JP3.3 USE OF A STATEWIDE MESOSCALE AUTOMATED WEATHER STATION NETWORK FOR REAL-TIME OPERATIONAL ASSESSMENT OF NEAR-SURFACE DISPERSION CONDITIONS

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1. INTRODUCTION

Developed in the late 1990s, the Oklahoma Dispersion Model (ODM) is a Web-based management tool that can be used to assess current and future atmospheric dispersion conditions for near-surface releases of gases and small particulates (diameters less than 20 microns). The ODM constitutes 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) to assess current weather conditions, the ODM generates statewide maps which depict current atmospheric dispersion conditions (dilution of plume) as well as transport conditions (direction of plume movement). For future conditions, the ODM utilizes 60-hour NGM MOS forecasts to create similar output. With such products, one can better assess appropriate times for conducting operations which involve the near-surface release of gases and small particulates so as to minimize downwind concentrations at sensitive non-target areas.

The Oklahoma Dispersion Model has been used largely as a management tool in the agriculture and natural resources arena in conjunction with such operations as prescribed burning (smoke), pesticide application, and dispersion of odors associated with animal agriculture. However, it has had unforeseen uses such as in the debris burning necessitated by the Oklahoma City F5 tornado of 3 May 1999.

2. MODEL DEVELOPMENT

The Oklahoma Dispersion Model has been designed to qualitatively assess concentrations at ground level near the plume centerline at downwind distances up to 4000 m (several miles). In developing the methodology for the model, we started with the classic Gaussian plume model (Figure 1) developed in the 1960s (Pasquill, 1961: Gifford, 1961; Turner, 1969; Hanna *et al.*, 1982). This model is generally considered valid out to distances of 10 km and simulates average concentrations over a 15-minute to 1-hour period under steady-state conditions.

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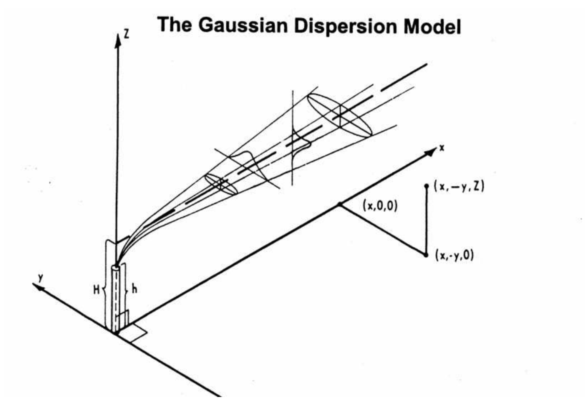

Figure 1. *Schematic of classic Gaussian plume model. Here, x represents the downwind direction, y the crosswind direction, and z the vertical.*

Including the term for reflection at the surface, for a ground-based pollution source with no plume rise and with an emission rate Q, the surface concentration C over flat terrain at a given downwind distance x at the plume centerline (y = z =0) is given by:

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

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 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 for both rural and urban conditions as a function of downwind distance and Pasquill stability class (Turner, 1969). His equations are considered valid for downwind distances ranging from 100 m to 10 km.

Using a constant value for Q/π, we used Equation (1) and the Briggs' equations for sigma-y and sigma-z (rural conditions) to calculate a matrix of downwind concentrations for the six Pasquill stability classes (A-F) and a range of wind speeds associated with these stability regimes. Concentrations were investigated at seven downwind distances: 500, 1000, 1500, 2000, 2500, 3000, and 3500 m). An increased sigma-y value (that for Pasquill class D) was used under light wind conditions (< 2 m/s) at nighttime (Pasquill classes E and F) to better represent well-documented plume meander (Van der Hoven, 1976; Hanna, 1983).

At each of the seven downwind distances, the concentration distributions were found to be similar with respect to stability and wind speed effects. Concentrations were highest in the 1-2 m/s range of the F category and lowest in the highest wind speeds of the A-C categories. For a given Pasquill stability class, concentrations decreased linearly with increasing wind speed in accord with Equation (1). For a given wind speed, concentrations were lowest for Pasquill stability class A and rose 2 to 3 times (as in a geometric series) for each successive stability class.

