

THE KENTUCKY MESONET: PERSPECTIVES ON DATA ACCESS, DISTRIBUTION, AND USE FOR A MESOSCALE SURFACE NETWORK

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1. INTRODUCTION

The Kentucky Mesonet is a high density, mesoscale network of automated meteorological and climatological sensing stations being deployed across the commonwealth. Established as the official source of climatological observations through joint resolution by the state legislature, the network is directed by the state climatologist at the Kentucky Climate Center (KCC), Western Kentucky University (WKU). It is operated in partnership with seven other higher education institutions – Eastern Kentucky University, Kentucky State University, Morehead State University, Murray State University, Northern Kentucky University, the University of Kentucky, and the University of Louisville – who, together with WKU, compose the Kentucky Mesonet Consortium. Funding for network construction and initial operation were provided via federal earmarks and direct grants from the National Oceanic and Atmospheric Administration (NOAA), and the network operates in close consultation with NOAA's National Weather Service (NWS). A typical network site is shown in Figure 1 below. (Mahmood and Foster 2008).



Figure 1. Kentucky Mesonet site "LSML", 7 miles south of Frankfort, KY in Franklin County.

Instruments at network sites routinely measure precipitation, air temperature (1.5 m), relative humidity, solar radiation, wind speed & direction (10 m), and wetness (precip. indicator). Data are recorded by network sites every 5 min and are transmitted to KCC at least once every 15 min. During periods of severe weather or other hazards data are retrieved every 5 min. Initial deployment and testing of soil moisture and temperature sensors at select sites should begin in the spring.

After establishing its first site just south of Bowling Green in May, 2007, the Mesonet has grown quickly over the last 2.5 yr. Figure 2 shows installation progression from Jan., 2008 through Jan., 2010.

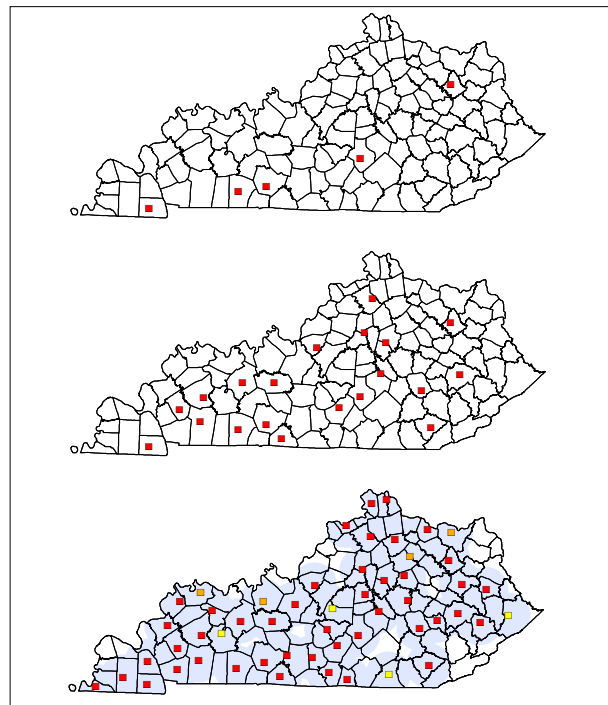


Figure 2. Mesonet locations (red) as of January 2008 (top), 2009 (center), and 2010 (bottom). Bottom includes sites under construction (orange), sites with a use agreement (yellow), & a 20 mi buffer radius (blue).

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Figure 3 shows that 2009 was the busiest year so far in terms of site installation, with 25 sites installed. Fifteen were installed in 2008 and five came on-line in 2007 for a total of 45 sites. Approximately 100 total sites are planned for the network, 65 of which should be operating by the end of summer.

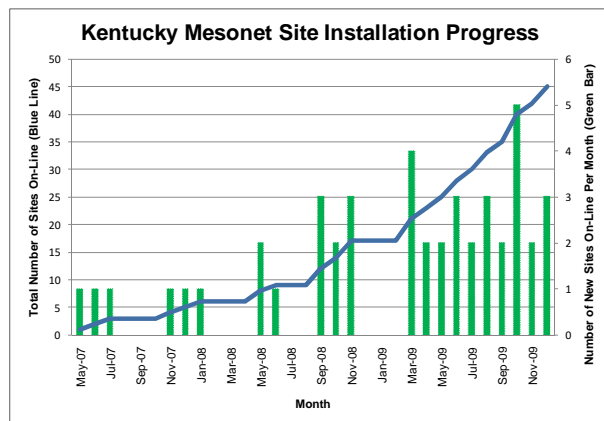


Figure 3. Mesonet site installation progress. Blue line indicates total number of sites on-line. Green bars indicate number of sites installed per month.

Certainly the Kentucky Mesonet is not the first of its kind. In fact, the best practices of other networks have been strongly considered in the design and operation of Kentucky's network. However, having made recent and significant accomplishments in mesoscale network development, the KCC offers here an additional perspective on the building of a statewide or regional network. A brief review of the network's computing and communications infrastructure is provided, as this paper is being presented as part of the 26th Conference on Interactive Information and Processing Systems. Having been submitted in the context of issues facing an emerging nationwide network of networks (NRC 2009), challenges of data access, distribution, and use are also examined, both in terms of how the Kentucky Mesonet has overcome them and also in terms of how such a national network must protect the local goodwill cultivated by individual networks.

2. NETWORK DESIGN & INFRASTRUCTURE

With instrumentation choices and siting criteria examined more thoroughly in companion presentations at the 90th annual AMS conference (Struebig et al., 2010; Thompson et al. 2010), this section focuses primarily on the design and configuration of the computing and communications infrastructure to support the network. However, a depiction of the typical layout for a solar-powered Kentucky Mesonet site is provided

in Figure 4. AC-powered sites have a slightly different configuration based in large part on the path of underground power trenches. Additionally, sites that are potentially more publicly accessible than others include a security fence.

