EPA-600/4-77-049
November 1977

NON-DIVERGENT WIND ANALYSIS ALGORITHM FOR THE ST. LOUIS RAPS NETWORK

by

Terry L. Clark and Robert E. Eskridge
Meteorology and Assessment Division
Environmental Sciences Research Laboratory
Research Triangle Park, NC 27711

Environmental Sciences Research Laboratory
Office of Research and Development
U.S. Environmental Protection Agency
Research Triangle Park, NC 27711

RESEARCH REPORTING SERIES

Research reports of the Office of Research and Development, U.S. Environmental Protection Agency, have been grouped into nine series. These nine broad categories were established to facilitate further development and application of environmental technology. Elimination of traditional grouping was consciously planned to foster technology transfer and a maximum interface in related fields. The nine series are:

1. Environmental Health Effects Research
2. Environmental Protection Technology
3. Ecological Research
4. Environmental Monitoring
5. Socioeconomic Environmental Studies
6. Scientific and Technical Assessment Reports (STAR)
7. Interagency Energy-Environment Research and Development
8. "Special" Reports
9. Miscellaneous Reports

This report has been assigned to the ENVIRONMENTAL MONITORING series. This series describes research conducted to develop new or improved methods and instrumentation for the identification and quantification of environmental pollutants at the lowest conceivably significant concentrations. It also includes studies to determine the ambient concentrations of pollutants in the environment and/or the variance of pollutants as a function of time or meteorological factors.

This document is available to the public through the National Technical Information Service, Springfield, Virginia 22161.

DISCLAIMER

AUTHORS' AFFILIATION

The authors are on assignment with the U.S. Environmental Protection Agency from the National Oceanic and Atmospheric Administration, U.S. Department of Commerce.

ABSTRACT

An objective wind analysis algorithm capable of producing non-divergent wind fields at up to ten levels in the atmospheric boundary layer for St. Louis, Missouri is described. Wind data collected during the St. Louis Regional Air Pollution Study (RAPS) and averaged over 15-minute intervals were used to construct u and v wind component fields on a 46 by 46 grid network with a grid spacing of 1 km via a scan-radius technique. The divergence across grid squares was minimized by a non-divergence algorithm.

Several analyses produced by the algorithm are illustrated. A user's guide and computer program listing are included.

CONTENTS

FIGURES

TABLES

ACKNOWLEDGEMENT

The typing of the drafts and final versions of this manuscript by Ms. Bess Flowers was greatly appreciated.

1. INTRODUCTION

The non-divergent wind field analysis procedure presented in this report utilizes modifications of techniques developed by Hovland et al. (1976) of Control Data Corporation (CDC) and Liu and Goodin (1976). The CDC objective analysis procedure generates, via a weighted scan radius technique, a horizontal wind field, which is not divergent-free. The Liu and Goodin procedure adjusts this field to produce a horizontal, divergent-free wind analysis. Divergent-free wind fields are required in most Eulerian air pollution models; Shir and Shieh's (1975) sulfur dioxide model and the Systems Applications, Inc. photochemical model (Reynolds et al., 1973) are examples.

These models treat the atmosphere as several vertically-stacked, two-dimensional layers. This implies, of course, that the vertical velocity is zero everywhere. If the two-dimensional velocity field is not divergent-free, or at least the divergence is small ($\vec{\nabla}_2 \cdot \vec{v} < 10^{-5} \sec^{-1}$), the divergence will act as a source or sink term (depending on the sign of the divergence) when the pollution species conservation equations are solved by numerical techniques.

The influence of the divergence on the calculated concentrations can be explained by first examining the simplest conservation-of-species equation

$$\frac{\partial c}{\partial t} = -\vec{\nabla}\cdot c\vec{V} \quad ,$$

where c is the concentration of a pollutant and $\vec{V}$ the wind. This equation can be written as

$$\frac{\partial c}{\partial t} = -\vec{V}\cdot\vec{\nabla}c \quad -c\vec{\nabla}\cdot\vec{V} \quad .$$

The first term on the right represents the change in the concentration due to advection and the second term represents the change due to confluence or difluence of the wind. If $\vec{\nabla}\cdot\vec{V} > 0$ (difluence), pollutant is lost from the system and if $\vec{\nabla}\cdot\vec{V} < 0$ (confluence), pollutant is added.

The non-divergent wind fields are constructed by first analyzing the wind field using the technique developed by Hovland et al. This objective analysis technique was originally developed for the St. Louis RAPS network for a grid which was 21 by 21 grid points with a spacing of 5 km. The technique was modified so that the procedure could be employed to construct wind fields on a grid which was 46 by 46 grid points with a spacing of 1 km. The resulting wind fields are two-dimensional and are not divergent-free.

The CDC wind fields (referred to as first-guess fields) are adjusted to generate divergent-free, vertically-stacked fields in the boundary layer by the technique developed by Liu and Goodin. From Liu and Goodin's routine, the computed winds at the grid points represent an average wind and have no vertical structure. Their published technique was modified to produce smoother wind fields and a divergent-free wind field at any level or levels in the boundary layer specified by the user.

The objective analysis techniques of Hovland et al. and Liu and Goodin and the modifications made by the authors are described in Sections 2 and 3, respectively. Section 4 illustrates and discusses several examples of the resultant wind fields using 15-minute averaged RAPS data. Section 6 is a user's guide to the computer program. The final section contains a listing of the computer program.

2. MODIFIED CDC OBJECTIVE ANALYSIS PROCEDURE

The modified version of the Control Data Corporation objective analysis procedure attempts to describe the u and v wind fields across an equally-spaced grid using time-averaged data from an unequally-spaced data network with a high density of stations in the center (see Fig. 1). This is performed via an iterative process using a variable-scan-radius technique. The values computed at the grid points after m

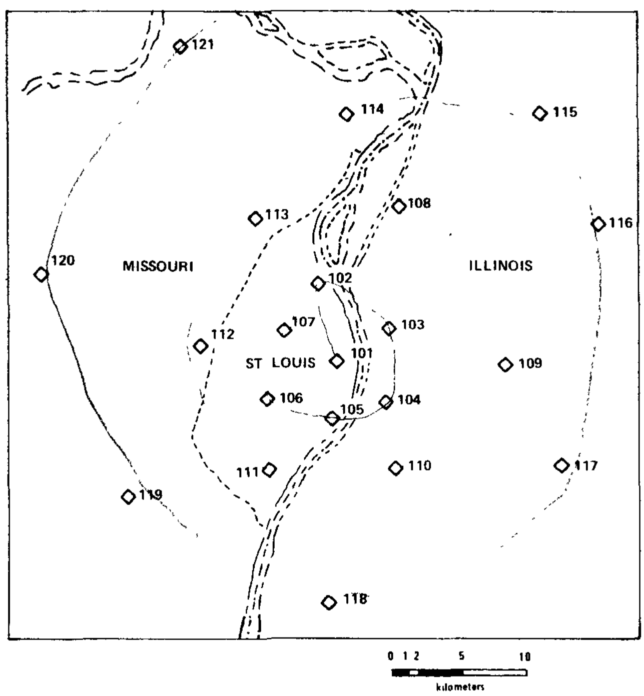

Figure 1. Analysis domain considered from a portion of the Regional Air Pollution Study (RAPS) monitoring network at St. Louis, Missouri. Winds at sites 108, 110, 114-118 were measured at the 10-meter level and at the 30-meter level elsewhere.

iterations ($X^m_{i,j}$) are based upon the observations at K data points (O^k), which lie within a circle of specified radius (R), and a weighted correction factor.

The original CDC procedure uses data from all 25 RAPS stations and a 21 by 21 grid with a 5 km grid spacing. The prescribed number of observation points and scan radii (measured in terms of grid points) used for the five iterations were 4,12,12,25,25 and 20,14,7,4,1, respectively. The number of the iterative step when data from the stations were first incorporated into the analysis is given in Fig. 2. This procedure uses data from the four outlying observation points (not within the grid domain illustrated by Fig. 1) and a large scan radius for the first iteration. With each subsequent iteration, data from additional observational points and a smaller scan radius are employed. Data from the inner-most observation points are used only when the scan radii are small.

The modified version uses a 46 by 46 grid with a grid spacing of 1 km. The grid domain does not include the four outer-most RAPS stations and the data from these stations are not used. New sets of data points and scan radii used for each iteration were established empirically. These new sets are 7,12,21,21,21, and 46,20,10,5,1, respectively. The highest numbered stations in Figure 1 are always used before the lower ones.

A rejection scheme is included to ignore data thought to be in error. Prior to the first iterative step, the standard deviations of the u and v components of the data are calculated. All components with values greater than $\pm 4\sigma$ from the mean are labeled as incorrect and

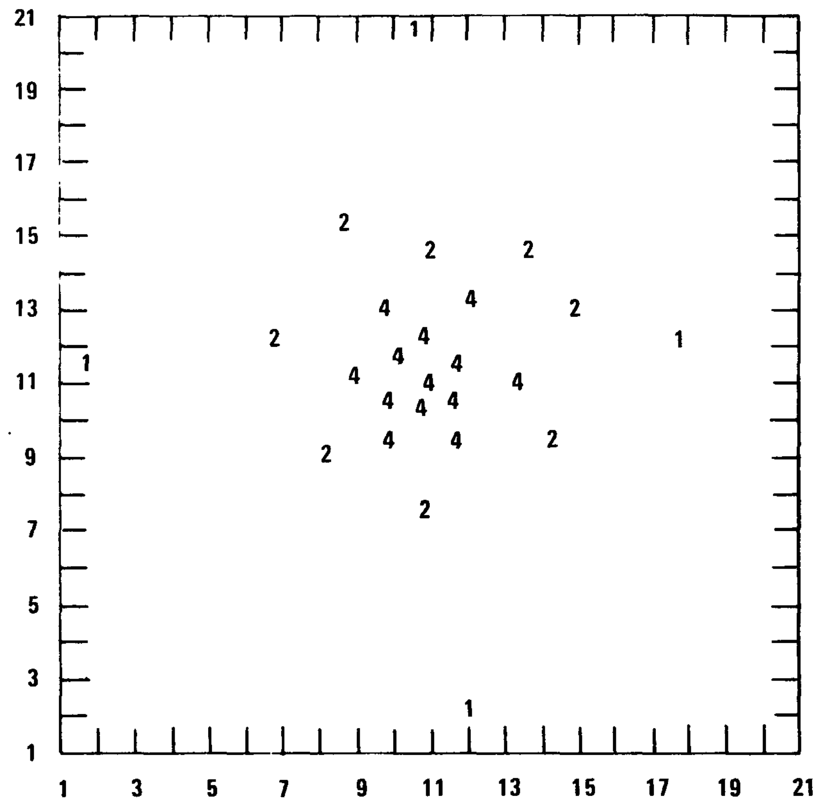

Figure 2. Analysis domain for the original CDC objective analysis technique. The numbers inside the grid boundary correspond to station locations and represent the number of the iterative step when the data value was used.

are ignored during the analysis procedure. If one component of the wind at a data point is ignored, the other component is likewise ignored.

After the gross errors in the data have been removed, the analysis begins with defining a first-guess field. The original version of the procedure used a field of zeroes, while the modified version defines the field as a uniform field of values equal to the mean of the data. In theory, the analysis would converge faster when the first-guess field is more comparable to the data.

The first-guess field is adjusted repeatedly until the values at each grid point converge. After five iterations, the values converge (tolerance of 0.1 m sec^{-1}). the grid point values are adjusted by

$$X^m_{i,j} = X^{m-1}_{i,j} + \frac{\sum_{k=1}^{K} W^k_{i,j}\ C^{k,m}}{\sum_{k=1}^{K} W^k_{i,j}} \quad , \qquad (1)$$

where K is the number of data points within the scan circle centered at the grid point i,j; $W^k_{i,j}$ is a weighting factor (described later); and $C^{k,m}$ is a correction factor determined at the m^{th} iteration for each of the non-rejected observations.

The value of the correction factor ($C^{k,m}$) is determined by substracting from the data value (O^k) the interpolated value from the previous iteration ($I^{k,m-1}_{i+p,j+q}$) at a point corresponding to the location of the station point

$$C^{k,m} = O^k - I^{k,m-1}_{i+p,j+q} \quad , \qquad (2)$$

where p and q are the distances along the x and y areas, respectively, from the observation point to the grid point (i,j). The four-point interpolation scheme is illustrated in Fig. 3 and given by

$$I^{k,m}_{i+p,j+q} = (1-p)\ (1-q)\ X_{i,j} + p(1-q)\ X_{i+1,j} + q(1-p)\ X_{i,j+1} + pq\ X_{i+1,j+1}\ . \qquad (3)$$

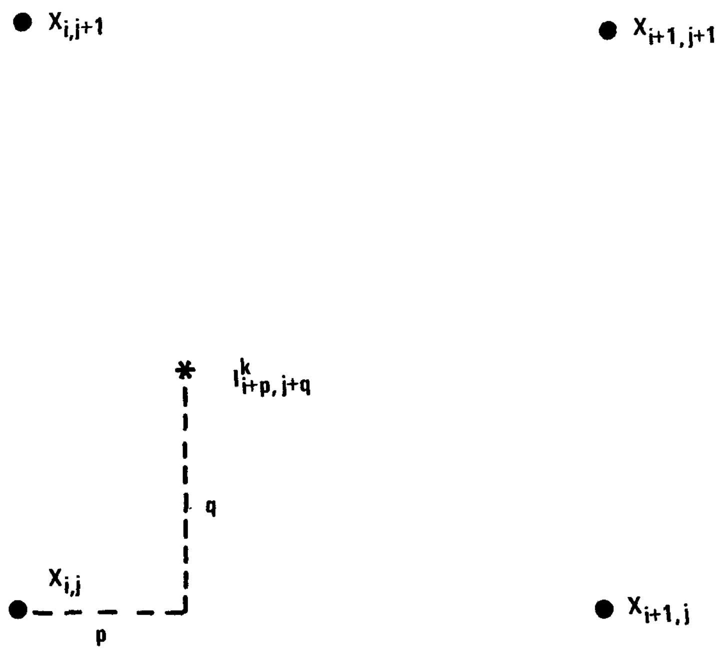

Figure 3. Illustration of the four-point interpolation scheme used to interpolate the value $I^k_{i+p,j+q}$ at a position on the grid corresponding to the location of observation point 'k' denoted by '*'.

The correction factor determined at a station point is applied to those grid points within a specified distance (R) of the station point (Fig. 4). The actual correction applied to the grid point value of the previous iterative step is weighted as a function of distance (r^k) between the grid point and the station point. The values at the station points would have no direct influence on those values at grid points outside the circle of radius R ($W^k_{i,j} = 0$ when $r^k \geq R$). The weighting function, illustrated by Fig. 5, is defined as

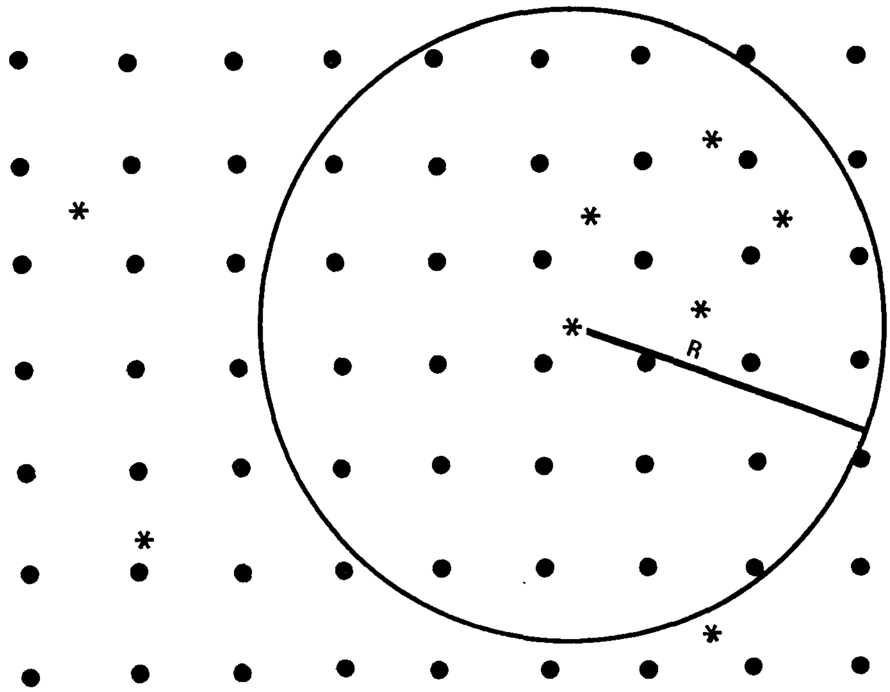

Figure 4. Scan circle centered at a station (*) enclosing 29 grid points.

