The Oklahoma Cooperative Extension Service

WE ARE OKLAHOMA

The Cooperative Extension Service is the largest, most successful informal educational organization in the world. It is a nationwide system funded and guided by a partnership of federal, state, and local governments that delivers information to help people help themselves through the land-grant university system.

Extension carries out programs in the broad categories of agriculture, natural resources and environment; family and consumer sciences; 4-H and other youth; and community resource development. Extension staff members live and work among the people they serve to help stimulate and educate Americans to plan ahead and cope with their problems.

Some characteristics of the Cooperative Extension system are:

- The federal, state, and local governments cooperatively share in its financial support and program direction.
- It is administered by the land-grant university as designated by the state legislature through an Extension director.
- Extension programs are nonpolitical, objective, and research-based information.
- It provides practical, problem-oriented education for people of all ages. It is designated to take the knowledge of the university to those persons who do not or cannot participate in the formal classroom instruction of the university.
- It utilizes research from university, government, and other sources to help people make their own decisions.
- More than a million volunteers help multiply the impact of the Extension professional staff.
- It dispenses no funds to the public.
- It is not a regulatory agency, but it does inform people of regulations and of their options in meeting them.
- Local programs are developed and carried out in full recognition of national problems and goals.
- The Extension staff educates people through personal contacts, meetings, demonstrations, and the mass media.
- Extension has the built-in flexibility to adjust its programs and subject matter to meet new needs. Activities shift from year to year as citizen groups and Extension workers close to the problems advise changes.

Issued in furtherance of Cooperative Extension work, acts of May 8 and June 30, 1914, in cooperation with the U.S. Department of Agriculture, Director of Oklahoma Cooperative Extension Service, Oklahoma State University, Stillwater, Oklahoma. This publication is printed and issued by Oklahoma State University as authorized by the Vice President for Agricultural Programs and has been prepared and distributed at a cost of 20 cents per copy. 1019 GH.

OSU EXTENSION

Movement of Odors Off-Farm

October 2019

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Oklahoma Cooperative Extension Fact Sheets are also available on our website at: **facts.okstate.edu**

The simplest way to visualize odors moving off the farm is to think of a smoke plume. Smoke is emitted, moves away from its emission source with the prevailing wind, and is diluted through **dispersion**. As an odor plume moves away from its source, it spreads vertically and horizontally, sometimes with erratic and agitated motion, due to **turbulence** in the atmosphere. Weather conditions as well as the type of terrain affect turbulence and, accordingly, how the odor plume moves off-farm. This fact sheet provides an introduction to atmospheric dispersion, the physical process which disperses odor, as well as the influences of weather and terrain on dispersion and how they affect the shape of the odor plume. It also describes the Oklahoma Dispersion Model, developed to aid farmers in assessing when they should curtail odor-generating activities in order to minimize downwind odor strength. It concludes by looking at the operational dispersion products available to farmers on the Oklahoma Mesonet, the state's automated weather station network.

Atmospheric Turbulence

There are two major types of turbulence: mechanical and thermal. Mechanical turbulence requires wind and is caused when the speed or direction of the wind changes within a short vertical or horizontal distance. Mechanical turbulence can also result from friction of the wind with surface features (e.g., ground, buildings and trees). Thermal turbulence occurs with sunny to partly cloudy skies and light to moderate winds. In particular, it occurs in an "unstable" atmosphere where the air temperature decreases with height at a rate greater than 5.4 F per 1,000 feet, which causes any displaced air parcels to vertically accelerate. However, when the air temperature decreases with height at a rate less than 5.4 F per 1,000 feet, the atmosphere is considered stable and displaced air parcels do not experience vertical acceleration, but tend to return to their original position[1]. This behavior is particularly strong when air temperature increases with height such as in a surface temperature inversion. With both mechanical and thermal turbulence, outside air is mixed with the plume and causes it to expand vertically and horizontally.

[1] If the displaced air parcels are saturated with moisture (relative humidity = 100 percent), they will only experience stable conditions if the air temperature decreases with height at a rate less than approximately 3.3 F per 1,000 feet.

