A Simulated Approach to Estimating PM_{10} and $PM_{2.5}$ Concentrations Downwind from Cotton Gins

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ABSTRACT. *Cotton gins are required to obtain operating permits from state air pollution regulatory agencies (SAPRA), which regulate the amount of particulate matter that can be emitted. Industrial Source Complex Short Term version 3 (ISCST3) is the Gaussian dispersion model currently used by some SAPRAs to predict downwind concentrations used in the regulatory process in the absence of field sampling data. The maximum ambient concentrations for PM_{10} and $PM_{2.5}$ are set by the National Ambient Air Quality Standard (NAAQS) at $150\,\mu g/m^3$ and $65\,\mu g/m^3$ (24 h average), respectively. Some SAPRAs use the NAAQS concentrations as property line concentrations for regulatory purposes. This article reports the results of a unique approach to estimating downwind PM_{10} and $PM_{2.5}$ concentrations using Monte Carlo simulation, the Gaussian dispersion equation, the Hino power law, and a particle size distribution that characterizes the dust typically emitted from cotton gin exhausts. These results were then compared to a 10 min concentration (C_{10}) and the concentrations that would be measured by an FRM PM_{10} and $PM_{2.5}$ sampler. The total suspended particulate (TSP) emission rate, particle size distributions, and sampler performance characteristics were assigned to triangular distributions to simulate the real-world operation of the gin and sampling systems. The TSP emission factor given in AP-42 for cotton gins was used to derive the PM mass emission rate from a 40 bale/h plant. The Gaussian equation was used to model the ambient TSP concentration downwind from the gin. The performance characteristics for the PM_{10} and $PM_{2.5}$ samplers were then used to predict what the measured concentration would be for two PSD conditions. The first PSD assumption was that the mass median diameter (MMD) and geometric standard deviation (GSD) were constant at 12 μm and 2, respectively, and the second scenario assigned a triangular distribution to the MMD and GSD of {15, 20, 25} μm and {1.8, 2.0, 2.2}, respectively. The results show that the $PM_{2.5}$ fraction of the dust emitted under either PSD condition was negligible when compared to the NAAQS for $PM_{2.5}$ of $65\,\mu g/m^3$. The results also demonstrate that correcting for wind direction changes within the hour using the power law reduces the ambient concentration by a factor of 2.45.*

Keywords. Dispersion modeling, Particulate matter.

While the national ambient air quality standards (NAAQS) for criteria pollutants were originally intended for use as ambient concentration standards, some air pollution regulations for cotton ginning facilities are based on compliance with the NAAQS as 24 h average property line concentrations (PLC). PM_{10} is the criteria pollutant emitted by cotton gins requiring the facility to obtain an operating permit from the state air pollution regulatory agency (SAPRA). PM_{10} is defined as the mass fraction of dust particles with aerodynamic equivalent diameter (AED) equal to or less than 10 μm. $PM_{2.5}$ is defined as the mass fraction of dust particles with AED equal to or less than 2.5 μm. It should be noted that $PM_{2.5}$ is currently not regulated by the U.S. Environmental Protection Agency (EPA) but is listed as a criteria pollutant in the NAAQS. The two methods regulators have to obtain the PLCs of PM_{10} for regulatory purposes are dispersion modeling and field sampling. There are errors in the protocol for both of these processes. Buser et al. (2001) demonstrate mathematically the measurement errors encountered when using federal reference method (FRM) PM_{10} and $PM_{2.5}$ samplers to measure particulate matter (PM) concentrations from sources emitting dust with mass median diameter (MMD) and geometric standard deviation (GSD) in excess of 10 μm and 1.5, respectively. The errors in the dispersion modeling process are a result of the assumption (by the developers of the model) that the concentrations calculated by the model are 1 h concentrations, while in reality, they are shorter time averages (approx. 10 min average concentrations) (Stiggins et al., 2003). These errors cause the measured and predicted PM concentrations downwind from agricultural low-level point sources (LLPS) (cotton gins, feed mills, grain elevators, etc.) to be in excess of the true concentrations.