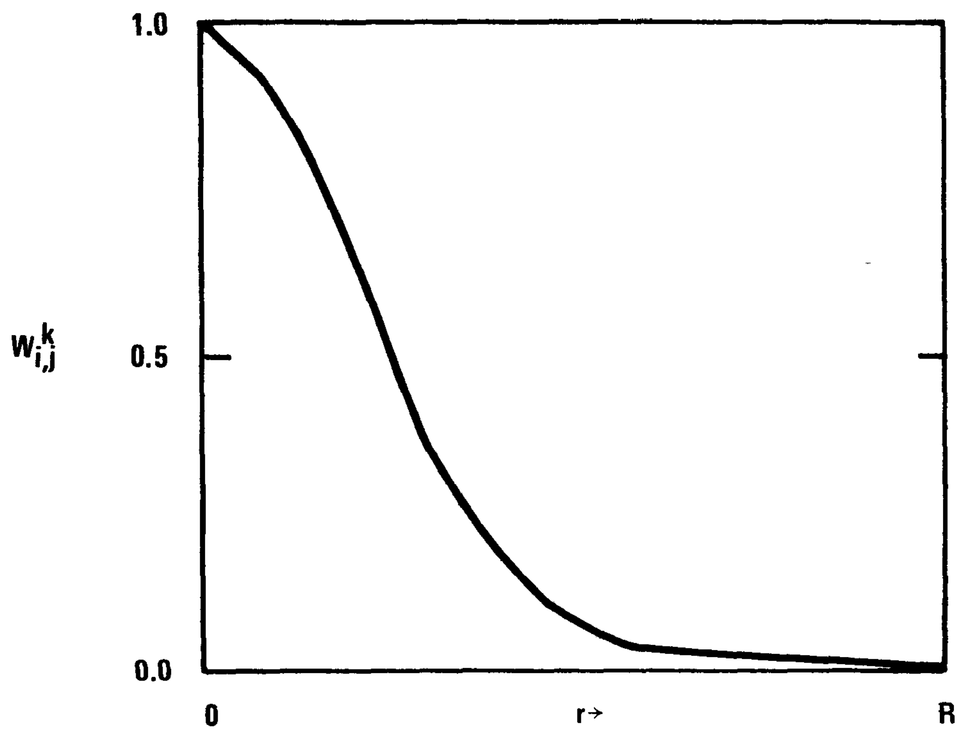

Figure 5. Depiction of weighting function, $W^k_{i,j}$, where R is the scan radius and r is the distance from grid point (i,j) to station (k).

$$W^k_{i,j} = \begin{cases} \left[\dfrac{R^2 - (r^k_{i,j})^2}{R^2 + (r^k_{i,j})^2}\right]^4 & r^k_{i,j} \leq R \\ 0 & r^k_{i,j} > R \end{cases} \qquad (4)$$

Since the data points are unevenly-spaced and concentrated in the center of the grid, the number of observation points and/or the scan radius are changed with each iteration. If all the data were used in each iteration with large scan radii, the gradients observed in the center of the grid, where the density of observation points are high, would be propagated outward. Furthermore, if the scan radii were not changed with each iteration, the radii would have to be large enough to guarantee that every grid point was within R grid points of at least one data point. This would result in a very smooth, non-representative analysis.

The application of this technique requires the availability of reliable data at the outer-most observation points, since the field created using this set of data in the first iteration greatly influences the final analysis. Moreover, when data are missing or ignored from several of the data points, the data configuration is altered. For this case, the chosen set of stations and radii may not yield an acceptable analysis.

3. MODIFIED NON-DIVERGENT WIND FIELD ANALYSIS PROCEDURE

The algorithm of Liu and Goodin adjusts the wind field (generated by the technique discussed in Section II) in order to construct a divergent-free wind field. This adjustment process usually makes only small changes in the value at any grid point. Therefore, if the analysis to be adjusted by the algorithm is poor, it will most likely remain poor.

The algorithm is based upon the uniform adjustment of values at grid points (i-1,j), (i+1,j), (i,j-1), and (i,j+1) using the divergence calculated at (i,j). The grid is scanned repeatedly until the maximum divergence meets an arbitrary value.

The simplest approximation to the continuity equation in a non-staggered grid (u,v defined at every point) is

$$D_{i,j} = \frac{u_{i+1,j} - u_{i-1,j}}{2\Delta x} + \frac{v_{i,j+1} - v_{i,j-1}}{2\Delta y} . \quad (6)$$

Liu and Goodin define the following relationships (the equal signs should be interpreted as replacement operations):

$$\begin{aligned} u_{i+1,j} &= u_{i+1,j} + f_{i+1,j}\,\tilde{u}_{i,j} , \quad (7)\\ u_{i-1,j} &= u_{i-1,j} - f_{i-1,j}\,\tilde{u}_{i,j} ,\\ v_{i,j+1} &= v_{i,j+1} + f_{i,j+1}\,\tilde{v}_{i,j} ,\\ v_{i,j-1} &= v_{i,j-1} - f_{i,j-1}\,\tilde{v}_{i,j} . \end{aligned}$$

where $f_{i,j}$ is a weighting factor. By substituting (7) into (6), Liu and Goodin find

$$\tilde{u}_{i,j} = -D_{i,j}\,\Delta x\,/\,(f_{i+1,j} + f_{i-1,j}), \qquad (8)$$
$$\tilde{v}_{i,j} = -D_{i,j}\,\Delta y\,/\,(f_{i,j+1} + f_{i,j-1}).$$

Liu and Goodin's procedure is as follows: first, the divergence is calculated by (6); second, $\tilde{u}_{i,j}$ and $\tilde{v}_{i,j}$ are calculated by (8) and then new values of u and v are calculated using (7). This procedure is repeated until $D_{i,j}$ is reduced to some desired level. The results depicted in Fig. 6 show a wind field that is somewhat irregular and not very satisfactory.

If one substitutes (7) into (6) and collects terms, this yields

$$(f_{i+1,j} + f_{i-1,j})\,\tilde{u}_{i,j}/2\Delta x + (f_{i,j+1} + f_{i,j-1})\tilde{v}_{i,j}/2\Delta y + D_{ij} = 0 \qquad (9)$$

from which (8) is derived. However, a second formulation of $\tilde{u}$ and $\tilde{v}$ is available. If the formulation of $\tilde{u}_{i,j}$ and $\tilde{v}_{i,j}$ given by Liu and Goodin for the eight point continuity equation is used, it can be reduced to a four point form,

$$\tilde{u}'_{i,j} = -2D_{i,j}\,\Delta x\,/\,(f_{i,j+1} + f_{i,j-1} + f_{i+1,j} + f_{i-1,j}), \qquad (10)$$
$$\tilde{v}'_{i,j} = -2D_{i,j}\,\Delta y\,/\,(f_{i,j+1} + f_{i,j-1} + f_{i+1,j} + f_{i-1,j}).$$

Substitution of (10) into (9) shows that (10) is also a solution.

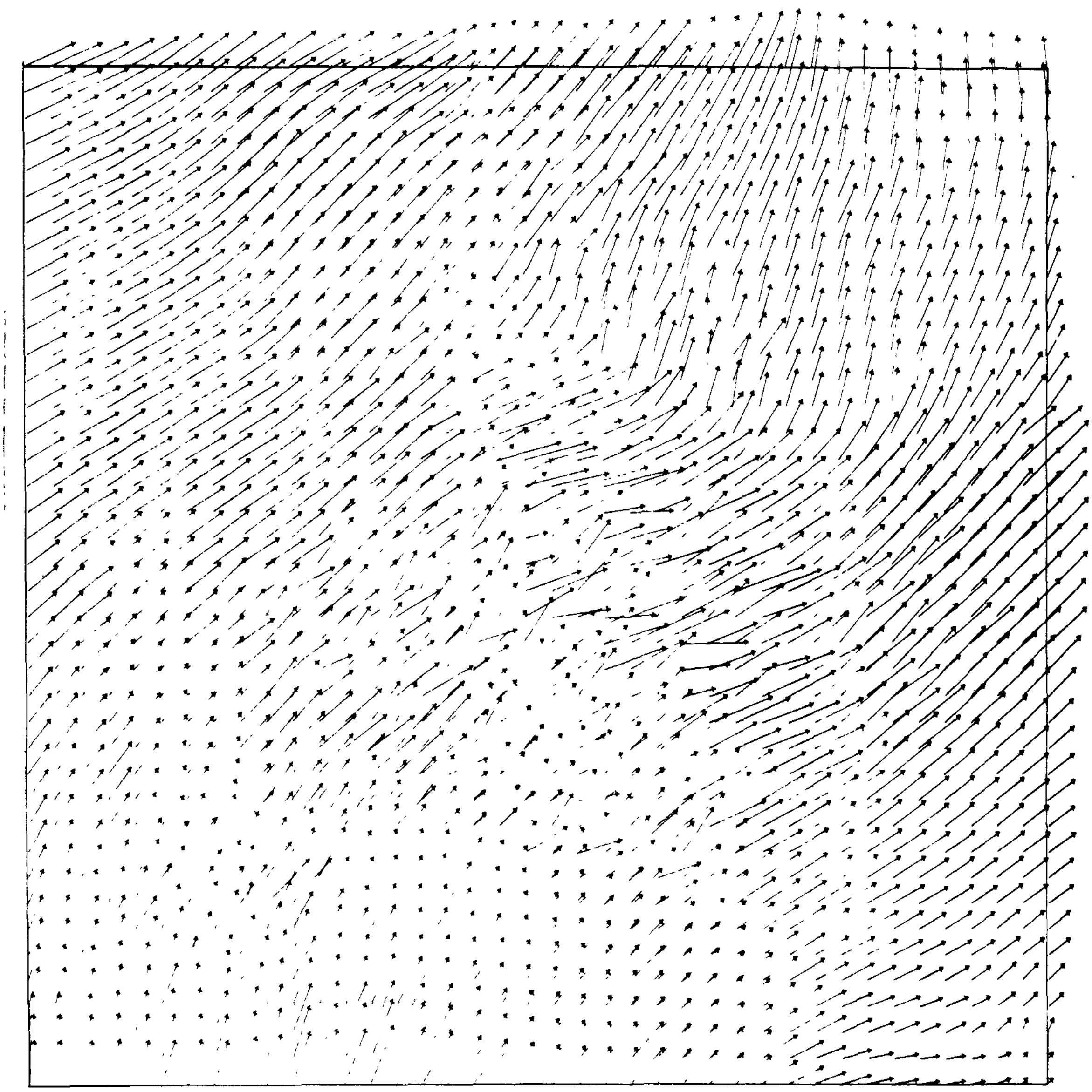

Figure 6. Analyzed wind field from the original Liu and Goodin technique.

The procedure used in this modified technique is to first calculate the divergence by (6), then $\tilde{u}'_{i,j}$ and $\tilde{v}'_{i,j}$ are calculated by (10). Finally, the new values of u and v are calculated using (7) after $\tilde{u}'$ and $\tilde{v}'$ are substituted for $\tilde{u}$ and $\tilde{v}$. The results of using this variation of the algorithm are shown in Fig. 7.

Fig. 7 clearly shows a smoother wind field to that of Fig. 6. To see the reason that (10) is a superior formulation it is necessary to examine the grid point weighting technique used in this modified algorithm. The grid point nearest the data point is treated as the station and assigned a weight of .25. The adjacent grid points are assigned weights of .50 and all other points are given a weight of 1.00 (see Fig. 8).

It is apparent from (10) and (8) that

$$\tilde{u}_{i,j} = \tilde{u}'_{i,j} \quad , \tag{11}$$

at grid points nearest data points and

$$\tilde{u}_{i,j} = -0.8D_{i,j}\Delta x \quad \text{and} \quad \tilde{u}'_{i,j} = -0.61D_{i,j}\Delta x \tag{12}$$

at grid points located one grid length from the grid points nearest the data points. Similar relationships hold for $\tilde{v}$ and $\tilde{v}'$. At a point 2 grid points away from the station,

$$\tilde{u}_{i,j} = -0.6667\ D_{i,j}\ \Delta x \quad \text{and} \quad \tilde{u}'_{i,j} = -0.57\ D_{i,j}\ \Delta x. \tag{13}$$

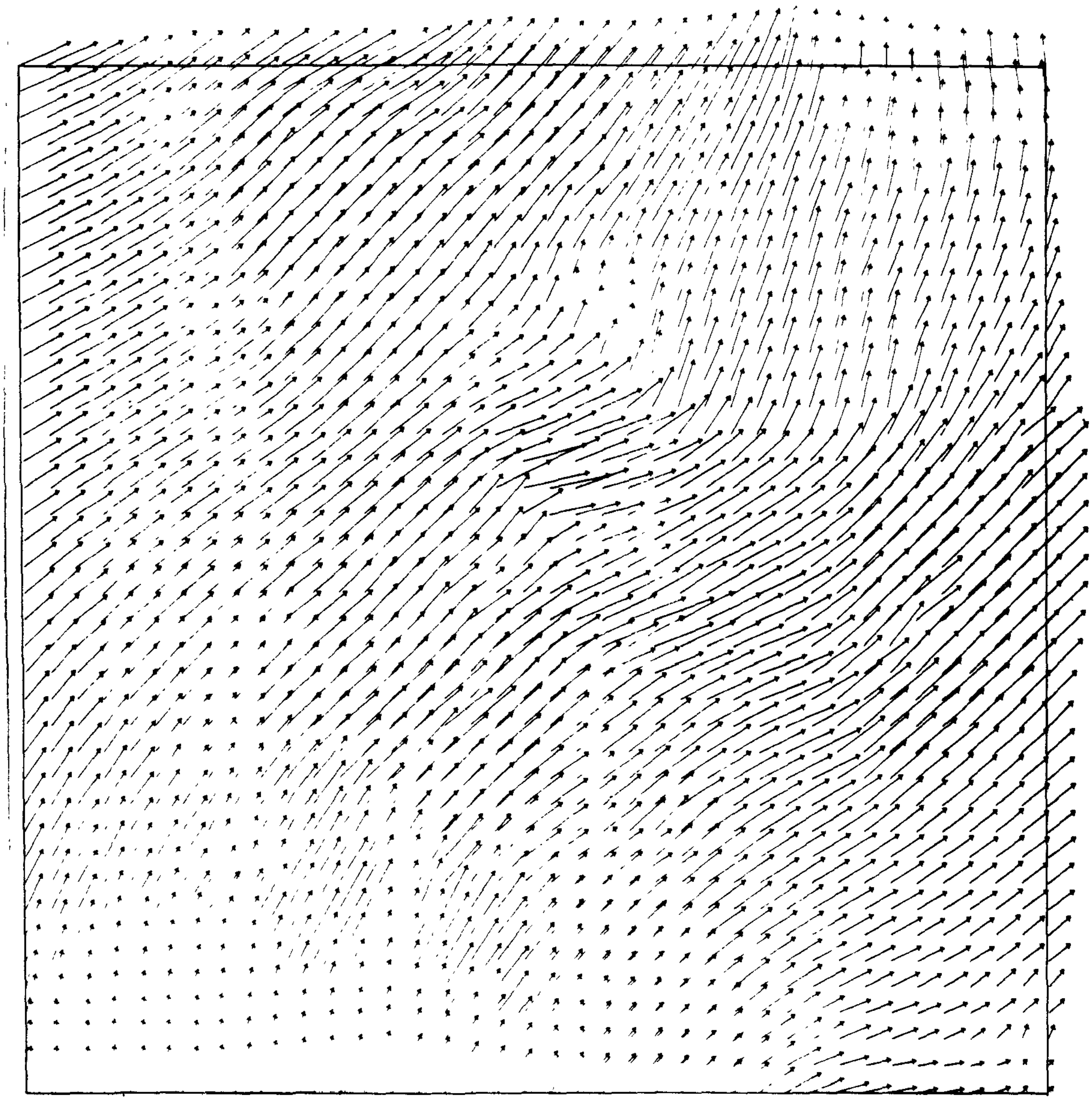

Figure 7. Analyzed wind field from the modified Liu and Goodin technique (using identical data to those in Figure 6).

