THE EFFECT OF METEOROLOGICAL DATA AVERAGING TIMES ON PLUME CONCENTRATIONS FROM EXPLOSIVE ORDNANCE DISPOSAL OPEN BURNING OPERATIONS

THESIS

Ida Lee Widmann, B.S.
Captain, USAF

AFIT/GEE/ENP/95D

DEPARTMENT OF THE AIR FORCE
AIR UNIVERSITY
AIR FORCE INSTITUTE OF TECHNOLOGY

Wright-Patterson Air Force Base, Ohio

AFIT/GEE/ENP/95D-11

THE EFFECT OF METEOROLOGICAL DATA AVERAGING TIMES ON PLUME CONCENTRATIONS FROM EXPLOSIVE ORDNANCE DISPOSAL OPEN BURNING OPERATIONS

THESIS

Ida Lee Widmann, B.S.
Captain, USAF

AFIT/GEE/ENP/95D

AFIT/GEE/ENP/95D-11

THE EFFECT OF METEOROLOGICAL DATA AVERAGING TIMES ON PLUME CONCENTRATIONS FROM EXPLOSIVE ORDNANCE DISPOSAL OPEN BURNING OPERATIONS

THESIS

Presented to the Faculty of the Graduate School of Engineering
of the Air Force Institute of Technology
Air University In Partial Fulfillment of the
Requirements for the Degree of
Master of Science in Engineering and Environmental Management

Ida Lee Widmann, B.S.
Captain, USAF

December 1995

AFIT/GEE/ENP/95D-11

THE EFFECT OF METEOROLOGICAL DATA AVERAGING TIMES ON PLUME CONCENTRATIONS FROM EXPLOSIVE ORDNANCE DISPOSAL OPEN BURNING OPERATIONS

Ida Lee Widmann, B.S.C.E.
Captain, USAF

Approved:

Clifton E Dungey — 1 Dec 95
Clifton E. Dungey, Captain, USAF
Chairman, Advisory Committee

Thomas R Hauser — 11/30/95
Thomas R. Hauser
Member, Advisory Committee

Dennis W Quinn — 12/1/95
Dennis W. Quinn
Member, Advisory Committee

Acknowledgments

First, I would like to thank my advisor, (Major Select) Cliff Dungey. His guidance and friendship was invaluable to my learning process and sanity. I didn't believe him when he said I could write a FORTRAN model from scratch . . . I am a believer. I would also like to thank Dr Dennis Quinn for being a member of my committee and for being excited to teach about air pollution. Additionally, I would like to thank Dr Thomas Hauser for always asking how I was doing and for helping me to focus and make decisions for myself.

Many thanks to Gordon Taylor and John Lindell for keeping our group focused on the big picture and for the encouraging words at just the right time.

Finally, I would like to thank my husband, Rob, for loving me, listening to my troubles and for sharing lessons learned from his thesis effort.

Ida Lee Widmann

Table of Contents

Page

List of Figures

List of Tables

Abstract

Explosive Ordnance Disposal (EOD) Open Burning (OB) operations are performed to treat and dispose of unserviceable munitions in the Department of Defense (DOD) inventory. Air pollution modeling of OB operations is an Environmental Protection Agency requirement for permit issuance at OB sites. Specific OB regulation is still in its infancy; therefore, establishment of OB modeling techniques is still in the early stages. This thesis effort sought to develop a computer model, based upon the Gaussian Puff Equation. The model varies from standard plume modeling practices by not making the assumption that the wind direction, wind speed and turbulence are uniform throughout the duration of the burn. The model assigns meteorological data to each explosion (puff) generated by the OB source. The experiments in this research effort assigned meteorological data to the puffs based upon averaging the weather data over 1, 10, and 60 minute periods. The results of the research showed that there was a statistically significant difference (95% confidence) between 1 minute and 60 minute weather data plume concentrations in the receptor grid in 100% of the experiments performed. In each case, the one minute weather data produced smaller average plume concentrations in the receptor grid than the sixty minute weather data. This suggests that a closer look is needed when establishing standard OB modeling techniques involving meteorological input data to insure permits are not denied due to conservative approaches involving uniform weather data.

OB operation, computer modeling is an acceptable way to determine plume concentrations in a receptor grid.

Current Gaussian Puff based models assume a steady state condition, i.e., uniform wind speed, direction, and turbulence throughout the time period of interest. Some of these models also use a single stability classification scheme to determine dispersion parameters in both the horizontal and vertical directions.

The purpose of this research is to develop a FORTRAN 77 model to simulate puff releases from an EOD open burning operation. The model used sets of meteorological data averaged over 1, 10, and 60 minutes. Each puff released from the OB source was assigned specific weather data based upon the averaging time of interest. The model's dispersion parameters were calculated using separate schemes for the vertical and horizontal dispersion parameters. The data produced by the model were used to determine whether a statistically significant difference exists between the use of 1, 10, and 60 minute meteorological data.

The following chapters will develop the argument for the need to examine the use of more appropriate averaging times when modeling EOD Open Burning sources. Additionally, the need to examine the use of site-specific meteorological data to model EOD Open Burning sources will also be investigated. Chapter Two reviews the importance of OB activities to DOD and the necessity to produce models which more closely mimic OB operations. Chapter Three explains the methodology employed in this study to examine the effects of meteorological data averaging times. Chapter Four presents the results of this study. Finally, Chapter Five interprets the meaning of the results and suggests future research possibilities.

II. Literature Review

Practical Justification

The stockpile of excess munitions in the Department of Defense (DOD) inventory requiring disposal as hazardous waste has drastically increased over the last ten years. "At the end of 1993, DOD estimated the size of the munitions stockpile requiring safe demilitarization by treatment and/or disposal at over 435,000 tons, almost doubling its size since 1982 when the stockpile was an estimated 250,000 tons" (Howell and Tope, 1994). "Because of the enormous backlog of military weapons that require timely demilitarization and/or disposal . . . DOD recognizes that the surplus of ordnance is fast approaching a critical level. . ." (Tope and Howell, 1994). There are two main reasons for this marked increase in the size of this stockpile of unserviceable munitions. First is the recent downsizing of military operations following the end of the Cold War. Downsizing has reduced the number of military installations, operations, and weapons systems which in turn increased the rate of unserviceable munitions generated (Tope and Howell, 1994). Second, there was and still is a great deal of confusion between the regulatory agencies and the regulated community regarding classification schemes for munitions. Since it appears the military is still in a downsizing mode, that source of increase of the munitions stockpile is not going away in the near future. Therefore, the regulatory confusion will be investigated as a way to decrease the stockpile. It is necessary to address exactly how munitions are handled and ultimately destroyed before the air quality issues associated with their destruction are discussed.

The Resource Conservation and Recovery Act (RCRA) governs the regulation of hazardous waste. Once an item can no longer be used for its intended purpose, it is subject to RCRA which identifies two classification schemes for determining whether an

item is hazardous waste. Either the waste is listed, i.e., the item is specifically mentioned on an Environmental Protection Agency(EPA) list, or it is a characteristic waste. Characteristic wastes display any the following properties: toxicity, ignitability, flammability or reactivity. Once classified as hazardous waste, the item is subject to stringent requirements, including a storage time limit of 90 days without a special permit. Herein lies the crux of the problem with the munitions stockpile -- storage time.

Military munitions "generally consist of an assortment of explosive [i.e., reactive] fill materials, associated metal and plastic casings, projectiles and primer components" (Tope and Howell, 1994). Common examples of munitions include: bullets, bombs, ejection seat cartridges, flares and smoke grenades. The base Munitions Accountable Systems Officer (MASO) closely monitors the munitions inventory by accomplishing daily inventory inspections to determine the condition of each item. Condition codes are assigned to each item based upon whether the item is obsolete, excess (expired shelf-life), or damaged (leaking, missing parts, etc.) (Johnson, 1994). Once a MASO declares an item to be unserviceable for any reason, the process of deciding how to ultimately deal with the item begins.

There are three primary options for dealing with unserviceable munitions. First, munitions supply personnel determine whether the item can be used at another installation. The second option is the use of the item for legitimate training by military personnel. The third option (and last resort) is a condition code H designation. Condition code H signifies the item is 'unserviceable' and therefore must be designated as RCRA hazardous waste since it can no longer be used for its intended purpose. Condition code H items are physically separated from serviceable munitions and the MASO schedules the items for disposal (HQ USAF Message, 1994). The 'RCRA 90-day storage clock starts ticking' as soon as the item is declared condition code H. Within the 90-day time limit, personnel must complete volumes of military paperwork intended to control these sensitive,

dangerous items, arrange for transportation to an authorized disposal site, and actually transport the items to the disposal site. Ultimately, RCRA requires munitions to be disposed of by means of open burning (OB) or open detonation (OD) within 90 days of the initial designation as condition code H, i.e. hazardous waste.

In accordance with Air Force regulations, highly trained Explosive Ordnance Disposal (EOD) personnel determine whether the item will be destroyed by OB or OD. EOD personnel must follow strict regulations which specifically outline the proper method of disposal, i.e. open burning or open detonation, for each item in the Air Force munitions inventory. Due to the fact that OB/OD operations involve the disposal of hazardous waste, the installations where OB/OD is conducted are regulated under RCRA as treatment, storage, and disposal facilities (TSDFs). This study focuses on destruction of munitions by open burning.

Very simplistic in nature, the OB process evolved over the past 40 years into the preferred munitions destruction method for items that cannot be destroyed by open detonation. EOD personnel begin OB events by stacking wooden cargo pallets in a shallow pit, bermed area or burn pan in order to provide fuel to keep the fire burning. Next, EOD piles the items to be destroyed on top of the dunnage and pours either jet or diesel fuel on top of the pile. Finally, they light the pile using initiator charges timed to allow EOD personnel to clear the area.

The explosions involved in OB activities are different from conventional ideas concerning explosions in one significant manner. An OB event does not involve one large explosion. Instead, OB events involve a series of small explosions as the munitions items being destroyed reach temperatures high enough to produce the exothermic (heat and energy releasing) reaction needed to thoroughly destroy the items (Tope and Howell, 1994).

OB operations are only one aspect of the mission of EOD personnel. Other duties include providing security for VIPs, emergency response to bomb threats, training, and classified missions. These other duties occupy a great deal of the EOD personnel's time; therefore, OB operations only occur on a monthly or quarterly basis. The rarity of OB events increases the size of the munitions stockpile because the supply cannot keep up with the demand, i.e., there are not enough OB facilities and EOD personnel to meet the disposal demand. Therefore, in order to reduce the stockpile and keep it at a manageable level, it is imperative that more facilities be fully permitted in a timely manner.

EPA RCRA permitting is a long process due to the large number of applications received. The Department of Defense's experience with the EPA's OB permit application process began in 1980 and to date, only one final permit has been issued (TNRCC and EPA, Apr and June 1992). The delay in permitting of OB units is due in part to the uniqueness of this disposal method.

OB units are regulated in the CFR as 'Miscellaneous Subpart X Units' (EPA, 1987). The CFR specifies design and operating standards for more common hazardous waste disposal methods, while standards for Subpart X units, such as OB units, are permit specific. The EPA's lack of sufficient knowledge to promulgate specific design and operating standards for OB causes major delays in the permitting process (Federal Register, 1987; Johnson, 1994). Except for the single permitted facility, other OB units operate under temporary 'interim-status' permits until final permits are issued or the interim-status expires and the unit is set up for closure (Davis, 1995).

Initially, a great deal of confusion existed regarding several issues surrounding OB operations. This confusion prompted several concerned wing commanders to temporarily shut down their OB/OD units until definitive guidance was formulated by DOD. Justifiably concerned, these commanders thought this regulatory confusion might lead to the receipt of a Notice of Violation, which could be accompanied by a fine, from

environmental regulators. The temporary shutdown of these units caused a bottleneck in the unserviceable munitions disposal process resulting in even more condition code H munitions items awaiting disposal.

Currently, RCRA and the Clean Air Act do not require a separate air permit to operate an OB thermal treatment unit. RCRA permits incorporate air emissions regulations by using umbrella statements such as, 'permittee shall comply with all applicable federal, state and local environmental regulations.' This all encompassing statement does not specifically mention air quality aspects such as limits on certain chemical constituents in the smoke plume generated by OB. Therefore, it would be difficult to pick out this requirements while wading through the multitude of enumerated hazardous waste requirements for compliance with the permit.

Due to the obscurity of air quality issues in the past, the issue of air emissions concerns has not been addressed until recently when EOD operations advanced to the forefront in the regulatory community. The growing stockpile of unserviceable munitions and the fifteen-plus years already spent toward applying for OB permits necessitates attention to and compliance with all environmental aspects of OB, including air quality standards.

Unfortunately, since the central focus of the regulations governing OB operations and munitions inventory control centers around RCRA, the issue of the air emissions associated with burning operations is sometimes hidden from view. The new attention paid to OB operations has made the issue of air pollution modeling a permitting requirement. Therefore, it is necessary to assess the compliance of OB units with air quality standards through the use of research methods.

Academic Justification

Air sampling during an OB operation is difficult at best. The explosive nature of the material being burned necessitates that personnel in the area stay a safe distance away. During the burn operation, certain items may 'kick out' of the burning pile creating a dangerous situation for anyone caught too close to the burn area. Unfortunately, these kick-outs also make the use of air sampling equipment prohibitive, since sample equipment could be destroyed by a projectile. Consequently, alternate methodologies must be established for determining compliance with air quality standards. This study focuses on modeling plume concentrations generated in a receptor grid from an OB source.

Since first being suggested in detail by Pasquill in 1961, air pollution modeling using the Gaussian distribution has developed well-established roots (Bowen, 1994). The Gaussian Puff Model (Eqn 1) is used to determine plume concentrations at a given receptor location coordinate at a given time (x, y, z, t). This model is used for cases involving instantaneous releases, i.e., an explosion (Turner, 1969).

Currently, there is no EPA recommended model to handle the special set of circumstances surrounding OB sources. In 1994, a model development program was undertaken by the Department of Defense (DOD) and the Department of Energy (DOE) to develop a model capable of handling OB sources (Weil and Templeman, 1995).

Standard models are based upon a Gaussian Puff Model (Eqn 1) which assumes uniform average wind speed ($\bar{u}$), wind direction and turbulence throughout the duration of the OB operation (Bowen, 1994; Griffin, 1994). The meteorological input data for these models is usually measured at a height of 10m over an averaging time of one hour (but not less than 10 minutes) (Mitchell, 1982). These models attempt to account for the changes experienced by the atmosphere through the use of the dispersion parameters to describe material spread in the puffs. This crude method does not sufficiently account for the constantly changing wind speed, direction and turbulence experienced by our

atmosphere. Examination of Equation 1 shows that these atmospheric characteristics have a direct effect on modeled plume concentrations in a receptor grid.

$$C(x,y,z,t) = \frac{2Q_T}{(2\pi)^{3/2}\sigma_x\sigma_y\sigma_z}\exp\left[\left(\frac{-(x-\bar{u}t)^2}{2\sigma_x^2}\right)-\left(\frac{y^2}{2\sigma_y^2}\right)-\left(\frac{H^2}{2\sigma_z^2}\right)\right] \quad (1)$$

The source term (Q_T) in the Gaussian Puff Model is the total mass of the material released during the time period of interest (Turner, 1969). This type of source term is valid when one explosion is involved, but would appear to be invalid when applying the puff model to OB operations involving a series of explosions.

