# Colorado Climate

**Spring 2000 Vol. 1, No. 2**

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**ISSN 1529-6059**

An earlier publication with the same name, "Colorado Climate," was published monthly from 1977 through 1996 with the support of the Colorado Agricultural Experiment Station and the Colorado State University College of Engineering.

The Colorado Climate Center is supported by the Colorado Agricultural Experiment Station.

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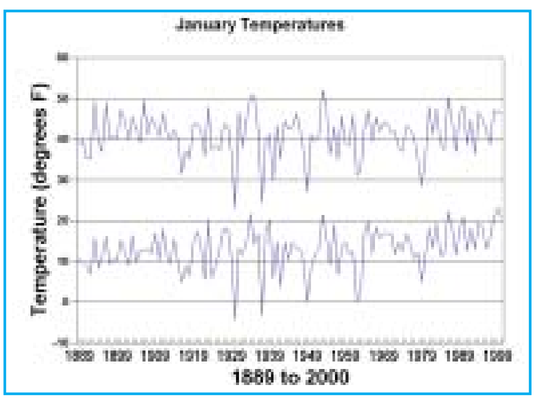
# A Time for Time Series

There has been much talk recently of the trend toward very mild winters here along the Colorado Front Range. Is it true? Will we all be playing golf in January from now on?

The following graph shows a time series since 1889 of average January maximum and minimum temperatures. The results are not as dramatic as you might think. If you look closely, there is a bit of an upward trend in January average minimum temperatures, but not much change in average maximum temperatures. In many ways, the climate of the last 20 years resembles that of 100 years earlier. The wild ups and downs of the 1930s, 1940s, and 1950s have not been repeated recently.




*January average maximum and minimum temperatures, 1889-2000, for Fort Collins, Colorado.*

The lack of any extreme January cold since 1979 is noteworthy. While 1934 and 1954 still stand out as exceptionally warm individual years (and the January warmth those years carried on into the spring and summer, as well), there have never been three years in a row as warm as January 1998, 1999, and 2000. Each year we figure the next January will be frigid – the law of averages taking over. But it just hasn't happened yet. After three years in a row, I assure you there are a lot of car batteries that have survived beyond their normal life spans. When the first arctic blast hits next winter, assuming it will, there will be an awful lot of cars in eastern Colorado that won't start.

Next issue we'll look at trends in Colorado cloudiness.

Subscription price is $15.00 for four issues.

Single issue price is $7.50.

**Cover Photo:** Lilacs thrive in Eastern Colorado despite the rigors of Colorado's springtime climate. *(Photo taken by Nolan Doesken)*

# Colorado Climate Summary – Second Issue!

The second issue of *Colorado Climate* appears after one of the warmest winters of the past century. Temperatures have averaged greater than six degrees Fahrenheit above the long-term mean at some locations in our state. The absence of cold, arctic high-pressure systems this past winter is a major reason for the warmer weather.

Has this arctic air disappeared? Well, when we look at weather maps for the entire Northern Hemisphere, we find that some locations, such as parts of Europe and eastern Russia, have had well below average temperatures. The average over the entire Northern Hemisphere is actually close to the long-term mean, and is quite a bit cooler than just a few years ago. The message for Colorado is that next winter may not be so warm!

In this issue we discuss whether we can predict the future climate of Colorado. A short answer is not very well! However, we need to still plan for any likely future climate. There needs to be a reduction in our vulnerability to drought, for example, as summarized in our discussion in this issue of Governor Owen's Flood and Drought Preparedness Conference.

Both of us serve on the State's Water Task Force Committee, which meets monthly when a water crisis may be developing. Resiliency to water shortages in Colorado ranges from just a few months for dryland agriculture and wildfire applications, which are highly affected by recent rains and snow, to as much as two to four years for urban supplies from large reservoir systems.

To the extent possible, which is environmentally responsible and fiscally possible, we need to manage water resources wisely if we are to continue to provide water for a growing population, for recreation, for environmental protection while still supporting a viable irrigated agriculture industry. As we reported in our first issue, we have not had significant statewide droughts in the last 20 years or so. Earlier in the 1900s and the later 1800s, several long-term droughts occurred, including the Dust Bowl years in southeast Colorado. Before historical weather records were kept, even more severe and longer duration droughts occurred. If we had a recurrence of even a historical drought, are we prepared since the state's population and our urban demand for water has grown? The subject of drought before European settlement of Colorado will be an article in one of our upcoming issues.

