AIR DISPERSION MODELING OF PARTICULATE MATTER FROM GROUND-LEVEL AREA SOURCES

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Abstract

The new National Ambient Air Quality Standards (NAAQS) for particulate matter less than 2.5 μm in diameter ($PM_{2.5}$) and ozone, which has recently been under review, will increase the number of nonattainment areas in the United States. Since a facility is responsible for *all* PM emissions originating from that property, an increased emphasis will be placed on the regulation of fugitive PM sources, as well. Dispersion modeling is often used by State Air Pollution Regulatory Agencies (SAPRA's) in determining whether the contribution of particulate matter from a facility meets the NAAQS. As such, a facility may be granted or denied an operating permit based on the results obtained from a dispersion model. However, the model currently approved by EPA over-predicts downwind concentrations of PM by as much as ten fold. This results in the possibility that a facility is denied a permit when, in fact, its emissions are well within the NAAQS. Dispersion models that provide accurate estimations of downwind concentrations of pollutant from these fugitive sources are needed to ensure reliable and fair regulation of pollutant sources. The current EPA-approved ground-level dispersion model uses a normal distribution in the vertical plane that mathematically reflects the area of the distribution that is below ground back onto the area above ground. This produces a distribution in which the point of maximum concentration is at ground level at any distance downwind of the source, which is intuitively incorrect. With the goal of developing a model that produces a more accurate result, we have replaced the reflected normal distribution in the vertical plane with a triangular distribution. In a triangular distribution the point of maximum concentration is no longer confined to ground level. Additionally, the three indices of the triangular distribution may be adjusted, based on what type of pollutant is being modeled, which provides an additional degree of versatility.

Introduction

With the passage of the Clean Air Act Amendments of 1970, a National Ambient Air Quality Standard (NAAQS) was created for the first time in America. Through the NAAQS, the Environmental Protection Agency (EPA) identifies and mandates the regulation of six criteria pollutants. These criteria pollutants include sulfur dioxide (SO_2), nitrogen dioxide (NO_2), carbon monoxide (CO), particulate lead, and two classifications of particulate matter: that less than 10μm in diameter (PM_{10}), and that less than 2.5μm in diameter ($PM_{2.5}$). The primary purpose of the NAAQS is to ensure public health and safety as it relates to airborne pollutants. Responsibility of enforcing the NAAQS is delegated to the State Air Pollution Regulatory Agency (SAPRA) within each state. One of the tools used by SAPRA engineers to accomplish this is air dispersion modeling.

Air dispersion modeling is a mathematical tool that allows for estimates of downwind concentrations of pollutant to be made based on the source emission rate and the meteorological conditions. As such, it is becoming a significant part of the regulatory process in many states. Most states require all new facilities to obtain a permit prior to construction. Part of this permit application is to demonstrate that once the facility is in operation it will be in compliance with air quality standards for all regulated pollutants. Since it is impossible to measure air quality impacts of a future source, air dispersion modeling is used. In addition to being used in the initial permitting process, modeling could also be used to determine the impact of sources that wish to amend their abatement system, if this amendment will result in increased emissions.

Traditionally, dispersion modeling has been used to determine downwind concentrations of particulate matter as described in the NAAQS (PM_{10} and $PM_{2.5}$) from an elevated point source. What is needed is a model that is appropriate for many different types of pollutants under conditions that more accurately reflect what is occurring in nature. SAPRA's, however, are required to use models that approved by the EPA. The current EPA-recommended dispersion model is Industrial Source Complex (ISC), which is based on the mechanics of Gaussian dispersion. As a result, the only option for dispersion modeling of an area source is the ISC Short Term, version 3 (ISC-ST3). Using this model results in downwind concentrations that are over-estimated as a result of the inappropriate application of time periods to calculated concentrations and the use of dispersion profiles that do not accurately describe dispersion of pollutants from ground-level sources.

ISC-ST3 applies a one-hour time period to a given concentration that is referenced in literature as a ten-minute concentration. This "one hour" concentration, in effect, assumes a constant wind speed and one wind direction for the entire one-hour time period. This assumption implies that during a one-hour time frame, pollutant release from a source is carried directly to the receptor, resulting in a significant exposure of the pollutant to the receptor. The result is a modeled concentration that is extremely conservative. This assumption is highly inappropriate. The natural variation of wind speed and direction yields a concentration much lower

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than is predicted by a model because the pollutant may only be carried directly from the source to the receptor for a fraction of the one-hour time period.