The horizontal (σ_X and σ_Y) and vertical (σ_Z) dispersion parameters in the standard Gaussian Puff Model are uniform throughout the time period of interest (usually 1 hour). Furthermore, typical puff models use a single dispersion parameter classification scheme to determine both the horizontal and vertical parameters. The use of uniform dispersion parameters throughout the time period of interest may be appropriate in situations involving one explosion, but is clearly inappropriate for OB activities involving a series of explosions.

Several schemes exist for the determination of the dispersion parameters (σ_X, σ_Y, and σ_Z). The most frequently used schemes are the Vertical Temperature Gradient, Sigma Theta, and Modified Sigma Theta. The Vertical Temperature Gradient (DT/DZ) involves the use of the difference in temperatures between two specified to determine the stability conditions and, subsequently, the dispersion parameters. The Sigma Theta method uses the standard deviation of the horizontal wind direction to determine stability conditions. The Modified Sigma Theta (MST) also uses the standard deviation of the wind direction to determine stability conditions. However, MST accounts for nighttime conditions by factoring in the wind speed when determining the stability class from which to calculate

the dispersion parameters. The MST is inappropriate for use in modeling OB activities since safety considerations dictate that OB activities occur only during daylight hours.

Models developed for air pollution typically use one atmospheric stability classification method to calculate all three stability parameters. This means that if DT/DZ is used, assumptions about horizontal stability class would be made based upon measurements taken in the vertical direction, i.e., temperature gradient. Additionally, if Sigma Theta is used, assumptions about vertical stability class would be made based upon measurements taken in the horizontal direction, i.e. wind direction. Puff models which do not assume ($\sigma_X = \sigma_Y = \sigma_Z$) will often assume that the puffs released from the source have a circular horizontal cross section; therefore, ($\sigma_X = \sigma_Y$).

Modification of horizontal dispersion parameters due to an averaging time different than the ten minutes established by the Pasquill-Gifford curves are typically modified by the one-fifth power law. The one-fifth power law is used to modify data from ten minute averaging time to another averaging time of interest (Kunkel, 1991). This law was derived from empirical data and may not be valid in all situations. Obtaining the meteorological data needed to calculate the dispersion parameters is preferable to using an estimated formula to calculate the dispersion parameters for differing averaging times. This formula is necessary when the meteorological data set is not available to perform calculations for differing averaging times.

The availability of site-specific meteorological weather data makes the modeling of OB operations more realistic. The creation of mobile meteorological towers enables researchers to gather site-specific data versus the common practice of calling the local airport to obtain weather data (Weil, 1995). The weather data received from the local airport may be valid for the immediate area around the airport, but may be vastly different from the weather at the location of the source.

EPA requirements for EOD Open Burning permit applications are likely to include site-specific assessments which assign risk numbers to facilities. The varying locations of OB sources necessitates the use of site meteorological data to insure the most accurate modeling is accomplished for that site.

III. Methodology

FORTRAN Computer Model

Due to the inherent difficulty and danger involved in performing air measurements above an Explosive Ordnance Disposal (EOD) Open Burning (OB) operation, mathematical modeling must be used to predict plume concentrations. A modified Gaussian Puff Equation was used to develop a FORTRAN computer model named PUFFY (See Appendix A for FORTRAN code). PUFFY is used to calculate pollutant concentrations in a Cartesian receptor grid extending 1 km from the source (the OB operation) in all four Cardinal directions, North, South, East, and West. PUFFY was designed with the assertion that the individual puffs released during the explosions occurring during an OB operation may potentially travel along various trajectories (Figure 1) versus the traditional assumption that puffs would travel along the same trajectory.

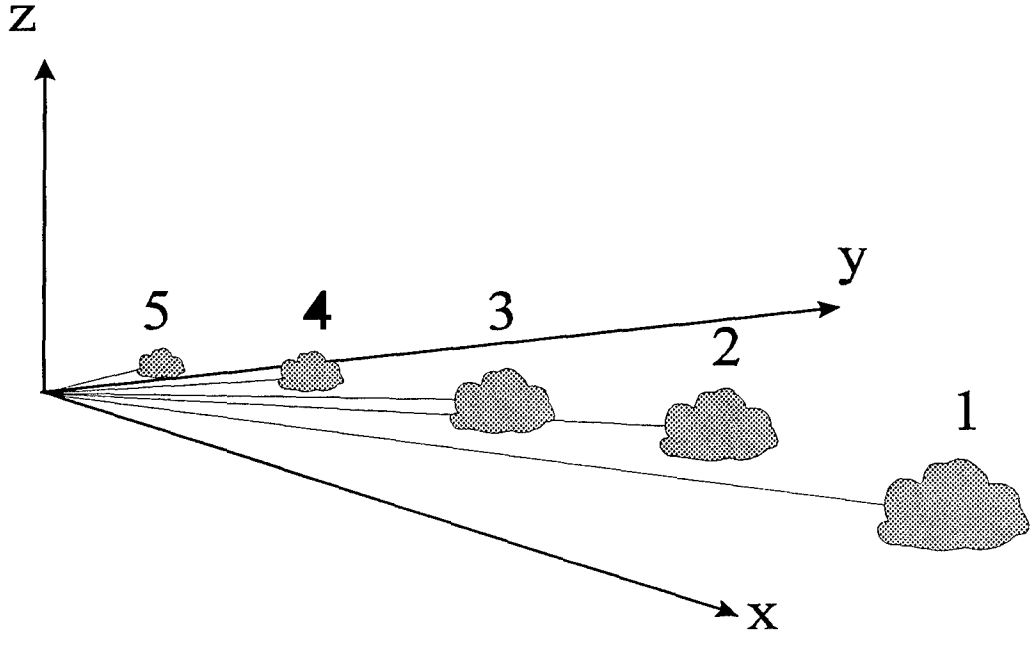

FIGURE 1 Example Trajectories for Puffs From OB Operations (Source is at the Origin)

Origin of Meteorological Data

The meteorological data used as inputs for the model developed in this thesis effort was gathered from five weather towers at various locations in and around Cedar Bog in (Springfield, OH) as part of an on-going research effort by Wright State University (WSU). The towers, purchased from Climatronics, Inc., measure the following parameters relevant to this thesis effort: temperature, wind speed, wind direction and standard deviation of the wind direction (σ_θ) at 1m and 10m heights. The towers were set using a thermosistor to measure temperature, anemometers to measure wind speed and a horizontal wind vane to measure the wind directions used to calculate the standard deviation. Originally set to take weather data at 15 minute intervals, the tower measurement interval was reset to one minute to gather data for this thesis effort. The one minute data was taken for a period of two days.

The data gathered from the Climatronics towers was manipulated by a FORTRAN program called 'METALL' so that it would be in a usable form for the FORTRAN program developed for this thesis effort. The program METALL was used to convert the relevant weather data from 1 minute averaging time to 10 minute and 60 minute averages.

The program separates the wind directions into x and y components during the time period of interest, i.e., ten minutes or sixty minutes, and totals them. Separate x and y component averages are calculated and the resulting wind direction is computed by taking the inverse tangent of the result of the y component divided by the x component. Next, 180 degrees was then added to the resulting angle due to meteorological convention for wind direction. Meteorological convention describes the direction from which the wind originated, i.e., from the South. Wind from due South is considered the 0 degree starting point with wind directions measured in a clockwise direction. In contrast, Cartesian coordinates describe wind direction in terms of the direction to which it is

blowing, i.e., wind blowing toward the East is considered the 0 degree starting point. Successive wind directions are measured in a counterclockwise direction.

Instead of using the weather tower values of σ_θ directly to eventually determine the value of $(\sigma y)_c$ by using the one fifth power-law (Eqn 1) to convert the σ_y values to the appropriate averaging times, the derivation in Appendix C was used to justify the formula (Eqn 2) used to calculate the (σ_θ) for the appropriate averaging times based upon one minute averaging time weather tower data.

$$\left(\sigma_y\right)_c = \sigma_y \left(t_c / 10\right)^{0.2} \qquad (1)$$

where,

$(\sigma Y)_c$ = Corrected Horizontal Dispersion Parameter (meters)

t_C = Weather Data Averaging Time (minutes)

$$\sigma_{\theta_c} = \sqrt{\frac{1}{N_T}\left[\sigma_\theta + \left(\mu - \bar{\mu}\right)^2\right]} \qquad (2)$$

where,

N_T = Ratio of the number of readings taken in one minute to the number of readings taken in the desired averaging time (i.e., for 10 minutes--60/600=1/10)

$\sigma_{\theta c}$ = Corrected Standard Deviation

σ_θ = Standard Deviation of the Wind

μ = Individual Wind Directions (from Climatronics Towers)

$\bar{\mu}$ = Average Wind Direction for Time Period of Interest (10 or 60 minutes)

Source Term

Each experiment conducted used a one hour time period of interest. The Open Burn activity was simulated by the release of one puff during each minute. Each puff is of

uniform strength. The model has the built-in flexibility for the user to change the strength of the puffs released. The user also has the capability to change the source strength so that each puff released has a different strength.

Calculation of Diffusion Parameters

Horizontal Diffusion Parameter. The standard deviation of the horizontal wind direction (σ_θ) was used to determine the stability parameter needed to calculate the horizontal diffusion parameters (σ_x and σ_y). The Turner Workbook describes more detailed information about the concept of the diffusion parameter (Turner, 1969). First, the value of (sigma theta) is read in from the data file generated by the FORTRAN program 'METALL.' Sigma Theta (σ_θ) is then used to determine the value of the stability parameter. Table 1 illustrates the discrete values commonly used to determine stability parameters from ranges of σ_θ values.

TABLE 1 Pasquill Stability Categories and Corresponding Stability Parameter Values with Associated Ranges of (Sigma Theta) -- Using the Modified Sigma Theta (MST) Method

Stability Category	A	B	C	D	E	F
Stability Parameter	0.5	1.5	2.5	3.5	4.5	5.5
Sigma Theta (degrees)	>22.5	17.5 to 22.5	12.5 to 17.5	7.5 to 12.5	3.8 to 7.5	<3.8

This thesis effort asserts that since the atmosphere does not normally behave in a discrete manner, the values of the stability parameters used in the puff model should not be discrete. Linear interpolation between stability parameters(SP) was used to determine a more precise value of the stability parameter than the established practice of choosing discrete stability classes and a corresponding discrete stability parameters. The value of

σ_Y is determined by the following power law expression (Equation 3) derived from the Pasquill-Gifford curves (Figure 2) (Seinfeld, 1986; Kunkel 1991)

$$\sigma_y = ax^b \tag{3}$$

where,

a = $0.479 - 0.1232*SP + 0.00904*SP^2$

SP = Stability Parameter

b = 0.9

The assumption was made that the puff released from the EOD operations has a circular horizontal cross-section; therefore, $\sigma_x = \sigma_y$

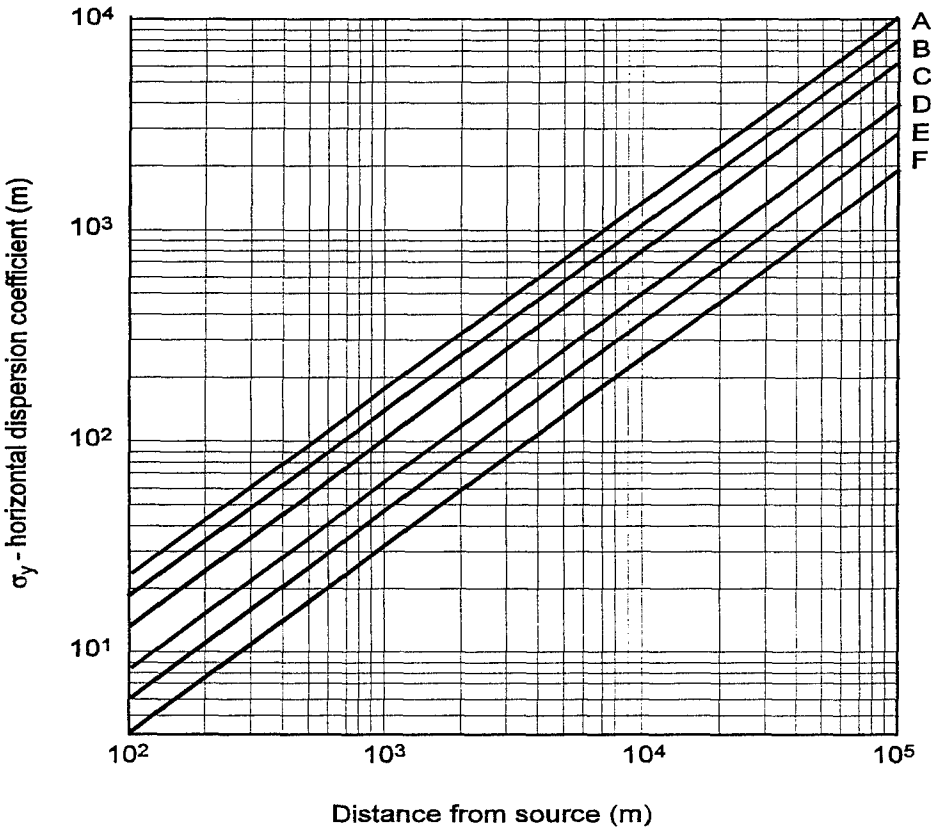

FIGURE 2 Correlations for σ_y based on the Pasquill stability classes A-F (Seinfeld, 1986)

Vertical Diffusion Parameter. The vertical temperature gradient (dT/dZ) was used to determine the stability parameter needed to calculate the vertical diffusion parameter (σ_Z). First, the temperatures at the 10m and 1m heights were converted from Fahrenheit to Celsius. Second, the temperature at 1m was subtracted from the temperature at 10m (dT). Next, dT was divided by the difference in heights where the temperatures were measured (dZ) to determine dT/dZ.

Table 2 illustrates the values for the stability parameter assigned by F. V. Hansen to each of the Pasquill stability categories (Kunkel, 1991). Table 2 also depicts the ranges of temperature gradient values associated with each stability category.

TABLE 2 Stability Parameter Values Associated with Temperature Gradient Ranges and Corresponding Pasquill Stability Categories

Stability Category	A	B	C	D	E	F
Stability Parameter	0.5	1.5	2.5	3.5	4.5	5.5
DT/DZ (degrees C/100m)	<-1.9	-1.9 to -1.7	-1.7 to -1.5	-1.5 to -0.5	-0.5 to +1.5	>+1.5

Once the value of DT/DZ was calculated, it was used to determine the value of the stability parameter based upon the ranges of the temperature gradient recommended for use by the Nuclear Regulatory Commission (NRC) method for determining vertical stability class. Using the value of the calculated stability parameter, the values of the coefficient, c, and exponent, d, are computed. The values of the coefficient and exponent are needed to compute σ_Z according to the power-law expression in Equation 4.

$$\sigma_z = cx^d \qquad (4)$$

The values of the coefficient and exponent for the power-law expression were determined by the use of the discrete values in Table 3. The values of the stability parameters were reconfigured as ranges in order to account for the continuous nature of the stability parameters generated by the use of the temperature gradient values.

