Colorado Climate

Water Year 2003 Vol. 4, No. 1-4

Colorado State University

Knowledge to Go Places

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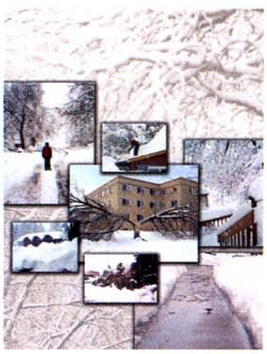

On the cover: Photos courtesy of (beginning with upper left and going clockwise) Toshi Matsui, M.J. Brodzik, Tara Green, Stacey Seseske (lower right and center), Tom Bliss, and D. Burrows.

From the Editors' laptop:

As you may know by now, we have failed to keep up with our original schedule of quarterly (four per year) issues of the Colorado Climate Magazine. We have been publishing "Colorado Climate" as a high quality science magazine since Winter 1999-2000, but we have been falling farther and farther behind. We are almost two full years behind schedule. Yikes!! We have some great excuses if you want to hear them. Drought comes to mind and the huge load of extra responsibilities that brought to us here at the Colorado Climate Center. But the bottom line is we told you there would be quarterly issues of "Colorado Climate" and we let you down. We are very sorry and want to try to make it up to you.

Our plan to get back on track is as follows. We simply do not have the time or resources to produce our publications in rapid succession. Therefore, for the next two issues, we are going to summarize and combine an entire Colorado Water Year into one issue. There will be one issue for 2003 covering the months of October 2002 through September 2003. Then this will follow a few months later with a comparable issue for 2004. If all goes well and this plan works, we will return to quarterly issues beginning with the winter of 2005 and will be more or less back on schedule. That will make all of us feel a lot better.

Be assured, if you are a paying subscriber, we WILL stick to our original promise of 4 issues for $15 until we get caught up, even if an issue covers an entire year. Thank you very much for your patience and tolerance. Regardless of how and when we write and publish, the weather remains as fascinating and variable as ever. We may think we know a great deal about weather and climate – the causes and the results. Yet every year brings something new and different.

What follows is a condensed summary of the 2003 Water Year. In an effort to catch up, we will skip the over some of the daily details. But we will still try to paint an accurate picture of what the year was like and what the most significant weather events and anomalies were. Years from now, when someone reads these summaries, they should have at least a reasonable idea of what we experienced and lived through.

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If you have a photo or slide that your would like considered for the cover of Colorado Climate, please submit it to the address at right. Enclose a note describing the contents and circumstances including location and date it was taken. Digital photographs can also be considered. Submit digital imagery via attached files to: odie@atmos.colostate.edu. Unless otherwise arranged in advanced, photos cannot be returned.

An unusually heavy snowfall in north central Colorado: or odd things that happen during severe droughts – A Meteorologist's View

by John F. Weaver, NOAA Research Meteorologist, CIRA/RAMM

On the morning of 19 March 2003, residents living along the east slope of the Rocky Mountains in north-central Colorado awoke to find themselves buried under two-to-four feet of extremely wet, heavy snow. The snow was so heavy that in Fort Collins alone 37 structures were completely destroyed and more than 200 severely damaged as roofs, walls, and entire buildings collapsed. Had this been a large tornado outbreak, the massive amount of destruction that occurred in dozens of Colorado cities up and down the northern Front Range[1] would have made national news for days. However, other than for a couple of thirty second spots on the networks, very little national attention was given the event. In large part, the lack of interest in the wide ranging impact of this record-breaking snowstorm[2] prevailed locally. Perhaps the explanation lies in the absence of violence that characterized the two-day-plus affair. After all, snow is nothing more than beautiful white crystals floating softly to earth. Ironically, the storm occurred during the worst drought in Colorado history, so most local residents were simply glad to have the moisture.

From a forecast point of view, the storm was not a surprise. The occurrence of a heavy snow event was accurately predicted, as was the fact that the storm would last for at least 48 hours. Computer model guidance correctly indicated that the heavier precipitation would begin over the Front Range on the evening of Monday, 17 March, and continue for at least 48 hours (e.g., Figs. 1, 2). The guidance even hinted at two periods of heavier activity. The first would start on the evening of the 17th, and taper off late the next morning. A second round would begin on late afternoon of the 18th, and continue into the morning of the 19th. That's pretty much what occurred, though the model forecast precipitation amounts were significantly understated for the populated areas along the Front Range corridor (e.g., Fig. 2).

There were misgivings amongst forecasters as to when (and in some cases whether) the changeover from rain to snow would occur. All of the computer models predicted that the 1000-500 hPa thickness (a measure of the "coldness" of the lower and middle layers of the atmosphere) was theoretically too high (i.e., too warm) to allow frozen snow crystals to reach the ground. In fact, several indicators suggested that snow levels would go no lower than about

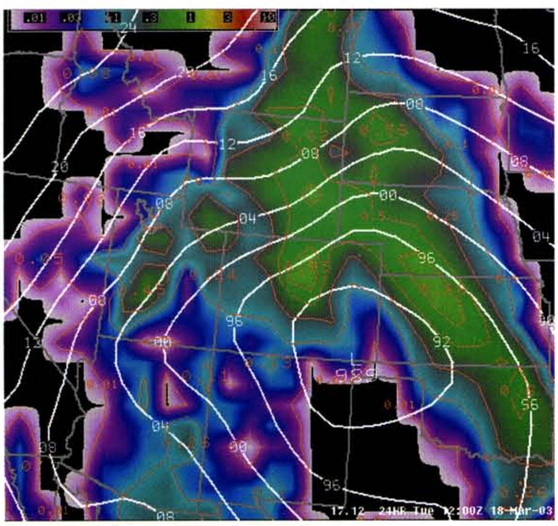


Figure 1. Computer-model output (eta 24-hr, forecast from 12:00 UTC, 17 March 2003) depicting forecast precipitation and surface pressures. The precipitation forecast is for the period 11:00 pm on 17 March through 5:00 am LST on 18 March 2003. The output shows 0.95" of liquid precipitation, or around 10"-12" at the snow:liquid ratios that were expected to occur. The interim, 6-hr map (not shown) indicates that the precipitation would be spread evenly over the 12-hr period (1 in = 25.4 mm).

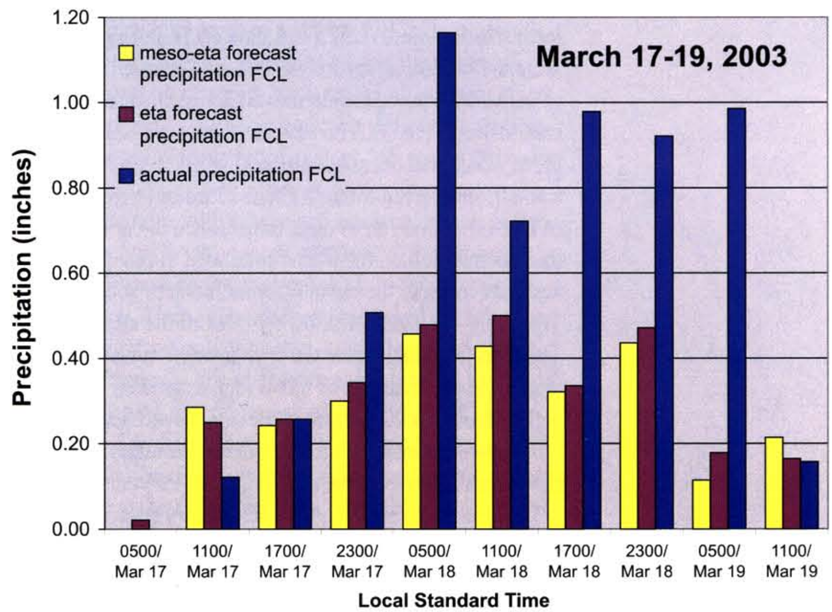


Figure 2. Meso-eta model (amounts from the eta-12 km grid output, extrapolated to a 29 km grid increment), and standard 80 km eta model (amounts from the eta-12 km grid output, extrapolated to an 80 km grid) precipitation forecasts (in inches) from the morning of 17 March 2003, plotted in yellow and red, respectively. Plotted in blue are actual liquid-equivalent precipitation amounts in 6-hr increments from observations taken at the Colorado State University Campus in central Fort Collins (FCL) (1 in = 25.4 mm).

