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Microscale rainfall variations as measured by a local volunteer network

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1. Introduction.

Following a devastating flash flood that killed 5 people, injured dozens of others and caused more than \$250m in property damage in Fort Collins, Colorado (Weaver et al 1998, Petersen et al. 1999), the Colorado Climate Center conducted a survey to document total storm rainfall across the city. In the two-to-three months following the flood, several dozen residents were identified who had been operating reliable, well-sited gages the night of the event. Subsets of data from

these sites provided an unexpectedly detailed time/space mapping of the rainfall, and helped to develop an unprecedented description of the catastrophe. Results show a large variance in rainfall across the 40 sq. mi urban area. Depending on the part of town being considered, rain totals ranged from 1.0" to 10.5" over the six hr period from 5:00 p.m. through 11:00 p.m. on the night of 28 July 1997.

Based on the obvious community interest, the Colorado Climate Center began organizing a special volunteer network of observers in 1998. The network has been named the Colorado Cooperative Rain and Hail Study (CoCo RAHS). The chartered purpose of the group is to involve local residents in studies of small scale variations in precipitation that affect Fort Collins and the surrounding environs. By 1999, there were 60 active volunteers within the city, with another 40 Larimer county participants outside the city limits. Volunteers are all properly trained in the siting of rain gauges and making daily observations; including issues of time of day, consistency, and interpreting the gage.

This paper presents preliminary analyses of data from the first two years of operation of the network.

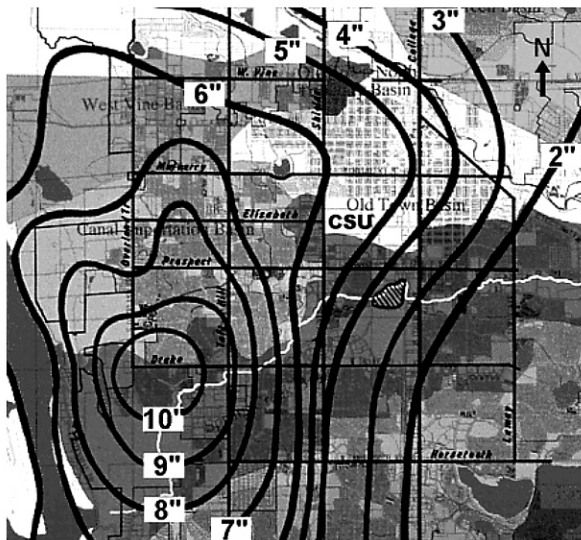


Figure 1. Rainfall over Fort Collins, CO in inches from 5:00 p.m. through 11:00 p.m. on 28 July 1997. Main arterial and collector streets for the city as shown. Roads are separated by 1 mile, the main campus of Colorado State University as indicated.

2. The Issue of "Representiveness."

The National Weather Service (NWS) Cooperative Network, with an average of one observing site every 600 mi² nationwide, is the primary data source for defining climatological patterns across the country. The density of this network is sufficient for developing a reasonable overview of temperature and large-scale precipitation patterns. However, that spacing is often inadequate for defining smaller-scale tendencies in convective precipitation, particularly in

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places where local terrain exerts significant controls on local weather (e.g. near sea coasts, major lakes, rivers, and mountains), or in and around large urban areas (Changnon, et al 1981) .

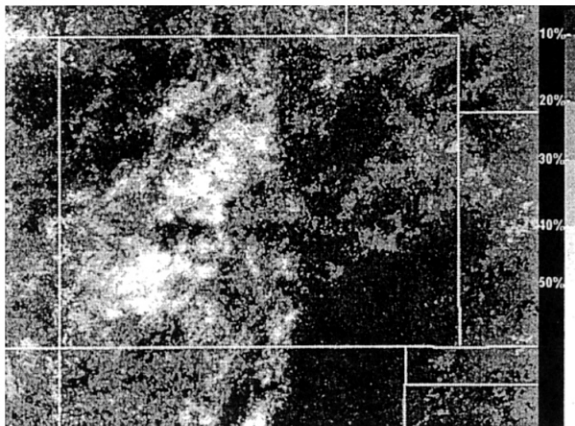


Figure 2. Cloud frequency at 1700 UTC (11:00 a.m. local) for the month of July 1986 from GOES satellite imagery centered over Colorado. Resolution is approximately one square mile per pixel.