TABLE 3 Coefficients and Exponents for the Vertical Dispersion Parameter

Stability Category	A	B	C	D	E	F
Stability Parameter	<1.0	1.0 to 2.0	2.0 to 3.0	3.0 to 4.0	4.0 to 5.0	>5.0
x(m)<	745	745	2000	1100	1400	1400
c	0.0414	0.1036	0.1173	0.0975	0.1050	0.0617
d	1.3155	1.0026	0.9112	0.8414	0.7692	0.7884
x(m)>	745	745	2000	1100	1400	1400
c	1.928E-04	0.0534	0.4422	0.6097	0.8788	0.9990
d	2.1234	1.1029	0.7382	0.5808	0.4771	0.4771

Unlike the coefficient, a, for the horizontal diffusion parameters, a reasonable line of best fit could not be found for the coefficient, c, used to calculate the vertical diffusion parameter (Figure 3). The curves used to calculate the coefficient, c, are not straight lines even when plotted on logarithmic paper. Therefore, linear interpolation between the values of the coefficient, c, and the exponent, d, would be an inappropriate approach.

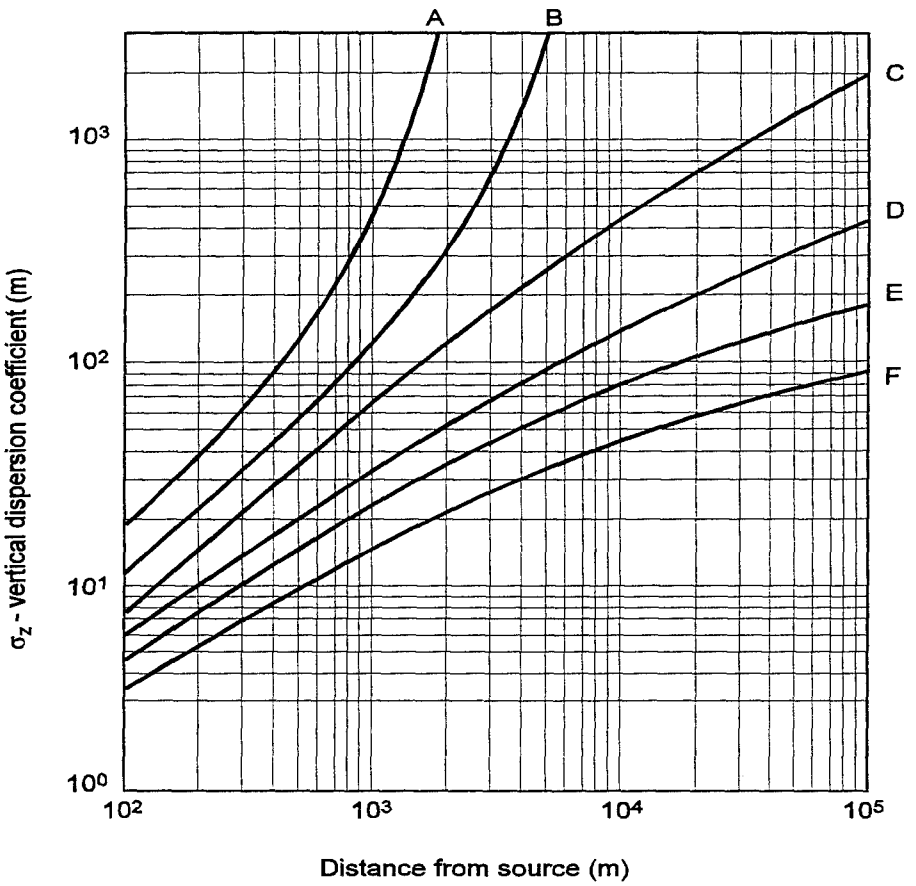

FIGURE 3 Correlations for σ_Z based on the Pasquill stability classes A-F (Seinfeld, 1986)

Assignment of Meteorological Data to Individual Puffs

Each puff released during the time period of interest was assigned its own set of meteorological data depending upon the averaging time under study. If a puff is released with one minute weather data, each puff is assigned a different set of one minute weather data, i.e., the weather changes every minute. If a puff is released with ten minute weather data, each set of ten puffs released during the time period of interest will have a separate set of ten minute weather data, i.e., the weather only changes every ten minutes. If the puff is released with sixty minute weather, each puff will be assigned the same weather data, i.e. the weather does not change in a one-hour period

X and Y Coordinate Determination

The Gaussian Instantaneous Plume Equation assumes that the wind is blowing along the x-axis of a 'right-hand' three-dimensional coordinate system. The coordinates of the receptor point of interest (x, y, z) represent the distance downwind of the source(x), the distance from the centerline of the puff to the receptor (y), and the vertical distance from ground-level to the receptor (z).

The computer used to calculate the plume concentrations in the PUFFY model does not use the meteorological convention for wind directions, i.e., in terms of where they originated. Instead, it uses the Cartesian coordinate system by manipulating angles in terms of which direction the wind is blowing. In order to insure the proper coordinates were used to determine the x, y, and z distances from the source to the receptor, the wind direction from the weather data set was converted to Cartesian coordinates. The transformation was accomplished by first adding 180 degrees to the wind direction of interest in order to represent the wind direction as blowing toward a direction instead of resulting from a direction. Second, the direction was separated into its x and y components. Third, the x component and y component were reversed to account for the meteorological convention of measuring angles in a clockwise rather than counterclockwise (Cartesian) manner. Finally, the inverse tangent function was used to determine the wind direction (Alpha) in Cartesian coordinates.

Since the PUFFY model assigns each puff released to a set of meteorological data, it was necessary to consider the receptor grid used in the experiment as a stationary (reference) grid which did not change when a new set of weather data was initiated. Instead, with the release of each puff, the coordinates in the receptor grid were transformed into coordinates for the wind direction assigned to the puff of interest. The angle (Beta) between the reference frame's x-axis and the receptor grid point was determined in order to calculate the transformed coordinates. The difference (Gamma)

between the angles (Alpha and Beta) was used to calculate the transformed coordinates. The transformed coordinates were used as the x and y values needed to calculate the plume concentrations.

Reference Grid Spacing and Time Step. The receptor grid used for this thesis effort consisted of grid points every 50 m extending out to 1 km from the Explosive Ordnance Disposal (EOD) Open Burning operation in all four Cardinal directions, i.e., North, South, East, and West, making the grid (1 km x 1 km). The grid spacing was set at 50m to ensure the puffs released from the source were over a grid point in close proximity to the source. If the grid spacing was any larger, i.e., 100m, a puff release may not have been detected until the puff was well downwind.

The time step was set at 15 second intervals to insure that puffs do not pass over the receptor site between measurements. For example, if a puff has not yet reached the receptor grid point of interest, at the 10 minute point the plume concentration is zero. If the puff passes by the grid point, then when a measurement is taken at the 11 minute point, the plume concentration is still zero. This could lead to serious error if these measurements were used to determine receptor dosage or maximum exposure concentrations.

Gaussian Instantaneous (Puff) Equation*

A modification of the Gaussian Instantaneous (Puff) equation was used to calculate the plume concentrations in the receptor grid. This equation is often used in cases involving an explosion. The 'Puff Equation' assumes the source term, Q_T, represents the total mass of material released during the time period of interest (Turner, 41). Equation 5 is the Gaussian Puff Equation to calculate plume concentrations from instantaneous sources.

$$C(x,y,z,t) = \frac{2Q_T}{(2\pi)^{3/2}\sigma_x\sigma_y\sigma_z}\exp\left[\left(\frac{-(x-\bar{u}t)^2}{2\sigma_x^2}\right)-\left(\frac{y^2}{2\sigma_y^2}\right)-\left(\frac{H^2}{2\sigma_z^2}\right)\right] \quad (5)$$

where,

Q_T = Total mass of material released in the time period of interest (mass)*

π = 3.141592654

σ_x = Diffusion parameter-Standard deviation of material concentration in the X direction

σ_y =Diffusion parameter-Standard deviation of material concentration in the Y direction

σ_z = Diffusion parameter-Standard deviation of material concentration in the Z direction

x = Distance downwind from the source

y = Crosswind distance from the centerline of the plume trajectory

z = Vertical distance from the ground to the receptor

u = Wind speed of individual puff at the time of release (distance/time)* at 10m

t = Time since puff was released from source

H = Effective stack height (includes the actual stack height + plume rise from buoyant forces)

** The puff is assumed to have a circular horizontal cross section; therefore, $\sigma_x = \sigma_y$

Statistical Analysis

The model, PUFFY, developed for this thesis effort incorporates a modified version of the Gaussian Puff Equation. Instead of assuming all material is released at once, PUFFY assumes that each puff released has a separate contribution to the concentration measurements at each grid receptor point depending upon the meteorological conditions when the puff was released. PUFFY assigns separate meteorological data to each puff.

Depending upon the averaging time of interest, for one minute averaging time, unique meteorological data is assigned to each puff during the one hour time period of interest used in this experiment. For ten minute averaging time, the first set of ten puffs have the same meteorological data, the second set of ten puffs have a different set of data, and so on until the sixth set of puffs has been released. When the averaging time is sixty minutes, each of the puffs released have the same meteorological data. Equation 6 was used to determine the maximum cumulative concentration to occur at the grid point (x, y, z=0).

$$C(x,y,0,t) = \sum_{p=1}^{60} \frac{2Q_p}{(2\pi)^{3/2}\sigma_{xp}\sigma_{yp}\sigma_{zp}} \exp\left[\left[\frac{-(x-u_p t_p)^2}{2\sigma_{xp}^2}\right] - \left[\frac{y^2}{2\sigma_{yp}^2}\right] - \left[\frac{H^2}{2\sigma_{zp}^2}\right]\right] \quad (6)$$

where,

p = Couner for order in which puffs were released

Q_p = Total mass of material released in the time period of interest (mass/time)*

π = 3.141592654

σ_{xp} = Diffusion parameter-Standard deviation of material concentration in the X direction for puff of interest

σ_{yp} =Diffusion parameter-Standard deviation of material concentration in the Y direction for puff of interest

σ_{zp} = Diffusion parameter-Standard deviation of material concentration in the Z direction for puff of interest

u_p = Wind speed of individual puff at the time of release (distance/time)* at 10m

t_p = Time since puff was released from source

H = Effective stack height (includes the actual stack height + plume rise from buoyant forces)

* Time units for source term (Q) must be consistent with time units for wind speed (u)

** The puff is assumed to have a circular horizontal cross section; therefore, $\sigma_x = \sigma_y$

TABLE 4 Origin of Coordinates for Experiments Conducted During Each 1 Hour Period

Treatment 1	Treatment 2	Treatment 3
1-(1:1)	10-(1:1)	60-(1:1)
1-(1:2)	10-(1:2)	60-(1:2)
1-(1:3)	10-(1:3)	60-(1:3)
1-(10:1)	10-(10:1)	60-(10:1)
1-(10:2)	10-(10:2)	60-(10:2)
1-(10:3)	10-(10:3)	60-(10:3)
1-(60-1)	10-(60:1)	60-(60:1)
1-(60-2)	10-(60:2)	60-(60:2)
1-(60-3)	10-(60:3)	60-(60:3)

"The question of central interest here is whether there are differences in true averages associated with the different treatments . . ."(Devore, 1991) In this experiment the null hypothesis is that there is no difference between plume concentrations in the receptor grid when one, ten, and sixty minute weather data averaging times are used. The alternate hypothesis is that there is a difference between plume concentrations in the receptor grid when one, ten, and sixty minute weather data averaging times are used. If the ANOVA rejects the null hypothesis, Tukey's Procedure is used to determine which of the population means are different from one another.

STATISTIX 4.0 was used to analyze the data to determine whether the null hypothesis was true. In this thesis effort, the objective was to study whether there was a statistically significant difference in plume concentrations modeled using one, ten, or sixty minute averaging times for meteorological data.

IV. Results

Chapter Overview

The following sections examine the difference between plume concentrations when varying averaging times are used. Analysis of Variance (ANOVA) and Tukey's Procedure with a 0.05 experiment-wise error rate were used to determine whether there was a statistically significant difference between the use of one minute, ten minute or sixty minute meteorological data averaging times to determine plume concentrations in a receptor grid.

Comparison of Maximum Concentrations by Averaging Time

A subjective comparison of the maximum plume concentrations calculated for each of the three averaging times was accomplished. Table 5 represents a sample of the maximum concentrations achieved in the receptor grid during each experiment. For each experimental period (1 hour), the maximum plume concentration occurred when 1 minute averaging time was used. The 60 minute averaging time always produced the smallest maximum concentration. A probable reason for this result is the calculation used to derive the σ_θ values for 10 minute and 60 minute averaging times. The use of averaging (use of the sample mean) to compute the ten minute and sixty minute weather data makes the data sensitive to outlying values. Computation of the value of (σ_θ) directly effects the value of the horizontal dispersion coefficients σ_x and σ_y. Examination of the Gaussian Instantaneous Plume Equation (Eqn 1) indicates that larger values of σ_x and σ_y yields smaller plume concentrations Another explanation for the results of the subjective maximum concentration comparison is the speed of dispersal of the plume. The 1 minute averaging time σ_θ values are likely to be smaller than the 60 minute averaging time σ_θ due

TABLE 5 Example of Maximum Concentration Reached Within the Receptor Grid Based Upon Specified Averaging Time (Day 153)

Time	1 Minute	10 Minute	60 Minute
1000	5.26E-04	3.02E-04	1.63E-04
1100	5.14E-04	2.83E-04	1.47E-04
1200	6.44E-04	2.42E-04	1.44E-04
1300	7.29E-04	2.81E-04	1.30E-04
1400	8.32E-04	3.24E-04	1.67E-04
1500	3.93E-04	1.95E-04	6.44E-05
1600	3.21E-04	2.17E-04	1.12E-04
1700	3.77E-04	2.35E-04	1.28E-04
1800	7.57E-04	2.71E-04	1.49E-04

to the averaging used to derive the 60 minute σ_θ. Larger values of σ_θ mean larger values of σ_x and σ_y. Larger values of the horizontal dispersion parameter yield smaller concentrations; therefore, the 1 minute averaging time will yield larger maximum concentrations.

Comparison of Average Concentrations by Averaging Time

A subjective comparison of the average concentrations calculated at the locations of the maximum concentrations show that the average concentration using sixty minute averaging time were larger than the average concentrations at one minute and sixty minute averaging times. In all but one case of the nine examined, the sixty minute averaging time yielded the highest average concentration at the grid point of the largest maximum concentration. The probable cause of this result is that the sixty minute meteorological

TABLE 6 Example of Average Concentration Reached at the Location of the Maximum Concentration Within the Receptor Grid Based Upon Specified Averaging Time

Time	1 Minute	10 Minute	60 Minute
1000	1.004E-04	9.563E-05	1.589E-04
1100	2.383E-05	1.030E-04	1.431E-04
1200	6.383E-05	7.487E-05	4.104E-04
1300	4.083E-05	8.700E-05	1.258E-04
1400	4.863E-05	1.161E-04	1.617E-04
1500	2.607E-05	5.847E-05	6.317E-05
1600	4.825E-05	9.032E-05	1.091E-04
1700	7.766E-05	1.042E-04	1.244E-04
1800	9.144E-05	1.144E-04	1.434E-04

data assumes only one wind speed and one wind direction for each of the puffs released; therefore, they follow one another on their trajectory in the grid. When using one minute weather data, there exists the possibility that sixty separate trajectories are generated for each puff which would tend to spread out the released material over a wider area. The same is true of ten minute averaging, but release would likely be over a area wider than the sixty minute data area, but narrower than the one minute data area.

