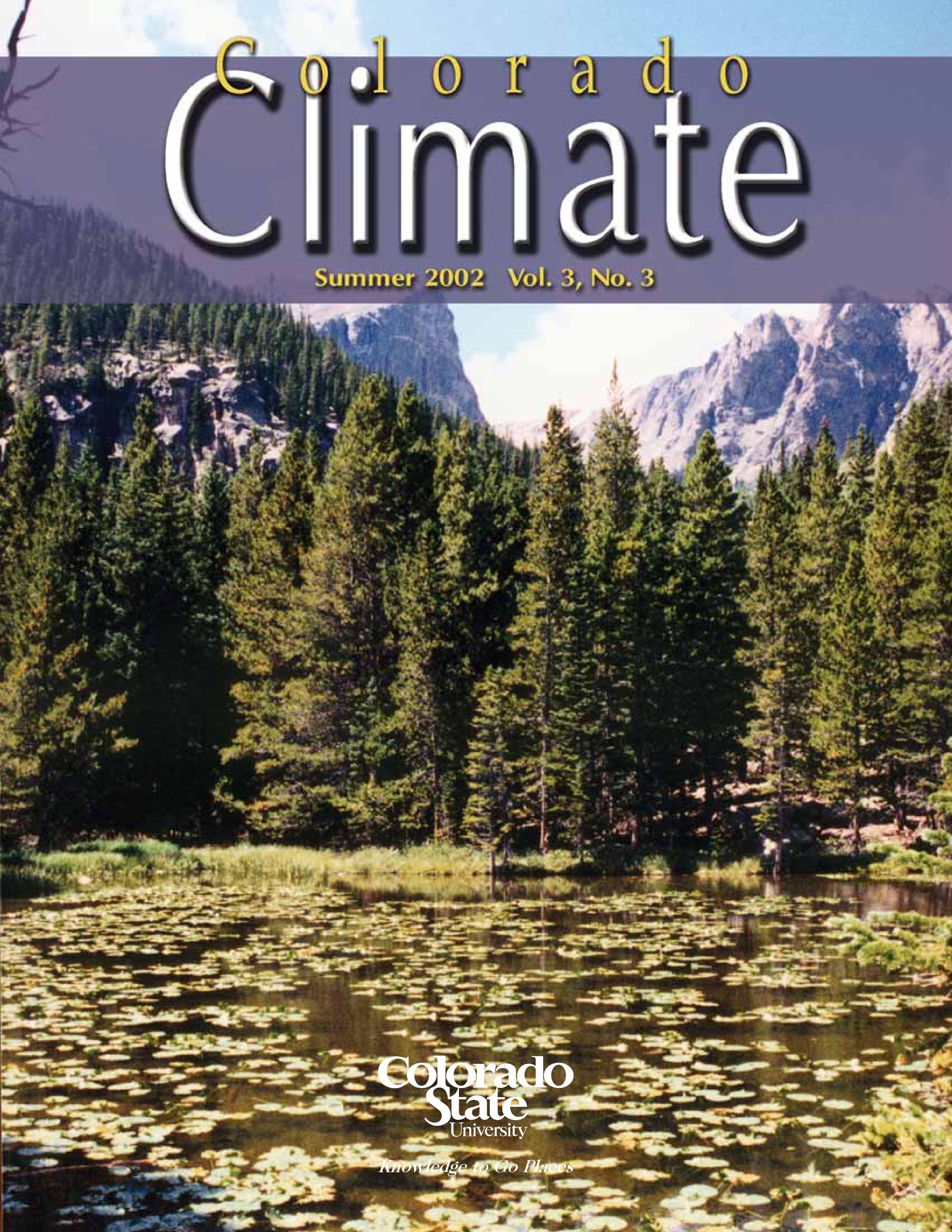
Colorado Climate

Summer 2002 Vol. 3, No. 3



Colorado State University

Knowledge to Go Places

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Cover Photo: Nymph Lake located in Rocky Mountain National Park in August. Photo by Brian McNoldy.

If you have a photo or slide that you 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.

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What Records Have We Been Breaking?

by John Bartholow and Bob Milhous, U.S. Geological Survey

"Today was another record-breaking day," the evening radio or television declares. High temperatures, low temperatures, floods, drought – take your choice. But how can we put these pronouncements in perspective? What do they really mean?

We present two types of information in this article: 1) an analysis of daily air temperature and precipitation for Fort Collins and 2) an analysis of annual precipitation for Fort Collins. Each analysis provides a different meaning to the statement about a record-breaking day or year.

Fort Collins historic weather station on the campus of Colorado State University. (Photo by James E. Bliss)

Fort Collins Daily Temperature and Precipitation

We conducted a simple investigation of daily maximum and minimum air temperature data downloaded from the Fort Collins weather station's web site (http://ccc.atmos.colostate.edu/). We used the meteorological data beginning with the first full year of available data, 1889, through the last full year, 2002. For each year, beginning in 1890, we calculated how many days in that year (omitting all 29-February leap days) broke the daily record that had been established in previous years.

We looked at four categories of records, two of which are commonly used and two of which may be just as relevant but are less often mentioned. The common metrics are 1) the maximum of the daily maximum and 2) the minimum of the daily minimum. The less common metrics are 3) the minimum of the daily maximum and 4) the maximum of the daily minimum. The first two metrics are the absolute highs and lows for the day and tell us something about how absolutely extreme the weather has become; by contrast, the last two metrics tell us something about how cool the days stay or how warm the nights are.

Our results for air temperature are shown in Figure 1. As you can imagine, broken records were common during the first several years at the beginning of meteorological data collection, so we begin these daily temperature graphs with calendar year 1900. The graphs appear to indicate that within the last few decades, Fort Collins continues to break daily air temperature records at a fairly high rate for both the maximum of the daily maximum and the maximum of the daily minimum temperatures. The minimum of the daily maximum and the minimum of the daily minimum records are being broken at a relatively low rate. Another way to think of this is that it is getting hotter all day, and all night, long.

We also wondered how these record-breaking events would look compared to a theoretical curve describing the number of records we expect to be broken based solely on random fluctuations in our daily weather. For example, in the second complete year of data collection

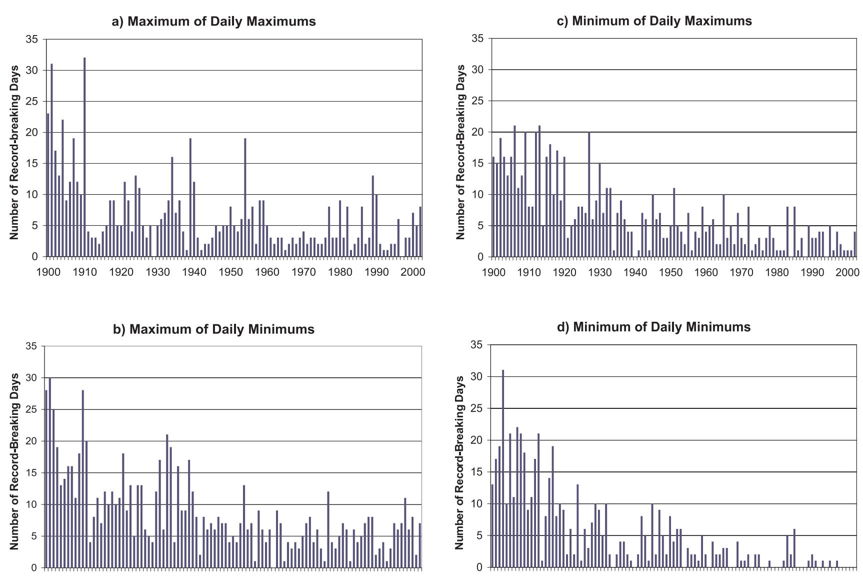

Figure 1. The number of days each year that broke the air temperature record for previous years for (a) maximum of the daily maximum, (b) maximum of the daily minimum, (c) minimum of the daily maximum, and (d) minimum of the daily minimum. The data represent full calendar years beginning in 1889 for Fort Collins, Colorado, but shown since 1900 only.