Enough said of this climate concern. We hope you enjoy our magazine!

Roger A. Pielke, Sr.
Professor and Colorado
State Climatologist

Nolan J. Doesken
Assistant State
Climatologist

*The message for Colorado is that next winter may not be so warm!*

# Governor's Flood and Drought Preparedness Conference

## December 2-3, 1999, Denver

***Nolan Doesken***

Normally, it takes a major drought or a damaging flood to get large numbers of people to sit down together to discuss problems, develop strategies, and formulate solutions. It is even more unusual to discuss opposites – floods and droughts – at the same time, especially when neither flood nor drought is occurring at the time. That is why it was an unprecedented, or at least highly unusual, event when more than two hundred water planners, elected officials, and government and business leaders from across Colorado gathered in Denver in early December to discuss strategies for preparing for both floods and drought. This unique conference was convened by Colorado Governor Bill Owens December 2-3, 1999 at the Adam's Mark Hotel near the State Capitol. The Colorado Department of Natural Resources, the Colorado Department of Agriculture, and the Colorado Department of Local Affairs co-sponsored the event.

Sunshine greeted meeting goers on the 2nd, but in the Colorado tradition, this gave way to a moderate snow on the 3rd that significantly reduced second day attendance. The meeting began with a welcome and introduction by Greg Walcher, Executive Director of the Colorado Department of Natural Resources. Governor Bill Owens then addressed attendees with a review of recent catastrophic floods in Colorado and a discussion of

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*Tom McKee, former State Climatologist, takes a break with Joe Garner of the Rocky Mountain News (photo courtesy of Cat Shrier, Colorado Water Resources Research Institute).*

## Governor's Preparedness Conference *(continued from page 1)*

*Tom McKee and Nolan Doesken listen to questions from the press (photo courtesy of Cat Shrier, Colorado Water Resources Research Institute).*

water demands and the apparent growing drought threat. Tom McKee, former State Climatologist, followed with a scientific overview of the causes and characteristics of floods and drought in the state. An economic assessment of flood and drought impacts was then offered by Nancy McCallin, Director of the Governor's Office of State Planning and Budgeting. She recalled for the audience that although drought has not been a big problem in Colorado for nearly two decades, in the winter of 1976-77 Colorado's ski industry and related businesses lost 40 percent of their normal revenue due directly to the lack of snow.

The keynote luncheon speaker was a familiar face to many. Former U.S. Senator Hank Brown, currently the President of the University of Northern Colorado in Greeley, reminded listeners of the nature of Colorado's water supplies. The vast majority of water supplies are only available during the brief snowmelt runoff period from April to early July. Without major water storage projects to capture this water for use at other times, other places, and in subsequent dry years, Colorado would not be the diversified state that it is today.

Brown was not subtle about expressing his views. He stated clearly what he believes is an urgent need to build new and expand existing water projects and potential transbasin water diversions to sustain a successful agriculture industry in Colorado while meeting the water needs of growing urban areas through the 21st Century. He felt this was the only prudent way to meet human water needs while still providing flexibility for meeting environmental challenges and interstate agreements. This would need to be done without the financial assistance of the Federal Government, which up until now has heavily subsidized most major water development projects in the West.

During the afternoon of December 2, concurrent sessions were held addressing flood issues, drought issues, and mitigation plans. This format allowed a variety of specialists to share their experiences.

On the second day of the conference, speakers representing federal perspectives on drought and flood mitigation spoke at a special breakfast panel discussion hosted by State Representative Brad Young. This was followed by presentations by local officials from outside of Colorado who have recently faced major flood and drought disasters. Participants then broke into smaller groups focused on drought and flood issues specific to particular stakeholders: Environmental, Business, Water Management, Agriculture, County and Municipal. Each group attempted to list and prioritize the hurdles and potential mitigation strategies involved with planning for floods and drought.

### Want more information?

A comprehensive summary of this conference and its recommendations are available on CD-ROM from the Colorado Department of Natural Resources, 1313 Sherman Street, Room 718, Denver, Colorado, 80203, phone: (303) 866-3311.

