AN ANALYSIS OF A PUFF DISPERSION MODEL FOR A COASTAL REGION. (U)

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THESIS

AN ANALYSIS OF A PUFF DISPERSION MODEL FOR A COASTAL REGION

by

Stephen K. Rinard

June 1982

Thesis Advisor: G. E. Schacher

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National Weather Service
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ABSTRACT

The Risø National Laboratory, Roskilde, Denmark, atmospheric puff dispersion model has been tested for an atmospheric-marine environment. This three-dimensional model simulates the release of Gaussian pollutant puffs and predicts their concentration as they are diffused and advected downwind by a horizontally homogeneous, time-dependent wind. Atmospheric characteristics such as turbulence intensity, potential temperature gradient, buoyant heat flux and maximum mixing depth have been considered. Model predicted pollutant concentrations have been compared to airborne sampled observations. The effect of coastal turbulence not observed by the single point meteorological measurements made onboard ship greatly affects the advection and diffusion of a plume as it moves onshore. Additional measurements/predictions particular to the coastal area will have to be incorporated into the model for it to accurately predict the onshore movement of pollutants.
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The professional advice of Mr. Richard Donat of the NPS Computer Center and the assistance of Mr. Michael McDermet in the drafting of several figures is acknowledged. Mr. T. Mikkelsen was very helpful in explaining different parts of the model.

The support and encouragement I received from my family greatly aided in the completion of this educational experience.
I. INTRODUCTION

The downwind transport and distribution of atmospheric pollutants from an isolated source over land or water has become an important environmental factor in today's society. The need to understand the distribution of smoke, unpleasant or potentially harmful foreign gases and perhaps radioactive debris from a nuclear powerplant accident are becoming more and more essential for industrial operations and construction planning. The dispersion of such atmospheric pollutants is commonly modeled by a standard Gaussian plume model which computes one-hour average plume characteristics.

The Meteorology Section of the Risø National Laboratory, Roskilde, Denmark, has recently developed a puff model for prediction and simulation of atmospheric pollutant diffusion. The model considers individual puffs of pollutants with specific release rates that are advected by a horizontally homogeneous wind over a grid. The wind input may be either the measured wind from a single point, a spatial average or a wind simulation. The model simulates the instantaneous plume characteristics by adding a group of puffs, growing in size, as they advect with the wind. A Gaussian plume model, on the other hand, provides a time...
averaged concentration pattern based on a single time average wind vector. In the puff model, the plume advects with a time series of actual wind data. Thus, the puff model is able to predict time varying concentration distributions in actual changing wind conditions, making it an appropriate tool for dynamical computations of downwind dispersions of pollutants.

A basic comparison of a puff model simulation and a typical plume is illustrated in Fig. 1. Looking from above, the instantaneous behavior of a plume being advected from a source by the wind is shown. The outer cone-shaped contours represent the outer limit of the plume boundary and are identical in both Figs. 1 (A) and (B).

Fig. 1(A) shows an instantaneous depiction of an actual plume. The long-term average plume concentration is shown on the extreme right as a smooth curve with a maximum on the central axis. Also shown is the instantaneous plume concentration considered realistic but is of such a short time scale that it cannot be predicted or easily measured.

The puff model prediction is depicted in Fig. 1(B). The circles show the boundaries of individual puffs of pollutants released from the source. These puffs are advected
Figure 1. Instantaneous Behavior of a Typical Plume and a Series of Puffs from a Puff Model

and diffused downwind by a frequently updated wind. The long term average concentration prediction of the puff model is expected to be identical to the long term concentration of Fig. 1 (A). The short term average pollutant prediction, a Gaussian curve shown on the extreme right, is not completely realistic but is a reasonable approximation to the instantaneous plume concentration profile.
The purpose of this thesis is to evaluate and test the general characteristics and capabilities of the Risø puff model. The adjustable input data will be varied and predicted results for various input combinations compared. A preliminary comparison will also be made between predicted results and data collected from a coastal region using observed meteorological forcing data as model input.
II. RISØ PUFF MODEL

A. GENERAL CHARACTERISTICS

The Risø Puff Model is a three-dimensional computer model used for the prediction and/or simulation of the diffusion and advection of atmospheric pollutants. The puff model technique is to simulate a plume with Gaussian shaped puffs with specified release rates within a specified grid. The initial size of the puffs is normally one meter in diameter although this can be easily adjusted. The amount of material in a puff is the release rate times the elapsed time between puffs. Therefore, a long elapsed time between puff releases results in a higher initial puff pollutant concentration than a short time interval. This should not normally be of concern if an adequate balance is maintained between grid size, advection speed and puff release rate.

The location of the puffs on the grid is determined by computing their movement for a finite time step using a measured wind field. The growth and buoyancy of the puffs are computed from simultaneous specifications of atmospheric turbulence intensity and stability and from buoyant heat
flux at the source. An inversion cap through which pollutants cannot pass and the source height where pollutants are released are variable and can easily be adjusted. Grid distances within the model may vary from meters to kilometers and time durations from seconds to hours are possible.

This puff model has the capability of monitoring a maximum of twenty-five sources of puffs and its grid may contain up to 100 puffs. A puff source can be located anywhere on the grid and have a unique release rate, start and stop of release time, and heat production. When the center of a puff moves outside the boundaries of the grid (either horizontally or vertically), that particular puff is dropped from memory. In this way the model does not store irrelevant puff information, thus keeping computer memory requirements to a minimum.

A variable to control the amount of reflection/absorption of the pollutant by the surface is easily adjusted in the puff model. Such a parameter is of great value both in actual dispersion problems and also for gaining understandings of the plume/surface relationship.

The model calculates the concentration at each grid point by summing the contributions from surrounding puffs.
for each advection step. The grid concentrations can be allowed to accumulate or simply be updated with the latest instantaneous value. A minimum grid concentration of interest can be set to reduce computer ran time by dropping concentrations too small to be of interest.

The output of the model contains periodic results of puff locations and concentrations as well as initial input verification. The time interval for the periodic results is adjusted by the input data. This recurrent lineprinter output contains:

- X-Y plane plots showing the position of the sources and of puffs inside the grid,
- X-Z plane plots of puff positions for evaluating plume rise for each vertical level of interest, and
- a table listing of the grid point concentrations for each level.

A computer drawn contour chart of the magnitudes of the pollutant concentrations is also available.
When considering distance between gridpoints (delta X,Y,Z), only spatial resolution and computer resources need be considered. Calculated concentration accuracy is not related to the grid-point separation. To insure that no essential information on individual puffs is "hidden" between grid points, the grid separation should be adjusted dependent upon the size of the puffs at the downwind distance of interest. Other specific model configuration considerations are described in the following sections. They are also discussed in more detail in the model behavior chapter.

B. WIND FIELD

Once a puff is released, it is advected based upon wind data measurements at a single point only, normally the release point. This limits the validity of the model to situations where the wind field and turbulence can be assumed to be horizontally homogeneous throughout the grid. It is therefore important to insure that the data obtained from such a single point measurement is representative of the wind structure for the whole area of interest.

The wind data are normally obtained in the form of a horizontal velocity time series. A vector sequence is formed
by averaging over a convenient interval. These data are read into the model after being segregated into turbulence classes as discussed in the next section.

C. TURBULENCE INTENSITY AND DIFFUSION

The growth/diffusion of a puff depends upon the turbulence intensity. To account for this growth, the puff model applies the theory for relative diffusion suggested by Smith and Hay (1961).

The turbulence intensity is defined to be the standard deviation (\(\sigma\)) of the wind direction (in radians) squared. The \(\sigma\) values are collected for the same short time periods as the wind speed measurements used to advect the puffs. Therefore, the intensity of the turbulence which governs the relative diffusion of the puffs, can be adjusted along with the the advecting wind speed after each time step, if conditions warrant.

A very low value of turbulence intensity (as 0.0002) represents a small standard deviation (0.9), normally a stable atmosphere and a weak puff dispersion/diffusion. As the atmosphere becomes more unstable, the turbulence intensity increases along with an increase of \(\sigma\) values and plume dispersion/diffusion. While these characteristics are
resentative of turbulence over land, they can be applied to over water cases in a broad sense.

D. PLUME RISE

In the vertical direction, puff-rise can be accounted for by Briggs (1970) plume rise theory. In this case buoyancy is assumed to be conserved (adiabatic motion), and pressure forces, molecular viscosity and local density changes are considered small and are neglected. The rate at which a puff rises as it is advected downwind is a function of the buoyancy flux, wind speed, puff distance traveled and stability of the atmosphere. Plume rise is considered separately for each individual puff.

E. REFLECTION

The interaction of the pollutant with the surface is adjustable and can be easily changed in the input data. Total reflection or absorption or a fraction between the two can be used.

F. LIMIT OF MIXING DEPTH

The effect of an atmospheric lid (inversion) can be applied in the model to limit the vertical movement of the pollutant. The model does not permit the plume to rise
above this cap. When a maximum mixing level is in effect, it acts to totally reflect the pollutants in the same manner as total reflection at the surface. This mixing cap would act as an inversion when the puff would be expected to grow much more readily in the horizontal than in the vertical direction.
III. DATA COLLECTION

An intensive field tracer study was performed during the fall of 1980 and winter of 1981 in the Santa Barbara Channel area of the California coast. The work was supported by the Bureau of Land Management (BLM) and performed by the Environmental Physics Group of the Naval Postgraduate School (NPS) and AeroVironment Inc (AV), Los Angeles, CA. This study was designed to help validate and/or modify Gaussian dispersion models for coastal use and to build a data base for future model development. Air pollution models in current use have not been adequately validated for the over-water regime.

In the experiment, a tracer gas ($SF_6$) was released several miles offshore from the NPS Research Vessel (R/V) Acadia. Ambient gas concentrations as low as 10 parts per trillion (PPT) were determined by an array of land based sensors, from a small boat and at various levels by an aircraft equipped with a continuous $SF_6$ analyser. A chart of the experimental area and locations of the various platforms is shown in Fig. 2.
Figure 2. Experimental Area showing Locations of R/V Anacapa, Aircraft Track and Numerical Grid.
The aircraft flew through the plume at various elevations offshore and overland. The plume transect tracks pertinent to this study were made parallel to the coast approximately one-half mile offshore. The airborne sampling consisted of instantaneous concentrations (PPT) at selected points at different levels over a period of six hours. The observations, recorded at locations 10-70 at altitudes of 61 and 91 m above MSL on January 29, 1980 are shown in Fig. 3. Average concentrations over the noted time period are shown at the bottom of each altitude block.

The following marine meteorological parameters were measured onboard the R/V Acania while anchored approximately 7.4 km offshore:

- relative wind speed
- wind speed fluctuation
- sea surface temperature
- sky cloud cover
- relative wind direction
- inversion height (acoustic sounder)
- vertical temperature and humidity profiles

(shipboard radiosonde launch every 12 hours).
Figure 3. Aircraft observed Plume Concentrations (PPT) at Grid Coordinates at 51 and 91 m above MSL, 29 September 1980.
The tracer gas was released at a fixed rate through the exhaust of one of the ship's motor generator sets. The generator was run at a constant speed resulting in a constant stack temperature and flow rate.