Industrial Source Complex Short Term version 3 (ISCST3) is the dispersion model (approved by the EPA) most commonly used to predict time-averaged PM con-

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centrations downwind from an LLPS. The concentration-time dependence is a result of the change in wind speed and direction over some time period. Boubel et al. (1994) states: "If emission and meteorological conditions remained unchanged hour after hour, concentrations at various locations downwind would remain the same. However, since such conditions are ever-changing, concentrations vary with time." Cooper and Alley (2002) state that "the longer the averaging time, the more likely many such shifts will occur. These random fluctuations help spread the plume over a larger downwind area." ISCST3 uses the Pasquill-Gifford atmospheric stability parameter estimates to estimate the horizontal and vertical plume dispersion parameters (σ_y and σ_z, respectively) used in the Gaussian dispersion equation. The values for σ_y and σ_z vary with atmospheric stability class and distance. The stability of the atmosphere has been divided into six classes, A through F, with A being the most unstable (Cooper and Alley, 2002). Pasquill (1962) discusses the plume spread characteristic results of several experiments with varying source emission durations ranging from 3 to 30 min. However, the time period associated with the Pasquill-Gifford σ_y and σ_z is the subject of much scientific debate. The following paragraph from Beychok (1996) summarizes the issue:

"A major problem with the Gaussian dispersion equation is defining what the calculated concentration C represents when using Pasquill's dispersion coefficients. D. B. Turner states that C represents a 3- to 15-minute average; an American Petroleum Institute dispersion modeling publication believes C represents a 10- to 30-minute average; S. R. Hanna and P. J. Drivas believe C is a 10-minute average; and others attribute averaging times from 5 minutes to 30 minutes. Most agree on a range of 10 to 15 minutes. However, many Environmental Protection Agency computer models used to determine regulatory compliance assume that the Gaussian dispersion equation yields 60-minute average concentrations. Assuming that the Gaussian dispersion equation yields 60-minute values rather than 10-minute values constitutes a built-in over-prediction error that may be as large as 2.5."

ISCST3 uses the concentration from the Gaussian equation as a 1 h average concentration (C_{60}) (Turner, 1994; EPA, 1995). This assumption that $C = C_{60}$ results in an overestimation of downwind concentrations from low-level point sources. The assumption by the developers of ISCST3, in essence, states that the variation of the wind direction and wind velocity over a 1 h time period is the same as that for a short time period (approx. 10 min) (EPA, 1995). This article assumes that the time period associated with the horizontal and vertical plume spread parameters (Pasquill-Gifford σ_y and σ_z) is 10 min.

Several sources have suggested that the relationship between short and long time-averaged concentrations follows that of a "power law" model. Hino (1968) suggests that a power law model with a p-value of 0.5 is appropriate to use in converting short time-averaged concentrations to longer time-averaged concentrations ranging from 10 min to 4 h. Research by Stiggins et al. (2003) indicate that the p-value can range from 0.172 to 0.607 depending on stability class. Wanjura et al. (2003) present p-values as a function of stability class and distance. Gifford (1960) states that the exponent used in the peak to mean equation can range from 0.2 to 0.7.

The performance characteristics of a federal reference method (FRM) ambient PM_{10} sampler are characterized by a lognormal distribution with a cutpoint (d_{50}) of 10 ±0.5 μm and slope of 1.5 ±0.1 (Hinds, 1982). EPA defines the performance characteristics of the FRM $PM_{2.5}$ sampler as having a $d_{50} = 2.5 \pm 0.2$ μm, with no slope specifically stated. Work by Peters and Vanderpool (1996) suggests a slope of the fractional efficiency curve (FEC) for the WINS Impactor ($PM_{2.5}$ sampler) of 1.18. Further work by Buch (1999) indicates the performance characteristics of the WINS Impactor to have a slope of 1.3 ±0.03. The lognormal distributions defined for the PM_{10} and $PM_{2.5}$ samplers describe the FEC in which the samplers are expected to operate. The FEC gives the expected collection efficiency of the sampler for any given particle diameter, or stated differently, it gives the percentage of particles in the PSD that should be prevented from penetrating to the filter. Buser et al. (2001) report that inherent sampler errors exist for PM_{10} samplers when sampling in dusts with MMDs larger than 10 μm and for $PM_{2.5}$ samplers when sampling in dusts with MMDs greater than 2.5 μm. Buser et al. (2001) further report that the ratio of the PM_{10} concentration measured by the sampler to the true PM_{10} concentration for PM_{10} samplers sampling a dust with MMD = 20 μm and GSD = 1.5 ranges from 1.81 (with the sampler operating with $d_{50} = 9.5$ and slope = 1.4) to 3.43 (with the sampler operating with $d_{50} = 10.5$ μm and slope = 1.6). The ratio of the measured concentration to the true concentration for a $PM_{2.5}$ sampler sampling the same PSD range from 14.8 (with the sampler operating at $d_{50} = 2.3$ μm and slope = 1.27) to 183 (with the sampler operating with $d_{50} = 2.7$ μm and slope = 1.33).