Results of ANOVA Based on Averaging Times

The first experiment examined using ANOVA and Tukey's procedure was a one-to-one comparison between the locations of the three maximum concentrations achieved in the receptor grid for the three averaging times examined. Table 6 indicates the total number of times that the indicated comparison occurred. This table indicates that the receptor grid concentrations computed using one minute and ten minute weather data are

TABLE 7 Total Number of Statistically Significant Differences of Calculated Maximum Concentration Between the Averaging Times Indicated

Averaging Times Compared	1 - 10 Differ	10 - 60 Differ	1 - 60 Differ
Total	15/26	17/26	26/26

statistically significantly different about the same number of times they are statistically the same. The comparison of the receptor grid concentrations computed using ten minute and sixty minute weather data were statistically significantly different from each other approximately 65% of the time during these experiment. However, concentrations computed using one minute and sixty minute weather data were statistically significantly different in all cases examined by this research.

Results of ANOVA Based on Coordinates Obtained from Averaging Times

The second experiment conducted using ANOVA and Tukey's Procedure was a comparison of concentrations at coordinates obtained from three maximum concentrations for each averaging time. Table 7 illustrates the results of this experiment. For example, 5/27 (row 2 - column 2) indicates that of the 27 experiments performed, 5 showed a statistically significant difference between using one minute and ten minute weather data at the coordinates of the three largest concentrations occurring in the receptor grid when one minute averaging time was used to determine the coordinates.

TABLE 8 Total Number of Statistically Significant Differences Between the Concentrations at the Coordinates of Averaging Times Indicated

Origin of Coordinates (Averaging Time)	1 - 10 Differ	1 - 60 Differ	10 - 60 Differ
1 Minute	5/27	12/27	4/27
10 Minute	13/27	21/27	9/27
60 Minute	18/26	26/26	17/26

Using coordinates determined from the locations of the three largest concentrations using one minute weather data, the results of the ANOVA show that there in these experiments, there were never more than 50% of the experiments showing a statistically significant difference between averaging times. The coordinates from the 10 minute weather data show that in slightly more than 50% of the experiments show a statistically significant difference between using 1 minute and 10 minute weather data. However, the same coordinates show that in more than 75% of the experiments, there was a statistically significant difference between 1 minute and 60 minute weather data. Additionally, the coordinates from the 60 minute meteorological data show that regardless of averaging time, at least 70% of the experiments show a statistically significant difference between the averaging times. Moreover, the 60 minute versus 1 minute weather data showed a statistically significant difference in 100% of the cases examined.

Summary

In each of the experiments performed in this study, 100% of the experiments showed a statistically significant difference between the use of one minute versus sixty minute meteorological data.

Comparison of ten minute averaging time to one minute or sixty minute averaging time was statistically significantly different in more than 50% of the experiments. Although when comparisons of averaging times were done using coordinates generated from the locations of the three largest concentrations for each averaging time, the results show that less than 50% of the experiments comparing the ten minute averaging time to the one minute or sixty minute averaging time are statistically significantly different.

V. Conclusions

Introduction

Analysis of the receptor grid plume concentrations for the varying averaging times reveals a distinct difference between using one minute and sixty minute averaging times in all cases examined by this research effort. The analysis also showed differences exist between using ten minute averaging time versus one minute or sixty minute averaging times. This chapter translates the recognition of these differences among averaging times into recommendations for future modeling of Explosive Ordnance Disposal (EOD) Open Burning (OB) operations.

Recommendations

Maximum Concentrations. The data from this research showed that in all cases, the largest maximum concentrations reached in each receptor grid occurred when one minute meteorological data was used. The mostly likely cause of this is that the ten minute and sixty minute standard deviations of the wind (sigma thetas) were affected by larger outlier values in the data set. A remedy for this problem would be the use of a "10% trimmed mean" which would rid the data set of extreme values (whether large or small). The use of the trimmed mean might bring the data closer to the true mean.

This result might also indicate that when examining acute, short-term, exposure, it is more important to use one minute or ten minute meteorological data. The one-minute and, to a lesser extent, ten minute data are less likely to have a large (sigma theta) during the times when OB is likely to take place, i.e., during the day. This smaller (sigma theta) signifies the likelihood that the puff will not diffuse out as quickly as a puff with a larger (sigma theta), i.e. sixty minute weather data. Due to the large number of chemicals which could be released during an OB event, constituents with acute exposure health standards

should be examined with the information concerning the maximum concentrations reached with one minute weather data.

Average Concentrations. The data from this research shows that in all but one case examined, the sixty minute averaging time yielded the highest average concentrations at the grid points where maximum concentrations were reached in the receptor grid. This information would tend to be useful when assessing chronic, long-term, exposures to variousl chemical constituents. The use of one set of meteorological data for the time period of interest would be the conservative approach because the puffs released during an EOD Open Burning operation would all follow the same trajectory; therefore, the average concentration would tend to be larger than puffs released with differing trajectories, i.e, more area over which to release material.

Comparison of Averaging Times. Analysis of Variance (ANOVA) and Tukey's Procedure were used to determine whether a statistically significant difference existed between the use of meteorological data with varying averaging times. In each case where one minute was compared to sixty minute averaging time, a statistically significant difference existed. This difference was most likely due to the method of determing the average (sigma theta) for the averaging time. Outliers in the data set can have a profound effect upon the concentrations in the receptor grid. The average concentrations for the receptor points examined in this research effort were larger for the sixty minute averaging. The use of sixty minute averaging time weather data tends to support the current air pollution modeling practice of one set of weather data during the time period of interest. Although, the weather data used in the PUFFY model is sixty minute weather data, i.e., the time period of interest, versus the ten minute weather data used in most air pollution models through out the time period of interest, i.e., one hour in this case.

Depending upon the reason why the PUFFY model is being used, i.e., acute vs chronic exposures, it may be appropriate to use one averaging time for acute exposure and

another averaging time for chronic exposures. In any case it is important for future EOD Open Burning models to account for this difference when designing the model.

Further Research

Several opportunities exist for future research on the issue of models for Explosive Ordnance Disposal OB operations. The model developed for this research effort employed several simplifying limitations. The effective plume height was assumed in the PUFFY model, while a more complicated model would calculate the effective plume height based upon meteorological data as well as data about the OB operation (the source).

The PUFFY model used an imaginary source term to calculate the plume concentrations. A more complex model's use of emission data generated by Dugway Proving Ground experiments to develop emissions factor could be used to develop a more realistic source term. The PUFFY model used a static value of the source term, i.e., the same source strength for each puff, a more complex model's use of randomized emission data would also make the model more realistic. The time of release for the puffs was set at one per minute for the PUFFY model. The use of randomized puff release times would also serve to make the model mirror reality more closely.

Finally, this research effort did not address the effects of the time of day on the plume concentrations in the receptor grid. The focus of future research on the time of day would seek to determine whether there is an optimal time of day to perform an EOD Open Burning operation. This could possibly help unpermitted facilities to be issued a permit to burn during specified hours of the day.

Bibliography

Bowen, Brent M. "Long-Term Tracer Study at Los Alamos, New Mexico. Part II: Evaluation and Comparison of Several Methods to Determine Dispersion Coefficients," Journal of Applied Meteorology, 33: 1236-1254 (November 1994).

Davis, Lasunda. Environmental Engineer, HQ AETC/CEVP, Randolph AFB TX Telephone interview. 9 Feb 95.

Devore, Jay L. Probability and Statistics for Engineering and the Sciences (Third Edition). Belmont: Duxbury Press, 1991.

Environmental Protection Agency. "40 CFR Parts 144, 260, 264, and 270 Hazardous Waste Miscellaneous Units; Standard: Applicable to Owners and Operators; Final Rule," Federal Register 10 Dec 1987. Washington: 1987.

Griffin, Roger D. Principles of Air Quality Management. Boca Raton: Lewis Publishers, 1994.

Howell, Walker F. and Timothy J. Tope. "Alternatives of Treatment of Waste Munitions Part I: Detonation An Approach to Technically Support Open Burning/Open Detonation Operations," Federal Facilities Environmental Journal, 5: 333-348 (Autumn 1994).

Johnson, Brent. "Bullets, Bombs and RCRA," Federal Facilities Environmental Journal, 5: 9-15 (Spring 1994).

Kunkel, Bruce A. AFTOX 4.0 - The Air Force Toxic Chemical Dispersion Model - A User's Guide. Environmental Research Papers, No. 1083; PL-TR-91-2119. Hanscom AFB: Phillips Laboratory Directorate of Geophysics, 1991.

Lucas, Joseph H. and John R. Bentley. "Development and Use of Critical Source Release Parameters for Air Dispersion Modeling of Open Burning and Open Detonation Treatment Units," Proceedings of the Air and Waste Management Association 88th Annual Meeting and Exhibition. 95-MP23.05. San Antonio: Air and Waste Management Association, 1995.

Mitchell, A. Edgar, Jr.. "A Comparison of Short-Term Dispersion Estimates Resulting from Various Atmospheric Stability Classification Schemes," Atmospheric Environment, 16: 765-773 (April 1982).

Seinfeld, John H. Atmospheric Chemistry and Physics of Air Pollution. New York: John Wiley and Sons, 1986.

Texas Natural Resource Conservation Commission and Environmental Protection Agency. "RCRA Part B Permit to Operate an OB/OD Thermal Treatment Unit and Subpart X Permit to Operate an OB/OD Thermal Treatment Unit" (Apr 1992, June 1992).

Tope, Timothy J. and Walker F. Howell. "Alternatives for Treatment of Waste Munitions Part I: The Role of Open Burning/Open," Federal Facilities Environmental Journal, 5: 137-150 (Summer 1994).

Turner, D. Bruce. Workbook of Atmospheric Dispersion Estimates. Cincinnati: U.S. Department of Health, Education and Welfare, 1969.

Weil, J.C., and others. "Atmospheric Dispersion Model Development for Open Burn/Open Detonation Emissions," Proceedings of the Air and Waste Management Association 88th Annual Meeting and Exhibition. 95-MP22A.05. San Antonio: Air and Waste Management Association, 1995.

Witt-Smith, Carol A. "RCRA Regulatory Requirements for Explosives and Open Burning and Open Detonation (OB/OD) Miscellaneous Units," Proceedings of the Air and Waste Management Association 88th Annual Meeting and Exhibition. 95-TA22B.03. San Antonio: Air and Waste Management Association, 1995.

