1),ID5(1),IS5(1),
     *  IX1S(86),IY1S(86),IX5S(86),IY5S(86),LINE1(135),LINE2(135),
     *  LINE3(135)
      IXC=1689 $ IYC=-342
      DO 1 L=1,N1
      IX1S(L)=(IX1(L)-IXC)/10
    1 IY1S(L)=(IY1(L)-IYC)/10
      DO 4 L=1,N5
      IX5S(L)=(IX5(L)-IXC)/10
    4 IY5S(L)=(IY5(L)-IYC)/10
      DO 7 L=1,135
    7 LINE1(L)=LINE2(L)=LINE3(L)=60B
      DO 8 IR=2,125
      DO 9 I=1,N1
      IF(IR.EQ.IX1S(I))10,9
   10 K=IY1S(I)
      IF(K.LT.1.OR.K.GT.135) 9,930
  930 IF(K.LT.4)200,201
  200 K=4 $ GO TO 203
  201 IF(K.GT.133)202,203
  202 K=132
  203 JJ=ID1(I)
      NH=JJ/100 $ NX=JJ-NH*100 $ NT=NX/10 $ NU=NX-NT*10
      LINE1(K-1)=NU
      IF(NH.EQ.0)11,12
   11 IF(NT.EQ.0)13,14
   12 LINE1(K-3)=NH
   14 LINE1(K-2)=NT
   13 LINE2(K)=54B
      JJ=IS1(I)
      NT=JJ/10 $ NU=JJ-NT*10
      IF(NT.EQ.0)15,16
   15 LINE1(K+1)=NU $ GO TO 9
   16 LINE1(K+1)=NT $ LINE1(K+2)=NU
    9 CONTINUE
      DO 20 I=1,N5
      IF(IR.EQ.IX5S(I))21,20
   21 K=IY5S(I)
      IF(K.LT.1.OR.K.GT.135)20,950
  950 IF(K.LT.4)300,301
  300 K=4 $ GO TO 303
  301 IF(K.GT.133)302,303
  302 K=132
  303 JJ=ID5(I)
      NH=JJ/100 $ NX=JJ-NH*100 $ NT=NX/10 $ NU=NX-NT*10
      LINE3(K-1)=NU
      IF(NH.EQ.0)22,23
```

```
   22 IF(NT.EQ.0)24,25
   23 LINE3(K-3)=NH
   25 LINE3(K-2)=NT
   24 LINE2(K)=54B
      JJ=IS5(I)
      NT=JJ/10 $ NU=JJ-NT*10
      IF(NT.EQ.0)26,27
   26 LINE3(K+1)=NU $ GO TO 20
   27 LINE3(K+1)=NT $ LINE3(K+2)=NU
   20 CONTINUE
      PRINT 900,LINE1
  900 FORMAT(1H ,135R1)
      DO 30 L=1,135
      LINE1(L)=LINE2(L)
      LINE2(L)=LINE3(L)
   30 LINE3(L)=60B
    8 CONTINUE
      PRINT 900,LINE1
      PRINT 900,LINE2
      PRINT 902
  902 FORMAT(12(/))
      RETURN
      END
```

```
      SUBROUTINE DIV(IW,IZGX,IZGY)
      DIMENSION IW(21,27),IZGX(21,27),IZGY(21,27)
      COMMON ZFAC,NOS,KNT,NI,NJ,NIM1,NJM1,NOP,IDX,IDY,IXO,IYO,IXFO,IYFO
      COMMON IR(4),IR2(4),IXGP(21),IYGP(27),ICALL(90),JCALL(90)
      DO 724 J=2,NJM1
      DO 724 I=2,NIM1
C   CALCULATE LATITUDE AND IMAGE PLANE SCALE FACTOR
      A1=(IXGP(I)*IXGP(I)+IYGP(J)*IYGP(J))*1.E-4
      PHI=1.5707963-2.*ATAN(SQRT(A1)/46.804209)
      SIG=1.8660254/(1.+SIN(PHI))
      SIG2=SIG*SIG*ZFAC
  724 IW(I,J)=-(IZGX(I+1,J)-IZGX(I-1,J)+IZGY(I,J+1)-IZGY(I,J-1))*SIG2
      RETURN
      END
```