A brief summary was published in the February 2000 issue of *Colorado Water,* the newsletter of the Water Center of Colorado State University. Copies can be obtained by contacting the Colorado Water Resources Research Institute, Colorado State University, Fort Collins, Colorado 80523. Phone (970) 491-6308, fax (970) 491-2293, or e-mail CWRRI@ColoState.edu.

# Growing Season Trends Across Eastern Colorado

***Roger A. Pielke, Sr. and Nolan Doesken***

There is considerable interest in trends in climate across Colorado. Is our climate warming or cooling, for example. In a recent study (Pielke et al. 2000), in collaboration with Tom Stohlgren, Bill Parton, Lisa Schell, and John Moeny of the Colorado State University Natural Resource Ecology Lab (NREL) and Kelly Redmond of the Western Regional Climate Center in Reno, Nevada, we have investigated this question with respect to the growing season in eastern Colorado.

We have reproduced several figures from that study for several observation sites in eastern Colorado. We chose sites with the longest set of data in order to see if long-term trends exist. The concept of statistical testing is used to estimate whether the trends are likely to be real or not.

The results show large variability in time and in space across eastern Colorado. No one station could possibly capture this variability. The trend in growing season length, for example, for the period 1940-1996 lengthened by 43 days according to this analysis, at one of the Agricultural Research Station's sites (CPER), while it decreased by two days at Rocky Ford. After the CPER site, the greatest increase in number of growing season days was Fort Collins with 24 days. For their period of record Wray had an increase of 14 days, while Las Animas increased by 11 days, based on this trend analysis.

We think we understand the lengthening of growing season at Fort Collins since the city has grown substantially, resulting in an urban heat island effect. The reason for the increase at the other locations is unknown. Over the century since 1917, however, the figures show considerable differences in trends between the sites. There is a tendency, if you clump the stations together, to conclude that growing season has lengthened, but the stations at Akron and Rocky Ford show a shortening of growing season.

What can we conclude from such studies? First, no single station can indicate what the trends are, even in a relatively homogeneous landscape such as eastern Colorado. Secondly, there are significant variations in the trends over time, as well as differences across the region. This variability suggests that the climate in Colorado is strongly influenced by local effects, as well as from any larger-scale climate effects. Finally, trend analyses cannot be used to extrapolate expected climate in the future. If you started in 1940, for example, and tried to predict the climate from 1940-1950 based on the trends prior to 1940, you would be off target! If it would be better to assume the variability observed in the previous decades will persist into the future.

Of more concern are climate anomalies that fall outside of the existing climate record. Recent tree core observations from northern Wyoming suggest there was a major drought in that region in the 1700s that lasted for 100 years! We will talk more about that