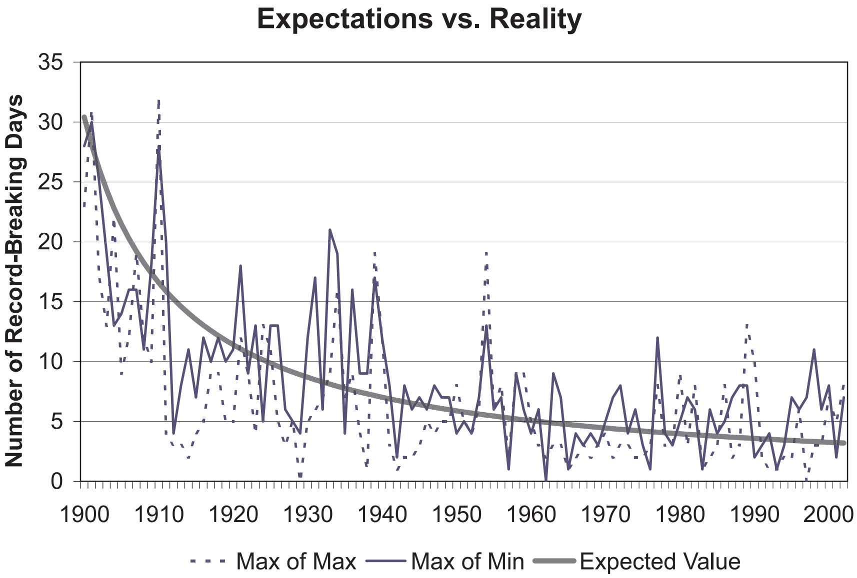

Figure 2. Number of record-breaking days for maximum of the daily maximum (max of max) and maximum of the daily minimum (max of min) compared with a theoretical curve describing a uniformly random process (expected value). The data represent full calendar years beginning in 1889 for Fort Collins, Colorado, but shown since 1900 only.

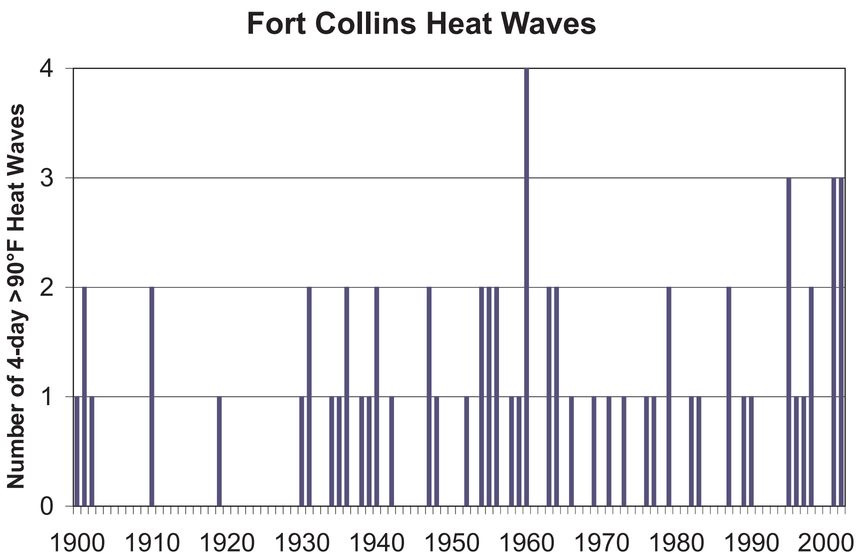

Figure 3. Annual number of "heat waves" in Fort Collins, Colorado, defined as non-overlapping 4-day periods when the maximum daily air temperature exceeded 90°F. The data represent full calendar years beginning in 1889 for Fort Collins, Colorado, but shown since 1900 only.

(1890), we would expect the record to be broken on one-half of the days, or 365/2 = 182.5. The next year we would expect 365/3 = 121.6 records to be broken, and so on. Figure 2 compares two of the metrics we looked at in Figure 1 with this expected value. The theoretical expectation predicts that we would break a total of about 82 records in the period 1980-2002. History confirms that we broke the maximum of the maximums record 102 times and the maximum of the minimums record a whopping 124 times in that time period. By contrast, we only broke the minimum of the maximums 61 times and the minimum of the minimums a mere 21 times, a good reason to believe things are heating up rather than cooling down.

This takes us to heat waves. Perhaps looking at single days is not the best way to characterize the brow-mopping heat we occasionally experience. Figure 3 illustrates the number of non-overlapping 4-day events each year when the maximum daily air temperature exceeded 90°F each day. Though it is not entirely clear from Figure 3, heat waves seem to be coming with a greater frequency in the later portion of the period.

Using the same techniques already applied, we examined the daily record for precipitation. Unlike air temperature, we looked only at the single measured daily value, ignoring all "trace" quantities. The results are shown in Figure 4 and appear to support that we have been staying well under the number of broken records we would expect from a purely random process. In addition, there appears to be some visual evidence for a recurring pattern illustrated by periodic especially low values.

Fort Collins Annual Temperature and Precipitation Records

We also examined how some records would look from an annual perspective. We first looked at the change in annual maximum temperatures for the period 1 July – 15 August (the hot part of the year in Fort Collins). Our objective was to see how the maximum annual temperature has changed over the 113 years of temperature record by looking at the change in the range of these maximum 4-day temperatures. Results are presented in Figure 5. The dashed colored line in the figure is the maximum 4-day temperature in each year; the black solid lines represent the annual maximum and minimum temperature records and when they changed. For example, 1889 begins the record with a maximum 4-day temperature of 92.5°F. In 1892, the maximum 4-day temperature set a new record at 97.5°F; in 1939 the record value rose to 98.3°F and then again to 101.3°F in 1954 setting our present record. There is about a 1% chance the 101.3°F record will be equaled or exceeded this year or next. Like Figure 5, Figure 6 looks at the variation of the 4-day minimum (usually night) temperatures for the same time period. This diagram indicates that nighttime temperatures have increased markedly, a conclusion similar to that seen from the daily analysis.

We performed a parallel analysis for annual water year precipitation data for Fort Collins. (A water year is from 1 October – 30 September and is used for water accounting purposes.) Results are presented in Figure 7. Changes in the limits of annual precipitation are of interest to many people because they tell us what conditions have existed and, to a certain extent, what we might face in the future. The concept illustrated here has been described as the Noah (rainy) and Joseph (drought) effect because the range of maximum-of-maximum and minimum-of-minimum water year precipitation becomes larger as our record becomes longer. In other words, we start out with whatever we observe as the maximum and minimum precipitation and this changes as the record length expands just like we saw for annual air temperature records.

We are very concerned about droughts in Fort Collins because of recent low precipitation. It is interesting that the last time the minimum-of-minimum record decreased was in 1966 where the record water year minimum was established as 7.40 inches, down from the 7.54-inch minimum established in 1954. The 2002 water year precipitation in Fort Collins was 8.39 inches – we still have a ways to go to break the earlier water year record.

We all tend to remember only the last few years of our weather and the land becomes parched if the precipitation is low for more than one year. In an attempt to illustrate longer-range effects, we have calculated an index to multi-year precipitation that is the sum of the present year, ¾ of the last year, ½ of two years ago, and ¼ of the year before that divided by 2.5 (1 + ¾ + ½ + ¼). This is not a perfect way of looking at long term "runs" in the precipitation data, but we found the results (Figure 8) interesting. This figure shows that we had a Noah (rainy) period in the late 1990s that established a new maximum multi-year precipitation record. Since then, we have moved rapidly toward a Joseph (drought) episode.

Discussion

Our results are relatively simple-minded ways to look at the widely acknowledged warming that many of us are experiencing. Warming could be the result of urbanization or it could be more global in nature. We have made no attempt to be rigorous here – we recognize that data collection methods have changed through time, and many skilled meteorologists have explored the detection of climatic trends far more than we (Pielke et al. 2000; Pielke et al. 2002). Simply tallying record-breakers or looking at yearly summer temperatures and water year precipitation does not fully describe the magnitude of the temperature and precipitation changes we have been experiencing, or whether they are biologically or culturally significant, like looking at the dates of first and last frost. But we do feel that the graphs we have presented can help put Fort Collins record-breaking in perspective.

Life would be boring if we broke no records. If our meteorological processes were completely stationary,

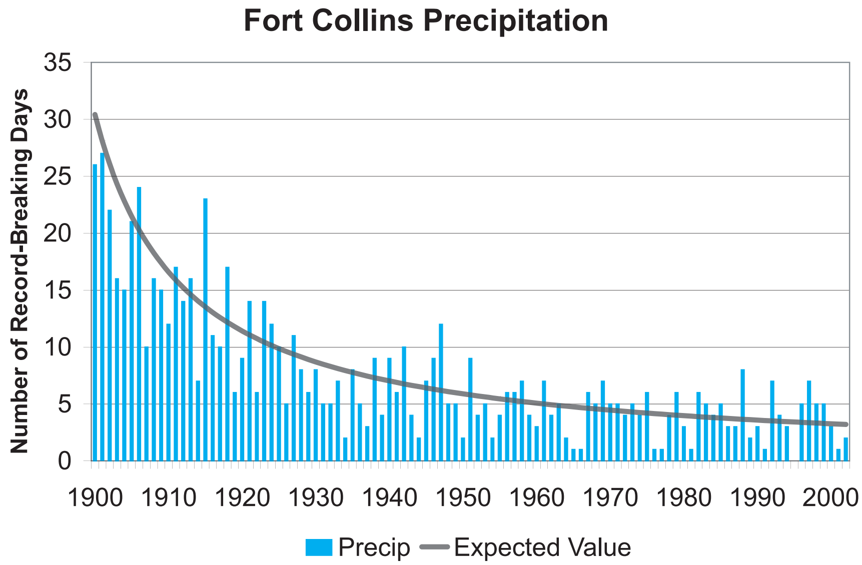

Figure 4. The number of days each year that broke the daily precipitation record for previous years. The data represent full calendar years beginning in 1889 for Fort Collins, Colorado, but shown since 1900 only. The solid black line represents an expected average value.