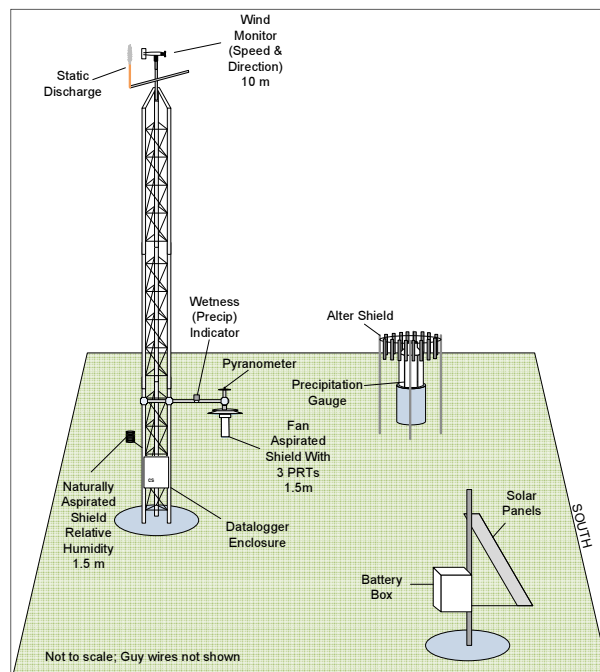


Figure 4. Typical layout for a solar-powered Kentucky Mesonet site (Struebig et al. 2010).

2.1 Standards- and best practices-based

Existing standards and best practices have been followed throughout the development of the Kentucky Mesonet, including in the design and operation of the supporting computing and communications infrastructure. Though a complete detailing of the numerous resources used in constructing Kentucky's network is beyond the scope of this conference paper, a few examples are reviewed below.

The National Research Council (1999) Panel of Climate Observing Systems Status noted that climate researchers often rely upon existing, operational networks for data but that confidence in research results can be severely limited by deficiencies in accuracy, quality, and continuity of network records. Therefore, it adopted ten climate monitoring principles that should be applied to climate monitoring systems. Five of these principles – metadata, data quality and continuity, continuity of purpose, data/metadata access, and climate monitoring requirements – directly impact network computing infrastructure and have been strongly considered.

The *Guide to Meteorological Instruments and Methods of Observation* from the World Meteorological Organization (WMO 2006) provides a wealth of guidance toward the operation of automated weather stations, including details related to their supporting information systems such as general design, data collection, metadata, and quality assurance/control. Modes, methods, and technology for data communications and transmission are also examined.

Karl et al. (1993) examined the requirements for databases derived from long-term measurements that can be used to document and help understand historical and ongoing climate variations and change. Since they are not a requirement for station functionality, Karl et al. (1993) notes station histories are often ignored by some networks, but holds that continuous documentation about station location, types of instruments used, their exposure and elevations above ground, information about local surroundings, observing schedules, and maintenance procedures are critical.

Realizing obstacles such as lack of funding or other resources constrain the ability of a sensing network to immediately implement all desired technology, Trenberth et al. (2002) offers some of the most practical guidance in network design, laying out the following sequential priorities, from highest to lowest: (i) data collection and archiving; (ii) distribution of raw data in near-real time; (iii) quality control of the data in delayed mode and archiving of datasets; (iv) development and maintenance of data access tools (e.g., web sites); and (v) follow-on processing to produce analyses and reanalyses. Trenberth et al. (2002) also maintains that a real-time quality control system should be implemented to guard or warn against biases, errors, or missing data, advancing the idea that the absence of a commitment to reliability ultimately leads to a network incapable of delivering quality data.

In addition to the resources detailed above, the experiences of existing, quality in situ surface network operators and aggregators have been invaluable in the design of the Kentucky Mesonet and its attendant information technology infrastructure. The well-established best practices of the Oklahoma Mesonet, the U.S. Climate Reference Network, the West Texas Mesonet, the Delaware Environmental Observing System, and others have been closely considered, as have the data handling operations of MesoWest and MADIS (Brock et al. 1995; Hubbard et al. 2005; Legates et al. 2005; McGuirk and May 2003; McPherson et al. 2007; Miller et al. 2007; Schroeder et al. 2005; Splitt et al. 2002; and numerous personal conversations).

2.2 Computing and communications

Though intended to be a dual-use network capable of supporting longer-term climatological research, the Kentucky Mesonet's computing and communications infrastructure has been largely designed around the need to support local meteorological observations in critical situations. Therefore, all aspects of the network's computing and communications technology have been, within budgetary constraints, architected to perform on a mission-critical basis. Mesonet computing systems are housed in an enterprise-class datacenter which also supports the continuous operation of critical municipal technology and which maintains connections to multiple, major internet backbone service providers. Physical computing assets are covered by critical maintenance plans with 4 hr response times and most software and operating system resources are covered by enterprise-level support services. Additionally, the Kentucky Mesonet is designated as a public safety entity by its site communications provider. Figure 5 provides a somewhat simplified but overall on-target depiction of the network's computing and communications infrastructure.

