1.3 THE OKLAHOMA MESONET: DECISION-SUPPORT PRODUCTS FOR AGRICULTURE AND NATURAL RESOURCES USING A MESOSCALE AUTOMATED WEATHER STATION NETWORK

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1. INTRODUCTION

Oklahoma's geographical position in the southern Great Plains gives it a diverse climatic regime, with average annual precipitation ranging from less then 406 mm (16") in the western panhandle to more than 1321 mm (52") in the mountains of southeast Oklahoma. Land types vary dramatically from the forested mountains and hills of eastern Oklahoma to the tallgrass prairie and cross timbers of central Oklahoma to the shortgrass prairies of the panhandle. The growing season (freeze-free period) varies by 9 weeks across the state, from 24 weeks in the northwestern panhandle to 33 weeks along the Red River in south central Oklahoma (Johnson and Duchon, 1995). It is not surprising, given the above, that Oklahoma also experiences a wide range of weather conditions, both in space and time.

Oklahoma's agriculture, with a 2004 production value of $4.62 billion (forest products not included), reflects the state's geographical diversity (Flynn and Shepler, 2005). Included in the top 17 in terms of economic importance in 2004 were: cattle and calves (#1), poultry and eggs (#2), hogs and pigs (#3), winter wheat (#4), hay (#5), milk (#6), corn for grain (#7), cotton (#8), soybeans (#9), pecans (#10), grain sorghum (#12), peanuts (#13), watermelons (#15), sheep and lambs (#16), and peaches (#17). With forests covering about 20% of the state, forest products, if included in the list above, would rank as the third most valuable "crop" (i.e., situated between hay and corn for grain).

In addition, over half of the state consists of wildlands, so that wildfire and prescribed burning frequently occur throughout the year. It is estimated that during an average year, about 810,000 ha (2 million acres) of land are burned, 80% of it through prescribed fire. Wildfire severity can be extreme, however, in certain years, with many more hectares being burned than normal. This past fire season in Oklahoma has been particularly severe, with about 2700 wildfires burning over 224,000 ha (555,000 acres) during the period 1 November 2005 through 17 March 2006.

This paper focuses first on the Oklahoma Mesonet, the state's mesoscale automated weather station network, and second on the variety of Web-based decision-support products that have been developed for agriculture and natural resources within Oklahoma.

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2. THE OKLAHOMA MESONET

Operational since 1994, the Oklahoma Mesonet is a statewide automated weather station network operated jointly by the University of Oklahoma and Oklahoma State University (Elliott *et al.*, 1994; Brock *et al.*, 1995). With an annual budget of $2.2 million, Mesonet obtains about 81% of its funding from the State of Oklahoma.

Each Mesonet station consists of an automated instrumented tower (10-m height) along with other sensors within a 10-m by 10-m plot of land. A typical Mesonet weather station is shown in Figure 1. A wide array of weather and soil variables are measured. Weather variables include air temperature (1.5 and 9 m), relative humidity (1.5 m), solar radiation, wind speed (1.5 and 10 m), wind direction (10 m), rainfall, and barometric pressure. Soil variables include soil temperature at various depths (5 and 10 cm under bare soil; 5, 10, and 30 cm under sod cover) and soil moisture at various depths under sod cover (5, 25, and 60 cm).

Figure 1. *Oklahoma Mesonet 10-m automated weather station tower at Goodwell, Oklahoma.*

The Oklahoma Mesonet is a *mesoscale* network with respect to both space and time. With respect to space, the network currently consists of 116 sites with an average spacing of 30 km (19 miles). The tower locations are shown in Figure 2. Note that there is at least one station in every county; some counties have 3 or 4 stations.

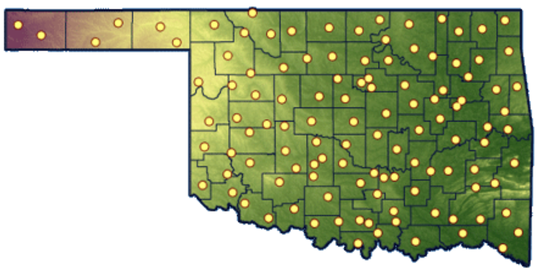

Figure 2. *Location of automated weather station sites in the Oklahoma Mesonet.*

With respect to time, the reporting of weather and soil observations by the Mesonet also falls in the mesoscale range. For this purpose, the Oklahoma Mesonet utilizes an already existing statewide telecommunications network, the Oklahoma Law Enforcement Telecommunications Network (OLETS). Observations are sent by radio signal to a nearby OLETS tower (or by a repeater to an OLETS tower). Weather observations are sent every 5 minutes, while soil temperatures are sent every 15 minutes and soil moisture measurements, every 30 minutes.

