EVALUATION OF A COOPERATIVE MOBILE WEATHER SYSTEM FOR DATA COLLECTION FROM MESOSCALE EVENTS

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ABSTRACT

Collection of weather data has improved significantly over the last decade, resulting in a mostly automated system that provides instant data access from stations around the world via the World Wide Web, though these stations do not provide the spatial resolution for adequate study of small-scale weather events. Recently, mobile weather stations have been developed in order to collect information for use in mesoscale research projects. These projects are able to overcome the spatial restrictions of fixed weather stations, but are done infrequently. Thus, there are many significant weather events for which there has been no data collected. A system designed to overcome these limitations has been developed. The Chase Positioning System (CPS) observation upload software, and the associated Mobile Met Net (MMN) web based mapping and data display system, provide a method for collecting and viewing weather data provided by volunteer weather observers such storm spotters and chasers. The CPS software collects an observer's position, speed, heading, camera images, and then sends the information to a collecting server using a cell phone internet connection. A future development will allow an observer's weather conditions to be either manually entered or retrieved automatically from portable weather instruments, then uploaded as well. The data collected are rated based on accuracy and validity. The MMN website employs Google maps to display live as well as archived weather information and the location (via Global Positioning System receivers) at which the information was collected. The MMN displays this information as well as fixed-station data such as provided by the Oklahoma Mesonet which is plotted simultaneously with the collected information from the portable weather stations. Current observer images are able to be displayed and are also archived with the intent to visually "document" the type of phenomena witnessed at the place of collected data. The result of this project is a fully functional CPS program and MMN website with the ability to archive and display current observations collected by multiple observers. The archived information is also available to anyone who is in need of the information for research purposes.

1. Introduction

The Oklahoma Mesonet contains 108 stations across the state of Oklahoma which is 500 kilometers in width. A specified requirement of the mesonet was that at least one site be in each of the counties of Oklahoma. The sites unfortunately cannot be equally spaced across Oklahoma. Small-scale weather phenomena are often missed due to the spatial and temporal scaling of fixed location weather stations. Jerry M. Straka, Erik N. Rasmussen, and Sherman E. Fredrickson developed a system of mobile weather observing systems for observing finer spatial scales in the early 1990s. These mobile units, known as Mobile Mesonets, were designed to augment existing meteorological networks in the study of severe local storms and other mesoscale phenomena used in conjunction with Verification of the Origins in Rotation in Tornadoes Experiment (VORTEX) (Straka et al. 1996). These weather observing systems are attached to the rooftops of vehicles which is how they obtain their mobility. The Mobile Mesonet units are designed to make meteorological observations of various phenomena associated with thunderstorms including rain and hail cores, front- and rear-flank downdrafts and outflows, gust fronts, mesocyclones, flows near tornadoes, and storm inflow regions. In addition, the Mobile Mesonet can be used for studies of surface boundaries (e.g., fronts, drylines), shear lines, circulations, and other small-scale weather phenomena (Straka et al. 1996). The International H_2O Project sampled drylines and cold fronts on the U.S. Southern Great Plains with an array of mobile observing systems (Weckwerth and Parsons 2003) to document the boundary layer processes that force the initiation of thunderstorms along these air mass boundaries (Ziegler et al. 2004). The mobile observing system used was an upgraded version of the Mobile Mesonets used in conjunction with VORTEX back in the 1990s. This paper describes the development, features and capabilities of a new system created to collect and display weather data and images captured by volunteer observers. The system is comprised of two components. A software program called the Chase Positioning System (CPS) allows an observer to collect and transmit information to a collecting server using a cell phone internet connection. The associated Mobile Met Net (MMN) website is designed to display all collected information including captured images and positions at which the data was collected. The MMN website is located at on the web at http://cps.okstorms.com. This site provides access to both current and archived observations. The uniqueness of this system is the ability to transmit data in real-time through the use of cellular phone technology, as well as having a system open for data collection by volunteer observers. It is believed this will result in a much more robust dataset of conditions near severe weather events.

