AN OVERVIEW OF THE KENTUCKY MESONET

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1. Introduction

Weather and climate are fundamental to the health, safety, and welfare of residents and communities throughout Kentucky. Extreme and severe weather pose threats of tornadoes, hail, ice storms, floods, droughts, and other natural disasters. The availability of continuously updated, locally accurate environmental data across the state is vital to decision makers who must be prepared to respond to changing conditions.

To serve this need, the Kentucky Climate Center (KCC) at Western Kentucky University (WKU) was the recipient of an earmark in the Federal FY'06 budget to begin development of a statewide environmental monitoring network known as the Kentucky Mesonet (referred to henceforth as "Mesonet"). In January 2006, a kickoff meeting at WKU was held, bringing together representatives from the National Oceanic and Atmospheric Administration (NOAA), National Weather Service (NWS), and the WKU Administration to announce the Mesonet project and form partnerships. Following extensive dialogue, the KCC developed and submitted a project funding proposal. The proposal outlined a 2-year project based on the expectation of a 2nd earmark in FY'07 for an additional $1.5M. The project start date was August 1, 2006.

The Kentucky Climate Center working in partnership with the Kentucky Council of Area Development Districts (ADDs) began conducting Mesonet kickoff meetings around the state. Starting in June 2006, designated ADD representatives began inviting potential stakeholders (including elected officials, emergency managers and other first responders, school officials, and others) to meetings to begin a dialogue about the benefits of the Mesonet and garner support among communities. These meetings have been instrumental in securing support for the Mesonet around the Commonwealth and have yielded a number of successful partnerships resulting in site installations.

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Figure 1: *Kentucky Mesonet station at the WKU Farm.*

In September and October 2006, the first Mesonet staff hires were made. Two Meteorology/Electronics Technicians and one Systems Architect/Administrator were hired with the initial task of determine the infrastructure necessary for such an endeavor. An office assistant was soon hired along with five students who would survey sites, provide Geographical Information Systems (GIS) support, and lead outreach efforts. In the summer of 2007, an Application Developer and Quality/Assurance Specialist joined the project to round out the staff.

While being housed at Western Kentucky University in conjunction with the Kentucky Climate Center, the Kentucky Mesonet is a statewide venture. To this end, the Kentucky Mesonet Consortium has been formed and includes the eight public universities of Kentucky (Eastern Kentucky University, Kentucky State University, Morehead State University, Murray State University, Northern Kentucky University, University of Kentucky, University of Louisville, and Western Kentucky University). The consortium members are expected to collaborate on research, education, and outreach issues and have open access to all Mesonet data. The strengths of the diverse educational institutions in Kentucky are a great asset to the Mesonet.

Initial proof-of-concept installation of three Mesonet sites was funded by WKU. The first Mesonet site began collecting data from the WKU Farm property (Figure 1) on 9 May, 2007 and was soon followed that summer by sites in Russellville and Morehead. An official website went live in January of 2008 and provides access to near real-time data and historical information.

As of August 2008, 10 stations have been installed across Kentucky with licensing agreements in place for 11 more. Site installations are aggressively scheduled in the summer months as winter precipitation and temperatures complicate outdoor work. The ultimate goal is to install close to 100 stations around the state, measuring 7 basic meteorological variables and as many as 23 derived and supporting variables. More than just a weather measuring network, the Kentucky Mesonet is building a flexible and expandable infrastructure for environmental monitoring, prepared to serve the needs of Kentucky in a changing world.

This paper will outline the important components of the Kentucky Mesonet and offer lessons learned in development. Much of the work in Kentucky has followed the work done on previous observing networks such as the Oklahoma Mesonet, the West Texas Mesonet, the U.S. Historical Climatology Network (USHCN), and NOAA's Environmental Real-Time Observation Network (NERON). Where possible, attempts were made to avoid overlap with previous network documentation including Brock et al. 1995, Schroeder et al. 2005, and McPherson et al. 2007.

