The Community Collaborative Rain, Hail, and Snow Network

Informal Education for Scientists and Citizens

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The Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS) originated in the aftermath of a flash-flood storm that dropped more than 12-in. of rain over a small portion of Fort Collins, Colorado, on 28 July 1997, and a similar storm the following evening over the grasslands of northeastern Colorado. These floods were responsible for several fatalities and at least $200 million in property damage. Neither event would have been accurately recorded by existing networks of official weather stations. National Weather Service (NWS) radar also failed to assess the severity of these storms (Kelsch 1998a,b; Petersen et al. 1999). However, when the citizens of these areas were asked to help, they enthusiastically provided scientists with a wealth of information from their own backyard observations.

These data eventually resulted in the very accurate mapping of precipitation from the Fort Collins flash flood that continues to be used by engineers, hydrologists, weather forecasters, city planners, emergency managers, attorneys, teachers, historians, and many others for such applications as flood forecasting, drought monitoring, verification of radar-estimated precipitation, and climate trends.

Encouraged by the enthusiastic public response, the Colorado Climate Center at Colorado State University (CSU) in Fort Collins began mobilizing a network of citizen rain and hail observers in the spring of 1998. The initial plans targeted teachers and students from all grades in Fort Collins. However, unexpected free publicity from local media spread the word to the general public. Within a matter of days over 150 people volunteered, including students from nearly 40 schools in the region and interested adults.

What started as a collaborative data-collection venture has developed into an exciting community-based science education program that includes classroom presentations, field trips, training sessions, picnics, and informal seminars. CoCoRaHS now includes over 1000 active volunteers across Colorado (see Table 1), as well as several hundred in Nebraska, Wyoming, Kansas, and New Mexico. They range in age from 6 to 80-plus years. This diversity of age and background of participants is one of the true

TABLE 1. Level of participation in the CoCoRaHS network (Colorado only) from 1998 through Oct 2004. Active volunteers are defined as observers who submit at least five observations between 1 Jun and 31 Oct for the calendar year. In addition to the numbers below, several hundred more observers participated for a few weeks but have not remained active.

Year	Active volunteers	No. of Colorado counties
1998	110	1
1999	240	3
2000	358	6
2001	432	9
2002	582	22
2003	760	43
2004	1036	60

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strengths of the program, providing a stimulating mix of experience and youthful curiosity. In 2003, CoCoRaHS was awarded a grant from the National Science Foundation (NSF) Informal Science Education (ISE) program to expand into rural areas of far eastern Colorado, southern Wyoming, western Nebraska, and western Kansas, as well as to increase formal teacher education.

An important feature of CoCoRaHS is its simplicity. Participants use the simplest of devices—a standard 4-in.-diameter rain gauge[1] to measure rainfall (and snow-water equivalent) and a 1-in.-thick styrofoam pad covered with heavy-duty foil to measure the number and size of hailstones (Fig. 1). These low-cost measurements help to fill the huge gaps between weather-observing sites across the CoCoRaHS region (Fig. 2). Another strength of the project has been local sponsorship. Water providers, storm-water utilities, private companies, educational organizations, and others have supported more than 20 high school and college student interns, and supplied rain gauges and hail pad materials. Local volunteers coordinate projects and help recruit and train volunteers.

