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THE OKLAHOMA MESONET: SITE SELECTION AND LAYOUT

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Over the past two years, a unique project has been undertaken to put real-time weather data into the hands of not only researchers and operational meteorologists but also the general public. This project is called The Oklahoma Mesonet, hereafter referred to as Mesonet. It is jointly administered by the University of Oklahoma (OU) and Oklahoma State University (OSU). Mesonet is a ~~meso~~scale ~~net~~work of 108 automated weather stations which report current weather and soil conditions to a central computer facility every fifteen minutes. The data are collected statewide and, together with various value-added products, are released for public use via a computer bulletin board system.

1. Description of the Mesonet

Mesonet began as a concept over ten years ago. In 1982 an effort began at OSU to install a dial-up system of weather sensors at each of their 20 Agricultural Experiment Stations in Oklahoma. In 1984 a devastating flood hit Tulsa. The ensuing development of a flood-warning system for Tulsa led members of the Norman meteorological community to develop ideas for expansion of the Tulsa network to a statewide system.

Realizing the benefit to both universities, OU and OSU joined together and approached the governor's office with a proposal in 1988. At the direction of the governor, the proposal was redrafted to focus on energy-related benefits and submitted for funding from the Exxon Oil Overcharge Settlement Fund. The proposal was accepted in 1990, and $2 million was appropriated to develop the network. An additional $700,000 was contributed to the project by the two universities.

The project is expected to reach completion during the spring of 1993. The network consists of 108 automated weather stations. Each station transmits data every fifteen minutes to a nearby base station. Data are then relayed across the Oklahoma Law Enforcement Telecommunications System (OLETS) to a central computer at the Oklahoma Climatological Survey (OCS) in Norman. Once all data have been collected and quality assurance programs have been run, the data are made available to users via a computer bulletin board system. Additional direct lines transmit data to computers at OSU.

2. Site Standards

Before any sites could be located, a set of guidelines needed to be developed to be used in the selection process. A Site Standards Committee was developed, consisting of researchers familiar with data quality issues. The committee's report outlined guidelines to be followed both in the selection and setup of the instruments in order to maintain a consistency between sites.

The committee considered the diversity of interests shown in the Mesonet project. Guidelines relating to application of data for meteorological, agricultural, hydrologic and 'other uses' were considered. The guidelines set for agricultural sites were essentially identical to those for meteorological sites but differed significantly from guidelines for hydrologic applications. The meteorological/agricultural guidelines where adopted for the selection process.

The guidelines set for meteorological and agricultural purposes are as follows:

~~Location:~~ Rural sites should be selected in order to avoid anthropogenic factors present in urban and suburban sites.
~~Representativeness:~~ The physical characteristics of a site, including soil properties, should be representative of as large an area as possible. Sites should be as far away as possible from irrigated areas, lakes and forests to minimize their influence.
~~Topography:~~ The land surface should be as flat as possible and there should be a minimum of

obstructions that impede ventilation at the site. The WMO standard is no obstructions within 300 m. A rule of thumb based on non-porus shelterbelt experiments suggests that the distance between an obstruction to the wind and the anemometer should be at least 20 times the height of the obstruction.

~~Accessibility:~~ Each site should be accessible by vehicles in all weather.
~~Vegetation:~~ Sites should be selected that have a uniform low-cover vegetation. Sites that have short grass such as Bermuda grass are preferred. Vegetation density should be such that bare soil is not visible.
~~Hydrologic support:~~ The existing and planned location of stream stage measurements should be examined to see if strategically located Mesonet sites could provide useful data for watershed studies.
~~Oversight:~~ Weekly monitoring of sites is recommended. Sites should be selected such that they are within reasonable driving distance for interested local communities or agencies to monitor site integrity.