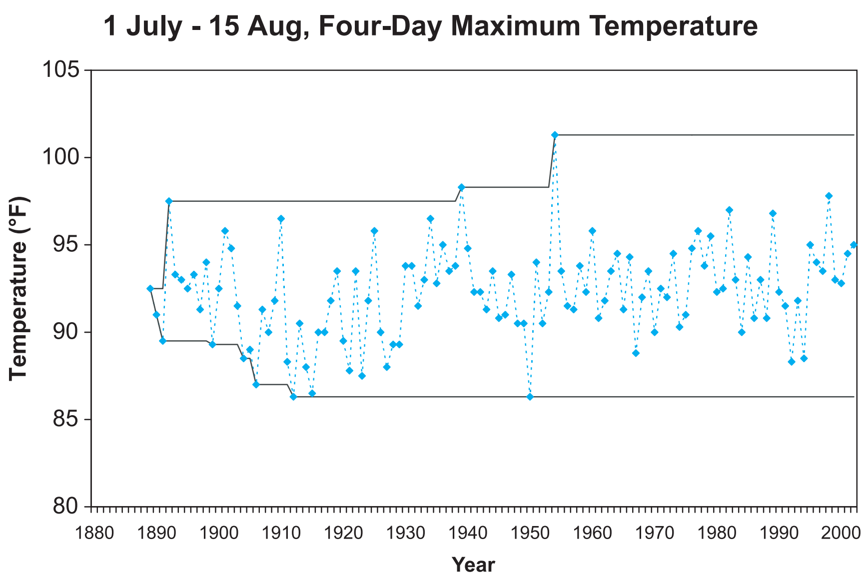

Figure 5. Variation in 4-day maximum air temperature in Fort Collins during the summer (1 July-15 August) along with the increase in maximum of the maximum 4-day temperature and decrease in minimum of the maximum 4-day temperature.

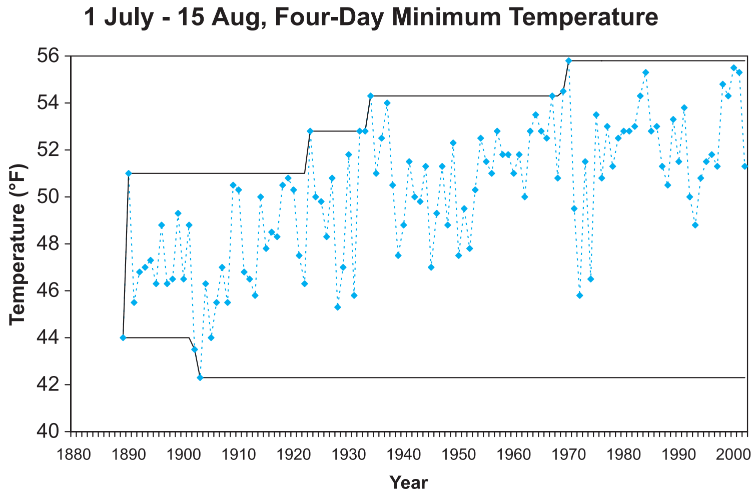

Figure 6. Variation in 4-day minimum air temperature in Fort Collins during the summer (1 July-15 August) along with the increase in maximum of the minimum 4-day temperature and decrease in minimum of the minimum 4-day temperature.

and we had no changing climate, we might expect to break only one air temperature record by the time the year 2254 rolls around. (But then we suppose that breaking no records would itself be a record-breaking experience!) Local, or more global, changes in our weather may make our historical records much easier to break, adding spice to our lives.

How many new records will we break in the next year?

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Pielke, R.A. Sr., T. Stohlgren, L. Schell, W. Parton, N. Doesken, K. Redmond, J. Money, T. McKee, and T.G.F. Kittel. 2002. Problems in evaluating regional and local trends in temperature: An example from Eastern Colorado, USA. *International Journal of Climatology*, **22**:421-434.

Figure 7. Water year precipitation records along with the ever-expanding maximum and minimum annual precipitation record. The dashed line in the center right is the median precipitation for the period of record.

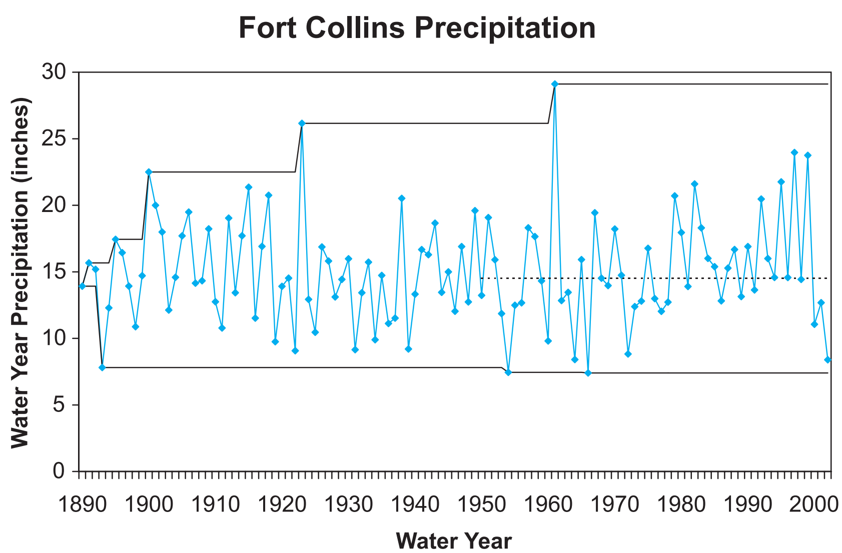
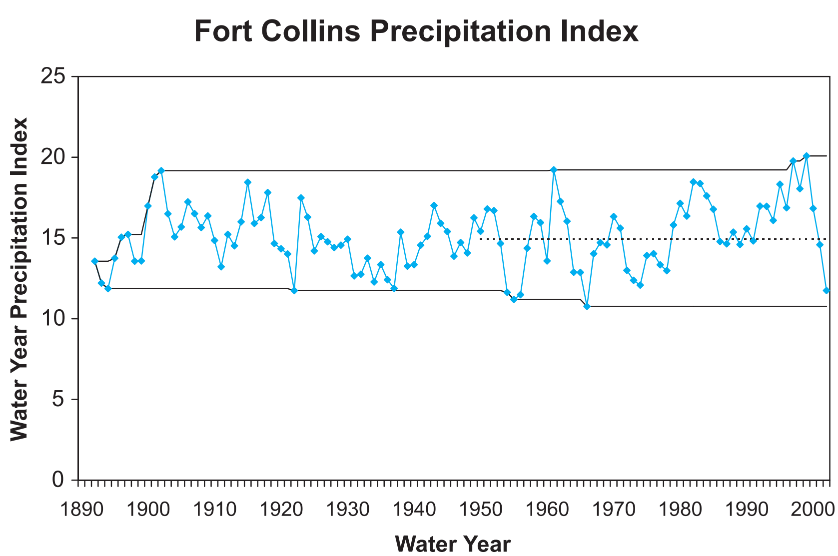


Figure 8. Index to the weighted 4-year run in precipitation in Fort Collins along with the ever-expanding maximum and minimum run record. See text for a description of the run index. The dashed line in the center right is the median index to precipitation for the period of record.



About the Authors: John Bartholow and Bob Milhous are employees of U.S. Geological Survey in Fort Collins, Colo., and budding climatologists!