For clientele in agriculture and natural resources, one of the major benefits of the Oklahoma Mesonet is the spatial density of the network. With the average station spacing of 30 km, growers and others are typically within 15 km (9 miles) of a Mesonet tower and are able to utilize essentially local weather information. Prior to Mesonet, all that was available in near-real-time was information from synoptic scale networks.

The other major benefit is the real-time availability of the data. Not only are weather and soil observations made and sent in time intervals ranging from 5 to 30 minutes, but these observations are made available on the internet within minutes after being received at the Oklahoma Climatological Survey in Norman, Oklahoma. Examples where such timeliness is important include prescribed burning and wildfires. Of course, this temporal and spatial density is useful for a wide range of other applications, such as weather and hydrological forecasting.

3. OKLAHOMA AGWEATHER WEB SITE

Since 1994 the Oklahoma Mesonet has become an increasingly used source for weather-based decision-support products for the agricultural and natural resources community. During the first two years, such products were offered to this community via a bulletin board service, whereby files were downloaded over telephone lines and then viewed/manipulated using Mesonet-developed software. With the increasing availability of the internet to clientele, however, this method of product distribution began to be replaced by the World Wide Web starting with our first Web page in March 1996, which featured the Oklahoma Fire Danger Model. The advent in 1996 of this Web product and others was particularly well timed, coinciding with the National Weather Service's cancellation of its agricultural and private fire weather services.

Products for agriculture and natural resources are currently offered on the "Oklahoma Agweather" Web site (***http://agweather.mesonet.org***). The home page is shown in Figure 3. Note that there are menu icons not only for weather and soil products, but also for specific commodities and markets.

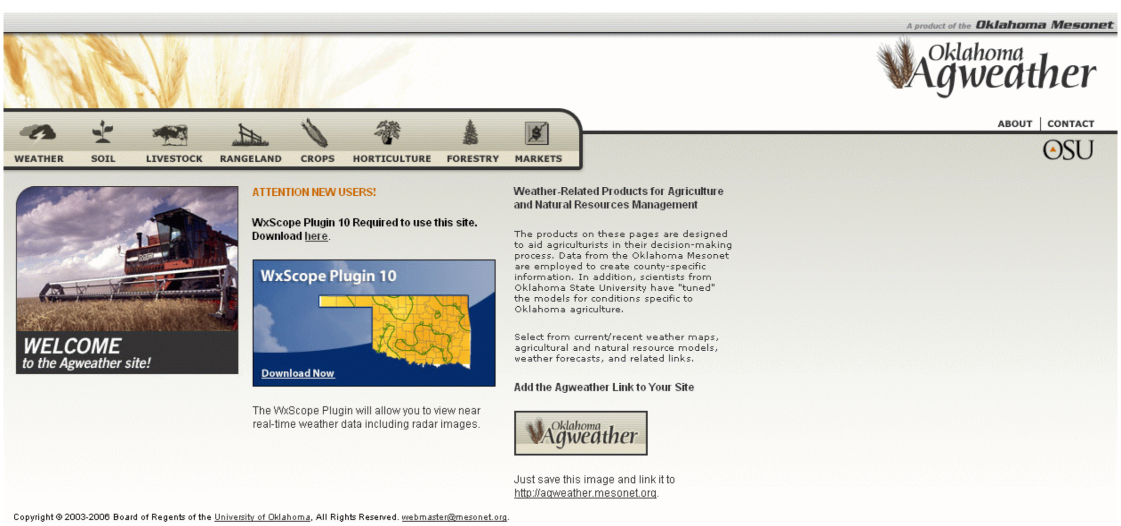

Figure 3. *The "Oklahoma Agweather" home page.*

Many of the products rely on "WxScope" plug-in software developed by the Oklahoma Climatological Survey (OCS). This innovative software, when resident on one's computer, allows the creation of specialty maps, graphs, tables, and other products locally (only the data is downloaded from OCS). With respect to map products, the software allows the viewer to zoom in and out, add county and other geographical boundary overlays, and animate the maps. An example of a contour map for relative humidity is shown below in Figure 4. It clearly shows the location of a "dry line", which is a sharp discontinuity of relative humidity. Relative humidity values ahead of (to the east) of the dry line are 60% or higher, while values behind the dry line fall to values lower than 15%. This day saw extreme fire behavior in the very dry and windy air behind the dry line.

