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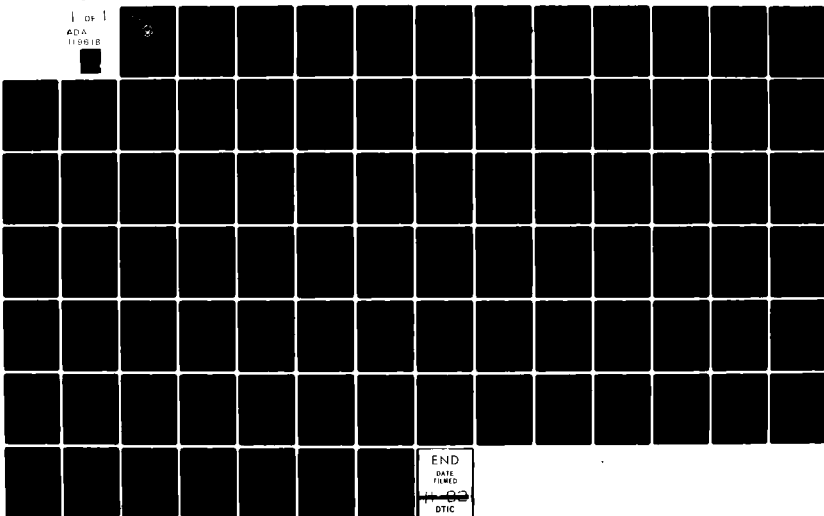
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AN ANALYSIS OF A PUFF DISPERSION
MODEL FOR A COASTAL REGION

by

Stephen K. Rinard

June 1982

Thesis Advisor:

G. E. Schacher

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An Analysis of a Puff Dispersion Model for a Coastal Region

by

Stephen K. Rinard
National Weather Service
B.S., Texas A&M University, 1964

Submitted in partial fulfillment of the
requirements for the degree of

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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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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

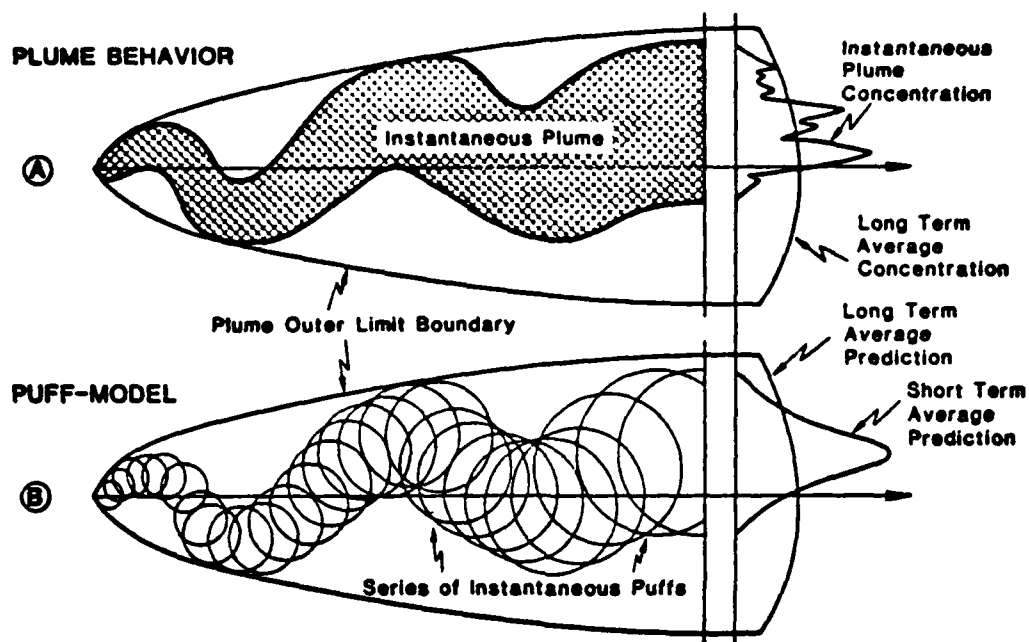


Figure 1. Instantaneous Behavior of a Typical Plume and a Series of Puffs from a Puff Model

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 run 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 (σ) of the wind direction (in radians) squared. The σ 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 warrent.

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 σ values and plume dispersion/diffusion. While these characteristics are

representative 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) Acania. 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.

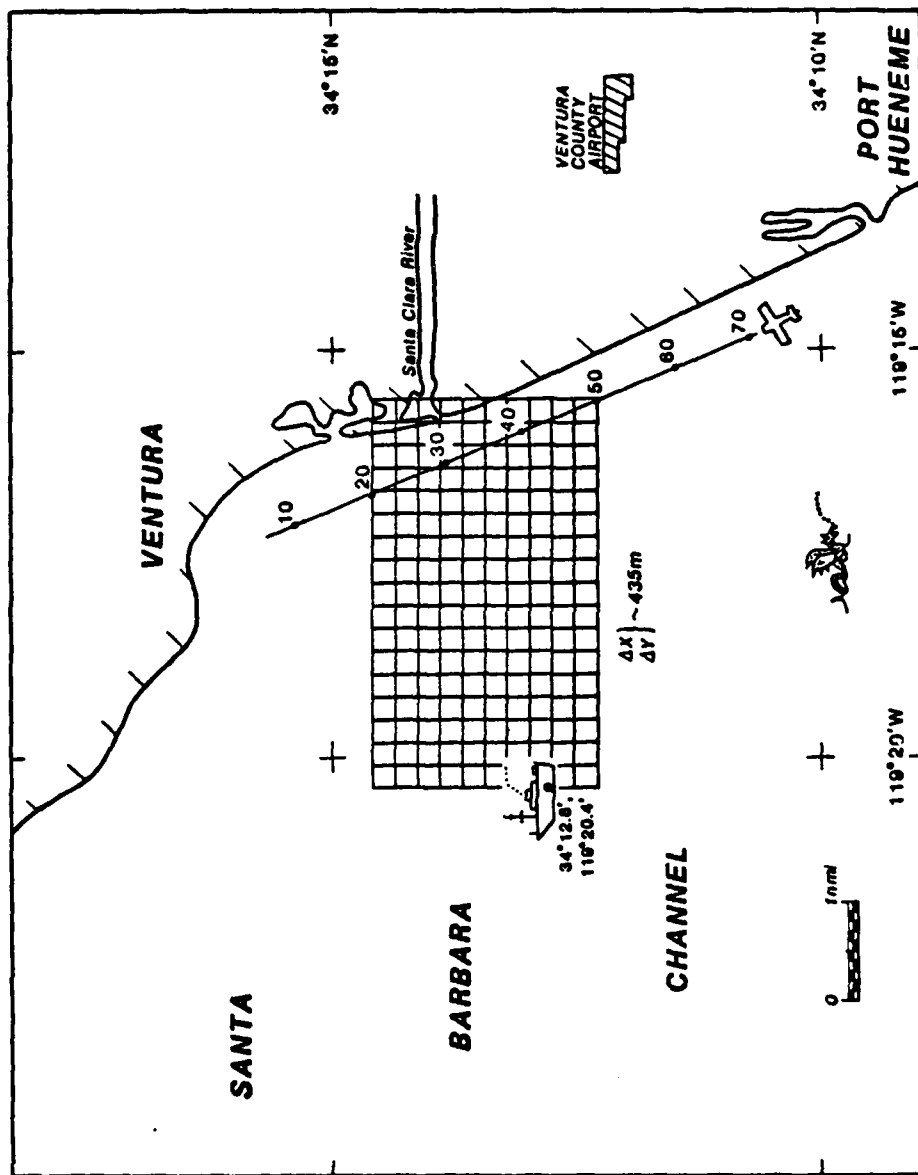


Figure 2. Experimental Area showing Locations of R/V Acacia, Aircraft track and Numerical Grid.

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 | • air temperature |
| • wind speed fluctuation | • dew point |
| • sea surface temperature | • ship roll |
| • sky cloud cover | • ship location |
| • relative wind direction | |
| • inversion height (acoustic sounder) | |
| • vertical temperature and humidity profiles | |

(shipboard radiosonde launch every 12 hours).