The site selection committee also set forth specific site standards relating to the layout of the site:

~~Wind speed and wind direction:~~ The WMO standard is 10 m above ground level with no obstructions within 300 m for anemometer and vane exposure. The slope of the terrain should be as horizontal as possible to minimize the Bernoulli effect. In any case, the slope should be less than 17 degrees to avoid separation of flow, producing large eddies. This can occur with flow over a steep hill. In the special case where evapotranspiration estimates are desired, the wind speed measurement should be at the height of the temperature and moisture sensors.
~~Shortwave and longwave radiation:~~ The site should be free of obstructions above the plane of the radiation sensing element. It is particularly important that no obstruction cast a shadow on a solar radiation sensor. To avoid having to consider aspect on surface radiation measurements, the slope of the terrain should be less than five degrees.
~~Temperature and relative humidity:~~ In order for these measurements to be compatible with existing cooperative observations and airport stations, temperature and relative humidity measurements should be made at the standard height of 1.5 m.
~~Pressure:~~ Pressure sensors in the field must be designed to minimize dynamic pressure, the excess pressure due to wind.
~~Precipitation:~~ The ideal site for a precipitation sensor is one where turbulence around the gage is minimized. Thus an open site is good for wind measurements but poor for precipitation measurements. Openings in a grove of trees, bushes or shrubbery provide the best exposures. There are a number of ways to reduce the "wind effect", including the use of a wind shield. According to WMO practice, the gage should be over level ground and surrounding objects should not be closer to the gage than a distance equal to four times their height.
~~Soil temperature and soil moisture:~~ Soil temperature and soil moisture measurements should be made in soil that is representative of the entire area. This should occur naturally if there is uniform slope. WMO standard depths for soil temperature measurements are 5, 10, 20, 50 and 100 cm. Soil surface temperature sensors must be carefully imbedded in the surface layer to avoid sunlight striking the sensor.

3. Site Selection

The site selection process encompassed (1) developing a list of potential site locations, (2) soliciting other agencies for input regarding their needs for environmental data in localized areas of the state, (3) seeking assistance on the local level for finding suitable sites, (4) contacting the individual landowners and (5) executing a land-use agreement.

A minimum of one site is located in each of Oklahoma's 77 counties, as prescribed in the contract which provided funding to the project. Approximate locations were identified for each of the 108 sites, beginning with the smallest counties. Larger counties often had 2-4 sites within their borders.

In the early stages of the project, consideration was given to locating sites near lakes or rivers to monitor hydrologic conditions. Included in this consideration was placement of sites to monitor stream stage, lake levels, ground-water levels, and surface and ground-water quality. It was found that satisfying hydrologic criteria would in many cases compromise criteria set for meteorological or agricultural uses.

For example, in order to monitor outflow from a reservoir, a site would have to be located immediately below the dam, which would pose an obstruction for accurate wind measurements. Monitoring lake levels or watersheds would require placement of sites adjacent to bodies of water, violating the recommendation for representativeness. It was also determined that monitoring ground-water level and quality was beyond the scope of the project.

Although sites were not selected which would satisfy many of the hydrologic criteria, Mesonet is working in cooperation with the Agricultural Research Service (ARS) to establish a network of 45 stations along the Little Washita River watershed in south-central Oklahoma.

The issue of 'other use' sites was not addressed by the site standards committee. In the course of the project, some sites were selected which fell into the 'other use' category and do not meet the established guidelines. Such sites are noted in technician files and documented with photographs of obstructions.

Attention was then turned to assessing regional interests. Primary emphasis was placed in locating sites at OSU Agricultural Experiment Stations, since this was part of the rationale for the project. A site at OU's North Campus was also selected. The Norman site is equipped with two instrument towers, one for operational use and the other to provide a comparison between laboratory-quality and field-quality sensors.

Input from other agencies was then taken into account to refine the remaining list of sites. Included among the agencies offering advice were the National Weather Service, Army Corps of Engineers and the Oklahoma Department of Agriculture Forestry Division. More than 150 sites were listed as possibilities. Additional consideration was given to municipal airports and cooperative weather observer locations.

The list was filtered down to the final set of 108 locations. Where more than one option for a site existed in a small area the request list was consolidated to include only one site. In a few cases sites were selected where none had been requested in order to fill gaps in coverage.

Another important consideration in site placement was ease of establishing communications. To minimize the number of repeaters needed in the network, preference was given to sites near OLETS facilities. Communication links are especially difficult in areas with sharp changes in terrain or regions where OLETS coverage does not reach. Knowing the height of the antenna at each OLETS facility allowed an estimation of the maximum distance from the facility at which a remote station could be located (see figure 1).