1 The geographical designation "Front Range" refers to the easternmost range of peaks of the Rocky Mountains, but the terms "Front Range," or "Front Range corridor" are also used locally to indicate the populated area just east of the Rockies in Colorado. In this article, the second meaning will apply.

2 The March 2003 snowstorm has erroneously been called a "blizzard," and there was certainly enough snow involved to qualify. However, to meet the official definition there would have to have been either sustained winds, or frequent gusts, to at least 35 mph (56 km/h) for a significant period of time, and there were not.

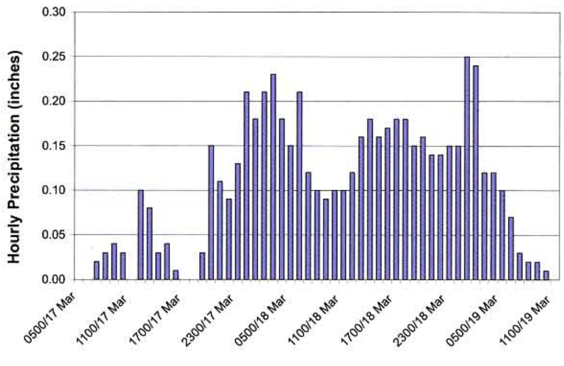


Figure 3. Hourly, liquid-equivalent precipitation (in inches) measured at the Colorado State University site (FCL) in central Fort Collins. Amounts shown are for the hour ending at the times appearing on the abscissa. (1 in = 25.4 mm)

6,000 feet (1830 m). The majority of the larger northern Front Range cities are situated about a thousand feet lower than that. Nevertheless, most Colorado forecasters ultimately agreed that diurnal cooling, combined with the cold precipitation, would chill things sufficiently to allow the changeover to occur just after sunset. My own assessment was that the rain would turn to snow around 6:00 pm, with snow totals reaching upwards of 10"-15" (25-38 cm) by the time the storm was over.

A pre-event, light rain began falling in northern Colorado early on the morning of 17 March (Fig. 3), and continued generally light-to-moderate throughout most of the day. It tapered off completely just before 4:00 pm local standard time (LST), but showers began again at around 7:00 pm, as several north-south-oriented bands of convective precipitation moved across the area from east-to-west (Fig. 4). The new showers were heavier than those which had occurred earlier (Fig. 3), even producing a small, short-lived tornado about 25 miles (~40 km) east of Denver. However, as dusk transitioned to dark, all of the precipitation on the plains continued to fall as rain. Just fifty miles to the north – across much of southeastern Wyoming – it had been snowing most of the afternoon. This was troubling, since the region where it was snowing is situated at elevations of 6,000 feet, or greater. This is the precise elevation where the models predicted the rain/snow line would be found. As temperatures and dewpoints hovered in the upper thirties (Fahrenheit) throughout northern Colorado, forecasters began to worry about their predictions of heavy snow. Denver television stations had played up the coming winter weather, but by this time there seemed a strong possibility that the official National Weather Service forecast for a 12"-20" (~30-50 cm) snowfall could turn to nothing more than 2"-3" (~50-75 mm) of cold rain.

The problem may have been in the anticipated, versus actual, location of key synoptic features. Here, the computer models were only a few miles off, but it was a critical few miles. The eta-model presented a scenario where a so-called "warm conveyor belt" (i.e., a warm, moist stream of air being drawn into a developing extratropical cyclone) would move moist air up from the Gulf of Mexico into southeast Wyoming. The developing extratropical cyclone would then wrap heavy precipitation over the top of the cold air, and back into Colorado from the north (recall Fig. 1). GOES satellite imagery (Fig. 5) showed that the center of the developing system was actually a little further south than expected, and that the warm conveyor belt was feeding directly into northeast Colorado. By 9:00 pm, as a second line of relatively heavy convective rain moved across the northern Front Range, a failed forecast was beginning to look more and more likely. It was raining steadily – relatively hard at times – but the temperatures and dewpoints were all staying well above freezing.

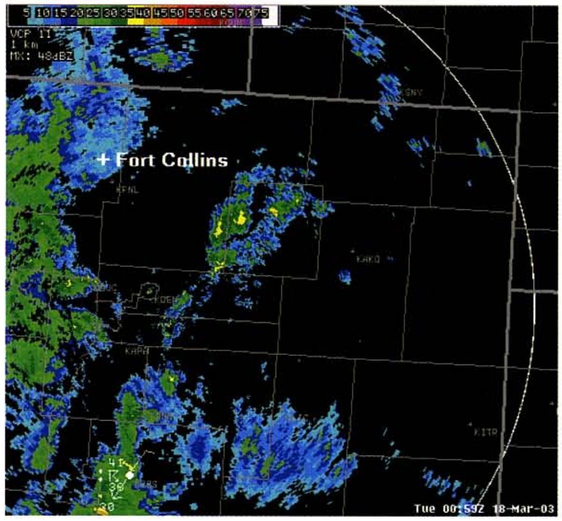


Figure 4. One line of convection moves off to the west of Fort Collins (squall lines were moving westward) as a second line forms to the east. Figure shows the 0.5 degree tilt, PPI reflectivity scan taken from the Denver, Colorado WSR-88D at around 6:00 pm on the evening of 17 March 2003.

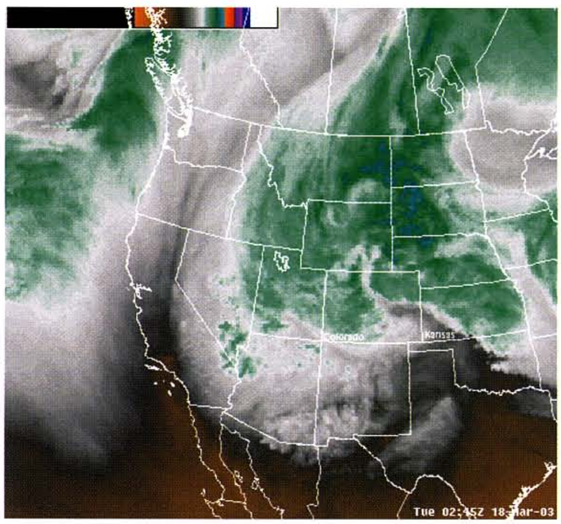


Figure 5 . GOES, 6.7 μm water vapor image taken at 7:45 pm on 17 March 2003. The image shows the moisture associated with the warm conveyor belt stretching from northeastern Oklahoma, across most of Kansas, and westward into northern Colorado. At this time the surface low pressure is moving into southeast Colorado.

continued on page 19

Just What the Drought Doctor Ordered: A summary and observations of the March 17-20, 2003 snowstorm – A Climatologist's View

by Nolan Doesken

I have to admit, I just don't get as excited about snow as I did when I was a kid. From the age of perhaps 5 or 6 up to when I was an older teenager I would stay up much of the night if it was snowing or predicted to snow – just watching the snow come down or waiting to catch sight of the first flake. The yard light over our driveway illuminated nighttime snowflakes perfectly so I could watch from the kitchen window. It didn't snow much back in my hometown in central Illinois, but I cherished each and every flake.