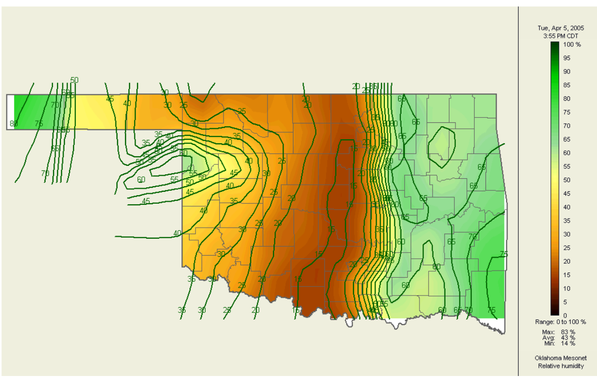

Figure 4. *Contour map of relative humidity at 1555 CDT (Central Daylight Time) on 5 April 2005. Map was produced by the WxScope plugin software.*

4. DECISION-SUPPORT PRODUCTS

A variety of decision-support products are available on the Oklahoma Agweather site. They fall generally into three main areas: (1) weather and soil products based on current, recent, or historical data, (2) weather-based models for specific applications in agriculture and natural resources, and (3) forecasts.

4.1 *Weather and Soil Products*

A wealth of products, most using the plugin software, are available for various weather and soil variables measured directly by or calculated through use of Mesonet data.

With respect to weather data, standard synoptic maps are available as are specialty maps for temperature, humidity (relative humidity and dewpoint), wind speed and direction, rainfall, atmospheric pressure, solar radiation, and lapse rate conditions near the surface. Through use of the plugin software, many of these maps permit zooming, geographical overlays, and animation. An example of a colorized contour map for solar radiation is

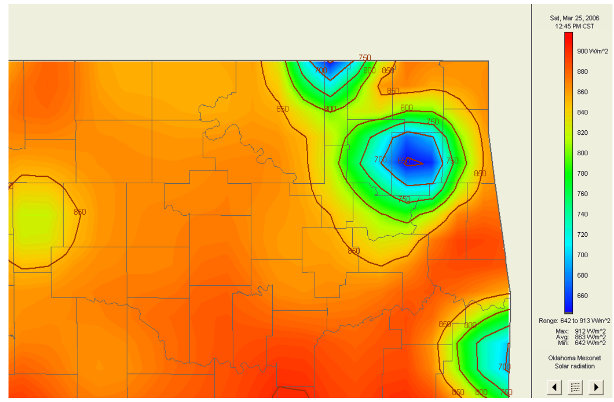

Figure 5. *Contour map of solar radiation at 1255 CST (Central Standard Time) on 25 March 2006.*

shown in Figure 5. The zooming feature has been used to focus in on northeast Oklahoma.

Meteograms, which are graphs/charts of various weather variables from a point in the past to the current time, are also available for specific Mesonet sites. Figure 6 shows a 24-hour meteogram for the Jay station. Air temperature and dewpoint are shown on the first chart, while wind information is shown on the second.

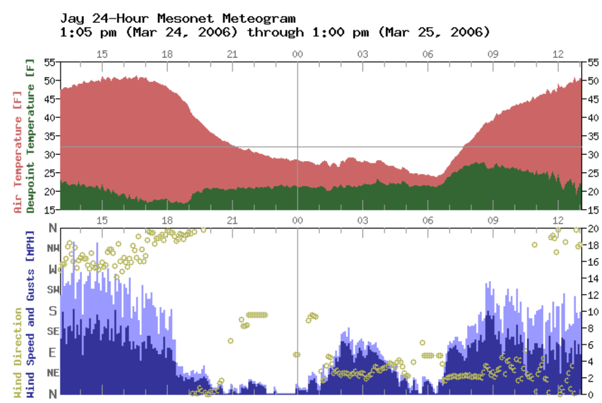

Figure 6. *Meteogram of temperature and wind conditions over the past 24 hours at Jay, Oklahoma as of 1300 CST on 25 March 2006.*

Other types of products include tables. Examples include cumulative rainfall and short- and tall-grass reference evapotranspiration for specific Mesonet sites over various time periods (e.g., last 7 days through last 90 days).