For purposes of developing an operational model, we decided to break 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, define six ranges in concentration Δ_{EX}, Δ_G, Δ_{MG}, Δ_{MP}, Δ_P, and Δ_{VP}, where Δ_j represents the difference between the maximum and minimum concentrations in dispersion category *j*. Furthermore, as suggested by the concentration patterns noted earlier, assume a geometric progression such that $\Delta_G = a\,\Delta_{EX}$, $\Delta_{MG} = a\,\Delta_G$, $\Delta_{MP} = a\,\Delta_{MG}$, $\Delta_P = a\,\Delta_{MP}$, and $\Delta_{VP} = a\,\Delta_P$, where *a* is the geometric multiplier. Finally, define C_0 as the concentration dividing the two categories MG and MP.

If C_{max} represents the maximum concentration in the entire matrix of concentrations at a given distance and C_{min} represents the minimum, the following equations can be written:

$$C_{max} = C_{min} + \Delta_{EX} + a\Delta_{EX} + a^2\Delta_{EX} + a^3\Delta_{EX} + a^4\Delta_{EX} + a^5\Delta_{EX} \quad (2)$$

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

If C_0 is known, Equations (2) and (3) can be solved for *a* and Δ_{EX}.

After a number of experiments using different concentrations for C_0, it was decided to make C_0 the value of the concentration occurring in the D stability class at a wind speed of 4 m/s. This gave the best looking distribution for the six dispersion categories. In addition, the *a* value at 1500 m (2.292) came closest to the value of *a* averaged across all distances.

Accordingly, the “template” used by the Oklahoma Dispersion Model is the dispersion category distribution pattern 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. If C is the actual concentration occurring at 1500 m, a relative concentration C_{rel} at 1500 m can then be defined as:

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

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

Table 1. Dispersion category in the Oklahoma Dispersion Model as a function of C_{rel}.

Relative Concentration C_{rel}	Dispersion Category
< 0.189	Excellent (EX)
0.189 - 0.435	Good (G)
0.435 - 1.00	Moderately Good (MG)
1.00 - 2.29	Moderately Poor (MP)
2.29 - 5.26	Poor (P)
> 5.26	Very Poor (VP)

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. While other choices for C_0 could have been made, resulting in different looking dispersion category distributions, the current scheme results in a distribution that appears 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 2. Dispersion category in the Oklahoma Dispersion Model as a function of Pasquill stability class and wind speed.

PASQUILL STABILITY CLASS	WIND SPEED (m/s)									
	1	2	3	4	5	6	8	10	12	14
A	G	EX	EX							
B	MG	G	EX	EX	EX					
C	MP	MG	MG	G	G	G	EX	EX	EX	EX
D	P	MP	MP	MG	MG	MG	MG	G	G	G
E	VP	P	P	MP	MP					
F	VP	VP	VP							

Again, these dispersion categories are used to qualitatively estimate surface concentrations near or at the plume centerline at various downwind distances up to 4000 m (several miles). 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 which happen to lie in the path of the plume.

3. MODEL METHODOLOGY

3.1 *Current Dispersion Conditions*

To calculate current dispersion conditions, the Oklahoma Dispersion Model (ODM) utilizes a real-time statewide mesoscale automated weather station network, the Oklahoma Mesonet. Operational since 1994, the Oklahoma Mesonet (Elliott *et al.*, 1994; Brock *et al.*, 1995) currently consists of 116 automated weather station towers (10-m height) with an average spacing of 30 km. A typical Mesonet weather station tower is shown in Figure 2. The tower locations are shown in Figure 3. Note that there is at least one station in every county; some counties have 3 or 4 stations. Weather observations are relayed by radio signal every 5 minutes, while soil temperatures are sent every 15 minutes and soil moisture measurements, every 30 minutes.

