The Oklahoma Dispersion Model: Using the Gaussian Plume Model as an Operational Management Tool for Determining Near-Surface Dispersion Conditions across Oklahoma

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ABSTRACT

The Oklahoma Dispersion Model (ODM) represents a current innovative application of the classic Gaussian plume model in an operational setting. Utilizing a statewide mesoscale automated weather station network (the Oklahoma Mesonet) for current weather conditions and 60-h gridded Nested Grid Model (NGM) model output statistics (MOS) forecasts for future conditions, the ODM is an Internet-based management tool that can be used to qualitatively assess current and future atmospheric dispersion conditions across Oklahoma for near-surface releases of gases and small particulates. The ODM is designed to qualitatively assess concentrations at ground level near the plume centerline at downwind distances of up to 4000 m. The Gaussian plume model is used in conjunction with rural Briggs sigma-y and sigma-z coefficients to estimate horizontal and vertical dispersion. Pasquill stability class is calculated in two ways: for current conditions, Oklahoma Mesonet weather data are used in conjunction with algorithms recommended by the Environmental Protection Agency; for forecast conditions, the Turner method is used. A method is employed that breaks the atmosphere into six dispersion categories, ranging from excellent to very poor. The ODM generates both graphical and text output. Statewide colored maps showing current conditions for dispersion (dilution of plume) and transport (direction of plume movement) are generated every 15 and 5 min, respectively. Similar maps for future conditions are generated every 12 h using gridded 60-h NGM MOS forecasts. In addition to graphical output, tabular output for future conditions at specific MOS locations is available. The ODM has been used as a management tool in the agriculture and natural resources arenas in conjunction with prescribed burning (smoke), pesticide application, and odors associated with animal agriculture.

1. Introduction

Although its initial development occurred in the 1950s, the classic Gaussian plume model as it is known today (Turner 1969; Hanna et al. 1982) was developed in the 1960s by Pasquill (1961) and was modified by Gifford (1961). Its use was widespread during the years following as a predictive tool for air-quality modeling, in particular in conjunction with emissions from utilities such as coal-fired power plants and nuclear facilities. More-sophisticated dispersion models have been developed since then, but the Gaussian plume model still remains a useful tool.

As part of this special journal collection celebrating the history of air-quality modeling, the Oklahoma Dispersion Model (ODM) represents a modern-day innovative application of the classic Gaussian plume model in an operational setting. Developed in the late 1990s, the ODM is an Internet-based management tool to qualitatively assess the current and future ability of the atmosphere to disperse gases and small particulates that are released near the ground. It utilizes a statewide mesoscale automated weather station network, the Oklahoma Mesonet (Elliott et al. 1994; Brock et al. 1995), for current weather conditions and 60-h gridded

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Nested Grid Model (NGM) model output statistics (MOS) forecasts (Dallavalle et al. 1992) for future conditions.

The ODM generates both graphical and text output that depicts current and future conditions for both near-surface atmospheric dispersion (dilution of plume) and transport direction (movement of plume). Originally developed in response to growing concerns over animal odors, the ODM has not only been used as a management tool within animal agriculture but also for operations such as prescribed burning (smoke dispersal) and pesticide application. It has also had unforeseen uses, such as in the debris burning necessitated by the Oklahoma City F5 tornado of 3 May 1999.

2. The Oklahoma Dispersion Model
   a. Model development

The motivation behind the development of the Oklahoma Dispersion Model was to create an Internet-based operational management tool that would use current and forecast weather data in conjunction with a dispersion model to qualitatively assess the ability of the atmosphere to disperse emissions from a ground or near-ground-level source. The focus was to be on concentrations at ground level (where people live and crops grow) near the plume centerline at downwind distances up to 4000 m (several miles). One key objective was to create a number of “dispersion categories” to qualitatively estimate downwind surface concentrations near the plume centerline. For a constant emission rate, the various dispersion categories would then be indicative of downwind concentrations (e.g., lower concentrations under one category than under another). The model could thus serve as a qualitative management tool to help those in agriculture (and other endeavors) assess the most appropriate times to carry out their operations so as to minimize downwind near-centerline concentrations to people or crops.