The mass and PSD of the particulate matter penetrating the abatement systems of cotton gins varies depending on the trash content of the cotton processed. The average PM_{10} percentage of TSP reported by AP-42 is 39%, which corresponds to a PSD with a 12 μm MMD assuming a GSD of 2. Buser et al. (2002) report MMDs in excess of 15 μm for gin exhausts. Agricultural dusts typically have PSDs characterized by an MMD ranging from 15 to 25 μm with a GSD typically ranging from 1.5 to 2.0 (Redwine and Lacey, 2001). Oversampling errors caused by MMDs larger than the sampler's cutpoint result in great inaccuracies in measuring downwind concentrations.

OBJECTIVES

The purpose of this article is to demonstrate the inaccuracies of the tools available to air pollution regulators for predicting and measuring PM concentrations (dispersion modeling and ambient sampling) downwind from low-level point sources, more specifically cotton gins. It is not the intent of this article to suggest a new dispersion model for modeling low-level point sources. The assumptions made in this article are:
- Gaussian dispersion modeling, when corrected for concentration time averaging errors, can be used to accurately predict downwind TSP concentrations.
- The PSD of the dust emitted from the gin is the same as the PSD of the dust downwind of the gin.
- Mass fraction versus particle size distributions applied to TSP concentrations can be used to accurately determine PM_{10} concentrations.
- The distribution of the MMD and GSD of the PSD of the dust emitted from a cotton gin can be described by a triangular distribution.

- The FRM PM_{10} and $PM_{2.5}$ sampler will operate within the specified ranges for d_{50} and slope.
- The distribution of the slope and cutpoint (d_{50}) of the FEC for an FRM PM_{10} and $PM_{2.5}$ sampler can be described by a triangular distribution.

The following analysis uses Gaussian dispersion modeling to estimate the TSP concentration downwind from a cotton gin. The initial TSP concentration is adjusted using a simulated PSD to determine the PM_{10} and $PM_{2.5}$ concentrations that would be reported by ISCST3. The initial TSP concentration is then corrected for the time-averaging errors associated with assuming that a 10 min concentration is a 1 h concentration using the power law (p = 0.5). Using this corrected TSP concentration with a simulated PSD and the simulated performance characteristics of the FRM PM_{10} and $PM_{2.5}$ sampler, the magnitude of the concentration that would be measured by the samplers is determined (quasi-measured concentrations). The true PM_{10} and $PM_{2.5}$ concentrations are obtained using the corrected TSP concentration with the simulated PSD. Finally, the modeled, true, and quasi-measured PM_{10} and $PM_{2.5}$ concentrations are compared to show the inaccuracies associated with the current concentration measurement and prediction methods.

METHODS

Two scenarios were developed to simulate the emission of particulate matter from a 40 bale/h cotton gin. Scenario A was performed under the assumption that the PSD of the dust emitted from the gin was constant and had an MMD = 12 µm and GSD = 2. Scenario B assigned a triangular distribution to the MMD and GSD of the PSD of the dust emitted from the gin. The parameters of the MMD and GSD distributions were MMD = {15, 20, 25} µm and GSD = {1.8, 2.0, 2.2}. The range of a random variable defined by a triangular distribution will be denoted by $\{a, c, b\}$. The triangular distribution is defined by equations 1 through 3, and figure 1 shows a graphical representation of the triangular distribution:

$$\Theta = \frac{c-a}{b-a} \qquad (1)$$

$$X = a + \sqrt{(b-a)*(c-a)*R}$$

$$\text{for } 0 \le R \le \Theta \qquad (2)$$

$$X = b - \sqrt{(b-a)*(b-c)*(1-R)}$$

$$\text{for } \Theta < R \le 1 \qquad (3)$$

where
Θ = constant ratio
a = minimum value of the simulated variable
b = maximum value of the simulated variable
c = most likely value of the simulated variable
X = simulated/random variable
R = random number.

The TSP emission factor for the 40 bale/h gin was defined by a triangular distribution of {0.91, 1.39, 1.82} kg/bale. It was assumed that the emission factor would change based on the trash content of the incoming seed cotton, so an emission factor range was assigned as ± 0.454 kg (± 1 lb) from the total 1996 AP-42 TSP (EPA, 1996) emission factor of 1.38 kg/bale (3.05 lbs/bale). Equation 4 was used to calculate the TSP emission rate for the gin:

$$ER_{TSP} = EF_{TSP} \times GR \times \frac{10^9}{3600} \qquad (4)$$

where
ER_{TSP} = TSP emission rate (µg/s)
EF_{TSP} = AP-42 TSP emission factor (kg/bale)
GR = ginning rate (bales/h)
$10^9/3600$ = unit conversion constants.