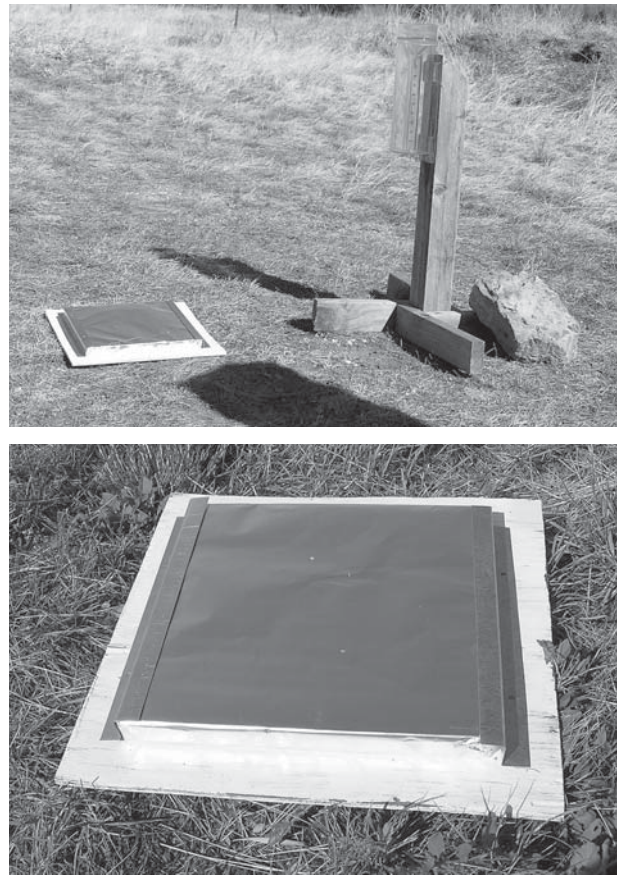

Fig. 1. (top) Instruments utilized by CoCoRaHS observers deployed for precipitation data collection: (left) 12 in. × 12 in. hail pad and (right) 4-in.-diameter rain gauge. (bottom) Close-up view of a hail pad mounted with holding brackets. The hail pad is made of styrofoam and is covered with aluminum foil.

DATA COLLECTION AND QUALITY CONTROL. The standard daily observation of total liquid precipitation (rain or melted snow) is performed at 0700 LT. This observation is submitted to the CoCoRaHS Web site (**www.cocorahs.org**) or phoned into the CoCoRaHS office. Precipitation maps (Fig. 3) are automatically created and updated throughout the day to include observations that are reported late.[2] The system also accepts multiple-day observations.

In addition to the daily precipitation observation, volunteers can also submit reports of intense rain or hail on the CoCoRaHS Web site. The intense rain report queries the observer for an estimate of the total rainfall over a specified time (e.g., 1 h) and any indications of flooding. Observers can submit a "quick" hail report that includes starting time, approximate hailstone size (maximum, minimum, average), the texture of the hailstone (i.e., hard versus soft), and any evidence of damage. Later, volunteers can submit a "detailed" hail report that further describes the duration of the event, size and depth of the hailstones, occurrence of rain with the hail, approximate fall angle of the hailstones, and evidence of damage.

The hail and intense rain reports are sent directly from the CoCoRaHS server to the Local Data Acquisition and Dissemination server at the NWS office in

[1] The rain gauges are manufactured by Productive Alternatives in Minnesota. Preliminary comparisons at the CSU campus weather station in Ft. Collins suggest that the 4-in. CoCoRaHS gauge has a collection efficiency of 101%–105% in rain with respect to the NWS 8-in. standard rain gauge (SRG). The difference appears to be that the SRG (copper) absorbs some precipitation before it enters the inner measurement cylinder. With snow, it is likely that the CoCoRaHS gauge has a reduced collection efficiency relative to the SRG, especially in open areas with significant wind. Observers are trained to pay attention to gauge placement and to collect core samples of snow in situations where undercatchment by the gauge is suspected.

[2] Daily precipitation observations must be collected at 0700 LT ± 2 h, and volunteers are encouraged to report their observations as soon as possible; however, the observations can be reported to CoCoRaHS at any time.

Boulder, Colorado. If criteria such as a certain hail size or rainfall rate are met, the report is reformatted and sent to the appropriate NWS offices. NWS workstations can be set to alarm upon receipt of this report, ensuring that the warning forecaster sees the data immediately. These reports are used for nowcasting and for the issuance and verification of flood and severe thunderstorm warnings (described below). As CoCoRaHS continues to expand, these data will be sent to other NWS offices in real time.

