Establishment and instrumentation of the Kessler Farm Field Laboratory piconet

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Abstract

Rain gauge networks are used worldwide to provide information regarding local rainfall and variances thereof over large areas. Most of these networks, however, are on regular grids in which the distance between each gauge is several kilometers or more. Since most convection is on a much smaller scale than the gauge spacing found in the networks, a higher resolution network is required to examine small-scale variabilities within any given storm.

Currently, a PicoNet is being developed to install at the Kessler Farm Field Laboratory (KFFL) near Purcell, Oklahoma. This PicoNet will consist of 6 different rain gauge sites variably spaced over a 350-acre property. Unlike other networks, the KFFL PicoNet will have gauge-to-gauge spacing of only several hundred meters, with a maximum spacing between any two locations of 1.5km. This high-resolution network will allow researchers to observe the small-scale variabilities in convective precipitation, and then in turn, compare these findings to the estimated precipitation intensities reported by the KTLX and KOUN radars to test rainfall retrieval algorithm accuracies.

1. Introduction

Over several decades, Doppler weather radars have come to the forefront of meteorological data assimilation and research. Current Weather Surveillance Radar-1988 Doppler (WSR-88D) radars use a beam with a 1° width and a wavelength of 10cm over which detailed information regarding hydrometeors can be acquired. The radars are capable of scanning 360° azimuthally, and in steps from 0.5° to 19.5° in elevation. During a precipitation event, each time a pulse is emitted, a portion of the beam is backscattered to the receiver from which information regarding the precipitation can be gathered. This information provides meteorologists and the general public with knowledge regarding the location, movement, and intensity of storms. Predefined algorithms are then used to process the data and put it into graphic format. However, one question that arises is whether the algorithms are operating to a standard which provides a fully accurate representation of rain rates and their respective locations. Researchers have examined this problem in recent years by constructing rain gauge networks that lie within a given radar's sampling area (e.g., Houze et al. 1996, Jendrowski et al. 1999, Chandrasekar et al. 2001). These gauge networks provide information regarding rain rates and total precipitation values that can be compared to the data analyzed using the radar return information.

Despite researchers' efforts, many rain gauge networks are not without problems of their own. A majority of high resolution networks used solely for precipitation analyses have distances of several kilometers between each gauge station, hindering the ability to discern information regarding small-scale variabilities in rainfall from convective systems (i.e., Nair et al. 2005). Most convection that is studied using these networks have an area of one square kilometer or less, and given movement speeds of the storm, it may only pass over a small portion of gauges in the network before reaching the end of its lifecycle. The only data that can then be gathered pertains to total rainfall accumulations at several sites spaced over several kilometers, which cannot plausibly be used to verify the small-scale variabilities in radar returns. Furthermore, some gauge networks do not have real-time data feeds, so it could be days or even weeks before the data can be extracted on-site and analyzed; therefore, archived radar data are the only means of comparing accuracy of the information gathered from the gauges. However, the network being established at the Kessler Farm Field Laboratory (KFFL) will potentially alleviate some of these common problems. First, the maximum spacing between any two gauges is 1.5 kilometers, and a typical spacing is only several hundred meters. This spacing allows for smaller sampling intervals within the storm and can provide more information regarding small-scale structures, which can be compared to the WSR-88D data to determine algorithm accuracy. This network will also have a data feed so the data gathered can be compared to the radar output in real time. Therefore, availability of archived data would not be a problem, as it tends to be with some of the current networks. Furthermore, the KFFL network is arranged in a non-redundant array on a square grid, allowing for a greater amount of discernable information regarding the complex structures of convective precipitation; this will be explored in more depth in section 2.

2. Background Information

In planning the KFFL PicoNet, it was decided to use 12-inch tipping bucket (hereafter TB) rain gauges. These gauges are approximately 21-1/4” high, weigh only 3 kilograms, and are calibrated to 0.01” rain per switch closure (tip) (MetOne 2004). TB gauges were chosen in place of other types of gauges for several reasons. First, TB gauges are low-maintenance, which allows them to be placed in the field for long periods of time without having to be recalibrated (however, it is a simple task to use a field calibration kit to calibrate the gauges, as is further discussed in section 3). These gauges are also extremely accurate; the structure allows the gauge to monitor rainfall at a continuous rate during the extent of a precipitation event, and only averages a ±1%

margin of error at rain rates of 1” to 3” per hour at 70° Fahrenheit (MetOne, 2004). Each time the bucket in the TB gauge tips, it induces a current which then sends a pulse signal through to a translator or datalogger used to count the number of tips. Several disadvantages of TB gauges that must be considered, however, are that measurement errors could arise from precipitation events during which heavy rainfall, light drizzle, or heavy winds are experienced (Flint et al. 1996). TB gauges have long been used in constructing both large- and small-scale rain gauge networks worldwide due to their simplicity, overall reliability, and versatility. One such network that uses TB gauges is the Oklahoma Mesonet, a network of weather stations encompassing the state of Oklahoma with at least 1 site in each of Oklahoma’s 77 counties (Oklahoma Mesonet 2005). This network and the precipitation information returned from its gauge locations has been used to verify radar algorithm precipitation estimates, but on a much larger scale than the KFFL PicoNet.

The location of KFFL is vital to the further development, abilities, and success of the PicoNet. Kessler Farm is situated on a 350-acre area approximately 30 kilometers south-southwest of the KOUN WSR-88D, which is located at the National Severe Storms Laboratory in Norman, Oklahoma. This places KFFL in a prime location over which to analyze radar returns, since the beam has not diffused to a threshold where accuracy could be lost. Once the beam has passed over KFFL, each sampling volume displayed in the return image corresponds to an area of approximately 520 meters by 250 meters. Though the data collected from the PicoNet will primarily be used for meteorological purposes - to study the small-scale spatial variabilities in precipitation events in order to validate radar return algorithms - a number of other researchers using KFFL have expressed strong interest in the data, and how it affects the biological characteristics of the area.