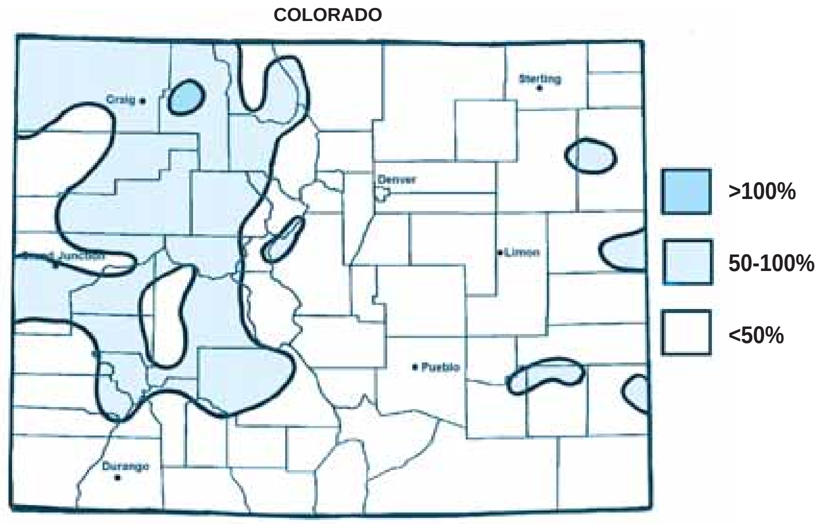
Colorado Climate in Review

by Nolan Doesken

April 2002

Climate in Perspective

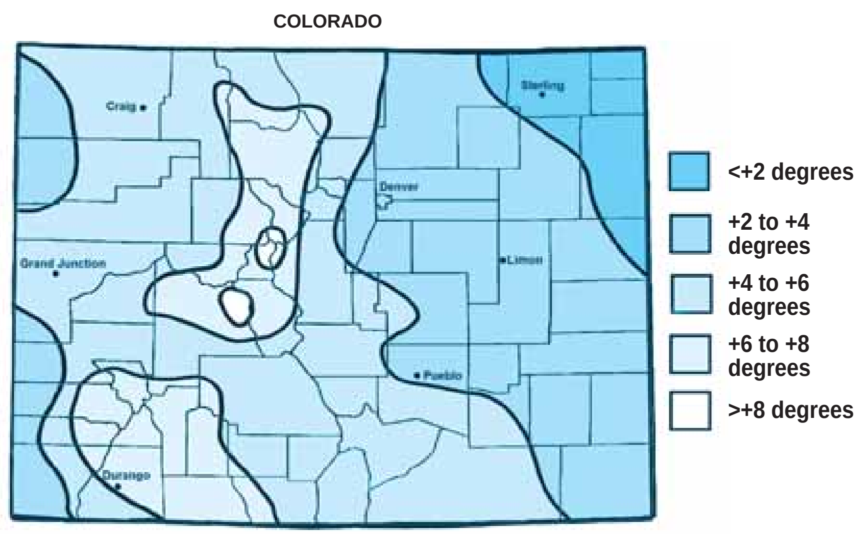
Drought conditions emerged emphatically in Colorado during April as much above average temperatures prevailed throughout the month accompanied by low humidity and frequent and persistent strong winds. Mountain snowpack disappeared amazingly quickly and produced very little runoff. While several storm systems did traverse the region, each passed quickly giving only brief bursts of precipitation rather than the long-duration widespread storms that often dampen Colorado during the spring months. The severity of the emerging drought became obvious late in the month when a small forest fire near Bailey quickly raced out of control forcing many evacuations and burning several structures. This wildfire occurred a full two months earlier than the typical Colorado forest fire cycle and set the tone for a long, hot fire season to come.



April 2002 precipitation as a percent of the 1961-1990 average.

Precipitation

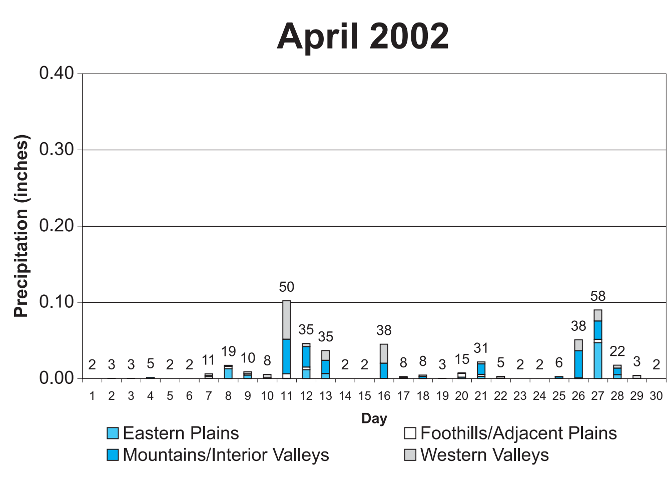
Several storm systems skipped across Colorado during April but none left widespread or heavy precipitation. A few thunderstorms rumbled over the eastern plains in early April. Decent moisture fell over northwestern Colorado April 11-12 with totals exceeding 0.50" in a few places. Precipitation was fairly widespread 26-27th, but when totals for April were computed, only one location – Hayden, in northwest Colorado – had above average precipitation totals for the month. In fact, the majority of Colorado ended up with less than half the April average. Several areas received practically nothing during the month. For example, Greeley received just a trace and Castle Rock totaled a mere 0.01". Southwestern Colorado, which has been extremely dry all winter, continued in the same pattern. Cortez totaled just 0.12" for April. By the end of April, drought conditions were undeniable over practically the entire state.



April 2002 temperature departure from the 1961-1990 average.

Temperature

While there were some ups and downs in Colorado's springtime temperatures, warm weather prevailed statewide. Unusual and in some cases record-setting warmth was especially pronounced in the mountains where the month ended up as much as ten degrees Fahrenheit warmer than average. Only northeastern Colorado, which caught the edge of a couple of cold Canadian air masses during the month, ended up near average. The exceptional and locally unprecedented April warmth contributed to the extremely early snowmelt in the mountains.



April Daily Highlights

1-3 April began warm and dry with northwesterly winds aloft and low elevation temperatures in the 70s and low 80s on the 1st. On the 2nd, a cold Canadian air mass backed into eastern Colorado with sharply colder temperatures and highs only in the 20s and 30s. Clouds with a few flurries developed along the Front Range. Cool weather continued east of the mountains on the 3rd while the Western Slope enjoyed more unseasonably warm and dry weather.

4-6 Sunny, mild and dry 4-5th but increasing clouds on the 6th in advance of an approaching low pressure area over the desert Southwest.

7-8 An upper level low pressure center passed just south of Colorado. Brisk winds continued but the humidity increased east of the mountains. Showers with a few claps of thunder developed over portions of southern and eastern Colorado as the system moved eastward. Most precipitation was very light, but Holyoke measured 0.52" early on the 8th.

9-12 Westerly winds aloft provided a continuation of unseasonably warm weather. High temperatures close to 80 degrees were widespread over southeast Colorado 9-10th. Pacific moisture worked its way into Colorado late on the 10th along with cooler temperatures. Valley rains and mountain snows continuing on the 11th. Steamboat Springs measured 0.60" of moisture from the storm, but most areas had less.

13-15 A ridge of high pressure over the Rockies brought a return to dry and warm weather. Westerly winds increased on the 14th and became strong and gusty on the 15th in advance of an approaching storm system. Temperatures soared to record levels on the 14th and 15th east of the mountains with temperatures in the 90s across SE Colorado on the 15th.

16-21 Unsettled weather as a trough of low pressure aloft set up west of Colorado. At times it looked like Colorado might be in for a good spring storm, but the main low stayed to our west. Some showers fell on the 16th. Glenwood Springs reported 0.44" but most areas had less. Areas east of the Continental Divide remained dry 16-18th. Strong winds were common statewide throughout the period. On the 19th, sharply colder air reached into eastern Colorado from the north. Chilly, damp upslope flow over northeast Colorado on the 20th produced some cold rain and a little snow. Most totals were very light, but Sedgwick reported a much needed 0.42" total. The upper level low pressure system exited the state on the 21st accompanied by some cold temperatures. A hard freeze with temperatures in the 20s hit Colorado's Western Slope orchard areas.

22-25 Dry and again very warm 22-23rd. Strong winds with local gusts in the mountains and foothills of up to 70 mph were observed. A human-caused forest fire near Bailey quickly spread out of control. A cold front cooled temperatures on the 24th and 25th but did not bring moisture.

26-27 A quick moving storm system zipped across the state from the SW. The storm moved too quickly to drop heavy precipitation, but many areas picked up some moisture. A few inches of snow fell in the mountains. Thunderstorms developed in eastern Colorado. Burlington measured a surprising 1.12" total from the storm.

28-30 High pressure and dry weather dominated the final three days of the month. Grand Junction hit 81 degrees F on the 30th and Pueblo reached 88. Leadville even hit a high of 60 degrees on the 29th and 30th to finish off the warmest April in their history.