```
      SUBROUTINE POUT(LW)
      DIMENSION LW(21,27)
      COMMON ZFAC,NOS,KNT,NI,NJ,NIM1,NJM1,NOP,IDX,IDY,IXO,IYO,IXFO,IYFO
      COMMON IR(4),IR2(4),IXGP(21),IYGP(27),ICALL(90),JCALL(90)
      PRINT 56,(LW(2,J),J=2,NJM1)
   56 FORMAT(4X,25I5)
      DO 732 I=3,NIM1
  732 PRINT 734,(LW(I,J),J=2,NJM1)
  734 FORMAT(/1H0,3X,25I5)
      RETURN
      END
```

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The NSSL Technical Memoranda, beginning with No. 28, continue the sequence established by the U. S. Weather Bureau National Severe Storms Project, Kansas City, Missouri. Numbers 1-22 were designated NSSP Reports. Numbers 23-27 were NSSL Reports, and 24-27 appeared as subseries of Weather Bureau Technical Notes. These reports are available from the Clearinghouse for Federal Scientific and Technical Information, 5285 Port Royal Road, Springfield, Virginia 22151, for $3.00, and a microfiche version for $0.65. CFTSI numbers are given below in parentheses.

No. 1 National Severe Storms Project Objectives and Basic Design. Staff, NSSP. March 1961. (PB-168207)

No. 2 The Development of Aircraft Investigations of Squall Lines from 1956-1960. B. B. Goddard. (PB-168208)

No. 3 Instability Lines and Their Environments as Shown by Aircraft Soundings and Quasi-Horizontal Traverses. D. T. Williams. February 1962. (PB-168209)

No. 4 On the Mechanics of the Tornado. J. R. Fulks. February 1962. (PB-168210)

No. 5 A Summary of Field Operations and Data Collection by the National Severe Storms Project in Spring 1961. J. T. Lee. March 1962. (PB-165095)

No. 6 Index to the NSSP Surface Network. T. Fujita. April 1962. (PB-168212)

No. 7 The Vertical Structure of Three Dry Lines as Revealed by Aircraft Traverses. E. L. McGuire. April 1962. (PB-168213)

No. 8 Radar Observations of a Tornado Thunderstorm in Vertical Section. Ralph J. Donaldson, Jr. April 19((PB-174859)

No. 9 Dynamics of Severe Convective Storms. Chester W. Newton. July 1962. (PB-163319)

No. 10 Some Measured Characteristics of Severe Storms Turbulence. Roy Steiner and Richard H. Rhyne. July 1962. (N62-16401)

No. 11 A Study of the Kinematic Properties of Certain Small-Scale Systems. D. T. Williams. October 1962. (PB-168216)

No. 12 Analysis of the Severe Weather Factor in Automatic Control of Air Route Traffic. W. Boynton Beckwith. December 1962. (PB-168217)

No. 13 500-Kc./Sec. Sferics Studies in Severe Storms. Douglas A. Kohl and John E. Miller. April 1963. (PB-168218)

No. 14 Field Operations of the National Severe Storms Project in Spring 1962. L. D. Sanders. May 1963. (PB-168219)

No. 15 Penetrations of Thunderstorms by an Aircraft Flying at Supersonic Speeds. G. P. Roys. Radar Photographs and Gust Loads in Three Storms of 1961 Rough Rider. Paul W. J. Schumacher. May 1963. (PB-168220)

No. 16 Analysis of Selected Aircraft Data from NSSP Operations, 1962. T. Fujita. May 1963. (PB-168221)

No. 17 Analysis of Methods for Small-Scale Surface Network Data. D. T. Williams. August 1963. (PB-168222)

No. 18 The Thunderstorm Wake of May 4, 1961. D. T. Williams. August 1963. (PB-168223)

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No. 22 Movement and Development Patterns of Convective Storms and Forecasting the Probability of Storm Passage at a Given Location. Chester W. Newton and James C. Fankhauser. January 1964. (PB-168226)

No. 23 Purposes and Programs of the National Severe Storms Laboratory, Norman, Oklahoma. Edwin Kessler. December 1964. (PB-166675)

No. 24 Papers on Weather Radar, Atmospheric Turbulence, Sferics, and Data Processing. August 1965. (AD-621586)

No. 25 A Comparison of Kinematically Computed Precipitation with Observed Convective Rainfall. James C. Fankhauser. September 1965. (PB-168445).

No. 26 Probing Air Motion by Doppler Analysis of Radar Clear Air Returns. Roger M. Lhermitte. May 1966. (PB-170636)

No. 27 Statistical Properties of Radar Echo Patterns and the Radar Echo Process. Larry Armijo. May 1966. The Role of the Kutta-Joukowski Force in Cloud Systems with Circulation. J. L. Goldman. May 1966. (PB-170756)

No. 28 Movement and Predictablity of Radar Echoes. James Warren Wilson. November 1966. (PB-173972)

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