2. Transmission of Collected Data

a. Historical projects: VORTEX and IHOP methods

The Mobile Mesonet was first deployed during VORTEX-1994 in a highly coordinated fashion to put instrumented vehicles in positions where they might obtain the most useful measurements of weather phenomena associated with severe thunderstorms. A central vehicle in the field (the FC) acted as the hub for all communication relating to coordination. This vehicle was equipped with cellular telephones, two 45-W VHF radios (ICOM), aircraft radios, and a satellite message system (QUALCOM INC. Omni-TRACS communication systems) (Straka et al. 1996).

During IHOP in June 2002, the National Severe Storms Laboratory (NSSL) re-designed and re-deployed a mobile digital network (MDN), which obtained mobile mesoscale weather observations, managed their transmission to a centrally located field coordination (FC) vehicle, and provided their improved real-time processing and display in the FC vehicle (Ziegler et al. 2004). Transmission capabilities increased greatly with the IHOP project due to then advancements in technology. Ziegler et al. 2004 indicated that cellular phone modems offered an alternate data communications method with slightly greater bandwidth than packet radio under ideal conditions. However, experience had demonstrated that there were several areas inside the planned IHOP domain with poor or nonexistent cellular phone coverage. Although broadband satellite Internet systems provided significantly higher bandwidth than packet radio or cellular phone modem systems, these high-bandwidth satellite dish systems could not be deployed unless the vehicular platform was parked.

A program known as MDN ingests and processes packets from the FC and the various ground-based nodes of the MDN. The MDN program optionally provides for the transmission of both complete data files and short observations in either a robust connection-oriented [i.e., transmission control protocol (TCP)-like] protocol with full retransmission requests, or in a simple and efficient diagram [i.e., user datagram protocol (UDP)-like]. The MDN program initiates a transfer when a file is placed in the outgoing directory of the FC computer (Ziegler et al. 2004). Ziegler et al. 2004 also notes that a program known as FC manages the display of packets from all mobile platforms in real time on a surface map. All data deposited in the incoming directory to the MDN program are available for automated ingest by the FC program. The FC program copies all arriving packets to an archive directory and features a playback mode that facilitates retrospective analyses of these archived MDN packet data. Customized versions of the MDN program control the data transmission from the Mobile Mesonets to the FC vehicle. The Mobile Mesonet's MM program processes, archives, and displays the weather observations from the rooftop instrumentation. A packet placed in the outgoing directory of the data system computer is transferred by the customized MDN program to the RF modem for transmission. Once received, the data packet is deposited in the incoming directory of the FC. The FC program scans the incoming directory, then copies and displays the newly arrived observation. A file is placed in an outgoing directory for the satellite system, from where it was automatically transferred by FTP software to the designated remote host. The ability to serve data to the Internet in near real time from the Field Coordinator vehicle provided a unique capability for "virtual participation" in IHOP. By analogy, participants in the oceanographic study reported by Potter and Cowles (2000) could access real-time field observations from any site served by the Internet. The performance of the MDN is summarized for periods of IHOP's mobile field observations in which packet data were archived by the FC program. Occasional gaps in transmitting, receiving, or recording packets occurred at times when either a mobile platform's data system or the FC computer was not operating (Ziegler et al. 2004).

b. CPS transmission method

The intentional method of data transmission through the internet by the CPS program was through the use of cellular telephone technology. Since the IHOP project, cellular telephone coverage and technology has continued to expand across the United States. The reason for selecting cell phones as the primary means of data transmission is that it is believed that most storm spotters and chasers have cell phones, and many of these phones can connect to the internet. Incorporation of the Automatic Positioning Reporting System (APRS), an Amateur Radio based data transmission system, as a means of transmitting data is a future possibility. A drawback to using this type of transmission is the inability to transmitting photographic or video recordings. Also, the means of transmitting through APRS is restricted to those who have an amateur radio license.

