REGIONAL EFFLUENT DISPERSION CALCULATIONS
CONSIDERING SPATIAL AND TEMPORAL METEOROLOGICAL VARIATIONS

G. E. Start
L. L. Wendell

Air Resources Laboratories
Idaho Falls, Idaho
May 1974
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PREFACE

In accordance with the letter of agreement of August 3, 1973, with the U. S. Atomic Energy Commission, Division of Reactor Research and Development, Environmental Safety Branch, the National Oceanic and Atmospheric Administration, Air Resources Laboratories, have continued their study of atmospheric transport and diffusion in the planetary boundary layer, micrometeorology, diffusion climatology, and the application of this work to the disposal of radioactive waste gases into the atmosphere. The research is technically administered and supervised through the Air Resources Laboratories Headquarters, 8060 13th Street, Silver Spring, Md. 20910.
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ABSTRACT

An objective regional trajectory analysis scheme has been combined with a Gaussian diffusion model to yield a technique called MESODIF (mesoscale diffusion). The trajectory analysis scheme utilized wind data from a network of tower-mounted wind sensors to consider the effects of spatial variabilities of horizontal wind flow near the surface, incorporated time changes in rates of diffusion, and used an upper level lid to vertical mixing. The MESODIF calculations of total integrated concentrations were compared with corresponding conventional calculations, using wind-rose joint frequency statistics (single wind station). Comparisons were made within a region about 100 by 130 km, and for time spans from 6 hr to 1 yr.

The diagnostic comparisons of regional dispersion effects from each technique showed significant differences over the range of scales considered. Effluent recirculations and stagnations, related to local wind variabilities about terrain features, were believed to produce localized zones of enhanced exposure to airborne effluents. These zones were not resolved by the conventional wind-rose model.

For short or accidental type of emissions, the greatest shortcoming of the single wind-station dispersion model was its failure to identify, when applied within a region of spatially variable winds, the subregion which would be affected.

At distances beyond about 25 to 50 km, the wind-rose model calculations were significantly biased to overestimation of annual total integrated concentrations by about an order of magnitude. The inability of the wind rose model to accommodate time changes in stability category during effluent transport to the more distant receptors was the single most influential factor of this bias.

Current usage of the wind rose technique for regional dispersion calculations, especially at the longer distances, incorporates some systematic bias in the evaluations. These shortcomings are points of concern and should be reconciled with whatever impact assessment schemes are to be utilized within the mesoscale or regional domain.
REGIONAL EFFLUENT DISPERSION CALCULATIONS CONSIDERING SPATIAL AND TEMPORAL METEOROLOGICAL VARIATIONS

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1. INTRODUCTION

During the last several decades, the understanding of the role of the atmosphere in dispersion of airborne material has been greatly increased. With the present body of knowledge, atmospheric dispersion calculations may be performed with confidence for distances out to several kilometers and for times of a few hours. However, calculations at greater distances, for longer times, within areas of marked topographic variability, or for atmospheric conditions which deviate from simple homogeneity, the confidence and reliability rapidly diminish. Research in recent years has begun to quantify dispersion within flows across mountain ridges, diffusion within deep canyons, and for disturbed airflows around buildings and obstacles. Likewise, significant variabilities may occur for longer time-averagings and at distances beyond a few kilometers, in light of the other significant effects noted.

From a background of several years of meteorological and climatological support of reactor siting and operations at the National Reactor Testing Station (NRTS), it was apparent that significant horizontal variability occurred in low altitude winds over the Upper Snake River Plain in southeastern Idaho. From simple meteorological considerations and later field measurement

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¹Research was carried out under the joint sponsorship of the Atomic Energy Commission, Division of Reactor Research and Development.
programs at other localities, these variabilities were judged to be common to many geographical settings and, therefore, were relevant to environmental-impact assessment calculations for a large number of potential sites. With these problems in mind, deployment of a network of tower-mounted wind sensors was begun in early 1968. As a consequence of data collected from this network, an initial understanding of mesoscale variability of winds has been gained. The initial results of this program have been reported by Wendell (1970, 1972).

The implications of such wind variabilities for calculations of atmospheric dispersion were recognized in 1966, and some simple diffusion model adaptations were examined (Start and Markee, 1967; Dickson et al., 1967). During the course of these examinations, it became apparent that effluent plume geometries could often attain complex forms or undergo transformations from one form into another; simple concepts such as a cross-wind-oriented line source and a continuous point source could not suitably describe these forms or remain applicable following their transformations.

Because dispersion estimates were to be made out to radial distances of 150 km and for time periods as long as a year, several current practices were suspected to be inappropriate. One such practice was the use of wind data measured at a single point. Their utilization to describe the dispersion of airborne material at distances far from the point of measurement would require an extreme degree of horizontal homogeneity in the airflow.

A surface continuous point-source was adopted for all illustrations and comparisons. More complex source configurations could have been utilized, but they would have only clouded the results with additional details.
The simplified model utilized in this project, MESODIF (mesoscale diffusion), incorporated a two-dimensional wind field within which effluent trajectories were calculated according to measured temporal and spatial variabilities of the winds (Wendell, 1970, 1972). Current practices for long-term regional pollution impact evaluations utilize the well-known stability wind-rose (WR) technique; this technique distributes the total period-source release within radial sectors emanating from the source point. The release is distributed in proportion to the frequency of source point winds blowing into the individual sectors. The comparisons of results from these two techniques do not constitute a "validation" of one technique over the other; rather, they illustrate variabilities induced by spatial and temporal changes of the winds. The research described herein was an investigation of these variabilities of total integrated concentrations within a mesoscale-sized region.

Several obvious questions come to mind when beginning an investigation of this type. First of all, will any significant differences occur between the two cited techniques? If so, will there be spatial and/or temporal boundaries on the significant differences; for example, will the two methods differ only at distances greater than 15 km, 30 km, or so forth? Will differences begin to appear almost immediately in time, but quickly disappear as soon as the point wind statistics accumulate a suitable number of occurrences in each wind category? If differences occur and either average out with longer term accumulations or remain with some residue, can physically meaningful causes or sources of these variations be identified?

A number of methods for examining these questions come to mind. Perhaps the simplest approach would be a comparison of the area frequency
distributions determined by each of the transporting wind assumptions or models (this amounts to assuming no diffusion of plume effluent and to counting the number of "exposures" resulting strictly from wind transporting of material to given receptors). This receptor-transport climatology study has been undertaken and initial results reported (Van der Hoven, 1971). Gifford (1973) aptly pointed out that these receptor climatologies should likely represent maximum differences because real plumes would have a larger size and, therefore, are more likely to smear out or to diminish any differences resulting solely from transporting winds. However, because receptor-transport climatology studies showed areas of differences as large as an order of magnitude for an annual cycle, similar diffusion-model calculations were needed to determine whether the addition of plume diffusion would negate these differences.

2. THEORY OF DIFFUSION MODELS

A continuous point source (CPS) has been postulated to examine the effects of spatial and temporal variations of the low-altitude wind flows upon time-integrated concentration estimates. Because the transporting wind flows could be expected to be curving, recirculating, and at times stagnating flows, a Gaussian simple CPS type of equation could not be used (because the plume geometry would likely be altered to the point of in-applicability). Because the CPS equation is an integration of the more general Gaussian instantaneous point-source (IPS), this IPS equation (Slade, 1968) will be the beginning point. For a ground-level source and receptors with total reflection at the earth's surface,
\[ \chi(x, y, z) = \frac{2Q}{(2\pi)^{3/2}\sigma_x \sigma_y \sigma_z} \exp \left[ -\frac{1}{2} \left( \frac{(x-\bar{u}t)^2}{\sigma_x^2} + \frac{y^2}{\sigma_y^2} + \frac{z^2}{\sigma_z^2} \right) \right] \] \tag{1}

where

\( \chi(x, y, z) = \) concentration (units/m\(^3\)),

\( Q = \) source strength (units),

\( x, y = \) distance downwind and crosswind from point of origin, respectively (m),

\( \bar{u} = \) mean windspeed (m/s\(^{-1}\)),

\( t = \) time of travel of the cloud (s), and

\( \sigma_x, \sigma_y, \sigma_z = \) standard deviations of effluent concentration in the downwind, crosswind, and vertical directions, respectively (m).

The \( \sigma \)-values used in MESODIF are the Pasquill A through F types of values (Yanskey et al., 1966) which were derived from continuous plume releases of 1/2- to 1-hr duration. The application of these rates to puff diffusion would tend to overestimate the dilution (and to underestimate the concentration) of puffs within the first few kilometers (Slade, 1968). It should be noted that the specifications of \( \sigma \)-values versus stability categories and trajectory distances primarily apply to distances of a few kilometers. Extrapolation of these curves to regional scale distances is substantiated by little or no data. However, because one dispersion method is to be compared to another, these factors should compensate one another because each model uses the same extrapolated curves.

If horizontal Gaussian symmetry is adopted, equation (1) may be re-stated as
\[ \chi(x,y) = \frac{2Q}{(2\pi)^{3/2} \sigma_H^2 \sigma_z^2} \exp \left[ -\frac{1}{2} \left( \frac{r^2}{\sigma_H^2} \right) \right] \]  

(2)

where

\[ r^2 = (x - \bar{u}t)^2 + y^2 \]

and

\[ \sigma_H = \sigma_x = \sigma_y. \]

Because the application of equation (2) must satisfy conditions of simple, straight-line flow and provide total integrated concentrations (TIC), equation (2) needs to be adapted. Normally, TIC values are obtained by using an integrated (with respect to the x or flow axis) form of the equation. Integration would negate the breaking of the continuous plume into appropriate subelements. Instead, what is used is an approximation to the integral by a summation of weighted concentrations of the form

\[ \frac{1}{u} \int_{-\infty}^{\infty} (x_{IPS})dx \sum_{j=1}^{N} (x_{IPS} \delta t)_{j} \approx \chi_{CPS} \]

(3)

where

\[ x = \bar{u} \delta t \text{ and } dx = \bar{u} \delta t \text{ are used for a transformation of variable.} \]

The summation process is similar to approximate integration by the trapezoidal rule, except the concentration at the end of a time interval \( j \) \( (x_j) \) is assumed to prevail over the entire time interval \( (\delta t_j) \). The area under the Gaussian-like curve of concentration versus time is proportional to the TIC at the receptor point. Depending upon the number of intervals (plume segments) used, the approximation may converge to the integral at any desired level of accuracy.
In application, the MESODIF model disperses plume effluent through the advective transport of plume segment (puff) centers and through the diffusion of effluent puffs about their individual centers. The transport of puffs is determined from a horizontal field of spatially and temporally varying winds. The diffusion of effluents is described by distance-dependent values of $\sigma_x$ (or $\sigma_y$) and $\sigma_z$ (Yanskey et al., 1966). These values are specified according to a general form

$$\sigma = \sigma_0 + \Delta\sigma$$

where

$\sigma_0$ = previous value (ideally zero at the point source),

$\Delta\sigma$ = incremental change during the advective displacement just completed, and

$\sigma$ = updated value following the completed advective step.