Atmospheric Dispersion

Another term for the mixing caused by turbulence is atmospheric dispersion. Odors, like smoke, are dispersed and diluted when outside air mixes with the plume. With increasing amounts of mechanical or thermal turbulence, dispersion increases. Odors are scattered far and wide under good dispersion conditions. However, under poor dispersion conditions, the odor plume experiences little dispersion and can be detected miles from the source under the right conditions. Regardless of the dispersion conditions, odor intensity generally decreases as the plume moves farther away from the source of the odors. In the case of good dispersion, this decrease in odor intensity is rapid, but in the case of poor dispersion it is very slow.

Figure 1 shows plume behavior under two different types of dispersion conditions. The lower smoke plumes (orange arrow) are situated within a surface temperature inversion where temperature is increasing with height. There is minimal turbulence and the smoke plumes experience little dispersion as they drift downwind within the inversion layer. The higher

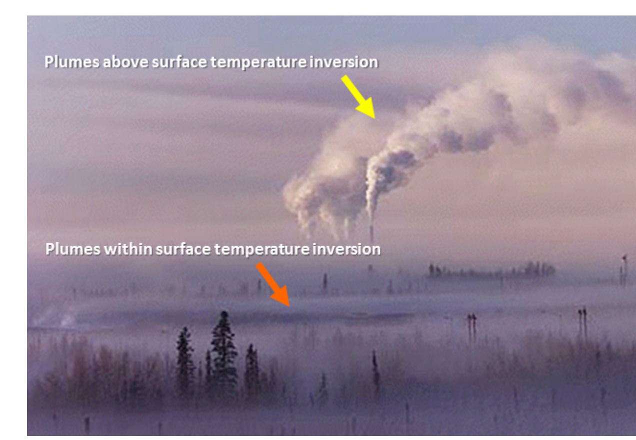

Figure 1. Behavior of smoke plumes under two different dispersion regimes.

smoke plumes (yellow arrow) are situated above the surface inversion and are in a region where temperature is decreasing with height and dispersion is much better. Odor plumes would behave in a similar fashion to these smoke plumes, with poor dispersion within the inversion layer and much better above it.

Weather Effects on Dispersion

Figure 2 shows how weather factors affect the shape of an odor plume. Plume shape reflects the amount and type of vertical and horizontal mixing in the plume. Think of the plume shapes in Figure 2 as smoke rising from a far off fire. If it were visible to the eye, the plume of odors rising from a field of freshly spread manure might look like a smoke plume rising from a burning pasture. The odors released by a relatively small source, such as a lagoon or storage pond, might resemble a trash fire or gas flare.

Weather factors can help predict dispersion of odors moving away from the farm. Six categories of dispersion conditions, based on solar radiation, cloud cover and wind speed are given in Figure 3. The chart shows that weather factors can cause dispersion to range from very poor (very little dilution of odors downwind) to excellent (odors are greatly diluted downwind). With reference to Figure 3, the following general statements can be made about atmospheric dispersion based on weather conditions:

1. Dispersion depends on both wind speed and the heating or cooling of the earth's surface.
2. With light wind speeds (less than 13 mph), the amount of heating or cooling of the earth's surface is the primary factor in dispersion. Dispersion conditions can range from very poor (VP) to excellent (EX). Dispersion is greatest during the daytime, and for a given wind speed, increases with the amount of solar radiation striking the earth's surface. Dispersion is poorest at night, and for a given wind speed, gets worse as cloud cover decreases.
3. With moderate to high winds (greater than 13 mph), wind speed is the primary factor in dispersion. Dispersion conditions range from moderately good (MG) to excellent (EX), with the best conditions for a given wind speed occurring under strong solar radiation.

Terrain Effects on Dispersion

The plume shapes shown in Figure 2 are characteristic of plumes travelling over a smooth, flat surface. Rarely is the terrain surrounding a farm perfectly flat and smooth, and under such conditions, landscape also plays a contributing role in the movement of odor off-farm.

Obstacles to wind flow such as hills, trees and buildings increase the roughness of the terrain and, accordingly, the dispersion in the odor plume. A filtering barrier, such as a row of trees placed downwind of the odor source, increases turbulence, forcing the air to mix and lifting odors upward. Variations in terrain elevation (topography) also can change the shape of the plume. Dispersion is increased if winds carry the plume upslope or up-valley. Downslope or down-valley winds lead to less dispersion and tend to concentrate odors in lower lying areas.