There is a limitation to using cellular phones as the primary means of transmitting data. There are still areas of the country that have no signal coverage. This problem has been addressed with the CPS program. In cases where the observer is unable to connect to the internet, the program stores collected information in queue until an internet connection is re-established. Once re-connected, the program sends the queued data, sending the newest data first.

3. CPS and MMN Development and Capabilities

The MMN began as a simple system of Global Positioning System (GPS) data plotted as markers on a Google™ Map. Figure 1 shows each marker which contained information about the observer's heading, speed, elevation, and a captured image (if available) from a webcam or camera. All information was initially captured by the CPS program then uploaded to the MMN server.

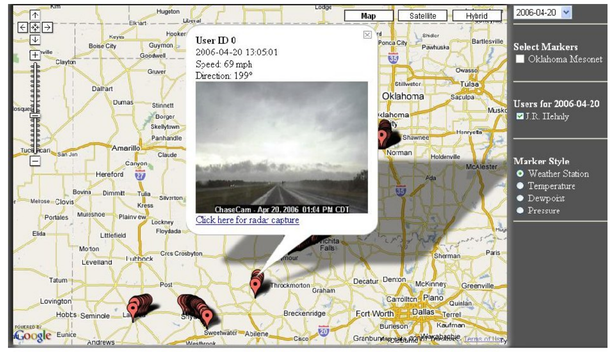

Fig. 1. The above figure shows the initial MMN website.