In designing the PicoNet, it was decided to use a non-redundant point array on a square grid. Using an array created by an algorithm as presented in Golay 1971, the gauge locations were chosen at KFFL in such a way to allow maximum coverage with minimal spacing between the gauges and such that no two baseline spacings are identical. Baseline spacings are simply separations between two sensor locations and can be plotted on a grid taking distance and angular separation into account. The KFFL array is different from those used at other gauge locations because the gauges are arranged on a square grid in such a way that an autocorrelative array in which no two distinct pairs of points share the same autocorrelation support (Golay 1971) (Figure 1a). Essentially, if a network is arranged on a regular grid with equal constant spacing between every gauge, the distance from each gauge to the four gauges closest to it are the same, and only form four distinct baseline spacings (Figure 1b). Since the KFFL array is non-redundant, this problem of correlative spacing does not exist, and therefore allows for a clearer representation of small-scale storm variabilities. Also, due to the optimized sampling area, fewer gauges are needed to obtain a larger amount of discernable information regarding storm structure, resulting in the network being much more cost effective.

3. Instrumentation

Prior to placing the gauges in the field, it was important that each one was calibrated to the standard of 0.01” of precipitation per switch closure (tip). Upon receiving the MetOne rain gauges, although they had been factory calibrated, it was in the best interest of the network to calibrate them by hand and make sure each gauge was operating properly. Two different calibration techniques were used, one being the use of a field calibration kit and the other being the use of the Oklahoma Mesonet's calibration equipment.

The field calibration kit contained a 653mL dispenser with a valve and 5 different discharge nozzles each corresponding to a given rain rate (50mm/hr, 100mm/hr, 200mm/hr, 300 mm/hr, and 500mm/hr). Given the knowledge of the volume of the dispenser, using any given rain rate, it was simple to discern whether or not the TB gauges were meeting the 0.01" criteria for each switch closure. Furthermore, by taking the number of tips with each rain rate and the time it took to empty the 653mL dispenser, it could also be calculated whether or not the rain rates were fully accurate. Several trials were performed with the gauges, using varying rates, and all appeared to coincide with the 0.01" criteria.

The second calibration method also proved to be very useful. Both methods were used in accordance with one another as a way to ensure the accuracy of not only the methods used to test, but also the gauges themselves. The calibration equipment used by the Mesonet was developed explicitly for its versatility and ease of use in the field. This equipment consists of a 1-liter bottle and a PVC pipe with one end closed and two small drip holes. Putty was used to cover the holes, and either one or both could be open, simulating varying rates of rainfall (Figure 2). This method, much like the field calibration kit, could be used to check that the buckets were tipping when filled with 0.01" of water. Both methods, however, provided insight to possible error sources that will need to be considered once the gauges are in the field. First, one factor to consider during periods of very heavy rainfall is that the bucket in a TB gauge could be prone to "bouncing" as it falls to release the water. This could result in a reading of two tips, when in actuality, only one has occurred. If this happens multiple times during one event, the data could be greatly skewed. Also, when an event ends and the bucket is no longer collecting precipitation, it could have excess water stored inside that was insufficient to warrant a tip, resulting in a slightly inaccurate reading.

The TB gauges will be used to record the amount of rainfall occurring, but additional equipment is needed to store and transmit the data. The CR200 datalogger, manufactured by Campbell Scientific, Inc. was chosen to handle data storage and transfer from the PicoNet. Essentially, dataloggers are small computers capable of measuring data coming from an outside source, processes the information, and outputs that information using either spread spectrum radios or a serial cable hooked up to a computer. During the calibrations, however, a CR1000 datalogger was used. When comparing the two loggers, there does not appear to be a distinct difference between them except the CR1000 is formatted to handle more input signals than the CR200, and the CR200 series datalogger may be equipped with its own spread spectrum radio, whereas the CR1000 does not. During the calibration process, these differences were negligible. The TB gauges used during calibrations were connected to the CR1000 datalogger, which kept track of the number of tips along with the time at which each tip was registered. Data from these trials were sent directly to a computer (connected by serial cable) running the PC200W datalogger software, where the data were then stored in a file for future alteration, study, and organization. Also, programs were written and uploaded to both loggers so only data collected while a rain event was actually occurring would be saved and transmitted, saving time by automatically removing unimportant data and saving space by eliminating records returning zeros. Though the CR1000 is ultimately a better, more expensive datalogger, they are more than is needed for the network, so CR200s will purchased and connected to external spread spectrum radios for communications.

Each gauge site constructed at KFFL will consist of the same equipment. Three TB rain gauges will be used at each site, in order to improve the accuracy of data collection. If only one gauge is used at a given site, there is no way to tell if the data collected by the gauge is accurate. With three gauges, however, it is easy to observe any inaccuracies between one gauge and the other two corresponding gauges, and therefore, any bad data can be excluded from the analysis phase to resolve the potential errors expected to arise in the results. The three TB gauges will be connected to one CR200 datalogger, supplied with power from two 20W solar panels and two 12V batteries. The 12V batteries are expected to provide enough power to the datalogger and radio given the event that there is absolutely no sunlight for two weeks. Therefore it is unlikely that data or power to the datalogger could be lost. Also, the two solar panels installed at each site allow for the addition of a disdrometer at a later time to gather additional information regarding rainfall characteristics. Furthermore, 2.4GHz spread spectrum radios used in conjunction with Yagi antennas will transfer the data collected by each datalogger to the hub where it is to be processed. The hub of the KFFL PicoNet will be located at the Atmospheric Radiation Measurement (ARM) site in the northeastern portion of the property, and the antennas should have no problem transmitting the data over the given distances. Also, for each site, enclosures will be needed to protect the loggers and batteries from the elements and local wildlife. The Oklahoma Mesonet generously supplied KFFL with the regulators, datalogger enclosures and solar panels that were needed, allowing for the addition of a sixth gauge site that was previously thought to be unaffordable if the enclosures and panels had to be purchased.