*(continued on page 4)*

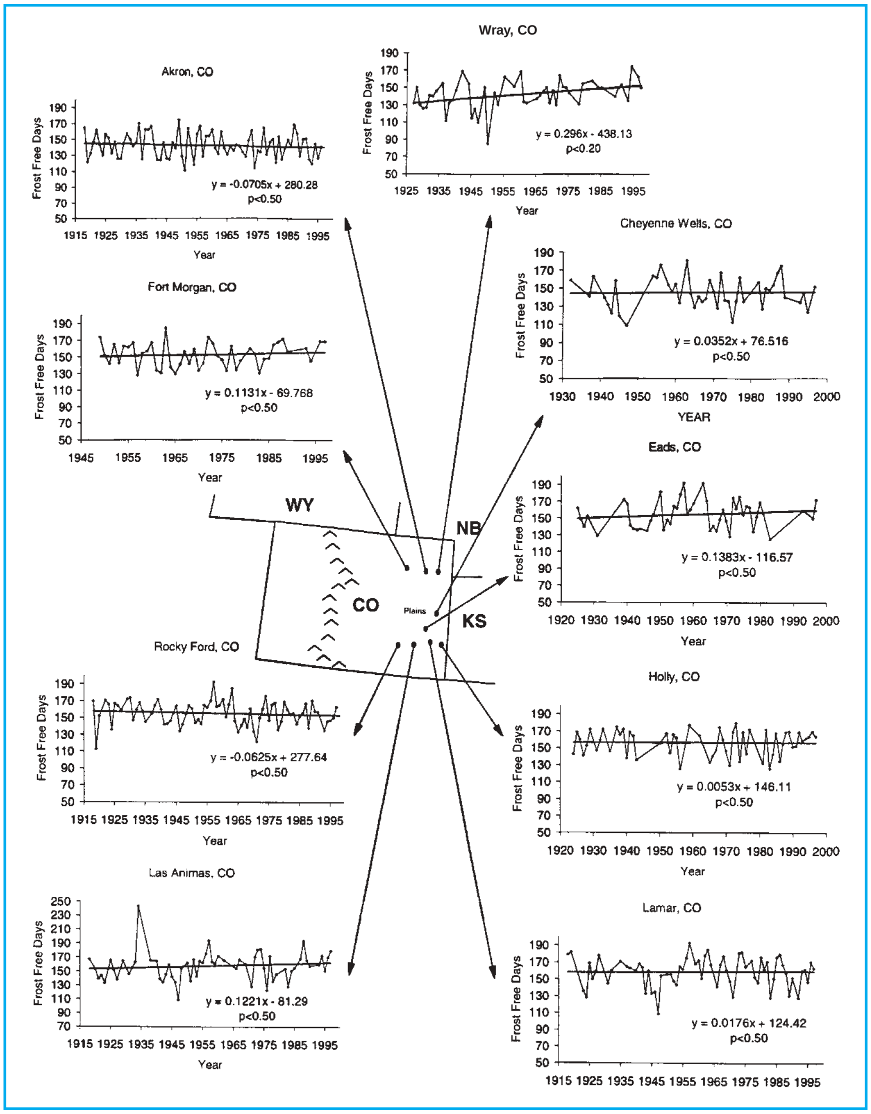
*Trends in number of growing season days per year (1940-1996) for several weather stations in eastern Colorado (from Pielke et al, 1999). A value of "P" less than about 0.2 suggests the trend is statistically significant and "n" is the number of years with complete data.*

| Station | Slope | P< | n |
|---|---|---|---|
| Central Plains Exp. Res. Sta. (CPER) | 0.7488 | 0.001 | 57 |
| Fort Collins | 0.4191 | 0.002 | 57 |
| Fort Morgan * | 0.0672 | 0.5 | 43 |
| Akron 4E | -0.0301 | 0.5 | 57 |
| Wray | 0.3735 | 0.05 | 37 |
| Cheyenne Wells ** | 0.1223 | 0.5 | 40 |
| Eads 2S | 0.0824 | 0.5 | 41 |
| Holly * | 0.1146 | 0.5 | 41 |
| Lamar | 0.0920 | 0.5 | 51 |
| Las Animas | 0.2439 | 0.2 | 45 |
| Rocky Ford 2SE | -0.0419 | 0.5 | 56 |

* data from 1949-1996
** data from 1941-1995

*Trends in number of growing season days per year but for the period 1970-1996 (from Pielke et al, 1999). A value of "P" less than about 0.2 suggests the trend is statistically significant and "n" is the number of years with complete data.*

| Station | Slope | P< | n |
|---|---|---|---|
| Central Plains Exp. Res. Sta. (CPER) | 0.8443 | 0.1 | 27 |
| Fort Collins | 0.4664 | 0.5 | 27 |
| Fort Morgan | 0.5062 | 0.2 | 22 |
| Akron 4E | -0.0342 | 0.5 | 27 |
| Wray | 0.3941 | 0.5 | 17 |
| Cheyenne Wells | 0.2110 | 0.5 | 20 |
| Eads 2S | -0.2002 | 0.5 | 15 |
| Holly | 0.4374 | 0.5 | 24 |
| Lamar | -0.2526 | 0.5 | 24 |
| Las Animas | 0.4842 | 0.2 | 21 |
| Rocky Ford 2SE | 0.0402 | 0.5 | 26 |