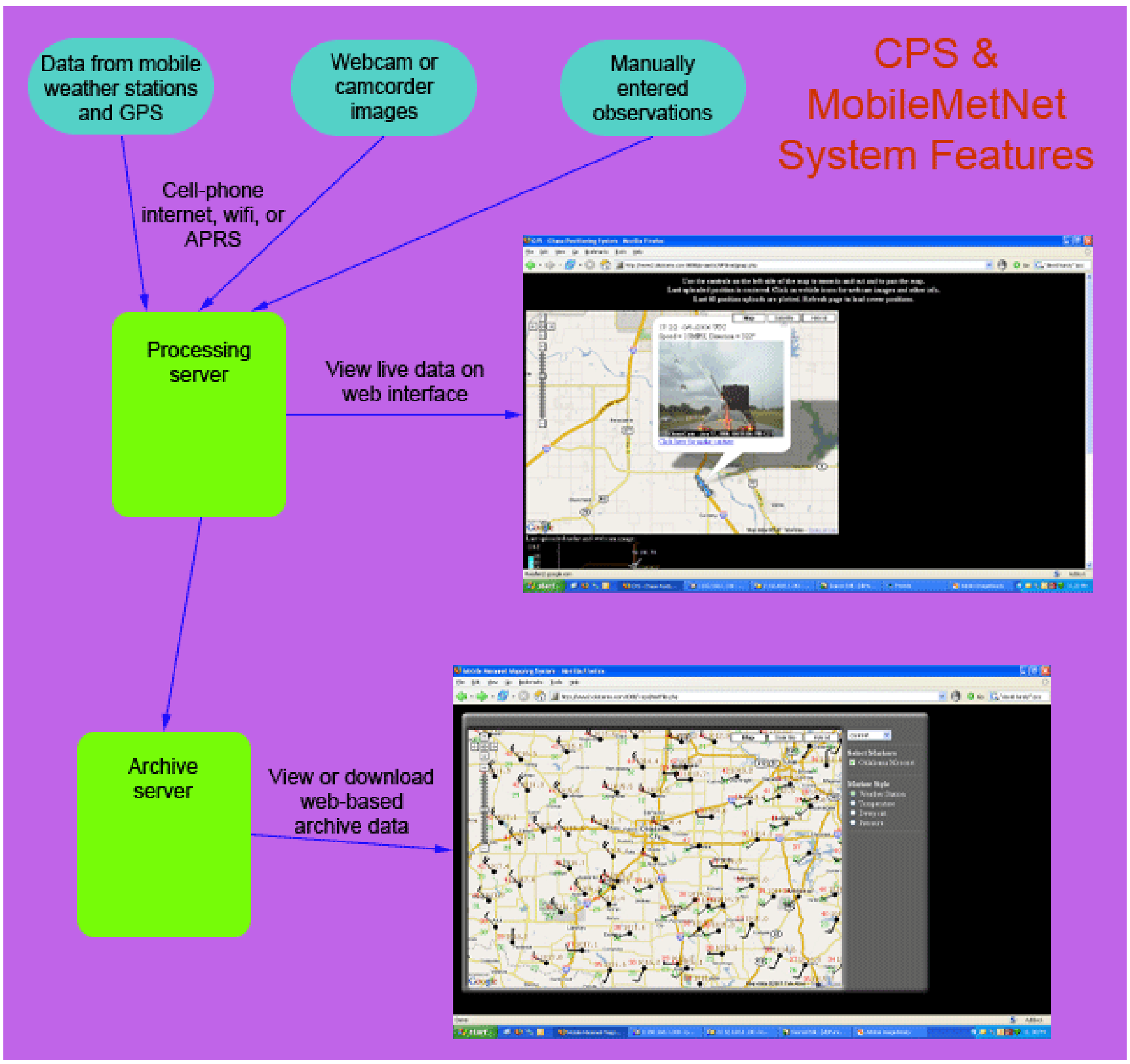

Fig. 2. The above schematic shows a developed flow chart indicating the capabilities of the web interface for both input and output.

After verifying that this type of software and web interface system could indeed be feasible, a more complete system was designed and implemented. Figure 2 shows the design of the complete version, including various methods of data collection that is planned for the system, and also shows some examples of the graphic outputs on the MMN website.

In the newer implementation Oklahoma Mesonet information was incorporated onto the Google™ map display. The station plots for the Oklahoma Mesonet on the MMN are the current observations that match those displayed on the Oklahoma Mesonet website.

The Google™ maps used on MMN are designed such that an observer can switch the background image. The default background, "map mode", displays a map containing roads, cities, and political boundaries. As seen in Figures 1 and 4, the upper right hand corner contains two other buttons to allow the observer to select alternate backgrounds. The "Satellite" tab displays a background made up of of satellite images of the earth's surface. The "Hybrid" tab shows the "Map" features overlaid on the "Satellite" features.

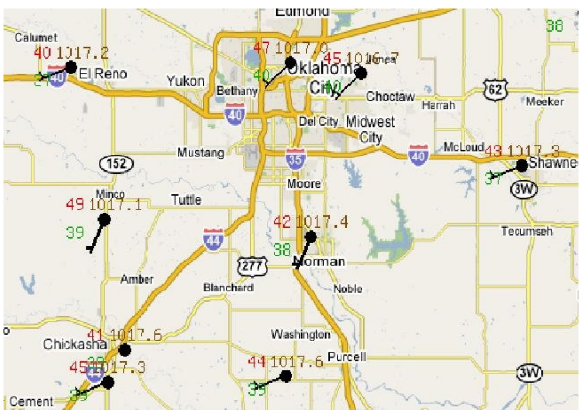

Fig. 3. Screen capture of the weather station markers representing the mesonet sites.

The Oklahoma Mesonet information displayed on MMN is limited to temperature, dew point temperature, wind speed, wind direction, and atmospheric pressure. Mesonet information can be displayed in multiple forms. Figure 3 shows the default display selection of the MMN. "Marker Style" controls on the page allow a viewer to choose which style of marker is desired. Figure 4 shows the selection of "temperature" as the marker style. This changes the marker from a weather station plot to numerical figures. Dew point temperature and pressure markers are also available. With the selection of the temperature, dew point temperature, or atmospheric pressure markers, each marker is given color corresponding to its value, with a range of values showing up as a color gradient across the Mesonet sites.