Discussion

The Gaussian Dispersion Model

Equation 1 is used to calculate the ambient downwind concentration associated with Gaussian dispersion from a pollutant source (Cooper and Alley, 1994):

$$C=\frac{Q}{2\pi u\sigma_y\sigma_z}\exp\left(-\frac{1}{2}\frac{y^2}{\sigma_z^2}\right)\left\{\exp\left(-\frac{1}{2}\frac{(z-H)^2}{\sigma_z^2}\right)+\exp\left(-\frac{1}{2}\frac{(z+H)^2}{\sigma_z^2}\right)\right\} \quad \text{(Eq. 1)}$$

where

C = steady state concentration ($\mu g/m^3$),
Q = emission rate ($\mu g/s$),
π = 3.141593,
u = wind speed at stack height (m/s),
σ_y = lateral dispersion parameter (m),
σ_z = vertical dispersion parameter (m),
z = receptor height above ground (m), and
H = plume centerline height (m).

Figure 2 illustrates the horizontal and vertical dispersion of pollutants from a source (Turner, 1994). The basis for the Gaussian model are two density functions (equations 2 and 3) that approximate dispersion of pollutants in these two planes.

$$f(y) = \frac{1}{\sigma_y\sqrt{2\pi}}\exp\left(-\frac{y^2}{2\sigma_y^2}\right) \quad \text{(Eq. 2)}$$

$$f(z) = \frac{1}{\sigma_z\sqrt{2\pi}}\left\{\exp\left(-\frac{(z-H)^2}{2\sigma_z^2}\right)+\exp\left(-\frac{(z+H)^2}{2\sigma_z^2}\right)\right\} \quad \text{(Eq. 3)}$$

The second term in equation 3, $(z+H)^2$, takes into account eddy reflection. The division of the emission rate by the wind speed results in units of [MASS/LENGTH] . This value is multiplied by the two normal density functions, one for the horizontal direction, and one for the vertical direction. The product of the two density terms has units of [1/AREA]. The overall product is a concentration with units of [MASS/VOLUME].

Associated with the Gaussian model and all dispersion models based upon the Gaussian model are the following assumptions (Turner, 1994):

- Continuous Emissions - The emission rate of pollutant does not vary over time.
- Conservation of Mass - During transport, no pollutant is lost due to chemical reaction, settling, or turbulent impaction.
- Steady-State Conditions - Meteorological conditions remain constant over the time of transport.
- Crosswind and Vertical Concentration Distributions - Both concentration distributions are assumed to be well represented by a Gaussian, or normal, distribution at any distance downwind or any distance in the crosswind directions.

It is obvious that there are cases where some or all of these assumptions do not hold. "The assumptions used in the derivation, frequently, do not hold. Emissions may vary with time. Pollutants may be lost due to settling or chemical reactions. Wind fields may vary with height. Inversion layers may exist. The diffusion constants may vary. Because of these and other cases where the assumptions do not hold, care must be taken when using the Gaussian equation." (Veigele and Head, 1978) In order to produce concentration estimates that are as accurate as possible, the Gaussian Dispersion Model should be applied to a situation that satisfies as many of these assumptions as possible.

While utilizing the normal distribution for the horizontal and vertical planes is logical for an elevated point source, a unique situation occurs when attempting to model a source that is at ground level: the ground prevents downward dispersion from the emitting point. In order to accommodate this phenomenon, the current EPA-approved ground-level dispersion model uses a normal distribution in the vertical plane that mathematically reflects the area of the distribution that is below ground back onto the area above ground (Figure 1a). This produces a distribution in which the point of maximum concentration is at ground level at any distance downwind of the source, which is intuitively incorrect. Shemel (1980) states that downwind from a ground-level source, for both high and low deposition rates, a maximum concentration occurs at some height above ground level (Figure 1b).

Purpose of New Model

The overall purpose of developing a new air dispersion model is to provide a method that can be used to accurately predict concentrations of pollutants downwind from ground-level area sources.

More specifically:

- To develop a more appropriate dispersion model for ground-level area sources.
- To develop a dispersion model that has the potential to accurately predict downwind concentrations of different pollutants with varying

physical characteristics, e.g. toxics, odors and heavy PM.

- To provide a regulatory tool that can be used to accurately determine emission factors from measurements of downwind concentrations for the purpose of developing state emissions inventories.

New Ground-Level Model Methodology

The major difference of the proposed new model relative to ISC is an alteration of the distribution used in the vertical plane. To improve performance for use with ground-level area sources the normal distribution in the vertical plane was replaced with a triangular distribution with indices that can be adjusted based on pollutant characteristics. Figure 3 shows the difference between the two distributions. The proposed new model also differs from ISC in the manner in which an area source contributes to a stationary receptor downwind. By breaking up an area source into a grid of equal sized point sources, the model determines the contribution of each unit to the total concentration measured by a receptor downwind of the source and calculates an emission rate based only on the amount each unit contributes. This algorithm is a function of wind speed and direction. The Gaussian calculation approach is used, but the concentration calculated by the equation uses the wind speed and wind direction for a 2 minute period, and is thus a 2 minute concentration. Zwicke, et al. (1999) published validation study results for modeling elevated point sources using concentrations that were measured at known downwind distances from a source with controlled emission rates.