The classic Gaussian plume model (Turner 1969; Hanna et al. 1982) was the dispersion model chosen for the development of the ODM. Including the term for reflection at the ground, for a ground-based pollution source with no plume rise and an emission rate \( Q \), the surface \( (z = 0) \) concentration \( C \) over flat terrain at a given downwind distance \( x \) at the plume centerline \( (y = 0) \) is

\[
C(x, 0, 0) = \frac{Q}{\pi u \sigma_y(x) \sigma_z(x)}, \tag{1}
\]

where \( u \) is the wind speed (taken at 10 m), \( \sigma_y(x) \) is the standard deviation of concentration (sigma \( y \)) in the lateral direction \( y \) at downwind distance \( x \), and \( \sigma_z(x) \) is the standard deviation of concentration (sigma \( z \)) in the vertical direction \( z \) at distance \( x \). Briggs (1973) developed equations for sigma \( y \) and sigma \( z \) as a function of downwind distance and Pasquill stability class (PSC; Turner 1969) for both rural and urban conditions. His equations are considered to be valid for downwind distances of 100 m to 10 km.

An initial exploration was conducted of the range in concentration values at various downwind distances as a function of Pasquill stability class and wind speed. Concentrations at seven downwind distances (500, 1000, 1500, 2000, 2500, 3000, and 3500 m) were investigated. For each downwind distance and using the same value for \( Q/\pi \), a matrix of concentrations was calculated using Eq. (1) and the Briggs equations (rural sigmas) for the six Pasquill stability classes (A–F) for a range of wind speeds typically expected under these stability regimes. For classes A and F, wind speeds of 1, 2, and 3 m s\(^{-1}\) were investigated; for classes B and E, the speeds chosen were 1, 2, 3, 4, and 5 m s\(^{-1}\); for classes C and D, the speeds considered were 1, 2, 3, 4, 5, 6, 8, 10, 12, and 14 m s\(^{-1}\). Thus, for a given downwind distance, 36 concentrations were calculated. It should be mentioned that an increased sigma-\( y \) value (that for Pasquill class D) was used under light wind conditions (\(<2 \text{ m s}^{-1}\)) at night for classes E and F to better represent well-documented plume meander (Gifford 1976; Van der Hoven 1976; Hanna 1983).

At each of the seven downwind distances, the concentration distributions were found to be similar. Concentrations were highest in the 1–2 m s\(^{-1}\) range of the F class and were lowest in the highest wind speed ranges of the A–C classes. For fixed Pasquill stability class, concentrations decreased linearly with increasing wind speed as per Eq. (1). For fixed wind speed, concentrations were lowest for Pasquill stability class A and rose 2–3 times (as in a geometric series) for each successive stability class.

The Oklahoma Dispersion Model breaks the atmosphere into six dispersion categories: excellent (EX), good (G), moderately good (MG), moderately poor (MP), poor (P), and very poor (VP). For a given downwind distance, six ranges in concentration \( \Delta_{EX}, \Delta_G, \Delta_{MG}, \Delta_{MP}, \Delta_P, \text{ and } \Delta_{VP} \) are defined, where \( \Delta \) represents the difference between the maximum and minimum concentrations in dispersion category \( j \). Furthermore, as suggested by the concentration patterns noted earlier, a geometric progression is assumed such that \( \Delta_G = a \Delta_{EX}, \Delta_{MG} = a \Delta_G, \Delta_{MP} = a \Delta_{MG}, \Delta_P = a \Delta_{MP}, \text{ and } \Delta_{VP} = a \Delta_P \), where \( a \) is the geometric multiplier. Last, \( C_0 \) is defined as the concentration dividing the two categories MG and MP.
If $C_{\text{max}}$ represents the maximum calculated concentration in the entire distribution (36 concentrations) and $C_{\text{min}}$ represents the minimum, the following equations can be written:

$$C_{\text{max}} = C_{\text{min}} + \Delta_{EX} + a\Delta_{EX} + a^2\Delta_{EX} + a^3\Delta_{EX}$$

and

$$C_{\text{max}} = C_0 + a^3\Delta_{EX} + a^4\Delta_{EX} + a^5\Delta_{EX}. \quad (3)$$

If $C_0$ is known, Eqs. (2) and (3) can be solved for $a$ and $\Delta_{EX}$.