The above collected meteorological information enabled the data grid to be established and the atmospheric wind field, turbulence intensity, stability and buoyancy flux to be derived for inputs into the puff model. The puff model prediction based on this actual data formed the basis for the model performance evaluations carried out here. From this basis, different input variables were adjusted to note the effect on the advected concentrations—both in relation to each other and to the airborne measurements.
IV. **MODEL BEHAVIOR**

The Puff Model was run on the NPS IBM S/370 Model 3033 AP computer with two goals in mind: (1) familiarization with model performance under actual conditions and (2) a comparison of model predictions with observed data. The two goals are interrelated in the sense that atmospheric data collected in the aforementioned tracer study were used to form an initial prediction of the plume dispersion, and variations of that data were used to evaluate the limits of the model. The data used as input to the model represented the marine atmospheric conditions as determined from R/V Acania meteorological data at the time of the experiment.

Proper grid spacing was arrived at by considering puff spread, mean wind direction and the geographical area of interest. With the initial prediction in hand, data input variables of the model were adjusted and their effects (changes in prediction) noted. All model predictions were compared with the aircraft observed data.

A 7.4 X 4.3 km downwind area of interest was initially gridded into an 17 X 10 array. Distances between horizontal and vertical grid points were approximately 435 m (Fig. 2).
Since many of the aircraft observation times centered around 1730 hours (all times are Pacific Daylight Time), model puff releases were initiated at 1630. The 30-minute wind speed averages obtained from data taken onboard the ship between 1630 and 1730 were 4.7 and 4.8 m s\(^{-1}\). The first advected puffs would be expected to arrive at the back edge of the grid slightly before 1703, and by 1730 a steady consistent plume would be passing through the area of the aircraft track. (The model showed, in fact, puffs leaving the back edge of the grid slightly before 30 minutes after puff release).

The average wind direction was recorded on the ship every 15 seconds. The standard deviations of the wind direction (sigma) were computed as approximate one minute averages. These, in turn, were averaged over 30 minutes to correspond with the 30-minute wind speed averages. The sigma values during the time of interest were 1.0 and 0.9 resulting in the very small turbulence intensity values of 0.0003 and 0.0002.

A delta Z value of 33 m was used to observe plume concentrations at the altitudes of 0, 33, 66 and 99 m above the surface. These levels were chosen for comparison with the aircraft transect altitudes of 61 and 91 m.
Fine scale vertical temperature and humidity plots were drawn based upon radiosonde soundings taken onboard the ship. The sounding taken at 1735 PDT (Figure 4) shows a shallow unstable layer near the surface topped by an inversion extending to near 400 m. A 80 m depth of the mixing layer was subjectively established. The potential temperature gradient computed by the formula

$$\frac{\partial \theta}{\partial z} = \frac{\partial T}{\partial z} + .0098 z \quad (1)$$

was found to be 1.0 deg K/100 m.

Basic data to determine source strength and heat emission from the ship's stack were taken from Schacher, et al (1981). As previously mentioned, SF₆ gas was released through the ship's motor generator exhaust at a constant rate. The stack temperature was 250 deg F, the flow rate was 7.13 * 10³ m³ s⁻¹. The SF₆ release rate was 47.91 lb hr⁻¹. The top of the ship's stack—considered to be the source elevation—was 4 m. The source strength was converted to 6.04 gm s⁻¹ for input into the model.

Heat emission (H) in KW was determined by the formula
Figure 4. Radiosonde sounding taken onboard R/V Acania, 1745 PDT, September 29, 1981.
\[ H = \Delta T \times \frac{P}{RT} \times C_p \times \text{Flow} \tag{2} \]

where

\[ \Delta T = \text{temperature (stack - air) deg K} \]
\[ R = \text{dry air gas constant} = 2.87 \times 10^6 \text{ erg/g deg K} \]
\[ P = 10^3 \times P(\text{mb}) = \text{dyne/cm}^2 \]
\[ C_p = \text{specific heat of dry air} = 0.24 \text{ cal/g deg K} \]
\[ \text{Flow} = 16.39 \times 7.13 \times 10^3 \text{ cm}^3/s \]

The heat emission was thus computed as 15.07 KW.

Initially the model grid was established after noting the area of maximum airborne sampled concentrations (between points 24 and 43 of Fig. 3) and the location of the ship. It became obvious during early model runs that, with the actual wind direction input, the model predicted plume was being advected south of the grid towards point 60 on the aircraft track. Obviously, the steering wind, as measured onboard ship, was not constant all the way to the shore. A northward turning of the plume was indeed detected several times during the experiments by the aircraft. To compensate
for this effect, the source of the plume release was moved in the model three grid spaces (1305 m) to the north so that the maximum predicted plume concentrations would pass through the areas of the maximum airborne measured concentrations. No corrections were made to the model predicted plume concentrations because of this adjustment. However, one could reason that the predicted concentration values would be higher in comparison with measured values since the coastal turbulence and wind shift—which would tend to diffuse the plume—were not considered.

Initial model runs with the small turbulence intensity classifications of .0003 and .0002 failed to show plume concentrations greater than $1 \times 10^{-12}$ in the grid at any level other than at the source. Apparently, the grid spacing was too large and the narrow plume was advecting between the grid points. In an effort to locate the plume, a combination of model runs were performed varying the turbulence intensity and grid spacing as shown in Table I.

In this table, a mixing level cap of 80 m was in effect for the model predictions. No concentrations above that level were allowed in the computations. As previously mentioned, the model mixing level cap totally reflects all pollutants back downward.
TABLE I. A Comparison of Predicted Concentrations at the Surface, 40 and 80 m at the East Edge of the Grid with Turbulence Intensities between .01 and .05. Mixing Level Limit is 80 m. $E = (*10)$. Numbers in Parenthesis are Grid Numbers along Y Axis from Table II.

<table>
<thead>
<tr>
<th>Turbulence Intensity</th>
<th>Delta Y</th>
<th>(4)</th>
<th>(5)</th>
<th>(6)</th>
<th>(7)</th>
</tr>
</thead>
<tbody>
<tr>
<td>.01</td>
<td>108.75</td>
<td>.68E-10</td>
<td>.16E-4</td>
<td>.22E-4</td>
<td>.20E-9</td>
</tr>
<tr>
<td>.01</td>
<td>217.5</td>
<td>.31E-10</td>
<td>.70E-5</td>
<td>.10E-4</td>
<td>.91E-10</td>
</tr>
<tr>
<td>.01</td>
<td>435</td>
<td>.69E-10</td>
<td>.22E-4</td>
<td>.47E-11</td>
<td>.15E-5</td>
</tr>
<tr>
<td>.02</td>
<td>435</td>
<td>.31E-10</td>
<td>.10E-4</td>
<td>.47E-11</td>
<td></td>
</tr>
<tr>
<td>.03</td>
<td>435</td>
<td>.66E-5</td>
<td>.48E-6</td>
<td>.62E-5</td>
<td></td>
</tr>
<tr>
<td>.05</td>
<td>435</td>
<td>.57E-8</td>
<td>.72E-5</td>
<td>.58E-8</td>
<td>.72E-5</td>
</tr>
</tbody>
</table>

Sfc
71.66E-8
74.5E-5
78.29E-9
80.28E-9
80.28E-9
With a grid spacing of 435 m and a turbulence intensity of .05, a plume concentration covering four grid spaces at the east end of the grid was produced. Predicted plume concentrations slowly decreased as the turbulence intensity was reduced to .02 (atmospheric stability increased). At an intensity of .01, the concentration dropped by about five orders of magnitude. Normally, one would expect increased concentrations with increased atmospheric stability. Perhaps the result noted here is due to the plume shrinking away from a grid point (and becoming more concentrated between the recorded grids) with the increase in stability.

To increase the grid resolution, the grid spacing was reduced by half to 217.5 m and again to 108.75 m. With each reduction the grid was reduced by half in the "Y" direction and doubled in the "X" direction thus keeping distances between grid spaces equal in all directions. This of course greatly increases the computational requirements. If only plume predictions along the back edge are needed (as in Table I), the downwind grid distance may be held constant at 435 m while the horizontal crosswind resolution is increased. In this way many unnecessary computations are not made. However, the increased horizontal crosswind resolution is
computed over the entire downwind grid, which in this case, is not necessary. A more satisfying solution to this problem is to install the capability of using a variable resolution grid with the model so that downwind areas of particular interest can be covered with a dense grid while other areas of not so much interest can be sparsely grided.

In order for the advection of the plume to remain on the array when increasing the horizontal crosswind resolution and decreasing the area exposed on the grid, the plume source was adjusted along the western boundary of the grid. The relationship of the vertical grid points to changes of the source location is shown in Table II. The plume source for each grid resolution is noted with an arrowhead. Grid points that are aligned vertically in the table have identical locations and should have the same predicted plume concentrations. As mentioned earlier, an increase of grid resolution does not affect the predicted concentration. Notice that for the same grid points in Table I, the predicted concentrations with a turbulence intensity of .01 remain constant with changes in grid spacing—only the grid resolution was changed.
TABLE II

The Relationship of the Y Axis along the Western Grid Edge to changes of Grid Distance between 435 and 108.75 m.

<table>
<thead>
<tr>
<th>DELTA Y (m)</th>
<th>Grid Points Along the Y Axis</th>
</tr>
</thead>
<tbody>
<tr>
<td>435</td>
<td>4 5 6 7 8 9</td>
</tr>
<tr>
<td>217.5</td>
<td>0 1 2 3 4 5 6 7 8 9</td>
</tr>
<tr>
<td>108.75</td>
<td>0 1 2 3 4 5 6 7 8 9</td>
</tr>
</tbody>
</table>

From Table I it is obvious that the 435 m grid spacing is too large and that the higher resolution does indeed "see" concentrations that would otherwise be missed.

The problem of an increasingly narrow distance covered on the grid as resolution is increased can sometimes be at least partly corrected by reversing the X and Y coordinates and adjusting or rotating the advecting wind direction. This can easily be done with the use of the "TURN" model input parameter. This procedure sometimes becomes necessary since one of the grid directions is limited by the width of the output printer paper to less than or equal 10 grid units.

The model input variables, meteorological and source values were adjusted to note their effect on plume concentrations. A deeper understanding of how the model works and how the atmosphere affects dispersion can also be gained by
such adjustments. A turbulence intensity class of .05 was used, except when studying intensity itself, because it had previously demonstrated a good downwind grid coverage of the plume.

In order to note the effect of the maximum mixing level on the plume concentrations, several model predictions were run, varying only the height to which the plume was allowed to rise. Exact grid point reproductions were not possible since the model only allows the height of the mixing level to be an integer multiple of delta Z. The vertical grid spacing is therefore not equal. However, the anticipated trend of increased concentrations as the mixing level is lowered is evident from Table III.

The reflection/absorption of the plume at the surface is controlled by the model variable "REFLEZ". Tests of the extremes of total absorption (0.0) and total reflection (1.0) were performed. The results showed a 50 percent reduction in plume concentrations at the west end of the grid with total absorption compared to total reflection in otherwise identical model runs.

The model has a self-imposed limitation of 100 puffs from all sources on the grid. The model will terminate if
TABLE III

Plume Concentrations between Surface and 99 m under Different Maximum Mixing Levels.