Most snows only lasted a few hours, and few would keep me up all night. Many would be disappointing as snow would all too often change to rain, but once in a while, a big snow would last all day and all night. Those were the storms that I longed for.

I still love watching and waiting for snow. The only problem is that now I seem to fall asleep when it gets close to 11 pm even if it's snowing.

Before the Storm

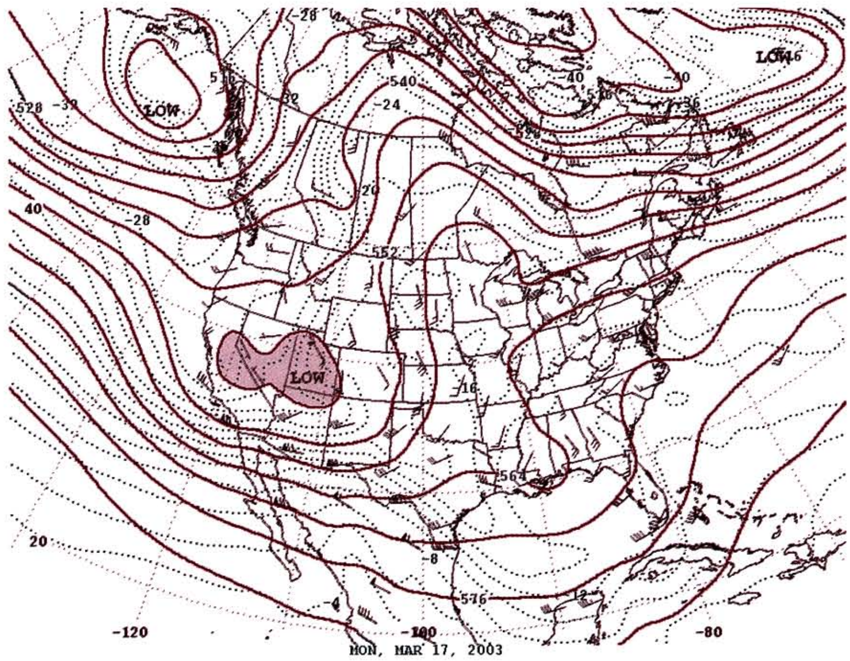
It was probably as early as March 11, 2003 when the weather chatter at work turned to snow. I wouldn't have paid much attention. After all, it felt very much like spring with warm sunny days and mild evenings. The grass would have been turning green except for the dry soil and ongoing watering restrictions. But the weather forecasters kept talking about a possible big storm for the following week. I know weather forecasting has improved. But snow is still one of the toughest forecasts to get right 5 to 7 days in advance. I knew the chances for a big storm were slim. But it was March, after all – a darn good time of year for snowstorms. Even if the storm failed to materialize, it was certainly more fun to think about snow than to continue to drag out more drought conversation. We were all sick of talking about drought.

With each passing day, the temperatures got warmer. By the 13th and 14th, daytime temperatures in the mountains were close to 60°F and snow was melting fast. At lower elevations temperatures soared in the 70s, with 80s in SE Colorado. Several new record highs were set. Of all the things that were hard to imagine, heavy snow was near the top of the list. Yet meteorologists continued to mention it in with ever increasing confidence.

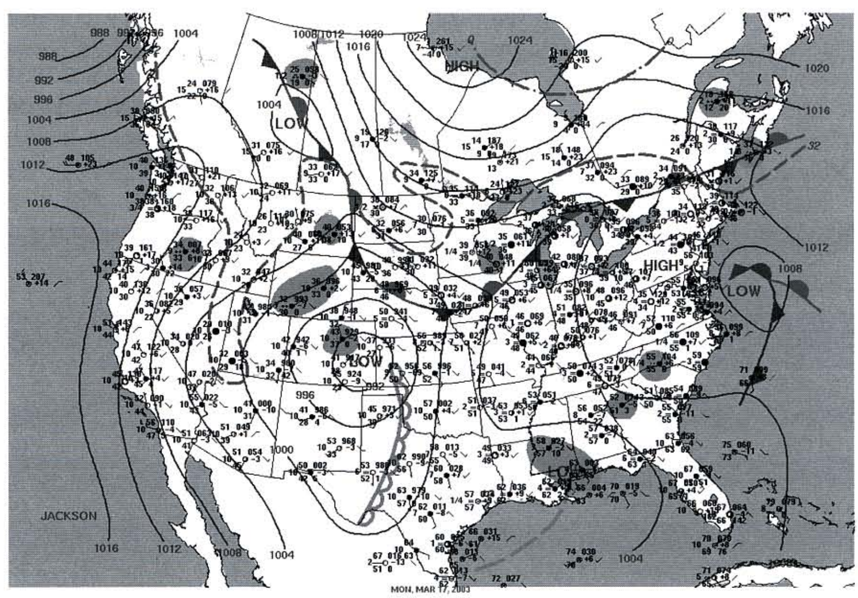
Saturday, March 15th was still warm and sunny with no hints of an impending storm, but weather maps were now showing the beginnings of deteriorating weather conditions west of Colorado. Barometers indicated falling pressure, and clouds began moving into western Colorado late in the day. A few storm-savvy Coloradans took advantage of the good weather to lay in a few extra supplies, just in case.

Residents of Southwest Colorado awoke to rain on Sunday morning (16th) as the early stages of a Four-Corners storm system took shape. Heavy snow began falling but only at high elevations of southern Colorado. Eastern Colorado enjoyed another mild, spring day but with thickening clouds as the day progressed. Weather forecasters did not back down from their early forecasts. Instead they began warning residents of the Colorado Front Range, that this could be a big one, even before the first flake had fallen.

500 mb chart (above) and surface map (below) for March 17, 2003 from Daily Weather Maps.



500-Millibar Height Contours at 7:00 A.M. E.S.T.



Surface Weather Map and Station Weather at 7:00 A.M. E.S.T.

By Monday morning, March 17th, a classic Four-Corners low pressure area was established centered southwest of Cortez, Colorado (see 500mb chart and surface map on previous page). A deep upper level low pressure trough slowed and then cut off from the main jet stream allowing this southern storm to spin like a top while moving very slowly across the southern Rockies. The counterclockwise flow around this low first drew moisture northward from the Gulf of Mexico and then pulled the warm, moist air westward towards the Colorado Front Range. Widespread light rain began falling over northern Colorado, especially in and just east of the mountains north of Monument Hill and Castle Rock. Farther north, heavy snows were falling in colder air over Wyoming. At the same time, colder air aloft moved over Colorado destabilizing the atmosphere. Thunderstorms developed east of the mountains, and there was even a report of a small tornado near Strasburg.

By Monday night, the upper level wind patterns had aligned to form a pipeline for moist Gulf of Mexico air directly into northeast Colorado. Temperatures dropped just enough to allow rain to turn to snow before midnight over most of the Front Range cities. See detailed explanation on page 2 and 17. Snow became heavy Monday night and by Tuesday morning (18th) a major storm was in full swing. From southern Wyoming southward to Monument and westward to the Continental Divide and beyond, people awoke to 6"-18" of new snow laden with water. At lower elevations from 5-6,000 feet above sea level, the snow water content was nearly 20%, meaning that 10" of new snow contained close to 2.00" inches of water. Most schools in the affected area were open on Monday but did not open on Tuesday with so much snow already on the ground.