2. Stations

a. Site Surveys

The first step in establishing a Mesonet site is to rate the location's suitability for meteorological measurements. A "site survey" is completed for each candidate Mesonet site based on World Meteorological Organization (WMO) standards (World Meteorological Organization, 2006). Sites should be representative of the local climate and exhibit a strong cellular signal for reliable transmission of observations. These standards closely follow those of the Oklahoma Mesonet and NERON. Emergency managers, NWS personnel, local officials, and the general public are encouraged to submit candidate site suggestions. General station siting concerns described by Brock et al. (1995) mostly apply and will not be covered here to avoid redundancy.

The majority of site surveys to date have been completed by student employees. After completing a training program, this gives graduate and undergraduate students a chance to perform a critical role for the Mesonet. As of August 2008, 87 site surveys have been completed with 68 scoring in the top two categories (out of five). The high number of acceptable sites is due in part to poor sites being discarded before a survey is ever completed based on a screening using a geographic information system. All site surveys are available in a password protected secure section of the Mesonet database.

The Appalachian region of eastern Kentucky has proved an especially difficult region to develop for the Mesonet. The main challenge is finding any plot of land not on a steep slope. Valley locations are either a floodplain or already built-up. Moreover, installing a station in a valley or on a mountain-top will result in unrepresentative measurements for locations not geographically similar, while sloping terrain will compromise the value of wind and other meteorological measurements. However, as all locations in many eastern Kentucky counties are either in a valley, on a mountain-top, or on a slope, it can be argued that a site representative of the weather in these counties could be located in any of these locations, as there is no weather in this region not heavily influenced by the terrain.

Of course, site score is not the only factor that decides where a Mesonet site will be located. Obtaining a site license agreement is necessary for each site and often is the most time consuming part of the process. Negotiations are often a complex issue involving multiple parties, sometimes slowing progress, but ensuring Mesonet stations have a home far into the future. It also enables the Mesonet to reach-out communities through local officials who often lead the effort to find a suitable site. The Mesonet attempts to serve diverse users across the entirety of Kentucky. It is of ultimate importance to balance the needs of all our users when choosing site locations. For example, school children can have a rewarding experience with a Mesonet station located on school grounds, as some stations are. However, agricultural customers may prefer a more rural station with more representative soil composition. It is our belief that once the network is fully implemented, there will be enough stations in every region to fully serve any customer's needs.

b. Site Design and Setup

Following site diagrams from NERON and consultation with USHCN, meteorology/electronics technicians sketched the site layout soon after their hire in September 2006. The only parameter considered inflexible in the design was the footprint, which must fit within a 160 ft perimeter fence (fence dimensions of 38x42 ft were chosen). While the design was mostly independent, it contains many similarities to other Mesonet and meteorological site designs. As of August 2008, there are two general site layouts, depending on the power source. Solar powered sites (Figure 2) are all identical; A/C powered sites differ slightly depending on where the utility feed is provided. Main considerations for site design were ensuring the tower shadow does not affect radiation and temperature measurement, the wind monitor is clear from obstruction, instruments are easy to reach and service, and the solar panels are positioned for maximum sun exposure. Uniform site design and implementation is crucial for data quality and measurement consistency.

Training for Mesonet technicians has been provided by Campbell Scientific Instruments (CampbellSci) and NOAA's Atmospheric Turbulence and Dispersion Division (ATDD). A four-day workshop at CampbellSci in Logan, Utah prepared the technicians to work with the integrated system of dataloggers, sensors, and software while visits to ATDD's facility in Oak Ridge, Tennessee have been invaluable for calibration training and research into site design and installation. Collaboration