It was decided to let the dividing concentration $C_0$ between the MG and MP dispersion categories occur somewhere within the Pasquill D stability class. In particular, three wind speeds (3, 4, and 5 m s$^{-1}$) within that class were investigated. With the same value of $Q/\pi$ used earlier in calculating the concentration matrices, values for $C_0$ were calculated with Eq. (1) at each of the seven downwind distances for Pasquill stability class D and the three wind speeds. Having $C_0$ along with $C_{\text{max}}$ and $C_{\text{min}}$, values for $a$ and $\Delta_{EX}$ were then calculated with Eqs. (2) and (3) for each of the 21 scenarios (seven downwind distances and three wind speeds). Having this information for each of the seven downwind distances, a dispersion category (EX, G, MG, MP, P, or VP) could now be assigned to each concentration in the matrix.

After inspection of the 21 resulting matrices of dispersion category, it was decided to pattern the dispersion model on the dispersion category distribution resulting when $C_0$ was calculated at a downwind distance of 1500 m and with a wind speed of 4 m s$^{-1}$. The choice of 1500 m as the downwind distance was based on the observation that for each of the wind speeds (3, 4, and 5 m s$^{-1}$) in Pasquill class D used in determining $C_0$, the $a$ value (geometric multiplier) at 1500 m was closest to the average of the 7 $a$ values calculated (for each of the 7 distances). With respect to the choice for wind speed, the ratios $C_{\text{min}}/C_0$ and $C_0/C_{\text{max}}$ at 1500 m were nearly identical when a wind speed of 4 m s$^{-1}$ was used to determine $C_0$, indicating that $C_0$ was right in the center of the geometric distribution. Last, the dispersion category distribution at 1500 m using 4 m s$^{-1}$ to determine $C_0$ ($a = 2.292$) appeared balanced and appropriate (see Table 2, to be discussed later).

In accordance with the above, the “template” used by the Oklahoma Dispersion Model is the dispersion category distribution occurring at 1500 m with a $C_0$ value defined as the concentration occurring in Pasquill stability class D at a wind speed of 4 m s$^{-1}$. If $C$ is the actual concentration occurring at 1500 m, a relative concentration $C_{\text{rel}}$ at 1500 m can then be defined as

$$C_{\text{rel}} = C/C_0. \quad (4)$$

The resulting dispersion category distribution at 1500 m with respect to this relative concentration is shown in Table 1.

Table 2 shows the resulting distribution of dispersion categories with respect to Pasquill stability class and wind speed. Note that, for a given Pasquill stability class, a range of categories is possible with dispersion increasing with higher wind speeds. For a given wind speed, the dispersion category gets progressively worse as one goes from Pasquill stability class A to F. Although other choices for $C_0$ could have been made, resulting in different-looking dispersion category distributions, the current scheme results in a distribution that is balanced and intuitive. For the range of wind speeds tested within each stability class, Pasquill classes E and F contain only VP, P, and MP dispersion categories; Pasquill class D has P through G; Pasquill class C has MP through EX; and Pasquill classes A and B contain only MG through EX.

### Table 1. Dispersion category in the ODM as a function of relative concentration $C_{\text{rel}}$ at 1500 m.

<table>
<thead>
<tr>
<th>Relative concentration $C_{\text{rel}}$</th>
<th>Dispersion category</th>
</tr>
</thead>
<tbody>
<tr>
<td>&lt;0.189</td>
<td>EX (excellent)</td>
</tr>
<tr>
<td>0.189–0.435</td>
<td>G (good)</td>
</tr>
<tr>
<td>0.435–1.00</td>
<td>MG (moderately good)</td>
</tr>
<tr>
<td>1.00–2.29</td>
<td>MP (moderately poor)</td>
</tr>
<tr>
<td>2.29–5.26</td>
<td>P (poor)</td>
</tr>
<tr>
<td>&gt;5.26</td>
<td>VP (very poor)</td>
</tr>
</tbody>
</table>

### Table 2. Dispersion category in the ODM as a function of Pasquill stability class and the wind speed at 10-m height.

<table>
<thead>
<tr>
<th>Pasquill stability class</th>
<th>Wind speed (m s$^{-1}$)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>A</td>
<td>G</td>
</tr>
<tr>
<td>B</td>
<td>MG</td>
</tr>
<tr>
<td>C</td>
<td>MP</td>
</tr>
<tr>
<td>D</td>
<td>P</td>
</tr>
<tr>
<td>E</td>
<td>VP</td>
</tr>
<tr>
<td>F</td>
<td>VP</td>
</tr>
</tbody>
</table>
Again, these categories pertain to relative concentrations at or near the plume centerline at various downwind distances. The scheme is conservative in the sense that a pollutant plume may not impact certain downwind areas at all, but if it does (i.e., areas at or near the plume centerline), concentrations would be higher under P conditions than under MP, for example. Thus, the current scheme conservatively estimates the relative effect of the pollutant plume on downwind sensitive areas that happen to lie in the path of the plume.