Because of the slow movement of the upper level storm system, this same general weather pattern held for over 48 hours. It was the combination of intensity and duration that made this storm exceptional. At first, roads could be cleared of snow since ground temperatures were so warm. But by Tuesday morning even main thoroughfares began to clog with snow and slush. As wet snow continued to fall hour after hour at a high intensity, transportation ground to a halt. Power failures occurred as snow-laden trees brought down power lines. Unusually high precipitation rates for a snowstorm were noted along the northern Front Range, with many areas reporting several hours with more than 0.20" of moisture per hour (Fig. 3, page 2). This is nothing special for summer storms where 2"-3" of rain can fall in an hour, but for moisture falling in the form of snow, this is very intense.

Tuesday (18th) afternoon into early Wednesday morning proved to be the worst of the storm. Snow fell without interruption. Radar and satellite images both showed wave after wave of rain sweep westward across Colorado's eastern plains and turn to snow at elevations of around 4500 feet. While nearly all of Colorado received precipitation, the center of the storm from start to finish was the Front Range urban corridor, foothills and mountains. Douglas, Jefferson, Clear Creek, Gilpin, Boulder and Larimer Counties all stayed in the cross hairs. The heaviest snows fell from about 2 pm on Tuesday through 2 am on Wednesday. By Tuesday evening, the rain/snow line pushed farther out into eastern Colorado, with areas from New Raymer south to Genoa, Rocky Ford and Kim getting a few hours of windblown snow. Also, very heavy snow fell in the northern mountains immediately west of the Continental Divide, but the mountain snow was much fluffier and less dense.

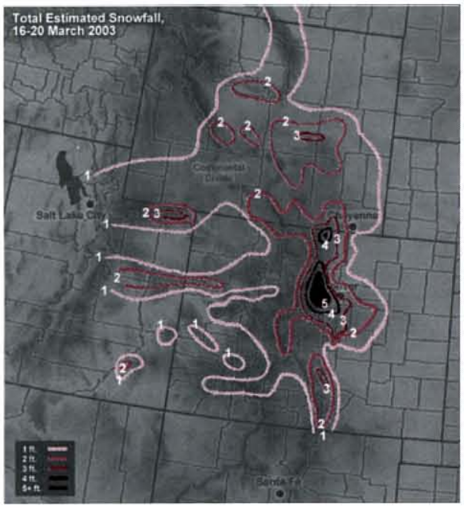
By Wednesday morning (19th) there were some indications that the storm would continue unabated for at least another 24 hours. But the upper level cut-off low pressure center moved slowly eastward. By 9 am snow began tapering off in northern Colorado. Snow came to an end statewide by late afternoon. For most of the area, the great storm of March 2003 was over and the cleanup was underway. One more burst of snow moved through on Thursday (20th) evening that brought 1 to 10 additional inches of snow to the mountains and foothills, but this was technically a separate and independent storm. It was enough, however, to slow the arduous process of digging out.

Facts, Figures and Local Variations

Total storm snowfall (the sum of each daily accumulation of fresh snow) for northern Colorado is shown in Figure 8 on page 18. The map on the next page shows the total reported snowfall for the entire central Rocky Mountain Region based on an analysis completed by the staff of the Cooperative Program for Operational Meteorology Education and Training (COMET). This analysis included data from the traditional National Weather Service observing network supplemented by the NWS snow spotter reports, automated observations from several USDA Natural Resources Conservation Service SNOTEL stations, and additional manual observations from a large number of volunteers along the Front Range that are participants in

Storm Data Compilations for Selected Stations

Station	County	Elevation (feet)	Obs Time (LST)	Monday, March 17, 2003			Tuesday, March 18, 2003			Wednesday, March 19, 2003			Thursday, March 20, 2003			Storm Total March 17-20, 2003		
				Precip (in.)	Snowfall	Snow Depth	Precip (in.)	Snowfall	Snow Depth	Precip (in.)	Snowfall	Snow Depth	Precip (in.)	Snowfall	Snow Depth	Precip (in.)	Snowfall	Snow Depth
Boulder	Boulder	5484	1700	0.26	0.0	0	2.47	11.7	11	1.96	10.8	16	0.00	0.0	13	4.69	22.5	40
Coal Creek Canyon	Jefferson	8950	Midnight	1.84	14.3	12	4.85	39.7	44	2.18	17.7	56	0.08	0.9	52	8.95	72.6	164
Colorado Springs	El Paso	6181	Midnight	0.11	T	0	0.13	1.4	1	0.03	0.3	2	0.00	0.0	0	0.27	1.7	3
Denver Stapleton	Denver	5286	600	T	0.0	0	1.16	6.6	5	3.10	22.9	22	0.28	2.3	18	4.54	31.8	45
Dillon	Summit	9065	700	0.14	2.0	2	0.50	8.0	8	0.21	4.0	11	0.11	2.0	11	0.96	16.0	32
Fort Collins	Larimer	5004	1900	0.39	0.0	0	3.30	18.0	16	1.60	14.2	23	0.00	0.0	18	5.29	32.2	57
Georgetown	Clear Crk	8520	800	0.42	6.5	7	1.34	19.1	21	3.14	34.5	46	0.32	6.8	42	5.22	66.9	116
Grand Lake 1NW	Grand	8720	1600	0.18	0.5	23	1.40	18.0	38	1.45	24.0	54	0.02	T	54	3.05	42.5	169
Greeley	Weld	4715	1600	0.08	0.0	0	0.82	4.0	4	0.80	5.0	8	0.00	0.0	6	1.70	9.0	18
Rye	Pueblo	7141	2000	0.11	T	T	2.59	21.0	21	1.96	23.3	36	0.11	1.8	26	4.77	46.1	83
Westcliffe	Custer	7860	1800	0.11	0.8	T	1.03	15.3	15	1.33	19.6	34	T	T	24	2.47	35.7	73



Total observed snowfall in feet (sum of individual daily totals) for the Central Rocky Mountain Region of Colorado-Wyoming and adjacent states for the 4-day period March 17-20th, 2003. (Figure courtesy Doug Wesley, Rick Koehler, and Heather McIntyre, of the COMET Program, Boulder, CO).

Colorado State University's CoCoRaHS (Community Collaborative Rain, Hail and Snow Network). This shows the entire area affected by heavy snow.

The greatest precipitation and snowfall occurred in a relatively narrow band along the east face of the Rockies where the moisture laden air from the Gulf of Mexico was forced by upslope winds to rise and cool as it banked up against the Front Range. Two to three feet of new snow were common from Denver through Fort Collins and northward to Cheyenne and Laramie, WY. A small area of northeast Utah and the mountains just south of Casper, WY, were also hit hard. Areas south of Denver and westward into the foothills saw 3 to 6 feet of new snow. The greatest reported accumulations of new snow were found in parts of Boulder, Jefferson, Gilpin and Clear Creek County with 70 to perhaps as much as 90 inches of new snow. Eastern Colorado received little if any snow, but substantial amounts of beneficial rain (one to two inches) were widespread.