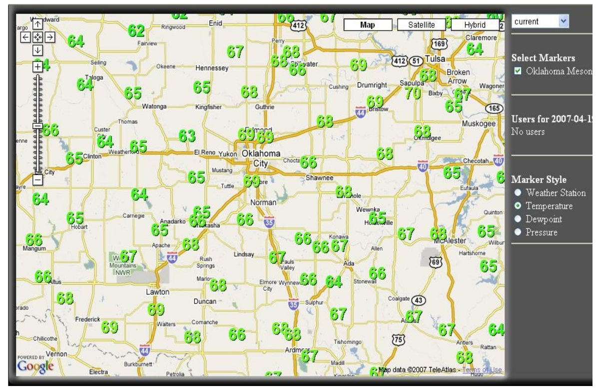

Fig. 4. The "marker style" on the right side indicates "temperature" selected as the marker style.

4. Data Quality

a. Temporal issues

Meteorological information obtained by the CPS must be accurately collected for use in research purposes. With multiple observers collecting information, the issue of data quality assurance is a concern. Instruments used by observers should be calibrated and compared with maintained instruments such as the instruments at Oklahoma Mesonet sites. An equipment profile is maintained for each observer signed up to participate in the network. For data quality assurance issues, the MMN requires a password and ID number from each observer for data upload to be permitted. This precaution ensures that the all data collected can be accurately matched to a corresponding equipment profile. While the overlay of Mesonet information provides somewhat useful information, the time scale of this information is not in real-time. Data being collected by observers is in real-time, but the Mesonet is updated every 15 minutes with 3, 5 minute averages of information. The comparison of 15 minute old data to collected information in real-time is impractical. The key to calibrating instruments to the Mesonet is to do it at the time of the update on the website http://www.mesonet.org. Variations in meteorological phenomena occur frequently under a span of 15 minutes, hence the importance of collecting information in real-time. Another drawback to comparing collected information with Mesonet information is the fact that outside of Oklahoma there are no Mesonet sites. The Texas panhandle contains the West Texas Mesonet, but this grid of meteorological stations is not yet incorporated into MMN.

b. Mobile measurements: wind speed, wind direction, and atmospheric pressure issues

Ideally, the MMN system would be able to collect wind speed and direction data continuously. However, collecting accurate environmental wind speed and direction from a moving vehicle is not an easy task. Straka et al. 1996 provides information for calculating wind speeds and wind directions for mobile weather stations.

Atmospheric pressure measurement from a mobile network of instruments is also problematic. Sloping terrain provide natural pressure changes due to changes in altitude. Pressure measurements from multiple locations in the field may experience different atmospheric pressures due to topographic effects. Also, pressure also cannot be accurately recorded while in motion unless the sensor is placed in region that is not effected by dynamic wind effects. Straka et al. 1996 also discusses the approach taken to correct the pressure perturbations encountered by the atmospheric pressure sensor.

5. CPS software and collected information

It is believed the establishment of the MMN system will lead to gathering high resolution data for small scale phenomena. Two files are sent back from the CPS software. These files consist of a data file of GPS, time, and user information, and an image file which is an image capture from a webcam or camcorder.

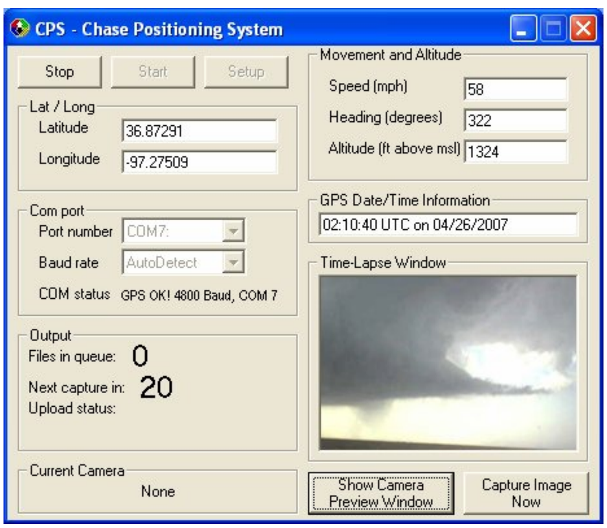

Fig. 5. The CPS program window as it typically looks in use.