Distribution in the Vertical Plane

The Gaussian model utilizes a normal distribution in the vertical plane. The new model will replace this normal distribution with a distribution whose vertical concentration profile is completely above ground. The proposed distribution to be used to replace the normal is the triangular distribution. Figure 3 illustrates how the triangular distribution is completely above ground, compared to the normal distribution. Note that the heavy dashed line is the vertical distribution after reflection and addition of the bottom half of the normal curve into the upper half of the curve.

Like the normal distribution, the triangular distribution can be mathematically represented by probability density functions. Figure 4 (Pritsker, 1979) is a graphical representation of the triangular distribution and the indices associated with it. Unlike the normal distribution, the triangular distribution allows for modification of the height of maximum concentration within the plume, and the height of the plume. The triangular distribution has three different indices that must be assigned values. By setting each of these indices, the size and shape of the plume is defined.

Equations 4 and 5 give the probability density function for vertical dispersion represented by a triangular distribution (Pritsker, 1979):

$$f(z) = \frac{2(z - A)}{(M - A)(B - A)} \rightarrow A \le z \le M \qquad \text{(Eq. 4)}$$

$$f(z) = \frac{2(B - z)}{(B - M)(B - A)} \rightarrow M \le z \le B \qquad \text{(Eq.5)}$$

Index A is set at ground-level, or 0 meters, in the proposed new model. We have chosen the other two indices, B and M, to be linear functions of σ_z. This approach allows the use of existing science associated with the currently used Gaussian model can be used. The use of sigma z in the triangular distribution will allow for an accounting of changes in the vertical concentration profile as a function of stability class and distance downwind. Another benefit to using these parameters, is that they are accepted and being used by present dispersion models. Indices B and M have the ability to be varied independently of one another. This results in numerous possible vertical concentration profiles. This approach provides an added flexibility in adjusting the vertical dispersion rate to more accurately estimate downwind concentrations that will vary with physical characteristics of different pollutants.

The new model is derived by replacing the probability density function in the vertical plane with a new distribution. Mathematically, when the normal distribution in the vertical plane (Equation 3) is replaced by the a triangular distribution (Equations 4 and 5), the new model takes on the form of Equation 6.

$$C = \frac{Q}{u} * fy * fz \qquad \text{(Eq. 6)}$$

where:

fy is Equation 2; and
fz is Equations 4 and 5.

Figure 5 is the proposed method of setting the indices of the triangular distribution. The indices B and M are both linear functions of sigma z, where K and L are scalar multipliers of sigma z. A is set at a constant 0 meters (ground level). Since the model assumes that no settling occurs, the total mass of particulate in the plume at the point of release equals the total mass in the plume at any point downwind. If a low value for K is used (a short plume), the mass of the particulate will be confined to a small area, resulting in the prediction of a high concentration. Conversely, if K is increased (resulting in a greater plume height), there exists a greater area in which the

same amount of mass can be distributed. Thus, increasing K results in the prediction of a lower concentration.

The triangular distribution also has a unique advantage over the normal distribution: a variable height of maximum concentration. This is index M in Figure 5. The reflected normal probability density function in the vertical plane for a ground-level release results in a maximum concentration at, or near, ground-level regardless of downwind distance. In contrast, with index M being a linear function of sigma z, the height within the plume at which the maximum concentration occurs increases as the downwind distance increases.

A major component of this research is to determine the scalar multipliers, K and L, for the indices, B and M. The key to setting these indices is the ability to correlate the plume height and the maximum concentration height to the stability class and the downwind distance from the source. One of the initial methods proposed to accomplish this was to obtain plume profiling sampling data as related to source emission rate, downwind distance, and recorded meteorological data. The difficulty was in locating this information. No small scale plume profiling data was to be found. There were several sources containing information on single point sampling downwind from sources. The problem common to all of these was the lack of credible area source emission rates. The emission factors or emission rates available in literature were determined by a process of measuring downwind concentrations from a source and using dispersion modeling to back-calculate the emission rate. If the dispersion model inaccurately calculates downwind concentrations as we have determined, the use of these models to determine emission factors would also be in error.

There are three key components needed for dispersion model validation and testing. These are: accurate, controlled emission rates; appropriate meteorological data in 2 minute intervals; and measured downwind concentration at known sampler locations. The Department of Agricultural Engineering at Texas A&M University is in the process of obtaining validation data for this new model. Obtaining validation data for a new model is not a simple process. To illustrate the utility of a new model for predicting downwind concentrations from ground level area sources using a combination normal (horizontal plane) and triangular (vertical plane), several values for B and M were assumed. Equations 7 and 8 were used to determine the B and M values.

$$B = F\sigma_z \qquad \text{(Eq. 7)}$$

where, F is a scalar.

$$M = L\,B \qquad \text{(Eq. 8)}$$

where, L is a scalar.