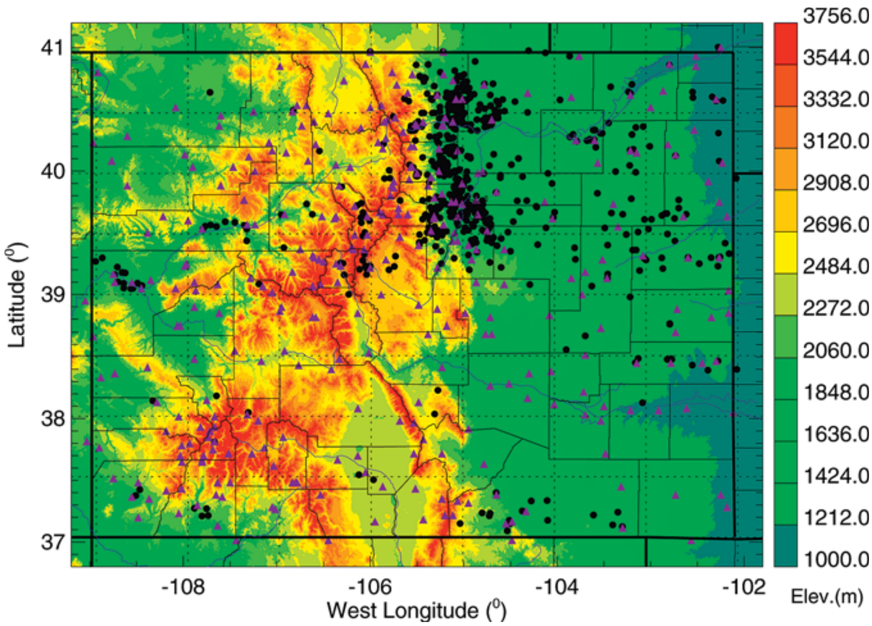

Fig. 2. Locations of active CoCoRaHS (black circles) and NWS (purple triangles) observers in Colorado during 2003. Elevation (m) is indicated by color contours.

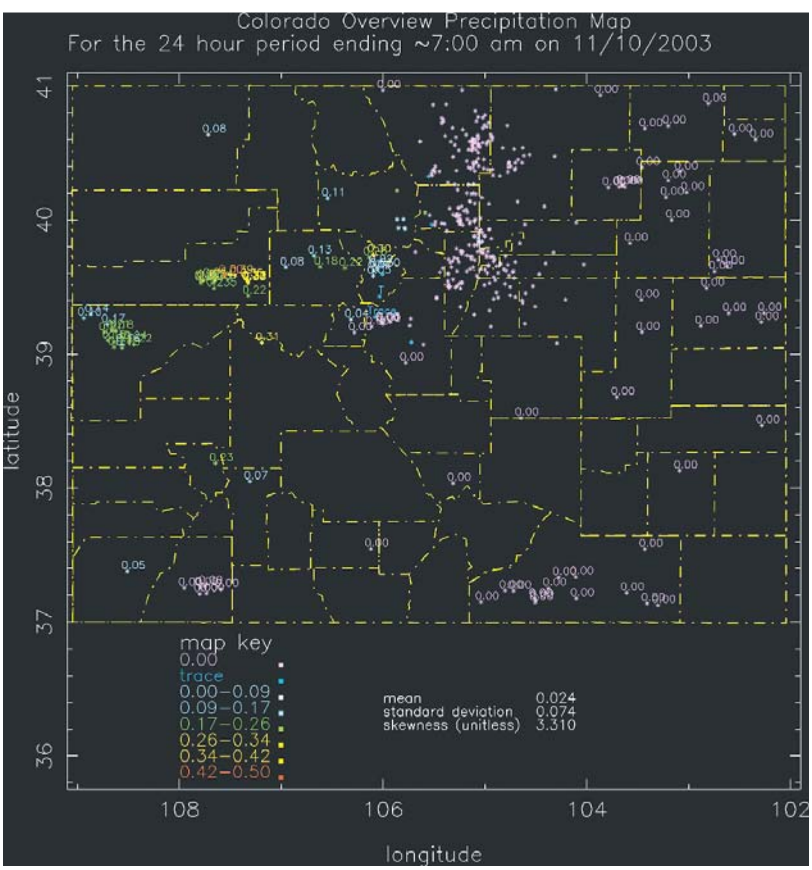

Fig. 3. Example CoCoRaHS daily precipitation map (in.) across Colorado, ending at 0700 LST 10 Nov 2003.

In addition to daily maps, a variety of data reports are produced that allow for the quick and easy analysis of frequency, magnitudes, and areal extent of rain, snow, and hail. Because data quality is a paramount concern, we have taken a number of steps to ensure data accuracy and consistency.

INITIAL TRAINING. All volunteers are strongly encouraged to attend a 2-hour training course. This course covers the placement of rain gauges and hail pads for maximizing gauge catch efficiency and practice at measuring precipitation from a variety of storm types. Participants are also given instructions on how to report daily and extreme-event data, and common errors and how to avoid them. We also provide written instructions to volunteers, including detailed information on snow-measuring techniques. Training materials are posted on the CoCoRaHS Web site. We are developing a training video to enhance the training process.