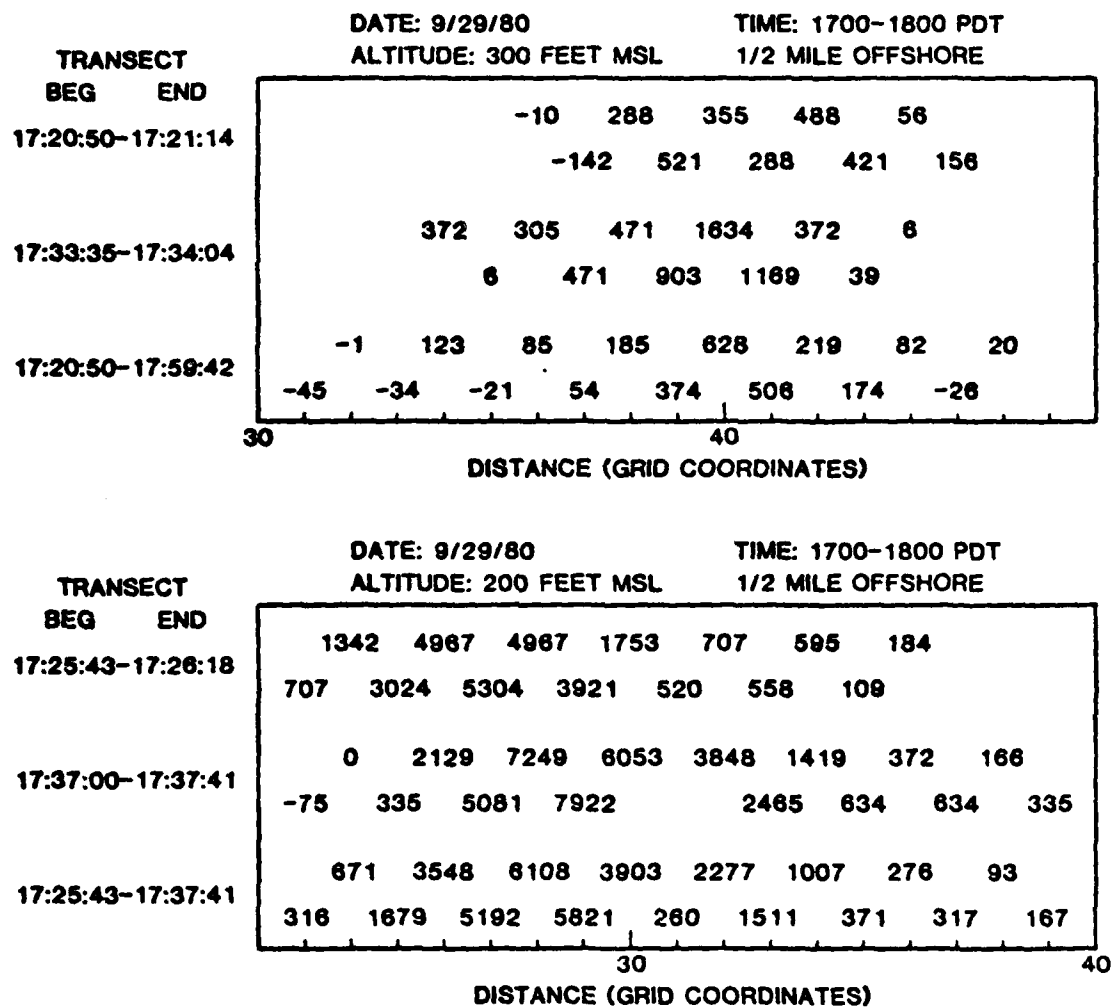


Figure 3. Aircraft observed Plume Concentrations (PPT) at Grid Coordinates at 61 and 91 m above MSL, 29 September 1980.

The tracer gas was released at a fixed rate through the exhaust of one of the ships 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 ms^{-1} . The first advected puffs would be expected to arrive at the back edge of the grid slightly before 1700, 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 (σ) 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 σ values during the time of interest were 1.0 and 0.9 resulting in the very small turbulence intensity values of .0003 and .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 ships stack were taken from Schacher, et al (1981). As previously mentioned, SF_6 gas was released through the ships motor generator exhaust at a constant rate. The stack temperature was 250 deg F, the flow rate was $7.13 \times 10^3 \text{ m}^3 \text{ s}^{-1}$. The SF_6 release rate was 47.91 lb hr^{-1} . The top of the ships 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

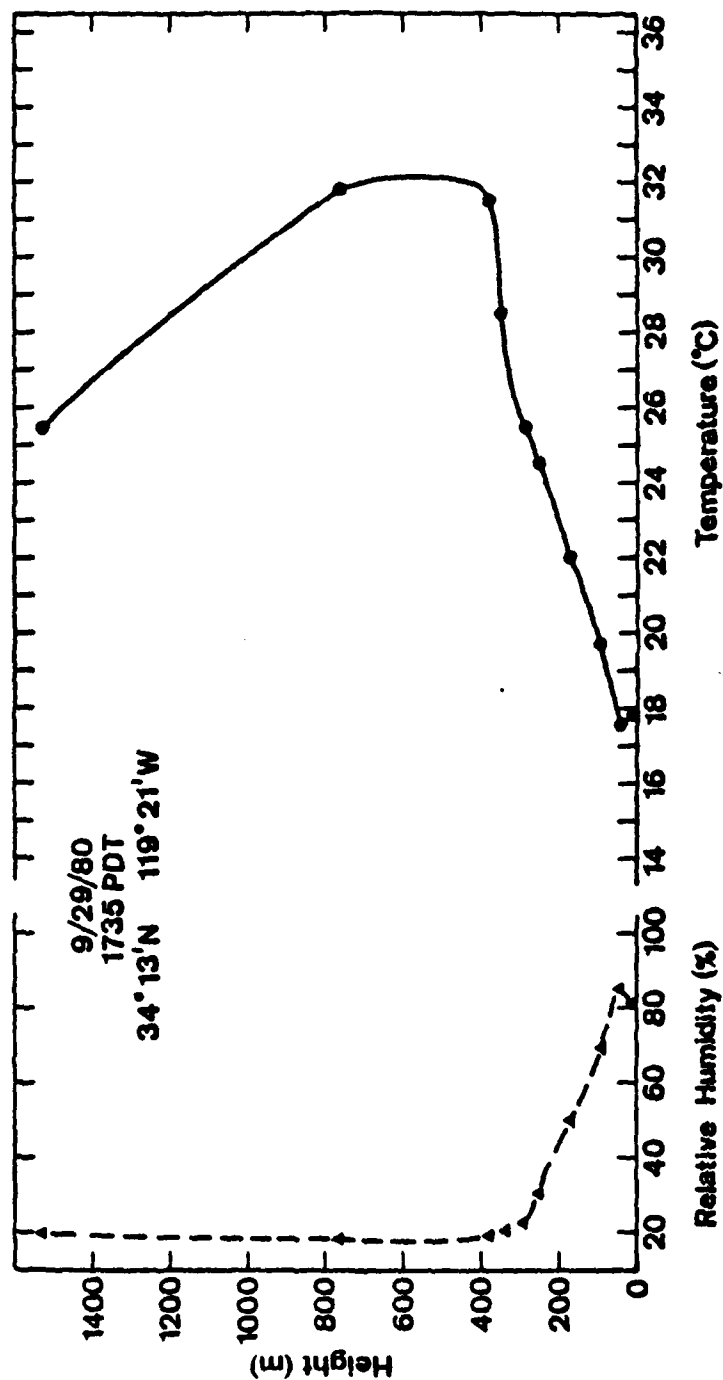


Figure 4. Radiosonde sounding taken onboard R/V Acania, 1745 PDT, September 29, 1981.

$$H = \Delta T * \frac{P}{RT} * C_p * \text{Flow} \quad (2)$$

where

delta T = temperature (stack - air) deg K

R = dry air gas constant

= 2.87×10^6 erg/g deg K

P = $10^3 * P(\text{mb})$ = dyne/cm²

C_p = specific heat of dry air

= .24 cal/g deg K

Flow = $16.39 * 7.13 * 10^3$ cm³/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 1×10^{-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.

Turbulence Intensity	Delta Y	(4)	(5)	(6)	(7)	Sfc 40 m 80 m
.01	108.75	.68E-10 .31E-10 .47E-11	.16E-4 .70E-5 .11E-5	.22E-4 .10E-4 .15E-5	.20E-9 .91E-10 .14E-10	
.01	217.5	(4) .69E-10 .31E-10 .47E-11	(5) .22E-4 .10E-4 .15E-5			
.01	435	(6) .69E-10 .31E-10 .47E-11				
.02	435	(6) .19E-5 .17E-5 .12E-5			(7) .56E-8 .50E-8 .37E-8	
.03	435	(6) .66E-5 .67E-5 .62E-5			(7) .48E-6 .49E-6 .45E-6	
.05	435	(5) .57E-8 .59E-8 .58E-8	(6) .72E-5 .74E-5 .72E-5		(7) .26E-5 .27E-5 .26E-5	(8) .28E-9 .29E-9 .29E-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.

DELTA Y (m)	Grid Points Along the Y Axis											
435	4		5		6		7		8		9	
217.5	0	1	2	3	4	5	6	7	8	9		
108.75			0	1	2	3	4	5	6	7	8	9

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 a 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 ΔZ . 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 "REFLEC". 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.

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

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 predominantly 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 $1. \times 10^{13}$ and then taking the logarithm. These logarithms are then smoothed. Thus, a contour plot representing order of magnitude concentrations was 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

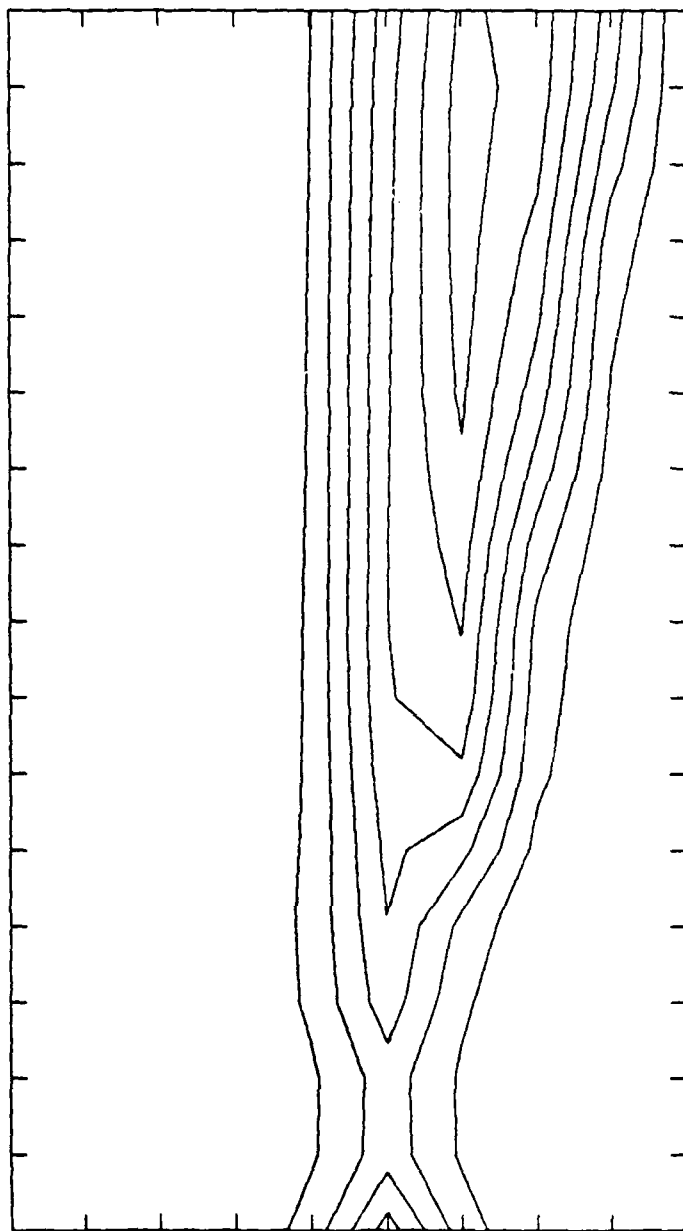


Figure 5. Orders of Magnitude of Plume Concentration with Turbulence Intensity equal to .05.