b. Model methodology

1) CURRENT DISPERSION CONDITIONS

To calculate current dispersion conditions, the Oklahoma Dispersion Model uses a real-time statewide automated weather station monitoring network, the Oklahoma Mesonet. Operational since 1994, the Oklahoma Mesonet (Elliott et al. 1994; Brock et al. 1995) at the time of writing consists of 116 automated weather station towers (10-m height) with an average station spacing of 30 km. A typical Oklahoma Mesonet weather tower is shown in Fig. 1. The tower locations are shown in Fig. 2. Note that there is at least one station in every county; some counties have three or four stations. Weather observations are relayed by radio signal every 5 min, soil temperatures are sent every 15 min, and soil moisture measurements are sent every 30 min.

In calculating the dispersion category for current conditions, the ODM first estimates the Pasquill stability class at each of the Oklahoma Mesonet sites. During the daytime, 15-min averages of solar radiation, 10-m wind speed, and standard deviation of 10-m wind direction (variables that are available at every Oklahoma Mesonet tower) are used to determine PSC at each Oklahoma Mesonet site. If 10-m wind speed is greater than 1 m $s^{-1}$ (the threshold value for the 10-m wind sensor), the ODM uses the average of two methods recommended by the U.S. Environmental Protection Agency (U.S. EPA 1987) to estimate PSC: 1) the “SRDT” method, which uses solar radiation (during the daytime) and 10-m wind speed, and 2) the “Sigma A” method, which uses 10-m wind speed and the standard deviation of 10-m wind direction. The standard deviation is based on 300 measurements of 10-m wind direction (3-s intervals) during the 15-min period. If 10-m wind speed is less than or equal to 1 m $s^{-1}$, the ODM uses only the SRDT method to calculate PSC.

For nighttime conditions, the following method is used to calculate PSC. If 10-m wind speed is greater than 1 m $s^{-1}$, the Sigma-A method is used. If the wind speed is less than or equal to 1 m $s^{-1}$, the ODM uses the observed vertical temperature gradient ($\frac{\partial T}{\partial z}$) from the 1.5- and 9-m air temperature sensors to assign either class E or F for sigma-z calculations (if $\frac{\partial T}{\partial z} < 0$, class E is assigned; if $\frac{\partial T}{\partial z} \geq 0$, class F is assigned). This method, incidentally, is identical to the SRDT method for nighttime conditions with wind speeds under 2 m $s^{-1}$. In all cases, if the wind speed is less than 2 m $s^{-1}$, the ODM assigns Pasquill stability class D for calculating sigma_y so as to better represent documented plume meander.

After the Pasquill stability classes have been deter-

Fig. 1. Oklahoma Mesonet 10-m automated weather station tower at Goodwell, OK.

Fig. 2. Locations of automated weather station sites in the Oklahoma Mesonet.
mined, the Briggs equations (Briggs 1973; Hanna et al. 1982) are used to calculate the sigma-y and sigma-z values (m) for a downwind distance of 1500 m. Equations (1) and (4) can then be used with the 10-m wind speed \( u \) to calculate the relative concentration \( C_{\text{rel}} \) at 1500 m:

\[
C_{\text{rel}} = \frac{(4 \text{ m s}^{-1})(112 \text{ m}) (49.9 \text{ m})}{u \sigma_y \sigma_z}.
\]

The numbers in the numerator represent the wind speed, sigma-y, and sigma-z values, respectively, for Pasquill stability class D at a distance of 1500 m and a wind speed of 4 m s\(^{-1}\). In this equation, if the wind speed is less than 1 m s\(^{-1}\), \( u \) is set to 1 m s\(^{-1}\). Using the above method, values of relative concentration \( C_{\text{rel}} \) are calculated for all Oklahoma Mesonet sites.

2) Future dispersion conditions

For future conditions, the Oklahoma Dispersion Model uses the NGM MOS forecasts for locations within and surrounding Oklahoma. These forecasts are updated every 12 h and predict various weather variables at 3-h intervals out to 60 h in the future (Dallalva et al. 1992).