Figure 2 portrays cloud frequencies at 1700 UTC for the month of July 1986 over Colorado. The work was done as part of a satellite cloud climatology project (Klitch, et al. 1985, Weaver and Doesken 1990). Cloud frequencies were computed as follows. First, individual GOES visible satellite images were modified such that cloudy areas were turned white and non-cloudy areas black using a visible/ infrared bi-spectral scheme. Resulting images were then summed and averaged for various months and times of day. One of the most fascinating results of that study was that average summertime cloud cover may vary by as much as 30-40% over 1-2 mi distances in regions dominated by significant topographic features – including the so-called Front Range region along the eastern foothills of the Rocky Mountains. And since convective clouds are frequently associated with rain showers in summer, it is clear that the current observational network may be too coarse to resolve these potentially important localized variations.

3. Quality Control

The primary means of data quality assurance for the 1998-99 seasons was the training program that all volunteers were required to attend. As noted, training classes included discussions of data accuracy, measuring techniques, and potential error sources.

Daily reports received cursory quality control by student interns who examined mapped observations

each morning during the summer months. When questionable data points were identified, observers were contacted by phone or e-mail to verify the report. Changes were made when appropriate. The most common data errors were misplaced decimal points and data entered on the wrong date. With a very high density of observations over a small area, this type of error can be easily detected by human scrutiny.

Other error sources were less obvious. For example, interns did not always have the confidence to question observer reports, so some errors may have passed initial examination. Also, differences in the time of observation among observers may also have been a problem. Observers were all asked to take their daily measurements at 7 a.m. local time. Most were punctual. However, for practical reasons some volunteers reported earlier or later on some days. This usually was not an issue, since most summer rainfall in Colorado falls during afternoon and evening hours. However, for those few days when precipitation was falling at or near 7 a.m., even minor differences in time of observation may have contributed to significant errors in the 24-hour precipitation. No attempt was made to adjust for these differences.

4. Interesting Findings.

Working on the relatively small scale of the Fort Collins urban area, one might question whether or not there are any systematic variations in rainfall. We quickly learned that there are both significant variations during individual events, as well as long-term, systematic patterns that begin to emerge upon analysis of the data set as a whole.

The first thing that stood out when we looked at the data were the large differences in rainfall amounts that occur during individual rain events (figure 3). This raised the question of just how representative the historical data from the CSU weather station are for the entire city. In order to focus on this problem, we arbitrarily defined concentric rings around the CSU site. The central “ring” was a circular area of two mile radius centered on CSU, the second was a ring from 2-4 miles around the site, and the third was a similar ring at 4-6 miles. Days were selected for inclusion in this data set if and only if each of the three rings in the set contained at least 5 observations, and each ring had an average of 0.09" of rain, or more. These thresholds were chosen arbitrarily based on the fact that lesser rainfall totals seemed to produce unreasonably large variances, while requiring a larger number of observing sites produced an unreasonably small data set. These constraints left us with 36 case days. The total rainfall for these 36 days was 17.65" at the CSU station. This amount was 85% of the 1999 calendar years' total precipitation.

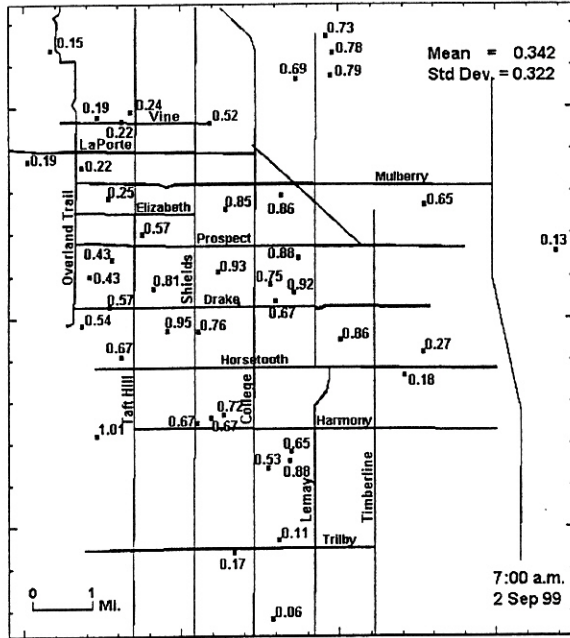


Figure 3. Precipitation map for 24 hr rainfall (in inches) in and near Fort Collins, CO on 01 Sep 99. Observations taken at 7:00 a.m. Mountain Daylight Time on 02 Sep 99. Map shows heavy precipitation swath from southwest to northeast through center of city with light rain along the edges.

The results from this "distance-from-site" set of statistics show that the difference between the mean rain in each area on a given day, compared with the CSU observation for the same day, generally increased as the distance from the CSU site increased. Thus, while the rainfall at CSU was 17.65", the close-in station mean was 17.07", for the middle ring it was 16.36", and in the outer ring the mean was 15.94". At least during the 1999 rainy season, stations furthest away from CSU experienced only about 90% of the rainfall recorded at the campus.