Soil products include maps for soil temperature and soil moisture at various depths. With respect to soil temperature, maps showing current values at 5, 10, and 30 cm are available as are maps showing averages over the past 1, 3, and 7 days. With respect to soil moisture, maps of "fractional water index" are available showing the fractional amount of saturation at that level (0=no water, 1 = complete saturation). Figure 7 shows a contour map of fractional water index at 60 cm depth.

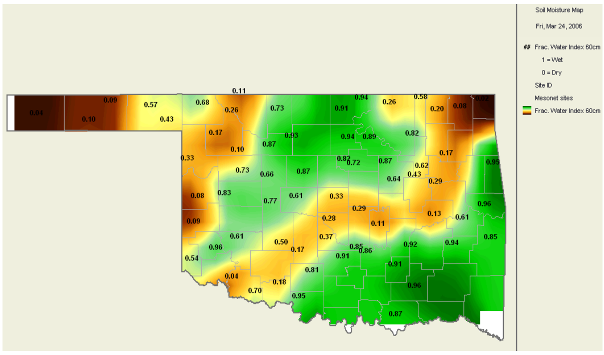

Figure 7. *Soil moisture map showing fractional water index at 60 cm depth as of 24 March 2006.*

Other Mesonet data products include monthly station site summaries showing both daily and monthly statistics for the site (e.g., daily/monthly averages and extremes for such variables as temperature, and daily/monthly totals and extremes for rainfall). Historical Mesonet weather and soil data, in digital format, are also available for research studies and other purposes.

While not based on Mesonet data, it should be mentioned that the user also has access to satellite and NEXRAD radar imagery, the latter of which also utilizes the plugin software, thus allowing zooming and animation. Figure 8 shows a thunderstorm line firing up just ahead of the dry line depicted in Figure 4.

Figure 8. *Formation of thunderstorms ahead of the dry line (Figure 4) at 1518 CDT on 5 April 2005.*

4.2 *Weather-Based Models for Specific Applications*

The Oklahoma Agweather site features a variety of weather-based models for agriculture and natural resources. While one could categorize them in a number of different ways, one illustrative way is based on how many Mesonet weather variables are utilized in the particular model.

A number of models are solely based on *temperature*, and, in particular, on cumulative degree days from a specific start date and using a specific temperature threshold for phenological development. Our insect management models fall into this category. Currently there are insect models for alfalfa weevil and pecan nut casebearer (PNC). These models utilize degree-day accumulation to predict a particular damaging growth stage of the insect pest, thus fostering optimal timing of scouting activities and insecticide application. The models are updated once daily. The PNC model is based on base 38F (3.3 C) degree days from site-specific start dates ranging from March 21 to April 24. The alfalfa weevil model is based on base 48F (8.9C) degree days from January 1 (Figure 9). Aside from the two insect models, there are also degree-day calculators for various crops (e.g. corn, soybeans, cotton) where the user can enter a specific start and end date for the degree-day accumulations.

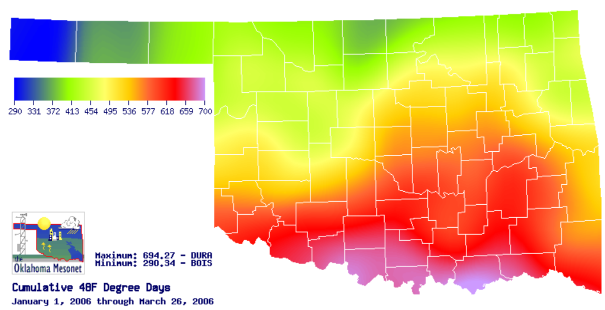

Figure 9. *Map from the alfalfa weevil model of cumulative base 48F degree days as of 26 March 2006.*

A number of models are based on *temperature and relative humidity*. These are our disease management models, of which there are currently four: peanut leafspot, pecan scab, watermelon anthracnose, and spinach white rust. These models were developed through field research by scientists at Oklahoma State University. The models are based on cumulative "infection hours", which are time periods when certain temperature and relative humidity constraints have been met. If the grower has sprayed a fungicide during the current crop season, the date of the last application is also taken into account. Figure 10 shows a sequence taken from the peanut leafspot model. The grower first chooses a Mesonet site (Figure 10a), and then enters the date the peanuts were planted and the date of the last fungicide application (Figure 10b). The model comes back with a recommendation to spray or not spray (Figure 10c). It should be mentioned that two of the models, pecan scab and spinach white rust, now have an 84-hour forecast component to anticipate infection hours over the next three days.