Appendix A. 'PUFFY' FORTRAN 77 Code

```
PROGRAM PUFFY
C
C  FILE NAME:  'PUFFY.F'
C
C  DECLARATION OF VARIABLE TYPES
      REAL     ALPHA, STEP
      REAL     STRM, XTRM, YTRM, ZTRM, SUM, CONCEN, AGAMMA, X, Y, HYP, H
      INTEGER  TPER, P, TM, PUFF, REM, XREF, YREF, GRIDX, GRIDY
      INTEGER  HOUR, HOUR10, HOUR60, TIM, MININCR, INCR, PERIOD, TPERIOD
      INTEGER  XCOORD, YCOORD, N
C
C
C  DIMENSION STATEMENTS
      REAL TEMP(60,4), RH(60,4), WSPEED(60,4), WDIR(60,4)
      REAL STHETA(60,4)
      REAL DIST(60),TOP10(10),COORDX(10),COORDY(10), WHEN(10)
      REAL CONC(-101:101,-101:101), MAXC(-101:101,-101:101)
      REAL CONCMX(-101:101,-101:101), AVG(-101:101,-101:101)
      REAL SP(60), A(60), SOURCE(60)
      REAL DTDZ(60), ZSP(60), C(60), D(60)
      INTEGER STN(60), YR(60), DATE(60), TIME(60)
      INTEGER HGT(60,4)
C
C
C  DATA STATEMENT
C**********************************************************************
C  SOURCE - Number of puffs released and the source strength assigned to
C           each puff
C**********************************************************************
      DATA SOURCE/60*1000.0/
C
C
C  VARIABLE INITIALIZATION
      REM = 0
      TIM = 0
      MININCR = 0
      N = 0
      CONCEN = 0.0
      AGAMMA = 0.0
      X = 0.0
      Y = 0.0
      HYP = 0.0
      STRM = 0.0
      XTRM = 0.0
      YTRM = 0.0
      ZTRM = 0.0
      SUM = 0.0
C
```

```
C
C  CONSTANTS
C*********************************************************************
C  H         - Effective Plume Height (meters)
C  GRIDX     - Number of grid points extending from the source in the +/-
C  GRIDY     - Number of grid points extending from the source in the +/-
C  STEP      - Distance between grid points (meters)
C  TPER      - Weather Data Averaging Time
C  INCR      - Number of divisions of one minute used to for calculations
C  HOUR      - Time of interest to begin reading 1 minute weather data
C  HOUR10    - Time of interest to begin reading 10 minute weather data
C  HOUR60    - Time of interest to begin reading 60 minute weather data
C  PERIOD    - Length of time of interest for run (hours)
C*********************************************************************
      H = 25.0
      GRIDX = 20
      GRIDY = 20
      STEP = 50.0
      TPER = 1
      INCR = 4
      HOUR = 1600
      HOUR10 = HOUR + 10
      HOUR60 = HOUR + 100
      PERIOD = 1
C
C
C  FILE DECLARATIONS
C*********************************************************************
C  WEATHER DATA FILES GENERATED BY 'metall.f':
C    First character, i.e.,  'S', = station
C    Second character, i.e., '1', = station number
C    Third - Fourth characters, i.e., '10', = averaging time (TPER)
C    Remaining characters, i.e., 'min', = minute
C*********************************************************************
      OPEN (UNIT = 7,  FILE = 's21min',    STATUS = 'OLD')
      OPEN (UNIT = 8,  FILE = 's210min',   STATUS = 'OLD')
      OPEN (UNIT = 9,  FILE = 's260min',   STATUS = 'OLD')
C

C*********************************************************************
C  'CONC1'  - store location (x,y) and concentration for each minute
C  'PTMAX1' - store location (x,y) and value of maximum concentration
C             ever reached during the time period of interest
C             (for each grid point)
C  'MAX1'   - store location (x,y) and value of cumulative concentration
C             reached during the time period of interest
C             (for each grid point)
C  'AVG1'   - store location (x,y) and value of average concentration
C             at each grid point during the time period of interest
C*********************************************************************
```

```
      OPEN (UNIT = 10, FILE = 'conc1',      STATUS = 'UNKNOWN')
      OPEN (UNIT = 11, FILE = 'ptmax1',     STATUS = 'UNKNOWN')
      OPEN (UNIT = 12, FILE = 'max1',       STATUS = 'UNKNOWN')
      OPEN (UNIT = 13, FILE = 'avg1',       STATUS = 'UNKNOWN')
      OPEN (UNIT = 14, FILE = 'conc10',     STATUS = 'UNKNOWN')
      OPEN (UNIT = 15, FILE = 'ptmax10',    STATUS = 'UNKNOWN')
      OPEN (UNIT = 16, FILE = 'max10',      STATUS = 'UNKNOWN')
      OPEN (UNIT = 17, FILE = 'avg10',      STATUS = 'UNKNOWN')
      OPEN (UNIT = 18, FILE = 'conc60',     STATUS = 'UNKNOWN')
      OPEN (UNIT = 19, FILE = 'ptmax60',    STATUS = 'UNKNOWN')
      OPEN (UNIT = 20, FILE = 'max60',      STATUS = 'UNKNOWN')
      OPEN (UNIT = 21, FILE = 'avg60',      STATUS = 'UNKNOWN')
      OPEN (UNIT = 22, FILE = 'ten1',       STATUS = 'UNKNOWN')
      OPEN (UNIT = 23, FILE = 'ten10',      STATUS = 'UNKNOWN')
      OPEN (UNIT = 24, FILE = 'ten60',      STATUS = 'UNKNOWN')
      OPEN (UNIT = 25, FILE = 'stat1',      STATUS = 'UNKNOWN')
      OPEN (UNIT = 26, FILE = 'stat10',     STATUS = 'UNKNOWN')
      OPEN (UNIT = 27, FILE = 'stat60',     STATUS = 'UNKNOWN')
C
C************************USED DURING ANALYSIS RUNS***********************
C*************** TAKE COMMENTS OUT DURING THE ANALYSIS RUNS*************
C  N LOOP - used to read the appropriate data file for the coordinates
C           of the TOP TEN concentrations reached in the receptor grid
C           for each of the averaging time
C
C      DO 800 N = 1,10
C        IF (TPER.EQ.1) THEN
C          READ (22,*) WHEN(N), COORDX(N), COORDY(N), TOP10(N)
C          XCOORD = COORDX(N)
C          YCOORD = COORDY(N)
C          WRITE(*,*) XCOORD,YCOORD
C        ELSEIF (TPER.EQ.10) THEN
C          READ (23,*) WHEN(N), COORDX(N), COORDY(N), TOP10(N)
C          XCOORD = COORDX(N)
C          YCOORD = COORDY(N)
C          WRITE(*,*) XCOORD,YCOORD
C        ELSEIF (TPER.EQ.60) THEN
C          READ (24,*) WHEN(N), COORDX(N), COORDY(N), TOP10(N)
C          XCOORD = COORDX(N)
C          YCOORD = COORDY(N)
C          WRITE(*,*) XCOORD,YCOORD
C        ENDIF
C************************END OF SECTION*******************************

C**********************************************************************
C  TPERIOD - time interval of interest (minutes)
C  P LOOP  - Keeps track of the puff releases and total time of interest
C  REM     - used to determine whether proper weather data is read
C**********************************************************************
      TPERIOD = PERIOD * 60
      DO 600 P = 1, TPERIOD
      REM = MOD(P,10)
```

```
C
C
C*********************************************************************
C  SUBROUTINE initializes the concentration grids, i.e.,
C  the changing concentration grid and the grid keeping track of the
C  maximum concentration at each grid poing during a 2 hour period
C*********************************************************************
      CALL INITIAL (CONC, GRIDX, GRIDY, P, MAXC, CONCMX)
C
        IF (N.GT.1) GOTO 2000
        IF (P.GT.60) GOTO 1000
C
C*********************************************************************
C  READING IN THE WEATHER DATA FOR THE TAGGED PUFF
C  ELSEIF  statements are used to make sure correct meteorological data
C          is read in at the correct time, i.e., one puff at a time
C  TPER    =  1 - new data will be read in each time through the loop
C  TPER    = 10 - new data will be read in after each set of 10 runs
C  TPER    = 60 - same data for each puff
C  RPTDATA - Reads in puff data that is the same as previous puff data
C*********************************************************************
  100   IF (TPER.EQ.1) THEN
         READ(7,*) STN(P), YR(P), DATE(P), TIME(P),
     +   (HGT(P,J),TEMP(P,J), RH(P,J), WSPEED(P,J),
     +   WDIR(P,J), STHETA(P,J),J=1,4)
C
        ELSEIF ((TPER.EQ.10).AND.(REM.EQ.1)) THEN
         READ(8,*) STN(P), YR(P), DATE(P), TIME(P),
     +   (HGT(P,J),TEMP(P,J), RH(P,J), WSPEED(P,J),
     +   WDIR(P,J), STHETA(P,J),J=1,4)
C
        ELSEIF ((TPER.EQ.10).AND.(REM.NE.1)) THEN
         CALL  RPTDATA (STN, YR, DATE, TIME, SP, A, DTDZ, ZSP, HGT,
     +                  TEMP, RH, WSPEED, WDIR, STHETA, P)
         GOTO 1000
C
        ELSEIF ((TPER.EQ.60).AND.(P.EQ.1)) THEN
         READ(9,*) STN(P), YR(P), DATE(P), TIME(P),
     +   (HGT(P,J),TEMP(P,J), RH(P,J), WSPEED(P,J),
     +   WDIR(P,J), STHETA(P,J),J=1,4)
C
        ELSEIF ((TPER.EQ.60).AND.(P.NE.1)) THEN
         CALL  RPTDATA (STN, YR, DATE, TIME, SP, A, DTDZ, ZSP, HGT,
     +                  TEMP, RH, WSPEED, WDIR, STHETA, P)
         GOTO 1000
        ENDIF
```

```
C*********************************************************************
C  These statements are used to make sure the data is read from the
C   appropriate place in the data file
C*********************************************************************
        IF ((TIME(P).EQ.HOUR10).AND.(P.EQ.1)) GOTO 2000
C
        IF ((TIME(P).EQ.HOUR60).AND.(TPER.EQ.60).AND.(P.EQ.1)) THEN
          GOTO 2000
        ELSEIF (P.EQ.1) THEN
          GOTO 100
        ENDIF
C
        IF ((TIME(P).EQ.HOUR).AND.(TPER.NE.10).AND.(P.EQ.1)) THEN
          GOTO 2000
        ELSEIF (P.EQ.1) THEN
          GOTO 100
        ENDIF
C
C
C ********PRINT OUT DATA LINES HERE TO CHECK FOR ACCURACY **************
 2000   WRITE(*,10)  STN(P), YR(P), DATE(P), TIME(P),
     +   (HGT(P,J),TEMP(P,J), RH(P,J), WSPEED(P,J),
     +   WDIR(P,J), STHETA(P,J),J=1,4)
  10    FORMAT(I2,I5,I4,I5,1X,4(I2,3F5.1, F6.1,F5.1))
        WRITE(*,11) P, N
  11    FORMAT(2I4)
C*********************************************************************
C
C  CONVERSION OF WIND SPEED FROM MPH TO M/S
        WSPEED(P,1) = WSPEED(P,1)*(1609./1.)*(1./60.)*(1./60.)
C
C
C*********************************************************************
C  SUBROUTINE calculates horizontal and vertical stability parameters
C  and horizontal coefficients and exponents
C*********************************************************************
         CALL STABPAR(STHETA, TEMP, ZSP, P, A, B)
C
C
C*****************************LOOP*************************************
C  TM    - time counter helps to ensure the proper puff is assigned
C          the proper "age" in the grid
C  PUFF - tag for the puff of interest
C*********************************************************************
 1000  DO 500 TM = 1,P
        PUFF = P - TM + 1
        IF (PUFF.GT.60) GOTO 500
C
C
```

```
C*****************************LOOP*************************************
C  MININCR - this counter is set to the number of partitions desired
C             per minute, i.e., (1,4 => 15 minute increments),
C             (1,10 => 6 minute increments)
C  (Depending upon what MININCR is changed to, the variable TIM must
C   also be changed (automatically) to reflect the new increment, i.e.,
C   [15 minute increments => TIM = (TM*60) + (MININCR*15) - 60],
C   [6 minute increments  => TIM = (TM*60) + (MININCR*6) - 60])
C  DIST     - distance downwind from source to center of puff
C            (SPEED*TIME = DISTANCE)
C**********************************************************************
        DO 400 MININCR = 1,INCR
          TIM = (TM*60) + (MININCR*(60/INCR)) - 60
          DIST(PUFF) = WSPEED(PUFF,1)*(TIM)
C
C
C**********************************************************************
C  SUBROUTINE calculates vertical diffusion coefficients and exponents
C**********************************************************************
        CALL CDSTAB(ZSP, DIST, C, D, PUFF)
C
C
C**********************************************************************
C  SUBROUTINE calculates wind direction in + Cartesian Coordinates
C**********************************************************************
        CALL DEGREE (WDIR, ALPHA, P)
C
C
C**********************************************************************
C  SUBROUTINE calculates the concentrations at each point in the
C  stationary frame of reference grid at each individual minute
C**********************************************************************
       CALL REFGRID(XREF, YREF, GRIDX, GRIDY, ALPHA, PUFF, A, B, C, D,
     +              DIST, SOURCE, WSPEED, TIM, CONC, STEP, H, INCR)
C
C  GO BACK TO CHANGE THE MINUTE INCREMENT (MININCR)
  400     CONTINUE
C
C  GO BACK TO CHANGE THE TIME INCREMENT (TM)
  500   CONTINUE
C
C
C**********************************************************************
C  SUBROUTINE calculates the maximum concentration ever reached during
C  the time period of interest (at each grid point)
 C*********************************************************************
      CALL PTMAX (CONC, CONCMX, GRIDX, GRIDY)
C
C
```

```
C*********************************************************************
C  SUBROUTINE calculates the cumulative concentration at each point in
C  the stationary frame of reference grid
C*********************************************************************
      CALL MAXCONC (CONC, MAXC, GRIDX, GRIDY)

C*********************************************************************
C  SUBROUTINE calculates the "Top Ten" concentrations reached in the
C  receptor grid
C*********************************************************************
      CALL TOPTEN (P, GRIDX, GRIDY, CONC, TOP10, COORDX, COORDY, WHEN)
C
C
C************************USED DURING REGULAR RUNS************************
C*****COMMENT (C) THIS SECTION OUT WHEN DOING THE ANALYSIS RUN**********
C  Writing the reference grid to the screen before returning to read
C   data about another puff
C  The reference grid is sized to fit the screen
C  Writes locations and concentrations to a file for later graphing
C  File Name:  'conc1'
C
      IF (TPER.EQ.1) THEN
        WRITE(*,*) 'CONCENTRATION AT EACH POINT DURING THIS RUN'
        WRITE(*,19) ((CONC(XREF,YREF), XREF = -6,6),
     +               YREF=GRIDY,-GRIDY,-1)
   19   FORMAT(13E10.3)
        DO 110 XREF = -GRIDX,GRIDX,1
          DO 120 YREF = GRIDY,-GRIDY,-1
            WRITE(10,23) XREF, YREF, CONC(XREF,YREF)
  120     CONTINUE
  110   CONTINUE
   23   FORMAT(2I4, E10.3)
        WRITE(*,21) P
        WRITE(10,21) P
   21   FORMAT(I5)
C
      ELSEIF (TPER.EQ.10) THEN
        WRITE(*,*) 'CONCENTRATION AT EACH POINT DURING THIS RUN'
        WRITE(*,19) ((CONC(XREF,YREF), XREF = -6,6),
     +               YREF=GRIDY,-GRIDY,-1)
        DO 130 XREF = -GRIDX,GRIDX
          DO 140 YREF = GRIDY,-GRIDY,-1
            WRITE(14,23) XREF, YREF, CONC(XREF,YREF)
  140     CONTINUE
  130   CONTINUE
        WRITE(*,21) P
        WRITE(14,21) P
C
      ELSEIF (TPER.EQ.60) THEN
        WRITE(*,*) 'CONCENTRATION AT EACH POINT DURING THIS RUN'
        WRITE(*,19) ((CONC(XREF,YREF), XREF = -6,6),
     +               YREF=GRIDY,-GRIDY,-1)
```

```
        DO 150 XREF = -GRIDX,GRIDX
          DO 160 YREF = GRIDY,-GRIDY,-1
            WRITE(18,23) XREF, YREF, CONC(XREF,YREF)
  160     CONTINUE
  150   CONTINUE
        WRITE(*,21) P
        WRITE(18,21) P
      ENDIF

C*************************END OF SECTION*********************************
C
C
C************************USED DURING ANALYSIS RUNS***********************
C**************TAKE COMMENTS OUT DURING THE ANALYSIS RUNS***************
C
C       IF (TPER.EQ.1) THEN
C         WRITE(*,*) 'CONCENTRATION AT THIS POINT DURING THIS RUN'
C         WRITE(*,20)  CONC(XCOORD,YCOORD)
C         WRITE(25,20) CONC(XCOORD,YCOORD)
C   20    FORMAT(E10.3)
C         WRITE(*,22) P
C         WRITE(25,22) P
C   22    FORMAT(I3)
C       ELSEIF (TPER.EQ.10) THEN
C         WRITE(*,*) 'CONCENTRATION AT THIS POINT DURING THIS RUN'
C         WRITE(*,20)  CONC(XCOORD,YCOORD)
C         WRITE(26,20) CONC(XCOORD,YCOORD)
C         WRITE(*,22) P
C         WRITE(26,22) P
C       ELSEIF (TPER.EQ.60) THEN
C         WRITE(*,*) 'CONCENTRATION AT THIS POINT DURING THIS RUN'
C         WRITE(*,20)  CONC(XCOORD,YCOORD)
C         WRITE(27,20) CONC(XCOORD,YCOORD)
C         WRITE(*,22) P
C         WRITE(27,22) P
C       ENDIF
C
C*************************END OF SECTION*********************************
C
C
C  GO BACK TO CALCULATE INFORMATION FOR ANOTHER PUFF
  600 CONTINUE
C
C
C***********************************************************************
C  SUBROUTINE calculates the average concentration at each grid
C  point over the time period of interest
C***********************************************************************
      CALL AVRG(AVG, MAXC, TPERIOD, GRIDX, GRIDY)
C
C
```

```
C************************USED DURING REGULAR RUNS************************
C*****COMMENT (C) THIS SECTION OUT WHEN DOING THE ANALYSIS RUN*********
C  Writing the maximum concentration to ever occur at each grid point
C    to the screen
C  File Name:  'ptmax1'
C
      IF (TPER.EQ.1) THEN
        WRITE(*,*) 'MAXIMUM CONCENTRATION AT EACH POINT AT ANY TIME'
        WRITE(*,19) ((CONCMX(XREF,YREF), XREF = -6,6),
     +                YREF=GRIDY,-GRIDY,-1)
        DO 170 XREF = -GRIDX,GRIDX
          DO 180 YREF = GRIDY,-GRIDY,-1
            WRITE(11,23) XREF, YREF, CONCMX(XREF,YREF)
  180     CONTINUE
  170   CONTINUE
        WRITE(*,*) 'TPER = ', TPER
        WRITE(11,21) TPER
C
      ELSEIF (TPER.EQ.10) THEN
        WRITE(*,*) 'MAXIMUM CONCENTRATION AT EACH POINT AT ANY TIME'
        WRITE(*,19) ((CONCMX(XREF,YREF), XREF = -6,6),
     +                YREF=GRIDY,-GRIDY,-1)
        DO 190 XREF = -GRIDX,GRIDX
          DO 210 YREF = GRIDY,-GRIDY,-1
            WRITE(15,23) XREF, YREF, CONCMX(XREF,YREF)
  210     CONTINUE
  190   CONTINUE
        WRITE(*,*) 'TPER = ', TPER
        WRITE(15,21) TPER
C
      ELSEIF (TPER.EQ.60) THEN
        WRITE(*,*) 'MAXIMUM CONCENTRATION AT EACH POINT AT ANY TIME'
        WRITE(*,19) ((CONCMX(XREF,YREF), XREF = -6,6),
     +                YREF=GRIDY,-GRIDY,-1)
        DO 220 XREF = -GRIDX,GRIDX
          DO 230 YREF = GRIDY,-GRIDY,-1
            WRITE(19,23) XREF, YREF, CONCMX(XREF,YREF)
  230     CONTINUE
  220   CONTINUE
        WRITE(*,*) 'TPER = ', TPER
        WRITE(19,21) TPER
      ENDIF

C************************END OF SECTION*****************************
C
C
```

```
C************************USED DURING ANALYSIS RUNS**********************
C**************TAKE COMMENTS OUT DURING THE ANALYSIS RUNS***************
C      IF (TPER.EQ.1) THEN
C        WRITE(*,*) 'MAXIMUM CONCENTRATION AT THIS POINT AT ANY TIME'
C        WRITE(*,20)  CONCMX(XCOORD,YCOORD)
C        WRITE(*,*) 'TPER = ', TPER
C
C      ELSEIF (TPER.EQ.10) THEN
C        WRITE(*,*) 'MAXIMUM CONCENTRATION AT THIS POINT AT ANY TIME'
C        WRITE(*,20)  CONCMX(XCOORD,YCOORD)
C        WRITE(*,*) 'TPER = ', TPER
C
C      ELSEIF (TPER.EQ.60) THEN
C        WRITE(*,*) 'MAXIMUM CONCENTRATION AT THIS POINT AT ANY TIME'
C        WRITE(*,20)  CONCMX(XCOORD,YCOORD)
C        WRITE(*,*) 'TPER = ', TPER
C      ENDIF
C
C*****************************END OF SECTION*****************************
C
C