The flexibility of the triangular distribution is illustrated in Figures 7 and 8.

The triangular distribution in the vertical plane may not be the best representation of actual plume dispersion. However, we are convinced that it is an improvement over the use of ISC for ground level sources. This model is a first estimate of the vertical profile of a dispersion model that can be used to more accurately estimate downwind concentrations from ground level area sources. We are in the process of obtaining data that can be used to validate this model or to provide insight as to a more appropriate vertical distribution profile.

Removal of Mass from the Plume

Particulate matter is composed of particles of various sizes. A particle size distribution (PSD) is used to illustrate the relationship between particle size and mass fraction. If a PSD indicates that 50 percent of a pollutant is composed of particles less than 10 μm aerodynamic equivalent diameter (AED) and the emission rate of the pollutant is 100 g/s, then the emission rate for PM_{10} is 50 g/s. At a given downwind distance a percentage of the mass in this particle size range settles out as a consequence of dry deposition. Once the dry deposition velocity is calculated, it can then be applied to a plume decay model given by:

$$r = e^{\left[\frac{-vx}{3z}\right]} \qquad \text{(Eq. 9)}$$

where

r = percent mass remaining in plume,
v = deposition velocity (m/s),
x = downwind distance (m), and
z = emission height (m).

This model calculates the fraction of mass of a particular size remaining at a given downwind distance. Multiplying the percent remaining by the initial mass emitted will yield a new emission rate that takes deposition into account. To reiterate, given an initial PSD of a pollutant and an initial emission height (assumed to be the point of maximum concentration in the plume), a deposition velocity is calculated and a fraction of the particulate is removed from the plume, thus generating a new PSD at the downwind distance x. This PSD is used to determine a new, corrected emission rate of the pollutant being modeled.

Peters and Blackwood (1977) calculated, using stability class C, that the vertical component of dispersion (plume height) was equal to four meters at a downwind distance of 50 meters. Further, Flocchini, et al. (1995) used a plume height of four meters in determining PM_{10} factors from agricultural field operations. As such, the assumption is made that there

is essentially no deposition within 50 meters of the source. Indeed, dry deposition calculations support this assumption. Given an emission height of four meters, at 50 meters, only 2% of the plume is deposited (see Table 2). This and the four meter plume height provide a "starting point" for the deposition velocity algorithm.

Particle Deposition

Particulate matter is removed from the atmosphere by one or more of the following methods: gravitational settling, dry deposition, and wet deposition. (Cole, et al., 1986). The plume centerline (point of maximum concentration) increases linearly as plume height increases. However, as gravitational settling begins to occur, the plume centerline shifts downward. The model should reflect this. An examination of Stokes's law reveals that nearly 93% of PM_{10} released at or near ground level settles out within 500 meters of the emitting point and that 99% settles out within 1000 meters (see Table 1).

Only one EPA-approved Gaussian model, ISC, incorporates particle deposition into its transport algorithm. The ISC model uses a technique called "partial reflection", in which the image term in the Gaussian dispersion equation is multiplied by a reflection coefficient that dictates how much of the initial dust plume is "reflected" back into the atmosphere. As the reflection coefficient decreases, more particulate matter is retained at the surface and thus, is removed from the plume. This makes the selection of the reflection coefficient crucial to the accuracy of the algorithm (Cole, et al., 1986).

However, it is apparent that the specification of reflection coefficients in the ISC model may have a systematic bias that underestimates the removal of small particles (<30 microns). This bias is introduced by a curve in the ISC User's Manual that relates the reflection coefficient to settling velocity and indicates that particle removal, as governed by a reflection coefficient, goes to zero as settling velocity decreases. For particles this size, however, the deposition velocity exceeds the settling velocity, making deposition the dominant removal mechanism. This error causes ISC to predict PM10 concentrations 2.0 times larger than concentration predicted by the widely-accepted [Horst's] source depletion model. Additionally, ISC systematically predicts 24-hour TSP concentrations that are a factor of 3.75 times larger than measured values (Cole, et al., 1986).

PM is brought to the surface through the combined processes of turbulent diffusion and gravitational settling. Once near the surface, they may be removed from the atmosphere and deposited on the surface. This removal can be modeled in terms of dry deposition velocity (v_d). As the plume of airborne particulate is transported downwind, such deposition near the surface reduces the concentration of PM in the plume and thereby alters the vertical distribution of the remaining particulate. Furthermore, the larger PM will also move steadily nearer the surface at a rate equal to their gravitational settling velocity (v_g). As a result, the plume centerline height is reduced and the vertical concentration distribution is no longer Gaussian (EPA, 1995).