April 2002 Monthly Extremes

Description	Station	Extreme	Date
Precipitation (day)	Kit Carson 9NNE	0.64"	Apr 27
Precipitation (total)	Steamboat Springs	1.72"	
High Temperature	Holly	97°F	Apr 16
Low Temperature	Meredith	6°F	Apr 22

May 2002

Climate in Perspective

Drought conditions over Colorado and adjacent states magnified in May. This is typically a stormy time of year with average precipitation approaching or exceeding three inches over portions of NE Colorado with lesser amounts to the south. Unfortunately, most storms skirted Colorado this year and May precipitation fell far short of the average. The severe weather season, which often begins in May, also was late in coming. There were some large swings in temperatures as the battle between winter and summer weather patterns played out. Late freezes may have damaged crops in some areas. By the end of the month, searing summer heat was already in place. Any chance for recovery from a winter and spring with poor mountain snow accumulation was lost.

Precipitation

May precipitation fell far short of the long-term average for nearly all areas of Colorado. The one exception was a small area of the northern Front Range including much of Boulder County. Boulder, for example, totaled 3.20" in May. This was due to the one major spring snow that brought cold rains and foothills snows to the area May 23-24th. For the rest of Colorado May was another painfully dry month. Several weather stations over southern and western Colorado reported little or no precipitation. Most of the state reported less than 50% of the average May precipitation at a time of year when moisture is greatly needed. As a result, the many grassland areas of Colorado failed to green up this spring and crisis conditions emerged quickly for Colorado ranchers. Forest conditions also became tinder dry.

Temperature

May temperatures were near to slightly below average over northeastern Colorado where cool, dry Canadian air masses invaded several times during the month. The remainder of Colorado was warmer than average with the warmest areas noted over southern and western counties. In the Durango-Cortez area in southwestern Colorado, nearly all months have been above average for the past several years, exacerbating the severe drought conditions over the region. But with persisting dry weather, very large day-night temperature swings have become common

May Daily Highlights

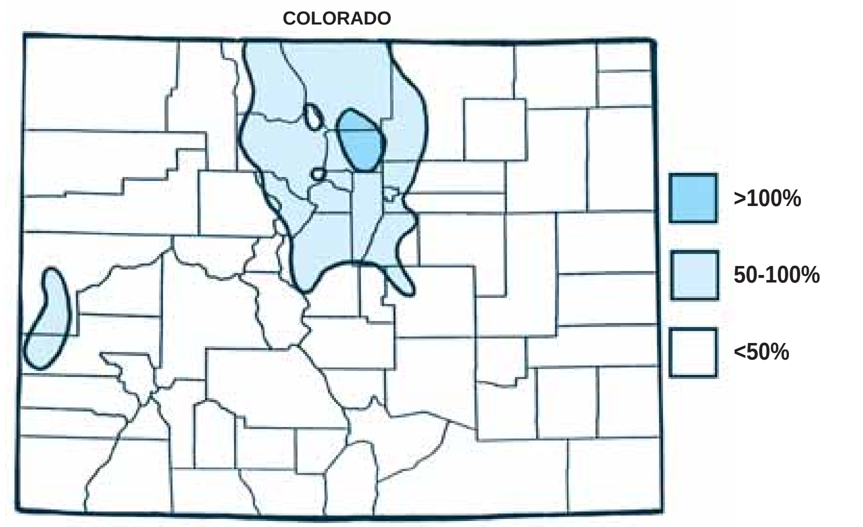
1-3 Cold air out of Canada combined with a weak upper disturbance but all we could muster was some clouds and a little light precipitation 1-2nd mostly along the Front Range. Fort Collins and Boulder each got a little snow late on the 1st. Sunshine increased and temperatures warmed on the 3rd.

4-6 Warm and dry statewide.

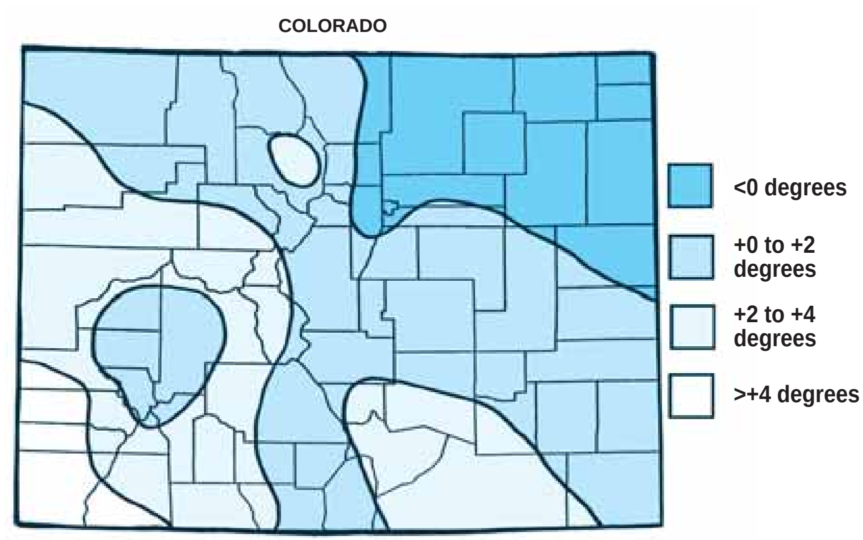
7-9 The exceptional warmth and lack of mountain snow this spring resulted in Trail Ridge Road in Rocky Mountain National Park opening on the 7th. This was the earliest opening since 1932. Cold air slipped into NE Colorado on the 7th followed by a stronger cold front from the NW later on the 8th. Once again, precipitation was scant despite the active weather pattern. Steamboat Springs recorded 0.40" of moisture and one inch of new snow, but most areas received little or nothing. Then temperatures plummeted behind the front. Most of eastern Colorado awoke to a hard freeze early on the 9th. Akron dipped to 21°F and a few areas in Weld and Logan Counties awoke to temperatures in the mid to upper teens. Some single digit readings were noted in the northern mountains.

10-12 Another storm system crossed Colorado. Clouds and winds increased on the 10th in advance of the storm. Showers and a few thunderstorms developed on the 11th followed by a period of steady cold rain turning to snow in the higher foothills of the northern Front Range late on the 11th. Western Colorado didn't get much

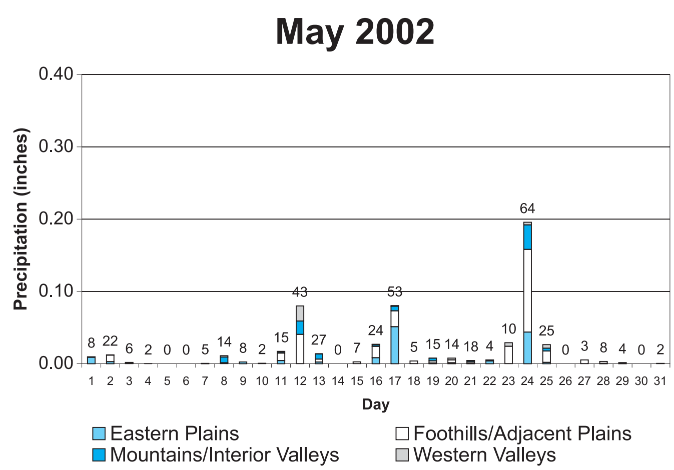
Statewide average daily precipitation graph(s) (right and throughout this article) shows relative amounts of precipitation for each region. Label on each column indicates percent of stations with measurable precipitation for each day.



May 2002 precipitation as a percent of the 1961-1990 average.



May 2002 temperature departure from the 1961-1990 average.



although Grand Junction reported 0.40" of rain from the storm. Some of the higher precipitation totals included 0.86" of moisture from 7 inches of snow at Allenspark and 0.92" of moisture from 8 inches of snow near Conifer. Southeastern Colorado missed all the precipitation.

13-16 Dry statewide on the 13th with comfortable temperatures. Then weak disturbances moved inland from California along with Pacific moisture. High-based thunderheads developed on the 14th and 15th over Colorado producing some light scattered showers and some lightning, especially east of the mountains. Showers were most numerous on the 16th. Much of northeastern Colorado picked up one quarter to one half inch of rain while southern and western Colorado continued dry.

17-19 A ridge of high pressure aloft developed over Colorado on the 17th and remained in place until early on the 20th when a new storm pushed eastward from California. Under the influence of this ridge, summer-like temperatures occurred. Northdale, in southwestern Colorado, reported high temperatures of 80 degrees F each day, while areas near Grand Junction approached 90 degrees. Temperatures were cooler from the mountains eastward, but the heat pushed into SE Colorado on the 19th with readings soaring into the 80s and low 90s. A few high-based convective showers developed from the mountains eastward but dropped very little moisture.