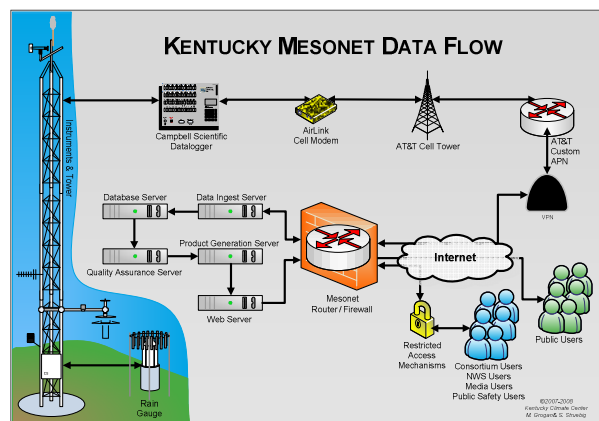


Figure 5. General depiction of Kentucky Mesonet computing and communications infrastructure.

2.2.1 Individual systems description

The Kentucky Mesonet relies on a number of systems in fulfilling its mission for the citizens of the commonwealth. Of course the face of the network for many of those citizens is the public web site available at <http://www.kymesonet.org>. Screenshots from that site are provided in Figure 6.

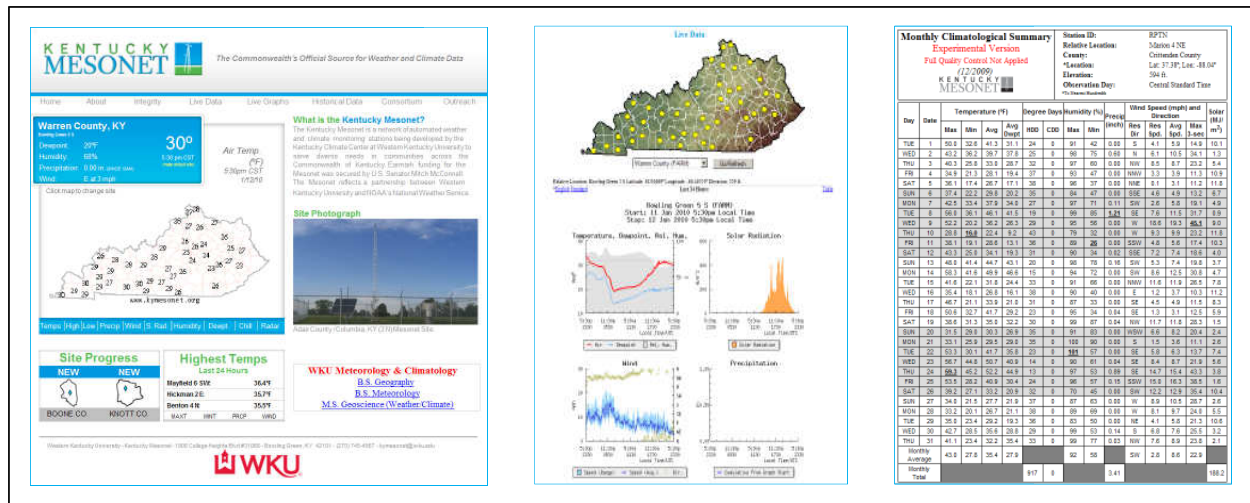


Figure 6. Screenshots from the Kentucky Mesonet website, which provides the primary means for direct, public data access.

Behind the scenes, of course, are a number of additional systems responsible for ingesting, processing, storing, and distributing network data both via the official website and other means. Data ingest systems, running both Campbell Scientific's Loggernet for Linux software and custom code, perform initial collection of data from network sites and populate tables in a relational database. Project developed automation code, along with external resources such as Unidata's GEMPAK application, are used to create some pre-generated website graphics as well as some data "snapshots" distributed to external partners. The majority of data displays and distributable datasets, however, are created on-the-fly, supported by high speed database queries and well indexed data tables. An intelligent caching system is used for the creation of daily weather graphs such as the ones in Figure 6; graphs for each site are created only upon the first request, then re-served upon subsequent requests for the same site and time period.

An automated quality assurance system, which contains multi-threading-capable code for intelligently and quickly performing numerous simultaneous data checks, has been developed and is currently undergoing operational testing before being fully integrated into the network data flow. However, before full incorporation of the system occurs likely in Q1 of this year, results of the system's algorithms are already available to the network's quality assurance specialists for use in their review processes. For instance, Table 1 shows WARNING flags for all data at the network's "LSML" site at 1930 UTC 6 January 2010. At that point, the site's datalogger enclosure had been opened to indicate the presence of Mesonet personnel who were giving a site tour.

Table 1. Sample results from the Kentucky Mesonet automated quality assurance system.

STID	UTME	Variable	Algorithm	Flag	Reason
LSML	1/6/2010 19:30	RELH	DoorCheck	WARNING	DOOR open
LSML	1/6/2010 19:30	WDSD	DoorCheck	WARNING	DOOR open
LSML	1/6/2010 19:30	WDIR	DoorCheck	WARNING	DOOR open
LSML	1/6/2010 19:30	TA02	DoorCheck	WARNING	DOOR open
LSML	1/6/2010 19:30	WSMN	DoorCheck	WARNING	DOOR open
LSML	1/6/2010 19:30	THMP	DoorCheck	WARNING	DOOR open
LSML	1/6/2010 19:30	SRAD	DoorCheck	WARNING	DOOR open
LSML	1/6/2010 19:30	WSMX	DoorCheck	WARNING	DOOR open
LSML	1/6/2010 19:30	TA03	DoorCheck	WARNING	DOOR open
LSML	1/6/2010 19:30	WSSD	DoorCheck	WARNING	DOOR open
LSML	1/6/2010 19:30	WSPD	DoorCheck	WARNING	DOOR open
LSML	1/6/2010 19:30	PRCP	DoorCheck	WARNING	DOOR open
LSML	1/6/2010 19:30	TA01	DoorCheck	WARNING	DOOR open
LSML	1/6/2010 19:30	WDMX	DoorCheck	WARNING	DOOR open

In addition to the systems responsible for network data flow, a number of other systems have been developed to help maintain network integrity. A metadata database helps track site and instrumentation changes while a version-control system helps track every modification to network code – both that used in centralized computing operations and on dataloggers in the field.