Horst (1983) describes a corrected source-depletion model based on dry deposition velocity. This model is used to obtain a vertical term that incorporates both the gravitational settling and the removal of plume mass at the surface. The importance in using deposition velocity, rather than Stokes settling velocity, is that Stokes settling velocity calculates gravitational settling in still air while deposition velocity includes explicit parameterizations of the effects of Brownian motion and inertial impaction in addition to gravitational settling. Table 2 illustrates results obtained by using each method to determine pollutant removal. As expected less pollutant is removed from the plume when deposition velocity is used in lieu of Stokes settling velocity. Deposition velocity, v_d, is given as the inverse of the sum of resistances to the pollutant transfer through various layers, plus gravitational settling (EPA, 1995):

$$v_d = \left[\frac{1}{r_a + r_d + r_a r_d v_g} \right] + v_g \qquad \text{(Eq. 10)}$$

where

v_d = deposition velocity (cm/s),
r_a = aerodynamic resistance (s/cm),
r_d = deposition layer resistance (s/cm), and
v_g = gravitational settling velocity (cm/s).

The rate of dry deposition is influenced by several factors. Among these are meteorological variables, pollutant properties, and surface characteristics. Two meteorological factors that affect the rate of deposition are the friction velocity, u_*, and the aerodynamic surface roughness, z_0. In fact, friction velocity is a function of aerodynamic surface roughness and is given by:

$$u_* = u \left[\frac{k}{\ln\left(\frac{z + z_0}{z_0} \right)} \right] \qquad \text{(Eq. 11)}$$

where

u_* = friction velocity (cm/s),
u = wind velocity (m/s),
k = von Karman's constant ($\cong$0.4),
z = measured height above ground (m), and

z_0 = aerodynamic surface roughness (m)

(Sehmel, 1980).

Additionally, the dry deposition requires surface roughness length, and the Monin-Obukhov length. These factors, along with friction velocity, are used to calculate the atmospheric resistance (EPA, 1995):

$$r_a = \frac{1}{ku_*}\left[\ln\left(\frac{z_d}{z_0}\right) + 4.7\frac{z}{L}\right] \quad \text{(Eq. 12)}$$

where

r_a = atmospheric resistance (s/cm),
k = von Karman constant (0.4),
u_* = surface friction velocity (cm/s),
z = height above ground (m),
L = Monin-Obukhov length (m)
z_d = deposition reference height (m), and
z_0 = surface roughness (m).

A minimum value for L of 1.0m is used for rural locations (EPA, 1995). Deposition layer resistance is calculated as:

$$r_d = \frac{1}{\left(Sc^{-2/3} + 10^{-3/St}\right)u_*} \quad \text{(Eq. 13)}$$

where

Sc = Schmidt number ($Sc = \mu/D_B$) (dimensionless),
D_B = Brownian diffusivity of pollutant (cm^2/s),
μ = viscosity of air ($\cong 0.15$ cm^2/s),
St = Stokes number [$St = (v_g/g)(u_*^2/\mu)$] (dimensionless), and
g = gravitational acceleration (981 cm/s^2)

The gravitational settling velocity, v_g (cm/s), is given as:

$$v_g = \frac{\left(\rho - \rho_{AIR}\right)gd_p^2c_2}{18\mu}S_{CF} \quad \text{(Eq. 14)}$$

where

ρ = particle density (g/cm^3),
ρ_{AIR} = air density ($\cong 1.2 \times 10^{-3}$ g/cm^3),
d_p = particle diameter (μm),
μ = absolute viscosity ($\cong 1.81 \times 10^{-4}$ g/cm/s),
c_2 = air units conversion constant (1×10^{-8} $cm^2/\mu m^2$),
S_{CF} = slip correction factor, computed as:

$$S_{CF} = 1.0 + \frac{2x_2\left(a_1 + a_2e^{-\left(a_3d_p/x_2\right)}\right)}{10^{-4}d_p} \quad \text{(Eq. 15)}$$

where

$x_2 = 6.5 \times 10^{-6}$,
$a_1 = 1.257$,
$a_2 = 0.4$, and
$a_3 = 0.55 \times 10^{-4}$

Brownian diffusivity is computed by:

$$D_B = 8.09x10^{-10}\left[\frac{T_aS_{CF}}{d_p}\right] \quad \text{(Eq. 16)}$$

where T_a is the air temperature (°K) (EPA,1995).

The Schmidt number found in Eq. 13 parameterizes the effects of Brownian Motion, which controls the deposition rate of small particles. The term involving the Stokes number deals with inertial impaction, which is the dominant force of removal of particles in the 2-20 μm AED size range (EPA, 1995). The resulting v_d is then used to calculate particulate removal from the plume.