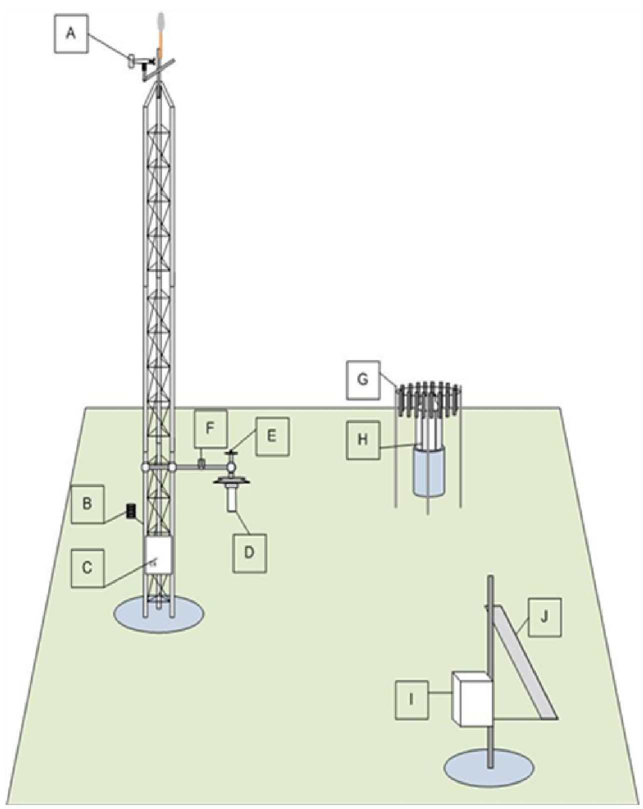

Figure 2: *Kentucky Mesonet site schematic*

with both organizations reduced technical challenges associated with building the Mesonet.

Site installation is a 2-step process. The first step involves preparing the site foundation, including digging holes, setting the tower and pedestal foundations, and pouring concrete. The second step involves instrument installation. Both steps normally take two days each. Labor is done by hand except in situations where equipment can be provided by the land owner/manager. The concrete curing process limits the speed with which a station can be constructed. Soil types vary greatly across Kentucky, necessitating the use of concrete to ensure stations are stable and durable. Many areas in the Commonwealth have a shallow fragipan of dense clay, which impedes progress in excavation.

3. Instrumentation

The choice of instrumentation and its deployment at Mesonet stations is designed to be broadly compatible with other weather and climate observing platforms within NOAA, including the NERON, the modernized U.S. Historical Climatology Network (USHCN), and USCRN. At the same time, we are committed to developing a scalable infrastructure to meet future needs and opportunities that may arise specific to the Kentucky Mesonet. Mesonet sites will include redundant temperature sensors housed in an aspirated shield with dual fans and an all-weather weighing bucket precipitation gauge enclosed by an alter shield. Mesonet sites will also be equipped to monitor solar radiation, relative humidity, and wind speed and direction. Soil moisture and temperature will be monitored at a majority of sites. The datalogger deployed at Mesonet sites has excess capacity to accommodate additional sensors. A list of instrumentation to be deployed at Mesonet sites is provided in Table 1. Soil moisture and temperature probes will be added in a later phase.

While most instruments have worked flawlessly for the project, the Vaisala VRG101 has provided technicians and quality assurance specialists with many challenges. One issue occurred in the first winter of deployment when condensation and pooled rainwater froze on the metal weighing pan, altering the orientation of the bucket. Any time the bucket orientation is disturbed, it becomes unbalanced and can hit the funnel of the outer shell, causing false precipitation to be reported to the datalogger. These weighing bucket rain gauges are a new design and the Mesonet was one of the first large-scale deployments. In a close collaboration with the Mesonet quality assurance and control specialist and meteorology/electronics technicians, Vaisala issued a comprehensive retrofit addressing the problems. New and improved gauges as well as retrofit gauges are expected to be installed this summer and fall and will be monitored this winter to assess the effectiveness of the changes. We look forward to further collaboration with Vaisala and other manufacturers as our network provides a four-season proving ground for instrumentation. Internal tests of instruments are on-going to improve accuracy, reduce power consumption, improve reliability, and to better understand the meaning behind the data collected, which will yield benefits to the users in the quality assurance and control process. Results of these tests will be published and be available for community use.