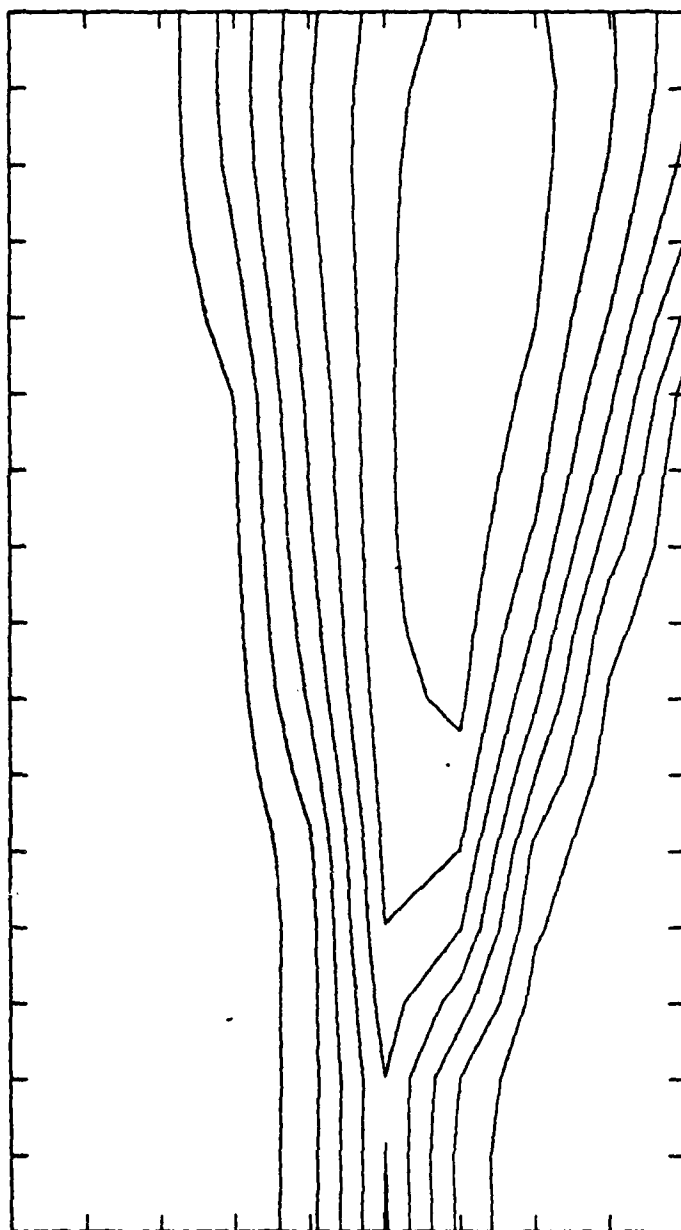


Figure 6. Same as Figure 5 except Turbulence Intensity equal to .10.

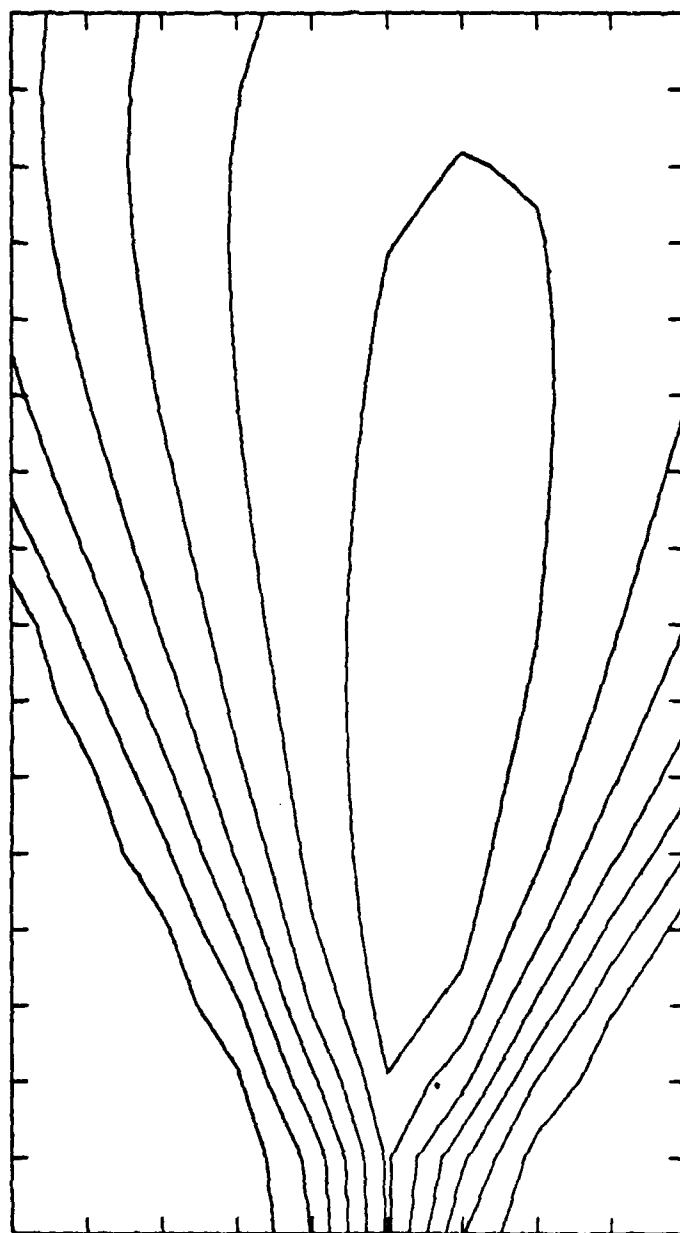


Figure 7. Same as Figure 5 except Turbulence Intensity equal to .25.

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. 8, from Mikkelsen (1979), showing the relationship between the puff size and concentration, the rate of puff release (τU) and the advecting wind speed U .

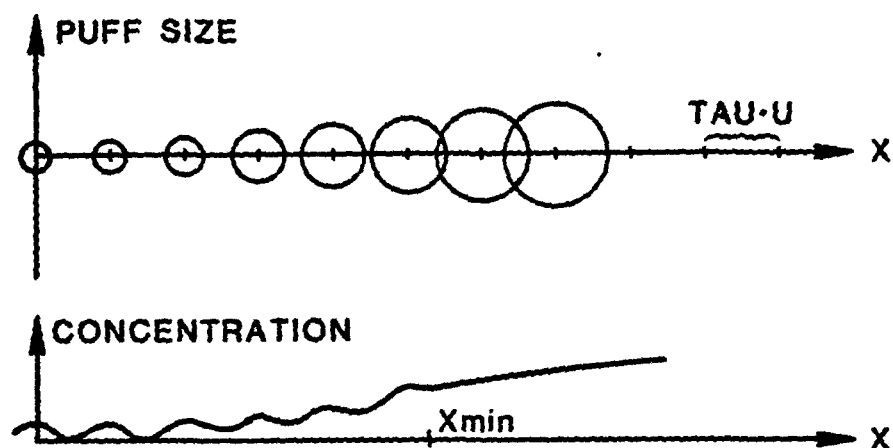


Figure 8. Relationship between Puff Size, Concentration, Puff Release Rate (τU) and Advecting Wind Speed U (Mikkelsen, 1979).

Puffs would have to travel the distance X_{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_{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_{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 SF_6 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

$\text{g/m}^3 = (.63 \times 10^{-11}) \times \text{observed concentration (PPT)}$
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 $.63 \times 10^{-9}$ and $.50 \times 10^{-7} \text{ g/m}^3$. 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^{-6} --closer to the observed concentrations. (This would require the wind direction standard deviation to increase from 1 to 28). 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 ΔZ . More flexibility in this parameter to include any level, regardless of ΔZ , 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 IV

Input Data Variables for the Puff Dispersion Model.

Wind History	Potential Temperature Gradient
Turbulence Intensity	Buoyant Heat Flux
Grid Dimensions	Minimum Concentration of Interest
Mixing Depth	Reflection at Ground Level
Source Locations, Start/Stop Time, Strength, Heat Emission	
Number of Seconds between Advection Steps	
Number of Seconds between Printouts/Plots	
Number of Seconds between Puff Releases	

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.