Results

The FZM model was put through its paces to determine if its basic algorithms were working properly. In the first run, a normal distribution in both planes was used to compare the model's performance to that of ISC-SCREEN and ISC-ST. In this setup, the only mathematical difference between FZM and the ISC models is the two minute versus one hour time averaging. As such, one would expect the models to produce similar results. The source used in the model run was an area of one square meter (the basic area unit in the FZM model). The emission rate in all three cases was set to 10 g/s and the receptors were placed 10, 50, 100 and 200 meters downwind of the source. The receptor heights were set at 1.8 meters in the FZM and ST models and were set at ground level in SCREEN. Stability Class C was used in all cases and a meteorology data file containing a constant wind speed of 3 m/s and a constant direction was created.

Figure 6 indicates that the models correlate quite well, as was hypothesized. This indicates that the FZM model uses the dispersion and transport parameters of Gaussian dispersion correctly. However, it is important to reiterate that the predicted concentration from the FZM model is a 2-minute average, while the predicted concentrations from the ISC models are 1-hour averages.

The next three model runs of the FZM model used the triangular distribution in the vertical plane. Using a triangular distribution in the vertical plane not only eliminates the point of maximum concentration being confined to ground level, it gives the modeler the ability to adjust the indices to fit the characteristics of the pollutant. These indices are based on the same Pasquill-Gifford (1961) dispersion parameters that are accepted for use in the ISC models. Plume height, B, is a scalar multiple of σ_z, ranging from 1 to 6 σ_z. The mode of the distribution, M, (also known as the point of maximum concentration), is some fraction of B. We hypothesize that pollutants having relatively heavy particle densities will best be modeled with a small M and a B in the 1-3 σ_z range. In a similar manner, we hypothesize that gases and odors will best be characterized by a plume height in the 4-6 σ_z range and a larger M, indicating a greater rate of dispersion. The results (Figures 7 and 8) illustrate this flexibility. In Figure 7 the model is set up for heavier particulate. Note that the triangular distribution set at B =1 σ_z and M = 0.1B gives virtually the same result as ISC-ST. Figure 8 illustrates the performance of the FM model with its parameters set for a pollutant with a light molecular weight (i.e. gas or odor). As expected, the predicted downwind concentrations are much lower, due to the pollutant dispersing more quickly. ISC-ST, however, still predicts the same downwind concentration, no matter what the physical characteristics of the pollutant are.

Since the point of maximum concentration is at ground level in the ISC-ST model, the receptor height of 1.8 meters will always be near the point of maximum concentration. This is not the case with the FZM model. As the distance from the source increases, the point of maximum concentration rises, while the receptor height remains constant. As an illustration of the comparison of points of maximum concentration between the reflected normal distribution and the triangular distribution, we set the receptor height of the FZM model equal to the index M at each receptor location. Figure 9 illustrates the results of that comparison. Note, however, that at 200 meters the point of maximum concentration (and thus the receptor height) is 16 meters, which is far above the height at which human respiration of PM would occur.

Conclusions

The Fritz-Zwicke-Meister Model is a new approach to dispersion modeling. The use of small increment time averaging (2 minute time periods instead of 1 hour) results in concentration estimates that are based on dispersion parameters consistent with Pasquill's original work. This results in concentrations that are more representative and accurate. Another major step toward developing a dispersion model that more accurately represents actual conditions, is changing the distribution associated with the vertical plane. The normal distribution, with reflection, in the vertical plane, which produced a profile with a spike at ground level, was removed. This was replaced with a triangular distribution whose indices represent the plume height and the height of maximum concentration. Both indices increase as a function of sigma z, which signifies that the maximum concentration of the plume does not remain in height at ground-level, but increases as the distance downwind increases. Finally, using the deposition velocity to calculate the plume's depletion and modeling the resulting PSD accounts for the settling of the pollutant as it travels downwind of the source.

This model is a step toward a more improved model. It provides the framework for a more robust model that can be adapted to predict dispersion of various pollutants ranging from particulate matter to gases and odors. This gives the modeler more freedom to tailor the model to a particular situation, resulting in the fair regulation of agriculture.

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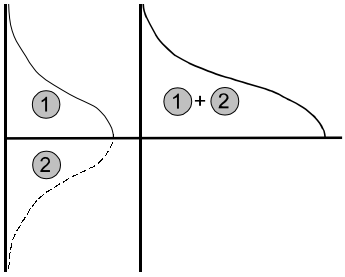

Figure 1a. Mathematical reflection of normal distribution from a ground level source.

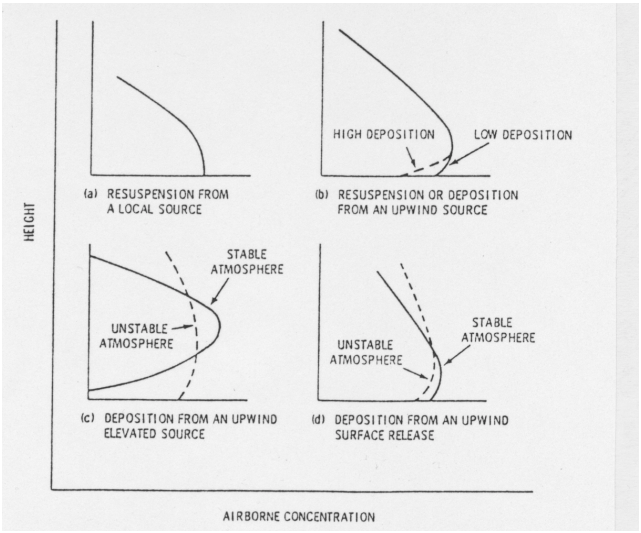

Figure 1b. Idealized plume profiles as a function of deposition conditions (from Sehmel, 1980).