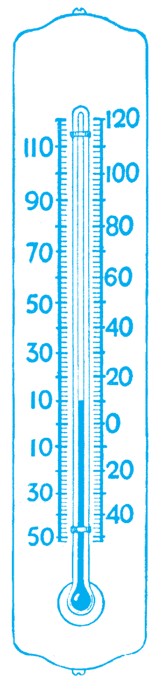


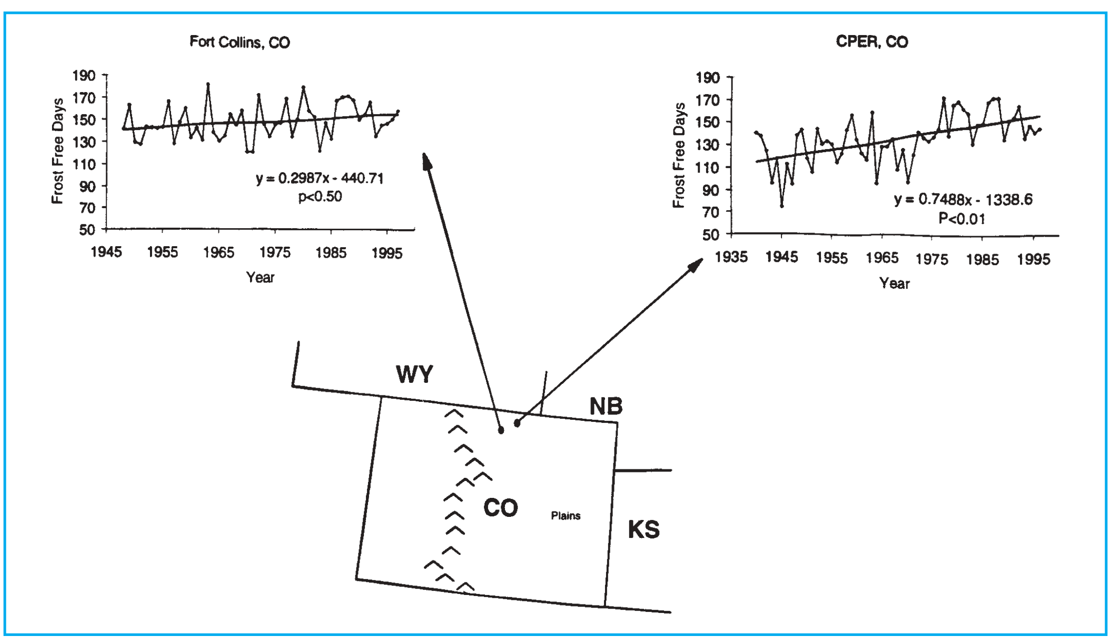

# Growing Season Trends

*(continued from page 3)*

subject, and what we can do to reduce our vulnerability, in our next issue!

Reference: Pielke, R.A. Sr., T. Stohlgren, W. Parton, N. Doesken, J. Moeny, L. Schell, and K. Redmond, 2000: Spatial representativeness of temperature measurements from a single site. *Bull. Amer. Meteor. Soc.*, v.81, #4, pp 826-830.





# Can We Predict Colorado Climate in the 21st Century?

*Roger A. Pielke, Sr.*

There is certainly a lot of news in the media reporting on gloom and doom for our weather in the coming decades. It seems that some scientists have concluded that increases in carbon dioxide will produce a positive feedback with other components of our climate system such that the Earth's atmosphere will warm and our climate will change. They base their conclusions on the knowledge that carbon dioxide is one of the "greenhouse gases."

A greenhouse gas, however, is actually an inaccurate analog to how a real greenhouse works. An actual greenhouse works by trapping heat when the glass roof is closed. Sunlight enters, but the heated air cannot easily escape. A greenhouse gas in the atmosphere, however, works by absorbing upward propagating radiative heat, and re-emitting some of it downward.

Carbon dioxide is a greenhouse gas, but it is also an essential gas for photosynthesis in plants. Moreover, the largest greenhouse gas is water vapor. Water vapor, of course, converts to clouds and precipitation, so that the net effect of the three forms of water in the atmosphere (as a gas, a liquid, or a solid) is not obvious. The latest research suggests that on the global scale, the effect of clouds is to cool our atmosphere slightly.

The conclusion that we can predict the future climate is based on an increase of sea surface temperatures, as the increased carbon dioxide warms the atmosphere. However, an enrichment of plant growth due to the increased carbon dioxide and/or an increase in cloud cover could prevent the atmosphere from warming due to the greenhouse gas effect of $CO_2$.