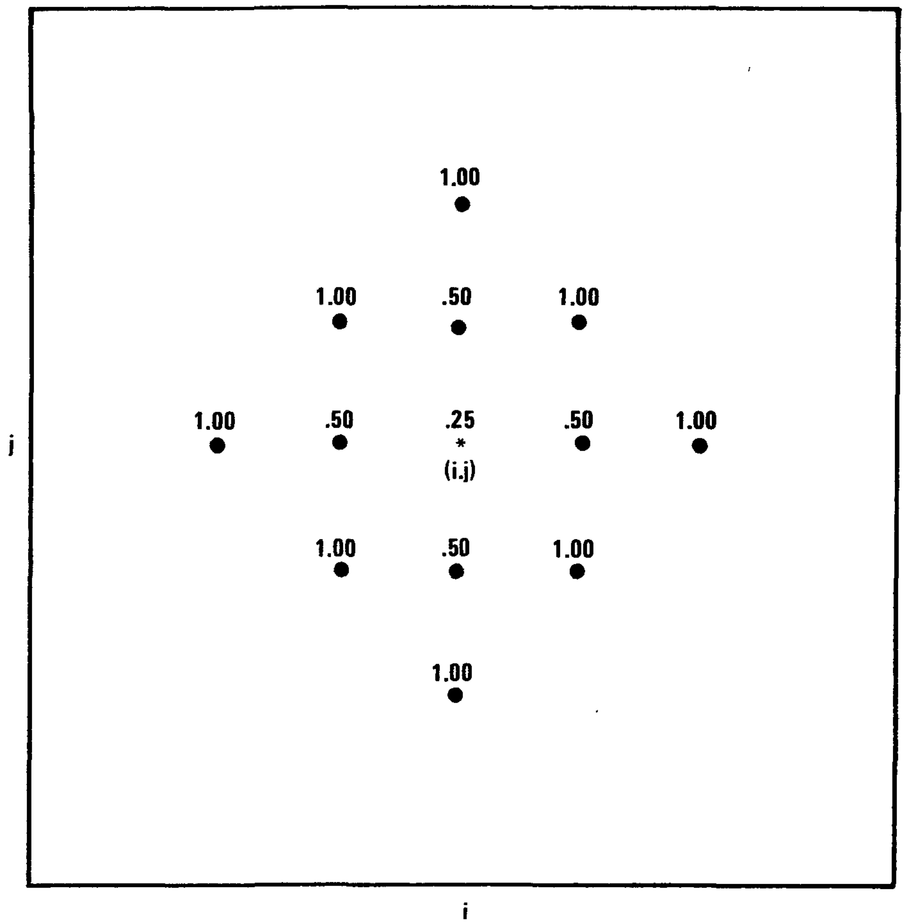

Figure 8. Weighting of grid points at and around a station denoted by '*' for the Liu and Goodin analysis procedure.

Now at a grid point 3 grid points away, it is found again that

$$\tilde{u}_{i,j} = \tilde{u}'_{i,j} \quad . \tag{14}$$

In effect, what occurs is that the correction at each iteration is smaller in the modified algorithm that the one given by Liu and Goodin resulting in a smoother analysis.

It should be noted that an iteration level does not appear in the above equations as it does in the equations in Liu and Goodin's paper. In a recent paper by Eskridge (1977), it has been shown that new values of u and v must be used as soon as they are calculated instead of maintaining two separate iterative levels as the Liu and Goodin paper implies.

In addition Eskridge (1977) demonstrates that the use of a four-point continuity equation in a non-staggered grid results in the iteration procedure acting as if there are two separate grids (Fig. 9) which do not interact or affect neighboring points at anytime. This division of the grid into two independent subgrids will result in an analysis with large oscillations of wavelength $2\Delta x$ if incorrect boundary conditions are used.

An examination of the computer code used by Liu and Goodin shows that they minimized this problem by setting the gradient at the boundary equal to zero. In other words, they connected the two independent grids at the boundary through common values. One can still expect to see some oscillation in the wind field analysis. However, it has been small and does not appear to be much of a problem.

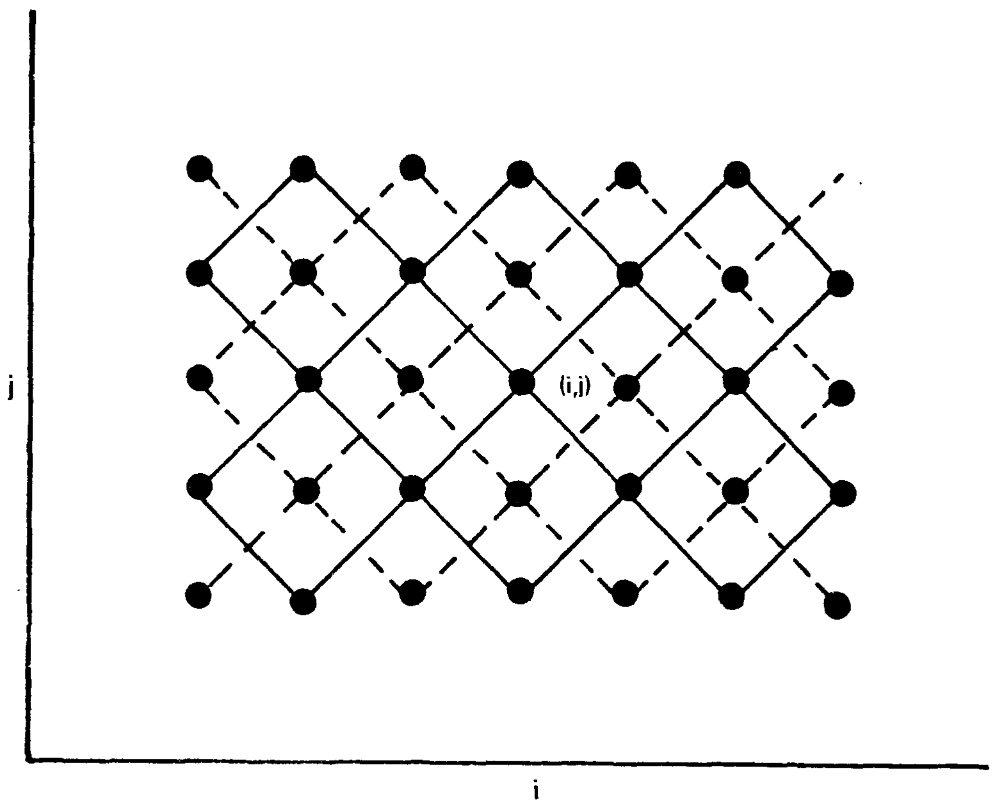

Figure 9. A portion of the computational grid showing the two independent subgrids.

4. ANALYSIS FIELDS

Both the first-guess and final wind analysis (i.e. divergent and divergent-free) fields from five different time periods are illustrated in this section. The 46 by 46 grid point fields are composed of vectors with points of origin corresponding to the grid points. These vectors point in the direction of the flow and have lengths proportional to the wind speed at the grid point. (0.6 cm vector length represents a wind speed of 1.0 m/sec).

The data used in the analyses were sampled and averaged over a 15-minute period at 20 of the 25 RAPS stations during selected periods in August of 1975. During this month station 111 was not operating. Of the periods selected, two involved cases where the wind field was relatively uniform. These two cases are discussed first.

The first-guess and final analysis fields for the first period are illustrated by Figures 10 and 11, respectively. The data used in these analyses were averaged temporally over the 15-minute period centered around 7:07 a.m. (C.S.T) of August 15. Most of the average winds during this period ranged in direction from 211 to 240° and in speeds from 1.8 to 3.2 m/sec. Those stations having average directions and speeds out of these ranges are listed in Table 1. The average winds at station 102 were noticeably different than winds measured at adjacent stations throughout the cases investigated. Although questionable, they were not rejected by the rejection criteria in the procedure.

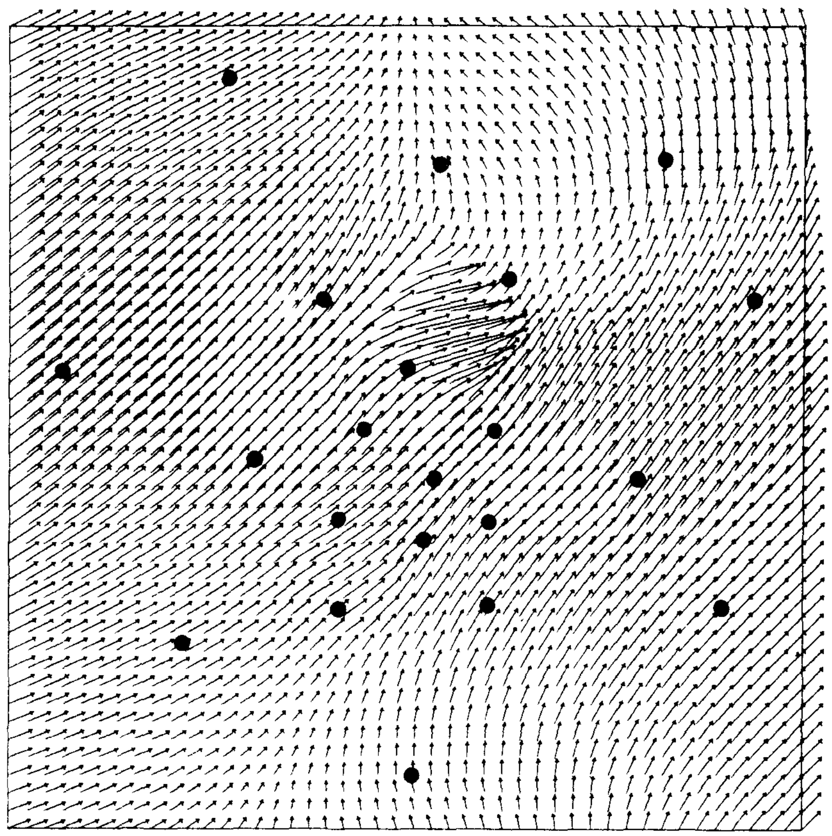

Figure 10. First-guess analysis for averaged data centered around 7:07 A.M. (C.S.T.) for August 15, 1975, St. Louis (RAPS).

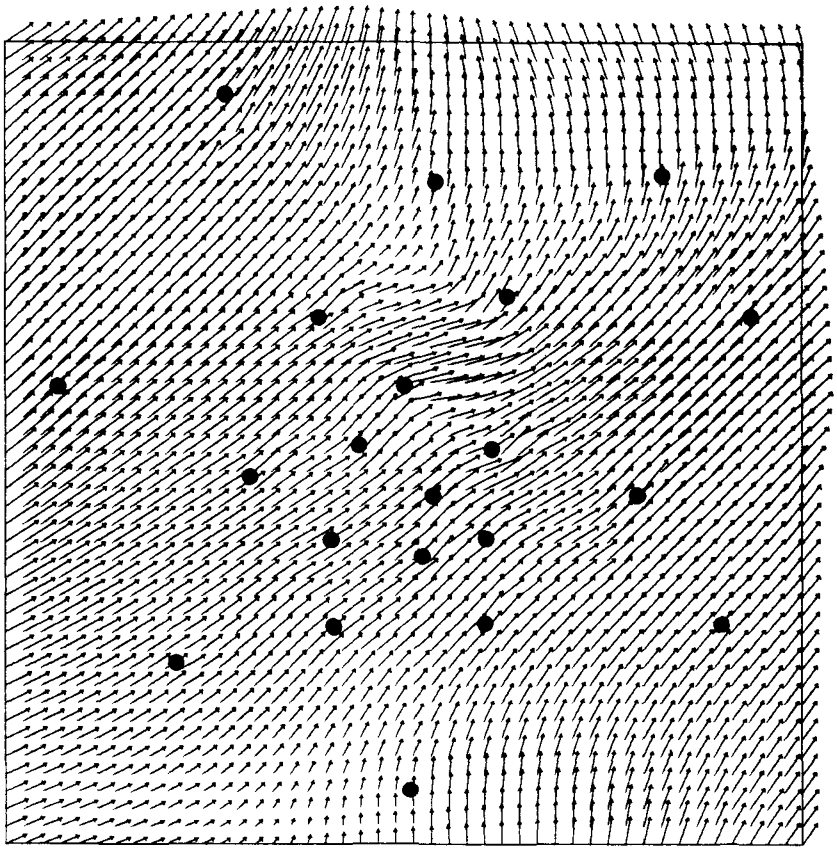

Figure 11. Non-divergent analysis for averaged data centered around 7:07 A.M. (C.S.T.) for August 15, 1975, St. Louis (RAPS).

Table 1. STATIONS HAVING AVERAGE WIND DIRECTIONS AND SPEEDS OUT OF THE RANGE 211 TO 240° AND 1.8 TO 3.2 M/SEC, RESPECTIVELY FOR THE ANALYSIS ILLUSTRATED BY FIGURES 10 AND 11

Station Number	Average Wind Direction	Average Wind Speed
102	260°	4.1 m/sec
108	199	0.9
114	155	0.8
115	173	1.3
118	181	1.0

The wind values listed in Table 1 were likely indications of the presence of mesoscale features of the atmosphere. By averaging the data over 15-minute periods, these features, which are significant in determining actual flow patterns, would not be ignored.

The CDC analysis (Fig 10) shows the variability in the wind near those stations listed above. As can be readily seen, especially north and northeast of St. Louis, the analysis is not divergent-free. This analysis was adjusted to minimize the divergence. The final analysis, illustrated by Figure 11, was generated by adjusting the u- and v-wind components at every grid point so that the quantity

$$\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y}$$

was minimized by the technique described in Section 3.

The most noticeable adjustment occurred in the area near station 102 and 108. The flow pattern here was made less chaotic. Another noticeable adjustment occurred near the middle of the top border where the flow converged. The wind speeds were greatly increased here and, to a lesser extent, near station 114. It should be noted, with the exception of the area near station 102, that the large adjustment in the CDC analysis occurred in areas outside the data network. Moreover, the wind determined at a grid point near a station will not always be exactly what was observed.