Because the NGM MOS forecasts only predict certain variables, other methods have to be used to determine Pasquill stability class. Wind speed, cloud cover, and ceiling height are used in conjunction with Turner’s (1964) algorithms to calculate a stability class from 1 through 7 at each MOS location for each 3-h interval. For purposes of the ODM, Turner’s stability class 7 is treated as a 6 (Pasquill class F). As with Oklahoma Mesonet data, the ODM assigns Pasquill class D for sigma-y calculations if it is nighttime and the wind speed is less than 2 m s\(^{-1}\).

At this point, the procedure for calculating relative concentration at 1500 m is identical to that described above [Eq. (5)]. Relative concentrations \( C_{\text{rel}} \) are calculated at each MOS location for each 3-h increment of the forecast.

3. Operational products from the Oklahoma Dispersion Model

The Oklahoma Dispersion Model is at the time of writing accessible through the “Oklahoma Agweather” Internet site (http://agweather.mesonet.org). With respect to current conditions, the ODM features two types of colored maps: one map for dispersion conditions (color coded for the six dispersion categories) and another map for transport conditions (to assess where the pollutant plume is headed). These maps are based on weather data from the Oklahoma Mesonet. With respect to future conditions, the ODM features similar maps at 3-h intervals out to 60 h in the future. These maps are based on weather predictions from the NGM MOS forecasts for locations within and surrounding Oklahoma. In addition, tables at specific MOS locations are available that show various weather variables and dispersion conditions at 3-h increments through the 60-h period. Details of product creation and examples of these products now follow.

a. Current conditions

The map for current dispersion conditions is created as follows. First, the relative concentration values \( C_{\text{rel}} \) at the 116 Oklahoma Mesonet sites are converted using Table 1 to integer values related to the 6 dispersion categories (EX = 1, G = 2, MG = 3, MP = 4, P = 5, and VP = 6). Then, using a Barnes objective analysis scheme (Koch et al. 1983), the integer values are interpolated to a 10-km rectangular grid. From there, bivariate interpolation is used to interpolate to a 1-km pixel level. Values at this resolution are then rounded up or down to the nearest integer, and a statewide colored map (color coded for each of the 6 integer categories) is created from this 1-km gridded map of integer values. Because of the highly nonlinear behavior of \( C_{\text{rel}} \) across dispersion categories, spatially interpolating dispersion categories (integer values) rather than \( C_{\text{rel}} \) is a more physically valid approach. This dispersion map is updated every 15 min.

The map for transport conditions is basically a station plot of certain weather conditions at selected Oklahoma Mesonet site locations. Wind direction and speed (in purple), temperature (in red), and relative humidity (in green) are shown. For the model’s clientele, wind speed is given in miles per hour and temperature in degrees Fahrenheit. In addition, wind gusts over 20 mi h\(^{-1}\) (9 m s\(^{-1}\)) are indicated. Calm conditions are indicated by a circle surrounding the site location. This map is updated every 5 min, corresponding to the frequency of transmission of weather data from the Oklahoma Mesonet towers.

Examples of these two types of ODM “nowcast” maps based on Oklahoma Mesonet weather data are given in Figs. 3 and 4. The first map (Fig. 3) is the synoptic mesoscale weather map for 2300 central standard time (CST) 18 November 2001. It shows a strong cold front entering Oklahoma from the northwest. Strong north-to-northwest winds can be seen behind the cold front while near-calm conditions exist just ahead of the front and generally light south winds are seen elsewhere. Temperature inversions (not shown) are also present ahead of the front. The second map (Fig. 4)
shows the color-coded dispersion conditions from the Oklahoma Dispersion Model. Note the presence of P to VP dispersion conditions just ahead of the front in the stable near-calm air while MG to G conditions exist behind the front in the windy and less stable air.

b. Future conditions

The maps for future dispersion conditions are created in a fashion that is similar to that described above. The relative concentration values $C_{rel}$ at the MOS locations are first converted using Table 1 to numerical integer values related to the six dispersion categories. These integer values are then interpolated to a 10-km rectangular grid and, from there, to 1-km resolution. Values are rounded up or down to the nearest integer, and a statewide colored map with the same color code is produced from this 1-km gridded map of integer values. These dispersion maps, which occur at 3-h intervals.
through the 60-h NGM MOS forecast period, are updated every 12 h in accordance with the production schedule of these forecasts.