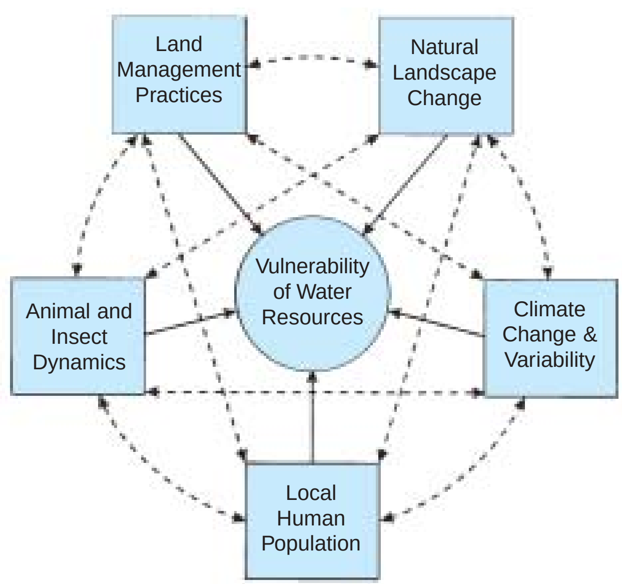
These two feedbacks (the biological effect of increased $CO_2$ and changes in cloud cover) are just two of the feedbacks in the climate system which make prediction so difficult, if not impossible. We are naïve if we think that human influences cannot alter the earth's climate. But understanding all the complex interactions of water, air, plants, and animals is quite a challenge.

While we may have great difficulty accurately predicting long-term climatic trends, progress will be made in anticipating some of the shorter term (weeks to months) variations in temperature and precipitation patterns. The last 20 years have brought some successes in relating long-memory ocean currents and oceanic temperature patterns to related weather patterns. The El Niño phenomenon, for example, has shown that there are times when accurate forecasts of temperature and precipitation anomalies can be made several months to a year in advance for some portions of the world. Continued slow progress in this type of climate forecast can be expected in the 21st century, but Colorado is too far from the ocean to expect much accuracy in these forecasts.

The conclusion of the Colorado Climate Center is that we cannot predict Colorado's climate in the future. It is misleading to the public to suggest we can. However, we can inform as to what the climate of the past has been, and how current weather patterns fit into this climate history. For instance, are we having above or below average temperatures, or is the current weather abnormal?

As an alternate to prediction, we propose a vulnerability perspective where assessments are made as to what are the environmental risks in Colorado. The figure displayed with this article illustrates this approach for water resources. Using this approach, we can assess, for example, what are our risks if the 1930s dust bowl drought reoccurred, with our current population and water uses. We do not need a prediction to be concerned about this threat!

*From Pielke, Sr., R.A, and L. Guenni, 1999; Vulnerability assessment of water resources to changing environmental conditions.* Global Change Newsletter, *No. 39, September, pp. 22-23.*




Predictability requires:

– the adequate quantitative understanding of these interactions
– that the feedbacks are not substantially nonlinear

Figure 1. Use of ecological vulnerability/susceptibility in environmental assessment (adapted from Tenhunen and Kabat, 1999)

# A Look at the Past: April 1900

***Nolan Doesken***

The older I get, the more interested I become in our history and how we have arrived where we are today. As a climatologist, I guess I qualify as a historian in my own right – a weather historian. We have the advantage here of many decades (back to the 1870s and 1880s) of hand written as well as published and digitized weather records from all portions of Colorado that we can look at any time we please. What these data show is that there may be some subtle changes that have occurred in our climate over the period of instrumental climate observations back into the 19th century. However, for the most part, the climate that we face today is largely similar to what our relatives faced generations ago as they discovered and settled this fine state in search of a better life.

*Leading up to April 1900, Colorado's weather had been on a wild roller coaster ride.*

Colorado was well on its way to becoming a settled state back in 1900. We had already been a state for 24 years. There were approximately 540,000 people (from Population Abstract of the U.S. 1900 Census) living in Colorado and perhaps 3.8 million cattle and sheep. Trains could get you almost anywhere in the state. Miners were still looking for gold and silver, but agriculture was the state's real hope for the future. Several dams had already been built, and hundreds of miles of irrigation ditches had already been dug to move water to fertile lands farther and farther from the immediate river bottoms.