4. KFFL/NSSL Surveys

Prior to installing the network and purchasing the equipment needed for the KFFL PicoNet, several trial surveys had to be done both at KFFL and the National Severe Storms Laboratory (NSSL). First, at NSSL, trial experiments using the radios had to be completed to test for interference between the radio signals and the 915MHz wind profiler since it is slated for relocation to supplement the 404MHz profiler currently at KFFL. Initially, it was decided to use 915MHz radios because they would have less difficulty than 2.4GHz radios when sending signals through heavy vegetation over long distances, and were thought to be best for use on the PicoNet. It was found that the radios operated to their full potential when in the vicinity of the radar, but that the radar received large amounts of interference. This finding resulted in switching to radios that operate on a 2.4GHz frequency, to avoid all possible interferences with the profiler once it is relocated to the field laboratory. One problem that could arise from the new radios, however, is possible attenuation in heavy precipitation events and due to vegetation; this has yet to be explored.

Prior to surveying KFFL, topographic maps and aerial photographs of the area were obtained to provide a clearer idea regarding where gauge sites could be located. Several primary locations were chosen, and in using Golay’s 1971 findings concerning non-redundant arrays (discussed in section 2 of this paper), a point array was designed for KFFL that was not only non-redundant, but also provided a wide range of topographic locations for the sites. The aerial photo was primarily used to discern the locations of heavily vegetated areas and whether they would hinder the construction of a gauge site or the radio signals to the hub. Neither of these concerns proved to be problematic, as was found during the survey (Figure 3).

In order to transmit the signals over the longer distances, though the radios were capable of doing so without additional antennas, a Yagi directional antenna had to be used due to line-of-sight problems. The topography of the farm causes changes in elevation of nearly 50 meters in places, resulting in the need to have an elevated antenna to transmit the signal back to the ARM site for data collection. Trials were completed at KFFL using Yagi antennas that were chosen for use on the PicoNet due to their reliability and efficiency. These antennas have a gain of greater than 10dB due to reduced interference by directing the power toward one point, the receiver antenna, resulting in a sizeable decrease in scattering (Sandler, 1995). The receiver antenna will be located at the ARM location, and as long as the Yagi antennas at the respective gauge sites have a line-of-sight connection, data should be transferred without error. Line-of-sight, regarding the antennas and data transfers, refers to the ability of an antenna to “see” the hub given a variety of connections. One way to achieve a line-of-sight is for the antenna to send a signal directly to the hub with no interference. If a situation arises, however, in which one of the antennas cannot directly transmit a signal to the hub, as long as there is another antenna within a line-of-sight, the data can be transferred to that antenna, and then to another antenna as needed before the data can be transmitted to the hub. This allows for ensured data transfer between all KFFL gauge sites and the ARM location where the data will be assimilated.

Again, as was mentioned in section 2, a non-redundant point array was chosen for the organization of the PicoNet. In choosing the point array to be used, the topography of the farm had to be examined, along with the arrays to see if they could be altered in any way to better fit the property. The final array chosen has 6 points, or gauge sites, in which the distance between any two sites never exceeds 1.5 km. In several instances, the distance between sites is a mere 350 meters, which allows for better observation of small-scale precipitation characteristics. Due to the high resolution of the network, it will enable data collection regarding finite characteristics of a storm's precipitation structure, allowing for relatively simple comparisons between observed rainfall amounts and radar algorithm estimations. At certain locations, as the radar beam scans above KFFL, there will be two gauge sites within one sampling volume of the radar return (Figure 4). As the beam diffuses over the site, a sampling volume will be approximately 520 meters by 250 meters, allowing for analysis of the algorithm accuracy when compared to two different readings, since the algorithm computes sampling volume reflectivities using an average over the entire sample volume. All sites within the array were found to have a line-of-sight to the hub as well; therefore data transmission will not be a problem.

5. PicoNet Test Site and Initial Data Collection/Analysis

After concluding the initial surveys of KFFL and NSSL, it was decided to construct a test gauge site in order to be certain that once in the field, the sites would function properly. It was primarily desired to set up the site at KFFL, however due to time constraints and pending approval of the PicoNet locations, it was constructed at NSSL within the vicinity of the KOUN phased array Doppler radar. The site was set up using the same equipment that will be used with the PicoNet, such as three TB rain gauges, a CR200 datalogger, and a 12V battery. The 2.4 GHz radios and antennas were not used, however, since the data were to be extracted directly from the logger using a laptop computer on-site. Also, the enclosures and solar panels were not used because the test site was to only be active for a short period of time; a makeshift enclosure was created that would allow for the protection of the battery, wiring, and datalogger (Figure 5).

The test site was operational for several days before a precipitation event occurred. The event occurred between approximately 0645Z and 0900Z on 27 July 2005, and when the data were collected the following afternoon, the time of the event correlated with radar observed precipitation over the area (Figure 6). One aspect noted regarding the data collected from the event and the radar image is that the precipitation was highly localized and originated from one of two very small cells that passed over the site. This event leads to the assumption that due to the high resolution of the gauge network to be implemented at KFFL that isolated convection may not be a large problem and at least one of the six sites will gather data.

After the precipitation event, data were collected at NSSL by establishing a serial connection to the logger and extracting the data directly to a computer. The data were processed and analyzed using a computer program to get results regarding the total rainfall observed by each gauge, the average total precipitation during the extent of the event for each gauge, and finally, the average rain rate recorded by each gauge at a given time. When the data were read into the program, it allowed a user-created input regarding the time interval over which to average the rain data. For this analysis, 180 seconds was chosen for the interval since the event was spread out over several hours, and that interval would allow for a general idea of the rainfall characteristics and still display some of the variabilities measured by each gauge. At this point in the experiment, however, the data were not compared directly to observed radar reflectivities because it was merely a test phase regarding the instrumentation and data analysis portions of the PicoNet.