The maps for future transport conditions are produced by taking the interpolated weather variables from the 10-km rectangular grid and plotting them in station plot format at every fifth grid point (50-km spacing). The same station plot is used as with the nowcast maps with the exception that expected wind gusts are not depicted and past 6-h probability of precipitation has been added. These synoptic maps, which occur at 3-h intervals through the 60-h NGM MOS forecast period, are similarly updated every 12 h.

Examples of these two types of ODM maps based on NGM MOS forecast weather data are given in Figs. 5 and 6. The maps are taken from the same synoptic

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**Fig. 5.** Map from the ODM of forecast conditions for pollutant transport at 1800 CST 19 Nov 2001 using the NGM MOS forecasts from 1800 CST 18 Nov 2001.

**Fig. 6.** Map from the ODM of forecast dispersion conditions at 1800 CST 19 Nov 2001 using the NGM MOS forecasts from 1800 CST 18 Nov 2001.
period as was shown earlier, except these forecast maps are for a time 19 h later. The first map (Fig. 5) is the forecast weather map at 1800 CST on the following day, 19 November 2001. Temperature and relative humidity conditions are uniform at this time, and winds are moderately strong out of the north-northwest over eastern Oklahoma but decrease in speed to calm conditions in the Oklahoma Panhandle. The second map (Fig. 6) shows the corresponding color-coded dispersion map as produced by the Oklahoma Dispersion Model. Note that dispersion conditions vary across four categories, ranging from MG in portions of southeast and south central Oklahoma to VP in the panhandle and parts of western and northern Oklahoma.

In addition to these two kinds of forecast maps, the user has access to tabular forecast information at specific MOS locations. Each table gives the weather and dispersion condition predictions at a specific location throughout the entire MOS forecast period. Figure 7 shows an example from this same synoptic period for the MOS location at McAlester in southeast Oklahoma. This table was constructed from the MOS forecast issued at 1800 CST 18 November 2001. Predictions are listed for various weather variables at McAlester in 3-h increments through 0600 CST 21 November 2001. In addition to the weather variables, the predicted dispersion category (e.g., MP) from the Oklahoma Dispersion Model is included, along with a variable called the “downwind pollution index” (DPI), which is simply 10 times the relative concentration ($10C_{rel}$) rounded to the nearest integer. The DPI gives the user an idea of the relative strength of the pollutant for downwind locations at or near the plume centerline. With reference to the DPI values from the table (Fig. 7) in this example, the downwind concentration (at the same distance) at 1800 CST 20 November would be about 30 times (121/4) what it would have been 3 h earlier at 1500 CST. This forecast table indicates that the cold front is expected to pass McAlester sometime between 0000 and 0300 CST 19 November with MG dispersion conditions after frontal passage. The two following nights, in contrast, are expected to have VP dispersion conditions. With respect to the daytime period, the ODM indicates more hours of MG-or-better dispersion conditions during the first day (19 November) than during the second (20 November).

4. Use of the Oklahoma Dispersion Model

The Oklahoma Dispersion Model can serve as an operational planning tool for activities involving the near-surface release of atmospheric “pollutants” that might adversely affect a sensitive downwind area. Examples from the agricultural arena include smoke from
prescribed burns, drift of pesticides from land-based or aerial applications, and odors generated from animal agriculture. Using the operational products for dispersion conditions and transport direction, one can better assess appropriate times to minimize downwind pollutant concentrations resulting from the near-surface release of gases and small particulates.

As can be seen from Figs. 4 and 6, the ODM dispersion maps are color coded to represent the six dispersion categories of the model. The green colors (EX = dark green, G = green, and MG = light green) depict appropriate dispersion conditions for near-surface releases of gases and particulates; of course, for a given wind speed, downwind concentrations will be lower for EX conditions than for G and lower for G conditions than for MG. The color beige represents the MP dispersion category. Under these conditions, dispersion may be acceptable if the downwind area is not an area of concern; otherwise, dispersion under these conditions should be avoided. The orange (P) and red (VP) colors represent times during which to avoid dispersion, especially if there is a sensitive area downwind.