Further details about the instrumentation used in the project will be discussed in presentation 2.1 at this conference, "Data collection and quality assurance of the Kentucky Mesonet."

4. Information Technology

Mesonet technology infrastructure is beyond the scope of this paper and will only briefly be touched upon here. A more detailed technology discussion will be presented later this year. Figure 3 shows the basic dataflow of the Mesonet system. Data from the sites flows through the cellular network to a custom AT&T Access Point Name (APN) that communicates with the Mesonet data ingest server running Campbell Scientific's Loggernet software. The Mesonet's IT hardware is housed in a network operations center located in Bowling Green, Kentucky.

c. Communications

A vital part of the Mesonet is the ability to transmit data in near real time from locations scattered across the state. Data is transmitted every 15 minutes from every site, creating a large number of connections to the Mesonet servers. This creates a need for an extensive and reliable communications network. Also desirable was the ability for 2-way communication with a site for remote

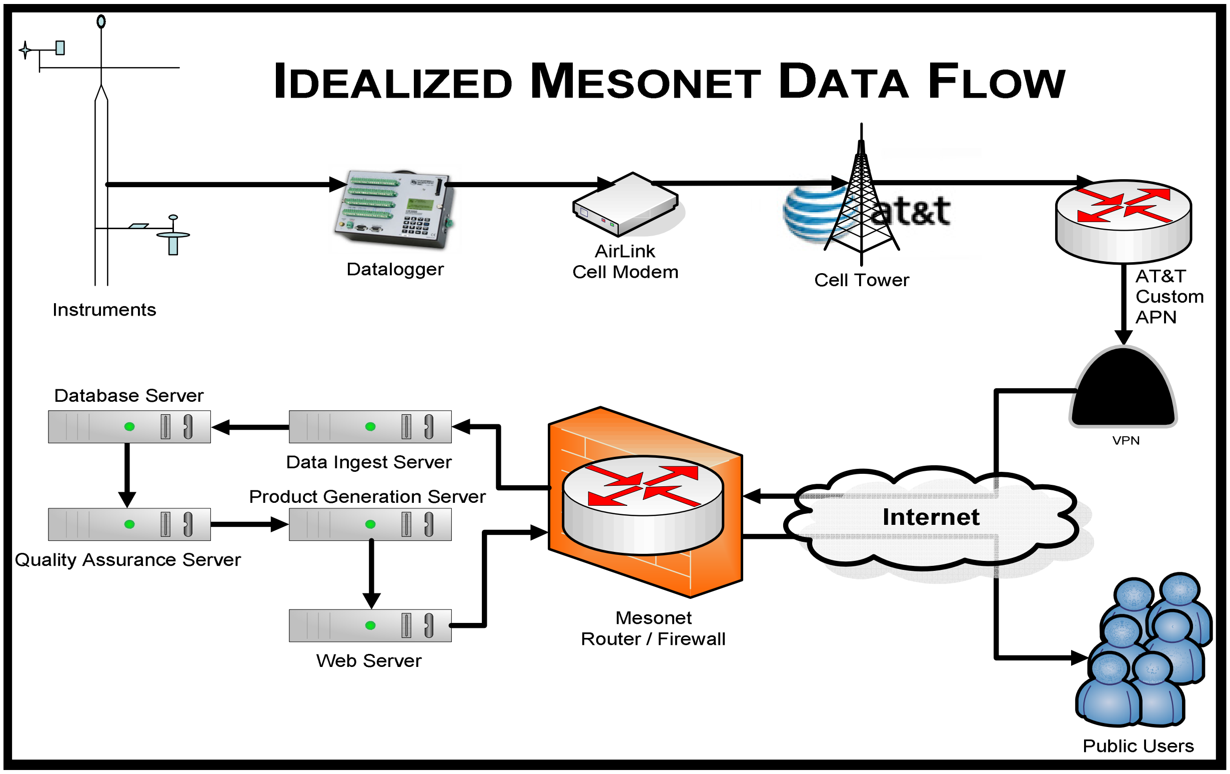

Figure 3: *Idealized data flow schematic for the Kentucky Mesonet. Note that not all servers and not every link in the communications process is represented.*