Figure 2. *Oklahoma Mesonet 10-m automated weather station tower at Goodwell, Oklahoma.*

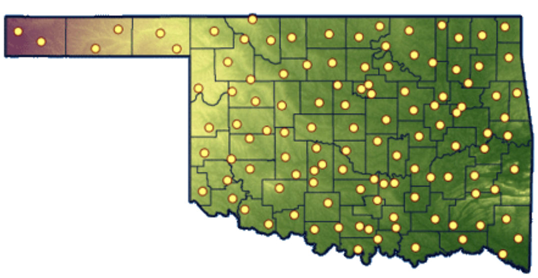

Figure 3. *Location of automated weather station sites in the Oklahoma Mesonet.*

In calculating dispersion category for current conditions, the ODM first estimates Pasquill stability class (PSC) at each of the Mesonet sites. During the *daytime* 15-minute averages of solar radiation, 10-m wind speed, and standard deviation of 10-m wind direction are used to determine PSC at each Mesonet site. If 10-m wind speed is greater than 1 m/s (the threshold value for the 10-m wind sensor), the ODM uses the average of two EPA-recommended methods (U.S. EPA, 1987) to estimate PSC: (1) the "SRDT" method, which utilizes solar radiation 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. If 10-m wind speed is less than or equal to 1 m/s, the ODM uses only the SRDT method to calculate PSC.

For *nighttime* conditions the following methodology is used to calculate PSC. If 10-m wind speed is greater than 1 m/s, the Sigma-A method is used. If the wind speed is less than or equal to 1 m/s, the ODM uses the observed vertical temperature gradient ($\partial T/\partial z$) to assign either class E or F for sigma-z calculations (if $\partial T/\partial z < 0$, class E is assigned; if $\partial T/\partial z >= 0$, class F is assigned). In all cases, if the wind speed is less than 2 m/s, the ODM assigns Pasquill stability class D for calculating sigma-y so as to better represent well-documented plume meander.

After the Pasquill stability classes have been determined, 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_{rel} at 1500 m:

$$C_{rel} = \frac{(4\ \mathrm{m/s})(112\ \mathrm{m})(49.9\ \mathrm{m})}{u\ \sigma_y\ \sigma_z} \qquad (5)$$

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. In this equation, if the wind speed is less than 1 m/s, u is set to 1 m/s. Using the above methodology, values of relative concentration C_{rel} are calculated for all Oklahoma Mesonet sites.

3.2 *Future Dispersion Conditions*

For future conditions the ODM uses the NGM (Nested Grid Model) MOS (Model Output Statistics) forecasts for locations within and surrounding Oklahoma. These forecasts are updated every 12 hours and predict various weather variables at 3-hour intervals out to 60 hours in the future (National Weather Service, 1992).

Because the NGM MOS forecasts only predict certain variables, different 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 1 through 7. For purposes of the ODM, Turner's stability class 7 is treated as a 6 (Pasquill class F). As with 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.

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

4. CREATION OF OPERATIONAL PRODUCTS

The Oklahoma Dispersion Model (ODM) can be accessed on the Oklahoma AgWeather Web site (***http://agweather.mesonet.org***). With respect to current conditions, the ODM features two types of colorized 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-hour intervals out to 60 hours 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 showing various weather variables and dispersion conditions at 3-hour increments through the 60-hour period. Details of product creation and examples of these products now follow.

4.1 *Current Conditions*

The map for current dispersion conditions is created as follows. First, the relative concentration values C_{rel} at the 116 Mesonet sites are converted via Table 1 to integer values related to the six dispersion categories (EX=1, G=2, MG=3, MP=4, P=5, 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, bilinear 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 colorized map (color coded for each of the six integer categories) is created from this 1-km gridded map of integer values. This dispersion map is updated every 15 minutes.

The map for transport conditions is basically a station plot of certain weather conditions at selected Mesonet site locations. Wind direction and speed at 10 m (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 Fahrenheit. In addition, wind gusts over 20 miles per hour (9 m/s) are indicated. Calm conditions are denoted by a circle around the dot depicting the Mesonet location. This map is updated every 5 minutes, 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 Figures 4 and 5. The first map (Figure 4) is the synoptic mesoscale weather map for 2300 CST (Central Standard Time) on 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 elsewhere. Temperature inversions (not shown) are also present ahead of the front. The second map (Figure 5) shows the color-coded dispersion conditions from the Oklahoma Dispersion Model. Note the presence of poor (P) to very poor (VP) dispersion conditions just ahead of the front in the stable near-calm air, while moderately good (MG) to good (G) conditions exist behind the front in the windy and less stable air.