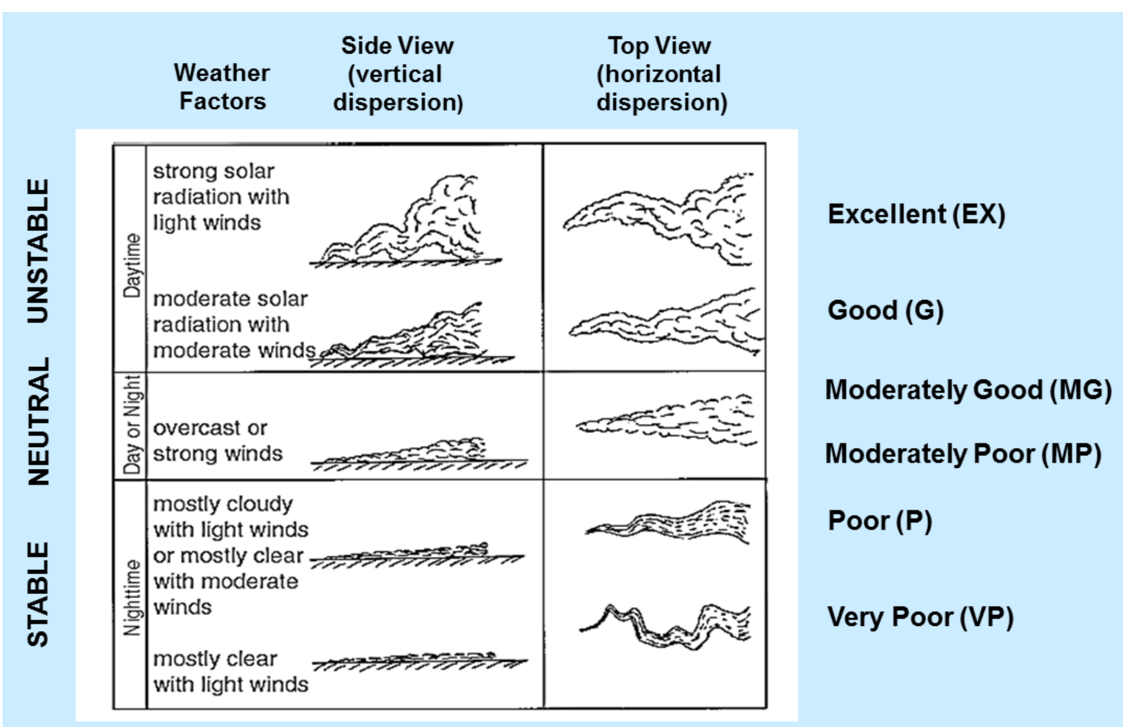

Figure 2. Behavior of odor plumes as a function of weather factors. Atmospheric conditions (unstable, neutral, and stable) are listed to the left of the plume diagram and dispersion categories from the Oklahoma Dispersion Model to the right.

Forecast Dispersion and Wind Conditions Table for Vinita

DATE / TIME	DISPERSION	WDIR	WSPD (mph)
Thu Jul 04, 2019 5:00 am CDT	P	SSE	8
Thu Jul 04, 2019 6:00 am CDT	MP	SSE	9
Thu Jul 04, 2019 7:00 am CDT	MG	SSE	10
Thu Jul 04, 2019 8:00 am CDT	G	SSE	11
Thu Jul 04, 2019 9:00 am CDT	MG	S	12
Thu Jul 04, 2019 10:00 am CDT	MG	S	13
Thu Jul 04, 2019 11:00 am CDT	MG	S	12
Thu Jul 04, 2019 12:00 pm CDT	G	S	12
Thu Jul 04, 2019 1:00 pm CDT	G	S	12
Thu Jul 04, 2019 2:00 pm CDT	G	S	11
Thu Jul 04, 2019 3:00 pm CDT	G	S	11
Thu Jul 04, 2019 4:00 pm CDT	G	S	11
Thu Jul 04, 2019 5:00 pm CDT	G	S	11
Thu Jul 04, 2019 6:00 pm CDT	G	S	11
Thu Jul 04, 2019 7:00 pm CDT	MG	SSE	11

Figure 8. Example of a forecast dispersion table for Vinita. Dispersion condition, wind speed, and wind direction are shown for each hour of the 84-hour forecast.