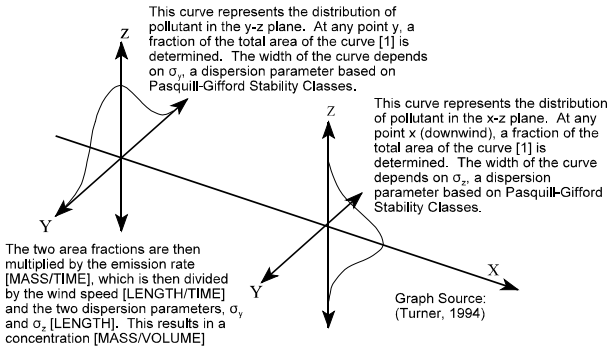

Figure 2. The Gaussian Model.

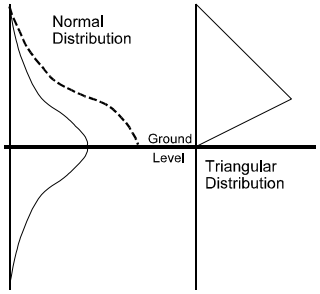

Figure 3. Distributions in the vertical plane: Reflected Normal vs. Triangular.

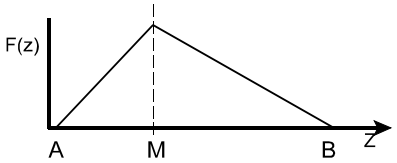

Figure 4. The triangular distribution (Pritsker 1979).

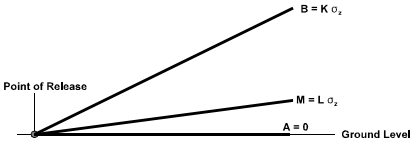

Figure 5. Indices of the triangular distribution.

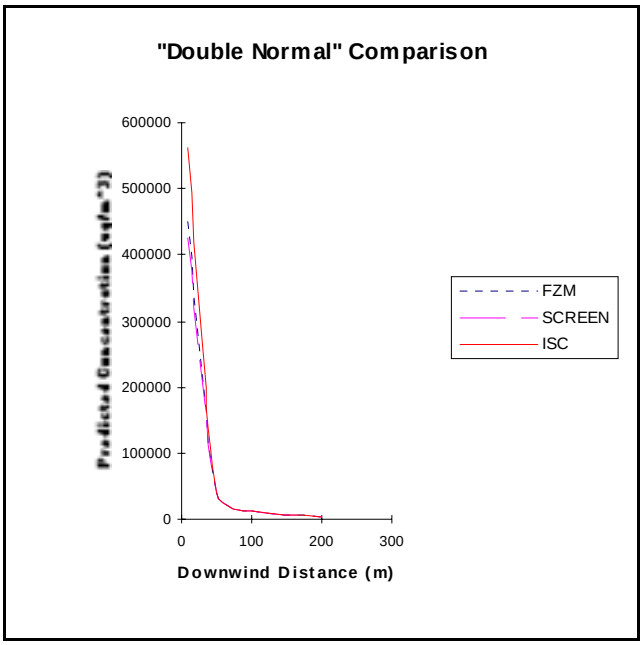

Figure 6: Comparison of the results of the FZM model with normal distributions in the horizontal and vertical planes with those of ISC-SCREEN and ISC-ST.

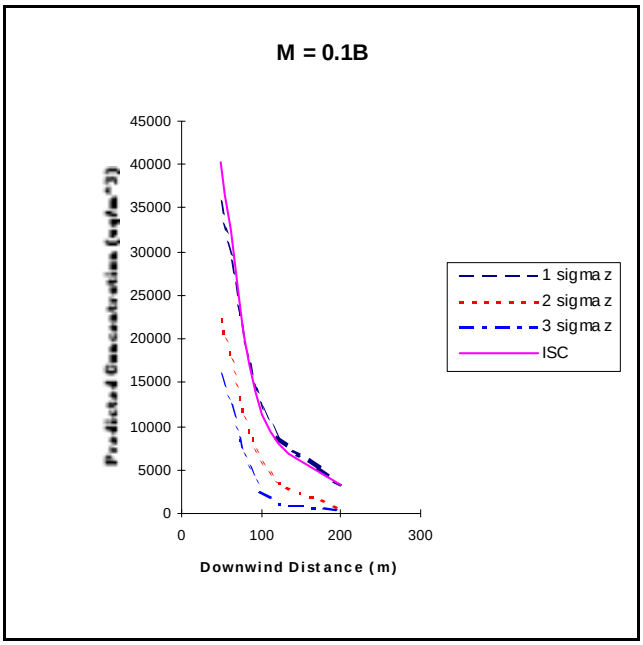

Figure 7: Comparison of ISC-ST with the FZM model with a triangular distribution in the vertical plane, a set mode of 0.1B, and plume height (B) varying from 1 σ_z to 3 σ_z (Hypothesized values for PM).