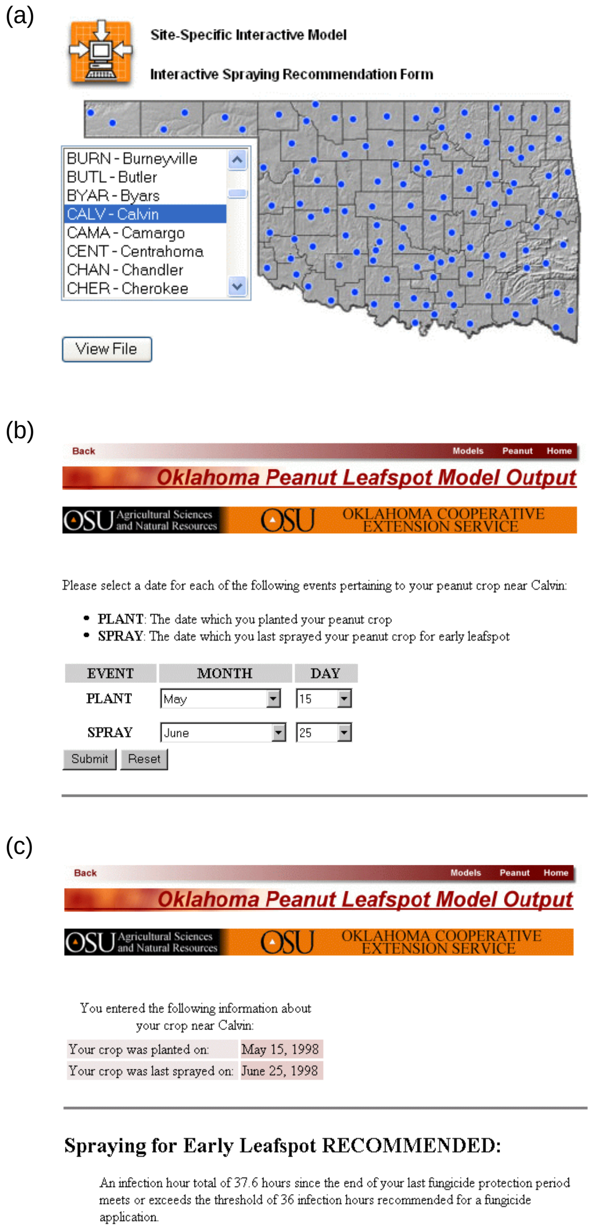

Figure 10. *Peanut leafspot site-specific interactive model. Grower chooses a Mesonet site (a), enters certain dates (b), and the model gives a spray or no-spray recommendation (c).*

Finally, there are a number of models which are based on *more than two weather variables*. In this category are our models for cattle heat/cold stress, evapotranspiration and irrigation scheduling, atmospheric dispersion, and fire danger.

With respect to cattle stress, the heat stress algorithm is a function of temperature and relative humidity, while the cold stress algorithm relies on temperature, wind speed, and precipitation. Figure 11 shows a sample map from the cattle stress model. Based on Mesonet data, the map shows a sudden transition from no stress to severe cold stress behind a cold front which was crossing the state. This model, like some of the disease management models, has a 60-hour forecast component based on incorporating output from the NGM MOS forecast locations within and surrounding Oklahoma.

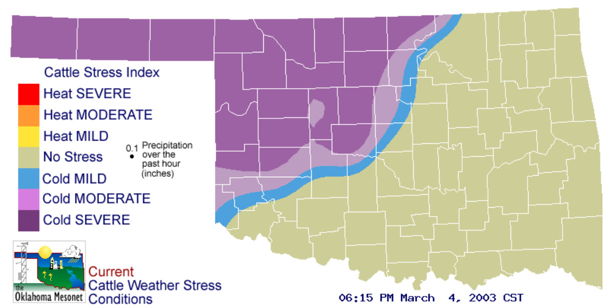

Figure 11. *Colorized map of cattle stress based on weather conditions occurring at 1815 CST on 4 March 2003.*

With respect to evapotranspiration (ET), the Oklahoma Mesonet routinely calculates daily short- and tall-grass reference evapotranspiration at each Mesonet site. Reference ET is calculated using the ASCE standardized Penman-Monteith equation (Itenfisu *et al.*, 2003) and utilizes a wide range of Mesonet-measured variables, including solar radiation, temperature, relative humidity, 2-m wind speed, and atmospheric pressure. Based on the reference ET values, daily values for pan evaporation and cool- and warm-season grass ET are also estimated. Using reference ET in combination with “crop coefficients”, daily crop-specific ET is then calculated for a number of agronomic and horticultural crops. This information can then be used in irrigation scheduling.