Some storms have been more widespread like the October blizzard of 1997. A few storms that have been more intense (e.g. April 14-15, 1921 – 76" in 24 hours at Silver Lake west of Boulder) . Many have had stronger winds. What was most unusual about the March 2003 storm was the extraordinary water content of the snow. This was an exceptionally wet snow with snow to water ratios of as low as 5:1 (one inch of water for every 5 inches of snow) up to 10:1 in the higher mountains. Only at elevations above 8,000 to 10,000 feet or at locations west of the Colorado Front Range were densities more like typical Colorado snows. Storm total water content of four to six inches was widespread over the region of greatest snowfall. The 8.87 inches 3-day total including 4.85 inches of water content in 24-hours measured at the official NWS Cooperative Weather Station at Coal Creek Canyon is truly remarkable and confirms what an extraordinary storm this was for the Colorado Front Range.

Some of the interesting local features of the storm included:

- There was a relatively small areas of extreme snowfall.
- It was not terribly cold – just barely cold enough for snow over portions of the storm area with a rain/snow boundary just east of the mountains throughout the storm.
- There was a fascinating local lack of snow near the town of Lyons (just north of Boulder at the mouth of the St. Vrain River) – this is currently a topic of in-depth research.
- There were a few areas, primarily in Grand County, where a great deal of snow fell west of the Continental Divide. The easterly winds were deep enough to cross the higher terrain in that region. Otherwise, most of western Colorado was not hit hard by the storm. Steamboat Springs, for example, only reported one inch of snow plus a little light rain.
- For the most part, the storm was very well forecast by meteorologists. The public had every opportunity to plan and prepare for the storm.

Aftermath and Impacts

Major impacts from this storm included:

- Closed schools and businesses.
- Disrupted transportation – both air and ground.
- Lengthy power outages.
- Stranded residents – particularly Jefferson County but some in Boulder, Larimer, Clear Creek, Gilpin, Douglas and Park Counties. In some areas, people could not get out of their homes for 5 to 7 days, and food was brought in by snowmobile
- There were hundreds of damaged or totally collapsed roofs due to the incredible weight of the snow. Fort Collins was especially hard hit. The weight of the snow did not exceed the engineering design snow load for Larimer County, but it came close. The non-uniformity of snow accumulation due to drifting, and the redistribution of roof loads as the snow melted seemed to contribute to several roof failures. Millions of dollars in damage were reported.

Not all impacts from this storm were negative. Wet snow is wonderful for recharging soil moisture and forest moisture. This storm brought the maximum moisture to the many of the very same areas of Colorado most impacted by the drought of 2002. It was arguably the best possible drought relief anyone could have wished for. For the thousands of residents of the Front Range foothills who rely on well water, this storm single-handedly recharged aquifers and restored the ground water supplies for many mountain and foothill locations.

Another impact of the storm was the many family experiences and a lifetime of memories that this storm created. While there were many hardships, there were surprisingly few injuries or fatalities. Instead there were many rich family times and opportunities for neighbors to help neighbors. For our own family, we will always remember the two-week spring break that our children got from school, and their once-in-a-lifetime experience snow boarding off the roof of our garage onto the huge snowbanks below. Watching our dogs just step over the top of the fence thinking they were free to roam, only to flounder and sink in the deep snow on the other side.

Personally, I remember this as the storm I had always dreamed of but didn't have to shovel. Our teenage kids and their friends shoveled all of our paths and driveway and made piles so large that they could dig out full-sized snow caves. Too bad the snow melted so quickly.

Will It Happen Again?

Of course it will. We know from experience tracking our climate that it is only a matter of time before the record storms of the past are exceeded. The snowstorm of December 1-5, 1913 seemed unsurpassable, yet the March 2003 storm dropped more water in less time in several areas of the Front Range. Yes, there will be another super snowstorm – maybe next year, maybe 50 years from now, but it will happen again. Hopefully, we will still be here to experience it. ✱

Observers Struggle to Measure Accurately by Nolan Doesken

Colorado's many volunteer weather observers did a great job measuring and reporting this storm, but it did not come easily. The wet snow clung to the rim and sides of gauges and in some cases totally capped over the top of gauges. The National Weather Service standard rain gauge stands two feet tall, but there were many areas in the foothills and mountains of the northern Front Range where daily snowfall exceeded two feet, especially on the 18th into the morning of the 19th. Blowing and drifting was a major observational challenge in the higher mountains and on the plains. The deep, dense snow was very difficult to traverse, so even getting to the gauge to begin an observation was a problem. Many observers had trouble finding their snow measurement boards. Daily snowfall exceeded the length of the snow measurement ruler at a few sites, and many stations did not have stakes long enough for measuring the total depth of snow on the ground. A few observers even had trouble finding their large precipitation gauges in the deep snow. Rain and snow were mixed together in some areas, and snow continued to melt from beneath at many lower-elevation weather stations. Finally, melting the snow to get a measure of the water content was laborious and time consuming since there was so much ice to change from the solid to the liquid phase. All in all, weather observers faced nearly every difficulty and challenge of snow observation.

At the campus weather station at Colorado State University we had five different types of gauges and two snow measurement boards in use during the storm. Not surprisingly, they gave different answers. One gauge was totally buried beneath the snow and did not provide useful readings. The tipping bucket gauge, which is not well suited for measuring snow, totally clogged up and did not provide accurate data. Two types of recording gauges worked to some extent, but the quantity of snow diluted the antifreeze causing one of the gauges to fill and cap over. When it was all said and done, the old fashioned manual approach worked best. Observers managed to fight the elements to check and empty the gauge every twelve hours during the storm. We were fortunate to have two "overflow cans" so an empty gauge could be set out while the full one was brought in to melt. Clearly, having two gauges proved to be very important, since it took more than one hour to melt the snow. (The campus weather station in Fort Collins only has a hot plate and tea kettle for melting snow!)

With all these observational challenges, we know that not all measurements and reports were perfect. Measuring the depth and water content of snow is surprisingly difficult even for small and moderate events. But observers rallied to do their best under difficult circumstances so we scientists have the data we need to document and study this storm.

Weather observers – Thank you!!

Well-hidden raingauge. Photo by Chris Spears, CoCoRAHS volunteer, Denver.

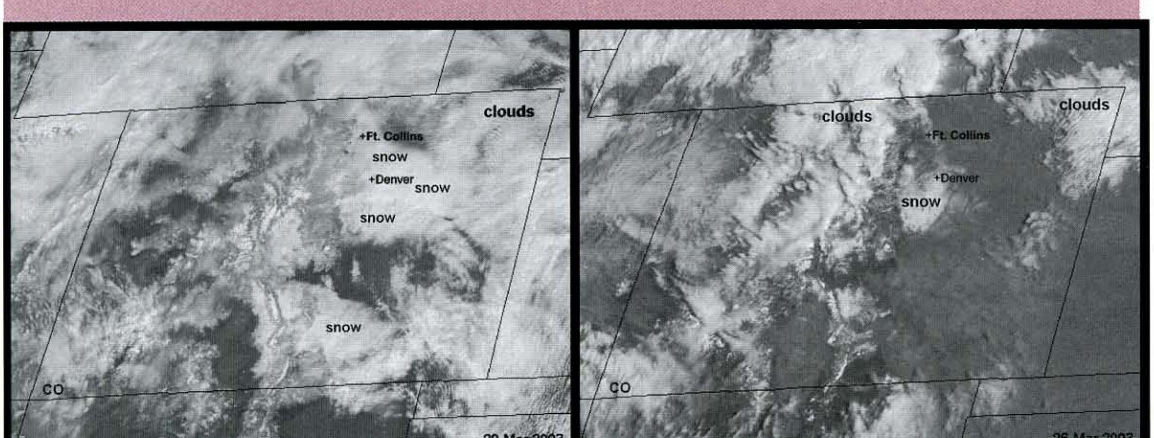
Richard Keen, NWS Cooperative observer at Coal Creek Canyon weather station, is shown here taking temperature readings from the weather shelter after the 72" March 2003 snowstorm. Photo courtesy of Richard Keen.