<table>
<thead>
<tr>
<th>Max Mixing Level</th>
<th>(5)</th>
<th>(6)</th>
<th>(7)</th>
<th>(8)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>None</td>
<td>.44E-8</td>
<td>.55E-5</td>
<td>.20E-5</td>
<td>.22E-9</td>
<td>Sfc</td>
</tr>
<tr>
<td></td>
<td>.43E-8</td>
<td>.54E-5</td>
<td>.19E-5</td>
<td>.21E-9</td>
<td>33 m</td>
</tr>
<tr>
<td></td>
<td>.40E-8</td>
<td>.50E-5</td>
<td>.18E-5</td>
<td>.20E-9</td>
<td>66 m</td>
</tr>
<tr>
<td></td>
<td>.36E-8</td>
<td>.45E-5</td>
<td>.16E-5</td>
<td>.18E-9</td>
<td>99 m</td>
</tr>
<tr>
<td>80 m</td>
<td>.57E-8</td>
<td>.72E-5</td>
<td>.26E-5</td>
<td>.28E-9</td>
<td>Sfc</td>
</tr>
<tr>
<td></td>
<td>.59E-8</td>
<td>.74E-5</td>
<td>.27E-5</td>
<td>.29E-9</td>
<td>40 m</td>
</tr>
<tr>
<td></td>
<td>.58E-8</td>
<td>.72E-5</td>
<td>.26E-5</td>
<td>.29E-9</td>
<td>80 m</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>&gt; 80 m</td>
</tr>
<tr>
<td>30 m</td>
<td>.64E-8</td>
<td>.81E-5</td>
<td>.29E-5</td>
<td>.32E-9</td>
<td>Sfc</td>
</tr>
<tr>
<td></td>
<td>.65E-8</td>
<td>.81E-5</td>
<td>.29E-5</td>
<td>.32E-9</td>
<td>30 m</td>
</tr>
<tr>
<td></td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>&gt; 30 m</td>
</tr>
</tbody>
</table>

This number is exceeded. A balance must be made between the rate at which puffs are released from the source (TAU) and the time it takes the puffs to be advected across the grid. A release rate of one puff every 40 seconds was predominately used during this study.

The turbulence intensity variable was varied to include conditions that are more unstable. As atmospheric instability increases, the plume would be expected to expand whereas, with stable conditions, the plume should remain narrow and highly concentrated.
With the use of NPS contouring routines and the subroutine "DRAW", a visual comparison of the plume disposition and concentrations is available. Since the computed plume concentration varies over many orders of magnitude, the concentration values were converted to integer numbers by multiplying by $1 \cdot 10^{13}$ and then taking the logarithms. These logarithms are then smoothed. Thus, a contour plot representing order of magnitude concentrations was be produced. As with the model variables "MAPTIM" and "KPLANS" which control the frequency and vertical levels of printer plots, "DRAW" can be called to contour concentrations at any time period and for any level required.

Plume concentration distributions for turbulence intensities of .05, .10 and .25, all other variables constant, are shown in Figs. 5, 6 and 7. As expected, the plume becomes wider and the concentration decreases as the turbulence intensity/diffusion increases and the atmosphere becomes less stable.

In Figs. 5-7, the plume source was located at grid point (0,6). The wide plume in the lower part of the plot is not real but is a function of the smoothing routine spreading the early puffs more than would be expected. Since the
Figure 5. Orders of Magnitude of Plume Concentration with Turbulence Intensity equal to .05.
Figure 6. Same as Figure 5 except Turbulence Intensity equal to .10.
Figure 7. Same as Figure 5 except Turbulence Intensity equal to 0.25.
smoothing routine would tend to smooth strong concentrations near the source, the smoothing should be eliminated if the primary interest is near the source. Actually one would expect the puffs to behave as in Fig. 3, from Mikkelsen (1979), showing the relationship between the puff size and concentration, the rate of puff release (TAU) and the advecting wind speed U.

Figure 8. Relationship between Puff Size, Concentration, Puff Release Rate (TAU) and Advecting Wind Speed U (Mikkelsen, 1979).
Puffs would have to travel the distance $X_{\text{min}}$ before they expand to a size where they effectively overlap and form a solid plume. From Figs. 5-7, one can see that plume concentrations have increased with distance and that a $X_{\text{min}}$ has been reached in the middle to upper part of the grid. It is at this point that the puff model would be expected to accurately predict plume concentrations. If the area of interest is before the present $X_{\text{min}}$, the release rate of puffs would need to be increased so that the successive puffs would overlap sooner. Also noted that as the turbulence intensity increases, the area of maximum concentration of the plume expands while the central concentration decreases. This agrees with conservation of mass theory.

To appreciate the relative importance of the source strength and buoyant heat flux, these variables (discussed in Chapter IV) were doubled separately and together and the concentrations compared to the concentrations from the actual conditions. Little or no changes in concentration were noted when the buoyant heat flux was doubled and source strength remained the same. However, when the source strength was doubled and heat flux held constant, the grid concentrations doubled as expected. Thus, under existing
conditions, the source strength was critical to the predicted plume concentrations while the buoyant heat flux, within the range tested, was not relevant. The vertical printer plots did show an initial puff rise soon after release due to the initial heat release but as the puff rose and expanded, it soon reached the ambient temperature and leveled off. The buoyant heat flux would probably be more important when dealing with a smaller scale grid or greater heat release.
V. DATA COMPARISON

No attempt was made to compare actual puff model concentration predictions at exact grid points to aircraft observations for the following reasons:

- The aircraft locations were approximations—the exact locations were not known. Large differences in predicted concentrations are seen with small grid separations as evidenced in Table II.

- As noted in Fig. 2, the aircraft observations were taken over a period of time at different levels—while the puff model produced multilevel instantaneous predictions.

- As mentioned earlier, the actual wind was not constant between the ship observation site and the opposite side of the grid near shore. Since the model advects the puffs based upon ship observed wind, the behavior of actual plume would be different from predicted.

- Calibration procedures for the SF₆ continuous analyzer mounted onboard the aircraft were not available for instantaneous concentrations greater than 10¹⁰ PPT.
Therefore, a question of actual levels of $SF_6$ concentration in the higher ranges exists.

The puff model predicted concentrations are expressed in $g/m^3$ while the aircraft observations are shown as the volume of $SF_6$ per unit volume of air in PPT. A conversion between the predicted and observed concentrations was obtained by computing the partial pressure and molecular weight of $SF_6$ at standard pressure and temperature. A conversion of

$$g/m^3 = (6.3 \times 10^{-11}) \times \text{observed concentration (PPT)}$$

was thus found.

Generally, the aircraft sampled concentrations (Fig. 2) show values between 100 and 8000 PPT. Converting these observed concentrations to predicted concentration units gives values between $0.63 \times 10^{-9}$ and $5.0 \times 10^{-7} g/m^3$. These observed concentrations are much smaller than the values shown in Table II. Perhaps this difference could be explained by the fact that the puff model advected the plume toward the coast in the same direction under the same very stable conditions as observed on the ship. Any consideration of increased turbulence and wind shifts near shore would be expected to reduce the actual plume concentrations toward the observed concentration levels.
Increasing the turbulence intensity to 0.25 and keeping all other variables constant, the concentration values would decrease to the order of magnitude of $10^{-4}$—closer to the observed concentrations. (This would require the wind direction standard deviation to increase from 1 to 20). However, the increased instability would cause the plume to spread over a much greater area (Fig. 7) than observed by the aircraft.
VI. CONCLUSIONS AND RECOMMENDATIONS

The puff model has been demonstrated to be a versatile working dispersion model. Different combinations of input variables showed the expected reasonable results. The differences between model predicted and aircraft observed plume concentrations do not seem to be the fault of the model but mainly that of the highly variable meteorological conditions found along a coast.

Probably the most obvious conclusion reached from this study is that predicting the behavior of a plume moving over a marine environment onto a coastal region has significant problems. In all probability, atmospheric boundary layer conditions 7.4 km offshore can be very different from those observed in the more turbulent coastal region. The single point meteorological measurement at the source should not be expected to adequately represent plume characteristics as it nears a meteorologically variable coastline. Additional observations (primarily wind speed and direction), or other means of predicting the coastal meteorological conditions, would have to be incorporated into the puff model to adequately handle this problem.
The advantage of incorporating variable grid spacing within the puff model and the obvious benefits have already been discussed.

Presently, the mixing cap of the puff model is required to be located at an integer multiple of delta Z. More flexibility in this parameter to include any level, regardless of delta Z, would be beneficial.

Along with the puff locations shown on the lineprinter output, a maximum concentration level of each puff would be helpful.

In future experiments, several aircraft tracks should be made further out from the coast in an attempt to avoid the turbulent coastal region. Observations thus obtained in a noncoastal environment would help to verify the model predictions without the coastal influence.
APPENDIX A

MAJOR SECTIONS OF THE PUFF MODEL

The Risø Puff Model has been described by (Mikkelsen, 1979). The code also is well documented with comment statements. With that information and the outline to be provided in this and the following appendices, the computational and input/output procedures will be obvious.

The program and input data are stored on cards for the sake of permanency. For efficient operational execution, the program and input data cards are read on a disk within the computer. The model can then be run at will without reference to the original data cards. Minor changes can easily be made directly on the disk both to the model and/or data before each execution.

The model can be separated into the following main sections:

A. Input Data
B. Initial
C. Calculating
D. Output
E. Error Diagnostics
F. Subroutines
These will be described separately in the following sections.

A. INPUT DATA SECTION

The input data includes the variables shown in Table IV.

<table>
<thead>
<tr>
<th>Table IV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Input Data Variables for the Puff Dispersion Model.</strong></td>
</tr>
<tr>
<td>Wind History</td>
</tr>
<tr>
<td>Turbulence Intensity</td>
</tr>
<tr>
<td>Grid Dimensions</td>
</tr>
<tr>
<td>Mixing Depth</td>
</tr>
<tr>
<td>Source Locations, Start/Stop Time, Strength, Heat Emission</td>
</tr>
<tr>
<td>Number of Seconds between Advection Steps</td>
</tr>
<tr>
<td>Number of Seconds between Printouts/Plots</td>
</tr>
<tr>
<td>Number of Seconds between Puff Releases</td>
</tr>
</tbody>
</table>

The wind field and stability class for the current time step are read at the start of the calculation section.

The variables listed above are printed as a input data check and a permanent record to accompany the actual output. In most cases the print command can be overridden by YES/NO options.

B. INITIAL SECTION

Based upon the input data from section (A), the initial section specifies and initializes parameters to be used in
the calculating section and is passed only once during execution of the model. The grid and some counters are initialized. Constants relating to reflectance, mixing depth and stability as well as those controlling the size of some of the loops within the model are established. Parameters such as number of puff releases per second, number of advection steps per second and number of advection steps per puff release are determined.

C. CALCULATION SECTION

Using current wind and stability class data read at the start of the calculation section, the model advects the puff centers and calculates the growth rate and plume rise of the puffs. It removes the puffs that have left the grid (horizontally and/or vertically). The predicted concentration is computed at the grid points to include pollutants from all nearby puffs.

D. OUTPUT SECTION

For time intervals designated by the input data, printer plots of the X-Y and Y-Z grid are produced. A maximum mixing level is marked on the Y-Z grid if in effect.
These plots include the source location and a trace of the plume from the release time to the maptime. Also printed at this interval is a X-Y table of grid concentrations for each vertical level of interest. These concentrations can be either accumulated or actual concentrations at the plot time.

Added to the puff model is a versatic plotter routine to smooth and contour the grid magnitude concentrations of the above tables.