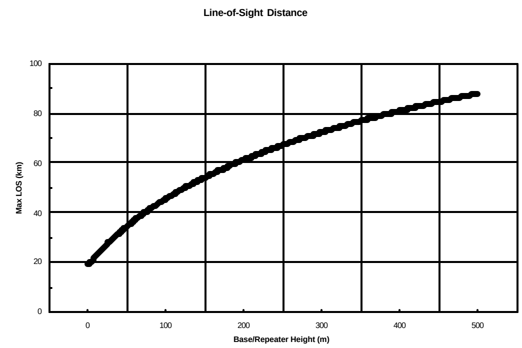

Figure 1. Maximum Line-of-Sight range over a smooth earth. One antenna is assumed to be at the remote station site at an elevation of 10 m while the other antenna is located at the base station or at a repeater site.

Contact at the local level was established primarily through statewide organizations operating through offices within each county. Among those contacted for assistance were the OSU Cooperative Extension Service (CES), the State of Oklahoma Conservation Commission / Soil Conservation Service (SCS) and county Civil Defense offices. Contact was established through attending area meetings of organizations or through direct requests for assistance to county offices.

County officials helped identify potential sites and approached individual landowners on behalf of Mesonet. Once one or more sites were offered, a visit was made to the region. In some cases an adequate site was immediately found. In most cases, however, multiple trips were necessary. Sometimes a local contact would be unclear of the guidelines, or in other cases a landowner of a prospective site hedged and decided to withdraw a site from consideration.

Following the recommendations of the site selection committee, it was found that rural grassland or rangeland was usually best suited to meeting the guidelines set forth. City and airport sites were an early consideration, but in order to be removed as much as possible from human interaction it was often necessary to place sites on privately-owned land. Care was also taken to place site in areas less prone to vandalism.

Additional emphasis was placed on locating sites in areas with little vertical variation in terrain. Not only was exposure a consideration here, but nighttime drainage winds and localized effects on winds were important considerations.

In a number of cases, no sites could be found that perfectly fit all guidelines. These were usually either attributable to (1) the nature of the terrain, (2) lack of enough sites offered, or (3) the necessity to locate on particular parcels of land. In virtually all cases sites were at least 100 meters away from any significant obstacles.

In the mountainous terrain of southern Oklahoma, hilltops were avoided in favor of wide valley locations, preferably within radio distance of a forestry tower which could serve as a repeater site. Valley sites also provide easier access for technicians, are more representative of mesoscale meteorological patterns and are more applicable to agricultural production areas.

Once a suitable site was found, the final step was executing a land-use agreement. This agreement sets limits of liability and establishes an indefinite termination date for a site as ninety days written notice. Developing a standard land-use agreement proved challenging. Many legal hurdles needed to be cleared, including questions as to who had the authority to sign the agreement. Even more challenging were situations where a landowner wanted a change to the standard agreement. Any changes were reviewed by legal counsel and several agreements were rejected because of liability issues.

Table 1 shows the breakdown of selected sites. Research sites include the 17 OSU Agricultural Experiment Stations and other OU or OSU Research Stations. Federal lands included two wildlife refuges and one historical landmark. The private sites are primarily owned by ranchers or farmers.

Table 1. Breakdown of Mesonet sites by type of ownership.

Research Sites	21
Academic Institutions	6
Federal/State Land	12
City-Owned Land	13
Foundations/Non-Profit	4
Private Ownership	52

4. Site Layout

A diagram of the site layout is given in figure 2. Following the committee's guidelines, the layout was designed to optimize instrument exposure and to maintain compatibility with other networks. Locations of sensors are based on the recommendations of the Site Selection Committee. WMO guidelines are followed where possible.

The instrument tower is made of galvanized steel and stands ten meters in height. It is assembled from four sections. A metal base plate is used to stabilize the tower and rests on the ground. Three guy-wires are used as additional support for the tower.