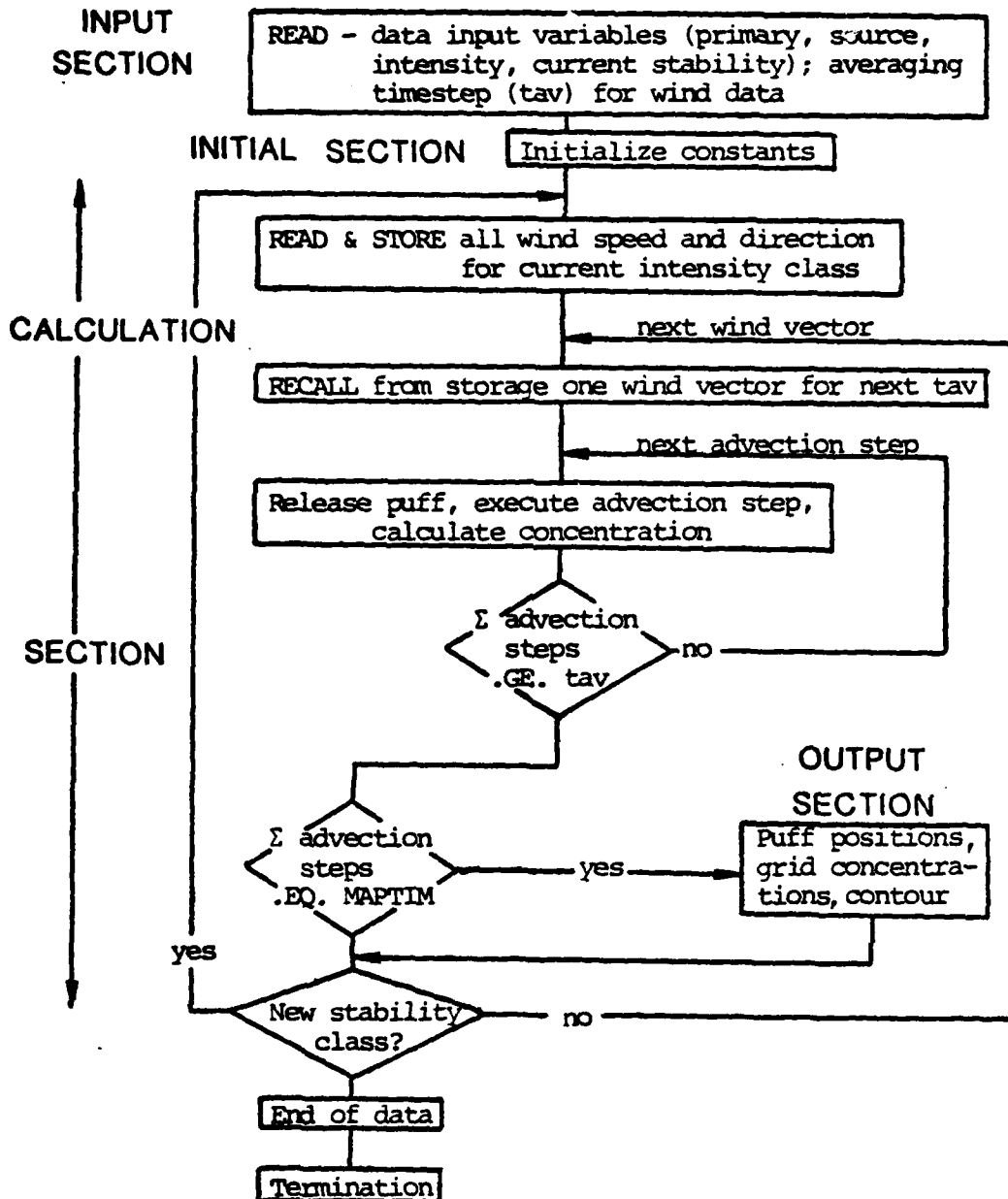
F. SUBROUTINES

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 a logarithmic values, smoothes and then contours them using NPS inhouse contour subroutines. The values are converted to their logarithm values so that the problem of contouring over many orders of magnitude is simplified.

APPENDIX B
PUFF MODEL FLOW CHART



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) (.GE. 0)

HEAT--Individual source heat emission (KW)

ICOLS--Number of columns in grid (.LE. 10)

INST--Instantaneous concentration matrix

ITIME--Start time

JROWS--Number of rows in grid

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

MAPTIM--Number of seconds between printer plots

NRELSE--Number of seconds to stop of release

NRMULT--Number of sources (.LE. 25)

NTADV--Integer number of seconds between advection steps

REFLEC--Reflection at ground level (0. none;1.0 total)

SOURNR--Number to identify source

SOURST--Strength for individual source (gm/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

ZN--Limited mixing depth (m)

LISTING OF PUFF MODEL COMPUTER CODE

```

// EXEC PGM=IEBGENER
// SYSPRINT DD DUMMY
// SYSIN DD DUMMY
// SYSUT2 DD UNIT=SYSDA, DISP=(NEW,PASS),
// DCB=(RECFM=FB,LRECL=80,BLKSIZE=6400),
// SPACE=(TRK,(1,1)),DSN=ZFT02
// SYSUT1 DD *
// WINDATA SEPT 29 81
// 0810929 1630 #1800#
//D
// 085*04.7" 085*04.8
//
// EXEC FRTXCLGN,NAME=CONRECQC
// FORT.SYSIN DD DUMMY
// FORT.SYSIN DD *
// CCFILE1(KIND=DISK,TITLE='PRIMDA',FILETYPE=
// CCFILE2(KIND=DISK,TITLE='VINDDA',FILETYPE=
// CCFILE3(KIND=DISK,TITLE='STABDA',FILETYPE=
// CCFILE4(KIND=DISK,TITLE='SOURCEDA',FILETYPE=
// CCFILE5(KIND=DISK,TITLE='INTSDA',FILETYPE=
// PRINT(KIND=PRINTER,FILETYPE=7)
// CCFILE6(KIND=PRINTER,FILETYPE=7)

```

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

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

```
COMMON HEATFX(25), I2,DMS,POINT,INTENS(14),STABPA,FBUFLX
1 SPEED,CONST1,DEL2,ANGLE,XSB,XLB,YSB,YLB,ZSB,ZLB,YINT,XINT
1 INTEGER TAU,POINT,WINDOW,TOTIM,SUMPUF,SOURNR,TPUFFS(25),XINT
1 ZMG,ZINTPF,WINDAY,YSOURCE(25),SIRTRL(25),STOPRL(25)
```

```
LOGICAL LINE, COINCD, NOMXDP, GRRFLX      PUF00410
DIMENSION STRING(105), HORFRM(105), VERFRM(105), VRFRMZ(105), VRFRMZ(105) PUF00420
105), VERPLS(105), VRPLSZ(105), PARENT(105), NBUF(7), SBUF(7) PUF00430
REAL BL(105), SN1(105), SN2(105), SN3(105), SN4(105), SN5(105), SN6(105), PUF00440
```

PUF00010
PUF00020
PUF00030
PUF00040
PUF00050
PUF00060
PUF00070
PUF00160
PUF00170
PUF00180
PU00190
PU00200
UF00210
PUF00220
PUF00230
PUF00240
PUF00250

PUF00280
PUF00310
PUF00320
PUF00340
PUF00350
PUF00360
PUF00370
PUF00380
UF00390

PUF00410
PUF00420
PUF00430
PUF00440


```

C      DO 934 J = 1,NRMULT
      IF (MAX-I.NE.YSOURC(J)) GO TO 934
      WRITE(6,914) VERFRM
      CALL ISPACE(XSOURC(J),STOPRL(J))
      CONTINUE
934    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))
      CONTINUE
940    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))
      CONTINUE
930    WRITE(6,913) VERFRM,VERFRM
C
      CONTINUE
      WRITE(6,1)
      WRITE(6,912) HORFRM
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
      INPUT FROM INTENSITY - DATA: INTSDA
C
960    FORMAT(14,F5.4)
965    FORMAT(1H0, 46H IN THE CURRENT RUN, THE STABILITY-CLASSES ARE, /41H
      CONNECTED TO INTENSITY DATA AS FOLLOWS:)
970    FORMAT(1H, 21H STABILITY CLASS NO.: ,13,1315)
975    FORMAT(1H, 21H INTENSITY DATA
      : , 14F5.4)
C
      READ INTSDA TITLE-STRING:
      READ(5,30) INSTX
      WRITE(6,30) INSTX
      READ INTSDA, NO OF INTENSITY-CLASSES: NRINCL
      READ(5,800) ABC(3),NRINCL,ABC(4)
      WRITE(6,802) NRINCL
      INPUT FORMATE TESTING:

```

```

PUF02420
PUF02430
PUF02440
PUF02450
PUF02460
PUF02470
PUF02480
PUF02490
PUF02500
PUF02510
PUF02520
PUF02530
PUF02540
PUF02550
PUF02560
PUF02570
PUF02580
PUF02590
PUF02600
PUF02610
PUF02620
PUF02630
PUF02640
PUF02660
PUF02670
PUF02680
PUF02700
PUF02710
PUF02720
PUF02730
PUF02740
PUF02750
PUF02760
PUF02770
PUF02780
PUF02790
PUF02800
PUF02810
PUF02820
PUF02830
PUF02840
PUF02850

PUF02870
PUF02880
PUF02890

```

```

802 FORMAT(IX,I5)
   IF(ABC(3).NE.AA.OR:ABC(4).NE.AA) GO TO 8890
   READ INTENSITY-CLASSES INTO REAL ARRAY: INTENS
   READ(5,960,END=801) (INTENS(I),I=1, NRINCL)
   WRITE(6,960) (INTENS(I),I=1, NRINCL)

   OUTPRINTING CURRENT INTENSITY CLASSES:

   SKIP PRINTING OF INTENSITY DATA IF SPECIFIED IN PRIMDA
801 IF(ABC(7).EQ. NO ) GO TO 980
   WRITE(6,2) INTSTX
   WRITE(6,35) INTSTX
   WRITE(6,1)
   WRITE(6,965) (I,I=1, NRINCL)
   WRITE(6,970) (INTENS(I),I=1, NRINCL)
   WRITE(6,1)
   WRITE(6,1)
980 CONTINUE

   END OF INTENSITY DATA SECTION.

   INPUT FROM STABILITY DATA: STABDA

   READ STABDA, IITLESTRING:
   READ(3,30) STABTX
   READ STABDA, POTENTIAL TEMPERATURE GRADIENT (>0).
   READ(3,889) DTDZ
   READ STABDA, LIMIT OF MIXING DEPTH: ZM (METERS).
   READ(3,992) ZM
   INDATA-TEST ON ZM:
   IF(AMOD(ZM,DELTZ).NE. 0.) GO TO 8880

   OUTPRINTING CURRENT STABILITY-DATA:
889 FORMAT(F10.4)
991 FORMAT(1H0,45H IN THE CURRENT RUN, THE POTENTIAL TEMPERATURE/21H
   RADIANT IS SET TO:, F10.4)
992 FORMAT(F10.2)
993 FORMAT(1H0,36H NO FINAL MIXING DEPTH IS SPECIFIED.)
994 FORMAT(1H0,32H THE MIXING LAYER IS LIMITED AT:, F10.2, 8H METERS.)
   WRITE(6,1)
   WRITE(6,1)
   WRITE(6,35) STABTX
   WRITE(6,1)
   WRITE(6,1)
   WRITE(6,1)
   WRITE(6,1)
   WRITE(6,991) DTDZ
   WRITE(6,1)