In summary, the operational dispersion products available on the Oklahoma Mesonet from the Oklahoma Dispersion Model can be of great utility in planning odor-generating activities. By avoiding such activities during poor dispersion conditions (MP through VP), farmers will be able to minimize negative odor impacts on their neighbors.

as well as through the 84-hour forecast. For either, select “Past” or “Forecast” as the time mode. Note that one can also select “Duration” and “Interval” for the animation. Then use the animation buttons at the bottom to advance through the time period that appears in the “Duration” field at the top. The middle button at the bottom is a play/pause toggle; the first button and last buttons take one to the first and last frames, respectively, of the animation; and the second and fourth buttons allow one to manually advance backward or forward in time. Figure 5 shows this map section of the website. The forecast animation has been stopped at 2:00 a.m. July 4, 2019, showing very poor to poor dispersion conditions across eastern Oklahoma and the extreme western panhandle, with moderately good conditions across the rest of the state. Wind direction arrows show the direction an odor plume would move, with the exception noted earlier, that under light wind conditions in the inversion areas (oranges and reds), the odor plume would flow downhill to lower terrain due to cold air drainage.

Charts and Tables

In addition to maps, one can get past and forecast charts or tables at any Mesonet site location. For site-specific odor applications, these product formats are likely to be more beneficial than maps as they provide a time series at one location of either past or forecast dispersion conditions, the latter being useful for planning purposes.

To access dispersion charts or tables, go to the “Past & Forecast Charts/Tables” section (left menu item) of the OK-FIRE website (Figure 6). Select the Mesonet site of interest, then “Dispersion and Wind Conditions” in the “Variable(s)” pull-down menu. Then select either “Charts” or “Tables”, and for the time mode, either “Past” or “Forecast”. “Duration” and “Interval” can be selected for either charts or tables. Finally, click “Get Data”.

Figure 7 is an example of a forecast dispersion and wind chart for Vinita through the 84-hour forecast period. The top graph shows the predicted dispersion conditions from 1 (VP) to 6 (EX) over time, while the bottom graph shows the corresponding wind speed and wind direction (staff/barb symbols). Winds blow in a direction along the staff beginning at the barbed end. During the daytime on Thursday, Friday and Saturday, the dispersion conditions are forecast to be 4 (MG) or better. During the overnight hours on Thursday, Saturday and Sunday mornings, dispersion drops to 2 (P) or 1 (VP) due to very light wind speeds and (likely) surface temperature inversions. Odor plumes during these conditions will drain gravitationally to lower elevations. However, during the overnight hours on Friday morning, dispersion is better with values of 3 (MP) or 4 (MG), due to slightly stronger wind speeds, and odor plumes are likely to move downwind to the north.

Figure 8 shows a portion of a forecast dispersion table for Vinita from 5:00 a.m. through 7:00 p.m. on July 4, 2019. Note that the dispersion condition is listed in the second column, the wind direction in the third column, and the wind speed in the fourth. Good (G) dispersion is predicted from noon through 6:00 p.m., which would be a very suitable period for any activity that would emit odors. The odor plume would move toward the north with the predicted south winds. If no sensitive areas were located to the north of the odor source, the time period for odor emission could be extended by several hours from 7:00 a.m. through 7:00 p.m. since MG or better dispersion conditions are predicted through this period.