The TSP emission rate was then used as the emission rate in the Gaussian equation, as shown in equation 5:

$$C_{10} = \frac{ER_{TSP}}{2\pi u \sigma_y \sigma_z} \exp\left(-\frac{1}{2}\frac{y^2}{\sigma_y^2}\right)$$

$$\times \left\{ \exp\left(-\frac{1}{2}\frac{(z-H)^2}{\sigma_z^2}\right) + \exp\left(-\frac{1}{2}\frac{(z+H)^2}{\sigma_z^2}\right) \right\} \qquad (5)$$

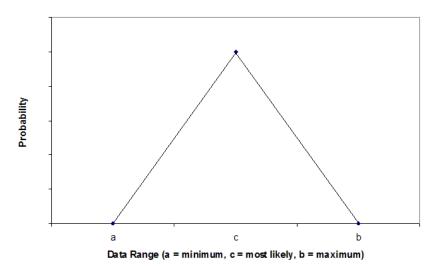

Figure 1. Triangular probability distribution showing the values of (a, c, b), where a is the minimum value of the data range, c is the most likely value of the data range, and b is the minimum value of the data range.

where

C_{10} = 10 min average steady-state concentration at a point (x, y, z) ($\mu g/m^3$)
u = average wind speed at stack height (m/s)
y = horizontal distance from plume centerline (m)
z = height of receptor with respect to ground (m)
H = effective stack height ($H = h + \Delta h$, where h = physical stack height and Δh = plume rise) (m)
σ_y, σ_z = horizontal and vertical plume dispersion coefficients (m).

The values for σ_y and σ_z were calculated according to the procedure outlined in Turner (1994). Turner's method of approximating the Pasquill-Gifford plume spread parameters (σ_y and σ_z) are used in ISCST3 to estimate the spread of the plume at different distances for the six atmospheric stability classes (A through F). Equations 6 through 8 are used by Turner (1994) to approximate the Pasquill-Gifford σ_y and σ_z:

$$\sigma_y = \frac{1000(X)\tan(T)}{2.15} \quad (6)$$

$$T = 8.3333 - 0.72382\ln(X) \quad (7)$$

$$\sigma_z = aX^b \quad (8)$$

where

X = downwind distance from source to receptor (km)
T = stability class dependent equation (degrees) (shown here for stability class D)
a, b = stability class dependent constants.

Note that the equation for T is stability class dependent and is shown here for stability class D only. The value of T represents one half of Pasquill's theta (Turner, 1994).

The downwind distances (X) used for both scenarios were 550 and 300 m. These distances were chosen to demonstrate the effect of the particle size distribution on the required distance between the property line and the emission point in order for the gin to be in compliance with the NAAQS at the property line.

The following assumptions were made for the model:
- Constant wind speed of 6 m/s.
- Stability class D.
- Average wind direction is directly from source to receptor ($y = 0$).
- Concentrations calculated at ground level ($z = 0$).
- Effective stack height of 10 m (typical cyclone height with rain cap preventing momentum plume rise).

These assumptions were made to simplify the execution of the model for demonstration purposes. Stability class D was chosen because it is the only stability class that can be used for both night time and day time conditions. According to the solar radiation/delta-T method (EPA, 2000), for stability class D to be used for daytime conditions, the wind speed must be greater than or equal to 6 m/s. There is no limit on the wind speed for stability class D at night. Thus, the minimum daytime wind speed was assumed (6 m/s). The assumption of the average wind direction being directly from source to receptor and the decision to calculate the concentrations at ground level help to further simplify equation 5. The effective stack height of 10 m was assumed to be the average height of the gas exit tube of a cyclone mounted on a commercially fabricated cyclone rack outside of a typical gin.

Equation 5 was evaluated once for every hour of ten days, resulting in a total of 240 C_{10} concentrations for each scenario. The meteorological data and TSP emission rates used to calculate these C_{10} values were input to ISCST3, and the hourly concentrations for each hour of the ten days were calculated. The C_{10} concentration values and the hourly concentration values from ISCST3 matched one another exactly, confirming that the ISCST3 hourly concentrations are in fact 10 min concentrations. The particle size distributions for scenarios A and B were used with the original 10 min average TSP concentrations modeled downwind to calculate the PM_{10} and $PM_{2.5}$ concentrations that would result from ISCST3. These concentration values are known as the "ISCST3 modeled concentrations."