E. ERROR DIAGNOSTIC SECTION

If the model is directed by the input data beyond the limits of the design of the program, the program is terminated by way of the error diagnostic section. It prints comments relating to commonly made input errors enabling the user to isolate problems.

F. SUBROUTINES

The subroutine "Sigris" calculates the puff size in the horizontal and vertical directions. It also estimates plume rise associated with pollutant buoyancy.

The subroutines "Ispace" and "Rspace" are used in the framework of the printer plots.
The subroutine "Draw" converts the plume concentrations to logarithmic values, smoothes and then contours them using NPS inhouse contour subroutines. The values are converted to their logarithmic values so that the problem of contouring over many orders of magnitude is simplified.
APPENDIX B

PUFF MODEL FLOW CHART

INPUT SECTION

READ - data input variables (primary, source, intensity, current stability); averaging timestep (tav) for wind data

INITIAL SECTION

Initialize constants

READ & STORE all wind speed and direction for current intensity class

next wind vector

next advection step

Release puff, execute advection step, calculate concentration

\[ \sum \text{advection steps} \leq \text{tav} \]

\[ \sum \text{advection steps} > \text{tav} \]

OUTPUT SECTION

Puff positions, grid concentrations, contour

New stability class?

yes

end of data

termination

no
APPENDIX C
PUFF MODEL CONTRACTIONS

CHEMIN—Minimum grid concentration of interest

DELX,DELY,DELZ—Distance in meters between grid points

DOSE—Allows the concentration matrix to accumulate

DTDZ—Potential temperature gradient (K/m) (\geq 0)

HEAT—Individual source heat emission (KW)

ICOLS—Number of columns in grid (\leq 10)

INST—Instantaneous concentration matrix

ITIME—Start time

JROWS—Number of rows in grid

KPLANS—Number of vertical levels in grid (includes surface)

NAPTIM—Number of seconds between printer plots

NRRELSE—Number of seconds to stop of release

NRMULT—Number of sources (\leq 25)

NTADV—Integer number of seconds between advection steps
REFLEC--Reflection at ground level (0. none; 1.0 total)

SOURWR--Number to identify source

SOURST--Strength for individual source (g/s)

STOPRL--Individual source stop time (s)

STRTRL--Individual source start time (s)

TAU--Integer number of seconds between puff releases

TURN--Angle of rotation of wind direction

XSOURCE--X coordinate of source in grid units

YSOURCE--Y coordinate of source in grid units

ZM--Limited mixing depth (m)
APPENDIX D

LISTING OF PUFF MODEL COMPUTER CODE

// EXEC PGM=IEBGENER
// SYSPRINT DD DUMMY
// SYSSIN DD DUMMY
// SYST2 DD UNIT=SYSDA,DISP=(NEW,PASS)
// DDB=(RECFM=FB,RECL=60,BLKS=4000)
// SPACE=(TRK,11,11),DSN=YPFST2
// WIND DATA SEPT 29 81
810929 1630 #1800#
/0
* 085*04.7* 085*04.8
// EXEC FRXCLG, NAME=CONRECQC
// SYSPRINT DD DUMMY
// SYSSIN DD *
CFILE 1(KIND=DISK,TITLE="PRINDA",FILETYPE=7)
PUF00010
CFILE 2(KIND=DISK,TITLE="VINDA",FILETYPE=7)
PUF00020
CFILE 3(KIND=DISK,TITLE="STADA",FILETYPE=7)
PUF00030
CFILE 4(KIND=DISK,TITLE="SOURCEDA",FILETYPE=7)
PUF00040
CFILE 5(KIND=DISK,TITLE="INTSDA",FILETYPE=7)
PUF00050
CFILE PRINT(KIND=PRINTER,FILETYPE=7)
PUF00060
CFILE 6(KIND=PRINTER,FILETYPE=7)
PUF00070

THIS MICRODIFFUSION PROGRAM REPRESENTS THE STATE-OF-THE-ART CONCERNING THE DEVELOPMENT OF A NUMERIC DIFFUSION MODEL FOR OBSCUSSION SMOKE. (RISO, MET. SEC. SEPT 1978)
PUF00200

THE PROGRAM IS DOCUMENTED BY HEAVY USE OF COMMENT STATEMENTS.
PUF00220

FOR COLLECTING AN OVERALL VIEW OF THE PROGRAM STRUCTURE, AS WELL AS TO SET UP INPUT DATA FILES, IT IS ADVISED TO CONSULT THE FLOWCHARTS AND DESCRIPTIONS IN THE CONSECUTIVE REPORT.
PUF00250

COMMON HEATFX(25), I2,DMS,POINT,INTENS(14),STABPA,FBUFLX

1,SPEED,CONST,DELZ
1,INTEGER TAU,POINT,ANGLE,XSB,XLB,YSB,YLB,ZSB,ZLB,YINT,XINTPF,YLINE
1,ZNG,ZINTPF,WINDAV,TRTIN,SUMPUF,SQURHR,TUPSS(25,3110)
1,INTEGER XSOUCR(25),YSOUCR(25),STRTRL(25),STOPRL(25)
PUF00360

LOGICAL LINE,CQINCD,DOMXDP,GRARFLX
DIMENSION STRING(105),HORFRM(105),VERFRM(105),VRFRMZ(105),VRFRMZTFP(105)
PUF00410
105),VERPLSL(105),VRPLSL(105),PARENT(105),NBWFT(7),SBWFT(7)
PUF00420
REAL BL/'/,SN1/'/,SN2/'/,SN3/'/,SN4/'/,SN5'/'/,SN6'/'/,PUF00430
DIMENSION TITLE(18), WINDTX(18), PUFFTX(18), INTSTX(18), STABTX(18)
DIMENSION PTABEL(25,100,1), SHIFT(100,1), CHI(50,50,10)
DIMENSION ABC(10), SOUR(25), CPOIT(10,17), SOHT(25)
REAL DATA(14), TYPE(14), INTENS
DATA NO/NO/*BLANK/* A/A/*B/B/* C/C/*D/D/*E/E/*
DATA PUNK/*/*ASTER/*/*, ANFO/*/SLASH/*/, DOSE/*DOSE/*
DATA AA/**/

**********************************************************************************
** INPUT DATA SECTION***************************************************************************
**********************************************************************************

INPUT DATA FROM DATA FILE PRIMDATA:
PRIMARY DATA FOR PUFF MODEL

READ PRIMDA, CARD NO. 1:
READ(1,10) TIME, NRELSE, NSTEPS, ICOLS, JROWS, KP, ANS, NTADV
READ PRIMDA, CARD NO. 2:
READ(1,20) MAPTIM, TAU, TURN
READ PRIMDA, TITLE STRING:
READ(1,30) TITLE
READ PRIMDA, CARD NO. 4 - 5:
READ(1,40) DELX, DELY, DELZ, CHEMIN, REFLEC
READ PRIMDA, CARD NO. 5-9:
READ(1,50) ABC(5), ABC(6), ABC(7), ABC(8), ABC(9)
END OF PRIMDA - INPUT FILE.

1 FORMAT(2H0 )
10 FORMAT(2H1 )
20 FORMAT(7I5 )
30 FORMAT(18A4 )
35 FORMAT(1H , 18A4 )
40 FORMAT(1F10,2,F10,4,F10,5 )
50 FORMAT(2A2/2A2/2A2/4A )
100 FORMAT(6X,3I1KEY PARAMETERS FOR CURRENT RUN:)
200 FORMAT(6X,13HTIME = , 15,6X,13HNRELSE = , 15,6X,13HNSTEPS
1 = , 15)
300 FORMAT(6X,13HICOLS = , 15,6X,13HJROWS = , 15,6X,13HKPLANS
1 = , 15)
400 FORMAT(6X,13HNTADV = , 15,6X,13HMAPTIM = , 15,6X,13HTAU
1 = , 15)
600 FORMAT(6X,8HDELY =, F10.2, 6X, 8HDELY =, F10.2P6F0960
700 FORMAT(6X,8HCHEMIN =, E10.4, 6X, 8HREFLEC =, F10.5, 6X, 13HTURN = PUF0980

C SKIPPING LINE PRINTING OF PRIMDATA IF SPECIFIED
IF(ABC(5) .EQ. 0) GO TO 751
DO 750 1 = 1, 5
WRITE(6,1) TITLE
WRITE(6,1) ICOLS, ICOLS, KPLANS
WRITE(6,1) NTADV, MAPTIM, TAU
WRITE(6,1) CHEMIN, REFLC, TURN
WRITE(6,1)

C 751 CONTINUE
C READ SOURCEDATA INPUT FILE
C
800 FORMAT(A1,I2,A1)
810 FORMAT(5I5,3F10.5)
820 FORMAT(48H CURRENT SOURCEDATA ; NUMBER OF ACTIVE SOURCES ; I4)

C READ PUFFDATA TITLE STRING
READ(4,30) PUFFTX
WRITE(6,30) PUFFTX
C READ NUMBER OF MULTISOURCES : NRMULT
READ(4,800) ABC(3), NRMULT, ABC(4)
WRITE(6,800) ABC(3), NRMULT, ABC(4)
C INPUT FORMAT TESTING :
IF(ABC(3) .NE. AA .OR. ABC(4) .NE. AA) GO TO 8920

C READ INDIVIDUAL SOURCEDATA :
C SETTING FRAMDATA: (M) SMALL-X, (M) FULL-X, ETC .
MFX = ICOLS
MSX = 1
MFZ = KPLANS
MSZ = 1
XSB = MSX - 1
XLB = MFZ - 1
YSB = MSY - 1
YLB = MFY - 1
VLL = YLB + 0.1