Figures 12 and 13 show some sample products dealing with evapotranspiration and irrigation scheduling. Figure 12 is a statewide map of the past 30-day accumulation of tall-grass reference evapotranspiration. Figure 13 is an example of a site-specific table which can be useful for irrigation scheduling. The particular example is for the Cherokee site and for the alfalfa crop. The table lists the daily and accumulated values of alfalfa ET and rainfall at the Cherokee site. As an example, if a grower had applied 1 inch of water (2.5 cm) on March 15, the last column (water balance) for March 15 shows that between the daily rainfall and alfalfa ET, there is a net of +0.44 inch of water in the soil since March 15 and that there would be no need to irrigate again until that column for March 15 reads -1.0 inch (assuming the grower’s plan was to apply one inch of water every time one inch was depleted in the soil column).

Another model using more than two weather variables is the Oklahoma Dispersion Model. This is a model which was developed to estimate the ability of the atmosphere to disperse gases and particulates released by ground-level emission sources. Details of the model can be found in

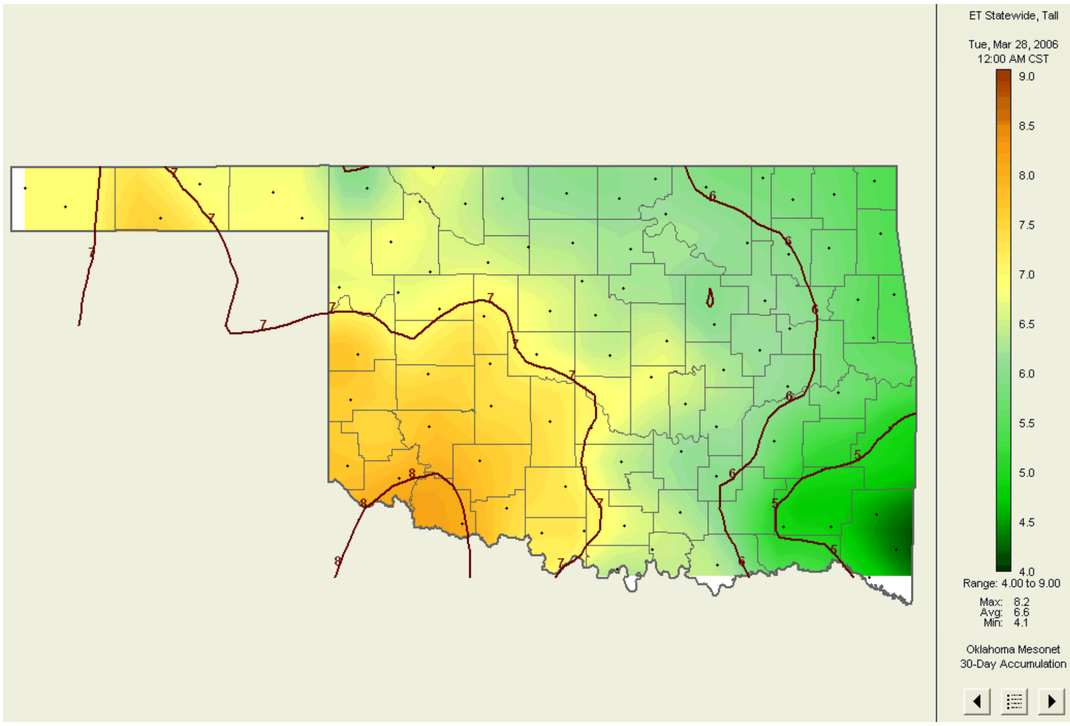

Figure 12. *Thirty-day accumulation of tall-grass reference evapotranspiration as of 28 March 2006.*