C************************USED DURING REGULAR RUNS************************
C*****COMMENT (C) THIS SECTION OUT WHEN DOING THE ANALYSIS RUN**********
C  Writing the cumulative concentration at each point in the receptor
C    grid to the screen and to a file
C  File Name:  'max1'
C
      IF (TPER.EQ.1) THEN
        WRITE(*,*) 'CUMULATIVE CONCENTRATION'
        WRITE(*,19) ((MAXC(XREF,YREF), XREF = -6,6),
     +                YREF=GRIDY,-GRIDY,-1)
        DO 240 XREF = -GRIDX,GRIDX
          DO 250 YREF = GRIDY,-GRIDY,-1
            WRITE(12,23) XREF, YREF, MAXC(XREF,YREF)
  250     CONTINUE
  240   CONTINUE
        WRITE(*,*) 'TPER = ', TPER
        WRITE(12,21) TPER
C
      ELSEIF (TPER.EQ.10) THEN
        WRITE(*,*) 'CUMULATIVE CONCENTRATION'
        WRITE(*,19) ((MAXC(XREF,YREF), XREF = -6,6),
     +                YREF=GRIDY,-GRIDY,-1)
        DO 260 XREF = -GRIDX,GRIDX
          DO 270 YREF = GRIDY,-GRIDY,-1
            WRITE(16,23) XREF, YREF, MAXC(XREF,YREF)
  270     CONTINUE
  260   CONTINUE
        WRITE(*,*) 'TPER = ', TPER
        WRITE(16,21) TPER
C
```

```
      ELSEIF (TPER.EQ.60) THEN
        WRITE(*,*) 'CUMULATIVE CONCENTRATION'
        WRITE(*,19) ((MAXC(XREF,YREF), XREF = -6,6),
     +                YREF=GRIDY,-GRIDY,-1)
        DO 280 XREF = -GRIDX,GRIDX
          DO 290 YREF = GRIDY,-GRIDY,-1
            WRITE(20,23) XREF, YREF, MAXC(XREF,YREF)
  290     CONTINUE
  280   CONTINUE
        WRITE(*,*) 'TPER = ', TPER
        WRITE(20,21) TPER
      ENDIF
C
C*****************************END OF SECTION*********************************
C
C
C************************USED DURING ANALYSIS RUNS***********************
C**********TAKE OUT COMMENTS (C) WHEN DOING THE ANALYSIS RUN************
C
C       IF (TPER.EQ.1) THEN
C         WRITE(*,*) 'CUMULATIVE CONCENTRATION'
C         WRITE(*,20)  MAXC(XCOORD,YCOORD)
C         WRITE(*,*) 'TPER = ', TPER
C
C       ELSEIF (TPER.EQ.10) THEN
C         WRITE(*,*) 'CUMULATIVE CONCENTRATION'
C         WRITE(*,20)  MAXC(XCOORD,YCOORD)
C         WRITE(*,*) 'TPER = ', TPER
C
C       ELSEIF (TPER.EQ.60) THEN
C         WRITE(*,*) 'CUMULATIVE CONCENTRATION'
C         WRITE(*,20)  MAXC(XCOORD,YCOORD)
C         WRITE(*,*) 'TPER = ', TPER
C       ENDIF
C
C*****************************END OF SECTION*********************************
C
C
C************************USED DURING REGULAR RUNS************************
C*****COMMENT (C) THIS SECTION OUT WHEN DOING THE ANALYSIS RUN**********
C  Writing the average concentration at each point in the receptor
C    grid to the screen and to a file
C
       IF (TPER.EQ.1) THEN
         WRITE(*,*) 'AVERAGE CONCENTRATION'
         WRITE(*,19) ((AVG(XREF,YREF), XREF = -6,6),
     +                YREF=GRIDY,-GRIDY,-1)
         DO 310 XREF = -GRIDX,GRIDX
           DO 320 YREF = GRIDY,-GRIDY,-1
             WRITE(13,23) XREF, YREF, AVG(XREF,YREF)
  320      CONTINUE
  310    CONTINUE
```

```
        WRITE(*,*) 'TPER = ', TPER
        WRITE(13,21) TPER
C
      ELSEIF (TPER.EQ.10) THEN
        WRITE(*,*) 'AVERAGE CONCENTRATION'
        WRITE(*,19) ((AVG(XREF,YREF), XREF = -6,6),
     +                YREF=GRIDY,-GRIDY,-1)
        DO 330 XREF = -GRIDX,GRIDX
          DO 340 YREF = GRIDY,-GRIDY,-1
            WRITE(17,23) XREF, YREF, AVG(XREF,YREF)
  340     CONTINUE
  330   CONTINUE
        WRITE(*,*) 'TPER = ', TPER
        WRITE(17,21) TPER
C
      ELSEIF (TPER.EQ.60) THEN
        WRITE(*,*) 'AVERAGE CONCENTRATION'
        WRITE(*,19) ((AVG(XREF,YREF), XREF = -6,6),
     +                YREF=GRIDY,-GRIDY,-1)
         DO 350 XREF = -GRIDX,GRIDX
          DO 360 YREF = GRIDY,-GRIDY,-1
            WRITE(21,23) XREF, YREF, AVG(XREF,YREF)
  360     CONTINUE
  350   CONTINUE
        WRITE(*,*) 'TPER = ', TPER
        WRITE(21,21) TPER
      ENDIF
C
C*************************END OF SECTION*******************************
C
C
C************************USED DURING ANALYSIS RUNS**********************
C**********TAKE OUT COMMENTS (C) WHEN DOING THE ANALYSIS RUN************
C
C       IF (TPER.EQ.1) THEN
C         WRITE(*,*) 'AVERAGE CONCENTRATION'
C         WRITE(*,20)  AVG(XCOORD,YCOORD)
C         WRITE(*,*) 'TPER = ', TPER
C
C       ELSEIF (TPER.EQ.10) THEN
C         WRITE(*,*) 'AVERAGE CONCENTRATION'
C         WRITE(*,20)  AVG(XCOORD,YCOORD)
C         WRITE(*,*) 'TPER = ', TPER
C
C       ELSEIF (TPER.EQ.60) THEN
C         WRITE(*,*) 'AVERAGE CONCENTRATION'
C         WRITE(*,20)  AVG(XCOORD,YCOORD)
C         WRITE(*,*) 'TPER = ', TPER
C       ENDIF
C
C*************************END OF SECTION*******************************
C
```

```
C
C************************USED DURING REGULAR RUNS************************
C*******COMMENT (C) OUT THIS ENTIRE SECTION DURING THE ANALYSIS RUN******
C  Writing the TOP TEN concentrations to the screen and to a file
C
      IF (TPER.EQ.1) THEN
        WRITE(*,*) 'TOP TEN CONCENTRATIONS AND WHEN/WHERE THEY OCCUR'
        DO 725 I = 1,10
          WRITE(*,25)  WHEN(I), COORDX(I), COORDY(I), TOP10(I)
          WRITE(22,25) WHEN(I), COORDX(I), COORDY(I), TOP10(I)
   25     FORMAT(3I5,E12.3)
  725   CONTINUE
        WRITE(*,*) 'TPER = ', TPER
        WRITE(22,21) TPER
        WRITE(22,21) HOUR
C
      ELSEIF (TPER.EQ.10) THEN
        WRITE(*,*) 'TOP TEN CONCENTRATIONS AND WHEN/WHERE THEY OCCUR'
        DO 750 I = 1,10
          WRITE(*,25)  WHEN(I), COORDX(I), COORDY(I), TOP10(I)
          WRITE(23,25) WHEN(I), COORDX(I), COORDY(I), TOP10(I)
  750   CONTINUE
        WRITE(*,*) 'TPER = ', TPER
        WRITE(23,21) TPER
        WRITE(23,21) HOUR10
C
      ELSEIF (TPER.EQ.60) THEN
        WRITE(*,*) 'TOP TEN CONCENTRATIONS AND WHEN/WHERE THEY OCCUR'
        WRITE(*,*) 'TOP TEN CONCENTRATIONS AND WHEN/WHERE THEY OCCUR'
        DO 775 I = 1,10
          WRITE(*,25)  WHEN(I), COORDX(I), COORDY(I), TOP10(I)
          WRITE(24,25) WHEN(I), COORDX(I), COORDY(I), TOP10(I)
  775   CONTINUE
        WRITE(*,*) 'TPER = ', TPER
        WRITE(24,21) TPER
        WRITE(24,21) HOUR60
      ENDIF
C
C***************************END OF SECTION*****************************
C
C
C************************USED DURING ANALYSIS RUNS************************
C************COMMENT THIS STATEMENT OUT WHEN DOING REGULAR RUN***********
C  End of N loop
C
C  800 CONTINUE
C***************************END OF SECTION*****************************
C
C
C**************************END OF MAIN PROGRAM*************************
      STOP
      END
```

```
      SUBROUTINE AVRG(AVG, MAXC, TPERIOD, GRIDX, GRIDY)
C
C  THIS SUBROUTINE CALCULATES THE AVERAGE CONCENTRATION OVER THE TIME
C    PERIOD OF INTEREST
C
C  DECLARATION OF VARIABLE TYPES
      INTEGER  GRIDX, GRIDY, TPERIOD
C
C  DIMENSION STATEMENTS
      REAL AVG(-101:101, -101:101), MAXC(-101:101, -101:101)
C
      DO 100 XREF = -GRIDX, GRIDX
        DO 200 YREF = GRIDY, -GRIDY, -1
          AVG(XREF,YREF) = MAXC(XREF,YREF)/TPERIOD
  200   CONTINUE
  100 CONTINUE
C
C      WRITE(*,15) ((AVG(XREF,YREF),XREF = -GRIDX,GRIDX),
C     +             YREF = GRIDY,-GRIDY,-1)
C   15 FORMAT (13E10.3)
C
      RETURN
      END
```

```
      SUBROUTINE CDSTAB(ZSP, DIST, C, D, PUFF)
C
C  THIS SUBROUTINE CALCULATES VERTICAL STABILITY PARAMETER COEFFICIENTS
C    AND EXPONENTS
C
C  DECLARATION OF VARIABLE TYPES
      INTEGER PUFF
C
C  DIMENSION STATEMENTS
      REAL DIST(60), C(60), D(60), ZSP(60)
C
      IF ((ZSP(PUFF).LE.1.0).AND.(DIST(PUFF).LT.745.)) THEN
        C(PUFF) = 0.0414
        D(PUFF) = 1.3155
      ELSEIF ((ZSP(PUFF).LE.1.0).AND.(DIST(PUFF).GE.745.)) THEN
        C(PUFF) = 1.928E-4
        D(PUFF) = 2.1234
      ELSEIF ((ZSP(PUFF).LE.2.0).AND.(DIST(PUFF).LT.745.)) THEN
        C(PUFF) = 0.1036
        D(PUFF) = 1.0026
      ELSEIF ((ZSP(PUFF).LE.2.0).AND.(DIST(PUFF).GE.745.)) THEN
        C(PUFF) = 0.0534
        D(PUFF) = 1.1029
      ELSEIF ((ZSP(PUFF).LE.3.0).AND.(DIST(PUFF).LT.2000.)) THEN
        C(PUFF) = 0.1173
        D(PUFF) = 0.9112
      ELSEIF ((ZSP(PUFF).LE.3.0).AND.(DIST(PUFF).GE.2000.)) THEN
        C(PUFF) = 0.4422
        D(PUFF) = 0.7382
      ELSEIF ((ZSP(PUFF).LE.4.0).AND.(DIST(PUFF).LT.1100.)) THEN
        C(PUFF) = 0.0975
        D(PUFF) = 0.8414
      ELSEIF ((ZSP(PUFF).LE.4.0).AND.(DIST(PUFF).GE.1100.)) THEN
        C(PUFF) = 0.6097
        D(PUFF) = 0.5808
      ELSEIF ((ZSP(PUFF).LE.5.0).AND.(DIST(PUFF).LT.1400.)) THEN
        C(PUFF) = 0.1050
        D(PUFF) = 0.7692
      ELSEIF ((ZSP(PUFF).LE.5.0).AND.(DIST(PUFF).GE.1400.)) THEN
        C(PUFF) = 0.8788
        D(PUFF) = 0.4771
      ELSEIF ((ZSP(PUFF).GT.5.0).AND.(DIST(PUFF).LT.1400.)) THEN
        C(PUFF) = 0.0617
        D(PUFF) = 0.7884
      ELSEIF ((ZSP(PUFF).GT.5.0).AND.(DIST(PUFF).GE.1400.)) THEN
        C(PUFF) = 0.9990
        D(PUFF) = 0.4771
      ENDIF
      RETURN
      END
```

```
      SUBROUTINE DEGREE (WDIR, ALPHA, P)
C
C  THIS SUBROUTINE CONVERTS WIND DIRECTION TO + CARTESIAN (DEGREES)
C
C  DECLARATION OF VARIABLE TYPES
      REAL  DIRNEW, XNEW, YNEW, XTRANS, YTRANS, ALPHA
      INTEGER  P
C
C  DIMENSION STATEMENTS
      REAL WDIR (60,4)
C
      DIRNEW = WDIR(P,1) + 180.
      IF (DIRNEW.LT.0.0) DIRNEW = DIRNEW + 360.
      XNEW = COSD(DIRNEW)
      YNEW = SIND(DIRNEW)
      XTRANS = YNEW
      YTRANS = XNEW
      ALPHA = ATAN2D(YTRANS,XTRANS)
      IF (ALPHA.LT.0.0) ALPHA = ALPHA + 360.
      RETURN
      END
```

```
      SUBROUTINE INITIAL (CONC, GRIDX, GRIDY, P, MAXC, CONCMX)
C  THIS SUBROUTINE ZEROES OUT THE GRID WHEN NECESSARY
C
C  DECLARATION OF VARIABLE TYPES
      INTEGER GRIDX, GRIDY, P
C
C  DIMENSION STATEMENTS
      REAL CONC(-101:101,-101:101), MAXC(-101:101,-101:101)
      REAL CONCMX(-101:101,-101:101), TOP10(10)
      INTEGER COORDX(10), COORDY(10)
C
      DO 100 I = -GRIDX, GRIDX
        DO 200 J = GRIDY,-GRIDY,-1
          CONC(I,J) = 0.0
  200   CONTINUE
  100 CONTINUE
C
      IF (P.GT.1) GOTO 1100
C
      DO 300 I = -GRIDX, GRIDX
        DO 400 J = GRIDY, -GRIDY, -1
          CONCMX(I,J) = 0.0
          MAXC(I,J) = 0.0
  400   CONTINUE
  300 CONTINUE
C
      DO 700 I = 1,10
        TOP10(I) = 0.0
        COORDX(I) = 0
        COORDY(I) = 0
  700 CONTINUE
C
 1100 RETURN
      END
```

```
      SUBROUTINE MAXCONC(CONC, MAXC, GRIDX, GRIDY)
C
C  THIS SUBROUTINE CALCULATES THE MAXIMUM CONCENTRATION AT EACH GRID
C    POINT DURING A TWO HOUR PERIOD
C
C  DECLARATION OF VARIABLE TYPES
      INTEGER XREF, YREF, GRIDX, GRIDY
C
C  DIMENSION STATEMENTS
      REAL CONC(-101:101, -101:101), MAXC(-101:101, -101:101)
C
      DO 100 XREF = -GRIDX, GRIDX
        DO 200 YREF = GRIDY, -GRIDY, -1
          MAXC(XREF,YREF) = MAXC(XREF,YREF) + CONC(XREF,YREF)
  200   CONTINUE
  100 CONTINUE
C
      RETURN
      END
```

```
      SUBROUTINE PTMAX(CONC, CONCMX, GRIDX, GRIDY)
C
C  THIS SUBROUTINE FINDS THE MAXIMUM CONCENTRATION AT ANY ONE GRID POINT
C    DURING THE TWO HOUR PERIOD OF INTEREST
C
C  DECLARATION OF VARIABLE TYPES
      INTEGER XREF, YREF, GRIDX, GRIDY
C
C  DIMENSION STATEMENTS
      REAL CONC(-101:101,-101:101), CONCMX(-101:101, -101:101)
C
      DO 100 XREF = -GRIDX, GRIDX
        DO 200 YREF = GRIDY, -GRIDY, -1
          IF (P.EQ.1) GOTO 1000
          GOTO 1100
 1000     CONCMX(XREF,YREF) = CONC(XREF,YREF)
 1100     IF (CONC(XREF,YREF).GT.CONCMX(XREF,YREF))
     +      CONCMX(XREF,YREF) = CONC(XREF,YREF)
  200   CONTINUE
  100 CONTINUE
      RETURN
      END
```

```
      SUBROUTINE REFGRID(XREF, YREF, GRIDX, GRIDY, ALPHA, PUFF, A, B,
     +          C, D, DIST, SOURCE, WSPEED, TIM, CONC, STEP, H, INCR)
C
C  DECLARATION OF VARIABLE TYPES
      REAL  X, Y, Z, SQ, HYP, BETA, GAMMA, AGAMMA, ALPHA, XSHIFT, YSHIFT
      REAL  STRM, XTRM, YTRM, ZTRM, SUM, CONCEN, PI, B, STEP, H
      INTEGER XREF, YREF, PUFF, TIM, GRIDX, GRIDY, INCR
C
C  DIMENSION STATEMENTS
      REAL  SIGY(60), SIGX(60), SIGZ(60), A(60), C(60), D(60)
      REAL  DIST(60), SOURCE(60)
      REAL  CONC(-101:101, -101:101)
      REAL  WSPEED(60,4)
C
C  CONSTANTS
      PI = 3.141592654
C
C  INTRODUCTION OF THE OVERALL FRAME OF REFERENCE
C  XREF=> downwind distance (METERS) from common frame of reference
C  X    => XREF * 100
C  YREF=> crosswind distance (METERS) from common frame of reference
C  Y    => YREF * 100
C  BETA=> angle between reference coordinate and the reference X-axis
C  ALPHA=> wind direction ("to-sees")
C  The Z value is zero for ground-level receptor (METERS)
      DO 100 XREF = -GRIDX,GRIDX
        X = XREF * STEP
C
        DO 200 YREF = GRIDY,-GRIDY,-1
         Y = YREF * STEP
C
         Z = 0.
C
         SQ = (X**2) + (Y**2)
         HYP = SQRT (SQ)
C
C  BETA => ANGLE BETWEEN THE REFERENCE X-AXIS AND THE RECEPTOR POSITION
C          Want BETA to be positive
        BETA = ATAN2D(Y,X)
        IF (BETA.LT.0.0) BETA = BETA + 360.
C
C  DETERMINATION OF WHETHER IT IS NECESSARY TO CALCULATE CONCENTRATION
C  If the difference between the wind direction and the angle to the
C    receptor falls in the third or fourth quadrant of the shifted
C    axis the concentration will be set to zero
        GAMMA = ALPHA - BETA
        AGAMMA = ABS(GAMMA)
        IF (GAMMA.LT.0.0) GAMMA = GAMMA + 360.
        IF ((AGAMMA.GE.90.).AND.(AGAMMA.LE.270.)) GOTO 1000

C
```

```
C  THE SIGN OF THE RECEPTOR IS NOT IMPORTANT HERE
C  Depending upon the quadrant of interest, the coordinates of the
C    reference frame are used to determine the coordinates on the
C    shifted frame (based upon the wind direction)
C  The concentration at the negative YSHIFT coordinates are the same
C    as the positive YSHIFT coordinates
         XSHIFT = HYP * COSD(GAMMA)
         YSHIFT = HYP * SIND(GAMMA)
C
C
C  CALCULATION OF THE CONCENTRATION AT RECEPTOR POINT
C
C  CALCULATION OF THE SIGMA VALUES
         SIGY(PUFF) = A(PUFF)*(DIST(PUFF)**B)
         SIGX(PUFF) = SIGY(PUFF)
         SIGZ(PUFF) = C(PUFF)*(DIST(PUFF)**D(PUFF))
C
C
C  NOW FOR THE PUFF EQUATION
         STRM = SOURCE(PUFF)/(((2.*PI)**(1.5))*SIGX(PUFF)*
     +          SIGY(PUFF)*SIGZ(PUFF))
         XTRM = -((XSHIFT-(WSPEED(PUFF,1)*TIM))**2)/
     +          (2.*(SIGX(PUFF)**2))
         YTRM = -(YSHIFT**2)/(2.*(SIGY(PUFF)**2))
         ZTRM = -((H)**2)/(2.*(SIGZ(PUFF)**2))
         SUM = XTRM + YTRM +  ZTRM
          IF(SUM.LT.-50.) SUM = -50.0
         CONCEN = 2*STRM*EXP(SUM)
           IF(CONCEN.LE.(0.1E-10)) GOTO 1000
         GOTO 1100
C
C  DESIGNATION OF CONC = 0 FOR THE APPROPRIATE CONDITIONS
 1000    CONCEN = 0.0
C
C  CONCENTRATION IS CALCULATED BY ADDING THE AVERAGE CONCENTRATION
C    DURING THE MINUTE TO PREVIOUS CALCULATED CONCENTRATION
 1100    CONC(XREF,YREF) = CONC(XREF,YREF) + CONCEN/INCR
C
C  GO BACK TO GET Y GRID VALUES
  200    CONTINUE

C  GO BACK TO GET X GRID VALUES
  100 CONTINUE
C
C
      RETURN
      END
```

```
      SUBROUTINE RPTDATA (STN, YR, DATE, TIME, SP, A, DTDZ, ZSP, HGT,
     +                    TEMP, RH, WSPEED, WDIR, STHETA, P)
C
C  THIS SUBROUTINE READS IN PUFF DATA THAT IS THE SAME AS THE PREVIOUS
C
C  DECLARATION OF VARIABLE TYPES
      INTEGER P
C
C  DIMENSION STATEMENTS
      REAL TEMP(60,4), RH(60,4), WSPEED(60,4), WDIR(60,4)
      REAL STHETA(60,4)
      REAL SP(60), A(60), DTDZ(60), ZSP(60)
      INTEGER STN(60), YR(60), DATE(60), TIME(60)
      INTEGER HGT(60,4)
C
         STN(P) = STN(P-1)
         YR(P) = YR(P-1)
         DATE(P) = DATE(P-1)
         TIME(P) = TIME(P-1)
         SP(P) = SP(P-1)
         A(P) = A(P-1)
         DTDZ(P) = DTDZ(P-1)
         ZSP(P) = ZSP(P-1)
         DO 100 J = 1,4
           HGT(P,J) = HGT(P-1,J)
           TEMP(P,J) = TEMP(P-1,J)
           RH(P,J) = RH(P-1,J)
           WSPEED(P,J) = WSPEED(P-1,J)
           WDIR(P,J) = WDIR(P-1,J)
           STHETA(P,J) = STHETA(P-1,J)
 100     CONTINUE
         RETURN
         END
```

```
      SUBROUTINE STABPAR (STHETA, TEMP, ZSP, P, A, B)
C
C  THIS SUBROUTINE CALCULATES VERTICAL AND HORIZONTAL STABILITY
C    PARAMETERS AND HORIZONTAL COEFFICIENT AND EXPONENT
C
C  DECLARATION OF VARIABLE TYPES
      INTEGER P
      REAL TEMP1, TEMP10, DT, DZ, DTDZ, B
C
C  DIMENSION STATEMENTS
      REAL SP(60), ZSP(60), A(60)
      REAL STHETA(60,4), TEMP(60,4)
C
        IF (STHETA(P,1).GT.(7.5)) THEN
          SP(P) = (-0.2) * STHETA(P,1) + 5.5
        ELSEIF (STHETA(P,1).EQ.(7.5)) THEN
          SP(P) = 4.0
        ELSEIF (STHETA(P,1).GT.(3.8)) THEN
          SP(P) = (-0.27 * STHETA(P,1)) + 6.03
        ELSEIF (STHETA(P,1).EQ.(3.8)) THEN
          SP(P) = 5.0
        ELSEIF (STHETA(P,1).GT.(2.95)) THEN
          SP(P) = (-0.59 * STHETA(P,1)) + 7.23
        ELSEIF (STHETA(P,1).LE.(2.95)) THEN
          SP(P) = 5.5
        ENDIF
C  CALCULATION OF THE VERTICAL STABILITY PARAMETER
C  Conversion of temperature from Fahrenheit to Celcius
C  NRC Method of classification is based upon DT/DZ (C/100m);
C   therefore, need to convert by multiplying temp by (9/100)
C
        TEMP10 = (5./9.)* TEMP(P,1) - 32.
        TEMP1  = (5./9.)* TEMP(P,4) - 32.
        DT = (TEMP10 - TEMP1)
        DZ = 9.0
        DTDZ = (9./100.)*(DT/DZ)
C
       IF (DTDZ.LT.-1.9) THEN
          ZSP(P) = 0.5
        ELSEIF (DTDZ.LE.-1.5) THEN
          ZSP(P) =  5*DTDZ + 10.5
        ELSEIF (DTDZ.LE.-0.5) THEN
          ZSP(P) = DTDZ + 4.5
        ELSEIF (DTDZ.LE.1.5) THEN
          ZSP(P) = 0.5*DTDZ + 4.25
        ELSEIF (DTDZ.GE.1.5) THEN
          ZSP(P) = 5.5
        ENDIF
        A(P) = 0.479 - (0.1231*SP(P)) + (0.00904*(SP(P)**2.))
        B = 0.9
        RETURN
        END
```

```
      SUBROUTINE TOPTEN(P, GRIDX, GRIDY, CONC, TOP10, COORDX, COORDY,
     +                  WHEN)

C  THIS SUBROUTINE CALCULATES THE "TOP 10" CONCENTRATIONS
C
C  DECLARATION OF VARIABLE TYPES
      INTEGER GRIDX, GRIDY, P, TEMPX, TEMPY
      REAL  TEMP
C
C  DIMENSION STATEMENTS
      REAL CONC(-101:101, -101:101), TOP10(10)
      INTEGER COORDX (10), COORDY(10), WHEN(10)
C
      DO 200 YREF = GRIDY, -GRIDY, -1
        DO 300 XREF = -GRIDX, GRIDX
C
C  IF VALUE IS LESS THAN TENTH PLACE, GO TO THE NEXT VALUE
          IF (CONC(XREF,YREF).LE.TOP10(10))GOTO 300

C  THIS LOOP DETERMINES THE POSITION OF THE NEW VALUE
          DO 400 I = 1,10
          IF (CONC(XREF,YREF).GT.TOP10(I)) GOTO 425
  400     CONTINUE
          GOTO 300

C  NOW PULL DOWN APPROPRIATE NUMBER OF VALUES TO MAKE ROOM FOR NEW
  425           DO 500 J=9,I,-1
                  TOP10(J+1)  = TOP10(J)
                  COORDX(J+1) = COORDX(J)
                  COORDY(J+1) = COORDY(J)
                  WHEN(J+1)   = WHEN(J)
  500           CONTINUE
                TOP10(I)  = CONC(XREF,YREF)
                COORDX(I) = XREF
                COORDY(I) = YREF
                WHEN(I)   = P
C
  300   CONTINUE
  200 CONTINUE
C
      RETURN
      END
```