Once analyzed, all three gauges though having differing switch closure times all displayed the same resultant total rainfall of 0.2 inches over the duration of the event (Figure 7). This variability in switch closure times is assumed to be directly attributed to microscale variabilities in rainfall over the test site. Also, all three gauges displayed average rainfall that made sense given the conditions, and there were no distinct differences observed between the gauges (Figure 8). Concerning the rain rates associated with the storm, for the most part, the gauges all agreed. At the onset of the event, one gauge recorded a 20mm/hr rain rate while the other two recorded approximately 15mm/hr (Figure 9). Due to the small dataset used for the analysis, it is known the larger rain rate is attributed to an additional bucket tip from one of the gauges. Despite the difference that occurred at the beginning of the precipitation event, rain rates recorded during the event were all very similar. At this point in time, the program used to analyze the data appears to be functioning properly and when implemented at KFFL, can provide abundant information regarding rainfall characteristics not only between 3 TB gauges at a specific site, but rather each TB gauge at 6 different locations.

5. Conclusions and Future Plans

This paper has gone into depth regarding the establishment and initial instrumentation of a high-resolution rain gauge network at the Kessler Farm Field Laboratory in Purcell, Oklahoma. At KFFL, 6 gauge sites will be constructed using a modeled non-redundant point array, each containing three tipping bucket rain gauges, a CR200 datalogger to store the data, two to three 12V batteries and two solar panels to provide energy for the datalogger and radios, and antennas to transmit the signals back to the hub at the ARM site. On 29 July 2005, the tentative locations were given full approval by the KFFL Executive Committee, allowing for further advancement in constructing the PicoNet.

A test site established at NSSL showed the instrumentation to be accurate and in working order to be placed on the sites at KFFL. Data were collected from the test site after a precipitation event and analyzed using the preliminary version of a program that reported the average rain rate, total rainfall, and average rainfall throughout the duration of the event. The data from the three gauges all displayed similar results regarding the precipitation event, and the time at which the data were recorded corresponds to the observation of a storm over the area using the KTLX WSR-88D radar.

As the project moves forward, the main goal is to use data gathered from the KFFL PicoNet in order to verify radar precipitation intensity estimates. Due to the high resolution of the network, small scale variabilities in rainfall will be easily recorded and observed, and will assess the accuracy of the algorithms used by the Radar Operations Center and the National Weather Service. If these algorithms prove to have a significant margin of error apart from the observed rainfall, new algorithms can be developed to enhance the quality of radar research and forecasting in the future.

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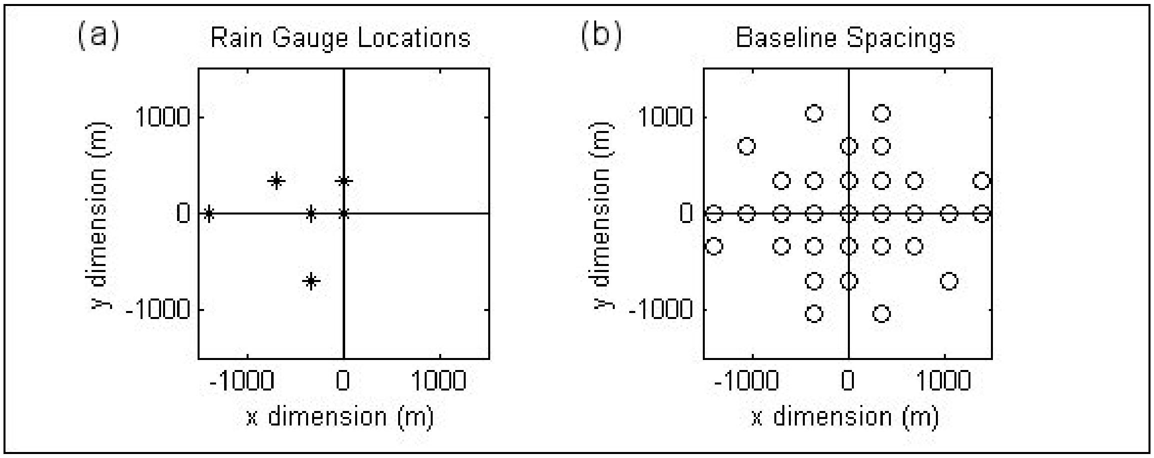

Figure 1a. Plot (a) displays the point array chosen for use at KFFL. The locations are relative to a center point that was chosen at random, and this does not affect the array in any way. One unit distance is equivalent to 350m. Plot (b) displays the corresponding auto-correlative array (or, baseline spacings) of the network at KFFL. These are the distances over which discernable information can be gathered regarding the storm.

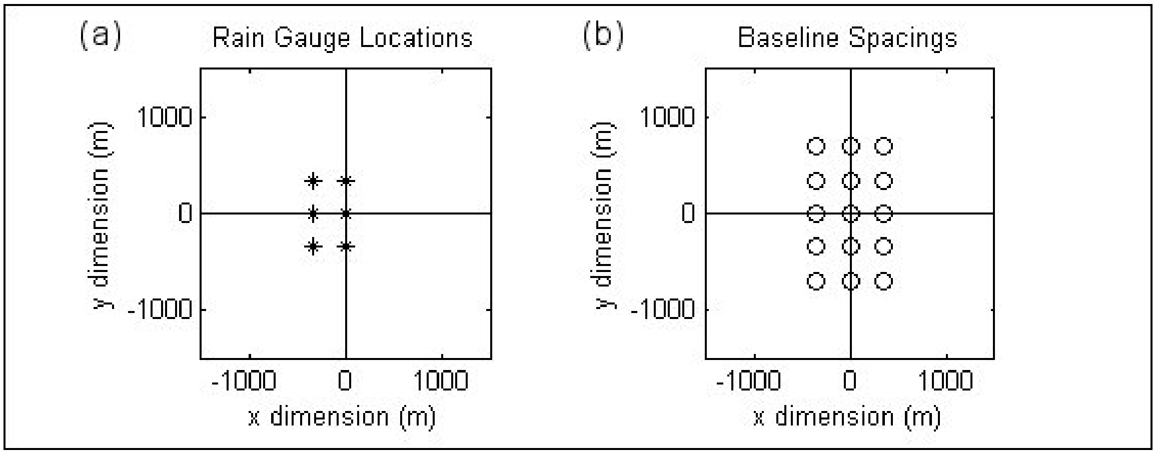

Figure 1b. Plot (a) displays a generic point array of rain gauges in a network. The gauges are separated using a constant distance of 350m. Plot (b) displays the corresponding baseline spacings, and when compared with Figure 1a (above), it can be observed that the array chosen for KFFL will be much more beneficial in surveying precipitation and storm structures.