The advective related growth $\Delta\sigma$ is different for $\sigma_y$ and $\sigma_z$ and has various constraints to conform better to observed plume behaviors. For horizontal diffusion, $\sigma_y$ is represented by the general forms (Slade, 1968),

$$\sigma_y = A x^{0.85} \quad \text{for} \quad x < 20 \text{ km}$$

(5a)

and

$$\sigma_y = A' x^{-0.5} \quad \text{for} \quad x \geq 20 \text{ km}$$

(5b)

where

$x = \text{distance along puff trajectory from the source},$

$A = \text{stability-category dependent coefficient of proportionality chosen to fit empirical curves of } \sigma_y \text{ versus distance (Yanskey et al., 1966)}$

$A' = \text{stability-category dependent coefficient of proportionality for continuity at 20 km between equations (5a) and (5b)}.$

The exponents of $x$ in equations (5a) and (5b) were selected to fit the
$\sigma_Y$-curves reported by Yanskey et al., (1966). At and beyond 20 km, the horizontal diffusion rate is slowed to the Fickian rate (proportional to the square root of time or distance). To describe $\sigma_Y$ during changes of stability category,

$$\Delta \sigma_Y = \frac{\partial \sigma_Y}{\partial x} \Delta x$$

(6)

where

$\Delta x = \text{advective displacement or distance}$

and

$$\frac{\partial \sigma_Y}{\partial x} = \text{rate of growth of } \sigma_Y \text{ derived from equation (5a) or (5b)}.$$

It should be noted that equation (6) incorporates A or A' and x through the derivatives of equation (5a) or (5b); thus the rate of growth is both dependent upon stability category and total distance traveled. Because the rate of growth is distance dependent, a value determined at the middle of the advection step just completed is the value used in equation (6).

The basic representation of $\sigma_z$ is

$$\sigma_z = B^*x^\gamma$$

(7)

where

$B = \text{stability-dependent coefficient of proportionality chosen to fit empirical curves of } \sigma_z \text{ versus distance (Yanskey et al., 1966)},$

$\gamma = \text{stability-dependent exponent of travel distance, and}$

$x = \text{distance along puff trajectory from source}.$

In practice, a form like equation (4) is utilized to update the previous value, assuring that $\sigma_z$ either remains constant or increases in magnitude.
For vertical dispersion, a capping stable layer or restricting lid to upward diffusion is considered (e.g., Turner, 1970). Three physical regimes are identified for specifying rates of growth of \( \sigma_z \). They are: (1) a region in which the upward spreading is little affected by the presence of the capping lid, and a Gaussian distribution is assumed in the vertical; (2) a region within which thorough mixing of the entire layer has created a nearly uniform distribution of effluent between the ground and the capping lid; and (3) a region between these two in which the plume begins to be affected by the capping lid, and the vertical distribution undergoes a transition from Gaussian to one nearly uniform.

The height of the base of the capping lid or stable layer is denoted \( L \). In MESODIF, \( L \) is specified hour-by-hour to permit an accounting for known diurnal variability of this depth of mixing. An hourly value of \( L \) is applied uniformly throughout the computational area. The effective value \( \sigma_z \) equals 0.8L (Turner, 1970) when the vertical distribution has approached uniformity. If previous values of \( \sigma_z \) already exceed 0.8L, they are held constant (\( \Delta \sigma_z = 0 \)); they are not reduced in any manner because a negative \( \Delta \sigma_z \) would imply negative diffusion. During a given hour in which an \( L \) applies, values of \( \sigma_z \) initially less than 0.8L are restrained from growing larger than 0.8L. Physically, this means the following. During any given hour, plume material may diffuse upward and be confined by the stable layer aloft. Material present from earlier times may have spread aloft to greater depths than permitted by the current stable layer. This earlier spreading is not compressed back into the more shallow layer now existing; it may be better visualized as being
partitioned into portions now below the stable layer and portions within or above the new stable layer. Material above the lid is dropped from further consideration.

The source emission strength $Q$ may be specified hour-by-hour if desired. For this memorandum and the comparisons to be presented, it has been held constant at one unit per hour; each puff then contains one unit divided among the number of puffs released per hour. Removal mechanisms, such as dry deposition, precipitation scavenging, and chemical and photochemical changes, are not incorporated.

3. COMPUTATIONAL METHOD

The two essential parts of the computation are the determination of the locations of the puffs as they are carried by the wind and the calculation of the growth and subsequent dilution of each puff. A third portion of the computation involves the determination of the contribution of the puffs to the time-integrated dosage on an array of grid points. Because the model has been used for long-term releases, up to 1-yr duration, as well as for 12- to 24-hr accident simulations, significant effort has gone into making the calculations as efficient as possible without sacrificing the integrity of the result.

The portion of the model which moves the puffs is based on a simple advective process, using a time series of wind measurements from a randomly spaced array of wind stations (Wendell, 1972). The hourly averaged winds at the stations are interpolated onto a rectangular grid with a subroutine, and the movement of the puffs is computed through a time and space interpolation of the gridded wind fields. This arrangement disengages the
transport and diffusion portion of the model from the wind determination. This separation provides the option of using the model with historical or predicted winds when they are available. As mesoscale wind-prediction techniques are developed and improved or as they might vary from one region to another, these techniques will be readily usable by this model in cases where TIC predictions are required.

The periodic sampling of the puffs for summing concentrations at the grid points is based upon a distance increment rather than a specified time increment to allow a more uniform approximation to the continuous plume at both high and low windspeeds. The displacement of each puff is computed for a specified time-step and divided by the distance increment specified for sampling the puff. This quotient is then rounded to the next highest integer which is used as the number of times to sample the puff along the computed displacement path. During periods of high windspeeds, the puffs will be sampled several times during an advection step, but only once during sufficiently low windspeeds. When all the puffs have been displaced and sampled, the process begins again for another advection step.

To calculate the growth of each puff as it is carried by the wind, several factors are carried over from one advection step to the next. These are: the emission strength of the puffs, the \( \sigma_y \) and \( \sigma_z \)-values for the puff, the total distance traveled by the puff, the horizontal coordinates of the puff center location, and a control parameter which indicates whether the puff has left the grid or has become so dilute that it is no longer to be considered in the calculations. The distance-dependent values of \( \sigma_y \) and \( \sigma_z \) are used to calculate the puff center concentrations. The
radius of influence of each puff is determined by the relation

\[ R_p = \sigma_y - 2 \ln \left( \frac{x_{\min}}{x_p} \right) \]  

(8)

where

\[ x_{\min} = \text{the minimum concentration of interest} \]

and

\[ x_p = \text{the concentration at the puff center.} \]

The concentration is computed and accumulated for each grid point which lies within the radius of influence of each puff.

It was indicated that the puffs are carried along in the computational scheme until they are totally off the grid or until their peak concentration falls below a specified level of interest. To keep the computer memory requirements to a minimum, especially for releases over an extended period of time, 400 has been set as the upper limit on the number of puffs which are carried simultaneously in the calculations. After the first 400 puffs have been released, the control parameter array is scanned; all information for the puffs, which can no longer contribute a significant concentration at any grid point, is eliminated to make room for puffs yet to be released. When the number of puffs remaining and the number subsequently released reach 400, the process is repeated. Under conditions of very low windspeed, the number of puffs simultaneously contributing to the dose may exceed 400. When more than 400 puffs exist, an attempt to eliminate noncontributing puffs occurs every hour. Under this condition, the number of puffs is allowed to grow to 500 before a message is printed and the program terminated. This termination has never occurred in several runs of 1-yr duration.
4. MODEL TESTING

A. Approximation of the Continuous Point Source

One of the concerns in the computation is whether the continuous point-source (CPS) equation is being approximated with a satisfactory degree of accuracy. If the trajectory of a plume is straight, one puff will approximate the dose pattern of a CPS to any degree of accuracy desired, provided it is sampled frequently enough as it passes each point of concern. The frequency required for the sampling will, of course, be a function of the speed of the puff and its rate of growth, which is dependent on the stability classification.

Calculations of values of total integrated concentration (TIC) were made for straight-line flow for various windspeeds and stability classes with both the puff model and the CPS equation. The most severe conditions considered for an accurate approximation were strong winds and class D stability (causes the slowest horizontal puff growth). The ratios of the TIC values for class D and a 25-m s$^{-1}$ speed computed by the puff model and by the CPS equation for four different sampling intervals are shown in figure 1. It is apparent that to obtain reasonable accuracy to within 10 km of the source, the sampling interval should be between 1 and 2 min. In terms of puff travel distance, this is between 1.5 and 3.0 km. For this reason, the puff travel distance between samples is restricted to less than 2.4 km in the operational model. This provides a more than adequate approximation of the CPS equation for all but a few isolated cases of hourly averaged winds over 25 m s$^{-1}$. The operational model has been thoroughly validated against the CPS equation for straight-line flow.
Figure 1. Ratios of total integrated concentrations (TIC) for: (a) 1- and 2-min, and (b) 4- and 10-min advection steps. All curves apply to D stability class and 25 m s$^{-1}$ windspeed. Individual curves are labeled in minutes for different time lengths of advection steps.
B. Approximation of the Instantaneous Line Source

Because the purpose of the puff model is to handle flow with spatial variation, another major concern is that the continuous release has been divided into a sufficient number of puffs to approximate the continuous plume adequately. For example, if a series of puffs becomes oriented perpendicular to the wind and is acting as if the puffs had been released from a line source, the spacing of the puffs will strongly affect the accuracy of the approximation to a continuous plume. This is illustrated in figures 2a and 2b in which the puffs are releases at rates of three and six per hour, respectively. The dots indicate the position of the puff centers, and the circles are contours of the minimum concentration of interest. During the first 5 hr of the release shown here, the winds are steady from the southwest. This period is followed by a clockwise shifting of the wind which moves a large segment of the plume as a line perpendicular to the direction of movement. The more complete coverage of the six puffs per release (fig. 2b) is especially noticeable in the western portion of the line, beginning at 0500 Mountain Standard Time (MST).