DO 850 I = 1, NRMULT
READ(4, 810) SOURNR, XSOURC(I), YSOURC(I), STRTRL(I),
2 STOPAL(I), SOURST(I), HEATFX(I), SOHT(I)
WRITE(6, 810) SOURNR, XSOURC(I), YSOURC(I), STRTRL(I),
2 STOPAL(I), SOURST(I), HEATFX(I), SOHT(I)
C TESTING INDIVIDUAL SOURCEDATA:
IF(N.E. SOURNR) GO TO 8910
C OFF GRID TEST FOR SOURCE COORDINATES:
IF(XSOURC(I).GT.XLB.OR.XSOURC(I).LT.XSB.OR.YSOURC(I).GT.YLB.OR.YSOURC(I).LT.YSB) GO TO 9000
850 CONTINUE
C
WRITE(6, 2)
WRITE(6, 1)
WRITE(6, 35) PUFFTX
WRITE(6, 11)
WRITE(6, 820) NRMULT
WRITE(6, 11)
C SETTING UP STRING VARIABLES FOR PLOTTING PURPOSES
DO 911 N = 1, 105
STRING(N) = BL
VFRAME(N) = BL
VERPLS(N) = BL
911 H0RFRM(N) = BL
NY1 = MFZ*10
DO 916 I = MSX, NY1
NY2 = I + 4
DO 915 NN = 1, NY2
915 H0RFRM(NN) = SN4
H0RFRM(I + 5) = SN2
NY3 = I + 6
NY4 = I + 9
DO 916 NN = NY3, NY4
916 H0RFRM(NN) = SN4
VERFRM(10*MFZ + 3) = SN5
VERPLS(10*MFZ + 3) = SN3
C
C OUTPRINTING CURRENT SOURCE POSITION(S) IN GRID PICTURE
C SKIP PLOTTING SOURCE POSITIONS IF SPECIFIED IN 'RIMDA'
C IF(icol.gt.10) go to 995
860 format(1h,16h,39x,'CURRENT SOURCE DATA AS SPECIFIED'/ '50X,27H IN SOURCE DATA INPUT FILE;'/ '55X,'SOURCE NUMBER',/ '55X,'START TIME [SEC]',/ '55X,'STOP TIME [SEC]',/ '55X,'SOURCE STRENGTH',/ '55X,'BUOYANT HEAT FLUX'/ '1')
870 format(2h0,16h,y coordinate of 25x,32h x coordinate of the grid / 10ints/2x,16h the grid points,18,9,10/ 10ints/2x,16h the grid points,18,9,10)
C WRITE(6,860)
WRITE(6,865) (i,i='XSB',XLB)
C WRITING DATA INTO GRID POINTS:
C 910 format(1h,111,5x,2h+,105a1)
C 912 format(1h,19x,105a1)
C 913 format(1h,17x,1h,105a1/1h,17x,1h,105a1)
C 914 format(1h,17x,1h,105a1)
C WRITE(6,913) VERFRM,VERFRM
MAX =JROWS-1
NY5=MAX+1
do 990 ny=1,ny5
i=ny6-1
maxm = max - i
write(6,910) maxm,verfrm
do 920 j=1,NRMULT
if(max-i .ne. ysource(j)) go to 920
920 continue
write(6,913) verfrm,verfrm
C do 932 j = 1,NRMULT
if(max-i .ne. ysource(j)) go to 932
write(6,914) verfrm
932 continue
write(6,913) verfrm,verfrm
C
C
DO 934 J = 1,NRMULT
IF(MAX-I .NE. YSOURC(J)) GO TO 934
WRITE(6,914) VERFRM
CALL RSPACE(XSOURC(J),STOPR(J))
934 CONTINUE
WRITE(6,913) VERFRM,VERFRM

C
DO 940 J=1,NRMULT
IF(MAX-I .NE. YSOURC(J)) GO TO 940
WRITE(6,914) VERFRM
CALL RSPACE(XSOURC(J),SOURST(J))
940 CONTINUE
WRITE(6,913) VERFRM,VERFRM

C
DO 930 J=1,NRMULT
IF(MAX-I .NE. YSOURC(J)) GO TO 930
WRITE(6,914) VERFRM
CALL RSPACE(XSOURC(J),HEATFX(J))
930 CONTINUE
WRITE(6,913) VERFRM,VERFRM
WRITE(6,913) VERFRM,VERFRM

C
GO TO 999
990 FORMAT(53H SOURCE DATA PLOT SUPPRESSED BECAUSE *ICOLS*EXCEEDS 10)
995 WRITE(6,990)
999 CONTINUE

C
DEFINE STABILITY AND INTENSITY CLASSES
C
INPUT FROM INTENSITY - DATA: INTSDA
C
960 FORMAT(14 F5.4)
965 FORMAT(1H0, 46H IN THE CURRENT RUN, THE STABILITY-CLASSES ARE, /41H
1 CONNECTED TO INTENSITY DATA AS FOLLOWS:
970 FORMAT(1H ,21H STABILITY CLASS NO.: 13 : 3 15)
975 FORMAT(1H ,21H INTENSITY DATA ; 14F5.4)

C
READ INTSDA, TITLE-STRING:
READ(5,30) INSTIX
C
READ(6,30) INSTIX
C
READ INTSDA, NO. OF INTENSITY-CLASSES: NRINCL
READ(5,800) ABC(3),NRINCL,ABC(4)
C
WRITE(6,802) NRINCL
C
INPUT FORMATS TESTING:
802 FORMAT(1X,15)
IF(ABC(3),NE.,AA.OR.,ABC(4).NE.,AA) GO TO 8890
C
READ INTENSITY-CLASSES INTO REAL ARRAY: INTENS
READ(5,960) END=801) INTENS(I),I=1,NRINCL)
WRITE(16,960) INTENS(I),I=1,NRINCL)
C
OUTPRINTING CURRENT INTENSITY CLASSES:
C
SKIP PRINTING OF INTENSITY DATA IF SPECIFIED IN PRIMA
801 IF(ABC(7),EQ.,NO ) GO TO 980
WRITE(16,92) INTSTX
WRITE(16,935) INTSTX
WRITE(16,995)
WRITE(16,970) (1.,I=1,NRINCL)
WRITE(16,975) (INTENS(I),I=1,NRINCL)
WRITE(16,91)
WRITE(16,91)
980 CONTINUE
END OF INTENSITY DATA SECTION.
C
INPUT FROM STABILITY DATA:STABDA
C
READ STABDA,TITLESTRING:
READ(3,30) STABTX
C
READ STABDA,POTENTIAL TEMPERATURE GRADIENT (>0).
C
READ(3,889) DTDZ
C
READ STABDA,LIMIT OF MIXING DEPTH: ZM (METERS).
C
READ(3,992) ZM
C
NO DATA-TEST ON ZM:
IF(AMOD(ZM,DELZ) .NE. 0.)GO TO 8880
C
OUTPRINTING CURRENT STABILITY-DATA:
C
889 FORMAT(F10.4)
991 FORMAT(1HO.45H IN THE CURRENT RUN,THE POTENTIAL TEMPERATURE/21H
1RADIENT IS SET TO:F10.4)
992 FORMAT(F10.4)
993 FORMAT(1HO.36H NO FINAL MIXING DEPTH IS SPECIFIED.)
994 FORMAT(1HO.36H THE MIXING LAYER IS LIMITED AT:F10.2,8H METERS.)
WRITE(6,91)
WRITE(6,91)
WRITE(6,95)
WRITE(6,95) STABTX
WRITE(6,91)
WRITE(6,91)
WRITE(6,991) DTDZ
WRITE(6,91)
WRITE(6,91)
WRITE(6,1)
IF(IZM .EQ. 0) WRITE(6,993) ZM
IF(IZM .GT. 0) WRITE(6,994) ZM
C
END OF STABILITY DATA SECTION.

C
INPUT FROM WINDDATA:
C
1110 FORMAT(16,1X,14,1X,14,1X,14,12X)
1120 FORMAT(IS,H,2X,CURRENT WINDDATA: STARTDATE=.I6,4X,10HSTARTHR=.I4,PUF03460 PUF03460
C
READ WINDDA, TITLE STRING:
READ(2,30) WINDTX
C
READ WINDDA, STARTTIME AND WINDFIELD AVERAGING TIME:
READ(2,1110) DATE, STR THR, ABC(1), WINDAV, ABC(2)
C
INPUT FORMAT TESTING:
IF(ABC(1).NE.AA.OR.ABC(2).NE.AA) GO TO 8990
C
WRITE(6,2)
WRITE(6,1)
WRITE(6,1)
WRITE(6,1)
WRITE(6,1)
WRITE(6,35) WINDTX
WRITE(6,1)
WRITE(6,120) DATE, STR THR, WINDAV
C
TESTING ON SPECIFIED TIME INCREMENTS: TAU, NTADV, WINDAV:
ITEST = MOD(TAU/NTADV)
IF(ITEST#.NE.0) GO TO 8980
ITEST2 = MOD(WINDAV, NTADV)
IF(ITEST2#.NE.0) GO TO 8970
C
END OF FIXED WINDDATA SPECIFICATIONS.

C
***************INITIAL SECTION***********************
C
***************INITIAL SECTION***********************
C
***************INITIAL SECTION***********************
C
THIS PART OF THE PROGRAM IS ONLY PASSED ONCE.
C
1130 FORMAT(14(A1,A4))
C
COUNTER FOR STABILITY SPECIFICATIONS GIVEN BY WINDDATA: NRSTAB
NRSTAB = 0
C
INITIATING A THREE DIMENSIONAL GRID: CHI
DO 1200 I = 1, ICOLS
DO 1200 J = 1, JROWS
DO 1200 K = 1, KPLANS
1200 CHI(I,J,K) = 0
C
NUMBER OF PUFF RELEASES PER SEC: TAUINVERS.
TUAINV = 1.0/ FLOAT(TAU)

NUMBER OF ADVECTION STEPS PER SEC.: ADSTPS.
ADSTPS = 1.0/ FLOAT(NADV)

BASIC DOSE PER PUFF: (GRAM/SEC.)*TAU = GRAM/PJFF.
BADOPP = I*TAU

NUMBER OF BASIC ADVECTION STEPS (INTEGER NUMBER) PER PUFF RELEASE:
NADPRP = TAU/NADV

NUMBER OF BASIC ADVECTION STEPS (INTEGER NUMBER) PER WINDFIELDSP.
NADPRW = WINDAV/NADV

TOTAL RUNTIME COUNTER: TOTTIM.
TOTTIM = 0

COUNTER FOR REMOVED PUFFS: LEAVE
LEAVE = 0

STABILITY PARAMETER FOR PLUMERISE:
STABPA = G/TM(THETE/DZ)
STABPA = .03*DTDZ

CONSTANT IN CONNECTION WITH PLUMERISE FORMULA FOR USE IN
SUBROUTINE SIGRIS: CONST1.
CONST1 = 0.6667 * 1.6**1.5

IF MIXING DEPTH IS NOT SPECIFIED, SET NOMXDP = .TRUE.
IF(ZM .EQ. 0.) NOMXDP = .TRUE.

IF REFLECTANCE AT GROUND LEVEL IS SPECIFIED, SET GRRFLX = .TRUE.
IF(REFLEC .GT. 0.) GRRFLX = .TRUE.