20 A small upper-air disturbance came up from the south and surprised folks in southern and southeastern Colorado with some rain and cooler temperatures. A storm developed in South Park over Fairplay during the afternoon of the 20th and quickly deposited 0.59" of moisture, much of which fell in the form of small hail. An approaching storm system from the west brought increasing clouds and strong winds

21-24 A deep low pressure area developed just west of Colorado and moved into Wyoming and Montana on the 21st. This brought cooler temperatures to the Western Slope accompanied by strong winds and local blowing dust. East of the mountains, hot and dry conditions developed with strong downslope winds and very high wildfire danger. Breezy, cooler and dry on the 22nd. Then a new storm developed quickly on the 23rd and snow began falling in the northern and central mountains by late afternoon. Heavy precipitation started later in the evening along the Front Range, falling as cold rain and wet snows. The storm moved quickly eastward on the 24th with clearing skies but not before depositing a foot of snow in the foothills of Boulder and Jefferson Counties. Precipitation totals along the Front Range exceeded one inch from Denver northward into Larimer County. Parts of southeastern Colorado also received beneficial rains. Holly and Sheridan Lake each reported at least 0.75". While this was the heaviest and most widespread storm of the month, it still managed to miss southwestern and northeastern counties.

25-27 A cold morning on the 25th with some local frost over portions of eastern Colorado. Then dry and warmer statewide. A few thundershowers developed along the southern Front Range on the 27th, while the rest of the state stayed dry.

28-31 A late-May heatwave set in across most of Colorado melting almost all remaining mountain snow. Temperatures by late in the month reached 80°F even at places like Breckenridge and Crested Butte. High temperatures on the 31st equaled or set new records for the date: 98°F in Greeley, 100°F at Grand Junction, 102°F at Pueblo and 106°F at Las Animas. The seriousness of the emerging drought could no longer be denied.

May 2002 Monthly Extremes

Description	Station	Extreme	Date
Precipitation (day)	Buckhorn Mtn. 1E	1.81"	May 24
Precipitation (total)	Gross Reservoir	3.30"	
High Temperature	Ordway 2ENE	107°F	May 31
Low Temperature	Walden	6°F	May 9

June 2002

Climate in Perspective

June was warmer and drier than average once again continuing the statewide plunge into drought. Typically June is a month of melting snow and tumbling streams rolling out of Colorado's high mountains. This year, almost all snow was gone by early June, and streams were only a trickle by the end of the month. Some severe storms clunked localized areas of eastern Colorado with hail and strong winds, but for the rest of the state it was a quiet month with persistent low humidity, bright sunshine, and hot daytime temperatures. Wildfires that ignited in the mountains early in the month continued to burn and spread all month. Smoke plumes were a common sight and even spawned some thunderstorms south of Denver and east of Durango.

Precipitation

June was another dry month for most of Colorado. June is often dry over southwestern Colorado, but this year seemed particularly harsh. Even near the mountains, places like Aspen and Glenwood Springs reported only a trace of moisture for the entire month. For the entire western half of Colorado, precipitation was at best half of average, and at worst, zero. Eastern Colorado fared better but still not great. Fort Collins, Denver, Pueblo, La Junta, and Sterling all ended up with less than 50% of their June average. A few spots struck the moisture jackpot. Genoa, just east of Limon, was the Colorado wet spot in June with 4.35". Areas near Kit Carson also got close to 4" of moisture. Most other areas of the plains were considerably drier.

Temperatures

Typically, Colorado experiences periods of coolish weather in June, especially early in the month. But in 2002, June started hot and stayed hot, even in the mountains. For the month as a whole, temperatures ended up four to as much as seven degrees above the long-term averages making this one of the hottest Junes in recorded history, challenging even the notable heatwaves of the past such as June 1954. Southern Colorado took the brunt of the heat. For example, high temperatures hit or exceeded 98 degrees on 15 days during the month at the Pueblo airport. Temperatures at the John Martin Dam weather station reached 108°F or higher on 4 days during the month. The heat served to magnify the ever-growing impacts of the current drought.

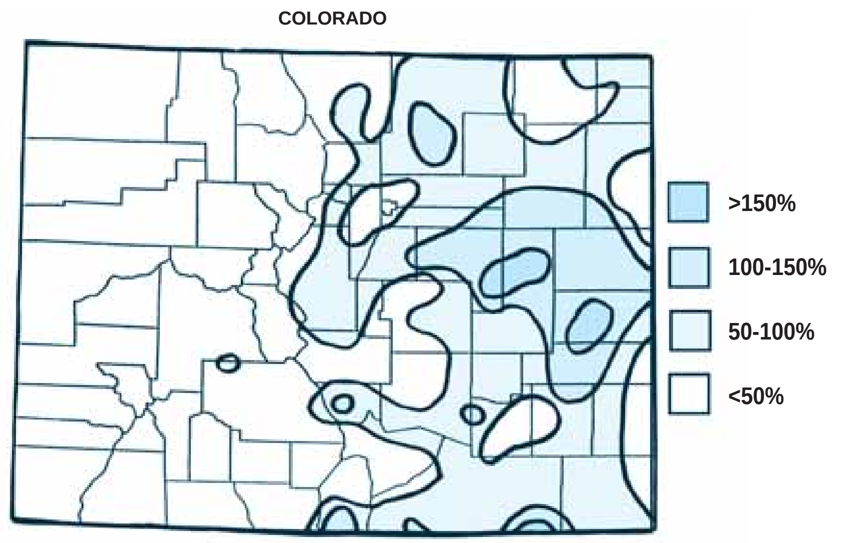
June Daily Highlights

1-2 Extremely hot. Las Animas hit 108°F on June 1. Some lightning triggered fires in NE Colorado from high-based dry T-storms.

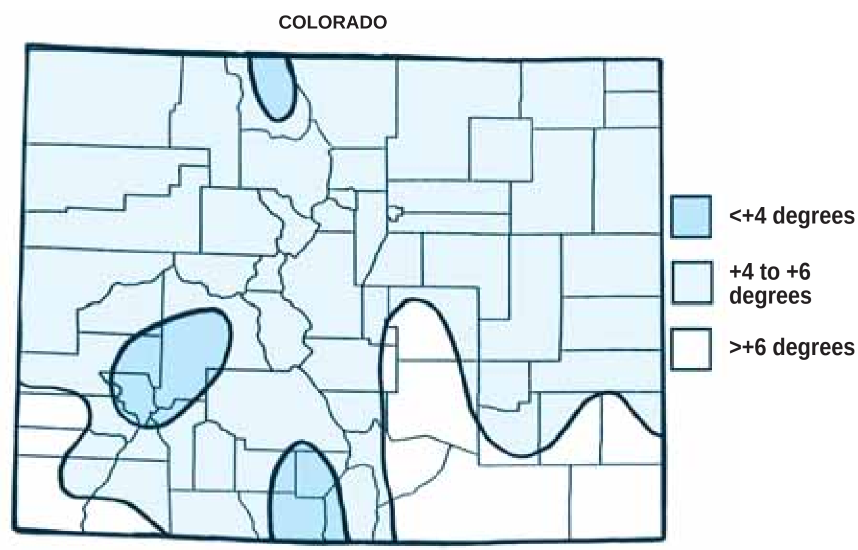
3-4 A cold front and upper level low pressure trough triggered the only widespread precipitation event of the month. Some severe storms with heavy rain crossed portions of east-central Colorado dropping more than 2" of rain in areas from Limon to near Lamar. But rain quickly ran off or evaporated and did surprisingly little to quench the thirst of the growing drought. Mountain peaks were whitened by the last snow of the season.

5-9 More heat with bone-dry weather and strong winds created the worst of wild fire conditions. High temperatures 6-9th climbed into the 90s at lower elevations with some 100 degree readings, especially in SE Colorado. The Hayman fire was started on the 8th southwest of Denver and the Missionary Ridge fire near Durango ignited on the 9th. Both fires soon grew to be infernos that were not controlled until more humid air arrived in July.