DATA ENTRY QUALITY CONTROL. Training is not

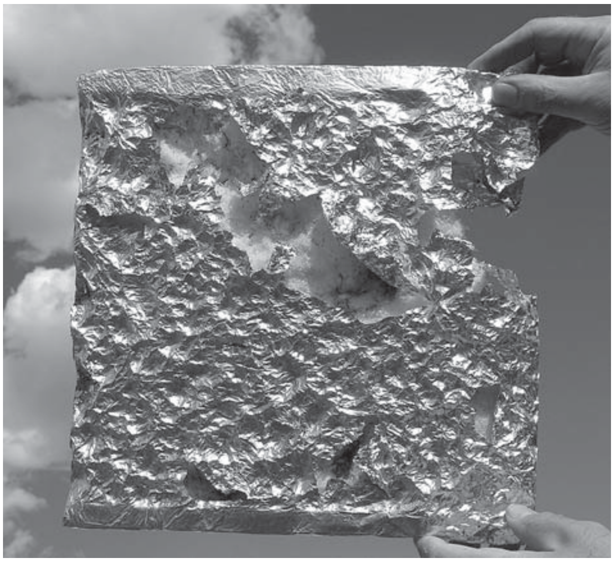

Fig. 4. CoCoRaHS hail pad after sampling 3-in. (7.6-cm)-diameter hail.

a sufficient guarantee of data quality. Automated checks during Web-based data entry sometimes identify and disallow incorrect station numbers, dates, time, or unrealistic precipitation values.[3] Meanwhile, experienced CoCoRaHS personnel process phone messages that are submitted by volunteers and correct detectable errors before entering observations into the database.

CONSISTENCY CHECKS. Currently, there is no automated data-quality control performed after data have been entered into the system. One or more CoCoRaHS volunteers check precipitation maps each day to visually identify potential errors. Sometimes errors and their causes are obvious, and corrections are submitted immediately. More often, however, observers are asked to confirm their data entry. As CoCoRaHS continues to expand, methods such as precipitation validation (PrecipVal; Urzen et al. 2004) could be adopted for CoCoRaHS spatial data checks in order to decrease random errors. PrecipVal utilizes independent data sources to increase confidence in a particular gauge estimate (Urzen et al. 2005). Typically, we ask volunteers to check their own station data to verify accuracy with their personal records (usually at the end of each water year—30 September).

STATION LOCATIONS. To ensure accurate station locations (for analysis, etc.), CoCoRaHS staff use commercial mapping software and hand-held global positioning system (GPS) units to determine latitude, longitude, and elevation for each station on the master list.

HAIL OBSERVATIONS. Perhaps the most interesting and unusual aspect of CoCoRaHS is hail-mapping and analysis. After a hailstorm, damaged hail pads (Fig. 4) are collected from volunteers. The pads, not the hail reports, are the final data source that is inventoried at the CoCoRaHS office. Paid student interns examine each hail pad and measure and count the size and number of dents and relate dent size to actual hailstone size. These data are entered into the archive along with digital images of each hail pad

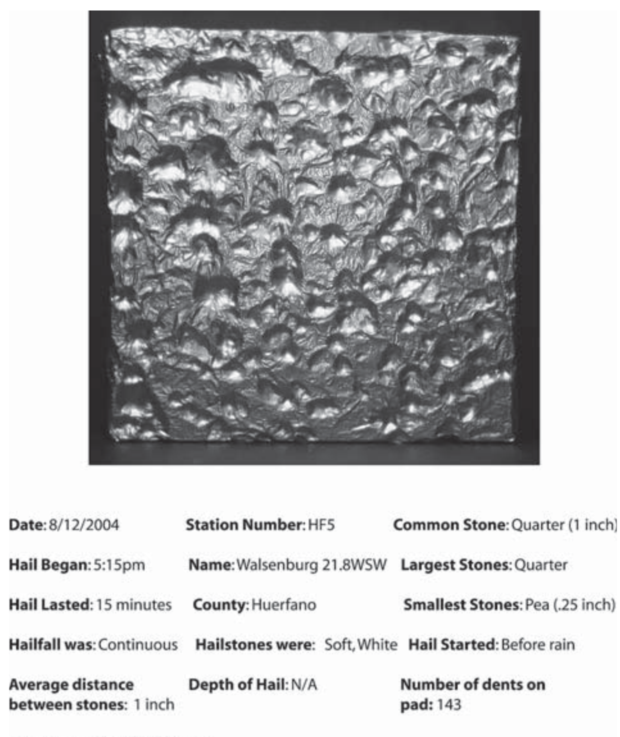

Fig. 5. Example of hail pad digital image and accompanying hailstone data (available on the CoCoRaHS Web site).