Leading up to April 1900, Colorado's weather had been on a wild roller coaster ride. February 1899 had been the coldest month in history for much of the state. Fort Collins, for example, had a stretch of 6 days in a 9-day period in early February with low temperatures at or below –30 degrees Fahrenheit. Incredible snows piled up in the mountains, cutting off fuel and food supplies to mountain communities like Aspen. In March 1899, the Ruby mining camp near Crested Butte reported 254 inches of snow in one month. That remains the state monthly snowfall record to this day. In comparison, the winter of 1899-1900 was very mild. Fuel supplies were generous and the half-million residents of Colorado were very thankful.

The thankfulness gave way to anxiety, however, as little snow fell in the mountains, and warm early-spring temperatures evaporated what had fallen. For the 5-month period, November 1899 through March 1900, Durango received only about 30 percent of their average precipitation. Drought reared its ugly head.

Then along came April 1900. Weather patterns shifted and one storm after another moved slowly across the state, each picking up moisture from the Gulf of Mexico as they reached eastern Colorado. In all, five major storms, each lasting about three days with only one to three dry days until the next storm, brought widespread and heavy rains and wet snows. In many ways, it was not unlike the weather pattern of late April 1999, which brought flooding to southeastern Colorado.

In 1900, there were about 80 weather stations reporting monthly precipitation. The statewide average precipitation for the month came to nearly six inches, nearly double the previous wettest month since systematic weather records began in the 1890s. The greatest precipitation totals were found east of the mountains. Monthly totals exceeded ten inches from Pikes Peak eastward to Hugo and Burlington. Totals also surpassed the ten-inch mark in the Fort Collins area, in extreme southeastern Colorado, and in the foothills west of Denver. Lake Moraine, on the slopes of Pikes Peak, recorded 16.52" of precipitation for the month of April 1900. It was one wild month there, as most of this moisture fell as wet snow.

This truly remarkably wet month pulled Colorado out of the grasp of widespread drought, and resulted in plentiful water on the South Platte and Arkansas Rivers for the first few months of the growing season. It was only a few months, however, until dry weather and expanding drought conditions again took command.

# Climate on the WEB

*Nolan Doesken*

**Let's visit the National Climatic Data Center at: http://www.ncdc.noaa.gov**

You may not know it, but when you type in this address you have made contact with the computer system of a remarkable organization located in a modern federal building in downtown Asheville, North Carolina. Asheville, the home of the Vanderbilt Estate, is nestled between Great Smoky Mountain National Park and Mount Mitchell, the highest peak in the southern Appalachians, reaching a height of 6,684 feet above sea level. Asheville experiences a humid, hazy climate, but with mild winters and "relatively cool" summers, at least when compared to the Carolina lowlands. Many back East find it to be a very delightful climate.

The National Climatic Data Center (NCDC) is the home of immense volumes of temperature, precipitation, snow, humidity, wind, pressure, and any other sort of weather data you can imagine. Not only do data from all 50 states reside there from last month, last year, last decade, and the last century, so do the weather data from most countries in the world. In addition to standard surface weather observations, many other special data sets exist at NCDC. Weather data, collected by high-flying balloons that have been launched now for over 50 years, can be obtained. You can get processed radar data from anywhere in the country from last summer's thunderstorms, or you can acquire tabulations of data from 150 years ago from the various forts that were established across the western states in the years following the Louisiana Purchase. Most likely they can tell you what the weather was like on the day you were born, and possibly even the day when your grandmother was born. You can even find weather data collected by sailing ships travelling from New York to San Francisco before the days of the Panama Canal.

I encourage you to visit the NCDC website. It will give you an idea of the magnitude of our nation's climate data resources. For the weather junkie who cares about what has happened in the past, this place is paradise. But be careful. For many long-term data sets, there are sizeable fees for extracting data. Don't start filling your e-shopping cart with fantastic climate data unless your credit card is handy. Increasingly, agencies need to collect revenue to cover data storage, handling, and dissemination costs. Yes, the data are free. Our tax dollars paid to gather it. However, keeping it and making it available to users like you and me is not free. Expect some fees along the way.