Obviously, the greater the number of puffs per hour, the better the approximation to a continuous plume; but the computation time is almost directly proportional to the number of puffs released. To determine a compromise, the 1969 set of trajectory plots for 12-hr releases was scanned for cases in which a wind shift caused a rapid spreading of the trajectories and the phenomena of the plume moving as a line. Sets of three matrices of TICS were calculated for each case in which three, six, and 12 puffs per hour were released.
Figure 2. Plots of two hourly positions of sequentially released puffs for: (a) three puffs per hour, and (b) six puffs per hour. Each puff is depicted by a dot showing the center position and by a circle representing the contour of the lowest concentration of interest.
A comparison of the TIC matrices for each case showed that for a large percentage of the time, three puffs per hour would probably be adequate; six puffs per hour resulted in dosages which were very close to dosages resulting from 12 puffs per hour in all but the most extreme cases of wind shift. The 2100 MST release on January 17, 1969, shown in figures 2a and 2b, represents such an extreme case. As the plumes leave the southern end of the site, the puffs actually separate in both the three and six puff per hour cases. The doses in the region where the plume separates differ by a factor of two for the six- and 12-puff per hour releases. However, the actual magnitude of the doses in this region are less by two orders of magnitude than the largest doses on the grid; thus, the indication that plume segment separation is not a very serious problem. Results of these tests would indicate that a release rate of six puffs per hour should be adequate for continuous-plume approximation. For long-term releases on the order of a year, three puffs per hour would probably provide reasonable results for one-half the cost. All subsequent illustrations are based upon releases of six puffs per hour.

5. DEMONSTRATION CASES

A. Short-Term Applications

MESODIF has the potential for providing concentration or TIC values on a regional scale for an unexpected release of effluents into the atmosphere. It could be used with forecast winds for evacuation purposes or with recently recorded winds to determine the area affected since the release began. In either case, winds based on data from a network of stations would be more reliable in providing the effluent transport than data from the source wind only.
Figure 3. Plots of sequentially released puffs for a continuous release through a period in which there is much spatial and time variation in the transporting flow.
A hypothetical continuous release from a point labeled PBF was chosen as a demonstration case of the short-term application. The computer program requirements and listing are shown in appendix A and B, respectively. The release was initiated at 1300 MST on March 4, 1969, and continued for 24 hr. To put the sequence of events into perspective, two-hourly plots of the puffs (every other one) are shown in figure 3. The plus sign in the first frame indicates the location of the source. From 1300 to 2100, the puffs move away from the source in a southerly direction across the boundary of the site and then turn and move in an easterly direction for about 80 km. Between 2100 and 2300, the wind begins carrying puffs in the vicinity of the source in a northwesterly direction. By 0100, a region of strong divergence has separated the plume (approximated by the puffs) southeast of the site. The older puffs move in an arc to the east of the site and curve back around toward the northeastern site boundary; later released puffs move in a northerly direction and also turn toward the northeastern site boundary, indicating an area of convergence. By 0700, the puffs more recently emitted from the source have formed a line which sweeps from north to south across the site and is followed closely by the older puffs from the beginning of the release.

The behavior of the puffs for this release indicates a fairly complex flow pattern involving a great deal of space and time variation over the area. To show the inadequacy of the source wind in determining the transport, the six-hourly TIC contours for both wind field (WF) and single station (SS) calculations are shown in figure 4. The difference between the two calculational models is that in the SS model the hourly wind field is homogeneous over the entire grid and is based on a time series of single,
Figure 4. Contours of total integrated concentration (TIC) for the same hypothetical continuous release as is shown in figure 3, beginning at 1300 MST on March 4, 1969, from the location of the Power Burst Facility for: (a) transport based on wind field (WF) data, and (b) transport based on single station (SS) source wind data only.
hourly winds observed at the point of emission. The contrast between
the TIC patterns for this case is extremely striking. The large area to
the east of the site shows no effects at all for the SS transport; it is
significantly affected when WF transport is considered. This difference
would imply that under flow conditions of this type, an error in the
diffusion calculations is far less serious than the extreme misrepresen-
tation of the transport.

An interesting feature of this case occurred during the first 6-hr
when all puffs followed essentially the same curved path, indicating that
the flow over that path was not changing with time. In this instance, a
forecast of no change in the WF for 1300 for the following 6 hr would have
been valid; using this forecast in MESODIF would produce essentially the
same dose pattern as seen in the R+6 hr (6 hr after start of release)
frame of figure 4a. The same forecast of an unchanging wind at the source
point would produce essentially the same pattern shown for R+6 of figure
4b. It is easily seen that longer term plans of action based on the ex-
trapolation of the 6-hr source wind sequence could be misleading. This
example is not meant to imply anything about the reliability of persist-
ence forecasting. It demonstrates, however, that when spatial variability
is present in the flow pattern, transport based on the source wind can
be seriously misleading.

B. Long-Term Applications

In the case of an accidental release of an effluent into the atmosphere
over a short period of time, the value of a diffusion model using a WF for
the transport has been demonstrated. For continuous long-term releases,
perhaps from an operating facility, a diffusion model using WF data has
has not been previously considered because of the relatively high cost of calculations and because a long record of wind data from a regional-scale network of wind stations has not been available. The most common procedure for evaluating the transport and diffusion effects from a long-term release is to use wind rose (WR) and stability data from the source location. The central assumption in this approach is that material leaving the source will travel in the direction of the source wind at the time of release until it reaches some specified boundary (the material flows radially outward within the same wind direction sector in which it began).

While this travel within sectors may not be satisfied case-by-case, the WR technique assumes that in the long-term average no systematic transverse turning of the flow occurs; losses of mass from the side of a sector are balanced by corresponding mass gains caused by an inflow from the adjoining sector. In this event, there could be a basis for use of the wind at the source to describe the distribution of effluent material at long distances for long times. In regions of topographic variations, this assumption could be invalid because of the systematic turning of the flow. This assumption will be examined in detail later.

A WR model currently being used by the AEC Directorate of Licensing (DRL) calculates $\chi/Q$ on an annual basis for various distances out to about 80 km in each wind direction sector. For a ground-level release, the rate of diffusion is a function of distance from the source, sector width, mean windspeed in the given windspeed class, $\sigma_z$ with no upper bound, and the joint probability of stability, windspeed, and direction. The model is used to evaluate the dispersion potential of the atmosphere in a possible reactor site area. Initially, the model was applied to site
areas where the boundaries were only a few hundred meters from the source; for that situation, it seemed to be the most logical method. However, in areas where spatial variation in the flow patterns is frequently observed on a regional scale (Wendell, 1972), extending this method to a radius of 80 km from the source would seem to be inappropriate.

With MESODIF designed to shift noncontributing puffs out of the computer memory, it can be used to calculate a TIC pattern resulting from a continuous release of indefinite length. The postulated effluent, in the form of a string of puffs, is carried by the flow determined from the wind network until it leaves the grid or becomes too dilute to be of any more interest. The TIC information may be stored on tape in segments of any desired length; for example, week, month, or season. These segments may be examined individually or combined to produce an annual average result.

To compare the annual average TIC values for the DRL and the MESODIF models, a hypothetical ground-level continuous source was postulated at the location of the EBR II wind tower. This site was chosen because it lies nearly at the center of the mesoscale grid network. The hourly averaged winds were chosen from the 1969 data set for the network because of the extensive WF and the trajectory analysis work that has been done using this data set. The puff release rate was six puffs per hour. The same hourly stability classes were used in each model. The DRL model used a joint frequency distribution, based on the winds from the EBR II wind station and the above-mentioned hourly stability classes. The transport winds for MESODIF were calculated from the network of wind stations within the computational grid. The
Figure 5. Contours of TIC for a continuous release from the ERB II location through the period from December 1, 1968, to November 30, 1969. The solid contours are for the MESODIF model results, and the dashed contours are for the DRL model results. Number identifiers on contour lines represent the following values: 8: \(5 \times 10^{-7}\); 7: \(1 \times 10^{-7}\); 6: \(5 \times 10^{-8}\); 5: \(1 \times 10^{-8}\); 4: \(5 \times 10^{-9}\); 3: \(1 \times 10^{-9}\); 2: \(5 \times 10^{-10}\); and 1: \(1 \times 10^{-10}\).
Figure 6. Ratios (MESODIF/DRL) of annual TIC values at the grid points over the computational area. Contours have been added to show the general pattern.
values of $\sigma_n^2$ in the DRL model were calculated from equation (7) for all
distances without any mixing depth restrictions. The resulting TIC
values were calculated with both models for the four seasons and the
entire year.

The comparison of TIC patterns for the full year is shown in figure
5. There is fairly good agreement for the first two contour levels. The
shapes are basically the same with a slight southeastward shift of the
DRL pattern. Within the area of these contours, the major and minor axes
of diffusion appear to agree quite well. Figure 6 shows the ratios of
the MESODIF/DRL TIC values at the computational grid points. The area of
fair agreement is approximated by the ratios near and larger than one.

Outside this 25- by 50-km area, however, the comparison is not so favorable.
The TIC values from MESODIF decrease more rapidly with distance (on a loga-

rithmic depiction) from the source, while the TIC values from the DRL
model decrease at a "straight-line rate." The different rates of decrease
of TIC values with distance are apparent from figure 6 which shows the
MESODIF/DRL ratios decreasing to less than 0.1 at some points near the
boundary. Figure 7 presents this phenomenon more quantitatively, using
plots of TIC values along the major and minor axes of dispersion. The
difference in the rate of decrease with distance of the TIC values from
the two techniques is most apparent. Discussion of reasons for the dif-
fferences will be presented in a later section.

The same type of comparisons (as shown in fig. 5 and 6) are shown
for the four seasons in figures 8 and 9. The most general observations
which can be made are that, on a seasonal basis, some MESODIF/DRL ratios
(fig. 9) are higher than for the annual computation (up to 4.5). The
Figure 7. Plots of annual TIC against distances from the source along the major and minor axes of diffusion. The solid lines are for MESODIF results, and the dashed lines are for DRL results.
Figure 8. Seasonal contours of TIC for the same release described in figure 5. (See fig. 5 for details.) Winter is for December through February, spring is for March through May, summer is for June through August, and autumn is for September through November 1969.
Figure 3. Seasonal ratios (MESODIF/DRL) of TIC values during the same data period are shown in figure 6. (See fig. 6 for details.)
areas of ratios greater than one show marked seasonal variability in shape and intensity. The TIC pattern comparisons in figure 9 show differences in the orientation of the major and minor axes of diffusion. Because c-values were derived from continuous plumes with release durations of 1/2 to 1 hr, their use may have inhibited the producing of ratios greater than one within the first 2 to 10 km of the release point.