[3] Despite the large number of daily observations, data problems are usually easy to spot because of the relatively high network density and because the data are inspected on a daily basis. New software is currently under development, based on observing 6 yr of volunteer data entry, to catch as many data-entry errors as is reasonably possible.

(Fig. 5). All data, including individual daily entry reports, summaries, maps (rain, snow, snow-water content, hail occurrence and size), and the digital hail-pad images, are available at the CoCoRaHS Web site.

Fig. 6. Demonstration at the CLT West math and science teacher workshop in Jun 2003 by one of the authors (N. Doesken) of how precipitation measurements are collected in CoCoRaHS.

EDUCATIONAL OPPORTUNITIES. CoCoRaHS offers a variety of learning opportunities and venues for project volunteers. During the initial training session, participants acquire basic skills in scientific data collection and research methodology that meet national science education standards. We also offer routine field trips to the CSU–University of Chicago–Illinois State Water Survey (CHILL) National Radar Facility and regional water storage facilities, as well as seminars and the annual Rocky Mountain Weather and Climate workshop.

This workshop, held annually in collaboration with the National Oceanic and Atmospheric Administration (NOAA) and National Center for Atmospheric Research (NCAR) facilities in Boulder, features scientific talks on a wide variety of topics, ranging from inaccuracies in numerical forecast models to regional climate variability. The 6-h workshop usually attracts about 100 participants, many of whom travel more than 50 miles to attend. We expect to hold more regional workshops as CoCoRaHS becomes established in nearby states.

Periodic e-mail and newsletters inform participants about how CoCoRaHS data are used by researchers, natural resource managers, and others. Informal surveys document that year after year, CoCoRaHS volunteers remain committed to the project because they know that the data they provide are important and are actually used.

Initially CoCoRaHS provided K–12 teachers with classroom materials only upon request. Workshops and widespread classroom involvement simply were not feasible. However, after receiving NSF ISE support, CoCoRaHS conducted its first teacher workshop in June 2003 in collaboration with the Center for Learning and Teaching in the West (CLT West; information available online at **www.csmate.colostate.edu/projects/cltwest.html**). The workshop was attended by about 30 fifth- through twelfth-grade math and science teachers from northeast Colorado. CoCoRaHS occupied a half-day of the 5-day CLT West workshop on Earth science. The teachers were given weather measurement, instrument, and map-contouring exercises, using CoCoRaHS data (Fig. 6) and then were introduced to radar estimation of rainfall. They identified areas of hail in a thunderstorm based on the CSU–CHILL radar data, then CoCoRaHS hail observations were overlaid to show both the usefulness of the polarimetric radar data and the value of ground validation.

In 2004, CoCoRaHS partnered with the Colorado Board of Cooperative Educational Services (BOCES) for a series of six half-day teacher workshops in rural northeast Colorado. The workshops were conducted in collaboration with the Global Learning and Observations to Benefit the Environment (GLOBE) project at CSU (information online at **www.globe.gov**), and covered weather instruments, weather analysis, the hydrologic cycle, cloud identification, and interpretation of radar and satellite images. Ultimately, the participants will develop a curriculum for classroom use, which will be posted on the CoCoRaHS Web site and will serve as resource contacts for other teachers. Participants received continuing education credit for participating in the workshop series.

RESEARCH APPLICATIONS: COLLABORATION WITH THE CSU–CHILL RADAR FACILITY. The precipitation data collected since 1998 are now used routinely by the NWS and others. CoCoRaHS data have been included in formal research and have improved our picture of local precipitation patterns and variability (Doesken and Weaver 2000). As described below, the CSU–CHILL radar facility has also used CoCoRaHS data to validate radar estimates of rainfall and hail size and location (Cifelli et al. 2003; Kennedy et al. 2003).