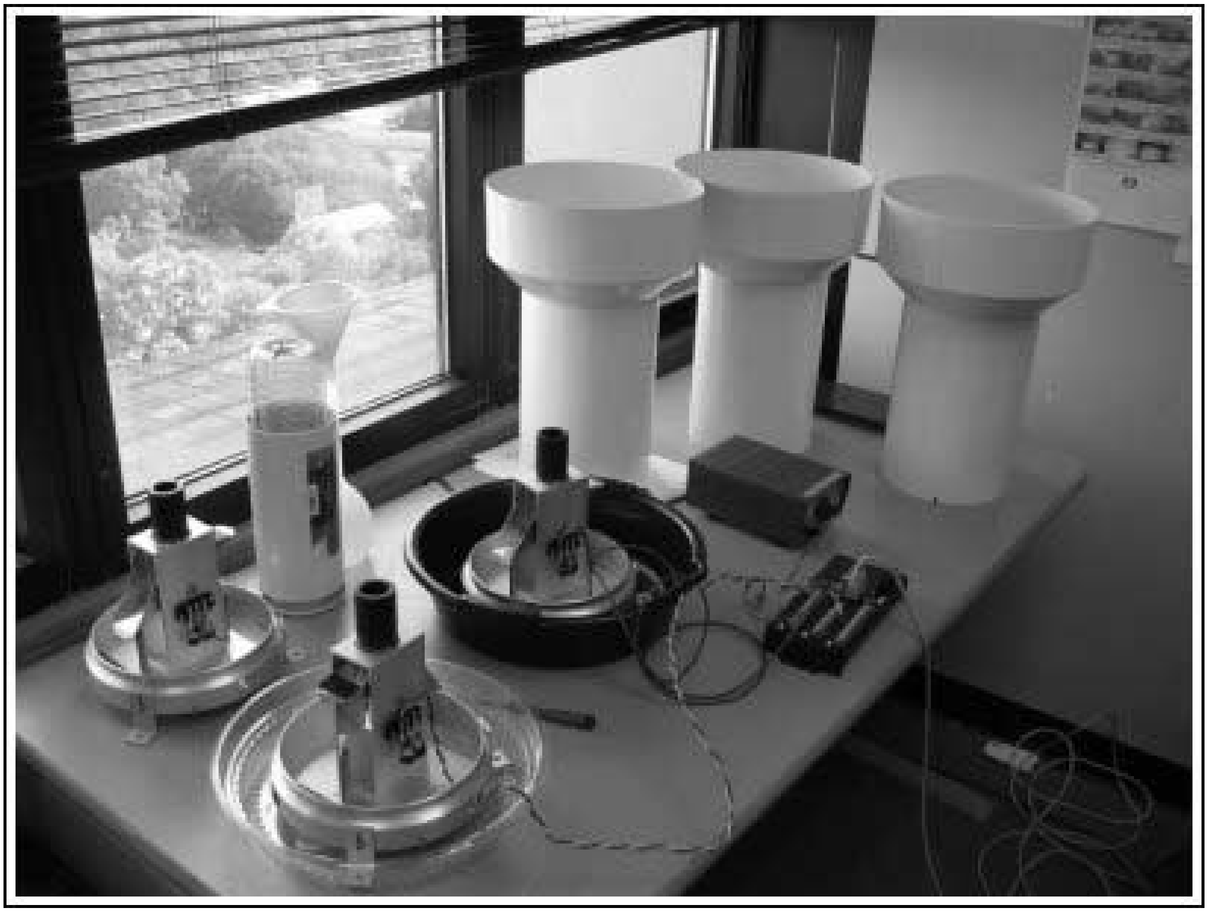

Figure 2. Display of the Mesonet calibration method used in accordance with the three gauges and CR1000 datalogger.