A site survey database is used to collect and store information about candidate network sites, including data related to site suitability such as nearby obstructions and any availability of nearby electrical service. The system is also used to maintain photographs of candidate sites.

Finally, both internal and external monitoring services are used to continuously check the status and availability of individual network sites, systems, data, and products. Mesonet personnel are immediately notified via e-mail and text message should problems arise.

2.2.2 Site communications

Communications with remote sites is facilitated through the use of wireless/cellular data connections contracted through AT&T Mobility. Though this method has not been short of its own headaches, cellular-based communications were chosen early in the project to avoid the hassle of developing a communications system from scratch. Figure 7 shows that AT&T was the logical choice of cellular providers, as their system's licenses covered the entire state by 2008.

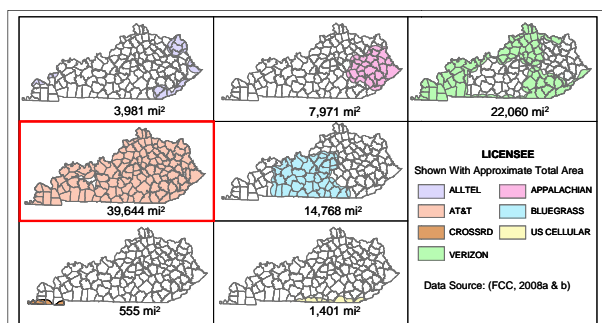


Figure 7. Cellular license data for Kentucky. (FCC 2008a & b).

Because of its mission-critical nature, the Kentucky Mesonet is classified by AT&T as a public safety entity, allowing it to receive high priority in case of data network issues. AT&T's Custom Access Point Name (APN) service, as well as virtual private networking technology, is used to create secure and full two-way communications with remote sites. Field data devices are on a segregated virtual network accessible only by KCC computing systems. IP addresses assigned to devices are even part of a KCC-internal, non-publicly-routable pool.

Unfortunately, quality cellular signals are not available everywhere in Kentucky. The use of satellite data services for prime sites with poor signal is currently being evaluated, as is a possible future use of the state's emergency management wireless communications backbone, which is currently being upgraded.

3. DATA DISTRIBUTION

While both near-real time and historical data are available on its public website, the Kentucky Mesonet also makes its data available in bulk via specialized distribution methods to a number of entities whose missions directly serve and impact the citizens of Kentucky. Agriculture is an important part of Kentucky's economy and surface meteorological data can be critical

to farmers and growers. Therefore, Mesonet data are provided to both the University of Kentucky Agricultural Weather Center and the Fusarium Head Blight Prediction Center (FHBPC) – a cooperative effort between Penn State, Ohio State, Kansas State, Purdue, North Dakota State, and South Dakota State universities – for use in predictive models of crop disease. Figure 8 shows use of Kentucky Mesonet data in the FHBPC's Risk Assessment Tool.

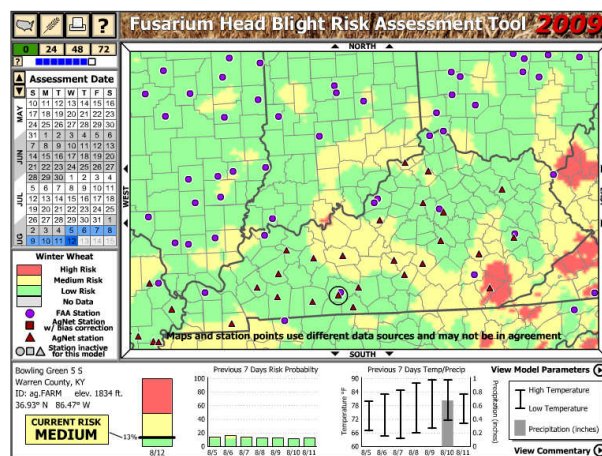


Figure 8. Fusarium Head Blight Prediction Center Risk Assessment Tool. Kentucky Mesonet sites shown as triangles (http://www.wheatcab.psu.edu/riskTool_2009.html).

Weather data are invaluable to critical state government operations such as environmental response and emergency management. To make data readily available to decision makers, the KCC has partnered with the Kentucky Division of Geographic Information to provide Mesonet data in the Kentucky Event Mapping & Analysis Portal, which contains 100+ layers of critical infrastructure and base mapping data and is used by the National Guard, Emergency Management, State Police, Homeland Security, and other entities.

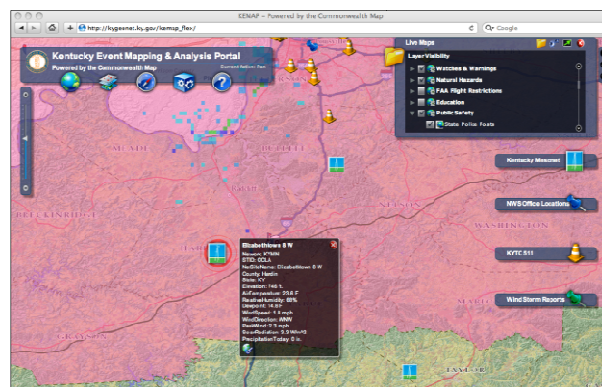


Figure 9. Kentucky Mesonet data in the Kentucky Event Mapping and Analysis Portal. (Kentucky Division of Geographic Information).