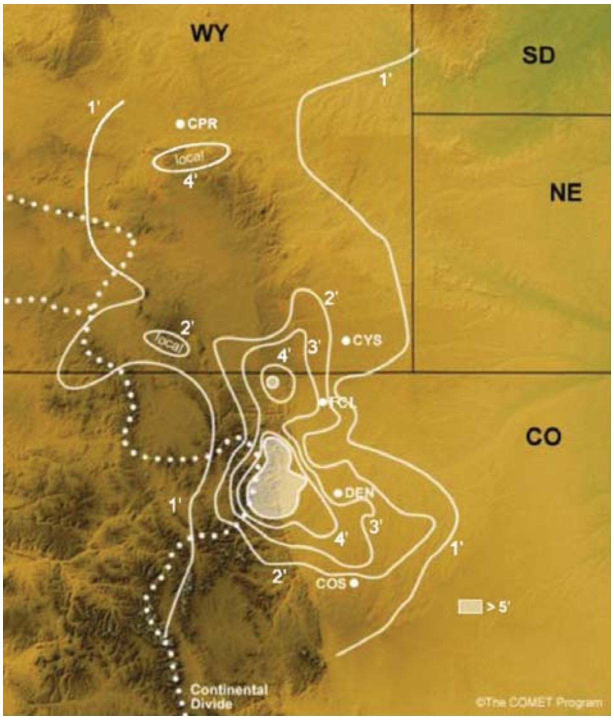

FIG. 7. Contour map (ft) of accumulated snowfall along the Colorado and Wyoming Front Range during the March 2003 blizzard event. Background shading indicates topographic relief. The map was compiled by the UCAR COMET program with assistance from the Colorado Climate Center. Data for the map were derived from a combination of CoCoRaHS and NWS observers. The locations of Colorado Springs (COS), Denver (DEN), Fort Collins (FCL), Cheyenne (CYS), and Casper (CPR) are indicated.

During June–September of 2002 and 2003, CoCoRaHS collaborated with the CSU–CHILL radar facility to explore the ability of polarimetric radar to improve the operational characterization of hail and the estimation of intense rainfall in northeast Colorado. The project was supported by a grant from the Cooperative Program for Operational Meteorology, Education, and Training (COMET).

The project involved surveys of the hail swaths. Witnesses were asked about hailstone sizes, hardness, and resultant damage, and helped estimate hailstone diameters with a series of calibration spheres. A hand-held GPS unit was used to identify the locations of the hail observations. Some of the most comprehensive observations were collected by a CoCoRaHS volunteer whose hail pad was partially destroyed by hailstones of nearly 3 in. (7.6 cm) in diameter (Fig. 4). He also collected some example hailstones, saved them in his freezer, and documented their size with photographs. The information collected by such dedicated volunteer observers is of great utility to both forecasters and researchers. Detailed comparisons of the CSU–CHILL polarimetric radar hail characterizations with the observers' data will be presented in a separate journal article.

RAINFALL ESTIMATION. The observations have also proven useful in a comparison of radar–rainfall estimation techniques involving the polarimetric CSU–CHILL and standard Next Generation Weather Radar (NEXRAD) *Z–R* algorithms (Cifelli et al. 2003). The 24-h accumulated precipitation data from CoCoRaHS within the domain of CSU–CHILL radar coverage were used for validation. A hydrometeor identification (HID) algorithm based on fuzzy logic was also used to identify the presence of various forms of precipitation ice over the rain-gauge networks. Precipitation ice was categorized as dry snow, wet snow, dry graupel, wet graupel, small hail, large hail, small hail and rain, and large hail and rain.

Not surprisingly, our results (not shown here) suggest that the identification of precipitation ice is essential for identifying situations where the NEXRAD *Z–R* method will likely provide poor precipitation estimation, with resulting implications for NWS flash-flood warnings. Several improvements of the CSU–CHILL polarimetric algorithm are planned in the near future, including better clutter suppression and integration of the HID in rain-rate estimation.

In the next stage of analyses, we hope that the information from hail pads (size distribution and density) can be correlated with polarimetric radar observations from the CSU–CHILL radar.