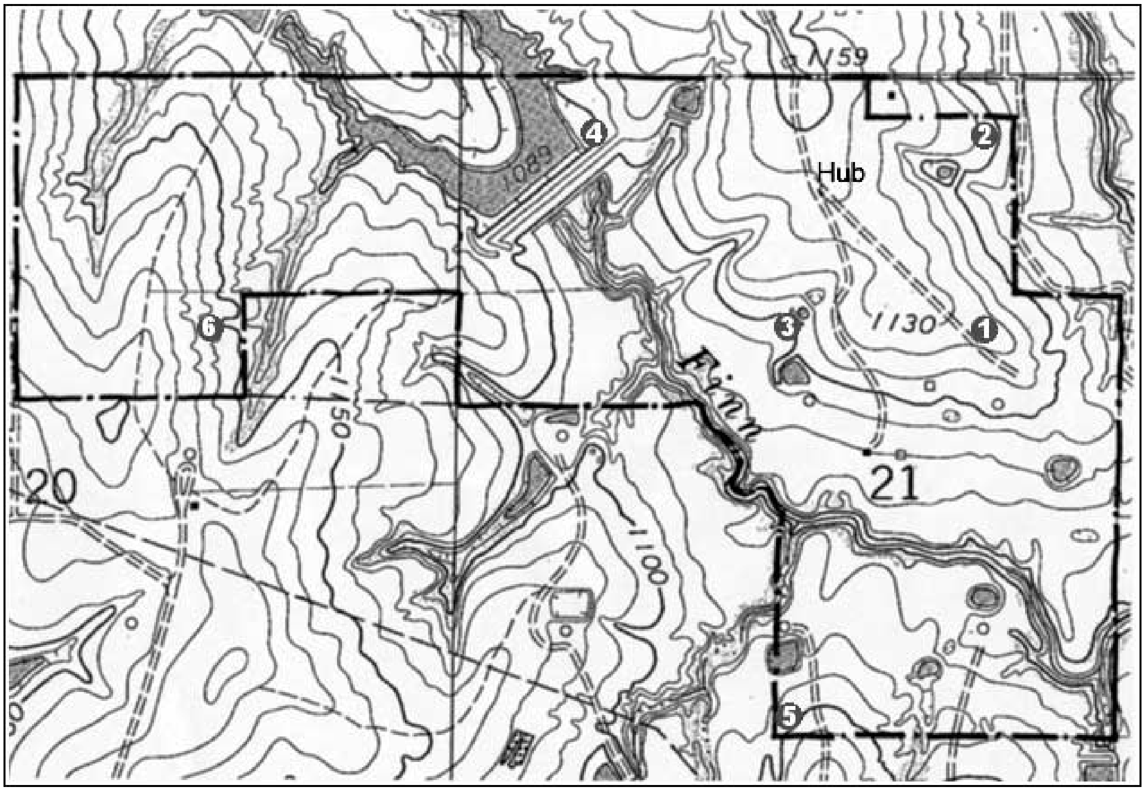

Figure 3. Topographic map of the Kessler Farm Field Laboratory with gauge sites 1-6 plotted. The distances between sites 1 & 2 and 1 & 3 are 350 meters.

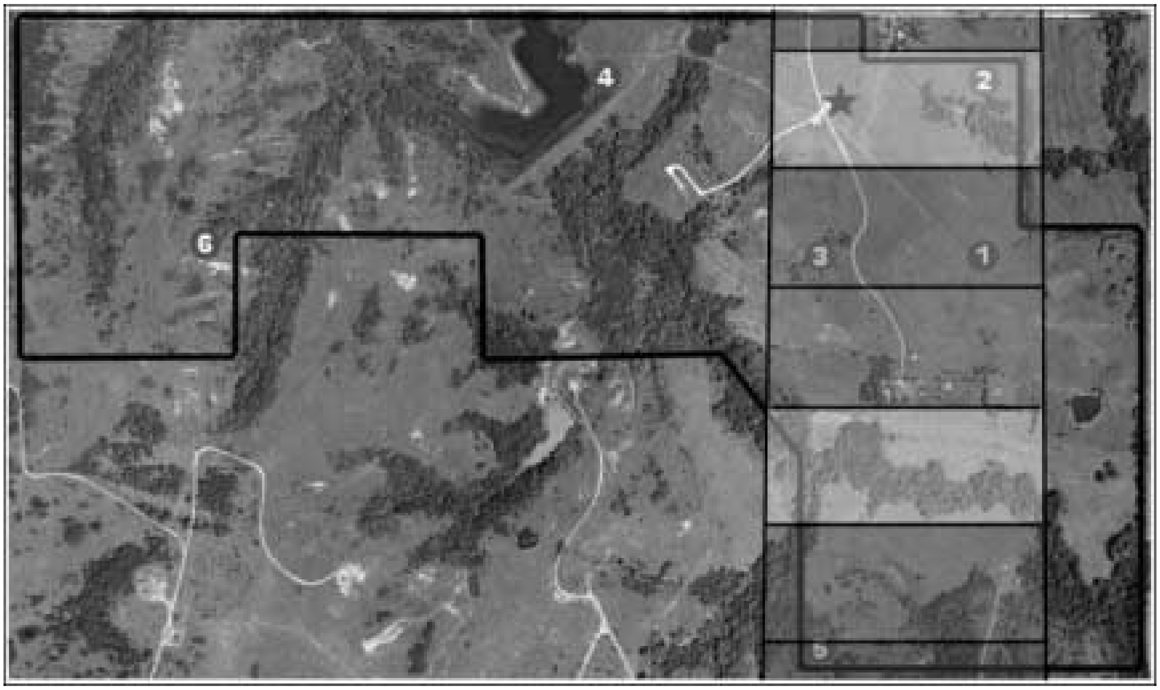

Figure 4. This is an aerial photo of KFFL with the PicoNet gauge sites plotted, and a theoretical radar beam passing over the site from KOUN. Each area represents one sampling volume (520m x 250m) on the radar display.

Figure 5. The PicoNet test site at NSSL, consisting of three rain gauges, 12V battery, CR200 datalogger, and the laptop used to extract the data.