MIXING DEPTH IN GRID-UNITS: ZMG
ZMG = ZM/DELZ

TESTING THAT MIXING DEPTH IS INSIDE GRID:
IF(ZMG .GT. (KPLANS -1)) GO TO 8070

END OF INITIAL SECTION

******CALCULATION SECTION***************

READING STABILITY CLASS AND WINDATA FROM INPUTFILE:
1135 READ (2,1130) ( TYPE(I),DATA(I) , I = 1,14)
PUF03860
PUF03870
PUF03880
PUF03890
PUF03900
PUF03910
PUF03920
PUF03930
PUF03950
PUF03960
PUF03970
PUF03980
PUF03990
PUF04000
PUF04010
PUF04020
PUF04030
PUF04040
PUF04050
PUF04060
PUF04070
PUF04080
PUF04090
PUF04100
PUF04120
PUF04130
PUF04140
PUF04160
PUF04170
PUF04190
PUF04210
PUF04250
PUF04260
PUF04270
PUF04280
PUF04290
PUF04300
PUF04310
PUF04320
PUF04330
BACKSPACE 2
IF(TYPE(1).EQ.ANFO) READ(2,113)(NBUFF(I),SBUFF(I),I=1,7)
IF(TYPE(1).EQ.ANFO)WRITE(6,113)(NBUFF(I),SBUFF(I),I=1,7)
1131 FORMAT(1X,1X,F4.1)
LOOP THRU WINDDATA AT SPECIFIED TIMESTEPS
I = 1
IF(TYPE(1).NE.SLASH)GO TO 1150
NRSTAB = NRSTAB + 1
C COUNTING NUMBER OF WINDDATA SPECIFICATIONS: IW)ASP
C READING STABILITY CATEGORY FROM WINDDATA:
CLASS =DATA(I)
IF(CLASS.EQ.5) POINT = 1
IF(CLASS.EQ.B) POINT = 2
IF(CLASS.EQ.C) POINT = 3
IF(CLASS.EQ.E) POINT = 5
IF(CLASS.EQ.PUNK)GO TO 8930
IF(CLASS.EQ.BLANK) GO TO 8940
1140 FORMAT(53H PROGRAM STOPPED ORDINARILY FM WINDDATA SPECIFICATION)
WRITE(6,1)
WRITE(6,1141) NRSTAB,POINT
WRITE(6,11)
1141 FORMAT(4H THE,13,38H. STABILITY SPECIFICATION ;CLASS IS NO.,11)
GO TO 1135
C INPUT STRUCTURE TEST:
1150 IF(TYPE(1).NE.ANFO .OR.TYPE(I+1).NE.ASTER) GO TO 1160
C CURRENT WINDDATA:
IW)ASP = IW)ASP + 1
C CURRENT WINDDATA:
J1 = I+1/2
ANGLE = NBUFF(J)
SPEED = SBUFF(J)
GO TO 1175
1160 IF(TYPE(1).NE.BLANK .OR.TYPE(I+1).NE.BLANK) GO TO 8950
C READ NEXT DATA IN LINE 1135
GO TO 1135
C INDATA PART OF PROGRAM TERMINATED.
1175 CONTINUE
C CURRENT WINDDATA PRESENT.
C OUTPRINTING CURRENT WINDDATA:
WRITE(6,1161) IW)ASP,ANGLE, SPEED
C
CALCULATING WIND VELOCITY IN GRID UNITS: VGX, VGY
VGY = SPEED*(SIN(ANGLE*3.142/180)) / DELX
VGX = SPEED*(COS(ANGLE*3.142/180)) / DELY

RENAMEING WIND AVERAGING TIME: WINDAV AS TAV:
TAV = WINDAV
1161 FORMAT(4H THE I4,49H WIND DATASET IN THE CURRENT 1E=+,I4,8H ,SPEED=F4.1)
CLASS IS: ANG, SPEED

LOOP THRU BASIC ADVECTION STEPS WITH CURRENT WIND FIELD
DO 5000 NN=1,NADPRW

JUMPING OVER "ZERO-SETTING" OF CONCENTRATION MATRIX : CHI, IF
"DOSE MODE" IS SPECIFIED IN PRIMDA.
IF(ABC(8).EQ. DOSE) GO TO 1256

DO 1255 IG=1,ICOLS
DO 1255 JG=1,JROWS
DO 1255 KG=1,KPLANS
1255 CHI(IG,JG,KG) = 0.0
1256 CONTINUE

TIMECOUNTER: TOTTIM (SEC.)
TOTTIM = TOTTIM + NTADV

SKIPPING RELEASE-SECTION IF SPECIFIED
IF(TOTTIM .GE. NRELSE) GO TO 1250

TESTING IF RELEASE CONDITIONS ARE FULLFILLED
IF(MOD(TOTTIM,TAU) .NE. 0) GO TO 1250

LOOP THRU MULTIPLE SOURCES
DO 1250 I2 = 1,NRMULT

INDIVIDUAL RELEASE CONTROL AS SPECIFIED IN SOURCE DATA:
IF(TOTTIM .LT. STRTRL(12)) OR, (TOTTIM .GT. STOPRL(12))) GO TO 1250

TOTAL NUMBER RELEASED FROM SOURCE(12): TPUFFS(12):
TPUFFS(12) = TPUFFS(12) + 1

SHIFTING PUFF TABLE ONE POSITION TO THE RIGHT AND THEREBY
GIVING SPACE FOR ONE NEW PUFF:
J = 1
1204 DO 1205 K=1,7
1205 SHIFT(J+1,K) = PTABEL(12,J,K)
J = J + 1
IF(J.GE.1000) GO TO 8900

IF(PTABL(12,J,1).NE. 0) GO TO 1204

DO 1210 L = 2,J

1200 DO 1210 K = 1,J

1210 PTABL(12, L, K) = SHIFTL(K)

C INSERTING NEW PUFF DATA IN PUFF TABLE AT J = 1
PTABL(12,1,1) = TRUFFS(12)

C DOSE RELEASED WITH EACH PUFF: SPECIFIED SOURCE STRENGTH*SEC.
C BETWEEN RELEASES
PTABL(12,1,2) = SOURS(12) * TAU

C LOADING IN INITIAL SOURCE POSITIONS
PTABL(12,1,3) = 1.0*SOURC(12)
PTABL(12,1,4) = 1.0*SOURC(12)
C
C TO AVOID NUMERICAL PROBLEMS IN ESTIMATING PLUME RISE,
C SET SOURC(12) = SOURCE HEIGHT 1.0. GE. 1 METER.
PTABL(12,1,5) = SOURC(12) / DELZ

C INITIAL SIZE OF PUFFS:
C SIGMA X SET TO 1 METER:
PTABL(12,1,6) = 1.0
C SIGMA Z SET TO 1 METER:
PTABL(12,1,7) = 1.0
C END OF PUFF RELEASE SECTION.
1250 CONTINUE

C ADVANCE OF PUFF CENTERS IN GRID UNITS (HORIZONTALLY)
DGX = VGX* NTADV
DGY = VGY* NTADV
C TOTALLY TRAVELED DISTANCE BY THE PUFFS IN METERS
C (CURRENT BASIC ADVECTION STEPS: DMS)
DMS = SQRT((DGX*DELX)**2 + (DGY*DELY)**2)
C ADVANCE SECTION FOR ALL EXISTING PUFFS:
DO 1300 IZ = 1, NRMULT

C SKIPPING SOURCE 12 IF THE LAST BORN PUFF HAS LEFT GRID
IF(PTABL(12, J, 1).EQ.0.0) GO TO 1300

1260 PTBL3 = PTABL(12, J, 3) + DGX
PTBL4 = PTABL(12, J, 4) + DGY

C CALLING SUBROUTINE SIGRIS: THEREBY ADDING DEVIATION INCREMENT
C AND PLUME RISE INCREMENT TO THE PUFF TABLE:
PUF05300
PUF05310
PUF05320
PUF05330
PUF05340
PUF05350
PUF05360
PUF05410
PUF05420
PUF05430
PUF05440
PUF05450
PUF05460
PUF05500
PUF05510
PUF05520
PUF05530
PUF05540
PUF05550
PUF05560
PUF05570
PUF05580
PUF05630
PUF05650
PUF05660
PUF05680
PUF05690
PUF05700
PUF05720
PUF05730
PUF05740
PUF05750
PUF05770
PUF05780
PUF05790
PUF05800
PUF05840
PUF05850
PUF05860
PTABLE(12,J,5): Z-POSITION IN GRIDUNITS
PTABLE(12,J,6): SIGMAXY IN METERS
PTABLE(12,J,7): SIGMAZ IN METERS

CALL SIGRSS(PTABLE(12,J,5),PTABLE(12,J,6),PTABLE(12,J,7))

INTRODUCING AN UPPER LIMIT FOR BUOYANCY CONVECTION: ZM.
IF (NOT.NOMXD.PF.AND.PTABLE(12,J,5).GT.ZM) TTABLE(12,J,5) = ZM

Z - POSITIONS IN GRIDUNITS; PTBL5
PTBL5 = PTABLE(12,J,5)

TESTING AND REMOVING PUFFS WHICH HAVE LEFT THE GRID:
IF (PTBL3.GT.X58.AND.PTBL3.LT.XLB.AND.PTBL4.GT.Y88.AND.PTBL4.LE.YL
1L.AND.PTBL5.LT.ZLB) GO TO 1290

REMOVE SECTION
LEAVE = LEAVE + 1
IF (PTABEL(12,J+1,1).EQ.0) GO TO 1265

REMOVING PUFF BORN AT SOURCE I2 WHICH IS NOT THE LONGEST LIVING:
JJ = JJ + 1

DO 1270 JJ = 1,7
1270 SHIFT(JJ,K) = PTABLE(12,JJ,K)
JJ = JJ + 1
IF (PTABLE(12,JJ,1).NE.0) GO TO 1269
SHIFT(JJ,1) = 0
JMAX = JJ

COPY SHIFT BACK INTO PTABLE:
NY7 = JMAX - 1
DO 1275 JJ = J, NY7
1275 PTABLE(12, JJ, K) = SHIFT(JJ+1,K)
DO 1275 K = 1,7

RETURNING TO INCREMENTAL PART WITHOUT INCREASE IN J:
GO TO 1260

REMOVING LONGEST LIVING PUFF FROM SOURCE(I2):
PTABLE(12,J,1) = 0
CONTINUING WITH NEXT SOURCE
GO TO 1300

REPLACING NEW PUFF POSITION IN PUFF TABLE
PTABLE(12,J,3) = PTBL3
PTABLE(12,J,4) = PTBL4

CALCULATING GRID CONCENTRATION IN EACH BASIC ADVECTION STEP
RENAMEING ESSENTIAL PARAMETERS:
DOSE IN CURRENT PUFF:
QI = PTABEL(I2,J,2)
SIGMA VALUES IN METERS:
SIGMXY = PTABLE(12,J,6)
SIGMZ = PTABLE(12,J,7)

CALCULATING MAXIMUM CONCENTRATION IN EACH PUFF CENTER
(PUFF-CHEM-CENTER), IN DIMENSION: GRAM/M**3
CONSTANT : (2*PHI)**(3/2)
CONST = 15.7496

PCHCEN = QI/(CONST*SIGMZ*SIGMXY**2)

SKIPPING SUMMATION SECTION IF CONCENTRATION IS TOO LOW
IF(PCHCEN.LT.CHEMEN) GO TO 1500

CALCULATING MAXIMUM RADIUS OF INTEREST FOR EACH PUFF:
MAXIMUM PUFF RADIUS IN METERS:
PFRMXY = SIGMXY * SQRT(-2.*ALOG(CHEMEN/PCHCEN))
PFRMZ = PFRMXY*SIGMZ/SIGMXY

X-DIRECTION:
PFRGX = PFRMXY/DELX
Y-DIRECTION:
PFRGY = PFRMXY/DELY
Z-DIRECTION:
PFRGZ = PFRMZ/DELZ

DETERMINING START AND STOP GRID POINTS FOR ACCUMULATION OF
THE PUFFS IN QUESTION:

ISTRX = PTLR + PFRGX + 1
ISTOPX = PTLR + PFRGX
ISTRY = PTLR + PFRGY + 1
ISTOPY = PTLR + PFRGY
ISTRZ = PTLR + PFRGZ + 1
ISTOPZ = PTLR + PFRGZ

CONTROL FOR EXCEEDING GRID DIMENSIONS

IF(ISTRX.LT.XSB) ISTRX=XSBB
IF(ISTOPX.GT.XLB) ISTOPX=XLB
IF(ISTRY.LT.YSB) ISTRY=YSB
IF(ISTOPY.GT.YLB) ISTOPY=YLB
IF(ISTRZ.LT.ZSB) ISTRZ=ZSB
IF(ISTOPZ.GT.ZLB) ISTOPZ=ZLB
UPPER LIMIT IN CASE OF SPECIFIED MIXING DEPTH: ZM
IF (NOT NOMXD AND, ISTOPZ.GT. ZMG ) ISTOPZ = ZMG
IF (ISTRZ .GT. ISTOPZ) GO TO 1500