Figure 12 shows the first-guess field of the flow using 15-minute-averaged data centered around 7:37 a.m. (C.S.T.) for August 15. These wind data were observed half an hour after the data used for the analysis in Figures 10 and 11.

All the stations, but one, had average wind speeds in the range of 1.4 to 3.4 m/sec. Station 102 had an average wind speed of 4.3 m/sec. Most of the stations had average wind directions falling into the 216 to 249^{o} range. Those stations having average wind directions out of this range are listed in Table 2.

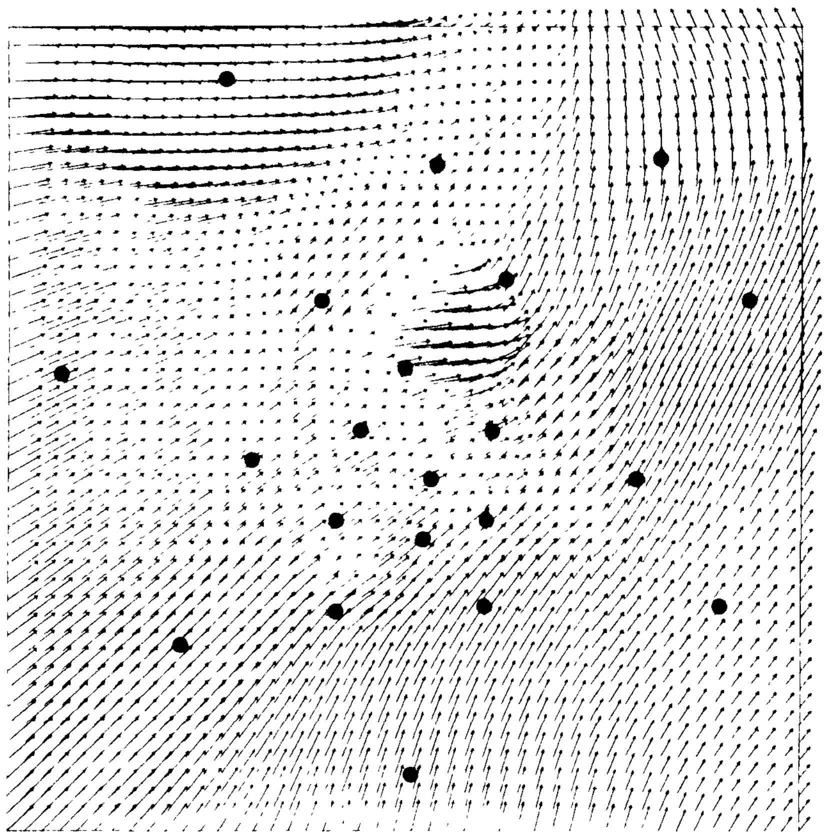

Figure 12. First-guess analysis for averaged data centered around 7:37 A.M. (C.S.T.) for August 15, 1975, St. Louis (RAPS).

Table 2. STATIONS HAVING AVERAGE WIND DIRECTIONS OUT OF THE 216 TO 249° RANGE FOR THE ANALYSIS ILLUSTRATED BY FIGURES 12 AND 13

Station Number	Average Wind Direction
102	265°
108	204
109	210
115	174
116	204
118	199
121	267

The influence of the data on the analysis from the outlying stations is illustrated in the upper-left corner of Figure 12. Many more grid point values are affected by the outlying stations than the inner stations. The average wind direction at station 121 is different than the others, but the grid point values in the corner reflect the value observed at this single station.

Figure 13 shows the non-divergent analysis after the winds were adjusted. Like the adjustment of the analysis of the previously mentioned period, the wind speeds near the top of the border of the grid were increased to compensate for the extensive convergence pattern. The analysis in the area near stations 102, 108, and 121 has been noticeably adjusted resulting in a smoother, non-divergent flow.

The next two analyses, illustrated by Figures 14 and 15, were generated using data averaged over the 15-minute period centered around

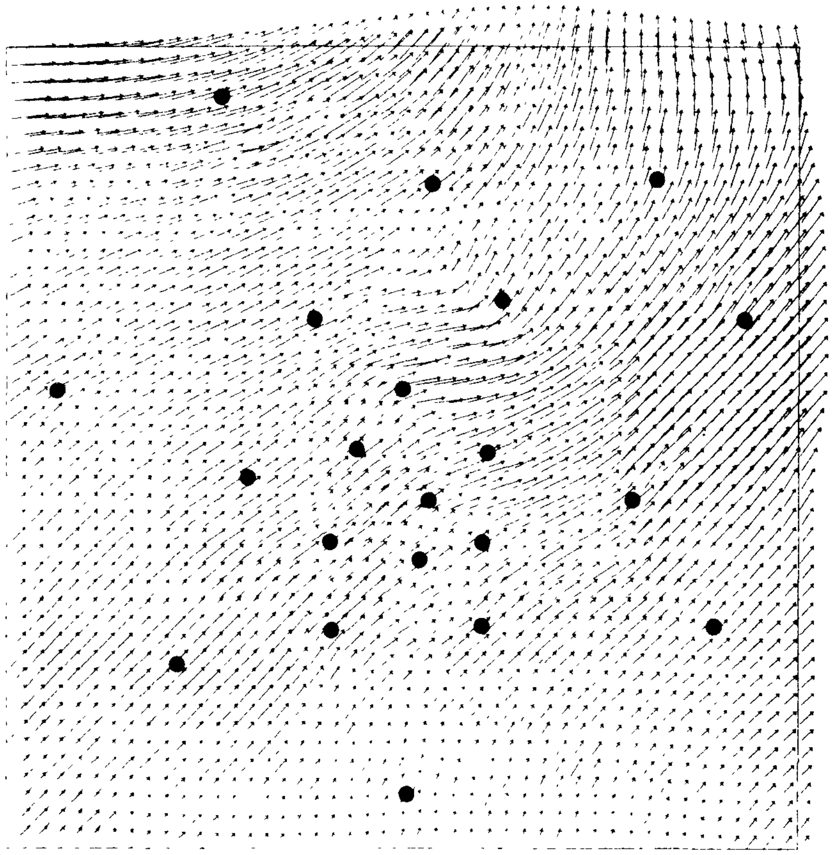

Figure 13. Non-divergent analysis for averaged data centered around 7:37 A.M. (C.S.T.) for August 15, 1975, St. Louis (RAPS).

8:22 a.m. (C.S.T) for August 15. These data were observed 45 minutes after the data analyzed in Figures 12 and 13 were observed.

Except for station 111, the set of data was complete and contained average wind directions which were more variable in the urban area than in the other sets. Most of the average wind directions ranged from 208 to 257° and the average wind speeds, with one exception, ranged from 1.7 to 3.6 m/sec. Station 102 had an average wind speed of 4.8 m/sec. Stations with average wind directions not in this range are listed in Table 3.

Table 3. STATIONS HAVING AVERAGE WIND DIRECTIONS OUT OF THE RANGE 208 to 257°, FOR THE ANALYSIS ILLUSTRATED BY FIGURES 14 AND 15

Station Number	Average Wind Direction
102	286°
105	189
114	200
121	273

The first-guess wind field analysis (Fig. 14) depicts the large variability in the wind direction. The average wind direction near stations 105 and 106 differed nearly by 60° and the average wind direction near station 102 differed by nearly 45° from the surrounding area.

The final analysis (Fig. 15) shows that the major adjustments occurred in the areas near stations 102, 108, and 106 and on the top center of the grid. The wind speeds were decreased slightly in the lower-left

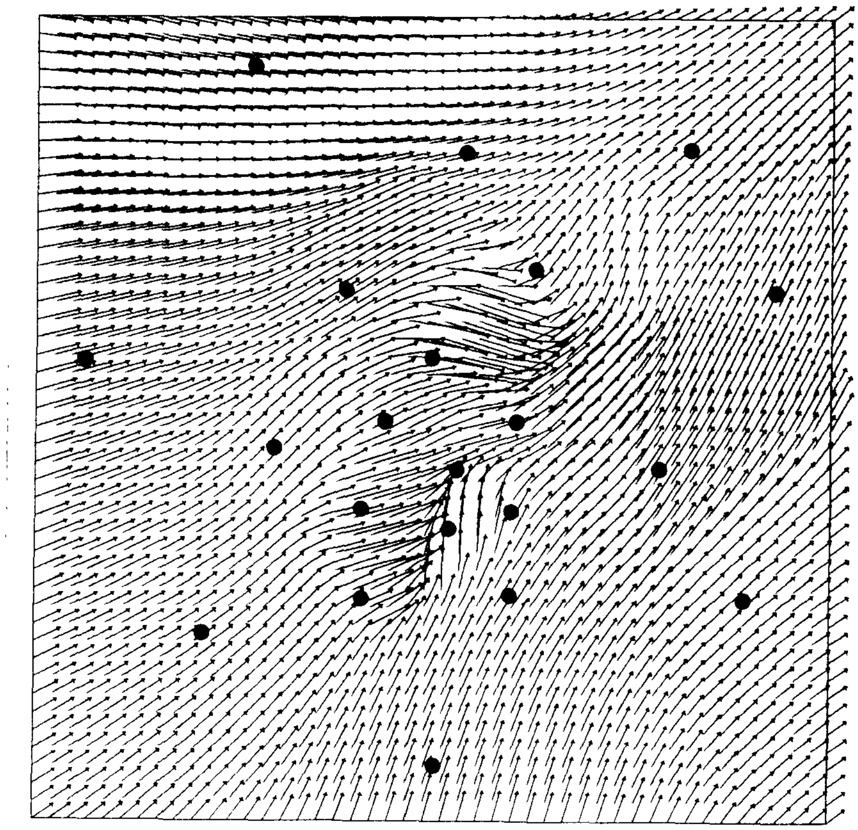

Figure 14. First-guess analysis for averaged data centered around 8:22 A.M. (C.S.T.) for August 15, 1975, St. Louis (RAPS).

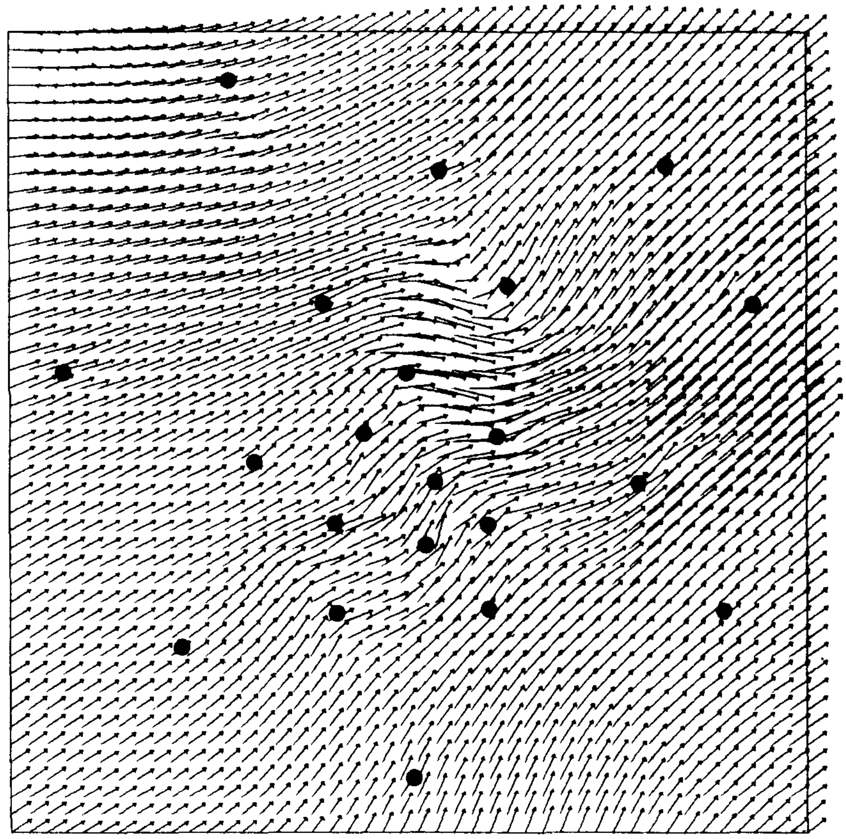

Figure 15. Non-divergent analysis for averaged data centered around 8:22 A.M. (C.S.T.) for August 15, 1975, St. Louis (RAPS).

corner and increased near the upper segment of the right border. As in this case, significant changes in the u- and v- wind components usually occurred outside the station network.

Figure 16 illustrates another analysis using data which were not uniform over the urban area. Data from stations 111 and 114 were missing during this period centered around 11:37 a.m. (C.S.T.) for August 14. The average wind direction ranged from 136 to 183^{o}, while most of the average wind speeds fell in the 3.3 to 4.8 m/sec. range. Stations 102 and 103 had average wind speeds of 6.6 and 5.7 m/sec., respectively.

The CDC wind analysis outside the city was fairly uniform with the winds from the south southeast at approximately 4 m/sec. The wind near stations 102, 103, 112 was more southerly at about the same speed. Therefore, areas of convergence occurred over the city.

The u- and v- components of the wind in these areas were adjusted to minimize the divergence. This non-divergent analysis, illustrated by Figure 17, might not appear to be as smooth as the previously discussed analyses. Due to the higher wind speeds and gradual wind direction changes near station 102, 103, 113, the longer vectors intersect others at angles, making the field appear chaotic.

The last pair of figures (Figs 18 and 19) illustrates the analyses for the 15-minute-averaged data centered around 2:37 p.m. (C.S.T.) for August 13. At this time, a squall line was moving through St. Louis from the northwest at approximately 20 km/hr. The position of the squall line during this time period can be located at grid points with west winds.

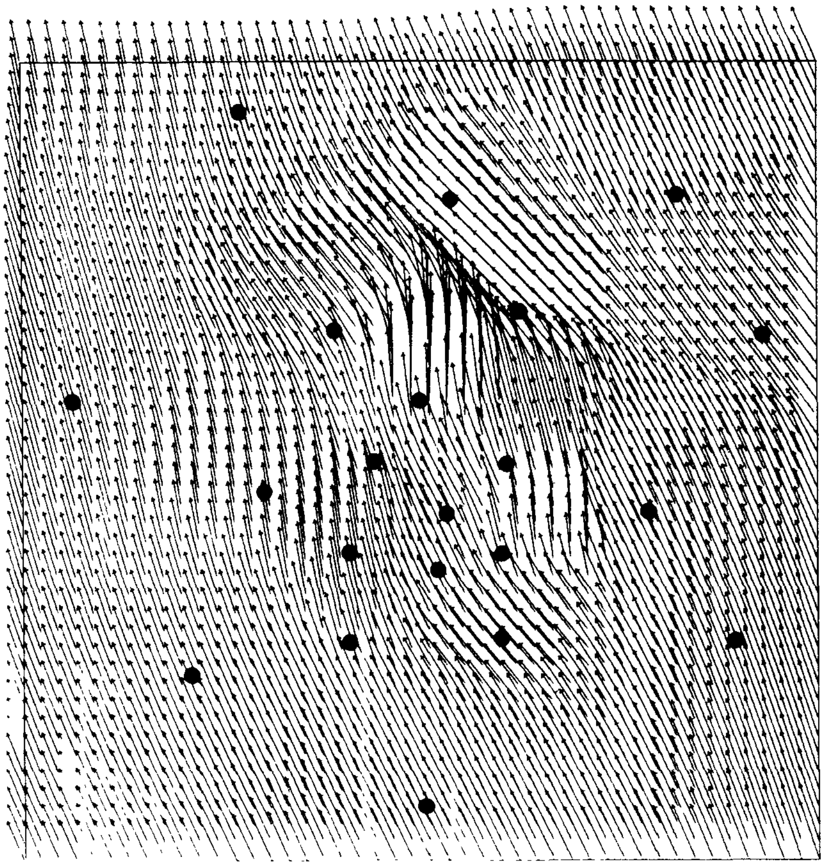

Figure 16. First-guess analysis for averaged data centered around 11:37 A.M. (C.S.T.) for August 14, 1975, St. Louis (RAPS).