Broadcast meteorologists are critical partners for dissemination of Mesonet data to the public. Specialized data feeds are made available to stations across multiple Kentucky television markets for direct import into their broadcast weather display systems. These specialized feeds – an example is shown in Figure 10 – are made available to stations which attribute the data directly to the Kentucky Mesonet.

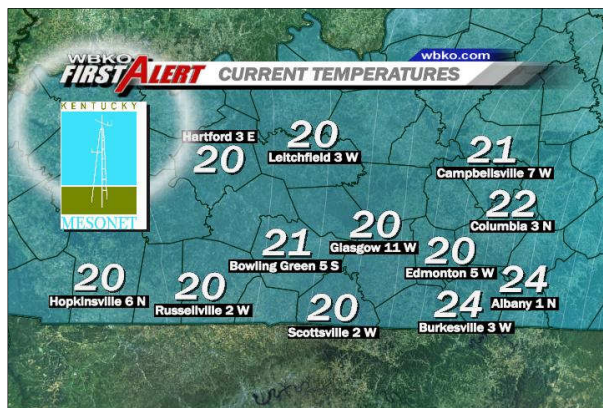


Figure 10. Kentucky Mesonet data in a broadcast weather map. Source: WBKO-TV, Bowling Green.

Being prime partners in the development of the network, the local NWS forecast offices (WFOs) serving Kentucky are not surprisingly prime users of Kentucky Mesonet data and can all receive a direct feed of data funneled through the Jackson, KY office. Figure 11 shows a Mesonet data display from the NWS Advanced Weather Interactive Processing System.

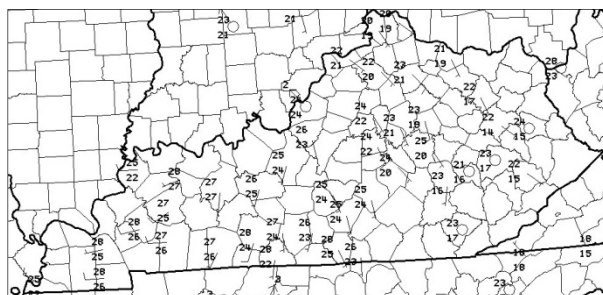


Figure 11. Kentucky Mesonet data, with some additional data from networks in other states, in AWIPS.

Mesonet data become more critical when they are used as part of the NWS warning and verification process, as they were when a large-scale gradient wind event impacted Kentucky on 9 December 2009. As shown in Figure 12, the Mesonet site near Harrodsburg lead the day with a maximum peak wind of 25 m s^{-1} (56 mph).

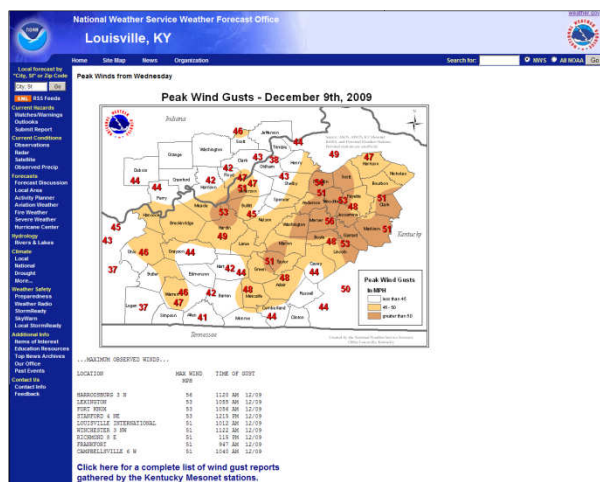


Figure 12. NWS website display which includes Kentucky Mesonet data, among others, during a strong gradient wind event on 9 December 2009.