Next, we wanted to know if the observed variance depended on elevation across the city -- an indication that upslope flow plays a key role in the city's rainfall distribution. We binned the data into three north-south oriented slices. The first was a 2 mile-wide swath on the west side of town, the portion of the city closest to the foothills. The second was a central slice centered on the CSU campus. The third was a 2 mile-wide strip on the east side of town. The mean for the west side was 17.18", for the central was 17.04", and for the east, 15.75". That is, the higher elevation side of Fort Collins, received about 9% more rainfall than did the slice further east. It is clear that the 1999 results did show a slight biasing toward the foothills side of the

city. However, from a subjective point of view, 1999 seemed to local observers to be a little more random than most years, i.e. we felt the bias had been even stronger in previous years.

To check that premise, we looked at some 1998 data collected over a shorter time period by a smaller, preliminary network. That data set only included 20 case days. Plus, while the 36 case days in 1999 represented about 85% of the total year's rainfall, the 1998 cases represented only about half. Nevertheless, the results seem to confirm the subjective impression. The total average rainfall for the campus site for June through October was 7.09", for the west side of town 8.30", and for the east 6.89". That is, there was about 20% more rain on the western (higher elevation) side of town compared to the east.

Finally, we wondered how well-correlated daily precipitation amounts were across the city. To quantify this problem we utilized the 36 case-day data set, but examined only the 20 sites that had a nearly complete data set (defined as reporting on 32 or more of the rain days) for the study period. Station-to-station correlations were computed. Figure 4 shows correlation coefficients plotted as a function of distance from the CSU weather station. Even over these short distances, the decay in the correlation is obvious.

Fort Collins, Colorado 1999 Daily Precipitation Correlations as Function of Distance

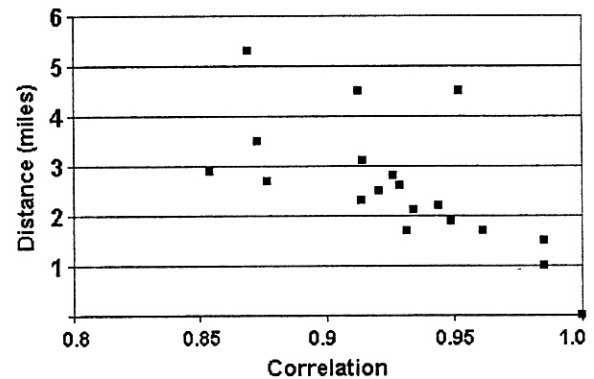


Figure 4. Station-to-station correlations for 20 sites in the 1999 precipitation data set. Showing correlation coefficients plotted as a function of distance from the CSU weather station. Note that everything over 2 miles is less than 90% correlated.

Hubbard (1994) showed that over the relatively homogeneous areas of the Great Plains, weather stations need only be about 35 miles apart to explain

at least 90% of the variance in daily maximum temperatures. However, he found that stations would need to be about 3 miles apart to achieve the same criterion for precipitation. Our results suggest this restriction may not be enough in topographically controlled areas.

5. Concluding Remarks.

The issue of whether the CSU weather station (the site on which the 110 year record for Fort Collins is based) is truly representative of the city as a whole is becoming increasingly important -- particularly when considering flood mitigation decisions in the aftermath of the July 1997 flood. This rainfall data base is used in a variety of applications including; storm water drainage engineering, general city planning, land use decision making, architectural design, and insurance requirements to name just a few. This question becomes more complex as the area of the city increases.

The distance-from-site results, the east-west bias statistics and the correlation study all give some information in this regard. At least for 1999, it appears that rainfall at the CSU station exceeded that for the two-mile-radius region around the campus by roughly 3%, for the 2-4 mi circular ring by about 8%, and for the 4-6 mile ring by 11%. Preliminary correlation statistics show that the site may only be representative within a couple of miles of the station. The correlations help confirm the distance-from-site findings, and show that the Hubbard (1994) results may actually represent an understatement for regions in which terrain exerts significant control on the precipitation process. For those years in which there is a stronger upslope signal (e.g. 1998), it appears that the CSU measurement may understate what's happening on the west side of town by a significant amount. For the 20 cases in 1998, the difference was a little over 17% -- for the night of 28 July 1997, precipitation on the west side was nearly double that recorded at the CSU campus.

Future research will focus on the types of analyses described above. Additionally, we plan to separate various rainfall events according to the "type" of weather event taking place (e.g., strong upslope cases, fronts, etc), and by season.

6. Acknowledgments.

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7. References

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