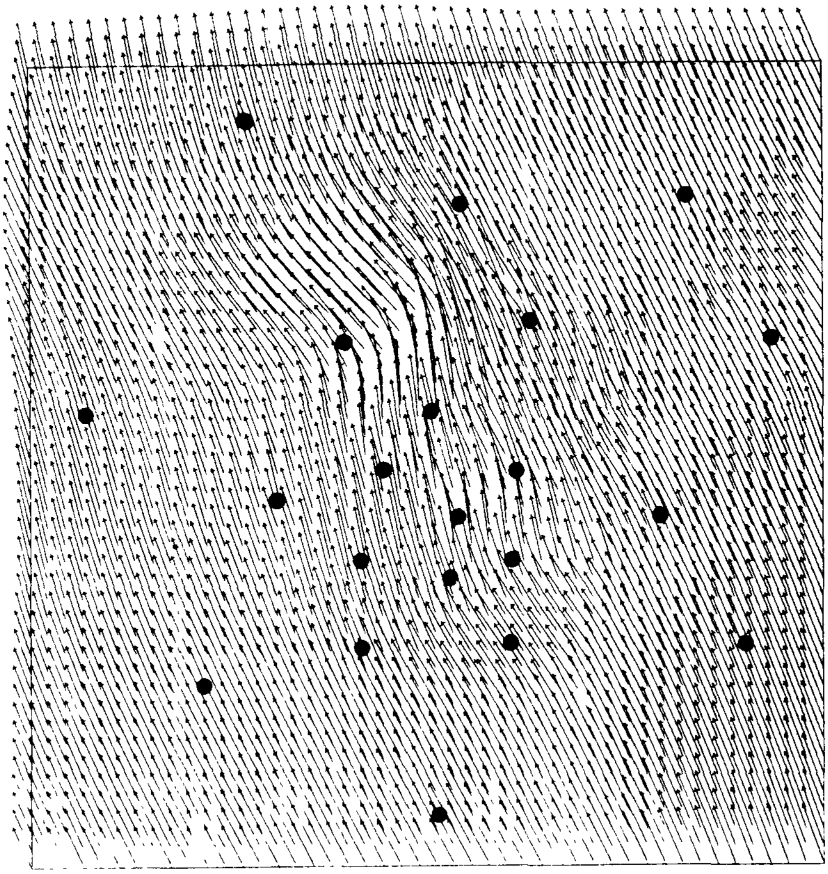

Figure 17. Non-divergent analysis for averaged data centered around 11:37 A.M. (C.S.T.) for August 14, 1975, St. Louis (RAPS).

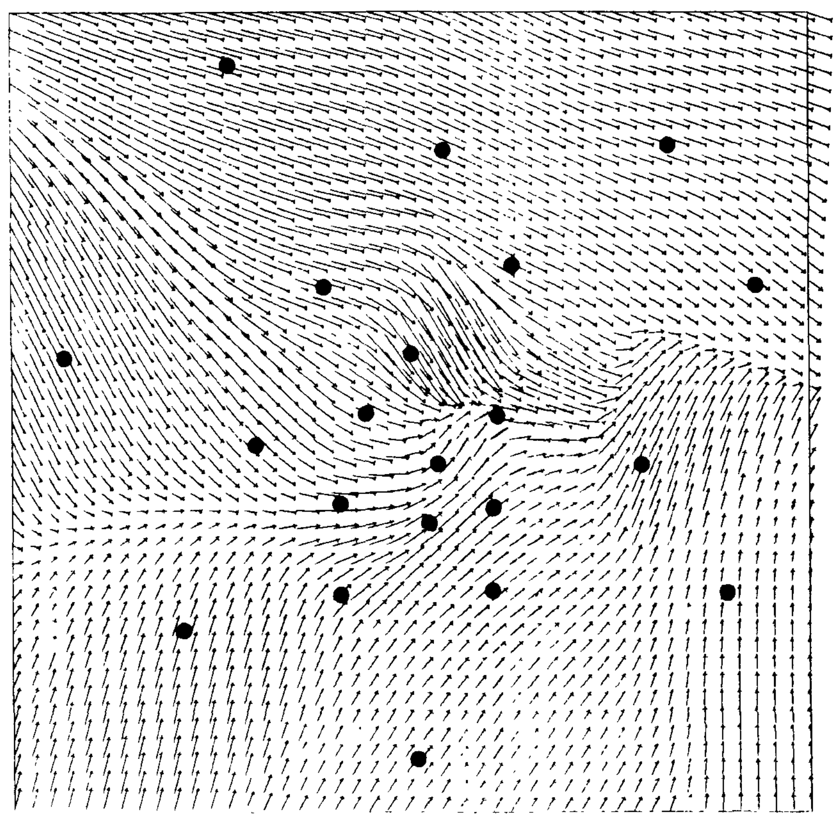

Figure 18. First-guess analysis for averaged data centered around 2:37 P.M. (C.S.T.) for August 13, 1975, St. Louis (RAPS).

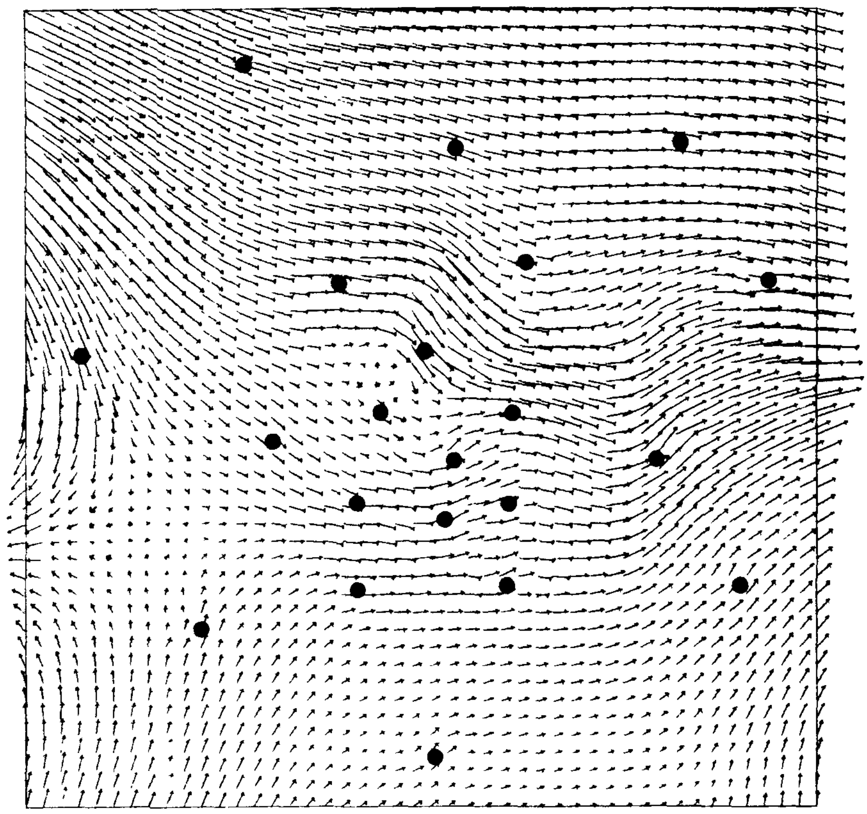

Figure 19. Non-divergent analysis for averaged data centered around 2:37 P.M. (C.S.T.) for August 13, 1975, St. Louis (RAPS).

During this period, all stations had data except for 111. The wind directions ranged from 188° at station 117 to 333° at station 120. The wind speeds ranged from 0.9 m/sec. at station 117 to 4.2 m/sec. at station 102.

This case was included to show the results of the non-divergent wind analysis routine starting from a first-guess field (Figure 18) generated from data characterized by an extensive area of strong convergence. Large adjustments were made to the first-guess field to minimize the convergence. As can be seen by Figure 19, the final analysis in some areas of the field was drastically changed.

Among the areas where changes were made, there were four areas where the winds were adjusted noticeably. These areas included the grid points near stations 107, 116, and 119. A col appeared on the final analysis field near station 119. To the left side of the col the wind directions at the grid points changed 180° .

The wind speeds at the grid points near station 107 were sharply decreased. Also, the wind speeds near 110 and 118 were decreased and the wind directions became westerly. On the right side of the grid, the wind speeds were increased sharply to minimize the convergence there.

These five cases were chosen as examples to illustrate what adjustments are made to the first-guess field by the non-divergent wind analysis procedure. The cases included data where the wind did and did not vary greatly across the field so that the extent of the adjustments for both types of cases would be known.

The CDC procedure, which generated the first-guess fields, proved to be adequate in analyzing the wind data over the St. Louis area.

Analyses proved to be very good when compared to the data at the station points.

The non-divergent wind analysis procedure used to generate the final analyses would be useful to produce wind fields for Eulerian air pollution models. In most areas of individual cases, the first-guess wind analysis is only slightly adjusted. However, there are cases when the adjustments are so extensive, that the final analyses are noticeably different.

5. SUMMARY AND CONCLUSIONS

An algorithm was created to analyze data from the RAPS network at St. Louis, Missouri. The algorithm is based on modified versions of an objective analysis technique developed by Hovland, et.al. (1976) at Control Data Corporation and a non-divergent wind analysis routine developed by Liu and Goodin (1976).

The algorithm was applied to five periods of 15-minute averaged wind data during August of 1975. The data from the first two periods showed a rather uniform wind field, while the data from the last three showed a more variable wind field. The last period involved a case where a squall line was passing through the St. Louis region.

In every case, the calculated wind values at the grid points on the first-guess field (modified CDC procedure) corresponding to station locations agreed well with the observations. It is uncertain how well the actual wind field was depicted by this field in areas far from the stations, particularly near the borders of the grid.

The final analyses (modified Liu and Goodin procedure) were generated by adjusting the u- and v- wind components from the first-guess analyses so that the divergence across grid squares was minimized. The wind was changed only slightly at most grid points. However, in areas of strong divergence, the wind speed and/or direction changed considerably. This type of analysis is desired for two-dimensional photochemical modeling, since the divergence would act as a spurious source or sink term.

There were several problems with the data used in the analyses presented in this report. The wind direction and speed at station 102 were consistently different than the winds at adjacent stations. Moreover, the winds were not measured at the same height at all stations. The wind at stations 108, 110, 114-118, and 121 were measured at 10 meters and at 30 meters at the remaining stations. No normalization of the winds was attempted in this algorithm.

6. USER'S GUIDE

The purpose of this section is to describe the format of the data set used by the algorithm and to inform the user about the multi-level capability of the algorithm. With this information, the user should be able to generate the non-divergent wind fields.

The algorithm requires input of the data summarized in Table 4. The grid parameters (number of grid points in the x and y directions and grid spacing) are defined in the context of the program, not the data set. This was done since the algorithm cannot be applied to a different grid configuration by merely changing the values of these parameters. The CDC technique, used to construct a first-guess field for the non-divergent wind analysis, employs two sets of parameters determined exclusively for a given grid configuration and data network.

Table 4. SUMMARY OF DATA INPUT TO THE NON-DIVERGENT WIND FIELD ANALYSIS ALGORITHM

	Variable Name	Format
Data card # 1	EPSI	E10.3
	IE	I3
	NPER	I3
	P	F5.2
	NLEV	I3
Data card # 2	ZK	10F5.0
Data cards # 3-23	NSTA	I3
	X	F6.2
	Y	F6.2
Data cards # 24-45	IDAY*	I3
(u,v-component form)	IHR*	I3
	MIN*	I3
	US, VS	F5.2,1X,F5.2
Data cards # 24-29 (direction,speed form)	MIN, IHR, IDAY, WDIR, WSPD	(I3,5X,I2,2X, I3,6(T21,4(4X, 2F5.1),/))

*typed on data card # 24

The value of "EPSI" is compared to the average value of the divergence calculated over the grid after each iteration. When EPSI is greater than the maximum divergence value, the analysis has converged to a satisfactory degree. At this point, the iterative process is terminated. The value of 1.0 by 10^{-5} proved to be adequate.

Parameters "IE" and "NPER" refer to the wind data set. The total number of periods of data to be used is defined by "NPER". "IE" serves a dual purpose. First, the value selects the desired 15-minute period to use form a data set containing many periods. This is especially useful when the data is stored on a mass storeage file. If the data corresponding to the fourth period of a data set is desired, the value of "IE" would be 3. The program would then skip over the first 3 data periods and start reading the data for the fourth period.

The value of "IE" also makes it possible for the program to accept averaged-wind data in two different forms. When "IE" is less than 100, the program would read the data as u and v wind components. When "IE" is greater than 100, the program would read the data in the form of wind direction and speed. In the latter case, 100 is subtracted from the value to identify the desired period to use in the algorithm.

The last two parameters on the first data card refer to the mulit-level analysis section of the program. The number of the levels where wind fields are desired is defined by "NLEV", which should not exceed 10. The height of these levels, in meters, are defined on the second data card and stored into array "ZK". If only the surface analysis is desired, the value of "NLEV" would be 1 and the second card would contain the number 20.

The wind speeds at height z_k are determined by the power law equation

$$|\vec{v}_k| = |\vec{v}_1| \quad (\frac{z_k}{z_1})^p \qquad , \tag{15}$$

where $|\vec{v}_1|$ and $|\vec{v}_k|$ denote the wind speed (m/sec) at the level of data measurement and level k respectively. The wind direction, in meteorological coordinates, at height z_k (meters) is determined by

$$\theta_k = \theta_1 + (\frac{1^o}{30m})(z_k - z_1) \quad . \tag{16}$$

The value of the exponent, p, is dependent upon ground roughness and lapse rate. In general, the exponent is small during the day and large at night (Munn, 1966). A value of 0.4 was assumed for general purposes. This value can be changed by changing the parameter "p" in the data set.

Data cards 3 through 33 contain the station identification number (101-121) and the x and y coordinates of the station relative to the south west corner of the 46 by 46 km grid. There is one data card for each station.

The averaged wind data are read last. The user has an option to use averaged wind data in the form of u-v components (m/sec) or in the form of wind direction and speed (m/sec). If the u-v component form is used, a data card containing the day and time (IDAY,IHR,MIN) must precede the actual wind data card set. The average u and v components for each of the stations are listed on individual data cards according to the format given in Table 4.

If the direction and speed form of data is chosen, the time and day (MIN,IHR,IDAY) are read from the first card containing averaged wind data in the first 15 columns. Each wind data card contains, wind direction and speed for four stations, except the last card which contains data for station #121.

All of the data input is read by the MAIN subroutine computer code. In addition, the MAIN subroutine 1) rejects wind data according to the rejection scheme described in Section II; 2) calls subroutine UVCMP1, if needed, to convert the average wind direction and speed (m/sec) input to the u and v component form; 3) calls subroutine INITIL; and 4) adjusts the wind fields generated by the modified CDC technique to produce non-divergent wind fields.

Subroutine INITIL defines the number of data points and the size of the scan radius to use in each of the five iterations in the CDC technique and calls subroutine GRID. Subroutine GRID generates wind fields from the averaged u and v -wind components at the 21 data points using the modified version of the CDC technique.