To further facilitate use of Mesonet data in critical situations, KCC personnel participate in the NWS Chat program, which provides instantaneous electronic messaging capability between the NWS, public safety entities, emergency managers, and broadcast meteorologists. The Mesonet's highest recorded windspeed to date was documented during a particular chat session on the evening of 11 June 2009:

```
00:23 <nwsbot> LMK issues Tornado
Warning for Barren, Green, Hart,
Metcalfe[KY] till 8:00 PM CDT ...
00:23 <WBKO Chris (home)> just south of
Park City
00:24 <kymesonet-grogan> 62 mile per
hour gust merry oaks - barren county
00:24 <kymesonet-grogan> just seconds
ago
00:24 <kymesonet-grogan> right in the
path of your tor
00:25 <nwsbot> LMK continues Tornado
Warning for Barren, Edmonson, Warren[KY]
till 8:00 PM CDT ...
00:25 <kymesonet-grogan> ** 74 MILE PER
HOUR GUST - MERRY OAKS MROK SITE -BARREN
COUNTY **
00:27 <nwslnk-Tom> PEOPLE IN AND
NORTHWEST OF GLASGOW SHOULD BE IN SAFE
SHELTER RIGHT NOW
00:29 <nwslnk-Tom> Intense rotation
south of Park City moving toward Glasgow
(timestamps are UTC on 12 June 2009)
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The tornado passed within approximately $\frac{1}{2}$ km of the Mesonet site, which fortunately sustained no damage itself.

In addition to cooperating closely with the WFOs during critical weather, the KCC is also working with them to use Mesonet data for better understanding and forecasting of Kentucky Weather. An ongoing study with the Jackson, KY WFO is closely examining the setup and destruction of ridge/valley temperature splits during which valley locations quickly decouple near nightfall, with their temperatures plummeting compared to their ridgetop counterparts. Figure 13 shows the elevation difference between the Breathitt County “QKSD” Mesonet site and the nearby ASOS at Jackson, which Figure 14 shows was as much as 13°C (23°F) warmer than the valley during an impressive overnight ridge/valley split 26-27 December 2008.

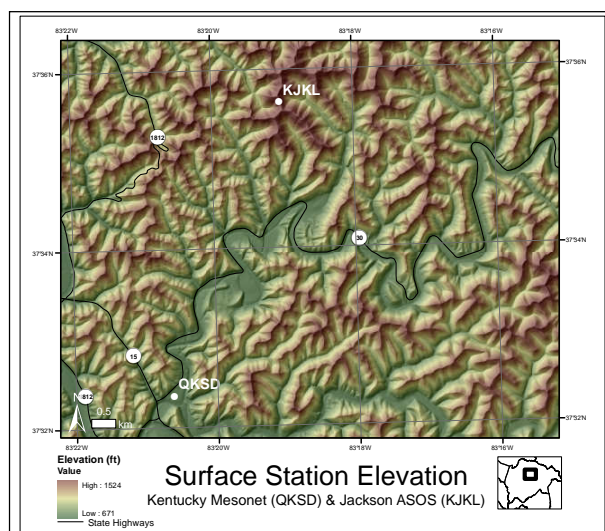


Figure 13. Elevation difference between Jackson, KY ASOS (KJL) and Kentucky Mesonet station (QKSD) in Breathitt County.

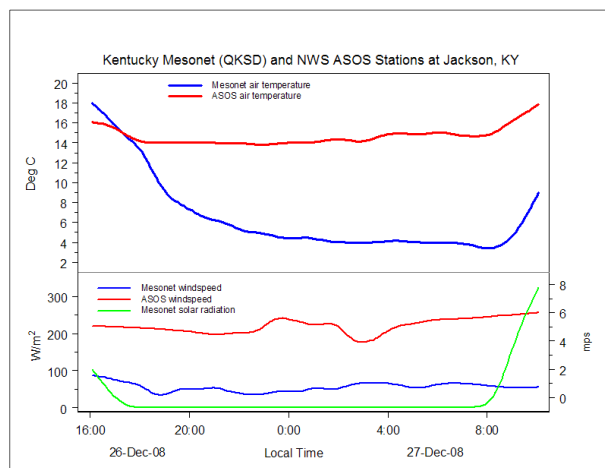


Figure 14. Ridge (ASOS) / valley (Mesonet) temperature split of 26-27 December 2008. Times are EST.

4. LOCAL IS KEY – REFLECTIONS ON A NATIONWIDE NETWORK OF NETWORKS

It is the position of the Kentucky Climate Center and Mesonet that people see the world from their community and relate to it based on their local experiences. This is certainly reflected in the needs of Mesonet data distribution partners examined in the previous section. As Mahmood et al. (2009) holds, “it is the regional responses, not a global average, that produce drought, floods, and other societally important climate impacts.” That the local relationships developed by a mesoscale sensing network are of utmost importance should not be surprising, given that two of the three classes of mesoscale phenomenon as defined by Orlanski (1975) have a spatial coverage of between 2 and 200 km. Therefore, it is the local relationships and interests that must be served by any network like Kentucky’s and that must be protected by any nationwide aggregation of local networks. Such relationships have certainly been credited for the success of the world-renowned Oklahoma Mesonet, with McPherson et al. (1999) noting “in the mind of a student or emergency manager, a feeling of ownership in this Mesonet weather information has incalculable results”.

Cultivation of local and statewide relationships has been absolutely fundamental to the development of the Kentucky Mesonet. As described in the Introduction, the KCC formed the Kentucky Mesonet Consortium with all public universities in the state to leverage the value of the network for the benefit of the citizens of Kentucky. As Figure 15 shows, without local involvement in the process, siting and construction of Mesonet sites in quality, useful locations would have been impossible.

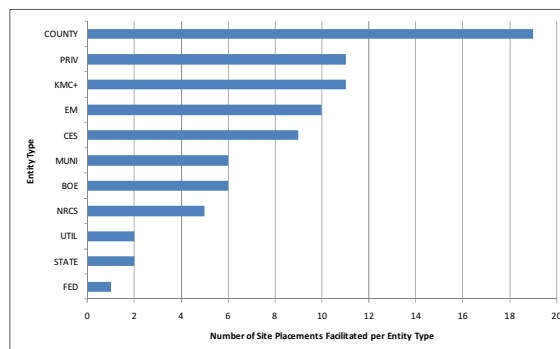


Figure 15. Site placement aided by local interests. COUNTY = county gov.; PRIV = private; KMC+ = KY Mesonet Consortium or other higher ed.; EM = emerg. mgr.; CES = U. of KY Coop. Ext. Svc.; MUNI = city gov.; BOE = board of ed.; NRCS = Nat’l Resources Conservation Svc.; UTIL = utility; STATE = state gov.; FED = federal gov. (above & beyond ongoing NWS assistance). Many sites were facilitated by multiple entities, which are each given “credit” for that site in the graph.

For all Kentucky Mesonet sites constructed to date, local interests have been directly involved throughout the planning and installation phases. In many cases, such as sites on publicly accessible lands, local governments or other entities have participated in a cost share to help fund erection of a security fence and/or digging of trenches for power conduits. In some cases, even when a Mesonet site could not be located on public land, local government officials facilitated the siting of a station on private property. While it executes a site license agreement for each station, to date the Mesonet has had to pay no rental or usage fees to any property owner. Figure 16 statistically breaks down Mesonet site locations by land owner type.

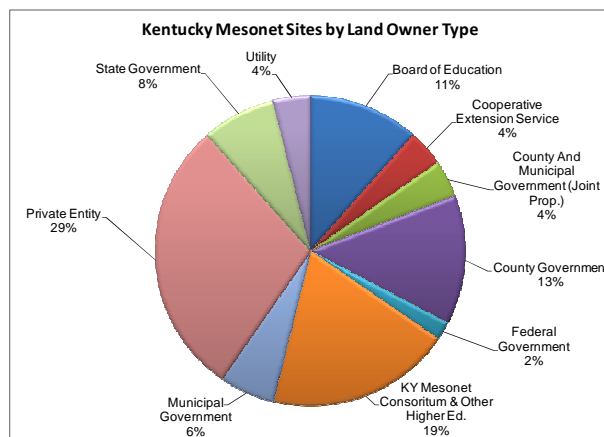