The operational products generated by the Oklahoma Dispersion Model are best applicable for flat uniform rural terrain and for times with no precipitation. For variable terrain under light wind conditions, winds will tend to move upslope during the daytime and downslope during the nighttime, altering not only the wind direction predicted by the NGM MOS forecasts but also the dispersion conditions themselves. Even during windy conditions, wind directions and dispersion conditions will be altered by variable terrain to some extent. During periods of precipitation, dispersion may be enhanced, resulting in better dispersion than the model suggests.

In addition, the dispersion conditions calculated by the ODM apply to dispersion alone and by themselves may not indicate appropriate conditions for a particular activity. For example, rainfall may sometimes occur during times the model shows good dispersion conditions; yet, one would not want to conduct a prescribed burn or apply a pesticide during rainy conditions. Consider another example with high winds in the 20–40 mi h⁻¹ range (9–18 m s⁻¹). The ODM dispersion maps may be showing good-to-excellent conditions, yet one would not want to conduct a prescribed burn or apply a pesticide under such windy conditions.

Another limitation of the model has to do with emission rate. The model’s dispersion categories were developed with the assumption of a constant emission rate across a wide range of varying weather conditions typically associated with Pasquill stability classes A–F. In certain instances, such as pesticide application or land application of animal waste, the chemicals involved are such that there is greater volatilization under high temperatures and other weather conditions typically associated with good dispersion conditions in the model. Thus, increased emission rates resulting from weather conditions usually associated with good dispersion conditions will increase the downwind concentrations above that anticipated by the model, resulting in a model calculation of better dispersion conditions than are actually occurring. At nighttime, with cooler temperatures, the reverse situation could occur, with the model calculating worse dispersion conditions than are actually occurring.

Despite the limitations of the model, however, the Oklahoma Dispersion Model constitutes a useful management tool for estimating relative strengths of downwind concentrations for gases and small particulates released near the surface. The operational products are being used in Oklahoma in conjunction with such activities as prescribed burning, pesticide application, and drift of odors from activities associated with animal agriculture. Analysis of Internet product statistics over a 30-month period (January 2004–June 2006) showed the current dispersion map (based on Oklahoma Mesonet data) having an average of 2028 “hits” per month, the NGM MOS tables (which include forecast dispersion information) having an average of 890 hits per month, and the NGM MOS maps (which include forecast dispersion maps) having an average of 287 hits per month.

This section concludes with two examples in which the Oklahoma Dispersion Model was actually used as a management tool within agriculture and natural resources. The first example, from March of 1999, is from a day on which a large prescribed fire was conducted in southeastern Oklahoma. The second example, from February of 2006, is from a day on which lagoon effluent from a swine operation in northwestern Oklahoma was applied to an agricultural field. Before both of these events, the clientele involved consulted the Oklahoma Dispersion Model the night before to see whether dispersion conditions the next day would be suitable for their respective operations. Because the ODM forecasts are not archived, the Oklahoma Mesonet–based “current” dispersion maps will be shown during various points throughout these two days.

The first example is from 3 March 1999 and is that of a prescribed burn in the Yourman Wildlife Management Area, located about 12 km south of Wilburton in southeastern Oklahoma. The burn unit was 635 ha (1570 acres) in size. The prescribed burn began at 1000 CST and ended at 1730 CST. Good fire intensity was observed over most of the area. During the burn, abundant sunshine was reported along with surface wind
speeds of 1–3 m s\(^{-1}\), temperatures of 8\(^\circ\)–15\(^\circ\)C, and relative humidities of 32%–42%. Figure 8 presents the dispersion condition maps (based on Oklahoma Mesonet data) for 0900 (before the burn), 1200, 1500, and 1900 CST (after the burn). The burn location is depicted by the yellow triangle. Note that dispersion conditions were in the G category (0900 CST) even before the burn started, improved to EX during midday (1200 CST), and were still G at 1500 CST. Other maps (not shown) indicate that dispersion conditions were MG or better through 1800 CST (after the burn ended). With the light winds and mostly clear skies, inversion conditions set in after sunset, resulting in VP surface dispersion conditions by 1900 CST.