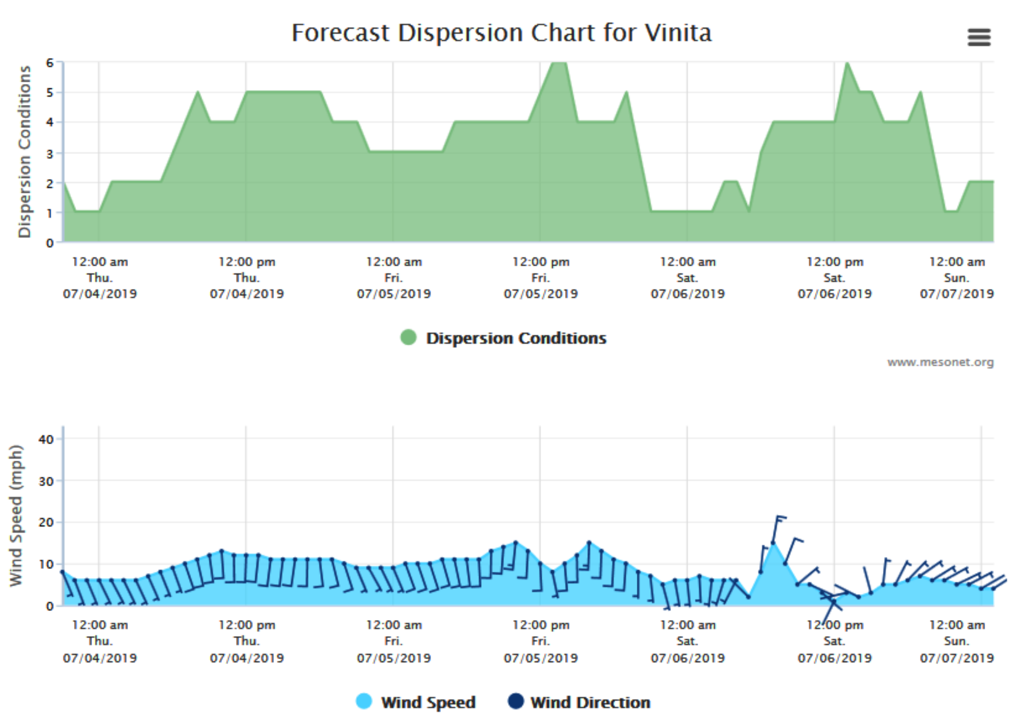

Figure 7. Example of a forecast dispersion and wind chart for Vinita. Predicted dispersion conditions (green) are shown in the top graph, and wind speeds (blue) and directions (staff/barb symbols) in the bottom graph.

A word of caution: the discussion about using topography and ground obstacles to increase dispersion assumes the presence of moderately good to excellent dispersion conditions and a breeze strong enough to carry the odor plume downwind. Under certain dispersion conditions—when the ground surface is cooling and winds are generally light, resulting in a surface temperature inversion—odors move by a process called cold air drainage. This typically occurs during poor (P) to very poor (VP) dispersion conditions (Figure 3). Gravity pulls the plume into valleys and low spots. Cold air drainage plays a very large role in the movement of agricultural odors. Most farmstead odors are heavier than air, increasing their tendency to settle in low-lying areas. Odors may travel great distances under such dispersion conditions, following the course of streams and valleys as a result of cold air drainage. Even in cases of flat terrain, dispersion will be extremely poor within an inversion layer as can be seen from the lower plumes in Figure 1.

The Oklahoma Dispersion Model

The Oklahoma Dispersion Model is a tool that was first developed in the late 1990s and later implemented operationally using the Oklahoma Mesonet to assess surface dispersion conditions up to several miles downwind. It was originally developed for dispersion of farmstead odors but also is used to assess dispersion of wildland fire smoke. The model breaks the atmosphere into six dispersion categories:

1 = Very Poor (VP)
2 = Poor (P)
3 = Moderately Poor (MP)
4 = Moderately Good (MG)
5 = Good (G)
6 = Excellent (EX)

The lower end of this scale (VP and P) typically occurs with surface temperature inversions, which inhibit mixing and cause poor dispersion. During such conditions, an odor plume will hang together as it drifts downwind and anyone near the narrow plume centerline will detect strong odor (e.g., lower plumes in Figure 1). The upper end of this scale (EX and G) typically occurs with unstable atmospheric conditions, where the dispersion is good, both in the vertical and horizontal directions. Figure 2 shows which plume patterns correspond with these six dispersion categories.

The six dispersion categories can be interpreted as follows - for a given distance downwind, odor concentrations near the plume centerline will be the lowest under the excellent (EX) category and highest under the very poor (VP) category.