A Brief History of Colorado's Most Notable Snowstorms by Nolan Doesken

Winter 1899	Series of mighty snowstorms in the mountains and extreme cold on the plains.
December 1913	Several feet of deep, heavy and wet snow along and just east of the mountains from New Mexico to Wyoming.
April 1921	76 inches of snow in 24 hours in mountains west of Boulder – national record.
November 1946	Feet of snow blanketed eastern Colorado – many deaths.
January 1949	Frigid midwinter blizzard in northeast Colorado, Nebraska, etc.
December 1951	Mountains and Western Slope snow blitz shut down all mountain transportation.
March 1977	Eastern Colorado snow and dust blizzard.
May 1978	Late snowstorm on Front Range.
December 1982	Denver's Christmas Eve Blizzard.
November-December 1983	Nonstop mountain snow blitz.
February 1989	"Alaska Blaster" brought rare combination of subzero cold and heavy snow.
March 1990	Front Range snowstorm was so dense that snowplows bogged down, trees and power-lines downed or damaged.
July 1994	Snow cancels 4th of July Fireworks in many mountain communities.
October 1997	Nasty blizzard cripples eastern Colorado and knocks down millions of trees near Steamboat Springs.
2003 March	Similar to the December 1913 storm but more intense over a smaller region.

Comparing Two Storms by John Weaver

Not only did the all-time record blizzard of 1-5 December 1913 produce more total snowfall, over a slightly larger area than did the 2003 storm, but it also occurred at the beginning of the cold season instead of near its end. According to Wilson (2003), persistent cold following the December 1913 storm caused deep snow to linger well into the following year. Its effects were adversely affecting various aspects of life in Denver well into February of 1914. The deep snow associated with the 2003 event, coming as it did at the beginning of spring, disappeared quickly. Within a week, most of the snow along the Front Range was gone. The quick melt-off is evident in the two visible wavelength satellite images taken one week apart. On the left is a GOES-12 visible image taken at 17:45 UTC on 20 March 2003 showing snow cover along the eastern Front Range of Colorado the day after the storm. A cloud field covers extreme northeast portions of the state. On the right is a GOES-12 visible image taken at 15:45 UTC on 26 March 2003. More than eighty percent of the snow cover along the Front Range has vanished. *



What Constitutes the "Worst Storm?" by John Weaver

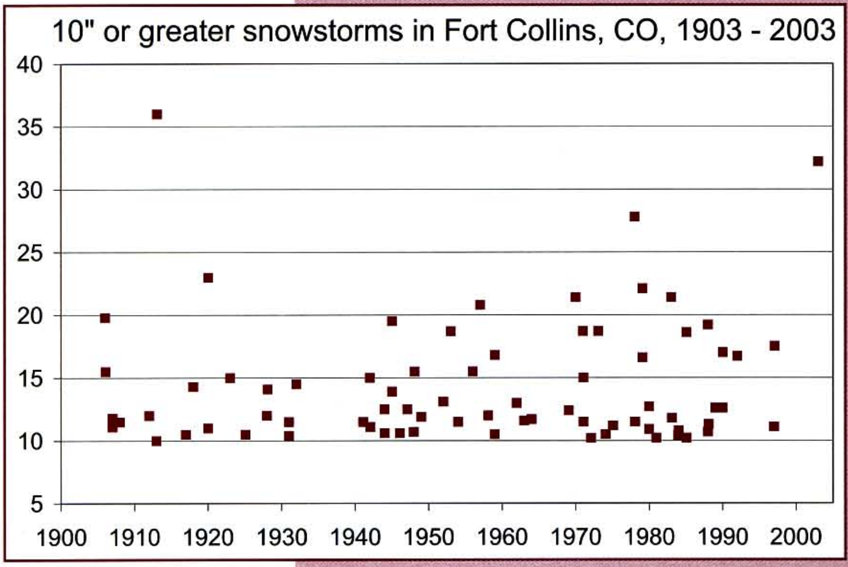
It is nearly impossible to rank snowstorms in any general way, simply because there are so many ways to do it. Trying to assess a storm's intensity in terms of so-called human impact is a serious challenge. For example, you might decide to compare storm related deaths/injuries as a measure of severity, but this would lead to a long series of questions. One would need to consider differing and/or changing population densities, time of day that the storm hits (nowadays a one foot of snow during rush-hour would have much more impact than the same storm in the middle-of-the-night), available communications technology, response and rescue resources, and many others. Dollar damage assessment might be another part of the equation, but then one would have to consider such variables as inflation, differing/changing building codes, the size of the urbanized area affected, and so on.

Making comparisons based on objective weather variables might (at least at first glance) seem to be a better approach, but in this arena the problems can be even more complex. Is a two-foot snow, at a 20:1 snow-to-water ratio, "worse" than a one-foot snow at a heavier, 5:1 ratio? Should one simply consider the greatest snow depths reported for large storms, or should the assessment include the size of the total area affected? Is one storm "worse" than another if it is followed by a period of very cold weather that causes snow to linger an inordinate amount of time, instead of melting away quickly? Would a one-foot snow, accompanied by strong winds and six-foot drifts, be "worse" than a three-foot snow with modest winds, and small drifts? What constitutes a single "storm." Should a break in snowfall of some arbitrary length of time suffice to represent the "end" of one storm, and the beginning of another? Should meteorologists make the determination based on whether a restart of snowfall is part of the same weather system?

Some climatologists contend that the snowstorm which occurred during the first week in December 1913 was actually two, separate events. Snow fell on the 1st and 2nd, then there was a period on the morning of the 3rd where the precipitation stopped entirely. By this time there was 16.5" (42 cm) of new snow on the ground in Fort Collins. Light snow began again late in the day, and continued to increase until it became spectacularly heavy on the 4th and 5th. By the time the five day period was over, a total of 36" (91 cm) had fallen. Looking back at the crude surface maps available for 1913, my guess is that both snows were part of the same low pressure system that moved up from the southwest.

It's a judgment call, but in the point-data shown here, I've chosen to classify the entire five day event as a single storm. My criteria, for this case and a few others, was as follows: 1) if there were two or three consecutive days upon which similar amounts of snow fell (within the same order of magnitude), I would class these days as a single event, and 2) if there were more than three days in a row with snow, then I would try to find maps that would confirm or deny a "single storm" interpretation. There were only five cases in category (2), and none seemed ambiguous.