```

```

PUF02900
PUF02910
PUF02920
PUF02930
PUF02940
PUF02950
PUF02970
PUF02980
PUF02990
PUF03000
PUF03010
PUF03020
PUF03030
PUF03040
PUF03050
PUF03060
PUF03070
PUF03080
PUF03100
PUF03110
PUF03120
PUF03140
PUF03150
PUF03160
PUF03170
PUF03180
PUF03200
PUF03210
PUF03220
GPUF03230
PUF03240
PUF03250
PUF03260
PUF03270
PUF03280
PUF03290
PUF03300
PUF03310
PUF03320
PUF03330
PUF03340
PUF03350

```



```

C      NUMBER OF PUFF RELEASES PER SEC: TAUINVERS.
C      TAUINV = 1.0/ FLOAT(TAU)
C      NUMBER OF ADVECTION STEPS PER SEC.: ADSTPS.
C      ADSTPS = 1.0/ FLOAT(NTADV)
C      BASIC DOSE PER PUFF: (GRAM/SEC.)*TAU = GRAM/PJFF.
C      BADOPP = 1*TAU
C      NUMBER OF BASIC ADVECTION STEPS (INTEGER NUMBER) PER PUFF RELEASE:
C      NADPRP = TAU/NTADV
C      NUMBER OF BASIC ADVECTION STEPS (INTEGER NUMBER) PER WINDFIELDSP.
C      NADPRW= WINDAV/NTADV
C
C      TOTAL RUNTIME COUNTER: TOTTIM.
C      TOTTIM = 0
C
C      COUNTER FOR REMOVED PUFFS: LEAVE
C      LEAVE = 0
C      STABILITY PARAMETER FOR PLUMERISE:
C      STABPA = G/T*(DIHETE/DZ)
C      STABPA = .033*DTDZ
C      CONSTANT IN CONNECTION WITH PLUMERISE FORMULA = OR USE IN
C      SUBROUTINE SIGRIS: CONST1
C      CONST1 = 0.6667 * 1.6**1.5
C
C      IF MIXING DEPTH IS NOT SPECIFIED, SET NOMXDP = .TRUE.
C      IF (ZM .EQ. 0.) NOMXDP = .TRUE.
C
C      IF REFLECTANCE AT GROUND LEVEL IS SPECIFIED, SET GRRFLX = .TRUE.
C      IF (REFLEC.GT. 0.) GRRFLX = .TRUE.
C      MIXING DEPTH IN GRID-UNITS: ZMG
C      ZMG = ZM/DELZ
C      TESTING THAT MIXING DEPTH IS INSIDE GRID:
C      IF (ZMG .GT. (KPLANS -1)) GO TO 8870
C
C      END OF INITIAL SECTION
C
C      *****
C      ***** CALCULATION SECTION *****
C      *****
C      1135 READ (2,1130) ( TYPE(I),DATA(I) , I = 1,14)

```

```

PUF03860
PUF03870
PUF03880
PUF03890
PUF03900
PUF03910
PUF03920
PUF03930
PUF03940
PUF03950
PUF03960
PUF03970
PUF03980
PUF03990
PUF04000
PUF04010
PUF04020
PUF04030
PUF04040
PUF04050
PUF04060
PUF04070
PUF04080
PUF04090
PUF04100
PUF04110
PUF04120
PUF04130
PUF04140
PUF04160
PUF04170
PUF04190
PUF04210
PUF04220
PUF04230
PUF04240
PUF04250
PUF04260
PUF04270
PUF04280
PUF04290
PUF04300
PUF04310
PUF04320
PUF04330

```

```

BACKSPACE 2
IF (TYPE(1).EQ.ANFO) READ(2,1131)(NBUF(1),SBUF(1),I=1,7)
IF (TYPE(1).EQ.ANFO) WRITE(6,1131)(NBUF(1),SBUF(1),I=1,7)
IF (TYPE(1).EQ.SLASH) READ(2,1130)
1131 FORMAT(7I4,1X,F4,1)
C LOOP THRU WINDDATA AT SPECIFIED TIMESTEPS
I = 1
IF (TYPE(1).NE.SLASH) GO TO 1150
NRSTAB = NRSTAB + 1
C
C COUNTING NUMBER OF WINDDATA SPECIFICATIONS: IWDASP
IWDASP = 0
C READING STABILITY CATEGORY FROM WINDDATA:
CLASS = DATA(1)
IF (CLASS.EQ. A ) POINT = 1
IF (CLASS.EQ. B ) POINT = 2
IF (CLASS.EQ. C ) POINT = 3
IF (CLASS.EQ. D ) POINT = 4
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(6,1)
1141 FORMAT(4H THE,13,38H. STABILITY SPECIFICATION :LASS IS NO.,11)
GO TO 1135
C INPUT STRUCTURE TEST:
1150 IF (TYPE(1).NE.ANFO .OR. TYPE(1+1).NE.ASTER) GO TO 1160
C
C IWDASP = IWDASP + 1
C CURRENT WINDDATA:
JI = (I+1)/2
ANGLE = NBUF(JI)
SPEED = SBUF(JI)
GO TO 1175
1160 IF (TYPE(1).NE.BLANK .OR. TYPE(1+1).NE.BLANK) GO TO 8950
C READ NEW DATA IN LINE 1135
GO TO 1135
C INDATA PART OF PROGRAM TERMINATED.
1175 CONTINUE
C
C CURRENT WINDDATA PRESENT.
C
C OUTPRINTING CURRENT WINDDATA:
WRITE(6,1161) IWDASP ,ANGLE, SPEED
C

```

PUF04350
 PUF04360
 PUF04370
 PUF04380
 PUF04390
 PUF04400
 PUF04410
 PUF04420
 PUF04430
 PUF04440
 PUF04450
 PUF04460
 PUF04470
 PUF04480
 PUF04490
 PUF04500

 PUF04530
 PUF04540
 PUF04550
 PUF04560
 PUF04570
 PUF04580
 PUF04590
 PUF04600
 PUF04610
 PUF04620
 PUF04630
 PUF04640
 PUF04650
 PUF04660
 PUF04670
 PUF04680
 PUF04690
 PUF04700
 PUF04710
 PUF04720
 PUF04730
 PUF04740
 PUF04750
 PUF04760
 PUF04770
 PUF04780

```

C C CALCULATING WIND VELOCITY IN GRID UNITS: VGX,VGY
C C VGX = SPEED*(COS(ANGLE*3.142/180)) / DELX
C C VGY = SPEED*(SIN(ANGLE*3.142/180)) / DELY
C C RENAMING WIND AVERAGING TIME:WINDAV AS TAV:
C C TAV = WINDAV
C C 1161 FORMAT(4H THE, I4, 49H WINDDATASET IN THE CURRENT STAB.CLASS IS: ANG
C C 1161 LE=, I4, 8H , SPEED=, F4.1)
C C LOOP THRU BASIC ADVECTION STEPS WITH CURRENT WIND FIELD
C C DO 5000 NN=1,NADPRW
C C JUMPING OVER "ZERO-SETTING" OF CONCENTRATION MATRIX : CHI , IF
C C "DOSE MODE" IS SPECIFIED IN PRIMDA.
C C IF(ABC(8).EQ. DOSE ) GO TO 1256
C C DO 1255 IG=1,ICOLS
C C DO 1255 JG=1,JROWS
C C DO 1255 KG=1,KPLANS
C C 1255 CHI(IG,JG,KG) = 0.0
C C 1256 CONTINUE
C C TIMECOUNTER:TOTTIM (SEC.)
C C TOTTIM = TOTTIM + NIADV
C C SKIPPING RELEASE-SECTION IF SPECIFIED
C C IF(TOTTIM.GT. NRELS) GO TO 1250
C C TESTING IF RELEASE CONDITIONS ARE FULFILLED
C C IF(MOD(TOTTIM,TAU) .NE. 0) GO TO 1250
C C LOOP THRU MULTIPLE SOURCES
C C DO 1250 I2 = 1,NRMULT
C C INDIVIDUAL RELEASE CONTROL AS SPECIFIED IN SOURCE DATA:
C C IF((TOTTIM.LT.STRTRL(I2)).OR. (TOTTIM.GT.STRPRL(I2))) GO TO 1250
C C TOTAL NUMBER RELEASED FROM SOURCE(I2): TPUFFS(I2):
C C TPUFFS(I2) = TPUFFS(I2) + 1
C C SHIFTING PUFF TABLE ONE POSITION TO THE RIGHT AND THEREBY
C C GIVING SPACE FOR ONE NEW PUFF:
C C J=1
C C 1204 DO 1205 K=1,7
C C 1205 SHIF1(J+1,K) = PTABEL(I2,J,K)
C C J = J + 1