The seasonal variations in the shape of the area of the MBESODIF/DRL ratios greater than one can be related to the transport as indicated by the trajectory plots. For the winter and spring seasons, these areas extend from the source to the boundaries in northeasterly and southerly directions, respectively. During the summer and autumn, these areas do not extend to any boundaries. The trajectory plots for summer and fall seasons show no particular preference for transport to any boundary; trajectory plots for winter and spring illustrate preferred zones of transport to the boundaries of the computational area.

6. DISCUSSION AND SUMMARY

Differences in areal coverages and magnitudes of total integrated concentration values have been shown in figures 4 through 9. During short release intervals (few hours) or specific case situations, the use of wind information from a single point (when spatial wind variability is present) can yield seriously misleading information if the single-point methodology were extrapolated to longer times and longer distances. Other model differences also contribute to the difference in TICs. But of all the differences, the failure to describe accurately the effluent trajectory (thereby giving a misrepresentation of the area which would be influenced) is probably the most serious error.
The extension of methodologies to regional distances and for weekly, seasonal, and yearly time intervals also retained significant residual differences in TIC estimates. However, at these extended times and distances, several factors contributed to produce the net differences illustrated in figures 5 through 9. The quantitative comparisons may be summarized as follows. The MESODIF model yielded one or more "hot spots" (regions in which TIC values were up to 4.5 times larger than the wind rose (WR) method) generally within 50 km or less of the source point. At greater distances, the WR model yielded TIC estimates about an order of magnitude greater than the MESODIF model. These differences are highly significant and should be reconciled if impact assessment calculations are to be utilized within this domain.

To understand these differences in TIC values, the models and the physical processes treated differently by each need to be reviewed. Table 1 lists six physical features treated differently in the two models. Both models treat vertical diffusion in the same manner at short distances from the source point. But when upward diffusion begins to be influenced by the presence of a capping inversion or lid, the calculated concentrations and resulting TICs begin to differ (the MESODIF values being the larger). In terms of short-distance and long-distance effects, this difference in vertical diffusion modeling should yield a region of general agreement about the source. This agreement should deteriorate with distance into a surrounding zone in which MESODIF values of TIC are progressively larger than WR values. The opposite effect is observed at the longer distances; some different process must be of greater importance.

Stagnation (or very slow speeds of transport relative to the initial source windspeed) leads to systematic increased dwell time of MESODIF
<table>
<thead>
<tr>
<th>Physical feature</th>
<th>Nature of influence upon long-term TICs</th>
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<tbody>
<tr>
<td>Vertical diffusion</td>
<td>Restrictive lid upon upward spreading tends to keep MESODIF TIC larger than for WR. Effect grows with distance traveled from source.</td>
</tr>
<tr>
<td>Horizontal dispersion (In the absence of terrain-related spatial variations of winds)</td>
<td>Two factors are considered—turbulent diffusion of effluent mass horizontally outward from the plume or puff center and dispersion of plume subelements or puffs through time changes of the horizontal wind direction. At short and intermediate times, the differences are large; at longer times, the mean directional transport differences would tend to decrease, and net results become similar at greater and greater outward distances.</td>
</tr>
<tr>
<td>Stagnation (or very low windspeeds)</td>
<td>MESODIF plume dwell time over receptors yields TIC values the same or greater than WR values. WR method provides a 1-hr influence at all points within the sector of the source point wind during the hour of emission. All points within a WR sector (outward to infinity) are affected by the 1-hr emission. Stagnation may be topographically influenced.</td>
</tr>
<tr>
<td>Recirculation</td>
<td>Not permitted by WR model. TIC values from MESODIF will be increased in regions of preferred recirculation due to repeated exposures. Terrain features could induce these effects in the wind fields.</td>
</tr>
<tr>
<td>Curved trajectories (versus straight flow outward within angular sectors)</td>
<td>A failure to reach distant receptors along straight-line paths outward from source point can occur. Either emission affects points outside of the sector of initial travel or fails to leave the general vicinity of source point. Failure to move far from the source is only temporary. Eventually, winds sweep the material out beyond the region of concern. In the absence of terrain influences, this effect should diminish with averaging or integrating times.</td>
</tr>
<tr>
<td>Stability changes (during times of dispersion over computational region)</td>
<td>By design necessity, the WR-modeled emissions reach all receptor points while having the stability category in effect during the hour of emission. MESODIF allows hour-by-hour changes of stability category as measured at source point; all emissions remaining within the computational region at the time of change then diffuse with rates specified by the new category. These influences are likely to be accumulative and most pronounced at the longer distances.</td>
</tr>
</tbody>
</table>
emissions over the computational region. MESODIF values of TIC will exceed WR values in these cases. In preferred zones of stagnation, TIC values would accent this difference in dwell time through successive summing of concentrations. Topography is believed to be the major source of this influence; stagnation effects may occur at any distance outward from the source point.

Recirculation, as in stagnation, would yield MESODIF values of TIC systematically larger than WR values because repeated passage of effluents over the same receptor would be analogous to longer dwell times. Again at longer distances, other factors must dominate. Terrain-related influences upon the wind flows could be expected to produce "hot spots" (MESODIF values of TIC greater than WR values) in the vicinity of those features in the topography.

Curved trajectories (rather than straight flow within a direction sector emanating outward from the source) or terrain-induced airflow channeling could produce bands or envelopes of either overestimation or underestimation of TIC values in one model versus the others. There should be compensating areas of TIC ratios so that the net difference within a source encircling-ring averages near zero. If curved trajectories exit the region from preferred areas, there must also be areas near the outer boundaries in which fewer than normal trajectories would exit. At the longer distances, the comparisons of long-term (annual) TIC values never showed MESODIF to exceed WR estimates. There may be short-distance, and certainly short-time, occurrences of this effect. However, at longer distances and times, trajectory curvature effects largely disappear and other factors still must yield those dispersion differences displayed in figure 7.
Horizontal dispersion of effluent emissions is treated differently. The WR model distributes an average concentration laterally along the arc of the sector in which the material lies. MESODIF utilizes the customary term $\sigma_y$, and concentrations decrease exponentially outward from the puff centers according to the exponential term in equation (2). When a time change of wind direction occurs, the MESODIF model includes an additional dispersion of plume effluent caused by transporting of plume segments (puffs) along different (diverging) trajectories. In the absence of terrain-induced flow variations, there should be a tendency for these diverging trajectories to average out or compensate for random divergent turning to either one side or another. At the source, this effect would be minimal for short- and long-time periods. With successively longer integrating time periods, the greater the opportunity for these random separations of trajectories to compensate and negate this effect. With longer times, the areas failing to have negated differences in diverging transport should occur only beyond progressively longer distances from the emission point. While this effect cannot be fully ruled out as a source of greater MESODIF dilutions at the longer distances, it is not believed to be a major contributor; most of the randomness should balance out.

Changes in the stability category, while MESODIF effluents released at earlier times remain within the computational area, are a major contributor to cumulative differences in longer term TIC values determined at the longer distances. By design, the WR technique prohibits the hourly effluent release from diffusing at a stability different from the hour in which it was emitted from the source; MESODIF has no such restriction. Two illustrations will help clarify the role of hour-by-hour changes in stability category in
producing systematic, additive differences. Two basic types of change in atmospheric stability category can be envisioned—change from stable to unstable and change from unstable to stable. Before proceeding, it is well to recall that atmospheric dispersion of effluents proceeds most rapidly during unstable or "daytime" conditions and least rapidly during stable or "nighttime" conditions. At distances approaching 50 km, effluent concentration estimates based upon standard empirical diffusion curves (e.g., Turner, 1970) could differ by about three orders of magnitude across the span of stability categories. A large fraction of this difference is related to the vast differences in vertical diffusion during daytime and nighttime. During daytime unstable categories, both MESODIF and WR plume effluents dilute very rapidly; their vertical dispersion would be the same until the MESODIF model experienced slower rates of dilution under the influence of a capping lid. Therefore, all other things being the same, concentrations and the resulting TIC values from MESODIF would equal or exceed values from WR during daytimes. Also, when hourly changes in stability category progress from unstable to stable, the MESODIF determined values of TIC would equal or exceed somewhat those values from the WR model. These differences are contrary to the net effect as shown in figure 7 at distances of about 50 km from the point of emission.

It is the transition from stable to unstable stability categories that yields significantly different estimates of dilution at the longer distances. The WR technique exposes all downwind receptors with concentration levels appropriate to the category of diffusion at the time of effluent emission. If the initial stability category were strongly stable, all WR model receptors downwind would be exposed to the greatest possible concentrations,
regardless of whether this atmospheric conditions would have to persist for 1/2, 10, or even 100 hr. Extremely poor dispersion conditions could conceivably persist for a sizable fraction of a day, but mean weekly, seasonal, or annual conditions certainly would not result in these extremely high TIC values at 50 to 100 km downwind from the source point. MESODIF considers hourly changes in stability category (rates of dilution). Because light windspeeds are associated with the most stable conditions, many hours of effluent transport are necessary to reach the outermost receptors. Consequently, most plume segments reaching receptors at large distances experience some periods of time in which dilution proceeds at a rapid pace. In most cases, MESODIF-modeled effluents which initially were diluting very slowly during stable conditions are rapidly diluted before reaching receptors at the longer distances. This effect is not compensated over 24 hr and longer periods of integrating time. Instead, these recurring differences in concentration estimates are systematically accumulated in the TIC values. Figures 6 and 7 clearly show these accumulated effects at the longer distances.

At distances within about 15 to 25 km, agreement of MESODIF and WR estimates was much better. In general, the two techniques either produced comparable values or MESODIF values were greater. Most of the physical processes enumerated in table 1 would tend to contribute to this type of comparison—except stability category changes.

Some insight into the development of "hot spots" at the shorter distances may be gained through examination of the local topography. Figure 10 shows this topography and has been discussed by Wendell (1972). The mountainous terrain is shown qualitatively by the shadowed relief. The gentle height variation over the relatively flat plain is depicted by height
Figure 10. Relief map of the Upper Snake River Plain in southeastern Idaho. The height values of the contour lines given are in hundreds of feet above mean sea level. The stippled area indicates the area of the plain which lies below 5,000 ft. The tick marks along the grid box border indicate the computational grid mesh size, 8.6 km. The letters a, b, and c show the locations of three prominent buttes. The large dots indicate the location of tower-mounted wind sensors.
contours of feet above mean sea level (MSL). The area in which the
terrain height is less than 5,000 ft MSL is stippled to emphasize an im-
portant feature of the comparatively mild terrain-height variation of the
plain. The terrain feature of importance is the protruding area of slightly
higher terrain extending from the west into the middle of the valley and
then up-valley toward the northeast. It has the effect of creating a fish-
hook-shaped depression which proceeds up along the Snake River on the right-
hand side of the boxed computational area. The depression turns toward the
northwest around the up-valley end of the 5,000-ft height contour and then
extends toward the southwest across the National Reactor Testing Station
(NRTS), the irregular bordered area. Three prominent buttes located along
the protruding ridge are identified by the letters a, b, and c. The solid
dots show the locations of tower-mounted wind sensors.