7. COMPUTER PROGRAM LISTING - FORTRAN

This section contains the FORTRAN computer code for the non-divergent wind field analysis algorithm. The code consists of a MAIN subroutine which calls subroutine UVCMP1, INITIL, and PRINT. Subroutine INITIL calls subroutine GRID. The code does not include any UNIVAC 1110 system routine.

```
C       DICTIONARY OF VARIABLES USED IN MAIN
C ***************************************************************************
C
C
C
C       AVGU    AVERAGE VALUE OF U-COMPONENTS
C       AVGV    AVERAGE VALUE OF V-COMPONENTS
C       DIR     THE DIRECTION OF THE WIND IN MET COORDINATES
C       DIV     POINT VALUE OF THE DIVERGENCE
C       DIVR    ARRAY CONTAINING THE DIVERGENCE VALUES
C       DMAX    MAXIMUM ABSOLUTE VALUE OF DIVERGENCE ACROSS A FIELD
C       DX      DISTANCE BETWEEN GRID POINTS IN THE X DIRECTION
C       DY      DISTANCE BETWEEN GRID POINTS IN THE Y DIRECTION
C       DZ      DISTANCE BETWEEN GRID POINTS IN THE Z DIRECTION
C       EPSI    A CONVERGENCE PARAMETER SET TO MUCH LESS THAN 1.
C       IDAY    JULIAN DAY OF DATA
C       IHR     HOUR OF DAY OF DATA
C       IE      NUMBER OF DATA SETS TO BE SKIPPED IN DATA FILE
C       IEND    NUMBER OF RECORDS TO BE SKIPPED IN DATA FILE
C       IOUT    DEVICE UPON WHICH ARRAYS ARE STORED FOR VECTOR OUTPUT;
C               IF IOUT = 0 , NO DEVICE USED
C       MIN     TEMPORAL MID-POINT OF DATA AVERAGING INTERVAL
C       NLEV    NUMBER OF FIELDS TO BE ANALYZED IN THE VERTICAL
C       NRPTS   NUMBER OF STATIONS TO BE USED IN ANALYSIS NOT GREATER THAN 25
C       NSKIP   DUMMY VARIABLE USED IN SKIPPING DATA SETS
C       NSTA    ARRAY CONTAINING STATION NUMBER
C       P       THE VALUE OF THE EXPONENT IN THE POWER LAW FORMULA
C       SIGU    STANDARD DEVIATION OF THE U-COMPONENTS
C       SIGV    STANDARD DEVIATION OF THE V-COMPONENTS
C       SPD     ARRAY CONTAINING WIND SPEED
C       SSU     SUM OF THE SQUARES OF THE U-COMPONENTS
C       SSV     SUM OF THE SQUARES OF THE V-COMPONENTS
C       SUMU    SUM OF THE U-COMPONENTS
C       SUMV    SUM OF THE V-COMPONENTS
C       U       ARRAY CONTAINING FINAL ANALYSIS
C       US      ARRAY CONTINING U COMPONENT OF STATION REPORT
C       U1      ARRAY USED TO SAVE SURFACE STATION REPORTS OF U COMPONENT
C       V       ARRAY CONTAINING FINAL ANALYSIS OF V VELOCITY FIELD
C       VS      ARRAY CONTAINING V COMPONENT OF STATION REPORT
C       V1      ARRAY USED TO SAVE SURFACE STATION REPORTS OF V COMPONENT
C       X       ARRAY CONTAINING X COORDINATE OF STATION LOCATIONS
C       Y       ARRAY CONTAINING Y COORDINATE OF STATION LOCATIONS
C       Z       HEIGHT OF ANALYSIS LEVEL ABOVE SURFACE
C
C
C
C
        DIMENSION NSTA(30),X(30),Y(30),US(30),VS(30),WDIR(25),WSPD(25)
        DIMENSION U(46,46),V(46,46),DIR(25),SPD(25),U1(25),V1(25)
        DIMENSION DIVR(46,46),F(46,46),ZK(10),UT(46,46),VT(46,46)
        COMMON IDAY,IHR,MIN
C
C*******************************************************************************
C       THE ALGORITHM PARAMETERS ARE DEFINED
C*******************************************************************************
```

```
C
      DATA PHI/3.141592654/,IOUT/8/,ALP/1./,BET/0./,KKMAX/250/
      DATA FC/1.0/,IMAX/46/,JMAX/46/,I1/2/,J1/2/,NRPTS/21/,
     *DX/1000./,DY/1000./
      FX=1.0-FC
      I2=IMAX-1
      J2=JMAX-1
      READ(5,6) EPSI,IE,NPER,P,NLEV
      WRITE(6,5) NRPTS,DX,DY,EPSI,IE,NPER,P,NLEV
    5 FORMAT(I3,2F6.0,E10.3,2I3,F5.2,I3)
    6 FORMAT(E10.3,2I3,F5.2,I3)
      READ(5,7) (ZK(I),I=1,NLEV)
    7 FORMAT(10F5.0)
      DO 15 I=1,NRPTS
      READ(5,12) NSTA(I),X(I),Y(I)
   12 FORMAT(I3,2F6.2)
   15 CONTINUE
C
C*****************************************************************************
C     THE WIND DATA ARE READ
C
C     IE>100 FOR DATA IN THE FORM OF DIRECTION AND SPEED(M/SEC)
C     IE<100 FOR DATA IN THE FORM OF U AND V COMPONENTS(M/SEC)
C*****************************************************************************
C
      DO 1000 NP=1,NPER
      IF(IE .GE. 100) GO TO 27
      IF(NP .GT. 1) GO TO 23
C
C     SKIP IE NUMBER OF PERIODS OF DATA IN THE FORM OF U AND V COMPONENTS.
C     (THERE ARE 22 RECORDS PER PERIOD)
C
      IEND = IE * 22
      IF(IEND .EQ. 0) GO TO 23
      DO 22 I=1,IEND
      READ(5,21) NSKIP
   21 FORMAT(I1)
   22 CONTINUE
   23 READ(5,24) IDAY,IHR,MIN
   24 FORMAT(' ',2I3,I2)
      PRINT 24, IDAY,IHR,MIN
      DO 26 K=1,NRPTS
      READ(5,25) US(K),VS(K)
   25 FORMAT(F5.2,1X,F5.2)
   26 CONTINUE
      GO TO 34
C
C     SKIP (IE-100) NUMBER OF PERIODS OF DATA IN THE FORM OF DIRECTION AND SPEED
C     (THERE ARE 7 RECORDS PER PERIOD)
C
   27 CONTINUE
      IF(NP .GT. 1) GO TO 30
      IEND = (IE-100)*7
      IF(IEND .EQ. 0) GO TO 30
      DO 29 I=1,IEND
      READ(5,28) NSKIP
   28 FORMAT(I1)
```

```
   29 CONTINUE
   30 READ(5,32) MIN,IHR,IDAY, (WDIR(I),WSPD(I),I=1,25)
   32 FORMAT(I3,5X,I2,2X,I3,7(T21,4(4X,2F5.1),/))
      WRITE(6,24) IDAY,IHR,MIN
C
C     CONVERT DIRECTION AND WIND SPEED TO U AND V COMPONENTS
C
      DO 33 K=1,NRPTS
      CALL UVCMP(US(K),VS(K),WDIR(K),WSPD(K))
   33 CONTINUE
   34 WRITE(6,35)
   35 FORMAT(' ',10X,'STA',15X,'X',17X,'Y',17X,'U',17X,'V',//)
      DO 40 K=1,NRPTS
      WRITE(6,37) NSTA(K),X(K),Y(K),US(K),VS(K)
   37 FORMAT(' ',10X,I3,2(13X,F5.2),2(12X,F6.2))
   40 CONTINUE
C
C***************************************************************************
C     CALCULATE MEAN AND SIGMA OF DATA SAMPLE.
C     REJECT DATA WHEN VALUES ARE 4 SIGMA FROM MEAN OR GREATER THAN 20
C***************************************************************************
C
      SSU=0.0
      SSV=0.0
      SUMU = 0.
      SUMV = 0.
      ICOUNT = 0
      DO 47 K=1,NRPTS
      IF(US(K) .GT. 20.0  .OR.  VS(K) .GT. 20.0) GO TO 47
      SUMU = SUMU + US(K)
      SUMV = SUMV + VS(K)
      ICOUNT = ICOUNT + 1
      SSU = SSU + US(K)*US(K)
      SSV = SSV + VS(K)*VS(K)
   47 CONTINUE
      AVGU = SUMU/ICOUNT
      AVGV = SUMV/ICOUNT
      SIGU = SQRT(SSU/ICOUNT - AVGU*AVGU)
      SIGV = SQRT(SSV/ICOUNT - AVGV*AVGV)
      PRINT 50
   50 FORMAT('1',35X,'STATISTICS FROM ALL DATA LESS THAN 20 M/SEC',//)
      PRINT 65, AVGU,AVGV,SIGU,SIGV
      SSU=0.0
      SSV=0.0
      SUMU = 0.
      SUMV = 0.
      ICOUNT = 0
      DO 60 K=1,21
      IF(US(K) .GT. 4*SIGU+AVGU .OR. VS(K) .GT. 4*SIGV+AVGV)
     *WRITE(6,57) K,US(K),VS(K)
      IF(US(K) .GT. 4*SIGU+AVGU .OR. VS(K) .GT. 4*SIGV+AVGV)
     *US(K) = 99.0
      IF(US(K) .GT. 4*SIGU+AVGU .OR. VS(K) .GT. 4*SIGV+AVGV)
     *VS(K) = 99.0
      IF(US(K) .LT. AVGU-4.*SIGU .OR. VS(K) .LT. AVGV-4.*SIGV)
     *WRITE(6,57) K,US(K),VS(K)
      IF(US(K) .LT. AVGU-4.*SIGU .OR. VS(K) .LT. AVGV-4.*SIGV)
```

```
     *US(K) = 99.0
      IF(US(K) .LT. AVGU-4.*SIGU .OR. VS(K) .LT. AVGV-4.*SIGV)
     *VS(K) = 99.0
      IF(US(K) .GT. 4*SIGU+AVGU .OR. VS(K) .GT. 4*SIGV+AVGV)
     *GO TO 60
      IF(US(K) .LT. AVGU-4*SIGU .OR. VS(K) .LT. AVGV-4*SIGV)
     *GO TO 60
   57 FORMAT(' ',2X,'THE FOLLOWING DATA HAVE BEEN IGNORED ',
     *' (EXCLUDING DATA FROM STA 108-121) --SINCE THE U AND/OR V '
     *'EXCEDE AVG + OR - 2*SIG',//,45X,I3,5X,2F6.1)
      SUMU = SUMU + US(K)
      SUMV = SUMV + VS(K)
      ICOUNT = ICOUNT + 1
      SSU = SSU + US(K)*US(K)
      SSV = SSV + VS(K)*VS(K)
   60 CONTINUE
      AVGU = SUMU/ICOUNT
      AVGV = SUMV/ICOUNT
      SIGU = SQRT(SSU/ICOUNT - AVGU*AVGU)
      SIGV = SQRT(SSV/ICOUNT - AVGV*AVGV)
      PRINT 63
   63 FORMAT(5(/),35X,'STATISTICS FROM DATA WITHIN 4*SIGMA OF MEAN'
     *,//)
      WRITE(6,65) AVGU,AVGV,SIGU,SIGV
   65 FORMAT(' ',6(/),45X,'AVGU =',F7.2,10X,'AVGV =',F7.2,//,
     *45X,'SIGU =',F7.2,10X,'SIGV =',F7.2)
C
C******************************************************************************
C     OBJECTIVE ANALYSIS PROCEDURE FIRST FINDS A FIRST GUESS FIELD USING THE
C     CDC PROCEDURE (CALL INITIL) THEN USING THE LIU AND GOODIN ALGORITHM
C     MINIMIZES THE DIVERGENCE
C******************************************************************************
C
      DO 500 LL=1,NLEV
      DO 70 J=1,JMAX
      DO 70 I=1,IMAX
      F(I,J)=1.00
   70 CONTINUE
      WRITE(6,71)
   71 FORMAT('1')
      CALL INITIL(X,Y,US,U,IMAX,JMAX,NRPTS,AVGU,SIGU)
      CALL INITIL(X,Y,VS,V,IMAX,JMAX,NRPTS,AVGV,SIGV)
      CALL PRINT(U,V,IMAX,JMAX,IOUT,1,ZK(LL))
      IF(LL .GE. 2) GO TO 75
C
C******************************************************************************
C     THE GRID POINTS NEAREST THE DATA STATIONS ARE IDENTIFIED
C******************************************************************************
C
      DO 74 K=1,NRPTS
      I=X(K)+.5
      J=Y(K)+.5
C
C *****************************************************************************
C     STORE SURFACE WIND VALUES FOR POWER LAW EXTRAPOLATION
C *****************************************************************************
C
```

```
      U1(K)=U(I,J)
      V1(K)=V(I,J)
   74 CONTINUE
   75 CONTINUE
C
      DO 80 K=1,NRPTS
      I=X(K) + 0.5
      J=Y(K) + 0.5
      IF(US(K) .GE. 99. .OR. VS(K).GE. 99.) GO TO 80
C
C ****************************************************************************
C     SET WEIGHTINGS FOR STATIONS AND SURROUNDING POINTS IF US OR VS IS GREATER
C     THAN 99. THIS MEANS THE DATA FROM THE STATION WAS REJECTED IN
C
C      THE FIRST PART OF THE ANALYSIS AND MUST BE IGNORED IN THE SECOND
C     PART
C ****************************************************************************
C
      F(I,J)=.25
      F(I+1,J)=.500
      F(I-1,J)=.500
      F(I,J+1)=.500
      F(I,J-1)=.500
C     WRITE(6,77) NSTA(K),X(K),Y(K),US(K),VS(K)
C  77 FORMAT(' ',10X,I3,10X,2F10.2,10X,2F10.2)
   80 CONTINUE
C
C*****************************************************************************
C     ITERATE TO REDUCE THE DIVERGENCE KKMAX TIMES OR UNTIL THE MAXIMUM
C     DIVERGENCE IS LESS THAN EPSI.
C     THE ITERATIONS BEGIN IN THE CENTER OF THE GRID SO THAT THE ERRORS
C     PROPAGATE OUTWARD. THE FOUR-POINT APPROXIMATION OF THE CONTINUITY
C     EQUATION IS USED.
C*****************************************************************************
C
      DO 115 KK=1,KKMAX
      DMAX=0.
      DO 100 MM=1,44
      IF(MOD(MM,2).EQ.1) J=24+MM/2
      IF(MOD(MM,2).EQ.0) J=24-MM/2
      DO 100 NN=1,2
      IF(MOD(NN, 2).EQ.0) IA=23
      IF(MOD(NN,2) .EQ. 0) IB=I1
      IF(MOD(NN,2) .EQ. 0) IC=-1
      IF(MOD(NN, 2).EQ.1) IA=24
      IF(MOD(NN,2) .EQ. 1) IB=I2
      IF(MOD(NN,2) .EQ. 1) IC=1
      DO 100 I=IA,IB,IC
      IMM=I-2
      IPP=I+2
      JMM=J-2
      JPP=J+2
      IM=I-1
      IP=I+1
      JM=J-1
      JP=J+1
      DIVR(I,J)=FC*(U(I+1,J)-U(I-1,J))/(2.*DX)+FX*(U(I+2,J)-U(I-2,J)
```

```
     1           )/(4.*DX)+FC*(V(I,J+1)-V(I,J-1))/(2.*DY)+FX*(
     2           V(I,J+2)-V(I,J-2))/(4.*DY)
      DIV=DIVR(I,J)
      IF(ABS(DIV).GT.DMAX) DMAX=ABS(DIV)
      UT(I,J)=-2.*DIVR(I,J)*DX/(F(I+1,J)+F(I-1,J)+F(I,J-1)+F(I,J+1))
      VT(I,J)=UT(I,J)
      U(IP,J)=U(I+1,J)+F(I+1,J)*UT(I,J)
      U(IM,J)=U(I-1,J)-F(I-1,J)*UT(I,J)
      V(I,JP)=V(I,J+1)+F(I,J+1)*VT(I,J)
      V(I,JM)=V(I,J-1)-F(I,J-1)*VT(I,J)
  100 CONTINUE
C
C***************************************************************************
C     THE BOUNDARY VALUES ARE SET USING A ZERO GRADIENT CONDITION.
C     THIS CONDITION JOINS THE TWO SEPARATE SUBGRIDS WHEN THE FOUR-
C     POINT APPROXIMATION IS USED.
C***************************************************************************
C
      DO 104 L=2,J2
      U(1,L)=U(2,L)
      U(IMAX,L)=U(I2,L)
      V(1,L)=V(2,L)
      V(IMAX,L)=V(I2,L)
  104 CONTINUE
      DO 106 L=2,I2
      U(L,1)=U(L,2)
      U(L,JMAX)=U(L,J2)
      V(L,JMAX)=V(L,J2)
      V(L,1)=V(L,2)
  106 CONTINUE
C
C***************************************************************************
C     DEFINE THE CORNER POINTS OF THE GRID AS THE AVERAGE BETWEEN
C     THE TWO ADJACENT BOUNDARY VALUES.
C***************************************************************************
C
      U(1,1)=.5*(U(2,1)+U(1,2))
      V(1,1)=.5*(V(2,1)+V(1,2))
      U(1,JMAX)=.5*(U(2,JMAX)+U(1,J2))
      V(1,JMAX)=.5*(V(2,JMAX)+V(1,J2))
      U(IMAX,1)=.5*(U(I2,1)+U(IMAX,2))
      V(IMAX,1)=.5*(V(I2,1)+V(IMAX,2))
      U(IMAX,JMAX)=.5*(U(I2,JMAX)+U(IMAX,J2))
      V(IMAX,JMAX)=.5*(V(I2,JMAX)+V(IMAX,J2))
C
C***************************************************************************
C    CHECK TO SEE IF THE WIND FIELD HAS CONVERGED
C***************************************************************************
C
      IF(DMAX .LT. EPSI) GO TO 120
  115 CONTINUE
C
C***************************************************************************
C     PRINT THE U AND V FIELDS ONTO COMPUTER PAPER
C***************************************************************************
C
  120 CALL PRINT(U,V,IMAX,JMAX,IOUT,2,ZK(LL))
```

```
      PRINT 200
  200 FORMAT('1')
      IF(NLEV .EQ. 1) GO TO 1000
C
C*****************************************************************************
C     SPEED AND DIRECTION AT LEVELS ABOVE THE SURFACE ARE DETERMINED BY
C     ASSUMING THAT THE WIND TURNS 10 DEGREES EVERY 304 METERS AND USING
C     A POWER LAW PROFILE
C*****************************************************************************
C
      Z=ZK(LL)
      PRINT 248,LL,Z,P
  248 FORMAT(20X,'LEVEL NUMBER  ',I2,10X,'HEIGHT (M) =',F7.2,
     *10X,'P =',F7.4)
      DO 260 M=1,NRPTS
      IF(US(M) .GT. 20.0  .OR.  VS(M) .GT. 20.0) GO TO 260
      CALL UVCMP1(US(M),VS(M),DIR(M),SPD(M))
      DIR(M)=DIR(M)+PHI*1.822688831E-4*Z
      SPD(M)=SQRT(U1(M)**2+V1(M)**2)*(Z/20.)**P
  260 CONTINUE
      PRINT 211
  211 FORMAT(3(/),20X,'STA',T34,'U',T45,'V',T55,'DIR',T65,
     *'SPD',//)
      DO 270 M=1,NRPTS
      IF(US(M) .GT. 20.0  .OR.  VS(M) .GT. 20.0) GO TO 270
      NST = 100+M
      CALL UVCMP(US(M),VS(M),DIR(M),SPD(M))
      PRINT 215,NST,US(M),VS(M),DIR(M),SPD(M)
  215 FORMAT(20X,I3,T32,F6.2,T42,F6.2,T53,F6.2,T64,F5.2)
  270 CONTINUE
  500 CONTINUE