The graph shows snowstorms which produced 10" (25 cm), or greater, snowfall in Fort Collins over the period 1904 through 2003. Of the one hundred years compiled, forty-nine had at least one such event, and several produced deep snow events. The months in which double-digit snowstorms occurred were at follows: March (17 times), April (15), December (10), November (9), February (8), January (7), October (5), May (2), and September (1). The graph clearly shows that, for Fort Collins, the March 2003 snowstorm (32.2" or 82 cm) was second only to the blizzard of 1913 (36.0" or 91 cm). The third greatest total shown on the graph occurred in early May 1978, when a total of 27.8" (71 cm) was recorded. ✱



continued from page 2

Satellite imagery offered a clue that changes were on their way. Figure 6 presents two GOES 10.7 μm infrared images that reveal an enhanced area of colder cloud tops associated with a shortwave trough (marked SW in the figure) approaching from the east. This disturbance didn't arrive along the Front Range until about 10:00 pm LST, but its arrival had a profound effect. It was at that time when most reliable observers at elevations around 5,000 ft reported a changeover from mostly rain to one hundred percent snow. By this time, FCL (on the Colorado State University campus in central Fort Collins) had reported 0.76" (~19 mm) of rain. There had been a little ice mixed in with the rain off-and-on throughout the evening, though it all melted on contact. But at 10:00 pm, the changeover took place, and snow began in earnest. By 07:00 am on Tuesday morning, 6"-12" (15-30 cm) were measured at various locations in Fort Collins, and it was still coming down[3]. The liquid equivalent at FCL (where 8" fell overnight) was 1.5" – yielding a snow/water ratio of about 5:1. Other observers in the region all reported ratios ranging from 5:1 to 7:1. These included several experienced observers who are part of the Colorado Climate Center's CoCoRaHS (Community Collaborative Rain Hail and Snow Network). CoCoRaHS is a network of trained volunteers with observers in most of the cities affected by the storm (http://www.cocorahs.org).

Tuesday morning, the intensity of the snowfall trickled off to less than half an inch per hour, but a second shortwave was rotating around the now extremely robust cyclone (Fig. 7). This second disturbance – accompanied by deeper moisture in a reinvigorated warm conveyor belt – arrived in central Colorado at around noon, and snow rates increased dramatically. This was the beginning of the second, and most persistent, segment of the event. As the hours passed, and the snow continued up and down the Front Range corridor, tree limbs began snapping, wide-expanse roofs bowed downward, and cars on the street morphed into massive white mounds. Heavy snow continued for another 24 hours, with some particularly heavy convective bursts just after midnight on the 19th. When it was over, central Fort Collins had received an additional 24" of snow, and several foothills observers reported more than 40".

By midday on Wednesday, 19 March, north central Colorado was buried (Fig. 8). Roads throughout the region were impassable, and most businesses were closed. The northern Front Range had been hit with its second largest snowfall in the region's history (Wilson 2003), and, according to *Claims* magazine, Colorado sustained the highest nationwide insured losses for the entire first quarter of 2003 as a result. The snow itself was so heavy that municipal snow plows in most cities were at first

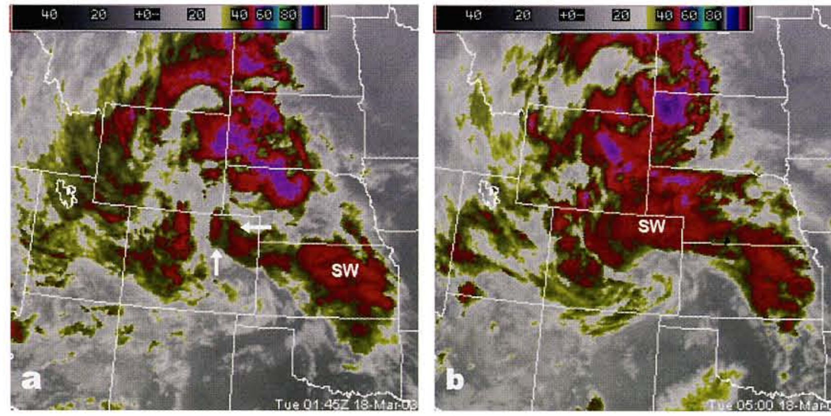


Figure 6. GOES, 10.7 μm infrared window images taken on the evening of 17 Mar. 2003. a) image taken at 6:45 pm LST showing infrared view of banded convection in northeastern Colorado (arrows) and approaching shortwave disturbance to the east southeast, over Kansas (SW), and b) image taken at 10:00 pm LST showing infrared view of shortwave at the time the rain changed over to snow along the Front Range in northern Colorado.

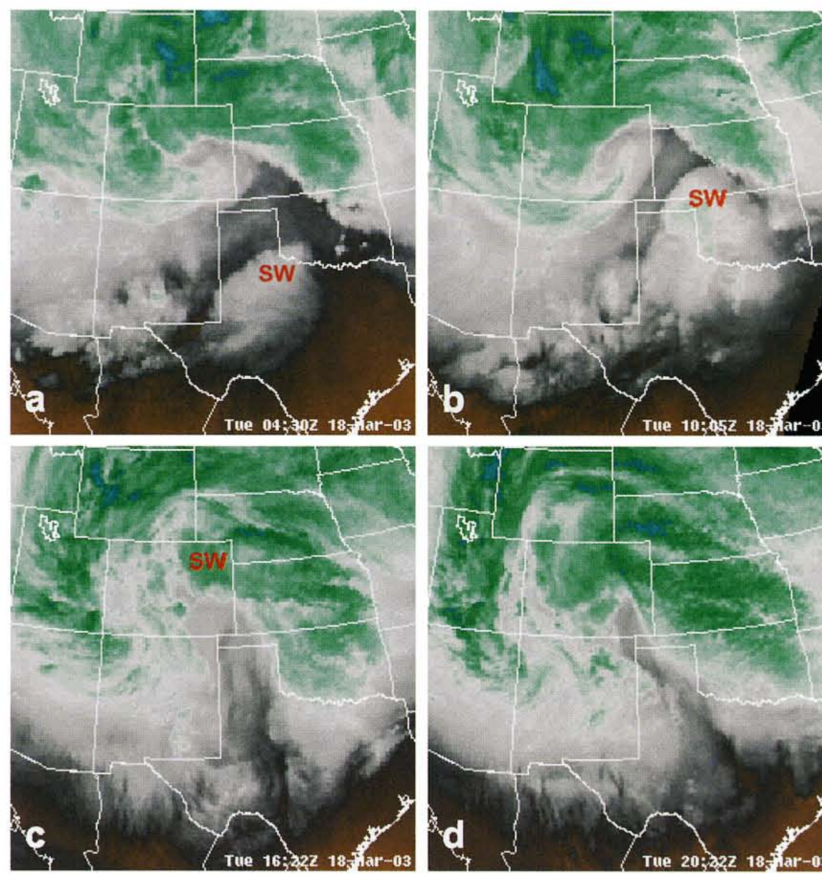


Figure 7. GOES, 6.7 μm water vapor image taken at a) 10:30 pm on 17 March, b) 3:05 am on 18 March, c) 9:22 am on 18 March, and d) 1:22 pm on 18 March 2003 showing an intensifying shortwave (marked SW in red) as it makes its way around the deepening cyclone which is still centered over southeast Colorado. Snow rates increased dramatically as this feature arrived along the Front Range. Note the expanding warm conveyor belt, especially over Kansas and Oklahoma.

[3] Interestingly enough, this first round of snow didn't present much of a problem for motorists along the urban corridor. In the week prior to the storm, daily high temperatures had ranged in the high 60s to low 70s (F), and the 2" (5 cm) soil temperatures had reached 50ºF (10ºC) the day before the storm. By early Tuesday morning, however, snow was finally beginning to accumulate on the roads.