Appendix B 'METALL' FORTRAN 77 Code

```
      program metall

      integer yr,time,tper,hgt(4)

c DIMENSION HEIGHT, ETC--FOUR; WX VARIABLES--FOUR BY SIXTY

      dimension sigth2(4), wddif2(4), avexcom(4),
     +          aveycom(4), rhtot(4)
      dimension avetemp(4), averh(4), avewd(4), avews(4),
     +          avesig(4)
      dimension ycomp(4), xcomp(4), xtot(4), ytot(4),
     +          wstot(4), temptot(4)
      dimension temp(4,60), relhum(4,60), ws(4,60),
     +          wd(4,60), stheta(4,60)
      dimension oldwd(4)

      open (unit=7, file='s5061001.dat', status='old')
      open (unit=8, file='average',      status='unknown')
      open (unit=9, file='s560min',      status='unknown')

c SELECT THE TIME PERIOD OVER WHICH THE AVERAGE WILL BE
c TAKEN: TPER SET THE COUNTERS WSTOT, XTOT, AND YTOT TO ZERO

      tper = 60

      do 55 i=1,4
      wstot(i) = 0.0
      xtot(i) = 0.0
      rhtot(i) = 0.0
      ytot(i) = 0.0
   55 continue

c COLLECT ALL THE WEATHER DATA FOR THE PERIOD

    1 do 100 j=1,tper
      read(7,*,end=999)id, yr, jd, time, (hgt(i), temp(i,j),
     +                 relhum(i,j), ws(i,j), wd(i,j),
     +                 stheta(i,j), i=1,4)
```

```
c PERFORM SOME OF THE PRELIMINARY CALCULATIONS
c BEGIN BY OBTAINING THE X AND Y COMPONENTS OF THE WIND
c  DIRECTION
c MULTIPLY BY 0.0174533 TO CONVERT DEGREES TO RADIANS FOR
c  TRIG FUNCTIONS

      do 45 i=1,4
      xcomp(i) =        cos((wd(i,j)-270.0)*0.0174533)
      ycomp(i) = -1.0 * sin((wd(i,j)-270.0)*0.0174533)

c TOTAL THE X AND Y COMPONENTS FOR WIND DIRECTION AND
c WSTOT FOR WIND SPEED, TEMPTOT FOR TEMPERATURE, AND RHTOT
c  FOR REL HUMIDITY

      xtot(i) = xtot(i) + xcomp(i)
      ytot(i) = ytot(i) + ycomp(i)
      wstot(i) = wstot(i) + ws(i,j)
      temptot(i) = temptot(i) + temp(i,j)
      rhtot(i) = rhtot(i) + relhum(i,j)

c RETURN TO READ NEXT LINE OF DATA

   45 continue

c WRITE THE PRELIMINARY OUTPUT FOR LATER COMPARISON

      write(8,10)jd, time,(hgt(i), temp(i,j), relhum(i,j),
                 ws(i,j), wd(i,j), stheta(i,j), i=1,4)
   10 format(I3, I4, 4(I2, 3F5.1, F6.1, F5.1))

  100 continue

c HAVING COMPLETED THE LOOP, FOR EACH LEVEL
c CALCULATE FINAL VALUES FOR X AND Y COMPONENTS OF WIND
c  DIRECTION, THE AVERAGE WIND SPEED, AVERAGE REL HUM, AND
c  THE AVERAGE TEMPERATURE
c ALSO IN THAT LOOP, RESET RHTOT, TEMPTOT, WSTOT, XTOT, AND
c  YTOT TO ZERO

      do 65 i=1,4
```

```
      avexcom(i) = xtot(i) / tper
      aveycom(i) = ytot(i) / tper
      avews(i) = wstot(i) / tper
      avetemp(i) = temptot(i) / tper
      averh(i) = rhtot(i) / tper
      if(averh(i).ge.100.0) averh(i) = 99.9

      xtot(i) = 0.0
      ytot(i) = 0.0
      wstot(i) = 0.0
      temptot(i) = 0.0
      rhtot(i) = 0.0

c DETERMINE THE AVERAGE WIND DIRECTION FROM XFIN AND YFIN
c REVERSE ARGUEMENTS TO CONFORM WITH CARTESIAN COORDINATES
c THEN ADD 180 DEGREES TO ACCOUNT FOR FACT THAT WINDS ARE
c "FROMSEES"

      avewd(i) = atan2d(avexcom(i),aveycom(i)) + 180.0

c THEN GET RID OF NEGATIVE WIND DIRECTIONS

      if(avewd(i).lt.0.0) avewd(i) = avewd(i) + 360.0

c IF WIND SPEED IS ZERO, AVERAGE WIND DIRECTION IS CARRIED
c  FROM PREVIOUS

      if(avews(i) .eq. 0.0) avewd(i) = oldwd(i)

c CALCULATE THE AVERAGE SIGMA THETA FOR PERIOD
c FIRST INITIALIZE COUNTERS SIG2TH AND WDDIF2

      sigth2(i) = 0.0
      wddif2(i) = 0.0

c SECOND: SUM THE SQUARES OF THE INDIVIDUAL SIGMA THETA
c  VALUES

      do 25 j = 1,tper
      sigth2(i) = sigth2(i) + stheta(i,j) * stheta(i,j)
```

```
c NEXT DETERMINE THE DIFFERENCE BETWEEN INDIVIDUAL WIND
c  DIRECTIONS AND MEAN WIND DIRECTION FOR PERIOD. REDUCE ALL
c  VALUES GREATER THAN 180 DEGREES, THEN USE SUPPLEMENTAL
c   ANGLE.  THEN SUM SQUARES.

      If(ws(i,j) .eq. 0.0) wd(i,j) = avewd(i)
      wd(i,j) = avewd(i) - wd(i,j)
      if(wd(i,j) .lt. -180.0) wd(i,j) = 360.0 + wd(i,j)
      if(wd(i,j) .gt.  180.0) wd(i,j) = 360.0 - wd(i,j)
      wddif2(i) = wddif2(i) + wd(i,j) * wd(i,j)
   25 continue

c FINALLY TAKE SUM OF SQUARES OF SIGMAS AND WIND
c  DIFFERENCES, DIVIDE BY NUMBER OF OBSERVATIONS TO GET THE
c  NEW SIGMA THETA.

      avesig(i) = sqrt((sigth2(i) + wddif2(i)) / tper)

      oldwd(i) = avewd(i)

   65 continue

c WRITE OUTPUT FOR THIS PERIOD

      write(8,70)jd,time,(hgt(i),avetemp(i),averh(i),
     &avews(i),avewd(i),avesig(i),I=1,4)
   70 format(i4,i4,4(I2, 3F5.1, F6.1, F5.1))


      write(9,75)id,yr,jd,time,(hgt(i),avetemp(i),averh(i),
     &avews(i),avewd(i),avesig(i),I=1,4)
   75 format(i2,i5,i4,i5,1x,4(I2, 3F5.1, F6.1, F5.1))

c RETURN TO BEGINNING AND PROCEED WITH NEXT AVERAGING PERIOD

      go to 1

  999 stop
      end
```