The tower stands nearly in the center of a 10-meter by 10-meter enclosure. A cattle panel fence, 1.3 m high, is used to secure the area from animals and inadvertent human intervention, including people walking

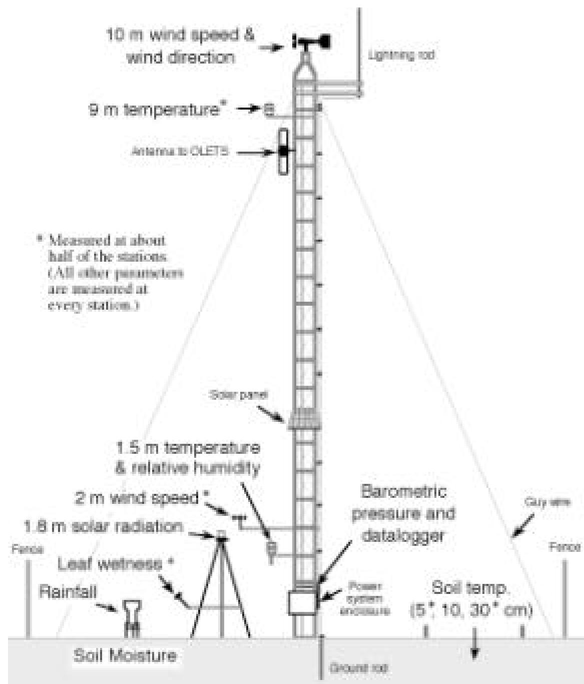

Figure 2. Schematic of instruments site layout (a) side view and (b) top view.

across the soil plot or clipping wires with farming equipment or mowers.

The rain gauge, pyranometer and soil plot are situated separately from the tower; all other instruments are located on the tower. The sensors are connected to a Campbell CR-10T datalogger, which collects and stores up to 7 days of data. Power to the site is supplied from a solar panel and battery, which allows for placement of sites far from AC power sources. A radio transmitter is installed with the datalogger, with an antenna mounted near the top of the tower.

The site is protected from lightning strikes by an eight foot grounding rod. On one quarter of the sites a lightning rod is installed. Since not much current is required to cause damage to sensors, lightning rods may do little to protect the equipment. Therefore, only a subset of sites were chosen to test the effectiveness of lightning rods in evading damage to sensors.

5. Parameters

A description of parameters measured by Mesonet is given in table 2. Parameters are broken into two categories, 'core' and 'supplemental'.

The data logger reads *wind speed and direction* from the propeller vane and produces five outputs each averaging period (five minutes): wind run, the average of the scalar wind speed; the vector average of the speed and

[INSERT FIGURE OF TOP VIEW]

Table 2. Parameters measured by Mesonet stations. Core parameters are measured at all sites. Supplemental parameters are measured only at specially selected sites. The number of sites recording supplemental parameters are indicated in brackets.

Parameter	Sensor	Model	Height
Core Parameters (all stations)			
Wind Speed/Direction	Propeller-Vane	R.M. Young 5103	10 m
Air Temperature & RH	Thermistor & Sorption Sensor	Vaisala HMP35C	1.5 m
	Radiation Shield	R.M. Young 41002	1.5 m
Barometric Pressure	Barometer	Vaisala PTB202	0.75 m
Rain	Rain gauge, tipping bucket	Metone 099M	0.6 m
	Wind Screen	None	0.6 m
Solar Radiation	Pyranometer	Licor 200	1.8 m
Soil Temperature (2)	Thermistors	Fenwal	10 cm
Supplemental Parameters [number of sites]			
Air Temperature [50]	Thermistor	Thermometrics	9 m
Wind Speed [50]	Cup Anemometer	R.M. Young 3101	2 m
Leaf Wetness [60]	Electrical Impedance Grid	None	0.3 m
Soil Temperature, bare [67]	Thermistors	Fenwal	5 cm
Soil Temperature, sod [43]	Thermistors	Fenwal	5 cm
Soil Temperature, sod [45]	Thermistors	Fenwal	30 cm

direction; wind direction standard deviation; and the maximum scalar wind speed within the averaging period. The maximum wind speed is the highest instantaneous speed measured at 2.5 second intervals.

Temperature and *relative humidity* are averaged over five minute intervals. Humidity was selected as a core parameter rather than dew point in order to reduce maintenance requirements. Since these sites are designed to be remote, it is difficult to maintain a water supply for hygrometers.