COLORADO FRONT RANGE SNOWSTORM: 17–19 MARCH 2003. The Front Range of the Rocky Mountains experienced some of the greatest snow accumulations in recorded history in March 2003 (Fig. 7). Approximately 2–7 ft (0.5–>2.0 m) of high-water-content snow fell over the core of the CoCoRaHS observation area in less than 48 h, closing schools, shutting down commerce, knocking out power—even destroying buildings due to the massive weight of the snow. While the gauges used in CoCoRaHS are suitable for measuring the water content of small-to-moderate snow events, this storm pushed the limits. Nevertheless, nearly 400 CoCoRaHS volunteers in northern Colorado sent in

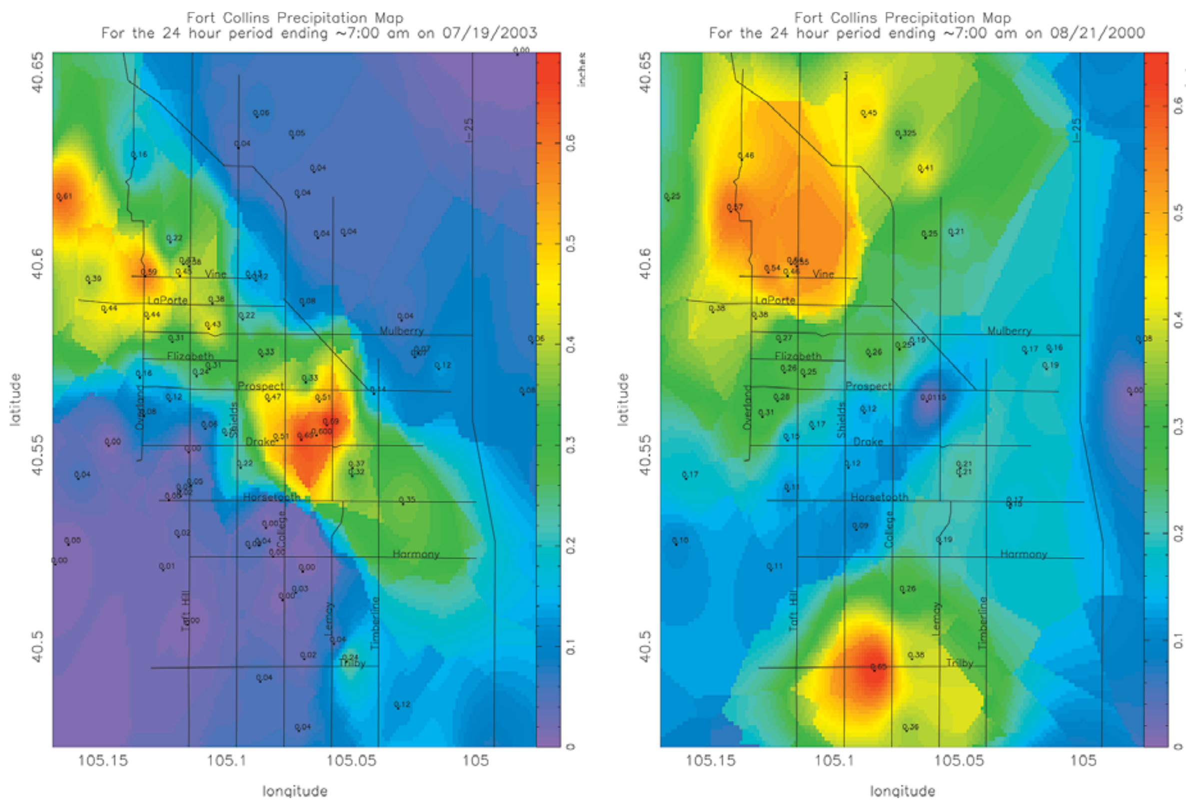

Fig. 8. Contour maps of precipitation (in.) for the 24-h period ending at 0700 mountain daylight time on (a) 19 Jul 2003 and (b) 21 Aug 2000 in Fort Collins, CO.

measurements from the storm. The deep and dense snow, combined with strong winds in many areas, made accurate measurements difficult. Yet, the spatial concentration of observers made it possible to capture fascinating local details of storm precipitation. As one observer aptly stated, "There was nothing else to do than to take measurements."