4.2 *Future Conditions*

The maps for future dispersion conditions are created in a similar fashion to that described above. The relative concentration values C_{rel} at the MOS locations are first converted via 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 colorized map with the same color code is produced from this 1-km gridded map of integer values. These dispersion maps, which occur at 3-hour intervals through the 60-hour NGM MOS forecast period, are updated every 12 hours 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 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-hour probability of precipitation has been added. These synoptic maps, which occur at 3-hour intervals through the 60-hour NGM MOS forecast period, are similarly updated every 12 hours.

Examples of these two types of ODM maps based on NGM MOS forecast weather data are given in Figures 6 and 7. The maps are taken from the same synoptic period as earlier shown, except these forecast maps are for a time 19 hours later. The first map (Figure 6) is the forecast weather map for 1800 CST on the following day, 19 November 2001. Temperature and relative humidity conditions are quite 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 panhandle. The second map (Figure 7) shows the corresponding color-coded dispersion map as produced by the Oklahoma Dispersion Model. Note that dispersion conditions vary across four categories, ranging from moderately good (MG) in portions of southeast and south central Oklahoma to very poor (VP) in the panhandle and parts of western and northern Oklahoma.

In addition to these two types 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 8 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 on 18 November 2001. Predictions are listed for various weather variables at McAlester in 3-hour increments through 0600 CST on 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 ten times the relative concentration ($10*C_{rel}$) rounded to the nearest

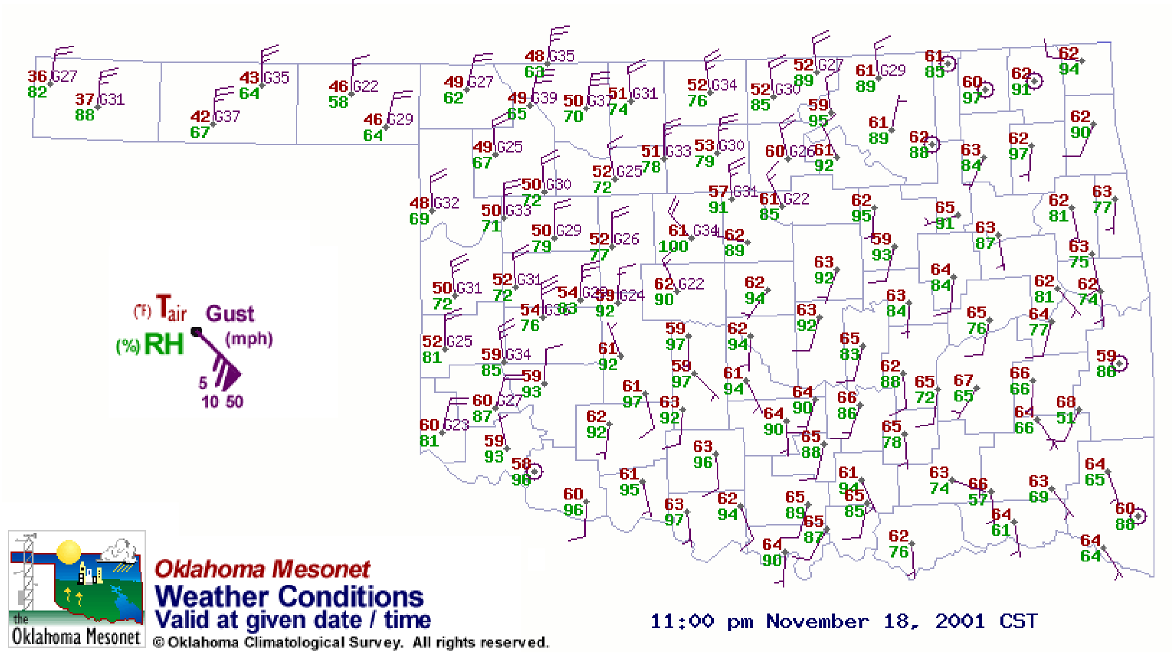

Figure 4. *Map from the Oklahoma Dispersion Model of current conditions for pollutant transport at 2300 CST on 18 November 2001 using weather data from the Oklahoma Mesonet.*