Barometric Pressure is averaged over five minute intervals.

Rainfall is measured using a tipping-bucket raingauge. The datalogger records the number of tips during a five minute period and converts to a five minute rainfall total. The gauge is mounted less than one meter above ground level. It is surrounded by a wind screen, designed to minimize turbulence around the gauge.

Solar radiation was selected as a core parameter to provide some unique opportunities for radiation studies with both meteorological and agricultural applications. It is also reported as a five minute average. The pyranometer is mounted on a tripod clear of the tower to avoid obstructions above the plane of the radiation sensing element and reflections from the tower. It is also mounted to the south to avoid shadows. Net radiation was not selected as a parameter due to difficulty in maintaining sensors.

Soil temperature measurements are made under both exposed soil and grass cover. Bare soil measurements are included to be more indicative of conditions in plowed fields, whereas a year-round cover is more indicative of grasslands and cover for other types of crops. Reported soil temperatures are five minute averages.

A sizeable subset of Mesonet sites will have additional parameters being measured: 9-m air temperature, 2-m wind speed, leaf wetness, 5-cm soil temperature under bare cover and grass cover and 30-cm soil temperature under grass. These parameters were largely chosen based on their usefulness to the agricultural community, as well as urban landowners.

Air temperature at 9 m, in conjunction with the 1.5 m temperature, is useful for surface stability/turbulence estimates, which are important to such agricultural practices as aerial and surface application of pesticides, prescribed burns of rangeland or forest understory, and frost protection measures.

Wind speed at 2 m is important for estimation of evapotranspiration, which is used in irrigation scheduling, pesticide application and prescribed burns.

Leaf wetness, although a relatively unknown parameter, appears to have potential in the development of models for plant disease protection. An electrical impedance grid is used to sense moisture across a surface representative of a leaf.

Soil temperature at 5 cm is needed for planting decisions and conditions for seed germination, as most crops are planted at this level or above. in Oklahoma the most common farming practice is clean cultivation, therefore more sites measure this parameter under bare soil cover than grass cover. Soil temperature under grass cover is useful for the turfgrass industry as well as monitoring conditions for some soil-borne diseases.

Soil temperature at 30 cm under grass cover is useful for monitoring the soil temperatures in the root zones of deeply rooted crops and brush, as well as for herbicide effectiveness in getting rid of the latter where it is not desired.

Sites for supplemental parameters were chosen to maximize the benefit to agriculture. Care was taken to make sure agriculturally sensitive areas were covered with a sufficient density of sites. Where possible, sites received the complete set of supplemental parameters, including all of the OSU ag/forestry experiment stations. This created more complete datasets which can be especially useful to crop modeling. Remaining supplemental sensors were distributed to provide adequate geographical coverage.

6. Conclusions

The site selection process began in early 1991 and was not completed until mid-1992. The early stages of the process involved establishing the Site Selection Committee, identifying personnel to be involved with the selection process and purchasing equipment necessary to begin the surveys. Included among equipment purchases were 4-wheel drive vehicles and a GPS (Global Positioning System) navigational aid.

The active phase of the site selection process began in mid-1991 with the survey of OSU Agricultural Experiment Stations. What was learned from these first surveys helped in evaluating other offered sites later. The identification of remaining sites began in late 1991 and lasted for approximately 9 months. Over 20,000 miles were driven to identify all sites.

Early preparation was critical in avoiding delays during the project. The enthusiasm shown by county agencies, private organizations and individuals was greatly underestimated. Sites were offered to Mesonet as early as May 1991, but in some cases it was more than a year before a visit to an offered site could be made. Some of the delays were attributable to paperwork, including arranging purchase of vehicles and developing a prototype land-use agreement to be used for privately-owned sites.

In a few cases, what was seen as a slow response time by Mesonet raised doubts about Mesonet's capability to deliver. Rather than acting too quickly, it was important to proceed deliberately to assure that a detailed set of criteria were developed for the site locations and layout and that these guidelines were followed as closely as possible. As more of the sites begin collecting and transmitting data, Mesonet is rapidly becoming a reality.

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