The original TSP C_{10} values were then converted to C_{60} values using the power law model with p-value of 0.5, as shown in equation 9:

$$C_{60} = C_{10} \times \left(\frac{10}{60}\right)^{0.5} \quad (9)$$

where

C_{60} = 1 h TSP concentration ($\mu g/m^3$)
10/60 = time ratio used to convert a 10 min concentration to a 60 min concentration.

The "true PM_{10} and $PM_{2.5}$" concentrations were calculated using the TSP C_{60} values calculated using equation 9 and the lognormal distribution defined by MMD = 12 μm and GSD = 2 for scenario A and by MMD = {15, 20, 25} μm and GSD = {1.8, 2.0, 2.2} for scenario B. AP-42 (EPA, 1996) states that the PM_{10} emission factor for a cotton gin is 0.54 kg/bale (1.2 lbs/bale) and that the TSP emission factor is 1.38 kg/bale (3.05 lbs/bale). The ratio of these two emission factors implies that the percentage of a TSP concentration that is PM_{10} is 39%. The PM_{10} percentage of a lognormal particle size distribution characterized by an MMD of 12 μm and GSD of 2.0 is 39%. The ranges used for the MMD and GSD for scenario B are taken from Redwine and Lacey (2001).

The lognormal mass density function is defined as:

$$f(d_p, MMD, GSD) =$$

$$\frac{1}{d_p \ln(GSD)\sqrt{2\pi}} \exp\left[\frac{-[\ln(d_p) - \ln(MMD)]^2}{2[\ln(GSD)]^2}\right] \quad (10)$$

where

d_p = particle diameter (μm)
$f(d_p, MMD, GSD)$ = mass fraction of particles having diameter d_p.

The mass fraction of particles less than a given size is found by integrating equation 10 from 0 to the particle diameter of interest; this is known as the lognormal cumulative distribution function. To find the concentration of a particular size range of particles in a TSP concentration, equation 11 is used:

$$C(x) = C_{60} * \int_0^x f(d_p, MMD, GSD) dd_p \quad (11)$$

where

x = particle size of interest (x = 10 for PM_{10}; x = 2.5 for $PM_{2.5}$) (μm)

$C(x) = 1$ h concentration of particles equal to or less than x μm (true PM$_x$ concentration) (μg/m^3).

The d_{50} for the PM$_{10}$ ambient air sampler in dust PSD scenarios A and B varied according to triangular distribution {9.5, 10, 10.5}, and the slope varied according to {1.4, 1.5, 1.6}. The d_{50} for the PM$_{2.5}$ sampler in both scenarios was constant at 2.5 μm with slope constant at 1.18. The lognormal density distribution function of the collection efficiency of a sampler is given by equation 12:

$$\eta(d_p, d_{50}, slope) =$$

$$\frac{1}{d_p \ln(slope)\sqrt{2\pi}} \exp\left[\frac{-[\ln(d_p) - \ln(d_{50})]^2}{2[\ln(slope)]^2}\right] \quad (12)$$

where $\eta(d_p, d_{50}, slope)$ is the collection efficiency of the sampler for particles of diameter d_p.

The cumulative distribution function of the collection efficiency curve is given by equation 13:

$$Í(x, d_{50}, slope) = \int_0^x \eta(d_p, d_{50}, slope) \quad (13)$$

where $N(x, d_{50}, slope)$ is the cumulative collection efficiency of particles equal to or less than x μm in diameter.

The collection efficiency, $N(x, d_{50}, slope)$, is used in equation 14 to find the cumulative penetration efficiency:

$$P(x, d_{50}, slope) = 1 - Í(x, d_{50}, slope) =$$

$$1 - \int_0^x \frac{1}{d_p \ln slope \sqrt{2\pi}} \exp\left[\frac{-(\ln d_p - \ln d_{50})^2}{2(\ln slope)^2}\right] \quad (14)$$

where $P(x, d_{50}, slope)$ is the cumulative penetration efficiency of particles less than x μm in diameter.

The concentration measured by the sampler is given by equation 15:

$$M(MMD, GSD, d_{50}, slope) =$$

$$C_{60} * \int_0^\infty f(d_p, MMD, GSD) * P(d_p, d_{50}, slope)dd_p \quad (15)$$

where $M(MMD, GSD, d_{50}, slope)$ is the concentration measured by the sampler using a 1 h TSP concentration (μg/m^3).