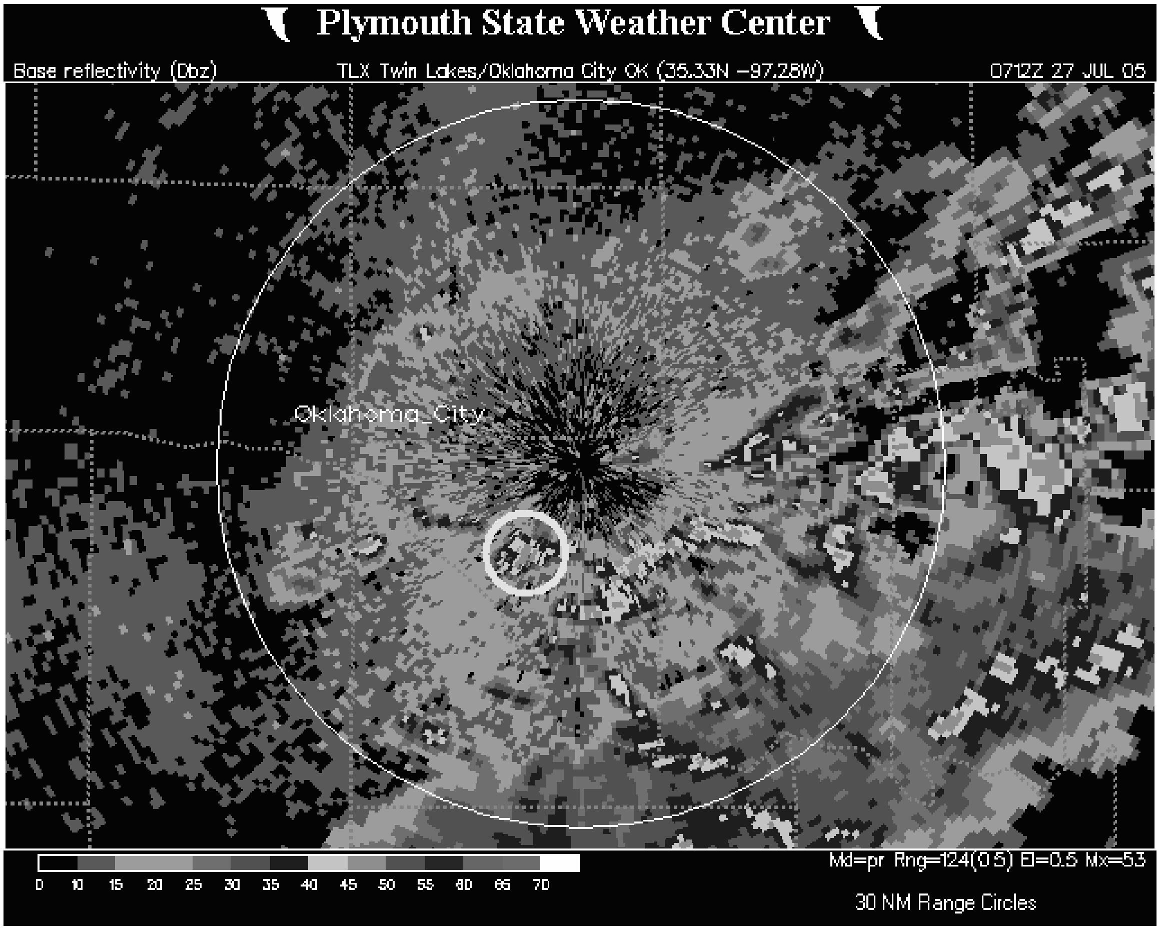

Figure 6. Radar image as seen by the KTLX radar toward the beginning of the event. A strong precipitation cell is identified over NSSL where the test site was located.

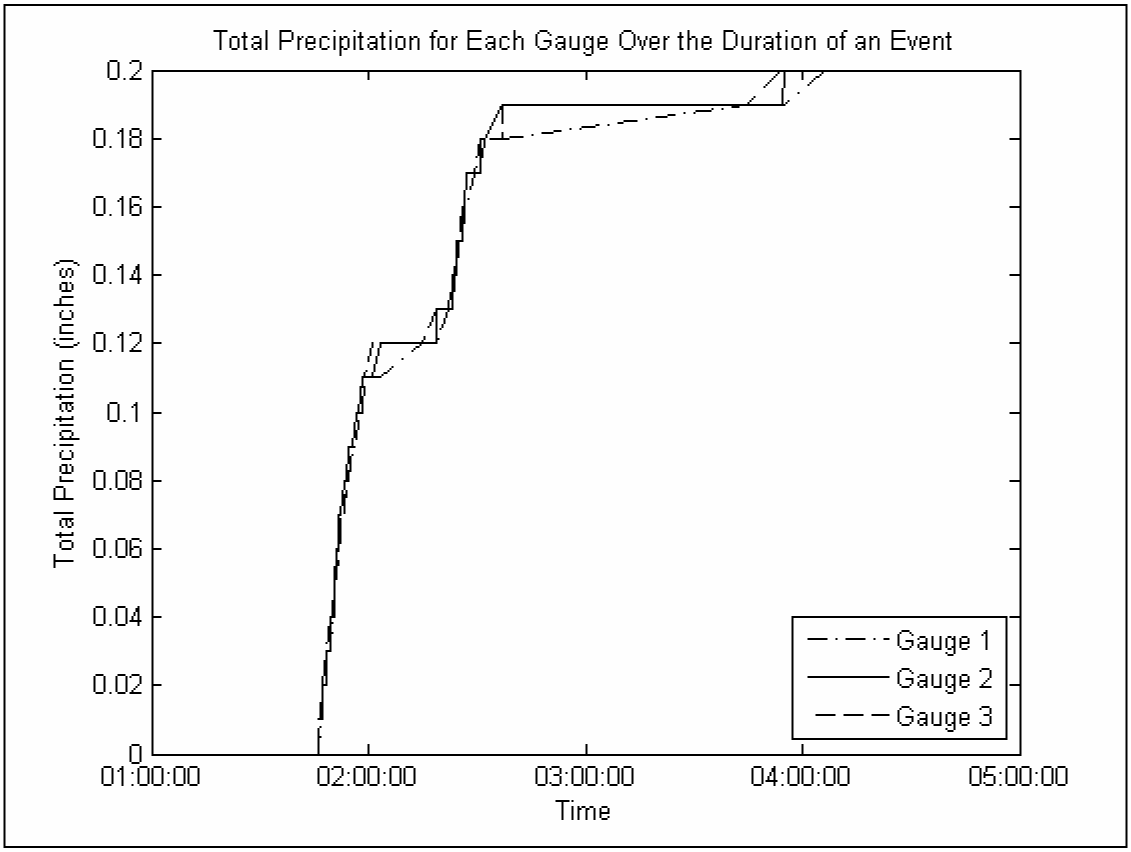

Figure 7. Graph displaying the total rainfall of 0.2 inches, as reported by all three gauges. The graph shows a cumulative total throughout the time of the event. All times in CST.