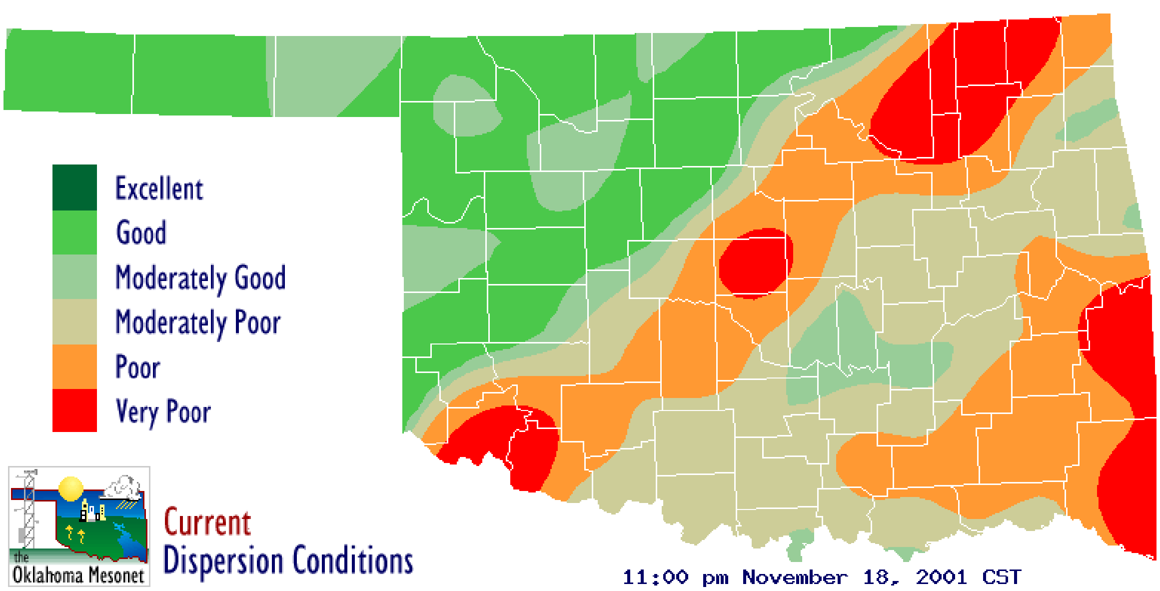

Figure 5. *Map from the Oklahoma Dispersion Model of current dispersion conditions at 2300 CST on 18 November 2001 using weather data from the Oklahoma Mesonet.*