When the 5,000-ft contour line was superimposed on observed wind fields,
varying degrees of conformity to this feature were observed during 57 per-
cent of the days within a 1-yr sample (Wendell, 1972). Part of the time
this conformance was reflected in a standing circular eddy along the up-
valley edge of the protruding ridge of higher ground; a preferred area of
stagnation and recirculation would be expected. The portion of the depres-
sion over the NRTS has also been observed to be an area more prone to stag-
nation or light and variable winds. Review of figures 6, 9, and 10 suggest
a degree of conformance of the hot spots to these two areas of topographic
wind influence.

In summary, the following aspects of regional effluent-dispersion cal-
culations are points of concern and should be reconciled with whatever im-
pact assessment schemes are to be utilized within the regional domain. For
assessments covering relatively short periods of time (such as individual cases, accidents, and intermittent operations, lasting from a few hours to a few days), the greatest single concern stems from underspecification of the detailed meteorological wind data necessary to define properly effluent trajectories and the region of potential influence. Complex, three-dimensional models may be required to describe fully impacts from accident-like emissions. A number of complex models exist, such as the particle-in-cell (PIC) types (Sklarew et al., 1971), which have been developed to describe such detailed, specific cases. However, there is one severe practical limitation common to these models; the detailed, three-dimensional meteorological data are not available on a regional scale and they are not likely to be available in the near future. From this point of view, the two-dimensional wind flow models such as MESODIF (the vertical dimension is partially treated by the limited mixing-depth concept) may be the type of practical working compromise needed for regional dispersion calculations until very detailed meteorological inputs become operationally or climatically available.

For regional assessments covering longer times, and to some extent short times, systematic terrain-related variations in the horizontal wind flows are significant. Monthly, seasonal, and annual accumulations of TIC estimates can retain residual differences compared with values determined using a single point or WR distribution of transporting winds. The WR technique is susceptible to bias toward underestimation in areas of recirculation and stagnation. At long distances, beyond about 25 to 50 km, the WR technique is likely to overpredict TICs significantly. This bias results primarily from a failure of this technique to permit modeled effluents to dilute at more rapid rates after an initially, strongly stable, stability category has modified to some category that is less stable.
The problem of a proper specification of diffusion coefficients is common to whatever method may be chosen, whether they be eddy diffusivities or Gaussian plume sigmas. Additional data are needed to extend known diffusion parameters to regional scales.

The MESODIF model and the continuous point-source equations have suitably predicted short-time (2 to 4 hr) total-integrated ground-level concentrations measured to distances near 90 km over the Upper Snake River Plain in southeastern Idaho. The meteorology of these diffusion cases was restrictively simple. Observed winds were about 15 m s⁻¹ with a fairly steady wind direction. Vertical shearing of wind direction was on the order of 10° or less and the stability category was near neutral. More stringent validations of modeling techniques are needed, but to date suitable data sets for long-time periods and distances are not available.

REFERENCES


APPENDIX A. MESODIF COMPUTER PROGRAM REQUIREMENTS

Machine Requirements

This program and the associated subroutines are written in FORTRAN IV and use approximately 105 K bytes of memory within an IBM 360-75 computer. The running time will vary with length of release; number of puffs released per hour; and the overall dimensions, mesh size of the computational grid, and the nature of the flow pattern over the grid. The last item has to do with the number of puffs remaining on the grid to be examined at each sampling step. A 24-hr calculation, based on a continuous release rate of six puffs per hour over an 86- by 130-km grid with a mesh size of 8.6 km, takes from 10 to 18 s of computer time. Releases of this type over a 1-yr period take about 1.5 hr.

Tape or Disc Input

For the sake of efficiency, the meteorological data for this program are read in from magnetic tape or disc. The stability class and mixing depth data are read in the main program into an array called MET which contains 24 by 5 locations; each record represents 1 day's data. The format of this array is as follows:

\[ \text{MET}(i,j) \]

- \( \text{MET}(1,1) = \text{MMDD} \), the first two digits denote the month and the second two the day.
- \( \text{MET}(i,2) = \text{Single digit from 1 to 6 denoting stability class. (I ranges from 1 to 24 indicating hour of day.)} \)
- \( \text{MET}(i,3) = \text{Height of mixing depth in meters.} \)
- \( \text{MET}(i,4) = \text{DDVV, DD denotes wind direction in tens of degrees and VV denotes the speed in mph. These data are not used in the version of the program presented here.} \)
- \( \text{MET}(i,5) = \text{At present, this variable is a dummy but is available for use if Q is known on an hourly basis. To use it would require only a minor change in the program.} \)
The month and day of the initiation of the release provided by the card input are used to search down the data string and bring in the proper record to begin the calculations.

The wind data used for transporting the puffs are read in by subroutine RNGRD9 into an array called IWD with a size of 24 by 31 words. Again, each record represents 1 day's data consisting of hourly averaged wind and some temperatures at the various locations in the tower network. The version of the program presented here uses only the wind data. The word IWD(1,1) contains the month and day and is used in the same fashion as MET(1,1) for obtaining the starting record. The wind data in this record are in the same format as MET(1,4). For each hour, the wind data are selected from the string by means of the variable ISKIP defined in card input section.
CARD INPUT DATA FOR MAIN PROGRAM

(All variables on cards #1-3 must be right justified)

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<td>NSTEPS</td>
<td>Total number of hourly steps for current run</td>
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<td>Day in which release was initiated</td>
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<td>TAU</td>
<td>Number of minutes between puff releases</td>
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<td>DT</td>
<td>Number of minutes between each puff sampling (Used only when KVDT = 0)</td>
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<td>NN1</td>
<td>Number of advection steps into first hour for release</td>
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<td>LIMPUFF</td>
<td>Maximum number of puffs carried before screening out no longer contributing puffs</td>
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<td>KCHIS</td>
<td>Store dose matrices on disc or tape at specified print intervals</td>
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<td>66-70</td>
<td>KVDT</td>
<td>Allows number of minutes between puff sampling to be variable as determined by speed of puff and specified minimum travel distance between sampling of puffs. KVDT = 1 variable DT, KVDT = .0 use or specified</td>
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<td>KFLSH</td>
<td>1 - zero out dose matrix after each print and storage, 0 - allow dose matrix to accumulate</td>
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<td>Number of minutes in basic advection steps</td>
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<td>PTIME(I)</td>
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<td>DELY</td>
<td>Spacing in miles between grid points in the Y-direction</td>
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<td>Dummy</td>
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<td>4</td>
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<td>CHIMIN</td>
<td>Minimum significant concentration value (this determines puff radius)</td>
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CARD INPUT DATA FOR WINDFIELD SUBROUTINE

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<tr>
<td>5</td>
<td>6-10</td>
<td>NSX</td>
<td>Same as MSX on card 4</td>
</tr>
<tr>
<td>5</td>
<td>11-15</td>
<td>NSY</td>
<td>Same as MSY on card 4</td>
</tr>
<tr>
<td>5</td>
<td>16-20</td>
<td>NFX</td>
<td>Same as MFX on card 4</td>
</tr>
<tr>
<td>5</td>
<td>21-25</td>
<td>NFY</td>
<td>Same as MFY on card 4</td>
</tr>
<tr>
<td>5</td>
<td>26-30</td>
<td>NSTL</td>
<td>Limit on number of stations to be used in interpolation if limiting radius has been reached</td>
</tr>
<tr>
<td>5</td>
<td>31-35</td>
<td>INPT</td>
<td>Source of wind data, 1 - tape, 0 - disc</td>
</tr>
<tr>
<td>5</td>
<td>36-40</td>
<td>NSKIP</td>
<td>Number of records to skip before beginning input of wind data</td>
</tr>
<tr>
<td>Card</td>
<td>Format</td>
<td>Variable</td>
<td>Description</td>
</tr>
<tr>
<td>------</td>
<td>--------</td>
<td>-----------</td>
<td>-------------</td>
</tr>
<tr>
<td>6</td>
<td>1-10</td>
<td>RTE</td>
<td>Angle, in degrees, of grid rotation from north</td>
</tr>
<tr>
<td>6</td>
<td>11-20</td>
<td>RCH</td>
<td>Radius, in grid units, within which all stations are to be used in interpolation</td>
</tr>
<tr>
<td>7</td>
<td>16F5.0</td>
<td>X(I)</td>
<td>X-coordinate of each station (I = 1,NP)</td>
</tr>
<tr>
<td>8</td>
<td>16F5.0</td>
<td>Y(I)</td>
<td>Y-coordinate of each station (I = 1,NP)</td>
</tr>
<tr>
<td>9</td>
<td>16F5.0</td>
<td>COR(I)</td>
<td>Corrections, if any, in degrees to wind direction (I = 1,NP)</td>
</tr>
<tr>
<td>10</td>
<td>16F5.0</td>
<td>CONFAC(I)</td>
<td>Multiplier of windspeed to adjust for height of sensor. Log profile may be used to adjust data to same height. If no adjustment desired, use one</td>
</tr>
<tr>
<td>11</td>
<td>16(1XA4)</td>
<td>NAMST(I)</td>
<td>One- to four-character identification of each station (I = 1,NP)</td>
</tr>
<tr>
<td>12</td>
<td>31I2</td>
<td>ISKIP(I)</td>
<td>Control parameter to extract selected information from data record (I = 1,31). 1 - use data, 0 - bypass</td>
</tr>
<tr>
<td>13</td>
<td>16A4</td>
<td>KMON(I)</td>
<td>Three-character month identifiers</td>
</tr>
<tr>
<td>14</td>
<td>1-2</td>
<td>YEAR</td>
<td>Two-digit year identification</td>
</tr>
<tr>
<td>15</td>
<td>1-5</td>
<td>MS</td>
<td>Month in which release begins</td>
</tr>
<tr>
<td>15</td>
<td>6-10</td>
<td>IDS</td>
<td>Day in which release begins</td>
</tr>
<tr>
<td>15</td>
<td>11-15</td>
<td>IHS</td>
<td>Hour in which release begins</td>
</tr>
</tbody>
</table>
APPENDIX B. MESODIF COMPUTER PROGRAM LISTING
PROGRAM TO COMPUTE RELATIVE CONCENTRATION FOR RECIRCULATING EFFLUENT