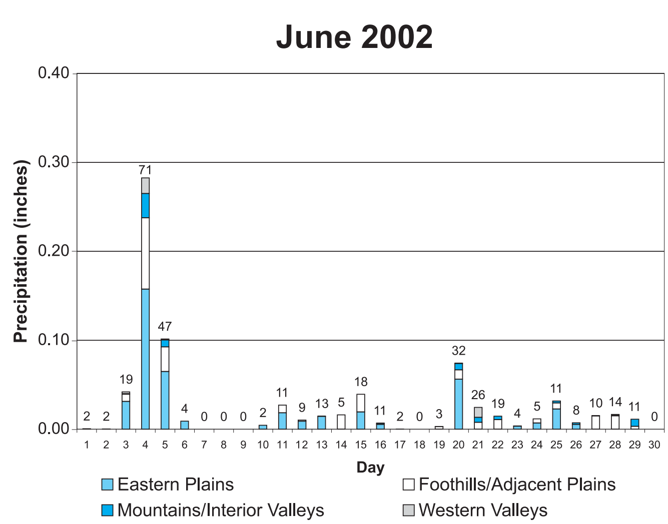
10-16 Dry but not as hot. Temperatures stayed in the 70s and 80s east of the mountains most days with some scattered, mostly high-based convective clouds. Rainfall was generally light, but a few of the storms were locally severe. Stratton picked up a quick inch of rain on the 11th and some hail was reported in eastern Colorado. Parts of Colorado Springs were pounded by



June 2002 precipitation as a percent of the 1961-1990 average.



June 2002 temperature departure from the 1961-1990 average.



hail on the 14th causing millions of dollars in property damage. More storms hit eastern Colorado late on the 15th. Kit Carson reported 1.92" of rain. Severe hail damaged what little was left of parched crops in other parts of Cheyenne County. Most of the state remained dry, however, and hot weather quickly returned to the Western Slope. Forest fires continued to burn and expand.

17-18 Very hot again with 90s and 100s. No precipitation.

19-20 A Pacific front moved across the state. Temperatures dropped a bit in the mountains and across the plains, but the main excitement was a round of big thunderstorms over northeastern Colorado. As much as one inch of rain fell over parts of Yuma County late on 19th, and some damaging hail was observed.

21-30 Heat and drought. Above average temperatures each day with highs in the 90s and 100s at lower elevations both east and west of the mountains and 80s in the mountain communities. Totally dry over western Colorado, but some widely scattered and mostly high-based storms east of the mountains. In SE Colorado, Kim 10SSE reported 2.43 inches on June 21st. One big storm near Cheyenne Wells on the 24th dropped tennis-ball sized hail. Forest fires continued to burn.

2002 Water Year to Date

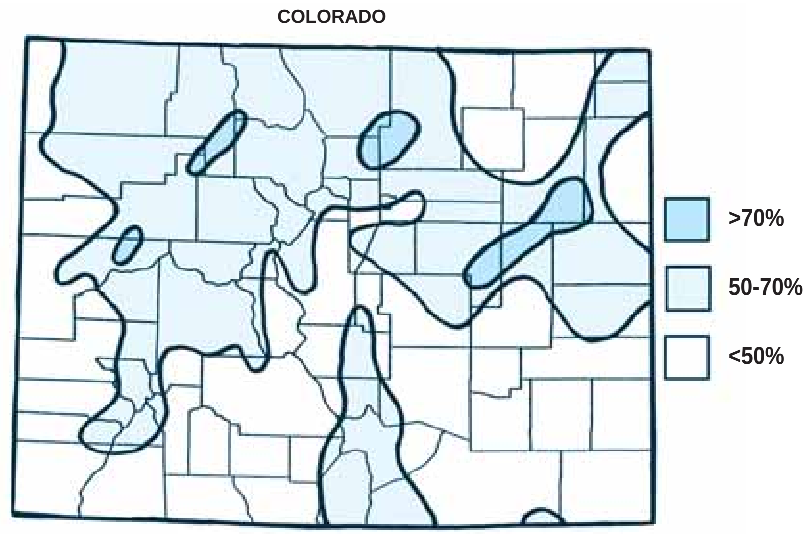
Three fourths of the way through the 2002 Water Year, no relief is in sight from the ever-spreading drought. The lower than average winter snowpack, followed by an exceptionally warm and dry April, May, and June has left all areas of Colorado far below average. Runoff from mountain rivers and streams has been tracking at record low levels for many watersheds. Reservoirs are being depleted at an extraordinary rate.

A few small areas of northern and central Colorado show water year precipitation totals slightly above 70% of average. All of the rest of Colorado is drier. Most of southern Colorado has received less than half the average October through June precipitation. For places like Durango, Cortez, Monte Vista, Pueblo, Salida, and Holly, 9-month precipitation totals stand at barely one-third the historic average.

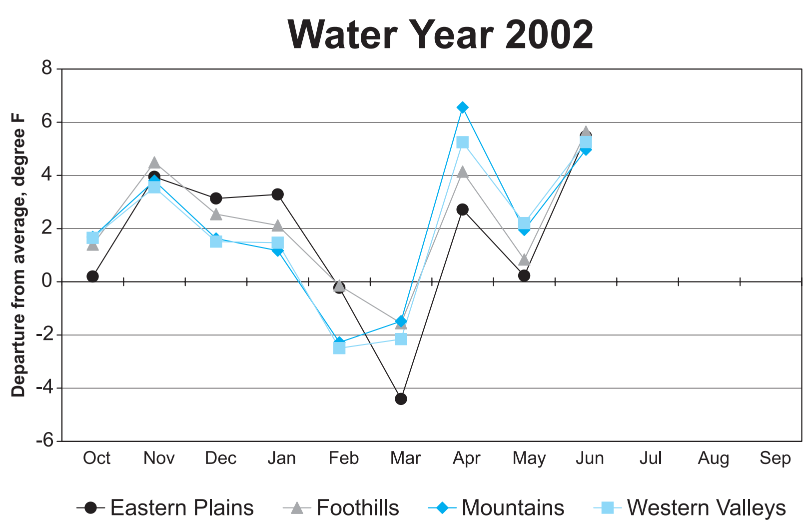
The large forest fires burning in the state correspond to areas that have received the least precipitation this year and over the previous several. Barring the onset of an extreme Southwest Monsoon in July and August, conditions are most likely to remain dry. Summer precipitation rarely is sufficient to keep pace with evaporation rates making drought recovery in midsummer very unlikely.

June 2002 Monthly Extremes

Description	Station	Extreme	Date
Precipitation (day)	Kim 10 SSE	2.43"	Jun 21
Precipitation (total)	Genoa	4.35"	
High Temperature	John Martin Dam	110°F	Jun 3
Low Temperature	Meredith	15°F	Jun 17



Water Year 2002 (October 2001 through June 2002) as a percent of the 1961-1990 average.



Chasing and Observing Storms in the High Plains

by Matthew D. Parker

***Author's note:** This article is not intended to teach you how to chase storms. Severe thunderstorms are dangerous. They pose real threats to your life and property. Lightning and tornadoes can be deadly. Large hail and heavy downpours can reduce visibility quickly and can make it very difficult to control an automobile. Experienced storm chasers understand storms' structures and motions and plan carefully to minimize their risk. Please do not attempt to chase severe thunderstorms without proper training. The sparse road network and general lack of shelter on the High Plains can make it very difficult to recover from errors.*

Many Americans are curious about the hobby and scientific pursuit of storm chasing. It received widespread public attention when Warner Brothers released the movie *Twister* in 1996. It is now featured regularly on The Weather Channel and numerous other news and documentary programs. However, the reality of storm chasing is rarely glamorous. It often involves long hours behind the wheel and unhealthful meals on the road; only very rarely does it involve intercepting and observing tornadoes. Nevertheless, it's all worth it for storm chasers like me, who love the scenery of the High Plains and thrill to see the atmosphere evolve . . . on days both amazing and disappointing. In the chase account that follows, I've tried to reproduce both the difficulties and rewards of storm chasing on the High Plains of Colorado.

May 31, 1999

Unlike many chases, my colleagues and I didn't depart in the early morning on this day. Cloudiness over eastern Colorado had us worried that less solar heating would occur than what the computer models had predicted. A lack of heating, in turn, would mean less of the instability needed to produce strong thunderstorms. However, we had grown more optimistic by 11 a.m. because the overcast had begun to dissipate to the south of Monument Ridge (the high terrain between Denver and Colorado Springs). The vertical wind shear was also quite large, a necessary ingredient for the rotating thunderstorms ("supercells") which are known to give birth to tornadoes. Seeing that the skies were continuing to clear, and that the surface observations across Colorado revealed warm, humid air, my colleagues and I finally left Fort Collins at 2 p.m. We began our chase with a target (chase destination based on our forecast) of Limon, Colorado, just east of Monument Ridge. The early morning cloudiness had set up a zone of strong horizontal temperature contrast extending from Limon to points eastward along I–70. We hoped to observe supercells

Figure 1. A tornado near Genoa, Colorado, looking north-northwestward at approx. 6:50 p.m., 31 May 1999. Photograph is copyright 1999 by M. D. Parker.

forming and moving eastward along that temperature contrast, a situation that often produces tornadoes.