Wind Speed (mph)	Daytime					Nighttime		
	Solar Radiation					Cloudiness		
	Strong	Moderate	Slight	Weak	Heavy Overcast	Heavy Overcast	Mostly Cloudy	Clear to Partly Cloudy
2	G	G	MG	MP	P	P	VP	VP
4	EX	G	MG	MP	MP	MP	P	VP
6	EX	G	MG	MP	MP	MP	P	VP
8	EX	EX	G	MP	MP	MP	MP	P
10	EX	G	G	MG	MG	MG	MG	MP
12	G	G	MG	MG	MG	MG	MG	MP
14	G	MG	MG	MG	MG	MG	MG	MG
16	G	MG	MG	MG	MG	MG	MG	MG
20	EX	MG	MG	MG	MG	MG	MG	MG
25	EX	G	G	G	G	G	G	G
30	EX	G	G	G	G	G	G	G

Figure 3. The effect of weather conditions on odor dispersion. Colors and categories correspond to the dispersion categories in the Oklahoma Dispersion Model (EX = excellent, G = good, MG = moderately good, MP = moderately poor, P = poor, VP = very poor). During the daytime the first four categories for solar radiation are functions of sun angle and cloudiness amount.

Farmers can use the model (via the products to be discussed next) to assess appropriate times for planned odor releases such as manure spreading and land application of lagoon effluent.

Operational Products of the Oklahoma Dispersion Model

A large number of dispersion products from the Oklahoma Dispersion Model can be found in various locations on the Oklahoma Mesonet website (https://www.mesonet.org). They are available in map format for viewing conditions over the entire state, as well as in chart and table formats for individual Mesonet site locations. While some dispersion products appear in the "Agriculture" section (upper menu tab) of the Mesonet website under "Dispersion", the most comprehensive set of dispersion products are located in the "Fire Management" (OK-FIRE) section (upper menu tab) of the website, as smoke dispersion is a major application of the dispersion model and used in both wildfire and prescribed fire applications. Discussion of available dispersion products from the Oklahoma Dispersion Model will henceforth be made with reference to this section (OK-FIRE) of the Mesonet website (https://www.mesonet.org/index.php/okfire).

There are two sources of data for the Oklahoma Dispersion Model: 1) the Oklahoma Mesonet for assessment of past and current dispersion conditions and 2) an 84-hour forecast model (the "North American Mesoscale" (NAM) model) for use in hourly dispersion forecasts up to three-and-a-half days in the future. For past and current dispersion conditions, the model uses solar radiation, wind speed, wind direction and temperature obtained from the Mesonet; all dispersion products based on Mesonet data are updated every five minutes providing real-time assessment of dispersion conditions. For future dispersion conditions the model uses forecasted solar radiation, wind speed, cloud cover amount and cloud ceiling height. The NAM dispersion forecasts are updated every six hours. For both Mesonet and forecast modes, different calculation procedures are used at nighttime than during the daytime.

Maps

In the map products, dispersion categories are color coded with categories 4 through 6 (MG, G, EX) in increasing shades of green, while category 3 (MP) is colored in beige, category 2 (P) in orange and category 1 (VP) in red. Figure 4 shows an example of a dispersion condition map with wind vectors (arrows) showing the wind directions. Dispersion category numbers are also shown at the Mesonet sites. This example is a rare case where all six categories were occurring across the state at the same time; odor plumes would experience increasingly poor dispersion in the beige (3), orange (2) and red (1) areas. These areas were experiencing heavy cloud cover with light winds at the time.

Current, past and forecast dispersion maps are available in the "Past & Forecast Animated Maps" section (left menu item) of the OK-FIRE website (Figure 5). To view current dispersion conditions, select "Dispersion Conditions & Winds" in the pull-down "Variable(s)" menu and then select "Current" as the time mode. Animations are possible for past time periods