Evapotranspiration for alfalfa for Cherokee							
Station	**Date**	**Number of Days**	**Evapotranspiration (inch)**	**Accumulated Evapotranspiration (inch)**	**Rainfall (inch)**	**Accumulated Rainfall (inch)**	**Water Balance (inch)**
CHER	2006-03-28	1	0.11	0.11	0.00	0.00	-0.11
CHER	2006-03-27	2	0.12	0.23	0.00	0.00	-0.23
CHER	2006-03-26	3	0.15	0.38	0.00	0.00	-0.38
CHER	2006-03-25	4	0.08	0.46	0.00	0.00	-0.46
CHER	2006-03-24	5	0.06	0.52	0.00	0.00	-0.52
CHER	2006-03-23	6	0.07	0.59	0.04	0.04	-0.55
CHER	2006-03-22	7	0.02	0.61	0.00	0.04	-0.57
CHER	2006-03-21	8	0.04	0.65	0.00	0.04	-0.61
CHER	2006-03-20	9	0.02	0.67	0.86	0.90	0.23
CHER	2006-03-19	10	0.01	0.69	0.31	1.21	0.52
CHER	2006-03-18	11	0.02	0.71	0.29	1.50	0.79
CHER	2006-03-17	12	0.06	0.77	0.02	1.52	0.75
CHER	2006-03-16	13	0.15	0.92	0.00	1.52	0.60
CHER	2006-03-15	14	0.16	1.08	0.00	1.52	0.44
CHER	2006-03-14	15	0.09	1.17	0.00	1.52	0.35
CHER	2006-03-13	16	0.14	1.31	0.00	1.52	0.21
CHER	2006-03-12	17	0.35	1.66	0.00	1.52	-0.14
CHER	2006-03-11	18	0.18	1.83	0.00	1.52	-0.31
CHER	2006-03-10	19	0.10	1.94	0.00	1.52	-0.42
CHER	2006-03-09	20	0.08	2.02	0.24	1.76	-0.26
CHER	2006-03-08	21	0.21	2.23	0.00	1.76	-0.47
CHER	2006-03-07	22	0.14	2.37	0.00	1.76	-0.61
CHER	2006-03-06	23	0.15	2.51	0.00	1.76	-0.75

Figure 13. *Alfalfa evapotranspiration and rainfall data for Cherokee, Oklahoma for use in irrigation scheduling.*

Carlson and Arndt (2006). With respect to Mesonet data, the model utilizes solar radiation, temperature, wind speed, and standard deviation of wind direction. An example is shown in Figure 14, a colorized map depicting the atmospheric dispersion conditions as a cold front was crossing the state. This model also features a 60-hour forecast component, utilizing the NGM MOS forecast output.

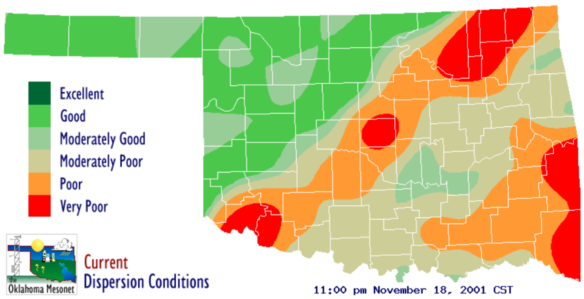

Figure 14. *Map from the Oklahoma Dispersion Model of current dispersion conditions at 2300 CST on 18 November 2001 using weather data from the Oklahoma Mesonet.*

We conclude this section by mentioning our most complex model as well as one of our most important and frequently used models, the Oklahoma Fire Danger Model. This model is an adaptation of the National Fire Danger Rating System (NFDRS) to the Oklahoma Mesonet. With respect to weather variables, the model utilizes temperature, relative humidity, wind speed, precipitation, and solar radiation. Details can be found in Carlson *et al.* (2002) and Carlson and Burgan (2003). The model is run hourly and features colorized maps to 1-km resolution of various NFDRS indices. Figure 15 shows a map of burning index corresponding to the same synoptic event of 5 April 2005 (Figure 4). Burning index is related directly to fireline intensity and to the difficulty of containing a wildland fire. Note the extremely high fire danger behind the dry line on that afternoon.