Figure 16. Kentucky Mesonet Sites by land owner type. Total sites represented = 53.

Without exception the local interests and land owners who have been willing to work with the KCC and WKU to host stations – often in prime locations – have done so out of a belief that the importance of Mesonet data to their local communities far outweighs their level-of-effort or value of their property.

While previous attempts to build a nationwide mesoscale sensing network have been abandoned, the National Research Council Committee on Developing Mesoscale Meteorological Observational Capabilities to Meet Multiple National Needs has called for a renewed, overarching national strategy to integrate or aggregate disparate systems to achieve a multi-purpose network that is national in scope (NRC 2009, p. 3) across the U.S. Interestingly, the preponderance of example events provided in the committee report's chapter supporting "National Needs for Mesoscale Observations" are localized or regional events, including an ice storm in the Carolinas, lightning, wind, hazardous materials releases, wildfires, train derailments, automobile crashes, and port closures (NRC 2009, Ch. 3). Perhaps it would be wise to make the distinction

that, while mesoscale observations are important across the nation, including in the initialization of computer models, and not discounting that upstream measurements may be important to downstream interests, the most critical needs for meoscale observations are truly local.

The KCC and Kentucky Mesonet are in no way diametrically opposed to the creation of a nationwide network of networks (NNoN) and certainly appreciate its potential benefits. In fact, the Mesonet Lead Systems Architect – the corresponding author of this paper – sits on the Architecture Working Group for the Amer. Met. Soc. Ad Hoc Committee on a NNoN. However, the KCC does urge an abundance of caution to ensure the importance and efforts of networks like the Kentucky Mesonet are not diminished in the process.

While the NRC (2009) committee does not propose to have a "national mesonet" entity overtake the control, management, or operations of the individual networks it incorporates, it does call for an infrastructure that enables "individually owned and operated networks to function, more or less, as one virtual network" (p. 138). But the potential providers of data for the NNoN are not one, they are many, some of whom have expended more effort than the KCC in developing their networks and many of whom may have expended much less.

The NRC (2009) report and follow-on town hall and community meetings have correctly cautioned against the exclusion of enthusiast monitoring networks and networks of limited scope from participation in the NNoN, noting that any and all data are potentially valuable as long as their quality is well understood. The suggestion of tiered provider levels, admission to which is governed by well articulated standards, is also squarely on-target, as are the requirements for proper network and site metadata.

The danger, however, in an NNoN is the loss of identity of individual, local networks in a sea of data providers. The value of the goodwill developed by the Kentucky Mesonet and similar networks with local stakeholders is critical and, at budget request time, is immeasurable. To survive, networks like Kentucky's – the ones likely to be able to routinely provide data of a quality most useful at the national level – cannot afford the slightest decrease in understanding among their local partners as to what constitutes a high quality monitoring location. Similarly, they cannot afford a perception among their funding sources that all-in-one weather stations that might cost 50+ times less are 'just as good' as well sited, properly instrumented scientific sensing platforms.

To gain and maintain the support of its high-value providers, any potential NNoN must continuously strive to protect or enhance the investments of individual

network operators. This effort must be engrained in the NNoN structure and must take place at all its levels, from the by-laws or policies governing its operation to its every interaction with end users. Distinctions in the metadata alone will not protect these investments.

5. SUMMARY

The Kentucky Mesonet is a high density, mesoscale network of automated meteorological and climatological sensing platforms being constructed and operated across the commonwealth by the Kentucky Climate Center at Western Kentucky University and is facilitated by the Kentucky Mesonet Consortium, a partnership between all eight public universities. Network growth has proceeded at a fair pace, with 45 sites brought on-line in the last 2.5 yr. Standards and best practices have been referenced throughout the development of the network, including in the design of its supporting computing and communications infrastructure, which includes a number of systems which collect, process, store, and distribute data to key users on a mission-critical basis. The relationships established by the Mesonet with its local constituents are invaluable, with local partners involved throughout the planning and installation phases of all network sites. An emerging nationwide network of networks aims to organize and aggregate the efforts of individual, local networks in the U.S. to support the greater national good. The Kentucky Mesonet supports such an effort, as long as the goodwill established with its stakeholders – and absolutely critical for its continued success – remains well protected.