 1000 CONTINUE
      STOP
      END
```

```
      SUBROUTINE PRINT(U,V,IMAX,JMAX,IOUT,IN,Z)
C
C
C     THIS SUBROUTINE PRINTS THE ENTIRE 46 BY 46 ANALYSIS FIELD ONTO
C     FOUR SHEETS OF COMPUTER PAPER (FIRST : UPPER LEFT * SECOND :
C     LOWER LEFT * THIRD : UPPER RIGHT * FOURTH : LOWER RIGHT) AND
C     RECORDS THE U AND V ARRAYS ON A MASS STORAGE OR TAPE FILE
C
C
C
C
C ************************************************************************
C     DICTIONARY OF VARIABLES USED IN PRINT
C ************************************************************************
C
C
C
C     IDAY   THE JULIAN DAY OF THE YEAR OF THE DATA SET
C     IHR    THE HOUR OF THE DAY OF THE DATA SET (0 = MIDNIGHT)
C     IMAX   THE NUMBER OF GRID POINTS IN THE X DIRECTION
C     IN      VARIABLE USED IN TITLE OUTPUT
C     IOUT   THE UNIT NUMBER OF THE MASS STORAGE OR THE TAPE FILE.
C            IF NO MASS STORAGE OR TAPE FILE RECORDING IS DESIRED,
C            SET IOUT=0 IN THE DATA STATEMENT IN THE MAIN SUBROUTINE
C     JMAX   THE NUMBER OF GRID POINTS IN THE Y DIRECTION
C     K      THE NUMBER OF THE PRINTED PAGE
C     MIN    THE TEMPORAL MID-POINT OF THE 15 MINUTE AVERAGING INTERVAL
C     Z      THE HEIGHT OF THE LEVEL AT WHICH WINDS WERE COMPUTED
C
C
C
C
      DIMENSION U(46,46),V(46,46)
      COMMON IDAY,IHR,MIN
      K2=4
  112 IF(IMAX .LE. 20 .OR. JMAX .LE. 20) K2=1
      DO 131 K=1,K2
      II=1
      IF=23
      JI=1
      JF=23
      IF(K .EQ. 2  .OR.  K.EQ.4) JI=24
      IF(K .EQ. 2 .OR.  K.EQ.4) JF=JMAX
      IF(K .EQ. 3  .OR.  K.EQ.4) II=24
      IF(K .EQ. 3  .OR.  K.EQ.4) IF=IMAX
      WRITE(6,11)
   11 FORMAT('1')
      IF(IN .EQ. 1) WRITE(6,117) Z,K
      IF(IN .EQ. 2) WRITE(6,118) Z,K
  117 FORMAT(' ',10X,'FIRST GUESS',23X,F5.0,'-M U-FIELD (M/SEC)',30X,
     *'PAGE ',I2,//)
  118 FORMAT(' ',10X,'FINAL ANALYSIS',20X,F5.0,'-M U-FIELD (M/SEC)',30X,
     *'PAGE ',I2,//)
      WRITE(6,119) (I,I=II,IF)
  119 FORMAT(5X,23I5,/)
```

```
      DO 130 JJ=JI,JF
      J=JMAX-JJ+1
      WRITE(6,120) J,(U(I,J),I=II,IF)
  120 FORMAT(' ',I3,3X,23F5.1,/)
  130 CONTINUE
  131 CONTINUE
      IF(IMAX .LE. 20 .OR. JMAX .LE. 20) K2=1
      DO 151 K=1,K2
      II=1
      IF=23
      JI=1
      JF=23
      IF(K .EQ. 2  .OR.  K .EQ. 4) JI=24
      IF(K .EQ. 2  .OR.  K .EQ. 4) JF=JMAX
      IF(K .EQ. 3  .OR.  K .EQ. 4) II=24
      IF(K .EQ. 3  .OR.  K .EQ. 4) IF=IMAX
      WRITE(6,11)
      IF(IN .EQ. 1) WRITE(6,132) Z,K
      IF(IN .EQ. 2) WRITE(6,133) Z,K
  132 FORMAT(' ',10X,'FIRST GUESS',23X,F5.0,'-M V-FIELD (M/SEC)',30X,
     *'PAGE ',I2,//)
  133 FORMAT(' ',10X,'FINAL ANALYSIS',20X,F5.0,'-M V-FIELD (M/SEC)',30X,
     *'PAGE ',I2,//)
      WRITE(6,119) (I,I=II,IF)
      DO 150 JJ=JI,JF
      J=JMAX-JJ+1
      WRITE(6,120) J,(V(I,J),I=II,IF)
  150 CONTINUE
  151 CONTINUE
      IF(IOUT .EQ. 0) RETURN
C
C ***************************************************************************
C     RECORD ONTO MASS STORAGE OR TAPE FILE
C ***************************************************************************
C
      WRITE(IOUT,180) IDAY,IHR,MIN
  180 FORMAT(3I4)
      WRITE(IOUT,190) U
      WRITE(IOUT,190) V
  190 FORMAT(10F8.3)
      RETURN
      END
```

```
      SUBROUTINE GRID(NDATA,XCOORD,YCOORD,STNVAL,GRDVAL,SUMWT,SUMCOR,
     1                ISTART,IEND,JSTART,JEND,NSCANS,RSCAN,CRIT)
C
C
C    GRID IS A CDC SUBROUTINE CALLED BY SUBROUTINE INITIL.
C    GRID WILL TRANSFORM UNEQUALLY SPACED STATION DATA TO EQUALLY
C    SPACED GRID POINT DATA.  WHEN GRID IS CALLED THERE MUST BE A
C    VALUE FOR EACH GRID POINT.  THE FIRST GUESS FIELD MAY BE A
C    PREVIOUS ANALYSIS, A FORECAST, OR SIMPLY A CONSTANT.  THE GRID
C    MUST BE ARRANGED SO THAT GRID POINTS SURROUND EACH DATA POINT.
C
C
C
C
C
C ***************************************************************************
C     DICTIONARY OF VARIABLES USED IN GRID
C ***************************************************************************
C
C
C
C     CRIT   CONVERGENCE CRITERION
C     ERROR  SUM OF SQUARES OF THE DIFFERENCES BETWEEN OBSERVATIONS
C            AT THE STATIONS AND INTERPOLATED VALUES ON THE FIELD.
C            USED IN THE CONVERGENCE TESTING.
C     GRDVAL ARRAY CONTAINING GRID POINT VALUES
C     IEND   NUMBER OF GRID POINTS IN THE X DIRECTION
C     INDEX1 I-VALUE OF GRID POINT ON SCAN CIRCLE AND TO LEFT OF STATION
C     INDEX2 I-VALUE OF GRID POINT ON SCAN CIRCLE AND TO RIGHT OF STATION
C     INDEX3 J-VALUE OF GRID POINT ON SCAN CIRCLE AND BELOW THE STATION
C     INDEX4 J-VALUE OF GRID POINT ON SCAN CIRCLE AND ABOVE THE STATION
C     JEND   NUMBER OF GRID POINTS IN THE Y DIRECTION
C     NDATA  NUMBER OF STATIONS WITH DATA USED IN A PARTICULAR
C            ITERATION. EXACT NUMBER DEFINED IN SUBROUTINE INITIL.
C     NPTS   COUNTER USED IN THE CONVERGENCE TESTING
C     RSCAN  RADIUS OF SCAN CIRCLE IN GRID UNITS. EXACT VALUE DEFINED
C            IN SUBROUTINE INITIL
C     RSQ    SQUARE OF SCAN RADIUS
C     STNVAL ARRAY CONTAINING STATION OBSERVATIONS
C     SUMCOR TEMPORARY STORAGE ARRAY CONTAINING CUMULATIVE CORRECTIONS
C            AT EACH GRID POINT WITHIN A SCAN CIRCLE OF THE STATIONS
C            DURING AN ITERATION
C     SUMWT  TEMPORARY STORAGE ARRAY CONTAINING CUMULATIVE WEIGHTINGS
C            AT EACH GRID POINT WITHIN A SCAN CIRCLE OF THE STATIONS
C            DURING AN ITERATION
C     XCOORD X-COORDINATE OF A STATION
C     YCOORD Y-COORDINATE OF A STATION
C
C
C
C
      DIMENSION XCOORD(NDATA),YCOORD(NDATA),STNVAL(NDATA)
      DIMENSION GRDVAL(IEND,JEND),SUMWT(IEND,JEND),SUMCOR(IEND,JEND)
      DIMENSION SDIFF(25),RSCAN(NSCANS)
      DATA NPTS/0/,ERROR/0/
```

```
      R(5)= 1
C
C ****************************************************************************
C     INVERT SOR,X1, AND Y1 ARRAYS TO FORM S,X, AND Y ARRAYS.
C     THIS IS DONE SO THAT THE DATA FROM THE OUTER STATIONS WILL
C     BE USED FIRST.
C ****************************************************************************
C
      DO 10 J=1,NRPTS
      I=NRPTS - J + 1
      S(I) = SOR(J)
      X(I) = X1(J)
      Y(I) = Y1(J)
C     PRINT 2,I,X(I),Y(I),S(I)
C   2 FORMAT(5X,I5,3F10.1)
   10 CONTINUE
C
C ****************************************************************************
C     USE A FIELD OF VALUES EQUAL TO AVG AS A FIRST GUESS FIELD
C     FOR THE CDC ANALYSIS
C ****************************************************************************
C
      DO 20 J=1,JF
      DO 20 I=1,IF
      G(I,J)=AVG
      W(I,J)=0
      C(I,J)=0
   20 CONTINUE
C
C ****************************************************************************
C     ITERATE ITMAX TIMES
C ****************************************************************************
C
      PRINT 23
      DO 60 IT=1,ITMAX
C     PRINT 23
   23 FORMAT('1')
      CALL GRID(N(IT),X,Y,S,G,W,C,1,IF,1,JF,1,R(IT),0)
      PRINT 35,N(IT)
   35 FORMAT(/11X,'NUMBER OF STATIONS =',I3//)
      GO TO 60
C
C     PRINT OUT EVERY OTHER GRID VALUE
C
      PRINT 40,(I,I=1,IF,2)
   40 FORMAT('0 ',3X,23I5,/)
      DO 45 JJ=1,JF,2
      J=JF-JJ
      PRINT 50, J,(G(I,J),I=1,IF,2)
   45 CONTINUE
   50 FORMAT(' ',1X,I2,1X,23F5.1)
   60 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE INITIL(X1,Y1,SOR,G,IF,JF,NRPTS,AVG,SIG)
C
C
C     THIS SUBROUTINE COMPUTES A  WIND FIELD FROM 15-MINUTE AVERAGED RAPS WIND
C     DATA USING THE OBJECTIVE ANALYSIS PROCEDURE DEVELOPED BY CDC.
C     THE VALUES OF N AND R WERE BASED UPON EXPERIMENTATION AND
C     INFORMATION PROVIDED BY CDC.
C
C
C
C ****************************************************************************
C      DICTIONARY OF VARIABLES USED IN INITIL
C ****************************************************************************
C
C
C
C     AVG    THE AVERAGE VALUE OF THE U OR V COMPONENTS FOR A GIVEN PERIOD
C     C      ARRAY STORING THE CUMULATIVE CORRECTIONS FOR THE GRID VALUES
C     G      ARRAY STORING THE CALCULATED GRID VALUES
C     IF     NUMBER OF GRID POINTS IN THE X DIRECTION
C     ITMAX  NUMBER OF ITERATIONS TO BE PERFORMED FOR THE CDC PROCEDURE
C     JF     NUMBER OF GRID POINTS IN THE Y DIRECTION
C     N      ARRAY STORING NUMBER OF STATIONS TO BE USED IN EACH ITERATION
C     NRPTS  MAXIMUM NUMBER OF STATIONS TO BE USED IN ANY ITERATION
C     R      ARRAY STORING SIZE OF SCAN RADIUS TO BE USED IN EACH ITERATION
C     S      ARRAY STORING STATION NUMBERS IN DESCENDING ORDER
C     SIG    STANDARD DEVIATION OF U OR V COMPONENTS
C     SOR    ARRAY STORING STATION NUMBERS IN ASCENDING ORDER
C     W      ARRAY STORING CUMULATIVE WEIGHTINGS FOR EACH GRID POINT
C     X      ARRAY STORING X COORDINATES OF STATIONS IN DESCENDING ORDER
C     X1     ARRAY STORING X COORDINATES OF STATIONS IN ASCENDING ORDER
C     Y      ARRAY STORING Y COORDINATES OF STATIONS IN DESCENDING ORDER
C     Y1     ARRAY STORING Y COORDINATES OF STATIONS IN ASCENDING ORDER
C
C
C
C
      DIMENSION X(25),Y(25),S(25),G(IF,JF),W(46,46),C(46,46),R(6),N(6)
     *,SOR(25),X1(25),Y1(25)
      DATA ITMAX/5/
C
C ****************************************************************************
C     DEFINE THE NUMBER OF STATIONS AND THE SIZE OF THE SCAN RADIUS
C     TO BE USED IN EACH ITERATION
C ****************************************************************************
C
      N(1)=7
      N(2)=12
      N(3)=NRPTS
      N(4)=NRPTS
      N(5)=NRPTS
      R(1)=46
      R(2)=20
      R(3)= 10
      R(4)= 5
```

```
      DO 10 I=ISTART,IEND
      DO 10 J=JSTART,JEND
      SUMWT(I,J)=0
   10 SUMCOR(I,J)=0
      ITER=0
   11 ITER=ITER+1
      IF(ITER.GT.NSCANS)GO TO 99
      RSQ=RSCAN(ITER)*RSCAN(ITER)
      ERROR=0
      NPTS=0
      NREJ=0
C
C ****************************************************************************
C     CALCULATE THE CORRECTIONS AT EACH GRID POINT WITHIN A SCAN
C     CIRCLE CENTERED AT THE STATIONS. THE CORRECTIONS ARE BASED
C     UPON THE WEIGHTED DIFFERENCES BETWEEN THE OBSERVATION AT THE
C     STATIONS AND THE INTERPOLATED VALUE ON THE FIELD.
C ****************************************************************************
C
      DO 50 NDT=1,NDATA
      SDIFF(NDT)=99.
      IF(STNVAL(NDT).EQ.99.0)GO TO 50
C
C     FIND INDICES OF NEAREST GRID POINT IN DIRECTION OF (1,1)
C
      I=XCOORD(NDT)+1.
      J=YCOORD(NDT)+1.
C
C     FIND X AND Y DISTANCE FROM GRID POINT (I,J)
C
      P=XCOORD(NDT)-(I-1)
      Q=YCOORD(NDT)-(J-1)
C
C     USE FOUR POINT BILINEAR FORMULA TO INTERPOLATE A VALUE AT
C     THE STATION LOCATION FROM FOUR SURROUNDING GRID POINTS.
C     IF A VALUE CANNOT BE INTERPOLATED, THE STATION IS SKIPPED.
C
      IF(I.LT.ISTART)GO TO 50
      IF(I+1.GT.IEND)GO TO 50
      IF(J.LT.JSTART)GO TO 50
      IF(J+1.GT.JEND)GO TO 50
      STNINT=GRDVAL(I,J)*(1.-P)*(1.-Q)
     1       +GRDVAL(I+1,J)*P*(1.-Q)
     2       +GRDVAL(I,J+1)*Q*(1.-P)
     3       +GRDVAL(I+1,J+1)*P*Q
C
C     FIND THE DIFFERENCE BETWEEN THE INTERPOLATED AND OBSERVED
C     VALUES AT THE STATIONS.
C
      DIFF=STNVAL(NDT)-STNINT
      SDIFF(NDT)=DIFF
C
C     THE MEAN SQUARED DIFFERENCE IS USED BELOW
C
      ERROR=DIFF*DIFF+ERROR
      NPTS=NPTS+1
```

```
C
C     A CORRECTION IS NOW COMPUTED FOR EACH GRID POINT WITHIN A CIRCLE
C     OF RADIUS RSCAN(ITER) CENTERED AT THE STATIONS.
C
      INDEX1=XCOORD(NDT)+1.-RSCAN(ITER)
      IF(INDEX1.LT.ISTART)INDEX1=ISTART
      INDEX2=XCOORD(NDT)+1.+RSCAN(ITER)
      IF(INDEX2.GT.IEND)INDEX2=IEND
      INDEX3=YCOORD(NDT)+1.-RSCAN(ITER)
      IF(INDEX3.LT.JSTART)INDEX3=JSTART
      INDEX4=YCOORD(NDT)+1.+RSCAN(ITER)
      IF(INDEX4.GT.JEND)INDEX4=JEND

      DO 30 M=INDEX1,INDEX2
      DO 30 N=INDEX3,INDEX4
C
C     FIND DISTANCE SQUARED FROM STATION TO GRID POINT (M,N).
C
      DX=XCOORD(NDT)-(M-1)
      DY=YCOORD(NDT)-(N-1)
      DSQ=DX*DX+DY*DY
C
C     GENERATE WEIGHT.  IF XNUM IS NEGATIVE, GRID
C     POINT (M,N) IS OUTSIDE THE SCAN CIRCLE.
C
      XNUM=RSQ-DSQ
      IF(XNUM.LT.0)GO TO 30
      XDEN=RSQ+DSQ
      WT=XNUM/XDEN
      WT = WT * WT
      WT = WT * WT
C
C     CORRECTIONS ARE NOT APPLIED NOW SINCE A GIVEN
C     GRID POINT MAY GET CORRECTIONS FROM SEVERAL DATA POINTS.
C
      SUMWT(M,N)=SUMWT(M,N)+WT
      SUMCOR(M,N)=SUMCOR(M,N)+WT*DIFF
 30   CONTINUE
 50   CONTINUE
C
C     END OF LOOP FOR DATA POINTS.
C
      RMS  =0
      CORMAX  =0
      ITOT  =0
      IMAX  =0
      JMAX  =0
C
C ****************************************************************************
C     APPLY THE CUMULATIVE CORRECTIONS TO THE GRID POINTS.
C ****************************************************************************
C
      DO 70 M=ISTART,IEND
      DO 70 N=JSTART,JEND
      IF(SUMWT(M,N).EQ.0)GO TO 70
      GRDVAL(M,N)=GRDVAL(M,N)+SUMCOR(M,N)/SUMWT(M,N)
      COR=SUMCOR(M,N)/SUMWT(M,N)
```

```
      RMS=COR*COR+RMS
      ITOT=ITOT+1
      IF(ABS(COR).LE.ABS(CORMAX))GO TO 69
      CORMAX=COR
      IMAX=M
      JMAX=N
   69 CONTINUE
      SUMWT(M,N)=0
      SUMCOR(M,N)=0
   70 CONTINUE
C
C     IF THE MEAN SQUARED CORRECTION IS SMALL ENOUGH, STOP ITERATING.
C
      ERROR=ERROR/NPTS
      PRINT 75,ITER,ERROR,RSCAN(ITER)
   75 FORMAT(5X,'       FOR ITERATION',I3,' THE MEAN SQUARED'
     1' DIFFERENCE AT THE STATIONS IS',F8.2,5X,'SCAN CIRCLE',
     2' RADIUS =',F8.2)
      IF(ITOT.GT.0)RMS=SQRT(RMS/ITOT)
      PRINT 80,RMS,CORMAX,IMAX,JMAX
   80 FORMAT(/11X,'RMS CHANGE AT GRID POINTS IS',F8.3,5X,
     1'MAXIMUM CHANGE IS',F7.2,' AT GRID POINT',2I5)
      IF(ERROR.GT.CRIT)GO TO 11

   99 RETURN
      END
```

```
      SUBROUTINE UVCMP1(U,V,WDA,WSP)
      DEG = 180. / 3.141592654
      IF(U .LE. 0. .AND. V .LE. 0.) GO TO 5
      IF(U .LT. 0. .AND. V .GE. 0.) GO TO 10
      IF(U .GE. 0. .AND. V .GT. 0.) GO TO 15
      IF(U .GT. 0. .AND. V .LE. 0.) GO TO 20
    5 WDA = ATAN(U/V)*DEG
      GO TO 90
   10 WDA = -ATAN(V/U)*DEG + 90.
      GO TO 90
   15 WDA = ATAN(U/V)*DEG + 180.
      GO TO 90
   20 WDA = -ATAN(V/U)*DEG + 270.
   90 WSP = SQRT(U*U+V*V)
      RETURN
      END
```