As we drove southward from Fort Collins along I–25, we were confronted with our first major choice of the day: our weather radios alerted us to severe thunderstorms that were beginning to develop west of Fort Collins. Should we continue toward our goal in Limon or try to intercept the storms to our west-northwest? The prospect of chasing closer to home, minimizing our driving time, was tempting. However, we trusted our scientific reasons for choosing Limon, and headed south.

As we passed through the northern and eastern suburbs of Denver and turned eastward on I–70, we began to watch an interesting storm that formed at the end of a line of storms near Denver International Airport. After pulling off the interstate to have a closer look at it, we realized that it was fairly weak. We were confronted with our second major choice of the day: should we continue to observe the line of periodically developing thunderstorms here, or press eastward? Our scientific intuition told us that the surface humidity would be better farther east. In addition, we were beginning to see new thunderstorms developing to our east-southeast, near Limon. Seeing healthy storms blossoming in our original target zone spurred us eastward.

On May 31, as on many chase days, numerous thunderstorms developed outside of the target region. More often than not, the best idea is to stick with the target zone that you carefully selected before departing. Changing your chase strategy on the spur of the moment (i.e. "chasing what you see") generally sidetracks you away from your lengthy scientific preparations, and often yields bad results.

As of 3:30 p.m., we were hustling east to try to catch a strong storm moving eastward from Limon.

Numerous storms in close proximity to one another often become visually confusing and make it difficult to both observe the primary storm and remain in a safe location with respect to the other storms. However, the storm to our east was isolated, which would have made it easy to maneuver around and observe. It was an impressive-looking supercell, and by 4:30 p.m. the storm had a tornado warning. The only thing that diminished our enthusiasm was the fact that, even at 75 miles per hour, we weren't getting into a good intercept position with any swiftness. We needed to catch up with the storm and then circumnavigate its southern side in order to obtain an optimal view. At approximately 6 p.m., as we were finally making a southward move to try to intercept it, the supercell weakened and the National Weather Service cancelled the tornado warnings for it. This caused my colleagues and I great consternation, both because of the amount of effort that we had expended to catch up to it and because the reasons for the storm's demise weren't at all clear to us.

Many, many chases end in disappointment: we call them "busts"

One of the many challenges of storm chasing is the great sensitivity of thunderstorms to small variations in the atmosphere: variations that we can't observe easily.

Familiar thoughts of defeat began to creep up among us. Many, many chases end in disappointment: we call them "busts." Outstanding chasers may only see tornadoes on 10-15% of their chases. Notwithstanding my low tornado intercept rate, I normally derive a great deal of satisfaction from observing interesting aspects of supercell thunderstorms' development and evolution. However, on this day we had done a lot of driving and hadn't even gotten close enough to the supercell to observe its structure. In order to succeed at storm chasing, however, you must remain optimistic and try to find the best in any situation. After all, there were still other storms out there to observe and, with two and a half hours of sunlight remaining, the day was far from over.

We were sitting in our cars, about 15 miles north of Kit Carson, Colorado, trying to devise a new plan. We observed new healthy storms to our west-northwest and decided to approach them by heading southward on state route 59, then northwestward on US-40. This would place us optimally, to the southeast of the storms, and would alleviate the need to make a southward move later on. By 6:30 p.m., as we headed northwestward toward Limon (again!), we became increasingly impressed by the new storm's structure, and noted that it was occasionally producing funnel clouds. The storm was due northwest of us, dead ahead, and began to exhibit obvious supercellular structure.

At 6:45 p.m. we were about 15 miles from Limon, approaching the small town of Hugo. We began to see a funnel cloud extending downward from the storm's base; this is often a sign that a tornado is forming. Very soon, the condensation funnel neared the ground and we observed an initial whirl of dust, surefire evidence that a tornado had "touched down" (Figure 1). The tornado began about 15 miles to our north-northwest, very near Limon. We could see it on the ground moving northeastward for about 14 minutes until intervening precipitation obscured our view from where we sat just southeast of Hugo. Two members of our chase group in another car chose not to stop to watch and photograph the storm at the time and instead drove through Hugo and headed northward in order to get closer to the tornado. Because of their different vantage point they were able to observe the tornado for 23 minutes. Storm chasers must constantly make similar choices, considering their own safety, their desire for an optimal vantage point, and their desire to merely enjoy watching the storm.

Once we could no longer see the tornado, we also drove through Hugo and northward with the intent of following the storm. However, the storm was evolving toward a "high precipitation" structure, and it forced us to creep back southward toward Hugo in order to avoid the rapidly advancing core of precipitation. We began to be hit by marble-sized hail, and we soon realized that a new storm was developing to our southwest. We quickly returned southward in order to avoid the hail. As we neared Hugo again, we observed a brief (30 second) tornado from the maturing storm to our southwest. Passing through Hugo we could hear the town's blaring tornado sirens, always an eerie sound. We continued southeastward on US-40 again, in order to gain a better point of view for the newly-developed supercell. From 7:40 to 7:50 p.m., we observed intermittent funnel clouds, which occasionally neared the ground. At 7:51, as we sat approximately 10 miles southeast of Hugo, we observed a third tornado, approximately 2–4 miles to our west-northwest. Initially erect, the tornado's condensation funnel began to exhibit a laterally extended (from cloud base) elephant's trunk shape (Figure 2). Backlit by the red light from the setting sun, it was a lovely-looking scene as the tornado moved across open range land for about 5 minutes.

After the decay of the third tornado, we observed several additional funnel clouds. The supercell then evolved toward a high precipitation structure and soon became part of a long squall line that stretched across much of eastern Colorado. Our chase day was over at that point, and with a dinner stop and three hours of driving, we returned to Fort Collins just before midnight. The fact that we saw several tornadoes within a short span of time might seem to confirm the image of storm chasing depicted in the film *Twister*. However, in reality, chases like ours on May 31, 1999 are exceedingly uncommon. A storm chaser is very lucky to have one day like this per year. Of course, chase days like May 31 make for far better reading.

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Figure 2. A tornado near Hugo, Colorado, looking northwestward at approximately 7:55 p.m., 31 May 1999. Photograph is copyright 1999 by M. D. Parker.

Afterthoughts

Viewing the May 31 tornadoes made me feel conflicted. On one hand, successful tornado intercepts are rare, and it was satisfying to observe a tornado so close to our original forecast target. On the other hand, because the tornado was very close to I–70, my "show" probably involved loss of property or even life for other people. Despite what some non-chasers suspect, however, storm chasing is not a morbid pursuit. Rather, it is one of fascination with the atmosphere. I console myself by remembering that storms will produce tornadoes whether I'm there to watch them or not, and by trying to alert people in tornadoes' paths by contacting the National Weather Service whenever possible.

Although the tornadoes on May 31 occurred near our forecast target, the actual chase day (like most chase days) was not linear: we did not drive directly to Limon and wait for a tornado to form. We chased multiple storms, experienced several disappointments, and had to make difficult choices along the way. Such is the nature of storm chasing; one can make an excellent forecast but "bust" because of poor chase decisions. On May 31, our chase strategy fortuitously kept us within the vicinity of the new storms that formed and produced tornadoes near Limon. Chasing severe thunderstorms isn't easy. On many days I make a poor choice or two and see no tornadoes. On a few days I experience the sense of accomplishment that comes from making enough good (or lucky) choices that I observe a tornado. In either case, storm chasing rewards me; by heading out to carefully observe thunderstorms I gradually increase my understanding of the atmosphere and my appreciation for its complexity.

About the Author: Matt Parker graduated from CSU's Atmospheric Science Department in 2002 and is currently a Professor at the University of Nebraska teaching meteorology. . . he still enjoys a good chase!

Errata for Benjamin Franklin Award, Spring 2002 Issue

Layton Munson, Sedgwick observer, received the Benjamin Franklin Award for 55 years of service. That part was true; however, we incorrectly reported that this award was named after the nation's first weather observer and was the highest award bestowed on an observer. Our apologies, we were a little overzealous. Let's set the record straight. The Holm award is to honor cooperative observers for outstanding accomplishments in the field of meteorological observations. It is named after John Campanious Holm who was the nation's first known weather observer that took observations in the American colonies in 1644 and 1645. The highest award that the NWS can bestow on a cooperative observer is the Thomas Jefferson award, which is given for unusual and outstanding achievements. For more information about these and other awards go to http://www.crh.noaa.gov/gjt/coop.php.

(Many thanks to John Kyle, Grand Junction NWS Office, for bringing this to our attention.)

Layton Munson (center) receives the Benjamin Franklin award from NWS employees Byron Louis (left) and Larry Mooney (right).

Photo by Ian Wittmeyer.

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Tornado near Jackson Lake. Photo provided by Melvin Lepper.

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Knowledge to Go Places