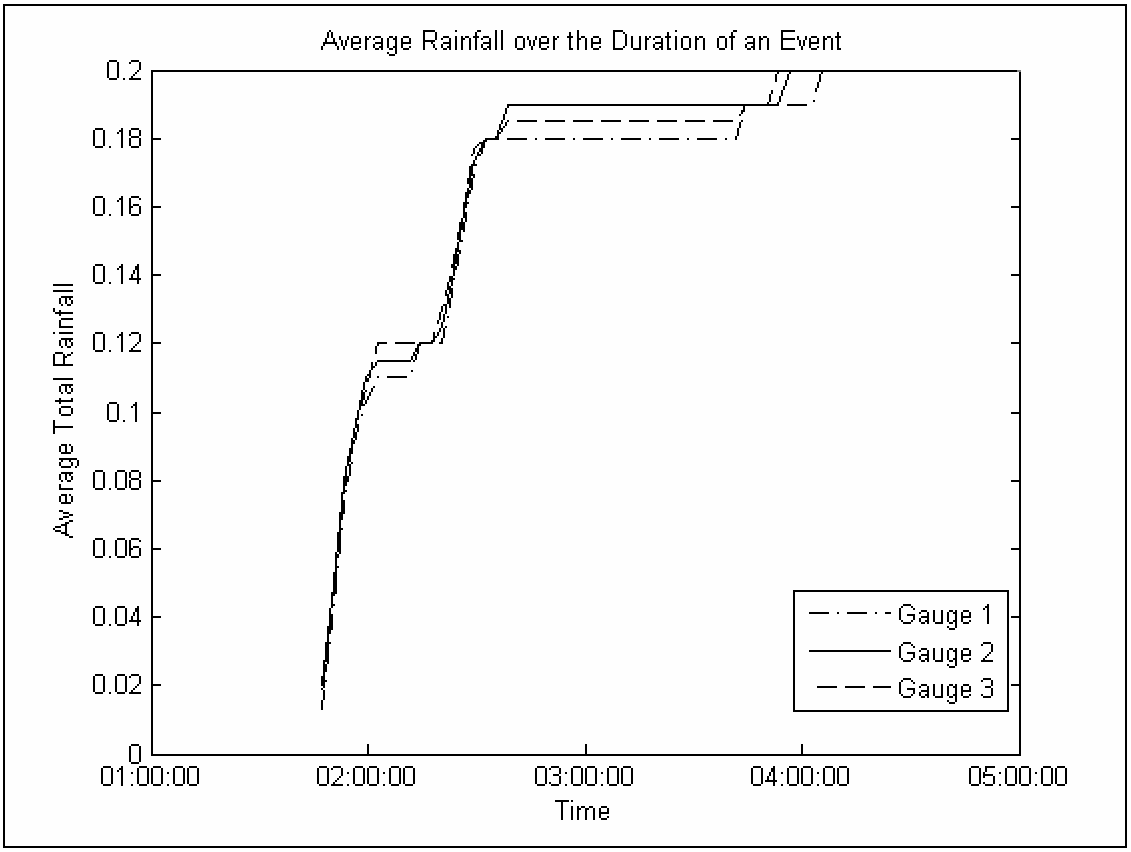

Figure 8: This graph displays the average rainfall for the three gauges throughout the event. Once again, all times in CST.

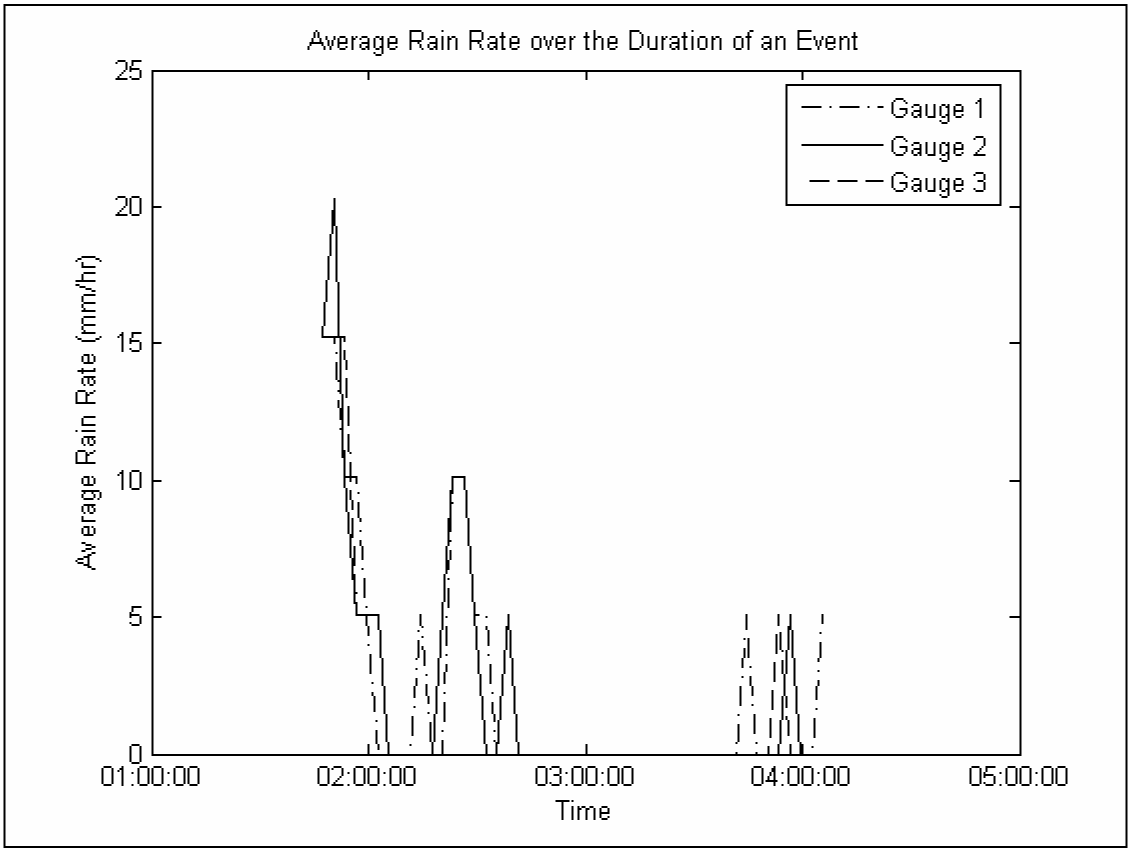

Figure 9: Graph displaying the total rain rate as derived from the gauge data. The spike in rain rate can be seen on Gauge 2 at the onset of the event. Overall, it can be noted that the rain rates were quite similar for all three gauges.