REFERENCES

Eskridge, R.E., 1977: Mon. Wea. Rev. Vol. 105, No. 8, August.

Hovland, D., D. Dartt, and K. Gage, 1976: An Objective Analysis Technique for the Regional Air Pollution Study, Final Report, EPA Contract 68-02-1827.

Liu, C.Y. and W.R. Goodin, 1976: An Iterative Algorithm for Objective Wind Field Analysis, Mon. Wea. Rev., Vol. 104, No. 6, June, pp. 784-792.

Munn, R.E., 1966: Descriptive Meteorology, Academic Press, New York. pp. 63-64.

Reynolds, Steven D., Philip M. Roth, and John H. Seinfeld, 1973: Mathematical Modeling of Photochemical Air Pollution I, Atm. Env., Vol. 7, pp. 1033-1061.

Shir, C.C. and L.J. Shieh, 1975: Development of An Urban Air Quality Simulation Model With Compatible RAPS Data, Final Report, EPA Contract 68-02-1833.

TECHNICAL REPORT DATA
(Please read Instructions on the reverse before completing)

1. REPORT NO. EPA-600/4-77-049	2.	3. RECIPIENT'S ACCESSION NO.
4. TITLE AND SUBTITLE NON-DIVERGENT WIND ANALYSIS ALGORITHM FOR THE ST. LOUIS RAPS NETWORK		5. REPORT DATE November 1977
		6. PERFORMING ORGANIZATION CODE
7. AUTHOR(S) Terry L. Clark and Robert E. Eskridge		8. PERFORMING ORGANIZATION REPORT NO.
9. PERFORMING ORGANIZATION NAME AND ADDRESS Environmental Sciences Research Laboratory, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, NC 27711		10. PROGRAM ELEMENT NO. 1AA603 AD-12 (FY-77)
		11. CONTRACT/GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Environmental Sciences Research Laboratory - RTP, NC, Office of Research and Development, U.S. Environmental Protection Agency, Research Triangle Park, NC 27711		13. TYPE OF REPORT AND PERIOD COVERED In-house
		14. SPONSORING AGENCY CODE EPA/600/09
15. SUPPLEMENTARY NOTES		

16. ABSTRACT

An objective wind analysis algorithm capable of producing non-divergent wind fields at up to ten levels in the atmospheric boundary layer for St. Louis, Missouri is described. Wind data collected during the St. Louis Regional Air Pollution Study (RAPS) and averaged over 15-minute intervals were used to construct u and v wind component fields on a 46 by 46 grid network with a grid spacing of 1 km via a scan-radius technique. The divergence across grid squares was minimized by a non-divergence algorithm.

Several analyses produced by the algorithm are illustrated. A user's guide and computer program listing are included.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
Air Pollution * Algorithms * Wind (Meteorology) grids (coordinates) * Atmospheric models	St. Louis, MO Regional Air Pollution Study	13B 12A 04B 08B 04A

18. DISTRIBUTION STATEMENT RELEASE TO PUBLIC	19. SECURITY CLASS (This Report) UNCLASSIFIED	21. NO. OF PAGES 71
	20. SECURITY CLASS (This page) UNCLASSIFIED	22. PRICE

EPA Form 2220-1 (9-73)

INSTRUCTIONS

1. **REPORT NUMBER**
Insert the EPA report number as it appears on the cover of the publication.

2. **LEAVE BLANK**

3. **RECIPIENTS ACCESSION NUMBER**
Reserved for use by each report recipient.

4. **TITLE AND SUBTITLE**
Title should indicate clearly and briefly the subject coverage of the report, and be displayed prominently. Set subtitle, if used, in smaller type or otherwise subordinate it to main title. When a report is prepared in more than one volume, repeat the primary title, add volume number and include subtitle for the specific title.

5. **REPORT DATE**
Each report shall carry a date indicating at least month and year. Indicate the basis on which it was selected *(e.g., date of issue, date of approvcl, date of preparation, etc.).*

6. **PERFORMING ORGANIZATION CODE**
Leave blank.

7. **AUTHOR(S)**
Give name(s) in conventional order *(John R. Doe, J. Robert Doe, etc.).* List author's affiliation if it differs from the performing organization.

8. **PERFORMING ORGANIZATION REPORT NUMBER**
Insert if performing organization wishes to assign this number.

9. **PERFORMING ORGANIZATION NAME AND ADDRESS**
Give name, street, city, state, and ZIP code. List no more than two levels of an organizational hirearchy.

10. **PROGRAM ELEMENT NUMBER**
Use the program element number under which the report was prepared. Subordinate numbers may be included in parentheses.

11. **CONTRACT/GRANT NUMBER**
Insert contract or grant number under which report was prepared.

12. **SPONSORING AGENCY NAME AND ADDRESS**
Include ZIP code.

13. **TYPE OF REPORT AND PERIOD COVERED**
Indicate interim final, etc., and if applicable, dates covered.

14. **SPONSORING AGENCY CODE**
Leave blank.

15. **SUPPLEMENTARY NOTES**
Enter information not included elsewhere but useful, such as: Prepared in cooperation with, Translation of, Presented at conference of, To be published in, Supersedes, Supplements, etc.

16. **ABSTRACT**
Include a brief *(200 words or less)* factual summary of the most significant information contained in the report. If the report contains a significant bibliography or literature survey, mention it here.

17. **KEY WORDS AND DOCUMENT ANALYSIS**
(a) DESCRIPTORS - Select from the Thesaurus of Engineering and Scientific Terms the proper authorized terms that identify the major concept of the research and are sufficiently specific and precise to be used as index entries for cataloging.

(b) IDENTIFIERS AND OPEN-ENDED TERMS - Use identifiers for project names, code names, equipment designators, etc. Use open-ended terms written in descriptor form for those subjects for which no descriptor exists.

(c) COSATI FIELD GROUP - Field and group assignments are to be taken from the 1965 COSATI Subject Category List. Since the majority of documents are multidisciplinary in nature, the Primary Field/Group assignment(s) will be specific discipline, area of human endeavor, or type of physical object. The application(s) will be cross-referenced with secondary Field/Group assignments that will follow the primary posting(s).

18. **DISTRIBUTION STATEMENT**
Denote releasability to the public or limitation for reasons other than security for example "Release Unlimited." Cite any availability to the public, with address and price.

19. & 20. **SECURITY CLASSIFICATION**
DO NOT submit classified reports to the National Technical Information service.

21. **NUMBER OF PAGES**
Insert the total number of pages, including this one and unnumbered pages, but exclude distribution list, if any.

22. **PRICE**
Insert the price set by the National Technical Information Service or the Government Printing Office, if known.