DIMENSION XIS(40), YIS(40), CHI(26, 32), CHY(500), Q(500),
10X(50), Y1(50), XP(50), YP(50), SI(50), ST(50),
2MF(50), SIGZ(500), TITLE(26), PTIME(15),
DIMENSION UU(13, 16), VV(13, 16), L(13, 16), V(13, 16), US(2), VS(2),
DIMENSION XG(2), YG(2), DX(2), DY(2),
INTEGER MET(24), 5)
INTEGER TPUFFS, TTIME, THOUR, TDAY, STAB, TAU, CT, QC, TITLE, PTIME
NRD=1
2 FORMAT (5F10.0, E10.6, 4I5)
3 FORMAT (3I10)
5 FORMAT(6H1A(N)=E10.3, 5X, 5F CXX=E10.3, 5X, 5F CYY=E10.3, 5X, 6F U(N)=E10.3, 5X, 5F PHII=E10.3, 5X, 6F LDEPTH=E10.3)
7 FORMAT(134X, 7H ITIME=I13, 16X, 7H NSTOP=I4, 6X, 7H NSTEP=S4, 6X, 7H IC=I4, 6X, 16F PRINT INTERVAL=S13, 6X, 16F TDAY=I3, 6X, 6H TAU =I13, 6X, 6F ATADV=S13, 6X)
8 FORMAT(134X, 8H CXX=10.3, 6X, 8H CY=10.3, 6X, 8H CYY=10.3, 6X, 8H A=10.3, 6X, 8H CH=10.3, 6X, 8H CHMIN=10.3, 6X)
9 FORMAT(/39X, 16H OUTPUT OF TABLE/34X, 7H MCUR, 01X, 10H STABILITY
17H LDEPTH/(3CX, 2IX, 3X, 19))
10 FORMAT(15X, 8E14.5)
11 FORMAT(/61X, 9H Q VALUES/(10X, 8E14.5))
13 FORMAT(2H0, 16H Y COORDINATE OF 25X, 32H X COORDINATE OF THE GRID
10POINTS/2X, 16H THE GRID POINTS=89, 110/)
14 FORMAT(111, 8X, 10E10.2)
15 FORMAT(2H0, 9H PAGE NO. 13, 24X, 56H DOSE FACTOR ACCUMULATED FROM ALL
100 HOURS PACKETS FOR THE/39X, 12, 15H TH DAY AND THE/15, 10H TH HOUR (215, 12, 10H HOURS AFTER RELEASE)/39X, 15, 12 HOURS AFTER LAST FLUSH)
20 FORMAT (20A4)
21 FORMAT(1HO, 28X, 20A4)
23 FORMAT(8E10.1)
24 FORMAT(51X ANGLE OF ROTATION GREATER THAN 90 OR LESS THAN -90)
26 FORMAT(40H X AND-OR Y CCORENATES OF SOURCE ARE OFF GRID)
NS = C
50 READ 702, ITIME, NRELE, NSTEP, ICCLS, JRCHE, NC, PRF, TDAY, TAU
51, DT, INN, LIMPF, KCHIS, KVDT, KFLSH, NTADV
702 FORMAT(16I5)
READ 703, FMSH
703 FORMAT (F5.0)
KFM=1.0+2
KK=NRELE
IHR=ITIME
IDAY=TDAY
IMON=MST
NU=45C
READ 7C2, (PTIME(1), I=1, 15)
KN=0
KJ=0
NPD=0
CDIST=1.5/5.3333
FTAU=TAU
KLGK=0

45 READ(5,20) TITLE
   READ(5,2) XSOURCE,YSOURCE,DELX,DELY,ANG,IWHIMF,MSX,MFX,MSY,MFY
IF(KFISH.EQ.1) GO TO 704
ICOLS=ICOLS#2-1
JROWS=JROWS#2-1
NSX=MSX#2-1
NSY=MSY#2-1
NFX=MFX#2-1
NFY=MFY#2-1
GO TO 705
704 NSX=MSX
   NSY=MSY
   NFX=MFX
   NYF=MFY
705 XSB=MSX-1
   XLB=MFX-1
   YSB=MSY-1
   YLB=MFY-1
   KTM=0

**** EVALUATION OF CONSTANTS FOR COMPUTATIONS IN GRID UNITS
CGXM=1609.35*DELX
CGX=CGXM/FSH
CGXI=1./CGXM
CGX2=-0.5*CGX**2
NSTOP=ITIME*NRELSE
C MAXIMUM MORS OF RELEASE IS NRELSE
552 WRITE(6,21) TITLE
     WRITE(6,7) ITIME,NSTOP,NSTEPS,ICOLS,JROWS,NC,IPRINT,TDAY,TAU,DT
     INTADV
     WRITE(6,8)XSOURCE,YSOURCE,DELX,DELY,ANG,IWHIMF,MSX,MFX,MSY,MFY
     TESTDT=MOD(60,DT)
     IF(TESTDT) 91C,9738,910
910 PRINT 911
911 FORMAT (1H0,20X,'DT IS NOT A FACTOR OF 60')
     GO TO 40
9738 TAUCHK=MOD(60,TAU)
     IF(TAUCHK) 912,9739,912
912 PRINT 913
913 FORMAT (1H0,20X,'TAU IS NOT A FACTOR OF 60')
     GO TO 40
9739 NCNTRL=TAU/DT
     IF(NCNTRL.GE.1) GO TO 58
     PRINT 9071
9071 FORMAT (20X,'DT IS LARGER THAN TAU')
     GO TO 40

49
IF(ANG.GT.90.0.OR.ANG.LT.(-90.0)) GC TO 5C8
NS = NS + 1
TPUFFS = 0
KSUM = 0
TTIME = ITIME
COLS = ICOLS - 1
ROWS = JROWS - 1
IF(XSOURC.GT.XLB.OR.XSOURC.LT.XLB.OR.YSOURC.GT.YLB.OR.YSOURC.LT.YLB) GC TO 904
C CODE TO SET UP MATRIX PRINTOUT FORMATS
65 NP = (ICOLS - 1) / 10 + 1
LL = (ICOLS * NP - 1) / NP
C CODE TO CALCULATE DISTANCES OF GRID POINTS
DO 76 J=1,JROWS
YS(J) = J-1
DO 76 I=1,ICOLS
CH1(I,J) = 0.0
76 CONTINUE
DO 78 I=1,ICOLS
78 XS(I) = I - 1
II = 1
PRSTAB = 0
NEL = 1
IDOT = PTIME(NEL)
SZMAX = 0.1
NPH = 60/TAU
NADV = 60/NTADV
KPFCHK = MOD(NADV,NPH)
IF(KPFCHK.EQ.0) GC TO 85
PRINT 80,NADV,NPH
FORMAT ('0 BAD SPECIFICATION OF ADVECTION AND RELEASE STEPS,NADV= ',1,i5,9,nph='1,i5')
STOP
85 KPFS = NADV/NPH
FADV = NADV
DTT = 1.0/FLOAT(NPH)
NPH1 = NPH + 1
DTH = FLOAT(DT)/60.
NDT = NADV/DT
FDNDT = NDT
ADT = 1.0/FLOAT(NADV)
FAC = ADT/DELX
ACNST = 2.0*DTH/(6.283185**1.5)
BCNST = 2.0/(60.*6.283185**1.5)
SYX = 20000.
CMHN = (CHMIN/60.)*FLOAT(KPFS)
CHIMIN = CHMIN*MOD(NPH,FLOAT(KPFS))
DTS = 60.*FLOAT(DT)
KS = 0
QPH1 = 1.0/FLOAT(NPH)
TPUFFS = 0
MOFG=C
PRINT 9085,NADV,KPFS
9085 FORMAT (' NADV=',I3,' KPFS=',I3)

C***** LOCATION OF STARTING RECORD OF MIXING DEPTH AND STABILITY DATA
98 REAC (9) MET
MT1=MET(1,1)
MMON=MT1/100
IF(MMON.GE.MNST) GO TO 98
MDAY=MT1-MMON*100
IF(MDAY.GE.IDAY) GO TO 98
9999 PRINT 99,MET(1,1),(MET(I,2),I=1,24)
99 FORMAT (1X25I5)
ITS=ITIME-1
IHTT=C

C
C LCP THRU TIME STEPS
100 DO 600 N=1,NSTEPS
   IHTT=IHTT+1
   ITS=ITS+1
   IF(ITS.LE.24) GO TO 115
   READ (9) MET
   PRINT 99,MET(1,1),(MET(I,2),I=1,24)
   ITS=1
115 STAB=MET(ITS,2)
   LDEPTH=MET(ITS,3)
   CGLD=FLOAT(LDEPTH)
   GO TO (131,132,133,134,135,136), STAB
C
C EMPIRICAL NRTS COEFFICIENTS FOR SIGY AND SIGZ CALCULATIONS
131 A = 0.718
     B = 0.100
     QG = 1.033
     QGI=0.968
     GO TO 137
132 A = 0.425
     B = 0.105
     QG = 0.975
     QGI=1.026
     GO TO 137
133 A = 0.349
     B = 0.128
     QG = 0.891
     QGI=1.122
     GO TO 137
134 A = 0.267
     B = 0.146
     QG = 0.824
     QGI=1.214
     GO TO 137
135 A = 0.299
     B = 0.331
CGLPD = 0.335 # CGLDP
CGT = 0.465 # CGLDP
CGLP = (CGT / CGT) ** CGI
SGLP = 0.8 # CGLDP
A05 = 0.85 * A
A16 = 16.0769 * A
NPCH = NN1
IF(TPUFFS.LT.2LIMPUF) GO TO 139
C**** SECTION TO REMOVE PUFFS WHICH HAVE LEFT THE GRID
I = 1
J = 1
340 IF(MF(I).EQ.0) GO TO 350
MF(J) = MF(I)
SGY(J) = SGY(I)
Q(J) = Q(I)
STOTAL(J) = STOTAL(I)
SIGZ(J) = SIGZ(I)
XP(J) = XP(I)
YP(J) = YP(I)
DXS(J) = DXS(I)
DYS(J) = DYS(I)
J = J + 1
350 I = I + 1
IF(I.LE.TPUFFS) GO TO 340
JS = J - 1
JP0F = TPUFFS - JS
PRINT 360, JP0F, JS
360 FORMAT (1HO, 15, ' PUFFS DROPPED ', 15, ' PUFFS LEFT')
TPUFFS = JS
C**** LOOP THRU ADEPTION STEPS FOR THE HOUR
139 DO 500 NN = NN1, NADV
TINS = FLOAT(NN - 1) * ADT
IF(NN.LT.NRELSE) GO TO 150
IF(AN.NE.NPCH) GO TO 150
NPCH = NPCH + KPFS
141 TPUFFS = TPUFFS + 1
IF(TPUFFS.LT.500) GO TO 142
PRINT 9142, TPUFFS
9142 FORMAT ('1 TPUFFS ', 15, ' EXCEEDS DIMENSION')
STOP
142 CONTINUE
MF(TPUFFS) = 1
SGY(TPUFFS) = 1.
XP(TPUFFS)=X SOURC
YP(TPUFFS)=Y SOURC
Q(TPUFFS)=Q PH
STOTAL(TPUFFS)=0.000156
SIGZ(TPUFFS)=.000012