```

```

PUF04790
PUF04800
PUF04810
PUF04820
PUF04830
PUF04840
PUF04850
PUF04860
PUF04870
PUF04880
PUF04900
PUF04920
PUF04940
PUF04950
PUF04960
PUF04970
PUF04980
PUF04990
PUF05000
PUF05010
PUF05020
PUF05030
PUF05040
PUF05050
PUF05060
PUF05080
PUF05090
PUF05100
PUF05110
PUF05130
PUF05140
PUF05150
PUF05170
PUF05180
PUF05190
PUF05200
PUF05210
PUF05220
PUF05230
PUF05240
PUF05250
PUF05260
PUF05270
PUF05280
PUF05290

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```

C 1209 DO 1210 K = 1,7
C 1210 PTABEL(12,L,K) = SHIFT(L,K)
C
C      INSERTING NEW PUFF DATA IN PUFF TABLE AT J = 1
C      PTABEL(12,1,1) = TPUFFS(12)
C      DOSE RELEASED WITH EACH PUFF: SPECIFIED SOURCE STRENGTH*SEC.
C      BETWEEN RELEASES
C      PTABEL(12,1,2) = SOURST(12) * TAU
C
C      LOADING IN INITIAL SOURCE POSITIONS
C      PTABEL(12,1,3) = XSOURC(12)
C      PTABEL(12,1,4) = YSOURC(12)
C
C      TO AVOID NUMERICAL PROBLEMS IN ESTIMATING PLUME RISE,
C      SET S0HT(12) (SOURCE HEIGHT) .GE. 1 METER.
C      PTABEL(12,1,5) = S0HT(12)/DELZ
C      INITIAL SIZE OF PUFFS:
C      SIGMAXY SET TO 1 METER:
C      PTABEL(12,1,6) = 1
C      SIGMAZ SET TO 1 METER:
C      PTABEL(12,1,7) = 1
C      END OF PUFF RELEASE SECTION.
C 1250 CONTINUE
C
C      ADVECTION OF ALL PUFF CENTERS
C
C      ADVANCE OF PUFF CENTERS IN GRID UNITS (HORIZONTALLY)
C      DGX = VGX*NTADV
C      DGY = VGY*NTADV
C      TOTALY TRAVELED DISTANCE BY THE PUFFS IN METERS
C      DURING CURRENT BASIC ADVECTION STEP: DMS
C      DMS = SQR((DGX*DELX)**2 + (DGY*DELY)**2)
C
C      ADVECTION SECTION FOR ALL EXISTING PUFFS:
C      LOOP THRU ALL SOURCES, COUNTING REMOVED PUFFS:LEAVE
C      DO 1300 I2 = 1, NRMULT
C      J = 1
C      SKIPPING SOURCE I2, IF THE LAST BORN PUFF HAS LEFT GRID
C      IF (PTABEL(12,1,1).EQ.0) GO TO 1300
C      PTBL3 = PTABEL(12,J,3) + DGX
C      PTBL4 = PTABEL(12,J,4) + DGY
C 1260
C
C      CALLING SUBROUTINE "SIGRIS" THEREBY ADDING DEVIATION INCREMENT
C      AND PLUME RISE INCREMENT TO PUFF TABLE:

```

PUF 05300
 PUF 05310
 PUF 05320
 PUF 05330
 PUF 05340
 PUF 05350
 PUF 05380
 PUF 05390
 PUF 05410
 PUF 05420
 PUF 05430
 PUF 05440
 PUF 05450
 PUF 05460

PUF 05500
 PUF 05510
 PUF 05520
 PUF 05530
 PUF 05540
 PUF 05550
 PUF 05560
 PUF 05570
 PUF 05580

PUF 05630
 PUF 05650
 PUF 05660

PUF 05680
 PUF 05690
 PUF 05700
 PUF 05720
 PUF 05730
 PUF 05740
 PUF 05750

PUF 05770
 PUF 05780
 PUF 05790
 PUF 05800
 PUF 05840
 PUF 05850
 PUF 05860

```

C      PTABEL(I2,J,5): Z-POSITION IN GRIDUNITS
C      PTABEL(I2,J,6): SIGMAX IN METERS
C      PTABEL(I2,J,7): SIGMAZ IN METERS
C      CALL SIGRIS(PTABEL(I2,J,5),PTABEL(I2,J,6),PTABEL(I2,J,7))
C      INTRODUCING AN UPPER LIMIT FOR BUOYANCY CONVECTION: ZM
C      IF(.NOT.NOMXDP.AND.PTABEL(I2,J,5).GT.ZMG) PTABEL(I2,J,5) = ZMG
C
C      Z - POSITIONS IN GRIDUNITS: PTBL5
C      PTBL5 = PTABEL(I2,J,5)
C
C      TESTING AND REMOVING PUFFS WHICH HAVE LEFT THE GRID:
C      IF(PTBL3.GT.XSB.AND.PTBL3.LT.XLB.AND.PTBL4.GT.YBB.AND.PTBL4.LE.YL
C      1L.AND.PTBL5.LT.ZLB) GO TO 1290
C
C      REMOVE SECTION
C      LEAVE = LEAVE + 1
C      IF(PTABEL(I2,J+1,1).EQ.0) GO TO 1265
C      REMOVING PUFF BORN AT SOURCE I2 WHICH IS NOT THE LONGEST LIVING:
C      LEFT JUSTIFICATION OF OLDER PUFFS:
C      JJ = J + 1
C      1269 DO 1270 K = 1,7
C      1270 SHIFT(JJ,K) = PTABEL(I2,JJ,K)
C      JJ = JJ + 1
C      IF(PTABEL(I2,JJ,1).NE.0) GO TO 1269
C      SHIFT(JJ,1) = 0
C      JMAX = JJ
C      COPY SHIFT BACK INTO PTABEL:
C      NY7 = JMAX - 1
C      DO 1275 JJ = J, NY7
C      DO 1275 K = 1,7
C      1275 PTABEL(I2,JJ,K) = SHIFT(JJ+1,K)
C
C      RETURNING TO INCREMENTAL PART WITHOUT INCREASE IN J:
C      GO TO 1260
C
C      REMOVING LONGEST LIVING PUFF FROM SOURCE(I2):
C      1265 PTABEL(I2,J,1) = 0
C      CONTINUING WITH NEXT SOURCE
C      GO TO 1300
C
C      REPLACING NEW PUFF POSITION IN PUFF TABLE
C      1290 PTABEL(I2,J,3) = PTBL3
C      PTABEL(I2,J,4) = PTBL4
C
C      CALCULATING GRID CONCENTRATION IN EACH BASIC ADVECTION STEP

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PUF05870
 PUF05880
 PUF05890
 PUF05900
 PUF05910
 PUF05920
 PUF05930
 PUF05940
 PUF05950
 PUF05960
 PUF05970
 PUF05980
 PUF05990
 PUF06000
 PUF06010
 PUF06020
 PUF06030
 PUF06040
 PUF06050
 PUF06060
 PUF06070
 PUF06080
 PUF06090
 PUF06100
 PUF06110
 PUF06120
 PUF06130
 PUF06140
 PUF06150
 PUF06160
 PUF06170
 PUF06180

PUF06200
 PUF06210
 PUF06220
 PUF06230
 PUF06240
 PUF06250
 PUF06260
 PUF06270
 PUF06280
 PUF06290
 PUF06300
 PUF06310
 PUF06320
 PUF06330
 PUF06340
 PUF06350
 PUF06360
 PUF06370
 PUF06380
 PUF06390
 PUF06400
 PUF06410
 PUF06420

```

C C RENAMING ESSENTIAL PARAMETERS:
C C DOSE IN CURRENT PUFF:
C C Q1 = PTABEL(I2,J,2)
C C SIGMA VALUES IN METERS:
C C SIGMXY = PTABEL(I2,J,6)
C C SIGMZ = PTABEL(I2,J,7)
C C CALCULATING MAXIMUM CONCENTRATION IN EACH PUFF CENTER
C C (PUFF-CHI-CENTER) ; IN DIMENSION: GRAM/M**3 :
C C CONSTANT : (2*PHI)**(3/2)
C C CONST = 15.7496
C C PCHCEN = Q1/(CONST*SIGMZ*SIGMXY**2)
C C SKIPPING SUMMATION SECTION IF CONCENTRATION IS TOO LOW
C C IF(PCHCEN.LT.CHEMIN) GO TO 1500
C C CALCULATING MAXIMUM RADIUS OF INTEREST FOR EACH PUFF:
C C MAXIMUM PUFF RADIUS IN METERS:
C C PFRMXY = SIGMXY * SQRT(-2.*ALOG(CHEMIN/PCHCEN))
C C PFRMZ = PFRMXY*SIGMZ/SIGMXY
C C X-DIRECTION:
C C PUFRGX = PFRMXY/DELX
C C Y-DIRECTION:
C C PUFRGY = PFRMXY/DELY
C C Z-DIRECTION:
C C PUFRGZ = PFRMZ/DELZ
C C DETERMINING START AND STOP GRID POINTS FOR ACCUMULATION OF
C C THE PUFFS IN QUESTION:
C C ISTRTX = PTBL3 - PUFRGX + 1
C C ISTOPX = PTBL3 + PUFRGX + 1
C C ISTRTY = PTBL4 - PUFRGY + 1
C C ISTOPY = PTBL4 + PUFRGY + 1
C C ISTRTZ = PTBL5 - PUFRGZ + 1
C C ISTOPZ = PTBL5 + PUFRGZ + 1
C C CONTROL FOR EXCEEDING GRID DIMENSIONS
C C IF(ISTRTX.LT.XSB) ISTRTX=XSB
C C IF(ISTOPX.GT.XLB) ISTOPX=XLB
C C IF(ISTRTY.LT.YSB) ISTRTY=YSB
C C IF(ISTOPY.GT.YLB) ISTOPY=YLB
C C IF(ISTRTZ.LT.ZSB) ISTRTZ=ZSB
C C IF(ISTOPZ.GT.ZLB) ISTOPZ=ZLB
C

```

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PUF06430
PUF06440
PUF06450
PUF06460
PUF06470
PUF06480
PUF06490
PUF06510
PUF06520
PUF06530
PUF06540
PUF06550
PUF06560
PUF06570
PUF06590
PUF06600
PUF06610
PUF06620
PUF06630
PUF06640
PUF06650
PUF06660
PUF06670
PUF06680
PUF06690
PUF06700
PUF06710
PUF06720
PUF06730
PUF06740
PUF06750
PUF06760
PUF06770
PUF06780
PUF06790
PUF06800
PUF06810
PUF06820
PUF06830
PUF06840
PUF06850
PUF06860
PUF06870
PUF06880
PUF06890
PUF06900
PUF06910

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C      UPPER LIMIT IN CASE OF SPECIFIED MIXING DEPTH:ZM
C      IF(ISTRTZ.GT.ISTOPZ) AND, ISTOPZ:GT.ZMG ) ISTOPZ = ZMG
C      IF(ISTRTZ.GT.ISTOPZ) GO TO 1500
C      CALCULATE CONTRIBUTIONS TO SURROUNDING GRIDPOINTS
C      PRELIMINAR CALCULATIONS:
C      SIGMAS IN GRIDPOINTS:
C      SIGGX = SIGMX/DELX
C      SIGGY = SIGMY/DELY
C      SIGGZ = SIGMZ /DELZ
C      CALCULATING DENOMINATOR UNDER EXP-SIGN:
C      SIGGX2 = (SIGGX**2)*(-2)
C      SIGGY2 = (SIGGY**2)*(-2)
C      SIGGZ2 = (SIGGZ**2)*(-2)
C      LOOPING THRU ALL GRIDPOINTS OF INTEREST:
C      DO 1500 KG = ISTRTZ,ISTOPZ
C      ZG2NEG = (KG-PTBL5)**2
C      PCHI1 = PCHCEN * EXP(ZG2NEG/SIGGZ2)
C      IF(GRRFLX) PCHI1 = PCHI1 + PCHCEN*REFLEC*EXP((KG+PTBL5)**2/SIGGZ2)
C      IF(NOMXDP) GO TO 1295
C      IF((PTBL5+PUFRGZ).LT.ZMG) GO TO 1295
C      ZG2MX = (KG+PTBL5-2*ZMG)**2
C      PCHI1 = PCHI1 + PCHCEN*EXP(ZG2MX/SIGGZ2)
C      DO 1500 IG = ISTRTX,ISTOPX
C      XG2 = (IG-PTBL3)**2
C      DO 1500 JG = ISTRTY,ISTOPY
C      YG2 = (JG-PTBL4)**2
C      INDIVIDUAL PUFFS CONTRIBUTION : PCHI,GRAM/M**3
C      PCHI = PCHI1 * EXP(XG2/SIGGX2 + YG2/SIGGY2)
C      IF(PCHI.LT.CHEMIN) GO TO 1500
C      ACCUMULATING IN GRIDPOINTS:
C      CHI(IG+1,JG+1,KG+1) = CHI(IG+1,JG+1,KG+1) + PCHI
C      1500 CONTINUE
C      END OF CONCENTRATION CALCULATIONS
C      ADVANCE IN PUFF TABLE (J) DURING BASIC ADVECTION STEP
C      J = J + 1

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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
 PUF07400
 PUF07410
 PUF07420
 PUF07430
 PUF07440
 PUF07450
 PUF07460