Figure 5 shows the CPS program window. This program is currently designed to run on Windows XP machines only. Photos and GPS information are collected at every minute, based on the GPS time. This ensures that all observers capture data simultaneously. A manual capture button is also available, which is useful if some short duration event is observed between captures. As seen in Figure 5, a window in the lower right of the program shows a time lapse video of image captures. This time lapse shows an animation of six images captured every thirty seconds for the last three minutes. This is useful because it allows an observer to be able to spot slow rotation of a storm not visible in real-time.

b. CPS and MMN test run

On 4/23/2007 J.R. Hehnly and Kenneth McCallister performed a test run of the system. This was the first time that the CPS software and the MMN site had been used with multiple simultaneous observers. J.R. was assigned User ID 0 and Kenneth User ID 1. The type of webcam used for image capturing on this test is the V-UJ15 Logitech USB Quickcam for Notebooks. BU-353 Waterproof WAAS enabled USB GPS receivers were used to capture the GPS information. The cell phone models used were a Motorola V551 which operated from a Cingular cell phone service provider, and a Sanyo SCP-4900 operated by Sprint cell phone service provider. Figure 6 below shows the selection of "current" in the date selection box. This displays the positions recorded in the last sixty seconds of all observers running the program. The Oklahoma Mesonet information can also be viewed along with the current position of observers. The MMN automatically refreshes itself every sixty seconds to keep the observer position and observed data current on the display.

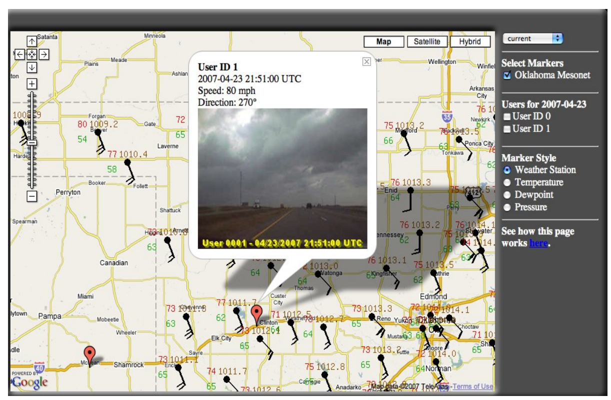

Fig. 6. MMN plots of User ID 0 and User ID 1.

The transmission by the CPS and the collection by the MMN for the test run was successful at every minute that the observers had the program running. There were data gaps that occurred, but these gaps were not a result of flaws in the system. They occurred when the CPS software was not running due to being turned off or during computer re-boots. The archived information displayed well after their test was performed. An issue arose though when both observers' archived information was displayed. Their plotted positions overlapped during a portion of the test, making it difficult to distinguish which plot belonged to whom. This issue is currently being addressed for future developments. A few supercell images were captured by the webcams and ingested into the server. Figure 7 shows a screen capture of the MMN taken during the test, with webcam captures and position markers visible. This test run accomplished our objective of collecting information from multiple observers and viewing it in real-time.