troubleshooting and datalogger programming. A decision was made to utilize the existing cellular network to provide communications for the Mesonet. This allows the Mesonet to use widely available off-the-shelf cellular modems and do minimal communications network development on our own. This has advantages and disadvantages. The advantage is that the network is well established across the state. We chose AT&T (formerly Cingular) as our provider as coverage is good in most of the state including rural areas. However, this leaves maintenance and development of the communications network up to professionals at AT&T and out of the Mesonet's hands. This is the main disadvantage to this arrangement. While cellular coverage and network reliability is good, it is not perfect, and when network access is below the promised level, it is entirely out of the Mesonet's control.

d. Database

Both meteorological data (i.e. observations) and metadata are stored and linked in a relational database system. This is a mostly unique approach among weather sensing networks. Many relational databases exist, but due to legacy reasons, most networks do not have linked data and metadata systems using a relational database. Since the Kentucky Mesonet does not have legacy concerns, the most current technology was chosen for the storage solution. Relational databases allow the Mesonet to efficiently store, retrieve, report, and assess data for internal monitoring and delivery to the user. This setup is an asset to development of quality assurance methods and allows the Mesonet to package data and metadata in numerous formats for the user. In the database system, each collected data point is linked to extensive documentation including current states of calibration, operation, and quality along with the history of instruments, sites, and networks involved in the collection of this data.

The Kentucky Mesonet database system is currently transitioning from an experimental development mode to an operational status. Work continues to add features and efficiency while data is served to the website and Mesonet employees use the system in an experimental mode.

5. Future Initiatives

Parallel to work on the infrastructure of the Mesonet is work on many initiatives

Function	Manufacturer	Model
Datalogger	Campbell Scientific Instruments	CR-3000 Micrologger
Modem	Airlink	Raven EDGE E3214
Air Temperature	Met One Instruments	Radiation Shield 076B
	Thermometrics	PRT R032
Precipitation	Vaisala	VRG101
Leaf Wetness	Vaisala	DRD118
Relative Humidity	Vaisala	HMP45C
Solar Radiation	Apogee Instruments	Precision PYR-P
Wind Speed and Direction	R. M. Young	Wind Monitor 05103-5

Table 1: *Instruments used by the Kentucky Mesone*t

designed to better serve residents of Kentucky. Results of collaborative work to develop an education portal to our website will be available this fall. Lesson plans, datasets, and tools will be provided to educators in the K-12 system to bring real-time and historical Mesonet data into the classroom. At the undergraduate level, students at Western Kentucky University (WKU) have used Mesonet data in a number of meteorology and geography classes. In the spring of 2008, two undergraduate students presented a poster at the WKU Student Research Conference that used Mesonet observations to understand the dynamics of a squall line severe wind event. This fall semester promises to integrate the Mesonet and the fledgling WKU Meteorology degree program even further.

While NWS personnel in Kentucky can already load a real-time data-stream of Mesonet observations in AWIPS, further work is being done to improve accessibility to emergency managers and users across the state. The kymesonet.org webpage currently provides the primary outlet for data and features are added on a routine basis. Near real-time data is available on the homepage with monthly summaries providing historical data. An automated data retrieval system will be available for consortium members and data access policies are under development for non-consortium users.

Also under development are display systems for Mesonet data. A sufficient number of stations will soon be online for maps to be generated using only Mesonet data. Future work may take advantage of GIS-based mapping solution.

Soil moisture and temperature sensors are planned for installation at a number of sites in the near future. These probes will provide valuable data for agricultural and hydrometeorological/hydrolclimatological interests around the state, and will be especially useful in extreme situations, such as the 2007 drought.

In summary, it could be argued that the Kentucky Mesonet has succeeded in building the infrastructure to support a high resolution environmental observing network.

6. References

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