Appendix C Derivation of Calculation Used to Determine Sigma Theta

σ_1	σ_θ (horizontal standard deviation of the wind) for each minute of data gathered from meteorological towers
σ_g	σ_θ for averaging time of interest, i.e., 10 or 60 minutes
x	individual one second wind direction readings taken by computer in meteorological towers (one second readings are not available as output data)
x_T	individual one-minute wind direction readings taken by computer in meteorological towers
μ_1	mean one-minute wind direction calculated by meteorological towers
μ_g	grand mean of 10 or 60 minute wind direction
N	number of one second readings (60) used to calculate the mean wind direction
N_T	number of one second readings needed to calculate the 10 or 60 minute averages (600 readings for 10 minutes -and- 3600 readings for 60 minutes)
N_R	ratio N/N_T

Calculation of Standard Deviations

For one minute readings

$$\sigma_1^2 = \frac{\sum (x - \mu_1)^2}{N}$$

$$\sigma_1^2 = \frac{\sum \left(x^2 - 2x\mu_1 + \mu_1^2\right)}{N}$$

$$\sigma_1^2 = \frac{\sum x^2}{N} - \mu_1^2$$

$$\sum x^2 = \left(\sigma_1^2 + \mu_1^2\right)N$$

For 10 and 60 minute readings

Calculation of the "grand" standard deviation

$$\sigma_g^2 = \frac{\sum \left(x_T - \mu_g\right)^2}{N_T}$$

$$\sigma_g^2 = \frac{\sum \left(x_T - 2x_T\mu_g + \mu_g^2\right)}{N_T}$$

$$\sigma_g^2 = \frac{\sum x_T^2}{N_T} - \mu_g^2$$

$$\sum x_t^2 = \left(\sigma_g^2 + \mu_g^2\right)N_T$$

$$\sum x^2 = x_T^2$$

From the above example for $\sum x^2$

Substituting and remembering $x_T^2 = \sum x^2$

$$N_T\left(\sigma_g^2 + \mu_g^2\right) = \sum\left[\left(\sigma_1^2 + \mu_1^2\right)N\right]$$

Simplifying by solving for σ_g^2

$$\sigma_g^2 = \frac{N}{N_T}\left[\sum\left(\sigma_1^2 + \mu_1^2\right)\right] - \bar{\mu}_g^2$$

$$\sigma_g^2 = \frac{1}{N_R}\left(\sum\sigma^2 + \sum\mu^2\right) - \bar{\mu}_g^2$$

Taking the square root of both sides and expanding

$$\sigma_g = \sqrt{\frac{1}{N_R}\left[\left(\sigma_1^2 + \sigma_2^2 + \ldots\right) + \left(\mu_1^2 + \mu_2^2 + \ldots\right)\right] - \bar{\mu}_g^2}$$

Since

$$\bar{\mu}_g^2 = \frac{\sum\bar{\mu}_g^2}{N_T}$$

$$\sigma_g = \sqrt{\frac{1}{N_R}\left(\sigma_1^2 + \sigma_2^2 + \ldots\right) + \frac{1}{N_R}\left[\left(\mu_1^2 + \mu_2^2 + \ldots\right) - \bar{\mu}_g^2\right]} *$$

Since

$$\sum\left(\mu - \bar{\mu}_g\right)^2 = \sum\left(\mu^2 - \bar{\mu}_g^2\right)$$

$$\sigma_g = \sqrt{\frac{1}{N_R}\left(\sum\sigma^2\right) + \frac{1}{N_R}\left(\sum\left(\mu - \bar{\mu}_g\right)^2\right)}$$

$$\sigma_g = \sqrt{\frac{1}{N_R}\left[\sum\sigma^2 + \sum\left(\mu - \bar{\mu}_g\right)^2\right]}$$

This equation for σ_g was used to calculate the σ for the appropriate averaging time, i.e., 1, 10, or 60 minutes, in the FORTRAN 77 code for 'METALL' (See Appendix B).

*See Proof on the next page

*Based upon $\sum(\mu-\mu_g)^2=\sum(\mu^2-\mu_g^2)$

$$\sum\left(\mu-\mu_g\right)^2=\sum\left(\mu^2-\overline{\mu}_g^2\right)$$

Expanding

$$\sum\mu^2-2\mu_g\sum\mu+\sum\mu_g^2=\sum\mu^2-\sum\overline{\mu}_g^2$$

Simplifying and combining terms

$$-2\mu_g\sum\mu=-2\sum\overline{\mu}_g$$

Simplifying

$$\sum\mu=\sum\overline{\mu}_g$$

$$\sum\mu=N\mu_g$$

therefore,

$$\frac{\sum\mu}{N}=\mu_g$$

Vita

Captain Ida Lee Widmann [redacted].

She graduated from Herndon High School in 1986 and entered the United States Air Force Academy Preparatory School the same year. She continued on to the United States Air Force Academy in 1987 and graduated in 1991 with a Bachelors of Science in Civil Engineering. Her first assignment was at Lackland AFB, TX as a Civil Engineering Officer. In May 1994, she entered the School of Engineering, Air Force Institute of Technology.

[redacted]

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. AGENCY USE ONLY *(Leave blank)*	2. REPORT DATE	3. REPORT TYPE AND DATES COVERED
	December 1995	Master's Thesis

4. TITLE AND SUBTITLE
THE EFFECT OF METEROLOGICAL DATA AVERAGING TIMES ON PLUME CONCENTRATIONS FROM EXPLOSIVE ORDNANCE DISPOSAL OPEN BURNING OPERATIONS

5. FUNDING NUMBERS

6. AUTHOR(S)
Ida Lee Widmann, Captain, USAF

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
Air Force Institute of Technology,
WPAFB OH 45433-6583
Capt Clifton E. Dungey

8. PERFORMING ORGANIZATION REPORT NUMBER
AFIT/GEE/ENP/95D-11

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Air Force Institute of Technology
WPAFB OH 45433-6583

10. SPONSORING / MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES

12a. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

Explosive Ordnance Disposal (EOD) Open Burning (OB) operations are performed to dispose of unserviceable munitions in the Department of Defense (DOD) inventory. Air pollution modeling is an Environmental Protection Agency requirement for permit issuance at OB sites. Specific OB regulation is still in its infancy; therefore, establishment of OB modeling techniques is still in the early stages. This thesis effort develops a computer model, based upon the Gaussian Puff Equation. The model varies from standard plume modeling practices by assuming non-uniform wind direction, wind speed and turbulence throughout the duration of the burn. The model assigns meteorological data to each explosion (puff). The experiments in this research effort assign meteorological data to the puffs based upon averaging the weather data over 1, 10, and 60 minute periods. The results of the research show a statistically significant difference (95% confidence) between 1 and 60 minute weather data plume concentrations. In each case, the 1 minute weather data produces smaller average plume concentrations than the 60 minute weather data. This suggests that a closer look is needed when establishing standard OB modeling techniques involving meteorological input data to insure permits are not denied due to conservative approaches involving uniform weather data.

14. SUBJECT TERMS	15. NUMBER OF PAGES
Averaging Time, Air PollutionExplosive Ordnance Disposal, Meteorological Data, Modeling, Munitions, Open Burning	79
	16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
Unclassified	Unclassified	Unclassified	UL

GENERAL INSTRUCTIONS FOR COMPLETING SF 298

The Report Documentation Page (RDP) is used in announcing and cataloging reports. It is important that this information be consistent with the rest of the report, particularly the cover and title page. Instructions for filling in each block of the form follow. It is important to *stay within the lines* to meet *optical scanning requirements*.

Block 1. Agency Use Only *(Leave blank)*.

Block 2. Report Date. Full publication date including day, month, and year, if available (e.g. 1 Jan 88). Must cite at least the year.

Block 3. Type of Report and Dates Covered. State whether report is interim, final, etc. If applicable, enter inclusive report dates (e.g. 10 Jun 87 - 30 Jun 88).

Block 4. Title and Subtitle. A title is taken from the part of the report that provides the most meaningful and complete information. When a report is prepared in more than one volume, repeat the primary title, add volume number, and include subtitle for the specific volume. On classified documents enter the title classification in parentheses.

Block 5. Funding Numbers. To include contract and grant numbers; may include program element number(s), project number(s), task number(s), and work unit number(s). Use the following labels:

C	- Contract	PR	- Project
G	- Grant	TA	- Task
PE	- Program Element	WU	- Work Unit Accession No.

Block 6. Author(s). Name(s) of person(s) responsible for writing the report, performing the research, or credited with the content of the report. If editor or compiler, this should follow the name(s).

Block 7. Performing Organization Name(s) and Address(es). Self-explanatory.

Block 8. Performing Organization Report Number. Enter the unique alphanumeric report number(s) assigned by the organization performing the report.

Block 9. Sponsoring/Monitoring Agency Name(s) and Address(es). Self-explanatory.

Block 10. Sponsoring/Monitoring Agency Report Number. *(If known)*

Block 11. Supplementary Notes. Enter information not included elsewhere such as: Prepared in cooperation with...; Trans. of...; To be published in.... When a report is revised, include a statement whether the new report supersedes or supplements the older report.

Block 12a. Distribution/Availability Statement. Denotes public availability or limitations. Cite any availability to the public. Enter additional limitations or special markings in all capitals (e.g. NOFORN, REL, ITAR).

DOD - See DoDD 5230.24, "Distribution Statements on Technical Documents."
DOE - See authorities.
NASA - See Handbook NHB 2200.2.
NTIS - Leave blank.

Block 12b. Distribution Code.

DOD - Leave blank.
DOE - Enter DOE distribution categories from the Standard Distribution for Unclassified Scientific and Technical Reports.
NASA - Leave blank.
NTIS - Leave blank.

Block 13. Abstract. Include a brief *(Maximum 200 words)* factual summary of the most significant information contained in the report.

Block 14. Subject Terms. Keywords or phrases identifying major subjects in the report.

Block 15. Number of Pages. Enter the total number of pages.

Block 16. Price Code. Enter appropriate price code *(NTIS only)*.

Blocks 17. - 19. Security Classifications. Self-explanatory. Enter U.S. Security Classification in accordance with U.S. Security Regulations (i.e., UNCLASSIFIED). If form contains classified information, stamp classification on the top and bottom of the page.

Block 20. Limitation of Abstract. This block must be completed to assign a limitation to the abstract. Enter either UL (unlimited) or SAR (same as report). An entry in this block is necessary if the abstract is to be limited. If blank, the abstract is assumed to be unlimited.