6. ACKNOWLEDGMENTS

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7. REFERENCES

- Brock, F. V., K. C. Crawford, R. L. Elliot, G. W. Cuperus, S. J. Stadler, H. L. Johnson, and M.D. Eilts, 1995: The Oklahoma mesonet: A technical overview. *J. Atmos. Oceanic Technol.*, **12**, 5-19.
- FCC, 2008a: Federal Communications Commission Licensing Database Extracts: Cellular Service Area Boundaries (aggregate by callsign) [Available online at: http://wireless.fcc.gov/geographic/index.htm?job=licensing_database_extracts & http://wireless.fcc.gov/geographic/data/db/cellular_aggregate_callsign_sab.zip]. 23 July 2008.
- _____, 2008b: Federal Communications Commission Universal Licensing System: Cellular – 47 CFR Part 22 – Licenses. [Available online at http://wireless.fcc.gov/uls/data/complete/l_cell.zip and <http://wireless.fcc.gov/uls/index.htm?job=transaction&page=weekly>]. 23 July 2008.
- Hubbard, K. G., X. Lin, and C. B. Baker, 2005: On the USCRN temperature system. *J. Atmos. Oceanic Technol.*, **22**, 1095-1101.
- Karl, T. R., R. G. Quayle, and P. Y. Groisman, 1993: Detecting climate variations and change: New challenges for observing and data management systems. *J. Climate*, **6**, 1481-1494.
- Legates, D. R., D. J. Leathers, T. L. DeLiberty, G. E. Quench, K. Brinson, J. Butke, R. Mahmood, and S. A. Foster, 2005: DEOS: The Delaware Environmental Observing Systems. *Extended Abstracts, 21st International Conf. on Interactive Information Processing Systems for Meteorology, Oceanography, and Hydrology*, San Diego, CA, Amer. Meteor. Soc., 18.10.
- Mahmood, R. and Foster, S. A. 2008. Meso-scale weather and climate observations in Kentucky for societal benefit. *Focus on Geography*, **50(4)**, 32-36.
- _____, R. A. Pielke Sr., K. G. Hubbard, D. Niyogi, G. Bonan, P. Lawrence, B. Baker, R. McNider, C. McAlpine, A. Etter, S. Gameda, B. Qian, A. Carleton, A. Beltran-Przekurat, T. Chase, A. I. Quintanar, J. O. Adegoke, S. Vezhapparambu, G. Conner, S. Asefi, E. Sertel, D. R. Legates, Y. Wu, R. Hale, O. W. Frauenfeld, A. Watts, M. Shepherd,

- C. Mitra, V. G. Anantharaj, S. Fall, R. Lund, A. Treviño, P. Blanken, J. Du, H. Chang, R. Leeper, U. Nair, S. Dobler, R. Deo, and J. Syktus, 2009: Impacts of land use land cover change on climate and future research priorities. *Bull. Amer. Meteor. Soc.* (in press)
- McGuirk, M. and E. May, 2003: Draft USCRN metadata management – survey to operations. NCDC report, 14 pp. [Available online at: <http://www1.ncdc.noaa.gov/pub/data/uscrn/documentation/metadata/MetaDataMangt.doc>].
- McPherson, R. A., K. C. Crawford, J. M. Wolfenbarger, A. D. Melvin, and D. A. Morris, 1999: From rags to riches – seven years in the life of a climate office's educational programs. Preprints, *8th Symposium on Education*, Dallas, Texas, Amer. Meteor. Soc., J1.5.
- _____, C. A. Fiebrich, K. C. Crawford, R. L. Elliott, J. R. Kilby, D. L. Grimsley, J. E. Martinez, J. B. Basara, B. G. Illston, D. A. Morris, K. A. Kloesel, S. J. Stadler, A. D. Melvin, A. J. Sutherland, H. Shrivastava, J. D. Carlson, J. M. Wolfenbarger, J. P. Bostic, and D. B. Demko, 2007: Statewide monitoring of the mesoscale environment: A technical update on the Oklahoma Mesonet. *J. Atmos. Oceanic Technol.*, **24**, 301-321.
- Miller, P. A., M. F. Barth, L. A. Benjamin, R. S. Artz, and W. R. Pendergrass, 2007: MADIS support for urbanet. Preprints, *14th Symposium on Meteorological Observations and Instrumentation*, San Antonio, TX, Amer. Meteor. Soc., JP2.5.
- National Research Council, 1999: *Adequacy of Climate Observing Systems*. National Academy Press, 66 pp.
- _____, 2009: *Observing Weather and Climate from the Ground Up: A Nationwide Network of Networks*. National Academy Press, Prepublication Form, 234 pp.
- Orlanski, I., 1975: A rational subdivision of scales for atmospheric processes. *Bulletin of the American Meteorological Society*, **56(5)**, 527-530.
- Schroeder, J.L., W.S. Burgett, K.B. Haynie, I. Sonmez, G.D. Skwira, A.L. Doggett, and J.W. Lipe, 2005: The West Texas Mesonet: A technical overview. *J. Atmos. Oceanic Technol.* **22**, 211-222.
- Splitt, J. H., L. Dunn, J. Pechmann, B. White, C. Ciliberti, S. Lazarus, J. Slemmer, D. Zaff, and J. Burks, 2002: MesoWest: cooperative mesonets in the western United States. *Bull. Amer. Meteor. Soc.*, **83(2)**, 211-225.
- Struebig, S., D. Grabowski, S. A. Foster, and R. Mahmood, 2010: Equipment and instrumentation used at a Kentucky Mesonet environmental monitoring station. *15th Symposium on Meteorological Observation and Instrumentation*. Atlanta, GA. Amer. Meteor. Soc. P257.
- Thompson, J. K., S. A. Foster, and R. Mahmood, 2010: Site identification and selection for the Kentucky Mesonet. *15th Symposium on Meteorological Observation and Instrumentation*. Atlanta, GA. Amer. Meteor. Soc. P263.
- Trenberth, K. E., T. R. Karl, and T. W. Spence, 2002: The need for a systems approach to climate observations. *Bull. Amer. Meteor. Soc.*, **83(11)**, 1593-1602.
- World Meteorological Organization, 2006: *Guide to Meteorological Instruments and Methods of Observation*. Prelim 7th ed. WMO 8, Geneva, Switzerland.