Equation 15 was used in both scenario A and B to determine the "quasi-measured" PM$_{10}$ and PM$_{2.5}$ concentration. The term "quasi-measured" is used because the concentrations reported were not physically measured by a sampler in the field.

RESULTS

The results of the concentrations 300 and 550 m downwind of the cotton gin in scenario A are shown in tables 1 and 2, respectively. The results from scenario A show that the ratio of the true concentrations to the ISCST3 modeled concentrations is 2.45 for both the PM$_{10}$ and PM$_{2.5}$ concentrations. The ratio of the quasi-measured concentration to the true concentration is 1.04 and 1.17 for the PM$_{10}$ and PM$_{2.5}$ concentrations, respectively. The ratio of the quasi-measured concentration to the true concentration is known as the oversampling rate. All of the concentrations (true, ISCST3 modeled, and quasi-measured) at a 300 m property line would cause the gin to exceed an air quality standard that applies the NAAQS for PM$_{10}$ (150 μg/m^3 24 h average) at the property line. The true and quasi-measured PM$_{10}$ concentrations at 550 m could be considered to be marginal when used to determine compliance with the NAAQS for PM$_{10}$. However, the ISCST3 modeled concentrations still indicate an exceedance at a 550 m property line. The PM$_{2.5}$ concentrations at either 300 or 550 m downwind were negligible compared to the NAAQS of 65 μg/m^3 (24 h average).

Tables 3 and 4 show the results of scenario B at 300 and 550 m downwind from a 40 bale/h cotton gin. The results for scenario B show differences between the true and ISCST3 modeled concentrations for both PM$_{10}$ and PM$_{2.5}$ that are similar to those of scenario A. The ratio of the true to ISCST3 modeled concentrations was 2.45 for both PM$_{10}$ and PM$_{2.5}$ at both 300 and 550 m downwind. The oversampling rate increased for both PM$_{10}$ and PM$_{2.5}$ to 1.21 and 1.26, respectively. The increase in oversampling rate was a consequence of the increase in the MMD and GSD of the PSD of the dust sampled. Over the ten-day period, the average MMD was 19.8 μm, and the average GSD was 2.0. For both

Table 1. Downwind 24 h average concentration results from scenario A with constant PSD (MMD = 12, GSD = 2) at 300 m downwind from a 40 bale/h cotton gin.

Day	True Concentration[a] (24 h average)		ISCST3 Modeled Concentration[b] (24 h average)		Quasi-Measured Concentration[c] (24 h average)	
	PM$_{10}$ (μg/m^3)	PM$_{2.5}$ (μg/m^3)	PM$_{10}$ (μg/m^3)	PM$_{2.5}$ (μg/m^3)	PM$_{10}$ (μg/m^3)	PM$_{2.5}$ (μg/m^3)
1	336.2	10.0	823.4	24.6	347.1	11.8
2	342.2	10.2	838.3	25.0	352.3	12.0
3	334.3	10.0	818.9	24.4	347.4	11.7
4	340.7	10.2	834.6	24.9	351.6	11.9
5	340.2	10.1	833.4	24.9	352.3	11.9
6	339.0	10.1	830.4	24.8	348.1	11.9
7	336.5	10.0	824.3	24.6	349.0	11.8
8	351.2	10.5	860.4	25.7	365.0	12.3
9	356.8	10.6	873.9	26.1	370.7	12.5
10	346.9	10.3	849.7	25.3	360.9	12.1

[a] Equations 5, 9, and 11 were used in the calculation of the true concentrations.
[b] Equations 5, and 11 were used in the calculation of the ISCST3 modeled concentrations.
[c] Equations 5, 9, and 15 were used in the calculation of the quasi-measured concentrations.

Table 2. Downwind 24 h average concentration results from scenario A with constant PSD (MMD = 12, GSD = 2) at 550 m downwind from a 40 bale/h cotton gin.

Day	True Concentration[a] (24 h average)		ISCST3 Modeled Concentration[b] (24 h average)		Quasi-Measured Concentration[c] (24 h average)	
	PM_{10} ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	PM_{10} ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	PM_{10} ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)
1	146.0	4.4	357.7	10.7	150.8	5.1
2	148.6	4.4	364.1	10.9	153.0	5.2
3	145.2	4.3	355.7	10.6	150.9	5.1
4	148.0	4.4	362.5	10.8	152.7	5.2
5	147.8	4.4	362.0	10.8	153.0	5.2
6	147.2	4.4	360.7	10.8	151.2	5.2
7	146.2	4.4	358.0	10.7	151.6	5.1
8	152.6	4.5	373.7	11.1	158.5	5.3
9	155.0	4.6	379.6	11.3	161.0	5.4
10	150.7	4.5	369.0	11.0	156.7	5.3

[a] Equations 5, 9, and 11 were used in the calculation of the true concentrations.
[b] Equations 5, and 11 were used in the calculation of the ISCST3 modeled concentrations.
[c] Equations 5, 9, and 15 were used in the calculation of the quasi-measured concentrations.