C### LOOP THRU ALL PUFFS
150 DC 500 M=1,TPUFFS
IF(YP(M).EQ.0)GO TO 500
TINC=TINC
QM=C(M)
STCLM=STOTAL(M)
SIGZM=SIGZ(M)
XPM=XP(M)
YPM=YP(M)
SIGY=SIGY(M)
IF(XPM-XSB)155,155,143
143 IF(XPM-XLB)144,144,155
144 IF(YPM-YSB)155,155,145
145 IF(YPM-YLB)146,155,155
146 MOFG=C
IF(KTM)205,205,210
205 KTM=KTM+1
NNS=1

C### DTIME= TIME IN HOURS BETWEEN MAPS
DTIME=1.
CALL RNRGRD9(KN,KJ,IHR,ICAY,[MON,U,V])
515 CONTINUE
GO TO 211
210 IF(AN-NNS)206,201,201
206 DO 411 I=MSX,MFX
DO 411 J=MSY,MFY
UI(I,J)=UU(I,J)
411 VI(I,J)=VV(I,J)
212 CALL RNRGRD9(KN,KJ,IHR,ICY,[MON,U,L,V])
201 XG(I)=XPM
YG(I)=YPM
DO 43 K=1,2
FM=K
C2=(TINC+(FM-1.)*ADT)
C1=1.0-C2
I=XG(K)+1.
IF (I.LT.MSX) GO TO 29
IF (I.GE.MFX) GO TO 29
J=YG(K)+1.
IF (J.LT.MSY) GO TO 29
IF (J.GE.MFY) GO TO 29
FI=I-1
FJ=J-1
RX=XG(K)-FI
RY=YG(K)-FJ
I1 = I + 1
J1 = J + 1
RX1 = 1 - RX
RY1 = 1 - RY
AA = RX1 * RY1
BB = RY * RX1
C = RX * RY
D = RX * RY1
CST = AA * (C1 * U(I, J) + C2 * LU(I, J))
CST = CST + BB * (C1 * U(I, J1) + C2 * LU(I, J1))
CST = CST + C * (C1 * U(I, J1) + C2 * LU(I, J1))
CST = CST + D * (C1 * U(I, J) + C2 * LU(I, J))
US(K) = CST
CST = AA * (C1 * V(I, J) + C2 * VV(I, J))
CST = CST + BB * (C1 * V(I, J1) + C2 * VV(I, J1))
CST = CST + C * (C1 * VV(I, J1) + C2 * VV(I, J1))
CST = CST + D * (C1 * V(I, J) + C2 * VV(I, J))
VS(K) = CST
DX(K) = US(K) * FAC
DY(K) = VS(K) * FAC
IF (K - 2) 34, 43, 34
34 MM = K + 1
XG(MM) = XG(K) + DX(K)
YG(MM) = YG(K) + DY(K)
43 CONTINUE
DXM = 0.5 * (DX(1) + DX(2))
DYM = 0.5 * (DY(1) + DY(2))
GO TO 230
29 MDFG = 1
230 NN$ = NN
280 CONTINUE
IF (MDFG) 153, 153, 155
153 DXS(M) = DXM
DYS(M) = DYM
GO TO 157
155 DXM = DXS(M)
DYM = DYS(M)
157 DS = SQRT (DXM**2 + DYM**2)
IF (KVDT .EQ. 0) GO TO 158
NDT = DS / COIST + 0.5
IF (NDD .LT. 1) NDT = 1
IF (NDD .GT. 5) NDT = 5
FDND = NDT
TFNND = FADV / FDND
ACNST = BCNST * TNND
CHMNM = CHMN * TNND
158 DS = DS / FDND
DXM = DXM / FDND
DYM = DYM / FDND
K20 = 1
IF (STOTL .LT. SYX) K20 = 0
DSMT = DS*CGXP
DSMF = DSMT*0.5

C**** LOOP THRU THE NUMBER OF SAMPLING STEPS DURING THE ADVECTION STEP
DC 494 JN=1*NDT
STOGLM = STOGLM + DSMT
SMDL = STOGLM - DSMHF
C CALCULATE SIGZ AND SIGY
IF(SIGZM*GE.*SZMAX) GO TO 168
161 IF(SIGZM*GE.*SZMAX) GO TO 165
C IF SIGZ(M) GE SZMAX USE LINEAR FORMULA
C IF SIGZ(M) LT SZMAX USE POWER FORMULA
162 TERM96 = SIGZM / B
TERM98 = TERM96 ** QG1 +DSMT
TERM99 = (TERM98 - SMX)*/ SMX
IF(TERM99) 163,164,164
163 DELTA = B * (TERM98 ** QG - TERM96)
C POWER FORMULA
GO TO 166
164 SIGZM = SZSMAX
C POWER TO LINEAR FORMULA CHANGE DURING THIS TIME INTERVAL
DELTA = CCCHGPT * TERM99
GO TO 166
165 DELTA = (DSMT/SMX)*CCCHGPT
C LINEAR FORMULA FOR COMPUTING DELTA FCR SIGZ
166 SIGZM = SIGZM + DELTA
IF(SIGZM*LE.*SZMAX) GO TO 168
167 SIGZP = SZSMAX
168 IF(M.LT.TPUFFS) GO TO 1681
SIGY = A*STOGLM**Q*0.85
GO TO 175
1681 IF(STOGL.GT.SYX) GO TO 1682
SIGY = SIGY + A85*DSMT/SMX**0.15
GO TO 175
1682 IF(K20.EQ.1) GO TO 1683
K20=1
STI = STOGLM - DSMT
DS1 = SYX - ST1
DS2 = STOGLM - SYX
SMDL = ST1 + DS1*.5
SIGY = SIGY + A85*DS1/SMX**0.15
SMDL = STOGLM - DS2*.5
SIGY = SIGY + A16*DS2/SQRT(SMDL)
GO TO 175
1683 SIGY = SIGY + A16*DSMT/SQRT(SMDL)
C CALCULATE RADIUS OF PUFF(RP) AND COORDINATES OF PUFF
175 SIGYSQ = SIGY * SIGY
HSYSQ = CGX2/SIGYSQ
178 PUFCHI = QM*ACNST/(SIGYSQ*SIGZM)
179 IF (PUFCHI.LE.CHIMIN) GO TO 194
180 PCDT = PUFCHI
RP=SIGY*SQR((-2.*ALOG(CHIMIN/PCCT))*CGX)
XP=XPM+DXP
YPM=YPM+DYM
C CHECK IF PUFF HAS MOVED OFF GRID
IF(XPM-RP.LT.XSB) GO TO 194
191 IF(YPM-RP.GT.XSB) GO TO 194
192 IF(YPP-RP.LT.YSB) GO TO 194
193 IF(YPP-RP.LE.YLB) GO TO 200
194 MF(M) = 0
GO TO 500
C
C***** DETERMINATION OF CONTRIBUTIONS TO SURROUNDING GRID POINTS
200 RP=RP*FMSH
XPN=XPM*FMSH
YPN=YPP*FMSH
RP*SQ=RP**2
ISTRT=XPN-RP+2
ISTP=XPN+RP+1
JSTART=YPN-RP+2
JSTP=YPN+RP+1
IF(ISTRT.LT.NSX) ISTRT=NSX
IF(ISTP.GT.NFX) ISTP=NFX
IF(JSTART.LT.NSY) JSTART=NSY
IF(JSTP.GT.NFY) JSTP=NFY
9991 DO 320 I=ISTRT,ISTP
XO2=(XPN-XSI(I))**2
DO 310 J=JSTART,JSTP
YO2=(YPP-YSI(J))**2
RSQ=XO2+YO2
IF(RSQ.GT.RPSQ) GO TO 310
PCHI=PCCT*EXP(HSGSQ*RSQ)
9995 FORMAT (*,I13,*,J=*,I3,*,PCHI=*,E13.6,9F9.4)
309 CHI(I,J)=CHI(I,J)+PCHI
310 CONTINUE
320 CONTINUE
494 CONTINUE
499 SIGZ(M)=SIGZM
SCY(M)=SIGY
STOTLM=STOTLM
XPM=XP
YPM=YPM
500 CONTINUE
AN1=1
IF(N.GT.KK.AND.MSUM.LE.0) GO TO 525
524 IF(N.NE.NSTEPS.AND.N.NE.IDOT) GO TO 560
525 MSUM=0
DO 505 MM=1,TPUFFS
505 MSUM=MSUM+MF(MM)
PRINT 9996
9996 FORMAT (1I1)
PRINT 510,MSUM
510 FORMAT (1HG*16*, PUFF(S) REMAING*)
    CHI(1,1) = IHR
    CHI(1,2) = IDAY
    CHI(1,3) = IPDN
    CHI(1,4) = IHTT
    DC 540 L=1, NP
    IL=L
    L2 = L * LL
    L3 = L2 - LL
    IF(L2 .LE. ICOLS) GO TO 531
530 L2 = ICOLS
531 L3 = TABS(L3)
    L1 = L3 + 1
    L4 = L2 - 1
    IF(L1 .GT. 1) GC TO 545
    WRITE (6,21) TITLE(I), J=1,14
    WRITE(6,15) I, L, L3, J, JROWS
    JJ=JROWS-J
    JJ = JJ+1
    WRITE(6,14) JJ, (CHI(I,J), I=L1, L2)
541 CONTINUE
540 CONTINUE
C**** SECTION TO SAVE CHI MATRIX ON DISK, THEN CLEAR IT OUT
IF(KCHIS.EQ.0) GO TO 449
WRITE (10) CHI
449 IF(KFLSH.EQ.0) GO TO 452
DO 450 I=1, ICOLS
DO 450 J=1, JROWS
450 CHI(I,J) = 0.
IHTT = 0
452 TMIN=C.0
5449 NEL = NEL+1
451 IF (NEL .GE. 15) GO TO 5453
5451 IF (PTIME(NEL).EQ.0.) GO TO 5453
5452 NUT=PTIME(NEL)
5453 IDICT = IDICT+NUT
560 TIME = TIME + N
   IF(NIF.GT.KK .AND. MSUM.LE.0) GO TO 40
600 CONTINUE
GO TO 40
904 PRINT 28
GO TO 40
908 PRINT 24
40 STOP
END
SUBROUTINE RNGRD9 (KN, KJ, III, IDAY, PCA, UG, VG)
C
NP - NUMBER OF WIND STATIONS
C
NSX - STARTING VALUE FOR X
C
NFX - END VALUE FOR X
C
NSY - STARTING VALUE FOR Y
C
NFY - END VALUE FOR Y
C
ITLE - TITLE OF PLOT
C
DIR - DIRECTION OF WIND AT STATION
C
SPC - VELOCITY OF WIND AT STATION
C
CRR(I) - CORRECTION (WHOLE DEGREES) AT STATION (I)
C
NAMEST - NAMES OF THE STATIONS
C
CONFACT - CONVERSION FACTOR TO CHANGE WIND SPEE TO THE 100 FT LEVEL
C
DIMENSION DIR(50), SPC(50), U(50), V(50), X(50), Y(50), UG(13, 16),
LVG(13, 16), ITLE(16), R3(10, 13, 16), NS3(10, 13, 16), RT(30), NSB(30)
DIMENSION D(31), S(31), LFLAG(25), COR(25), NSV(13, 16)
DIMENSION ISKIP(31), I1(31), I2(31), I3(31), NAMPST, KI, IK2(12)
INTEGER I2, N1(24, 31)
DATA 11, 12/2, 3, 5, 2, 4, 11/
C
RTE - ROTATION OF NORTHS ON GRID
C
RCH - RADIUS OF CIRCLE ENCLOSING DATA VALUES FOR INTERPOLATION
C
DX - SPACING OF GRID POINTS IN X-DIRECTION
C
DY - SPACING OF GRID POINTS IN Y-DIRECTION
C
DT - INCREMENTS OF TIME IN HOURS
C
DS - LENGTH OF SHAFT ON WIND ARROW
C
H - GRID INTERVAL IN MILES
C
X - X COORDINATE OF STATION
C
Y - Y COORDINATE OF STATION
C
IF (KJ.EQ.1) GO TO 800
IF (KN.EQ.0) GO TO 1313
KNR=0
200 FORMAT (16A4)
READ 11, NP, NSX, NSY, NFX, NFY, NSTL, INPT, NSKIP, KIST
11 FORMAT (1615)
READ 12, RTE, RCH
12 FORMAT (8F10.0)
READ 10, (X(I), I=1, NP)
10 FORMAT (16F5.0)
READ 10, (Y(I), I=1, NP)
READ 10, (COR(I), I=1, NP)
READ 40, (CONFACT(I), I=1, NP)
RCH=RCH**2
READ 40, (CONFACT(I), I=1, NP)
40 FORMAT (16F5.2)
CF1=CONFACT(1)
CF2=CONFACT(2)
CF4=CONFACT(4)
READ 45, NAMEST, I=1, NP
45 FORMAT (16(1XA4))
READ 71, (ISKIP(I), I=1, 31)