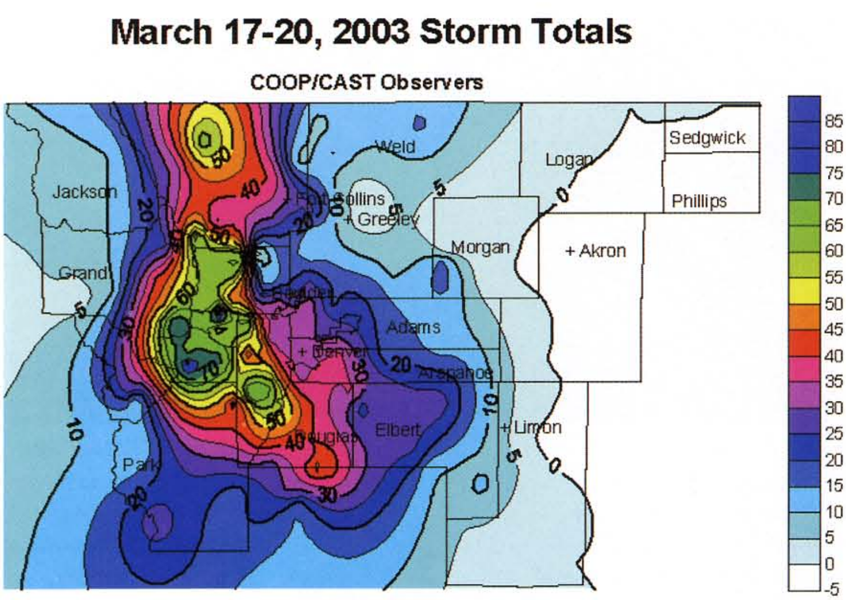


Figure 8. Map showing total snowfall (in inches) for the March 2003 snowstorm in north central Colorado. Observations were collected by National Weather Service (NWS) cooperative observers and members of the Colorado All-Season Spotter Team (CAST) – a volunteer spotter network that provides real-time weather information, year-round, to forecasters at the NWS office in Boulder, Colorado over a toll free, 800 number. Map courtesy of the Boulder, Colorado, NWS forecast office. (1 in = 2.54 cm)

Figure 9. Now what?! Shoveling the driveway doesn't help very much when the street has nearly thirty inches (~75 cm) of snow blocking it. Photo taken by the author in northeast Fort Collins late on the morning of 19 March 2003.

unable to clear roads. Many plows were damaged while trying. Thousands of residents in Jefferson county (west and southwest of Denver) were trapped in their homes for several days, and deep snow closed the major interstates. Yet – other than for hospitals, and emergency responders – no one that I've spoken with locally ever felt any real sense of danger. From a more personal perspective, I certainly didn't feel threatened at any time. The storm, to most, seemed more of an interesting phenomenon – partly fun, and partly an inconvenience. Figures 9 and 10 illustrate the absurdity of the situation. I broke two snow shovels, and finally succeeded in shoveling out my driveway, only to find deep, extremely heavy snow blocking the street. Figure 11 is an example of building damage in Fort Collins. And this was one of the salvageable structures.

CIRA research associates working for the Virtual Institute for Satellite Integration Training (VISIT) were tasked with developing a winter weather teletraining course for National Weather Service forecasters. The course focuses on satellite imagery as a value-added tool within the short-range forecast/nowcast suite of products. The March 2003 storm is one of the examples chosen for presentation. Two questions concerning the case remain partially unanswered. First, and most important, why was the changeover from rain to snow delayed for so many hours (alternatively, why did it change, at all)? Second, why did precipitation amounts right along the Front Range exceed all of the model forecast values by nearly a factor of two? The solution to neither is trivial. The "late" changeover probably had to do with the fact that northeast Colorado was directly beneath the feed of warm, moist Gulf air aloft. The warmer rain may have been modifying the cold air that was trying to move in from the north. The changeover was probably due to layer lifting (and consequent adiabatic cooling) associated with the arrival of the shortwave disturbance illustrated in Fig. 6. Once the changeover occurred, the colder air from the north gained a foothold, and the precipitation never changed back. It is likely that model underestimates of precipitation amounts just east of the foothills are directly related to local topography. The excessive precipitation in this region most probably resulted from a locally deepened boundary layer associated with cold air damming along eastern slopes of the Front Range – a phenomenon that occurs regularly in upslope precipitation situations (Richwien 1980, Gage and Nastrom 1985, Dunn 1987, or Wesley et al. 1990). The "piling up" of cold, moist air serves to extend the effect of the foothills several miles eastward. In Weld county – whose western border is just a few miles east of the mountains – both snow and liquid precipitation totals were closer to the model-predicted values. For the VISIT training, that aspect of the case is heavily emphasized for session participants in offices near mountainous terrain.

The March 2003 snowstorm was a wonderful example of the extreme weather events that occur frequently on the High Plains of the United States. The average annual precipitation along most of the Front Range corridor runs around 15" (~380 mm) per year, yet exceptionally heavy precipitation occurs somewhere in the region nearly every season. The most notable event for the City of Fort Collins was a flash flood which took place on the evening of 28 July 1997 (Petersen et al. 1999). That remarkable weather system dropped 14.5" (~370 mm) of rain onto large portions of the urban area in less than thirty hours; 10.5" (267 mm) fell in just over five. Thousands of buildings were damaged, and five people were killed.

The largest snowstorm in north-central Colorado history occurred on 1-5 December 1913 (Wilson 2003). It dumped 30"-45" of snow onto communities all along the northern Front Range, including Fort Collins and Denver, and that storm was accompanied by strong, gusty winds. It was a true blizzard. Worse, since it occurred near the beginning of winter, the snow was slow to melt off. The aftermath caused serious continuing problems for nearly two months.

The March 2003 snowstorm would certainly be classified as an extreme event anywhere in the country. A three-foot-deep, one-foot-square column of snow, at a snow-to-water ratio of 5:1 to 7:1, weighs from 27-38 pounds (12-17 kg). Putting that much weight on every square foot of a wide-expanse roof challenges even the most advanced engineering. As a witness to the event, I find it surprising that more structures weren't damaged. It was a large and quietly-ferocious beast.

But another way to look at it is to remember that the March 2003 snowstorm brought 5" (~127 mm), or more, of welcome precipitation to portions of a drought parched state, and may have represented the first glimmers of hope for an end to Colorado's long drought. ✱

Figure 10. Ironically, the athletic fields at Colorado State University had been closed until the Fall term due to drought conditions. Watering restrictions made it impossible to revitalize the dry, brittle grass. This photo of a six-foot sign was taken on the morning of 19 March 2003. Photo courtesy of Stacey Seseske (NOAA/FSL), former CSU graduate student.

Acknowledgments

The author would like to express his thanks to Drs. Mark DeMaria and Don Hillger (NOAA/CIRA), Dr. John Knaff (CIRA), Dr. Roger Pielke (Colorado Climate Center), and Mr. Robert Glancy (NWS forecast office, Boulder, CO). When writing informally there is a tendency to be a little more relaxed than when writing for a refereed journal. These folks not only kept me honest, but also helped make the piece a little more interesting with a number of valuable suggestions. Chad Gimmestad of the NWS forecast office in Boulder, CO went out of his way to provide model output data that we'd overlooked when we assembled the data set for the case here at CIRA. Finally, I'd like to thank Ms. Odie Bliss of the Colorado Climate Center, without whose help none of the fascinating statistics presented herein would have been available.

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Figure 11. Collapsed roof of the large Bed, Bath, and Beyond store on south College Avenue in Fort Collins, CO. The roof on this structure was replaced and the store reopened several months later. Photo courtesy of Ron Phillips, City of Fort Collins.

Gas Station Canopy Collapse. Photo by G. Merlo.

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South Meadow. Photo by M.J. Brodzik.

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