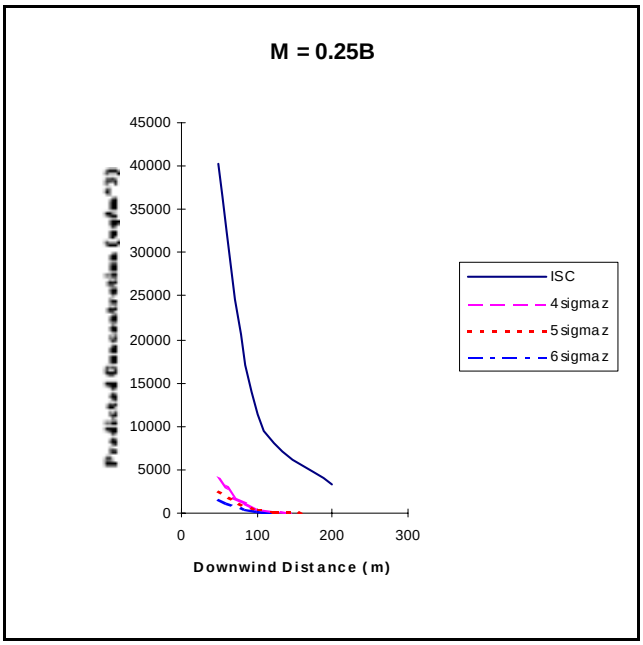

Figure 8: Comparison of ISC-ST with the FZM model with a triangular distribution in the vertical plane, a set mode of 0.25B, and plume height (B) varying from 4 σ_z to 6 σ_z (Hypothesized values for gases and odors).

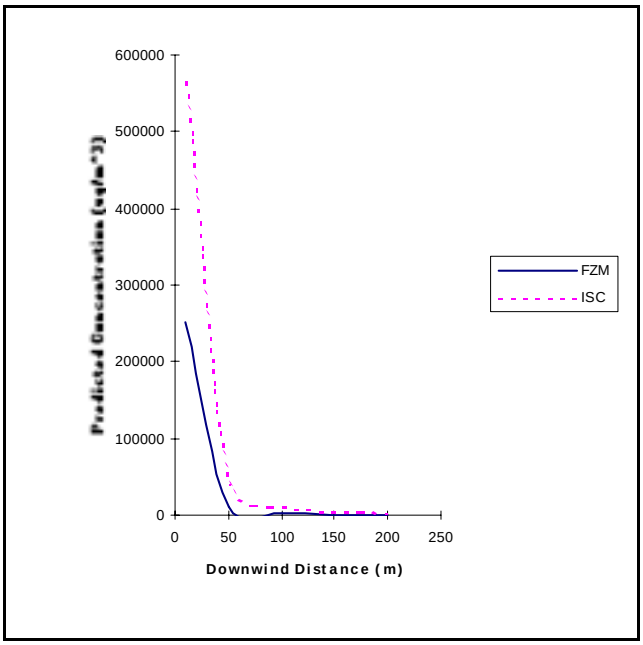

Figure 9: Comparison of points of maximum downwind concentration for given receptor distances.

Table 1. Percent of pollutant removed the plume using Stokes settling velocity

Particle Size (um)	Emission Height (m)	Downwind Distance				
		50m	100m	200m	500m	1000m
10	0.5	23.65	41.70	66.02	93.27	99.55
	1.0	12.62	23.65	41.70	74.05	93.27
	1.5	8.60	16.46	30.22	59.32	83.45

Particle Density = 2.63 g/cm^3
T = 25°C
P = 1 atm
Wind Velocity = 3 m/s
*Aerodynamic Equivalent Diameter

Table 2. Percent of 10 micron pollutant removed from the plume at emission height of 4.0m and distance.

Method	Settling Velocity (m/s)	Downwind Distance				
		50m	100m	200m	500m	1000m
Horst	0.0049	2.02	4.00	7.84	18.47	33.52
Stokes	0.0081	3.32	6.52	12.62	28.63	49.06

Particle Density = 2.63 g/cm^3
T = 25°C
P = 1 atm
Wind Velocity = 3 m/s
*Aerodynamic Equivalent Diameter