```

C      MAX = JROWS - 1
C      OUTER LOOP THRU INTEGER Y-VALUES:
C      NY8=MAX+1  NY9=1,NY8
C      DO 1350
C      I2=NY9-1
C      MAXI2 = MAX - I2
C      WRITE(6,1327) MAXI2 , VERPLS
C
C      PLOTTING SOURCE POSITIONS
C      K1 = 0
C      DO 1330 J = 1,NRMULT
C      IF (MAX-I2,NE,YSOURC(J) ) GO TO 1330
C      NUMBER OF SOURCES IN MAINLINE: K1
C      K1 = K1 + 1
C      CALL ISPACE(XSOURC(J),J)
C      SOURCE POSITIONS IN EACH MAINLINE: XINT(K1)
C      XINT(K1) = 10*XSOURC(J)
C      CONTINUE
C      1330
C
C      LOOPING 9 LINES DOWN TO NEXT MAINLINE:
C      DO 1345 NY10=1,10
C      IDECI=NY10-1
C      YLINE = 10*(MAX - I2) - IDECI + 10
C      IF (IDECI .GE. 1) WRITE(6,1326) VERFRM
C
C      SCANNING THRU WHOLE PUFF TABLE
C      DO 1340 II = 1,NRMULT
C      J = 0
C      J = J + 1
C      IF (PTABEL(II,J,1) .EQ. 0) GO TO 1340
C      TRUNCATING Y-VALUE OF PUFF TO INTEGER:
C      YINT = PTABEL(II,J,4)*10 + 10.5
C
C      PRINTING "*" IN GRIDFRAME IF X-POSITION OF PUF= NOT COINCIDE
C      WITH ONE OF THE SOURCE POSITIONS
C      IF ( (YINT .NE. YLINE) .OR. (IDECI .NE. 0) ) GO TO 1338
C      COINCED = .FALSE.
C      INTEGER = VALUE OF PUFFS X-POSITION: XINTPF
C      XINTPF = PTABEL(II,J,3) * 10 + .5
C      DO 1336 KK = 1,K1
C      1336 IF (XINTPF .EQ. XINT(KK)) COINCED = .TRUE.
C      IF (COINCED) GO TO 1335
C      STRING(XINTPF + 1) = SNI
C      GO TO 1335
C
C      1338 IF (YINT .NE. YLINE) GO TO 1335
C      PRINTING PUFF POSITIONS BETWEEN Y-GRID LINES:
C      XINTPF = PTABEL(II,J,3) * 10 + .5

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PUF07960

PUF08000
PUF08010
PUF08020
PUF08030
PUF08040
PUF08050
PUF08060
PUF08070
PUF08080
PUF08090
PUF08110
PUF08120
PUF08130
PUF08140

PUF08160
PUF08170
PUF08180
PUF08190
PUF08200
PUF08210
PUF08220
PUF08230
PUF08240
PUF08250
PUF08260
PUF08270
PUF08280
PUF08290
PUF08300
PUF08310
PUF08320
PUF08330
PUF08340
PUF08350
PUF08360
PUF08370
PUF08380
PUF08400

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      STRING(XINTPF + 1) = SN1
      GO TO 1335
C 1340 CONTINUE
C 1341 END OF PUFF TABLE LOOP.
C
      WRITE(6,1325) STRING
      DO 1342 NST = 1,105
      1342 STRING(NST) = BL
C 1345 CONTINUE
C
      RESET "SOURCE IN LINE COUNTER" XINT(KK)
      DO 1349 KK=1,10
      1349 XINT(KK) = -1
C 1350 CONTINUE
C 1351 END OF PUFF POSITION PLOT.
      WRITE(6,1)
      WRITE(6,912) HORFRM
      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)
      881 FORMAT(1H+120X,15,10H SOURCE(S))
      WRITE(6,1)
      HORFRM2: STRING CONTAINING HORIZONTAL GRID FRAME
      DO 1410 N = 1,105
      VRFRM2(N) = BL
      VRPLS2(N) = BL
      PARENT(N) = BL
      HRFRM2(N) = BL
      NY11=HFZ+10
      DO 1418 IHFZ = MSZ,NY11,10
      NY12=IHFZ+4
      DO 1411 MN = IHFZ,NY12
      HRFRM2(MN) = SN4
      1411 HRFRM2(IHFZ+5) = SN2
      NY13=IHFZ+6
      NY14=IHFZ+9
      DO 1416 MM=NY13,NY14
      HRFRM2(MM) = SN4
      1416

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PUF084430
PUF084440
PUF084450
PUF084460
PUF084470
PUF084480
PUF084490
PUF084500
PUF084510
PUF084520
PUF084530
PUF084540
PUF084550
PUF084560
PUF084570
PUF084580
PUF084590
PUF084600
PUF084610
PUF084620
PUF084630
PUF084640
PUF084650
PUF084660
PUF084670
PUF084680
PUF084690
PUF084700
PUF084710
PUF084720
PUF084730
PUF084740
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PUF084760
PUF084770
PUF084780
PUF084790
PUF084800
PUF084810
PUF084820
PUF084830
PUF084840
PUF084850
PUF084860
PUF084870
PUF084880
PUF084890

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1418 CONTINUE 912) HRFRMZ
WRITE(6,10)ZMG + 1) = SN6
PARENT(10)MFZ + 3) = SN5
VRFRMZ(10)MFZ + 3) = SN3
VRPLSZ(10)MFZ + 3) = SN3
WRITE(6,1326) VRFRMZ
MAX = JROWS-1
DO 1445 NY15=1,JROWS
  I2=NY15-1
  MAXI2 = MAX - I2
  WRITE(6,1327) MAXI2,VRPLSZ
  KI=0
DO 1430 J=1,NRMULT
  IF (MAX-I2 .NE. YSOURC(J)) GO TO 1430
  KI = KI + 1
C CONTINUE NUMBER OF SOURCES IN EACH Y-GRIDLINE: VN SOURCE(S)
  IF (KI .GT. 0) WRITE(6,881) KI
  DO 1445 NY16=1,10
    IDECI=NY16-1
    YLINE = 10*(MAX-I2) - IDECI + 10
    IF (IDECI .GE. 1) WRITE(6,1326) VRFRMZ
    ILLUSTRATING MIXING DEPTH IN Y-Z FRAME:
    IF (ZMG .GT. 0) WRITE(6,1328) PARENT
    DO 1440 JJ = 1,NRMULT
      J=0
1435 J = J + 1
      IF (PTABEL(11,J)) .EQ. 0) GO TO 1440
      YINT = PTABEL(11,J) * 10 + 10.5
      IF (YINT .NE. YLINE) GO TO 1435
      ZINTPF = PTABEL(11,J,5) * 10 + .5
      STRING(ZINTPF + 1) = SN1
      GO TO 1435
C CONTINUE
1440 CONTINUE
C WRITE(6,1325) STRING
DO 1442 NS1 = 1,105
  STRING(NS1) = BL
C CONTINUE
1445 CONTINUE
C WRITE(6,1)
  WRITE(6,912) HRFRMZ
C SECTION FOR OUTPRINTING GRID CONCENTRATIONS

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PUF08900
PUF08910
PUF08920
PUF08930
PUF08940
PUF08950
PUF08960
PUF08970