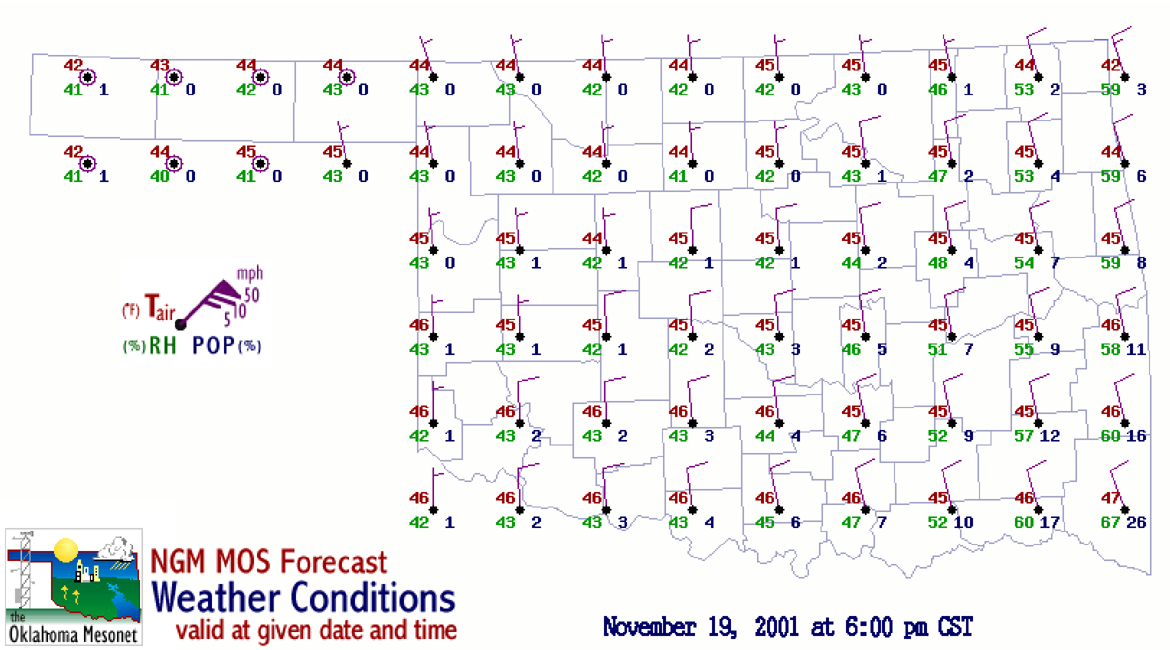

Figure 6. *Map from the Oklahoma Dispersion Model of forecast conditions for pollutant transport at 1800 CST on 19 November 2001 using the NGM MOS forecasts from 1800 CST on 18 November 2001.*

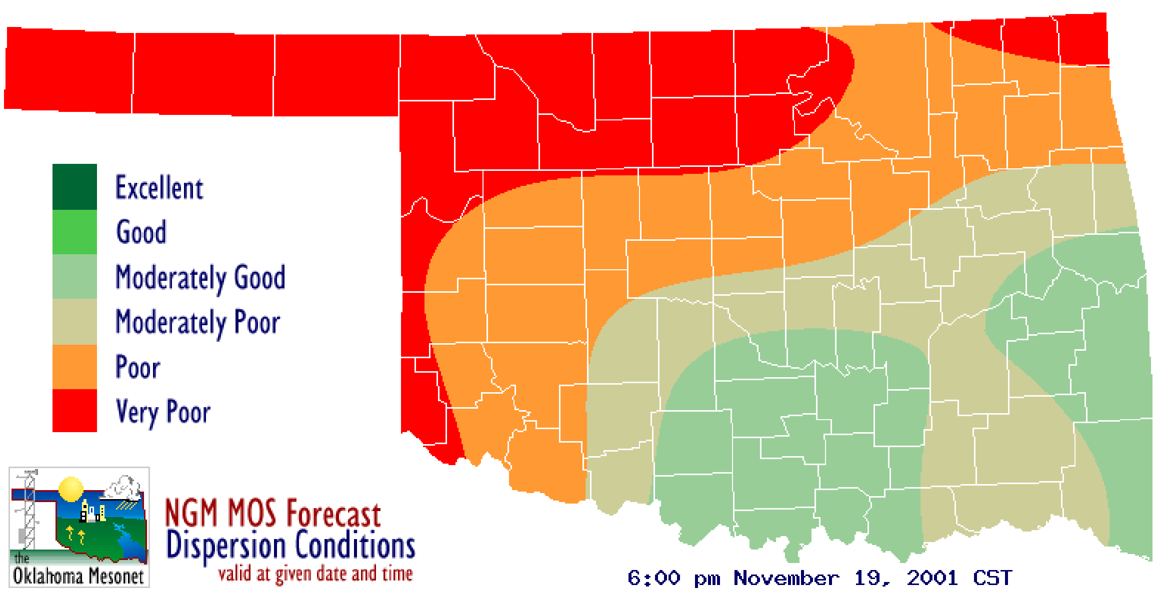

Figure 7. *Map from the Oklahoma Dispersion Model of forecast dispersion conditions at 1800 CST on 19 November 2001 using the NGM MOS forecasts from 1800 CST on 18 November 2001.*

Forecast for McAlester, OK based on data taken on November 18, 2001, at 6:00 pm CST