CALCULATE CONTRIBUTIONS TO SURROUNDING GRIDPOINTS
PRELIMINARY CALCULATIONS:
SIGMAs IN GRIDUNITS:
SIGGX = SIGMX/DELX
SIGGY = SIGMY/DELY
SIGGZ = SIGMZ/DELZ

CALCULATING DENOMINATOR UNDER EXP-SIGN:
SIGGX2 = (SIGGX**2)*(-2)
SIGGY2 = (SIGGY**2)*(-2)
SIGGZ2 = (SIGGZ**2)*(-2)

LOOPING THRU ALL GRIDPOINTS OF INTEREST:
DO 1500 KG = ISTRZ, ISTOPZ
   ZG2NEG = (KG-PTBL5)**2
   PCHI1 = PCHCEN + EXP(ZG2NEG/SIGGZ2)
   IF (GRRLFLX) PCHI1 = PCHI1 + PCHCEN*REFLEC*EXP((KG+PTBL5)**2/SIGGZ2)
   IF (NOMXD) GO TO 1295
   IF (PTBL5+PUFGRZ).LT. ZMG) GO TO 1295
   ZG2MX = (KG+PTBL5-2*ZMG)**2
   PCHI1 = PCHI1 + PCHCEN*EXP(ZG2MX/SIGGZ2)
   IF (ISTRZ.PF 1295)
   DO 1500 IG = ISTRY, ISTOPY
      XG = (IG-PTBL3)**2
      DO 1500 JG = ISTRY, ISTOPY
         YG = (JG-PTBL4)**2
         INDIVIDUAL PUFFS CONTRIBUTION: PCH1, GRAM/M**3
         PCH1 = PCHI1 * EXP(XG2/SIGGX2 + YG2/SIGGY2)
         IF (PCH1 .LT. CHEMIN) GO TO 1500
         ACCUMULATING IN GRIDPOINTS:
         CHI1(IG+1, JG+1, KG+1) = CHI1(IG+1, JG+1, KG+1) + PCH1
   1500 CONTINUE

END OF CONCENTRATION CALCULATIONS

ADVANCE IN PUFF TABLE (J) DURING BASIC ADVECTION STEP
J = J + 1

PUF06940
PUF06950
PUF06960
PUF06970
PUF06980
PUF06990
PUF07000
PUF07010
PUF07020
PUF07030
PUF07040
PUF07050
PUF07060
PUF07070
PUF07080
PUF07090
PUF07100
PUF07110
PUF07120
PUF07130
PUF07140
PUF07150
PUF07160
PUF07170
PUF07180
PUF07190
PUF07200
PUF07210
PUF07220
PUF07230
PUF07240
PUF07250
PUF07260
PUF07270
PUF07280
PUF07290
PUF07300
PUF07310
PUF07320
PUF07330
PUF07340
PUF07350
PUF07360
PUF07370
PUF07380
PUF07390
PUF07400
PUF07410
PUF07420
PUF07430
PUF07440
PUF07450
PUF07460
IF(PTABEL(I2,J,1) .NE. 0) GO TO 1260

1300 CONTINUE

END OF ADVECTION SECTION

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SECTION FOR OUTPRINTING PUFF POSITIONS IN GRID.

SKIPPING PUFF POSITION PLOT IF SPECIFIED:

TOTTIM TRUNCATED TO INTEGER NUMBER: ITOTIM.

IF(MOD(ITOTIM,3APTIM) .NE. 0) GO TO 1600

1301 FORMAT(I1)

1310 FORMAT(I10,3X,'PLOT OF CURRENT PUFF POSITIONS',I6,

& 'SEC AFTER START OF RELEASE.')

1320 FORMAT(I10,3X,'TOTALLY',I6,'PUFFS HAVE BEEN RELEASED AND',I6,

& 'PUFFS HAVE LEFT THE GRID.')

1325 FORMAT(I1+24X,105A1)

1326 FORMAT(I1+17X,14H+105A1)

1327 FORMAT(I1+11.3X,2H+105A1)

1328 FORMAT(I1+25X,105A1)

SUMMING UP ALL PUFFS RELEASED: SUMPUF

SUMPUF = 0

DO 1329 NPUF = 1,NRMULT

1329 SUMPUF = SUMPUF + TPUFFS(NPUF)

WRITE(6,1301)

WRITE(6,1310) ITOTIM

WRITE(6,1311)

WRITE(6,1320) SUMPUF,LEAVE

WRITE(6,1321)

WRITE(6,1322)

IF(ICOLS .GT. 10) GO TO 1595

WRITE(6,1370) (I2,I2 = XSB,XLB)

WRITE(6,1371)

WRITE(6,1392) MORFRM

WRITE(6,1393) VERFRM,VERFRM

C

LOOPING THRU ALL Y-VALUES OF GRID, STARTING UPPERMOST:
MAX = JROWS - 1
OUTER LOOP THRU INTEGER Y-VALUES:
NY8=MAX+1
DO 1350  NY9=1, NY8
12=NY9-1
MAXM12 = MAX - 12
WRITE(6,1327) MAXM12, VERPLS
C PLOTTING SOURCE POSITIONS
K1 = 0
DO 1330  J = 1, NRMULT
IF (MAXM12 .NE. YSOURC(J) ) GO TO 1330
C NUMBER OF SOURCES IN MAINLINE: K1
K1 = K1 + 1
CALL ISPACE(XSOURCE(J), J)
C SOURCE POSITIONS IN EACH MAINLINE: XINT(K1)
XINT(K1) = 10*XSOURCE(J)
C 1330 CONTINUE
C LOOPS 9 LINES DOWN TO NEXT MAINLINE:
DO 1345  NY10=1, 10
1DECI=NY10-1
YLNE = 10*(MAX - 12) - IDECI + 10
IF (1DECI .GE. 1) WRITE(6,1326) VERFRM
C SCANNING THRU WHOLE PUFF TABLE
DO 1340  II = 1, NRMULT
J = 0
1335  J = J + 1
IF (PTABLEL(II,J,1) .EQ. 0) GO TO 1340
C TRUNCATING Y-VALUE OF PUFF TO INTEGER:
YINT = PTABLEL(II,J,4)*10 + 10.5
C PRINTING "**" IN GRIDFRAME IF X-POSITION OF PUFF NOT COINCIDE
C WITH ONE OF THE SOURCE POSITIONS
IF ( (YINT .NE. YLINE) .OR. (1DECI .NE. 0) ) GO TO 1338
C INTEGER VALUE OF PUFFS X-POSITION: XINTPF
XINTPF = PTABLEL(II,J,3) * 10 + .5
DO 1336  KK = 1, K1
1336  IF (XINTPF .EQ. XINT(KK)) COINC = .TRUE.
IF (COINC) GO TO 1335
STRING(XINTPF + 1) = SNI
GO TO 1335
C 1338 IF(YINT .NE. YLINE) GO TO 1335
C PRINTING PUFF POSITIONS BETWEEN Y-GRID LINES:
XINTPF = PTABLEL(II,J,3) * 10 + .5
STRING(XINTPF + 1) = SN1
GO TO 1335
C
1340 CONTINUE
END OF PUFF TABLE LOOP.
C
WRITE(6,1325) STRING
DO 1342 NST = 1,105
1342 STRING(INST) = BL
C
1345 CONTINUE
RESET "SOURCE IN LINE COUNTER" XINT(KK)
DO 1349 KK=1,10
1349 XINT(KK) = -1
C
1350 CONTINUE
END OF PUFF POSITION PLOT.
WRITE(6,1)
WRITE(6,912) HORMAT
1400 CONTINUE
C
PLOTTING PUFFS IN "Y-Z FRAME" FOR COMMENTS REFER TO THE EQUI-
VALENT "Y-X FRAME" PLOTTING DESCRIBED ABOVE.
C
WRITE(6,1)
WRITE(6,1)
WRITE(6,1)
WRITE(6,1)
881 FORMAT(1H,15X,1O,F10.0)
WRITE(6,871) (12,12=ZSB,ZLB)
WRITE(6,1)
HRFRM2 : STRING CONTAINING HORIZONTAL GRID FRAME
DO 1410 N = 1,105
HRFRMZ(N) = BL
VRPLSZ(N) = BL
PARENT(N) = BL
1410 HRFRM2(N) = BL
NY1=MFZ*10
DO 1418 IHFZ = MSZ,NY1,10
NY2=IHWFZ+4
DO 1411 MN = IHFZ,NY2
1411 HRFRM2(MN) = SN4
HRFRM4(11IHFZ+5) = SN2
NY13=IHFZ+6
NY14=IHFZ+9
DO 1416 MM=NY13,NY14
1416 HRFRM2(MM) = SN4
1410 CONTINUE
WRITE(6,912) HRFRMZ
PARENT(10*ZMG + 11) = SN6
VRFRMZ(10*MFZ + 3) = SN5
VRPLSZ(10*MFZ + 3) = SN3
WRITE(6,1326) VRFRMZ
WRITE(6,1326) VRFRMZ
MAX = JROWS - 1
DO 1445 NY15=1,JROWS
I2=NY15 - 1
MAXM2 = MAX - 12
WRITE(6,1327) MAXM2,VRPLSZ
K1=0
DO 1430 J=1,NRMULT
IF(MAXM2 .NE. YSOURC(J)) GO TO 1430
K1 = K1 + 1
1430 CONTINUE
C  
1430 CONTINUE
C WRITING NUMBER OF SOURCES IN EACH Y-GRIDLINE: VN SOURCE(S)
C IF(K1 .GT. 0) WRITE(6,881) K1
DO 1445 NY16=1,10
IDECl=NY16 - 1
YLlNE = 10*(MAXM2 - IDECl) *10
IF(IDECl .GE. 1) WRITE(6,1326) VRFRMZ
C ILLUSTRATING MIXING DEPTH IN Y-Z FRAME:
C IF(ZMG .GT. 0) WRITE(6,1328) PARENT
DO 1440 IT=1,NRMULT
J0=0
1435 IF(PTABLEL(I1,J1) .EQ. 0) GO TO 1440
YINT = PTABLEL(I1,J1) *10 + 10.
5
IF(YINT .NE. YLINE) GO TO 1435
C ZINTPF = PTABLEL(I1,J,5) * 10 + .5
STRING(ZINTPF + 11 = SN1
GO TO 1435
C 1440 CONTINUE
C WRITE(6,1325) STRING
DO 1442 NST = 1,105
C 1442 STRING(NST) = BL
C 1445 CONTINUE
C WRITE(6,1) HRFRMZ
WRITE(6,912) HRFRMZ
C SECTION FOR OUTPRINTING GRID CONCENTRATIONS
C  SKIPPING CONCENTRATION PRINTING IF SPECIFIED IN PRIMDA.
    IF(ABC(9).EQ.0) GO TO 1600
C
1510 FORMAT(11H0, 49X, 17H PRINT OF CURRENT GRID CONCENTRATIONS ,/50X
1520 FORMAT(11H0, 49X, 32H GRID CONCENTRATION IN THE PLANE ,/51X, 3H = 6.2
1525 FORMAT(111, 8X, 10E10.2)
C
WRITE(6,1301)
WRITE(6,1510) ITOTIM
WRITE(6,1)