PUF08980
PUF08990
PUF09000
PUF09010
PUF09020
PUF09030
PUF09040
PUF09050
PUF09060

PUF09080
PUF09090

PUF09110
PUF09120
PUF09130
PUF09140
PUF09150
PUF09160
PUF09170
PUF09180
PUF09190
PUF09200
PUF09210
PUF09220
PUF09230
PUF09240
PUF09250
PUF09260
PUF09270
PUF09280
PUF09290
PUF09300
PUF09310
PUF09320
PUF09330
PUF09350

```

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C      SKIPPING CONCENTRATION PRINTING IF SPECIFIED IN PRIMDA.
C      IF(ABC(9).EQ.NO) GO TO 1600
C
C 1510 FORMAT(1H0,49X,37H PRINT OF CURRENT GRID CONCENTRATIONS,/50X
C 16,29H SEC. AFTER START OF RELEASE.)
C 1520 FORMAT(1H0,49X,32H GRID CONCENTRATION IN THE PLANE: ,51X,3HZ =F6.2
C 125H METER ABOVE THE SURFACE.)
C 1525 FORMAT(11,8X,10E10.2)
C
C      WRITE(6,1301)
C      WRITE(6,1510) ITOTIM
C      WRITE(6,1)
C      WRITE(6,1)
C
C      LOOP THRU ALL Z LEVELS
C
C      DO 1550 KC=1,KPLANS
C      DEMKMI = DELZ*(KC-1)
C      WRITE(6,1520) DEMKMI
C      WRITE(6,1)
C      WRITE(6,1)
C      PRINTING EACH LINE IN CONCENTRATION TABLE:
C      DO 1560 JC = 1,JROWS
C      JJC = JRCWS - JC
C      JJC = JJC + 1
C      WRITE(6,1525) JJC, (CHI(IC,JCI,KC), IC = MSX,MFX)
C      DO 1551 IC=MSX,MFX
C      CPLLOT(IC,JCI)=CHI(IC,JCI,KC)
C      FORMAT(5X,10E10.2)
C      CONTINUE
C
C      KC IS THE NO. OF LEVELS PRINTED...HERE CONTROLS WHICH
C      LEVELS ARE CONTOURED.
C      IF (KC.EQ.1) CALL DRAW(CPLOT,10,17)
C      CONTINUE
C      WRITE(6,1)
C      WRITE(6,1)
C      GO TO 1600
C
C 1590 FORMAT(95H PUFF POSITION PLOT AND GRID CONCENTRATION PRINTING AR
C 1595 SUPPRESSED BECAUSE "ICOLS" EXCEED 10.)
C 1595 WRITE(6,1590)
C
C 1600 CONTINUE
C      END OF GRID CONCENTRATION PRINTING SECTION
C

```

PUF09360
 PUF09380
 PUF09390
 PUF09410
 PUF09420
 PUF09430
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 PUF09450
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 PUF09840
 PUF09870

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PUF10860
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PUF10890
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PUF10910

```

8930 WRITE(6,1140)
8940 GO TO 9999
8940 NRM1 = NRSTAB - 1
8940 WRITE(6,1030) NRM1
8950 GO TO 9999
8950 WRITE(6,1025) NRSTAB
8970 GO TO 9999
8970 WRITE(6,1015) WINDAV,NTADV
8980 GO TO 9999
8980 WRITE(6,1010) TAU,NTADV
8990 GO TO 9999
8990 WRITE(6,1005)
9000 GO TO 9999
9000 WRITE(6,1000) I
C 9999 CONTINUE
CALL EFRAME
STOP
END

```

CCCCC

SUBROUTINE SIGRIS(HGN,SIGXY,SIGZ)

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

FOR Z-COORDINATES OF PUFFS: HEIGHT , GRID UNITS(N) : HGN

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

1, UNN, CONST1, DELZ

INTEG FR POINT

REAL INTENS

CALCULATING GROWTH RATES FOR SIGMAS; DSIGDS

DEFINING EXPERIMENTAL FITTING CONSTANT: FITCST

FITCST = 2.0

DSIGDS = DSIGDS * FITCST

DSIGDS = DSIGDS * DMS

SIGZ = SIGZ + DSIGDS * DMS

CALCULATING PLUME-RISE INCREMENT:

CC

CC


```

      RETURN
1  IF (ITENFT.NE.1) GO TO 2
   WRITE(6,20) INR
      RETURN
2  IF (ITENFT.NE.2) GO TO 3
   WRITE(6,30) INR
      RETURN
3  IF (ITENFT.NE.3) GO TO 4
   WRITE(6,40) INR
      RETURN
4  IF (ITENFT.NE.4) GO TO 5
   WRITE(6,50) INR
      RETURN
5  IF (ITENFT.NE.5) GO TO 6
   WRITE(6,60) INR
      RETURN
6  IF (ITENFT.NE.6) GO TO 7
   WRITE(6,70) INR
      RETURN
7  IF (ITENFT.NE.7) GO TO 8
   WRITE(6,80) INR
      RETURN
8  IF (ITENFT.NE.8) GO TO 9
   WRITE(6,90) INR
      RETURN
9  IF (ITENFT.NE.9) GO TO 1000
   WRITE(6,100) INR
1000 RETURN
      END

```

SUBROUTINE DRAW (A,M,N)

THIS SUBROUTINE CONVERTS THE GRID CONCENTRATIONS TO LOG VALUES
THEN SMOOTHES AND CONTOURES THE PUFF ARRAY...

DIMENSION A(M,N)

A IS THE ARRAY TO BE SMOOTHED AND CONTOURED
M,N IS THE DIMENSION OF ARRAY A

```

DO 1553 JC=1,N
  JJC=N-JC
  JC1=JJC+1
  DO 1554 IC=1,M
    IF (A(IC,JJC).LT. 1E-12) A(IC,JC1)=0.0
    A(IC,JC1)=A(IC,JJC)*1.E13
  
```

CC
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CC
CC

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PUF11700
PUF11710
PUF11720

```

1554 IF(A(IC,JCL).EQ.0.0) GO TO 1554
1555 A(IC,JCL)=ALOG10(A(IC,JCL))
1556 CONTINUE
1557 WRITE(6,1555) (A(IC,JCL),IC=1,M)
1558 FORMAT(5X,10E10.2)
1559 SMOOTH ARRAY
1560 MM1=M-1
1561 MM1=N-1
1562 DO 200 J=1,N
1563   TEMP=A(I,J)
1564   DO 100 I=2,MM1
1565     TEMPI=A(I,J)
1566     A(I,J)=.20*(TEMP+3.*TEMPI+A(I+1,J))
1567     TEMPI=TEMP
1568   CONTINUE
1569   DO 400 I=1,M
1570     TEMP=A(I,1)
1571     DO 300 J=2,MM1
1572       TEMPI=A(I,J)
1573       A(I,J)=.20*(TEMP+3.*TEMPI+A(I,J+1))
1574       TEMPI=TEMP
1575     CONTINUE
1576     DO 1559 J=1,17
1577       WRITE(6,1555) (A(I,J),I=1,10)
1578       CALL SET (.1,31,2,58,0,1,0,1,1)
1579       CALL CONREC(A,10,10,17,0,0,1,0,1,1,0)
1580       CALL TICK4(5,8,5,8)
1581       CALL PERIM(9,0,16,0)
1582       CALL FRAME
1583       RETURN
1584     END

```

CCCC CCCCCC

PUF11750

PUF11760
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PUF11780
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PUF11800
PUF11810
PUF11820
PUF11830
PUF11840
PUF11850
PUF11860

SUBROUTINE RSPACE(ITENFT,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)

```

PUF11870
 PUF11880
 PUF11890
 PUF11900
 PUF11910
 PUF11920
 PUF11930
 PUF11940
 PUF11950
 PUF11960
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 PUF11980
 PUF11990
 PUF12000
 PUF12010
 PUF12020
 PUF12030
 PUF12040
 PUF12050
 PUF12060
 PUF12070
 PUF12080
 PUF12090
 PUF12100
 PUF12110
 PUF12120
 PUF12130
 PUF12140
 PUF12150
 PUF12160
 PUF12170
 PUF12180
 PUF12190
 PUF12200
 PUF12210
 PUF12220
 PUF12230
 PUF12240
 PUF12250

50 FORMAT(IH+,59X,F6.1)
 60 FORMAT(IH+,69X,F6.1)
 70 FORMAT(IH+,79X,F6.1)
 80 FORMAT(IH+,89X,F6.1)
 90 FORMAT(IH+,99X,F6.1)
 100 FORMAT(IH+,109X,F6.1)

C

IF(I TENFT.NE.0) GO TO 1
 WRITE(6,10) RNR
 RETURN
 1 IF(I TENFT.NE.1) GO TO 2
 RETURN
 2 IF(I TENFT.NE.2) GO TO 3
 RETURN
 3 IF(I TENFT.NE.3) GO TO 4
 RETURN
 4 IF(I TENFT.NE.4) GO TO 5
 RETURN
 5 IF(I TENFT.NE.5) GO TO 6
 RETURN
 6 IF(I TENFT.NE.6) GO TO 7
 RETURN
 7 IF(I TENFT.NE.7) GO TO 8
 RETURN
 8 IF(I TENFT.NE.8) GO TO 9
 RETURN
 9 IF(I TENFT.NE.9) GO TO 1000
 RETURN
 1000 RETURN

//GO.F01F001 DD *
 12 3600 0 10 17 4 1
 3600 40 90
 PRIMDATA SEPT 29 81
 217.50 435.00 40.00 1.000E-13 1.0000

YES
 YES
 YES

```

INST
//GO.FT02F001 DD UNIT=SYSOA,DISP=(OLD,DELETE),DSN=&FT02
//GO.FT03F001 DD *
STABILITY-DATA, SEPT 29 81
1.0000
80.00
//GO.FT04F001 DD *
INDIVIDUAL SOURCE DATA
#01# 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

```

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