Several areas in the lower foothills of the Colorado Front Range received significantly less snowfall than areas all around them, despite upslope flow throughout the storm (e.g., the area southwest of Fort Collins in Fig. 7). Scientists at the University Corporation for Atmospheric Research (UCAR) in Boulder, Colorado, and at CSU, many of whom have become project volunteers, are scrutinizing the CoCoRaHS and CSU–CHILL radar data to better understand the dynamics of this truly monstrous storm.

CLIMATE APPLICATIONS OF COCORAHS DATA. CoCoRaHS observations are a rich data source to help the Colorado state climatologist's office answer questions about precipitation characteristics that are not easily understood with data from traditional sources. Storms in the Rocky Mountain area produce complex and highly variable precipitation patterns. Resolving precipitation patterns, such as those shown in Fig. 8, where rainfall swaths are restricted to several city blocks, simply would not be feasible with conventional observation networks. Indeed, one of the most evident conclusions since CoCoRaHS began is that the most unusual storm is the one that produces fairly uniform rainfall or snowfall patterns across the region.

Furthermore, U.S. surface-weather observer networks collect very little quantitative hail data. The NWS Severe Weather Spotter network and the Cooperative Observer network document storm occurrences and maximum hailstone diameter, but provide very little information on storm duration, area, and hailstone characteristics, such as concentration, density, shape, and size distribution. CoCoRaHS hail pads, in combination with spotter reports, are producing a useful dataset for exploring the behavior of hailstorms in one of the most hail-prone regions of the United States.

OPERATIONAL APPLICATIONS. As noted earlier, the CoCoRaHS intense-rain reports are often used by forecasters to supplement NEXRAD radar-rainfall estimates for flood advisories. Hail reports are used to assess the quality of the radar hail algorithm estimates and help the forecaster develop their expected correlation between the radar data, the hail algorithm estimates, and the actual hail size.

There have been a number of occasions when CoCoRaHS hail reports were the only severe weather reports that the NWS received. For example, in the small 10 July 2002 storm south of Denver, the CoCoRaHS observer (with the hail pad broken by 3-in.-diameter hail; Fig. 4) provided the only report of severe hail, even though NWS spotters were located nearby. On another occasion in 2002, the Boulder NWS office lost access to NEXRAD radar data at the same time that several warnings were in effect. A CoCoRaHS report submitted from east of Fort Collins made it clear that another warning was needed as the storm moved near that location.

Rain, snow, and hail data from CoCoRaHS are also proving valuable for more than just meteorologists. The U.S. Department of Agriculture's Farm Service Agency and the Natural Resources Conservation Service (NRCS) are utilizing CoCoRaHS data to document drought and other weather contributing to crop loss. The U.S. Bureau of Reclamation is preparing to incorporate CoCoRaHS precipitation data into the management of reservoirs and electric power generation. CoCoRaHS data are being integrated into an increasing number of municipal utility databases. Detailed maps of urban precipitation (e.g., Fig. 8) allow water managers to better predict summer water demand. Officials use CoCoRaHS data to confirm rainfall affecting storm-water collection systems, urban runoff, and floodplain management. The Urban Drainage and Flood Control District in the Denver area and the Fort Collins Utilities office also use CoCoRaHS precipitation reports to perform quality control on rainfall reports from their real-time automated flood-warning system.

As the number of volunteers increases, the opportunities for applications expand. Insurance companies are beginning to look at CoCoRaHS hail reports to get an early indication of potential damage claims. The rainfall and hail data are also useful for projecting future crop yields.

FUTURE DIRECTIONS. As CoCoRaHS continues to expand through Colorado and into surrounding states, more benefits of the project will be realized. At the same time, however, the project continues to place increasing demands on its infrastructure and coordination. CoCoRaHS has benefited tremendously from a network of local coordinators to distribute supplies, provide training, and keep in contact with volunteers. Also, our partnerships with the NWS, NRCS, and land-grant university cooperative extension have provided a foundation for continued expansion across the country. Recently, CoCoRaHS hired a full-time coordinator to oversee the daily project needs, as well as to facilitate continued growth into other states that are interested in joining the network. CoCoRaHS is also investing significant effort in updating its database and Web page in order to improve our mapping capabilities, facilitate data sharing with other entities, and accommodate continued expansion of the network. Future success will depend, in large part, on an ability to manage its increasing volunteer base and maintain the local "feel" of the project in communities far removed from the Colorado Front Range.

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FOR FURTHER READING

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