	/Nov 19								/Nov 20								/Nov 21		
HOUR OF DAY (CST)	00	03	06	09	12	15	18	21	00	03	06	09	12	15	18	21	00	03	06
MAX MIN TEMPS (F)							50				30				60				34
TEMPERATURE (F)	62	57	53	48	48	48	42	37	36	33	32	41	55	60	50	42	39	38	37
RELATIVE HUMIDITY (%)	80	86	89	89	68	53	59	69	69	75	78	64	36	28	45	62	61	67	69
WIND DIRECTION	S	NNW	N	N	N	N	N	N	N	N	NNW		W	W					
WIND SPEED (MPH)	8	12	16	19	21	21	11	6	5	3	1	0	1	3	0	0	0	0	0
DISPERSION CONDITION	MP	MG	MG	MG	G	G	MP	VP	VP	VP	VP	MP	MG	G	VP	VP	VP	VP	VP
DOWNWIND POLLUTION INDEX	11	7	6	5	4	4	17	78	94	78	121	14	6	4	121	121	121	121	121
SKY CONDITION	OV	OV	OV	OV	OV	SC	CL	CL	CL	CL	CL	CL	CL	CL	CL	CL	CL	CL	CL
CEILING	5	4	4	3	5	7	7	7	7	7	7	7	7	7	7	7	7	7	7
CHANCE OF PRECIP (%)			80		52		10		1		0		0		0		0		0
AMOUNT OF PRECIP (in)			0.17		0.05		0.00		0.00		0.00		0.00		0.00		0.00		0.00
PRECIP TYPE (if any)	R	R	R	R	R	R	R	R	R	R	R		R		R		R		R
DEW POINT TEMP (F)	56	53	50	45	38	32	29	28	27	26	26	30	29	27	30	30	27	28	28

SKY CONDITION	PRECIPITATION TYPE
CL = Clear	R = Rain
SC = Scattered	Z = Freezing Rain
BK = Broken	S = Snow
OV = Overcast	

DISPERSION CONDITION		DOWNWIND POLLUTION INDEX
EX	Excellent	< 2
G	Good	2 - 4
MG	Moderately Good	4 - 10
MP	Moderately Poor	10 - 23
P	Poor	23 - 53
VP	Very Poor	> 53

CEILING	
1 =	< 200 ft
2 =	200 - 400 ft
3 =	500 - 900 ft
4 =	1000 - 3000 ft
5 =	3100 - 6500 ft
6 =	6600 - 12000 ft
7 =	> 12000 ft

Figure 8. *Table from the Oklahoma Dispersion Model of forecast weather and dispersion conditions for McAlester, Oklahoma using the McAlester NGM MOS forecast from 1800 CST on 18 November 2001.*

integer. The DPI gives the user an idea of the relative strength of the pollutant for downwind locations at or near plume centerline. With respect to this example, the downwind concentration (at the same distance) at 1800 CST on 20 November would be about 30 times greater (121 / 4) than it would have been 3 hours earlier at 1500 CST. This forecast table indicates that the cold front is expected to pass McAlester sometime between 0000 CST and 0300 CST on 19 November with moderately good (MG) dispersion conditions after frontal passage. The two following nights, in contrast, are expected to have very poor (VP) dispersion conditions. With respect to the daytime period, the ODM indicates more hours of moderately good (MG) or better dispersion conditions during the first day (19 November) than during the second (20 November).

5. SUMMARY

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 conditions and 60-hour gridded NGM MOS forecasts for future conditions, the ODM is a Web-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 a Web-based operational tool which clientele could use to better time agricultural activities which 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 in Section 2, but briefly, a methodology is employed which 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 at a downwind distance of 1500 m. Pasquill stability class is calculated in different ways, depending on whether Mesonet weather data or NGM MOS weather predictions are used.

The Oklahoma Dispersion Model generates both graphical and text output. Statewide colorized maps showing current conditions for dispersion (dilution of plume) and transport (direction of plume movement) are generated every 15 and 5 minutes, respectively. Similar maps for future conditions are generated every 12 hours using gridded 60-hour 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 commonly, however, the model is used within the agriculture and natural resources arena. Examples include dispersion of smoke from prescribed burns, drift of pesticides from land or aerial-based application, and dispersion of odors associated with activities within animal agriculture (such as land application of lagoon effluent from swine operations).

Since the NGM MOS forecast technology used in the Oklahoma Dispersion Model is well over ten years old, future work will include developing another version of the ODM that incorporates 84-hour numerical forecast output from a version of the new Weather Research and Forecasting (WRF) Model currently in operational use at the National Centers for Environmental Prediction. Also, additional user-friendly products such as site-specific graphs will be developed.

Despite its limitations, 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 which result in near-surface releases of gases and small particulates.

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