The second example is from 25 February 2006 and is that of a land application of lagoon effluent from a swine operation in northwestern Oklahoma (near Gage). In contrast to the first example, where light winds were reported, daytime conditions featured moderately strong northeast winds (10-m level) of about 10 m s\(^{-1}\) in the morning decreasing slowly to 5 m s\(^{-1}\) by the end of the afternoon. Encompassing the period during which the application occurred, Fig. 9 presents the dispersion condition maps (based on Oklahoma Mesonet data) for 0800, 1100, 1400, and 1700 CST. The land application site is denoted by the yellow triangle. Note that the moderately strong winds resulted in MG dispersion conditions at 0800, 1100, and 1400 CST; dispersion conditions improved to G by 1700 CST because of the lighter winds.

5. Summary

Appropriate for discussion in this special journal collection that celebrates the history of air-quality modeling, the Oklahoma Dispersion Model represents a current innovative application of the classic Gaussian plume model in an operational setting. Using a statewide mesoscale automated weather station network (the Oklahoma Mesonet) for current conditions and 60-h gridded NGM MOS forecasts for future conditions, the ODM is an Internet-based management tool that can be used to qualitatively assess current and future atmospheric dispersion conditions across Oklahoma for near-surface releases of gases and small particulates.

The motivation behind the development of the Oklahoma Dispersion Model was to utilize real-time mesoscale weather observations from the Oklahoma Mesonet in conjunction with a several-day forecast to produce an Internet-based operational tool that clientele could use to better time agricultural activities that release gases and small particulates near the surface. The focus was on concentrations at ground level (where people live and crops grow) near the plume centerline at downwind distances up to 4000 m (several miles).

The classic Gaussian plume model was the dispersion model chosen for the development of the ODM. The details of this development are given fully in section 2. In brief, a method is employed that breaks the atmosphere into six dispersion categories, ranging from excellent to very poor. To this end, the Gaussian plume model is used in conjunction with rural Briggs sigma-\(y\) and sigma-\(z\) coefficients to estimate horizontal and vertical dispersion conditions at a representative downwind distance of 1500 m. Pasquill stability class is calculated in different ways, depending on whether Oklahoma Mesonet weather data or NGM MOS weather predictions are used.

The Oklahoma Dispersion Model generates both graphical and text output. Statewide colored maps showing current conditions for dispersion (dilution of plume) and transport (direction of plume movement) are generated every 15 and 5 min, respectively. Similar maps for future conditions are generated every 12 h using gridded 60-h NGM MOS forecasts for locations within and surrounding Oklahoma. In addition to graphical output, tabular output for future conditions at specific MOS locations is available.

Developed in the late 1990s, the ODM has seen a variety of uses. One unforeseen use was as a planning tool for debris burning after the Oklahoma City F5 tornado of 3 May 1999. More common, however, is for the model to be used within the agriculture and natural resources arenas. Examples include dispersion of smoke from prescribed burns, drift of pesticides from land or aerial-based application, and odors associated with activities within animal agriculture (such as land application of lagoon effluent from swine operations).

Because the NGM MOS forecast technology used in the Oklahoma Dispersion Model is well over 10 yr old, a new version of the ODM has been developed (since the work described in this paper) that incorporates 84-h numerical forecast output from the North American Model (NAM), which now uses the Nonhydrostatic Mesoscale Model of the new Weather Research and Forecasting system currently in operational use at the National Centers for Environmental Prediction. Because the NAM predicts solar radiation, forecast Pasquill stability classes during the daytime are now calculated using the SRDT method rather than the Turner method. In addition, current dispersion conditions (based on the Oklahoma Mesonet, now at 119 sites) are updated every 5 min rather than every 15 min; ODM forecasts are updated every 6 h instead of every 12 h. Also, the formats of ODM products have changed.
Fig. 8. Dispersion condition maps (based on Oklahoma Mesonet data) for 3 Mar 1999. The prescribed burn site is denoted by the yellow triangle. Maps are for 0900, 1200, 1500, and 1900 CST, as labeled.
Fig. 9. Dispersion condition maps (based on Oklahoma Mesonet data) for 25 Feb 2006. The land application site is denoted by the yellow triangle. Maps are for 0800, 1100, 1400, and 1700 CST, as labeled.
through the use of custom “plug in” software, which allows for animated, zoomable maps and user-friendly charges and tables.

Despite its limitations (which were discussed in section 4), the Oklahoma Dispersion Model is an example of how the classic Gaussian plume model developed in the 1960s can still prove useful today. Its incorporation within the Oklahoma Dispersion Model has created a useful management tool for clientele in agriculture and natural resources who engage in activities that result in near-surface releases of gases and small particulates.

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REFERENCES