Table 3. Downwind 24 h average concentration results from scenario B with simulated PSD (MMD = {15, 20, 25}, GSD = {1.8, 2.0, 2.2}) at 300 m downwind from a 40 bale/h cotton gin.

Day	True Concentration[a] (24 h average)		ISCST3 Modeled Concentration[b] (24 h average)		Quasi-Measured Concentration[c] (24 h average)	
	PM_{10} ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	PM_{10} ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	PM_{10} ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)
1	134.3	1.3	329.1	3.3	162.9	1.7
2	133.5	1.5	327.0	3.7	163.5	1.9
3	127.7	1.3	312.9	3.3	156.4	1.7
4	146.2	1.6	358.1	3.8	174.9	2.0
5	146.4	1.7	358.7	4.1	178.3	2.1
6	135.8	1.4	332.7	3.5	163.9	1.8
7	154.2	1.8	377.8	4.3	186.4	2.2
8	134.8	1.2	330.3	3.0	164.9	1.6
9	135.3	1.3	331.4	3.2	163.6	1.7
10	160.9	1.8	394.2	4.3	195.1	2.2

[a] Equations 5, 9, and 11 were used in the calculation of the true concentrations.
[b] Equations 5, and 11 were used in the calculation of the ISCST3 modeled concentrations.
[c] Equations 5, 9, and 15 were used in the calculation of the quasi-measured concentrations.

Table 4. Downwind 24 h average concentration results from scenario B with simulated PSD [MMD = (15, 20, 25), GSD = (1.8, 2.0, 2.2)] at 550 m downwind from a 40 bale/h cotton gin.

Day	True Concentration[a] (24 h average)		ISCST3 Modeled Concentration[b] (24 h average)		Quasi-Measured Concentration[c] (24 h average)	
	PM_{10} ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	PM_{10} ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)	PM_{10} ($\mu g/m^3$)	$PM_{2.5}$ ($\mu g/m^3$)
1	58.3	0.6	142.9	1.4	70.8	0.7
2	58.0	0.7	142.0	1.6	71.0	0.8
3	55.5	0.6	135.9	1.4	67.9	0.7
4	63.5	0.7	155.5	1.7	76.0	0.9
5	63.6	0.7	155.8	1.8	77.4	0.9
6	59.0	0.6	144.5	1.5	71.2	0.8
7	67.0	0.8	164.1	1.9	81.0	1.0
8	58.6	0.5	143.5	1.3	71.6	0.7
9	58.8	0.6	143.9	1.4	71.1	0.7
10	69.9	0.8	171.2	1.9	84.8	1.0

[a] Equations 5, 9, and 11 were used in the calculation of the true concentrations.
[b] Equations 5, and 11 were used in the calculation of the ISCST3 modeled concentrations.
[c] Equations 5, 9, and 15 were used in the calculation of the quasi-measured concentrations.

300 and 550 m downwind, the PM_{10} true concentrations indicate that the gin would be in compliance with the NAAQS of 150 $\mu g/m^3$ (24 h average) at the property line. The ISCST3 modeled concentrations at either distance (300 or 550 m) result in an exceedance of the NAAQS for PM_{10}. The quasi-measured PM_{10} concentrations at 300 m were not in compliance with the NAAQS for PM_{10}. However, the quasi-measured PM_{10} concentrations at 550 m were in compliance with the NAAQS for PM_{10}. All of the $PM_{2.5}$ concentrations at either distance under scenario B were negligible when compared to the NAAQS for $PM_{2.5}$ of 65 $\mu g/m^3$ (24 h average).

CONCLUSIONS

The following conclusions can be drawn from the results of this work:

- Using the power law (with p = 0.5) to correct for the time-averaging errors associated with concentrations predicted by ISCST3 results in more accurate downwind estimations of PM_{10} and $PM_{2.5}$ concentrations. On average, the concentrations from ISCST3 will be reduced by a factor of 2.45 using the power law with p = 0.5.