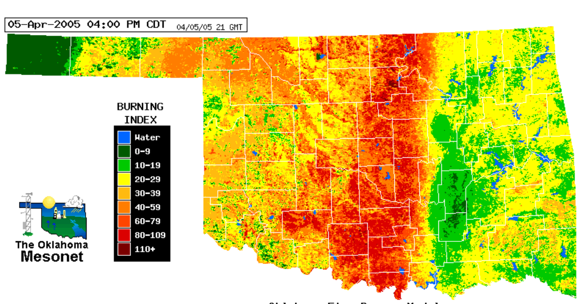

Figure 15. *Map from the Oklahoma Fire Danger Model of burning index at 1600 CDT on 5 April 2005. Note the high fire danger behind the dry line (see Figure 4).*

The Oklahoma Fire Danger Model has seen extensive use since its existence. Oklahoma Forestry Services uses the model regularly for purposes of issuing Red Flag Fire Alerts and in recommending burn bans to the Governor. This model, in conjunction with other Mesonet weather products, has seen extensive use over the past number of months, as over 550,000 acres (224,000 ha) have burned during the period 1 November 2005 through 17 March 2006.

4.3 *Forecast Products*

The Oklahoma Mesonet, being a weather and soil data reporting system, does not make forecasts. However, forecasts are especially important to those in agriculture and natural resources, so we have made an effort at the Oklahoma Agweather Web site to include links to various forecast products of the National Weather Service. Over time our goal is to incorporate 2-3 day weather forecast output into all of our models, as we have currently done for two of the disease management models, the cattle stress, and the dispersion models.

Aside from the above, we did develop in the late 1990s a stand-alone forecast product for use within the agriculture and natural resources community. This product utilizes 60-hour MOS (Model Output Statistics) forecast output from the NGM (Nested Grid Model) for locations within and surrounding Oklahoma (National Weather Service, 1992). Tabular as well as graphical (maps) output is available. The tables are specific to the MOS locations and include forecasts for various weather variables in 3-hour increments throughout the 60-hour forecast period. Output from the Oklahoma Dispersion Model has been added as well. These forecasts are updated twice daily. An example is seen in Figure 16.

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	DISPERSION CONDITION | DOWNWIND POLLUTION INDEX			CEILING
CL = Clear	R = Rain	EX	Excellent	< 2	1 = < 200 ft
SC = Scattered	Z = Freezing Rain	G	Good	2 - 4	2 = 200 - 400 ft
BK = Broken	S = Snow	MG	Moderately Good	4 - 10	3 = 500 - 900 ft
OV = Overcast		MP	Moderately Poor	10 - 23	4 = 1000 - 3000 ft
		P	Poor	23 - 53	5 = 3100 - 6500 ft
		VP	Very Poor	> 53	6 = 6600 - 12000 ft
					7 = > 12000 ft

Figure 16. *60-hour NGM MOS forecast for McAlester, Oklahoma using the McAlester NGM MOS forecast from 1800 CST on 18 November 2001.*

This product is very popular, serving as a planning tool for those in agriculture and natural resources. One activity for which it is useful is prescribed burning, where temperature, relative humidity, and winds must be within certain "prescribed" ranges for a burn to occur. The NGM MOS product can give wildland fire managers a view of these variables over the next 2-3 days. A decision can then be made as to whether a window of opportunity for a burn is possible.

5. SUMMARY

Operational since 1994, the Oklahoma Mesonet is operated jointly by the University of Oklahoma and Oklahoma State University. With an average station spacing of 30 km and a data transmission interval ranging from 5 minutes in the case of weather data to 15 to 30 minutes for soil data, the Oklahoma Mesonet constitutes a mesoscale real-time monitoring network. Weather and soil data are available on the Web within minutes of being reported.

Such a weather station network is invaluable to a large number of enterprises, not the least of which is agriculture and natural resources. Since the inception of the Oklahoma Mesonet in 1994, an increasing number of weather-based decision-support products have been developed for this clientele base. Currently these products are made available on a dedicated Web site (***http://agweather.mesonet.org***), called Oklahoma Agweather.

This paper has highlighted these decision-support products, which fall generally into three main areas: (1) weather and soil products based on current, recent, or historical Mesonet data, (2) weather-based models for specific applications in agriculture and natural resources, and (3) forecasts. Details of these products can be found in Section 4 and will not be repeated here.

The Oklahoma Agweather site, along with its products, has been promoted at numerous agricultural commodity trade shows and other events. We have also made a concerted effort to educate Oklahoma county extension educators as to how to use these products to serve their clientele. Educational materials have been developed for certain of the products. As a result of these efforts, the Oklahoma Mesonet has enjoyed increasing visibility within the agriculture and natural resources community. More and more "success stories" have been heard as increasing numbers of clientele use the Oklahoma Agweather site and its products.

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