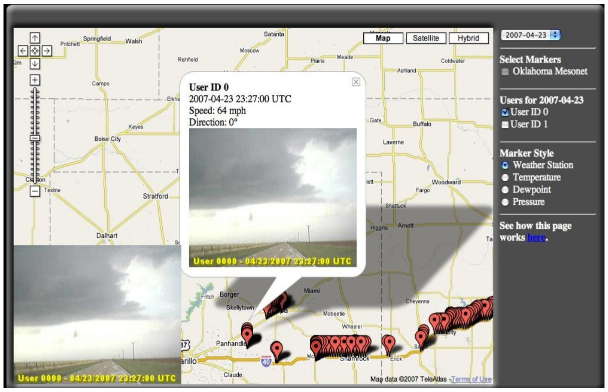

Fig. 7. User ID 0 webcam captured while the observer was in the Texas panhandle, along with previous position markers.

6. Future Development

Many upgrades are currently planned in order to expand the CPS and MMN capabilities. These upgrades include:

• A CPS program upgrade will allow for manual entry of observed weather information and automated data collection from mobile weather stations.

• Plotted markers of observer locations will be changed to weather station plots such as those shown in Figure 8.

• The individual plots of temperature, dewpoint temperature, and atmospheric pressures will be changed to highlight the exact location of each observation.

• Each observer that uploads information will have color coded observer ID number and markers to further differentiate multiple observers.

• Addition of the West Texas Mesonet station information on the Google^{TM} map.

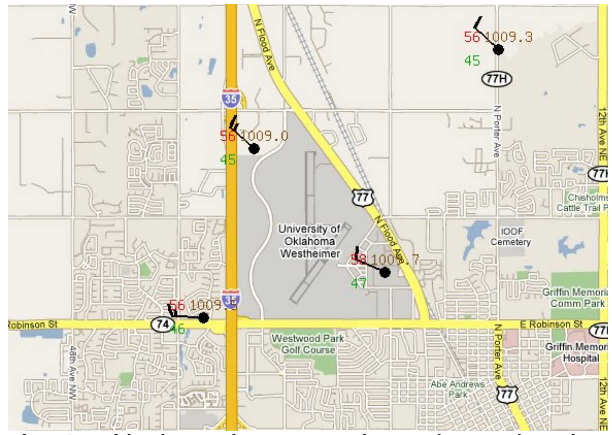

Fig. 8. This demo shows example weather station plots that will be implemented for each observer.

7. Conclusions

This paper reports the development of the Chase Positioning System program and the Mobile Met Net website. With the inclusion of Oklahoma Mesonet information into the Google^{TM} maps on the website, this provided a comparison for data accuracy. The CPS program has demonstrated the capability to transmit information in real-time by the use of a cellular phone internet connection as the means of data transmission. All observed information was successfully archived by date and time. This design is adaptable to incorporate manual input and automated data retrieval from mobile weather stations. As noted in the list of future developments, the program will receive multiple upgrades to expand the capabilities and uses of the program and website. The website continually updated itself every sixty seconds, which allowed the viewers of the website to track the positions of observers and the information being ingested every sixty seconds. During the test run on 4/23/2007, the only issue that occurred was a computer error that required a reboot. This caused gaps in the data that is available in the archive. Aside from this issue the program, data transmission by the use of cell phones, and archiving ran smoothly in real-time.

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REFERENCES

Potter, N. D., and T.J. Cowles, 2000. A high-speed, wireless network for ship-to-ship and ship-to-storage data exchange. *J. Atmos. Oceanic Technol.,* **17**, 963-970.

Straka, J. M., E. N. Rasmussen, and S. E. Fredrickson, 1996: A mobile mesonet for finescale meteorological observations. *Journal of Atmospheric and Oceanic Technology,* **13**, 921-931.

Weckwerth, T., and D. Parsons, 2003: An overview of the International H_2O Project (IHOP_2002). Preprints, *Observing and Understanding the Variability of Water in Weather and Climate,* Long Beach, CA, Amer. Meteor. Soc., CD-ROM, 1.1.

Ziegler, C. L., D. Kennedy, and E. R. Rasmussen, 2004: A wireless network for collection and synthesis of mobile mesoscale weather observations. *J. Atmos. Oceanic Technol.*, **21**, 1659-1668.