- The particle size distribution of the PM plays a significant role in accurately measuring downwind concentrations of PM_{10} and $PM_{2.5}$ when measuring concentrations with FRM samplers. PM_{10} concentration measurements of PM with MMDs close to 10 μm will result in measurements that are close to the true concentration of PM_{10}. However, as the MMD of the dust increases over 10 μm, the oversampling rate also increases.

- Assuming a typical PSD range as specified by Redwine and Lacey (2001), the $PM_{2.5}$ fraction of TSP concentrations from agricultural sources (such as cotton gins) is negligible when compared to regulatory limits (NAAQS for $PM_{2.5}$ = 65 μg/m^3 24 h average).

REFERENCES

Beychok, M. R. 1996. Air-dispersion modeling and the real world. *Environmental Solutions* 9(6): 24-29.

Boubel, R. W., D. L. Fox, D. B. Turner, and A. C. Stern. 1994. *Fundamentals of Air Pollution.* 3rd ed. San Diego, Cal.: Academic Press.

Buch, U. M. 1999. Performance analysis of the cascade impactor, the federal reference method $PM_{2.5}$ sampler, and the improved $PM_{2.5}$ sampler. MS thesis. College Station, Texas: Texas A&M University, Department of Agricultural Engineering.

Buser, M. D., C. B. Parnell, R. E. Lacey, B. W. Shaw, and B. W. Auvermann. 2001. Inherent biases of PM_{10} and $PM_{2.5}$ samplers based on the interaction of particle size and sampler performance characteristics. ASAE Paper No. 011167. St. Joseph, Mich.: ASAE.

Buser, M. D., C. B. Parnell, Jr., B. W. Shaw, and R. E. Lacey. 2002. Characterization of dusts emitted by cotton gins in terms of true PM_{10}. In *Proc. 2002 Beltwide Cotton Production Conferences*, CD-ROM. Memphis, Tenn.: National Cotton Council.

Cooper, C. D., and F. C. Alley. 2002. *Air Pollution Control: A Design Approach.* 2nd ed. Prospect Heights, Ill.: Waveland Press.

EPA. 1995. Vol. II: Description of model algorithms. In *User's Guide for the Industrial Source Complex (ISC3) Dispersion Models.* EPA-454/B-95-003b. Research Triangle Park, N.C.: U.S. Environmental Protection Agency.

EPA. 1996. Emission factor documentation for AP-42, Section 9.7: Cotton ginning. EPA Contract No. 68-D2-0159. Work Assignment No. 2-03. Research Triangle Park, N.C.: U. S. Environmental Protection Agency, Office of Air Quality Planning and Standards Emission Factors and Inventory Group.

EPA. 2000. Meteorological monitoring guidelines for regulatory modeling applications. EPA-454/R-99-005. Research Triangle Park, N.C.: U. S. Environmental Protection Agency.

Gifford, F. 1960. Peak to average concentration ratios according to a fluctuating plume dispersion model. *Int. J. Air Poll.* 3(4): 253-260.

Hinds, W. C. 1982. *Aerosol Technology: Properties, Behavior, and Measurement of Airborne Particles.* 1st ed. New York, N.Y.: John Wiley and Sons.

Hino, M. 1968. Maximum ground-level concentration and sampling time. *Atmospheric Environment* 2(3): 149-165.

Pasquill, F. D. 1962. *Atmospheric Diffusion: The Dispersion of Windborne Material from Industrial and Other Sources.* London, U.K.: Van Nostrand Company.

Peters, T. M., and R. W. Vanderpool. 1996. Modification and evaluation of the WINS impactor. Final report. EPA Contract No. 68-D5-0040. Research Triangle Park, N.C.: U.S. Environmental Protection Agency, National Exposure Research Laboratory.

Redwine, J. S., and R. E. Lacey. 2001. Concentration and emissions of ammonia and particulate matter in tunnel-ventilated broiler houses under summer conditions in Texas. *Trans. ASAE* 45(4): 1101-1109.

Stiggins, T. E., C. B. Parnell, Jr., R. E. Lacey, and B. W. Shaw. 2003. Errors associated with time average concentrations in Gaussian modeling. In *Proc. 2003 Beltwide Cotton Production Conferences*, 2482-2488. Memphis, Tenn.: National Cotton Council.

Turner, D. B. 1994. *Workbook of Atmospheric Dispersion Estimates: An Introduction to Dispersion Modeling.* 2nd ed. Boca Raton, Fla.: CRC Press.

Wanjura, J. D., C. B. Parnell Jr., B. W. Shaw, and R. E. Lacey. 2003. Dispersion modeling of agricultural low-level point sources. ASAE Paper No. 034117. St. Joseph, Mich.: ASAE.