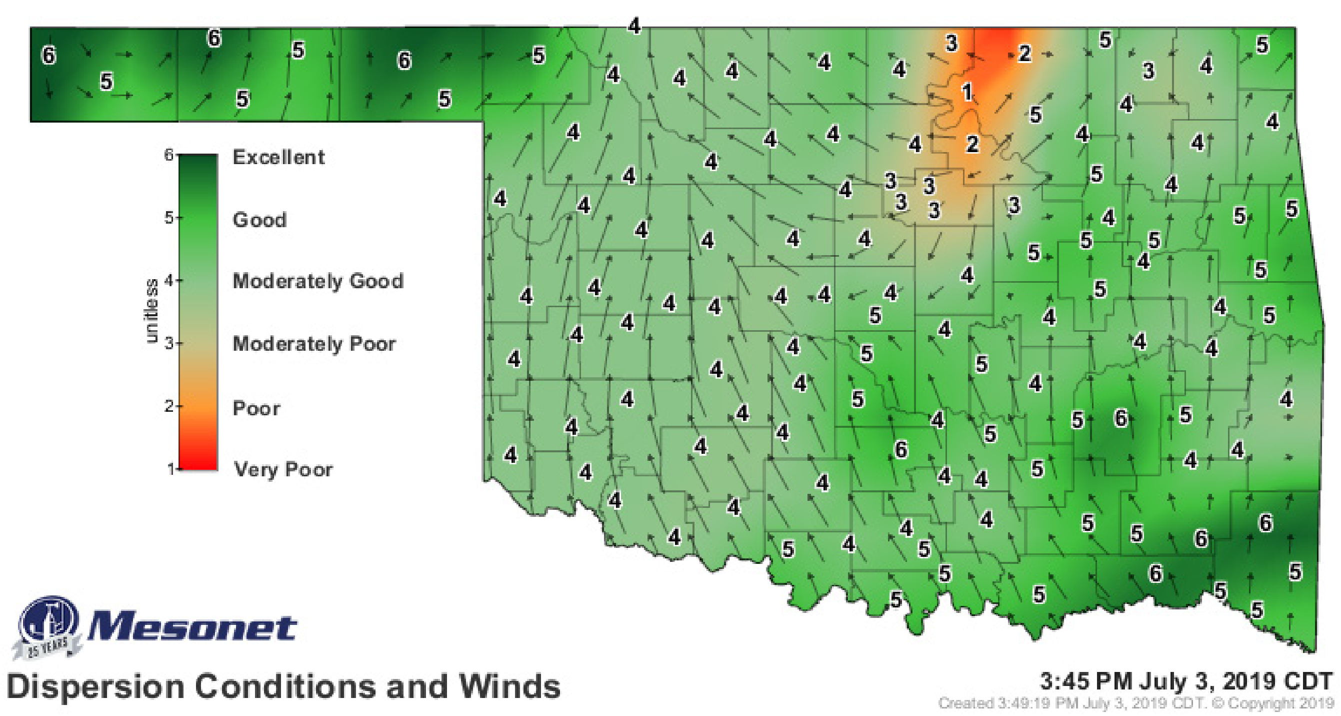

Figure 4. Example of a current map of dispersion conditions from the Oklahoma Dispersion Model using Mesonet data.