C  LOOP THRU ALL Z LEVELS
C
DO 1550 KC=1,KPLANS
   DEMKMI = DEL2*(KC-1)
   WRITE(6,1520) DEMKMI
   WRITE(6,1525) IC, IC = XS0, XLB
   PRINTING EACH LINE IN CONCENTRATION TABLE:
   DO 1560 JC = 1, JROWS
      JJC = JRCWS - JC
      JJC = JJJC + 1
      WRITE(6,1525) JJJC, CHI(IC, JCL, KC), IC = MSX, MFX
   DO 1551 IC=MSX, MFX
   DO 1551 IC=MFX, MSX
   1553 CPLOT(IC, JC)=CHI(IC, JCL, KC)

1560 CONTINUE
C
KC IS THE NO. OF LEVELS PRINTED...HERE CONTROLS WHICH
C LEVELS ARE CONTOURED.
C (KC < 0.1) CALL DRAW(CPLOT, 10, 17)
1550 CONTINUE
    WRITE(6,1)
    WRITE(6,1)
C
GO TO 1600
C
1590 FORMAT(95H PUFF POSITION PLOT AND GRID CONCENTRATION PRINTING AR
1595 WRITE(6,1590)
C
1600 CONTINUE
C END OF GRID CONCENTRATION PRINTING SECTION
C
C END OF OUTPRINT SECTION.
C
C 5000 CONTINUE
C END OF ADVECTION STEPS DURING CURRENT WIND FIELD SPECIFICATION
C
C END OF CALCULATION PART.
I = I + 2
IF(I GE 14) GO TO 1135
C RETURN FETCHING NEW ANGLE,SPEED:
GO TO 1150
C
C OUTPUT DIAGNOSTICS :
1000 FORMAT(37H X AND/OR Y COORDINATES OF SOURCE NR:15,12H IS OFF GRID)
1005 FORMAT(12H 0 FORMAT ERROR IN SECOND WINDFRA CARD;MISSING OR WRONG PL
1ACED #-CARACTER1)
1010 FORMAT(55H BAD SPECIFICATION OF PUFF RELEASE AND ADVECTION STEP,
15H TAU=15,6X7H NTADV=15)
1015 FORMAT(66H BAD SPECIFICATION OF WINDAVERAGING TIME AND ADVECTION S
1LTEP; 8H WINDAV=15,7X 7H NTADV=15)
1025 FORMAT(64H ERROR IN WINDDATA SPECIFICATION OF: *SPEED,"ANGLE, AFTER
1ER THE 16,24H STABILITY SPECIFICATION)
1030 FORMAT(86H MISSING STABILITY CLASS SPECIFICATION, THE LAST SPECIFI
1ED STABILITY CLASS NUMBER WAS 16)
1035 FORMAT(72H FORMAT ERROR IN SECOND PUFFDA-CARD; MISSING OR WRONG PL
1ACED #-CARACTER1)
1040 FORMAT(16H MISMATCH IN THE 15,22H SOURCE SPECIFICATION)
1045 FORMAT(12H SOURCE NR:15,72H HAS MORE THAN 100 CONTRIBUTING PUFFS
1 IN THE GRID. TAU MUST BE INCREASED.)
1050 FORMAT(47H MIXING LAYER DEPTH EXCEEDS 2 DIMENSION OF GRID)
1055 FORMAT(47H混合层深度超过网格的2维)
1060 FORMAT(47H MIXING LAYER DEPTH EXCEEDS 2 DIMENSION OF GRID)
C
C 8870 WRITE(6,1060)
GO TO 9999
C
C 8880 WRITE(6,1055)
GO TO 9999
C
C 8890 WRITE(6,1050)
GO TO 9999
C
C 8900 WRITE(6,1045) I
GO TO 9999
C
C 8910 WRITE(6,1040) I
GO TO 9999
C
C 8920 WRITE(6,1035)
GO TO 9999
8930 WRITE(6,1140)
   GO TO 9999
8940 NRMI = NRSTAB - 1
   WRITE(6,1030) NRMI
   GO TO 9999
8950 WRITE(6,1025) NRSTAB
   GO TO 9999
8970 WRITE(6,1015) WINDAV,NTADV
   GO TO 9999
8980 WRITE(6,1010) TAU,NTADV
   GO TO 9999
8990 WRITE(6,1005)
   GO TO 9999
9000 WRITE(6,1000) 1
C 9999 CONTINUE
   CALL EFRA ME
   STOP
   END

SUBROUTINE SIGRIS(HGN,SIGXY,SIGZ)

THE SUBROUTINE "SIGRIS" (SIGMA-RISE) CALCULATES THE INCREMENT
IN SIGMA-X AND SIGMA-Z DURING EACH BASIC ADEVIATION STEP.
FURTHER, THE SUBROUTINE ESTIMATES PLUME-RISE ASSOCIATED WITH
BOUYANCY IN THE EFFLUXES.

FOR Z-COORDINATES OF PUFFS: HEIGHT, GRID UNITS(N) : HGN
COMMON HEATFX(25),12,DMS,POINT,INTENS(14),STABPA,F8UFLX
1:UNN, CONSTI,DELZ
INTEGER POINT
REAL INTENS
C CALCULATING GROWTH RATES FOR SIGMA1: DSIGDS
C DEFINING EXPERIMENTAL FITTING CONSTANT: FITCST
FITCST = .20
DSIGDS = .22 * INTENS(POINT)
DSIGDS = DSIGDS + FITCST
SIGXY = SIGXY + DSIGDS * DMS
SIGZ = SIGZ + DSIGDS * DMS

C CALCULATING PLUME-RISE INCREMENT:
FI : BUOYANT FLUX FROM SOURCE I

AFTER BRIGGS:

F = 8.9 * M**2.5 * SEC**3 * Q < MWATT>

HEATFX(I) UNITS ARE KW

FI = 8.9 * 0.001 * HEATFX(I)

IF(STABPA.LE.0.0) GO TO 2501

MAXIMUM PLUME LIFT IN STABLE ATMOSPHERE; HSMAX:

HSMAXG = 2.9*(FI/(UNN*STABPA))**1.5 / DELZ

CONTINUE

CALCULATING PLUME HEIGHT AFTER FILFILLED ADVECTION STEP

MGRID=1+1: HGNP1 = HGN + CON1*SQRT(FI/HGN)/(DELZ*UNN)**1.5*OMS

IF(STABPA.LE.0.0) GO TO 2510

IF(HGNP1.GT.HSMAXG) GO TO 2520

CONTINUE

RETURN

END

SUBROUTINE ISPACE(ITENFT,INR)

THE SUBROUTINE "ISPACE" MAKES VARIABLE TABULATING POSSIBLE
IN CONNECTION WITH FRAMEPLOTS.

ITENFT: NUMBER OF TEN SPACES, THE FIGURE IN QUESTION HAS TO BE MOVED RIGHTMOST.

INR : INTEGER NUMBER TO BE PRINTED.

10 FORMAT(1H+19X,16)
20 FORMAT(1H+29X,16)
30 FORMAT(1H+39X,16)
40 FORMAT(1H+49X,16)
50 FORMAT(1H+59X,16)
60 FORMAT(1H+69X,16)
70 FORMAT(1H+79X,16)
80 FORMAT(1H+89X,16)
90 FORMAT(1H+99X,16)
100 FORMAT(1H+109X,16)

IF(ITENFT.NE.0) GO TO 1
WRITE(6,10) INR
IF(A1C, JC1) .EQ. 0.0) GO TO 1554
A1C, JC1) = ALOG10(A1C, JC1)
1554 CONTINUE
WRITE (6, 1555) (A1C, JC1), IC=1, M)
1555 FORMAT(5X, 10E10.2)
C
SMOOTH ARRAY
NM1 = N-1
NM1 = N-1
DO 200 J=1, N
TEMP = A(I,J)
DO 100 I=2, NM1
TEMP1 = A(I,J)
A(I,J) = .2*TEMP + 3.*TEMP1 + A(I+1, J))
TEMP = TEMP1
100 CONTINUE
200 CONTINUE
DO 400 J = 1, M
TEMP = A(I, J)
DO 300 I = 2, NM1
TEMP1 = A(I, J)
A(I, J) = .2*TEMP + 3.*TEMP1 + A(I, J+1))
TEMP = TEMP1
300 CONTINUE
400 CONTINUE
WRITE (6, 1559) (A(I, J), I=1, 10)
CALL SET (11, 3, 2, 58, 0.1, 0.1, 0.1, 1, 1)
CALL CONREC(4, 10, 10, 17, 0., 0., 1., -1, 1, 0)
CALL TICK4(5, 8, 8)
CALL PERIM9, 0, 16, 0)
CALL FRAME
RETURN
END
SUBROUTINE RSPACE(ITEMFT, RNR)
THIS SUBROUTINE HAS THE SAME PURPOSE FOR REAL FIGURES, AS
ISPACE HAS FOR INTEGER FIGURES.

RNR : REAL NUMBER TO BE PRINTED.

10 FORMAT(1H+, 19X, F6.1)
20 FORMAT(1H+, 29X, F6.1)
30 FORMAT(1H+, 39X, F6.1)
40 FORMAT(1H+, 49X, F6.1)
50 FORMAT('H+59X,F6.1')
60 FORMAT('H+69X,F6.1')
70 FORMAT('H+79X,F6.1')
80 FORMAT('H+89X,F6.1')
90 FORMAT('H+99X,F6.1')
100 FORMAT('H+109X,F6.1')

C C
IF(ITENFT.NE.0) GO TO 1
WRITE(6,10) RNR
RETURN
1 IF(ITENFT.NE.1) GO TO 2
WRITE(6,20) RNR
RETURN
2 IF(ITENFT.NE.2) GO TO 3
WRITE(6,30) RNR
RETURN
3 IF(ITENFT.NE.3) GO TO 4
WRITE(6,40) RNR
RETURN
4 IF(ITENFT.NE.4) GO TO 5
WRITE(6,50) RNR
RETURN
5 IF(ITENFT.NE.5) GO TO 6
WRITE(6,60) RNR
RETURN
6 IF(ITENFT.NE.6) GO TO 7
WRITE(6,70) RNR
RETURN
7 IF(ITENFT.NE.7) GO TO 8
WRITE(6,80) RNR
RETURN
8 IF(ITENFT.NE.8) GO TO 9
WRITE(6,90) RNR
RETURN
9 IF(ITENFT.NE.9) GO TO 1000
WRITE(6,10) RNR
1000 RETURN
END
//GO.FTOF001 DD *
12 3600 0 10 17 4 1
3600 40 90
PRIMDATA SEPT 29.81
217.50 435.00 40.00 1.00E-13 1.0000
YES
YES
YES
YES
YES
INST
//GO.FT02F001 DD UNIT=SYSDA,DISP=(OLD,DELETE),DSN=GFT02
//GO.FT03F001 DD *
STABILITY-DATA, SEPT 29 81
  1.0000
  80.00
//GO.FT04F001 DD *
INDIVIDUAL SOURCE DATA
  #018
    1    2    0    0    3600    6.04    15.07    4.0
//GO.SYSIN DD *
INTENSITY-DATA, SEPT 29 81
# 5#
 .2500 .1000 .0500 .0100 .0300
LIST OF REFERENCES


Mikkelsen, T., 1979: "Simulation of Obscuration Smoke Diffusion", Danish Defence Research Establishment/RISO, Physics Department, Meteorology Section (TD).


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