58
71 FORMAT (31I2)
    READ 2CC, (KMON(I), I=1,12)
    READ 42, YEAR
42 FORMAT (A4, I6)
    PRINT 6666, (NAPST(I), I=1, NP)
6666 FORMAT (1H14X22(1XA4))
    PRINT 630, (X(I), I=1, NP)
630 FORMAT (*) X = *, 22F5.1
    PRINT 635, (Y(I), I=1, NP)
635 FORMAT (*) Y = *, 22F5.1
    PRINT 44, (CONFAC(I), I=1, NP)
44 FORMAT (*) CGF = *, 22F5.2
19 FORMAT (1H1, 16A4)
    KMP=0
    KN=1

C****SECTION FOR SETTING UP STATION ARRAY FOR EACHERIC POINT
    XG = NSX-1
    DO 730 I = NSX, NFX
    YG = NSY-1
    DO 720 J = NSY, NFY
    DO 705 L = 1, NP
    NSB(L) = L
    705 RT(L) = (X(L)-XG)**2 + (Y(L)-YG)**2
    CALL ASCNC(RT, NSB, NP)
    DO 706 L = 1, NP
    R3(L, I, J) = RT(L)
    706 N3(L, I, J) = NSB(L)
    720 YG = YG+1.
    730 XG = XG+1.
    NPP = NP+1
    P18 = 3.1415927/180.
    IS = 1
    READ 11, NS, IDS, IHS
    KDS = IHS
    IF (NSKIP.EQ.0) GO TO 800
    DO 733 JLM = 1, NSKIP
    XG = NSX-1
    IF (INPT.EQ.1) GO TO 731
    READ(8, END=732) IWD
    GO TO 733
    731 CALL BUFIN(8, IWD, 186, NTATE, ICNT)
    CALL BUFDLY(8, O, 0, NTATE, ICNT)
    IF (NTATE.NE.3) GO TO 733
    732 PRINT 734, IWD(24, 1)
    734 FORMAT (*) END OF FILE READ FROM INPUT UNIT IN SKIP LOOP, I6
    STOP

733 CONTINUE
800 NTATE = 0
    ICNT = 0
    IF (INPT.EQ.1) GO TO 735
    READ(8, END=736) IWD
    GO TO 5
CALL BUFIN(8, IWD, I86, NTATE, ICNT)
CALL BUFDLY(8, O, G, NTATE, ICNT)
IF (NTATE.NE.3) GO TO 5
736 CONTINUE
PRINT 50, IWD(24, 1)
50 FORMAT(* END CF.FILE RCAC ON THE INPUT UNIT*, 1G10, 1S)
STOP
5 MON=IWD(1, 1)/100
IDAY=IWD(1, 1)-MON*100
IF(KNR.EQ.1) GO TO 1312
IF (MON.NE.MS) GO TO 800
IF (ICAY.NE.IDS) GO TO 800
PRINT 16C0, IH, MON, IDAY, YEAR
1600 FORMAT (*0 STARTING TIME = 'I2, 38C0, I3, 'I2, 'I2, 'I, A3)'
1312 KJ=0
KNR=1
IJI=KDS-1
1313 IJI=IJI+1
IF(IJI.EQ.1) PRINT 1610, IJI, KCH, IDAY, YEAR
1610 FORMAT (' 95X *NEW RECORD ', I2, '00', I3, 'I2, 'I2, 'I, A3)
IF (IWD(IJI, 1).NE.0) GO TO 1615
IJI=IJI-1
GO TO 806
1615 M=0
DO 210 J=1, 31
IRRAY1(J)=0
IRRAY2(J)=0
IF (ISKIP(J).EQ.0) GO TO 210
M=M+1
IRRAY1(M)=IWD(IJI, J)/100
IRRAY2(M)=IWD(IJI, J)-IRRAY1(M)*100
210 CONTINUE
PRINT 9300, (IRRAY1(J), IRRAY2(J), J=1, M)
930C FORMAT(1HC0, 5X, 25(2T2, 1X))
300 CONTINUE
DO 60 J=1, M
DI(J)=IRRAY1(J)
60 SI(J)=IRRAY2(J)
C#### END STATION ARRAY SECTION
JI=0
MR=111=100
JJ=0(I)+1
JK=S(I)+1
1501 DO 1317 IN=2, NPP
JI=JI+1
DI=D(IN)
SI=S(IN)
IF (DI.LE.89.) 1315, 1314, 1314
1314 LFLAG(JI)=1
U(JI)=0.0
V(JI)=0.0
1315 1315 1315 1315
GO TO 1317
1315 IF (SI + 89. ) 1316, 1314, 1314
1316 LFLAG(JI)=0
    IF (DIN.LE.36) GO TO 1320
    LFLAG(JI)=2
    DIN=DIN-50.*
1320 DIR(JI)= DIN *10. *CCH(JI)
    SPD(JI)= SI *CCH(JI)
    CONTINUE
1317 CONTINUE
1319 KSR=0
    DO 15 I=1, NP
        IF (LFLAG(I)-1) 1318, 15, 1318
1318 CR=DIR(I)-RTE
    ANG=(270-DEG)*PI/18
    U(I)=SPD(I)*COS(ANG)
    V(I)=SPD(I)*SIN(ANG)
    CONTINUE
    IF (KIST.GT.0) GO TO 900
C***** INTERPOLATION SECTION BEGIN
49 DO 895 I=NSX, NFX
    DO 890 J=NSY, NFY
        SNU=0.0
        SNV=0.0
        SND=0.0
        NS=C
        DO 870 L=1, 10
            LS = N3(L, I, J)
            RS = R3(L, I, J)
            IF (LFLAG(LS).EQ.1) GO TO 870
            IF (RS.LE.1.E-15) GO TO 850
            IF (NS.LT.NSTL) GO TO 820
            IF (RS.GT.RCH) GO TO 875
820 RI=1/R
    SNU=SNU+U(LS)*RI
    SNV=SNV+V(LS)*RI
    SND=SNV+RI
    NS=NS+1
    GO TO 870
850 UG(I,J)=U(LS)
    VG(I,J)=V(LS)
    NSV(I,J)=1
    GO TO 890
870 CONTINUE
875 UG(I,J)=SNU/SND
    VG(I,J)=SNV/SND
890 CONTINUE
895 CONTINUE
    NSV(I,J)=NS
    PRINT 9500, (U(I,J), J=1, NP)
    PRINT 9500, (V(I,J), J=1, NP)
9500 FORMAT(11X,23FS.1)
GO TO 950
900 IF(LFLAG(K1ST),NE.,1) GO TO 920
     PRINT 910,NAMST(K1ST),III,IOAY,MON,YEAR,L(K1ST),V(K1ST)
910 FORMAT (6H0,A4,* ',MISSING AT ',2I4,'/14/',4A9,'/4A3,* SINGLE STA
     TION ANALYSIS CONTINUING WITH L,V= '2F6.2')
920 DO 930 I=NSX,NFX
     DO 930 J=NSY,NFY
     UG(I,J)=L(K1ST)
930 VG(I,J)=V(K1ST)
950 CONFC(1)=CF1
     CONFC(2)=CF2
     CONFC(4)=CF4
     KMAP=KMAP+1
825 IF (III.LT.24) GO TO 896
     KDS=1
     KJ=1
896 RETURN
END
SUBROUTINE ASCND (X,N,NP)
DIMENSION X(20),N(20)
NP1=NP-1
DO 50 I=1,NP1
KI=0
DC 40 K=1,NP1
IF(X(K+1).GT.X(K)) GO TO 40
KI=K+1
TPI=X(K)
NTMP=N(K)
X(K)=X(KI)
N(K)=N(KI)
X(KI)=TPI
N(KI)=NTMP
40 CONTINUE
   IF (KI.EQ.0) GO TO 60
50 CONTINUE
60 CONTINUE
RETURN
END