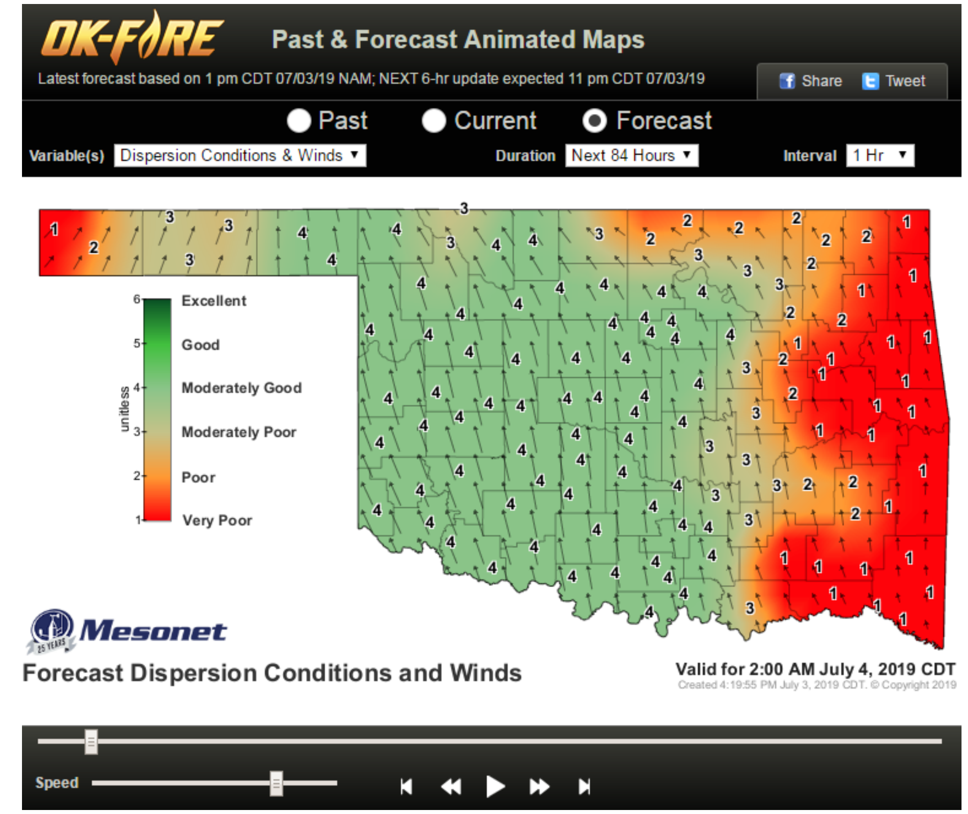

Figure 5. The dynamic map interface in the OK-FIRE website where past, current and forecast dispersion maps can be viewed.

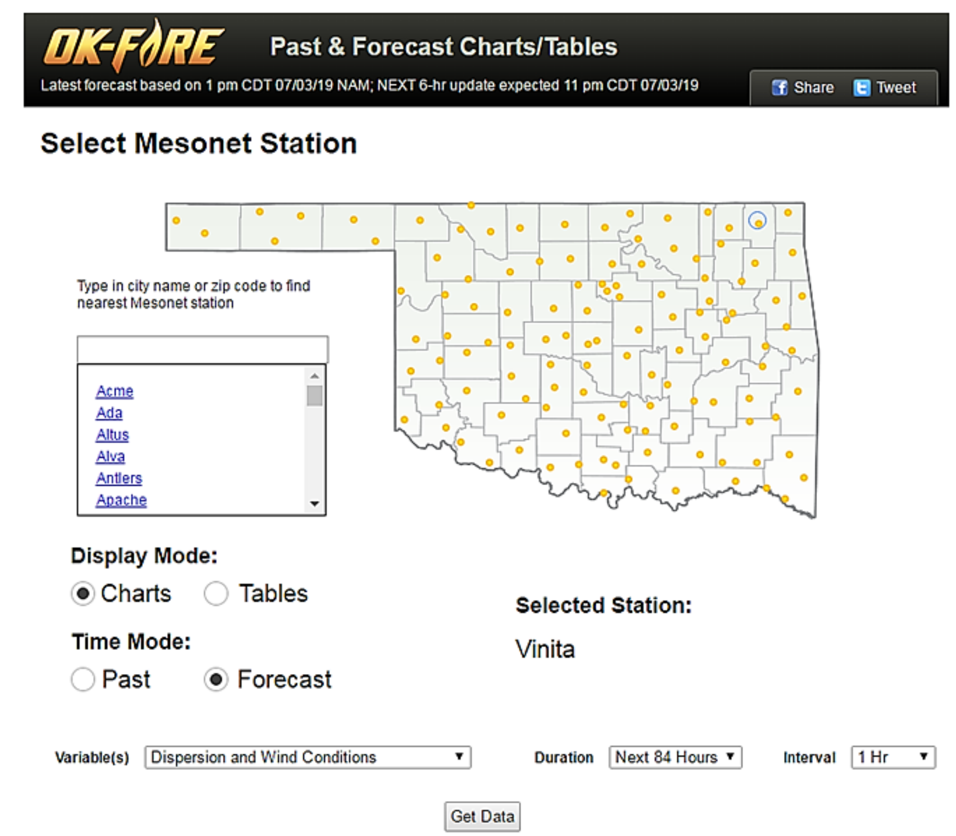

Figure 6. The interface for charts and tables in the OK-FIRE website where past and forecast charts or tables can be viewed.