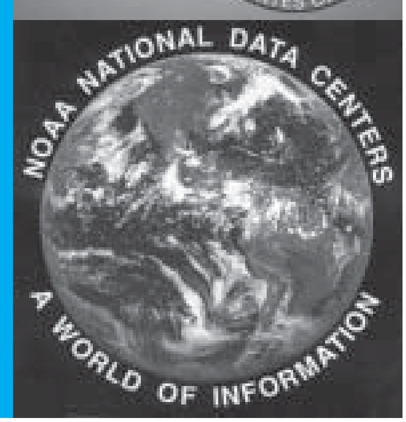
## NOAA National Data Centers (NNDC)
## Contact Information
## http://www.nndc.noaa.gov

**National Oceanographic Data Center (NODC)**
Telephone: 301-713-3277 Fax: 301-713-3302
E-mail: services@nodc.noaa.gov
http://www.nodc.noaa.gov

**National Geophysical Data Center (NGDC)**
Telephone: 303-497-6826 Fax: 303-497-6513
E-mail: info@ngdc.noaa.gov
http://www.ngdc.noaa.gov

**National Climatic Data Center (NCDC)**
Telephone: 828-271-4800 Fax: 828-271-4876
E-mail: orders@ncdc.noaa.gov
http://www.ncdc.noaa.gov

We interpret the present in the context of the past
for the prediction of the future.



# Where Do Our Climate Data Come From?

***Nolan Doesken***

It is an interesting world we live in. If you have a trained eye for spotting weather stations, it has gotten to the point that it is difficult to drive 10 miles without seeing a weather station somewhere along the highway or out in a field, or on garage roofs, or at schools, or along rivers. You may even be driving a mobile weather station. Many new cars are equipped with on-board thermometers – a great way to study the climate of Colorado. Yes, there are some parts of the state, like out west of Maybell, or down south of Las Animas, where weather stations are still a rarity. But if you're in any of the populated areas or transportation corridors, you're going to see weather stations if you look. It's a new game you can have your kids play as you drive cross-country – spot that weather station.

In this age of technology, you probably assume that all the maps and data graphs we show in this report are all based on fancy electronic weather data gathered by computerized weather data collection systems at airports, schools, mountain observatories, and cell-phone agricultural weather stations. Actually, nothing can be farther from the truth. We do utilize data from these many electronic weather stations practically every day. But when it comes time to monitoring our climate; to compare this year to last, or this decade to the climate of many years ago; we revert back to one of the best and longest-lived observing networks in our country. Most of the data we show in our reports come from volunteer weather stations – in people's yards, at local businesses, at water and sewage treatment plants, and at reservoirs, universities, and National Parks.

*Harold Reinhart, cooperative weather observer, Crestone, CO*

Instead of tapping into the ever-growing list of automated weather stations scattered across Colorado, we are still relying on the data from the Cooperative Program of the National Weather Service.

Why do we use the data from this seemingly outdated network? There are several good reasons.

First and foremost, this is the oldest continuous source of weather data from both urban and rural locations in Colorado. Data are collected in a similar manner today as 100+ years ago. This makes comparisons with the past possible. Many stations have been operated at or near the same location and with the same instruments for several decades. This is very important for historic climate comparisons. You can't do that with the automated weather station along the Interstate Highway.

Second, temperature readings are likely to be consistent. Three major sources of variability in temperature readings are 1) the height above ground, 2) how the thermometer is shielded from the sun, and 3) the local instrument location and exposure. For more than 100 years, the National Weather Service Cooperative Observer Program has striven for consistency in each of these areas. Meanwhile, other weather stations use a variety of radiation shields for keeping sunlight off their temperature sensors. Some of these shields have never been tested and compared to official instrumentation.

The Cooperative Observer Program, with its simple but rugged large diameter (eight inches) standard rain gauge, is the most accurate source of year-round daily precipitation measurements for both rain and water content of snow and ice.

The Cooperative Program is now the only source of daily snowfall observations nationwide. Snowfall is not measured by most automated weather stations.

Finally, data collected by the Cooperative Observer Program have a personal human touch. In some ways this can be a problem since humans make errors and aren't always reliable. However, the human touch adds something that no computer can, such as useful personal remarks that help explain and interpret what certain weather conditions were really like and what impacts they had in the community.

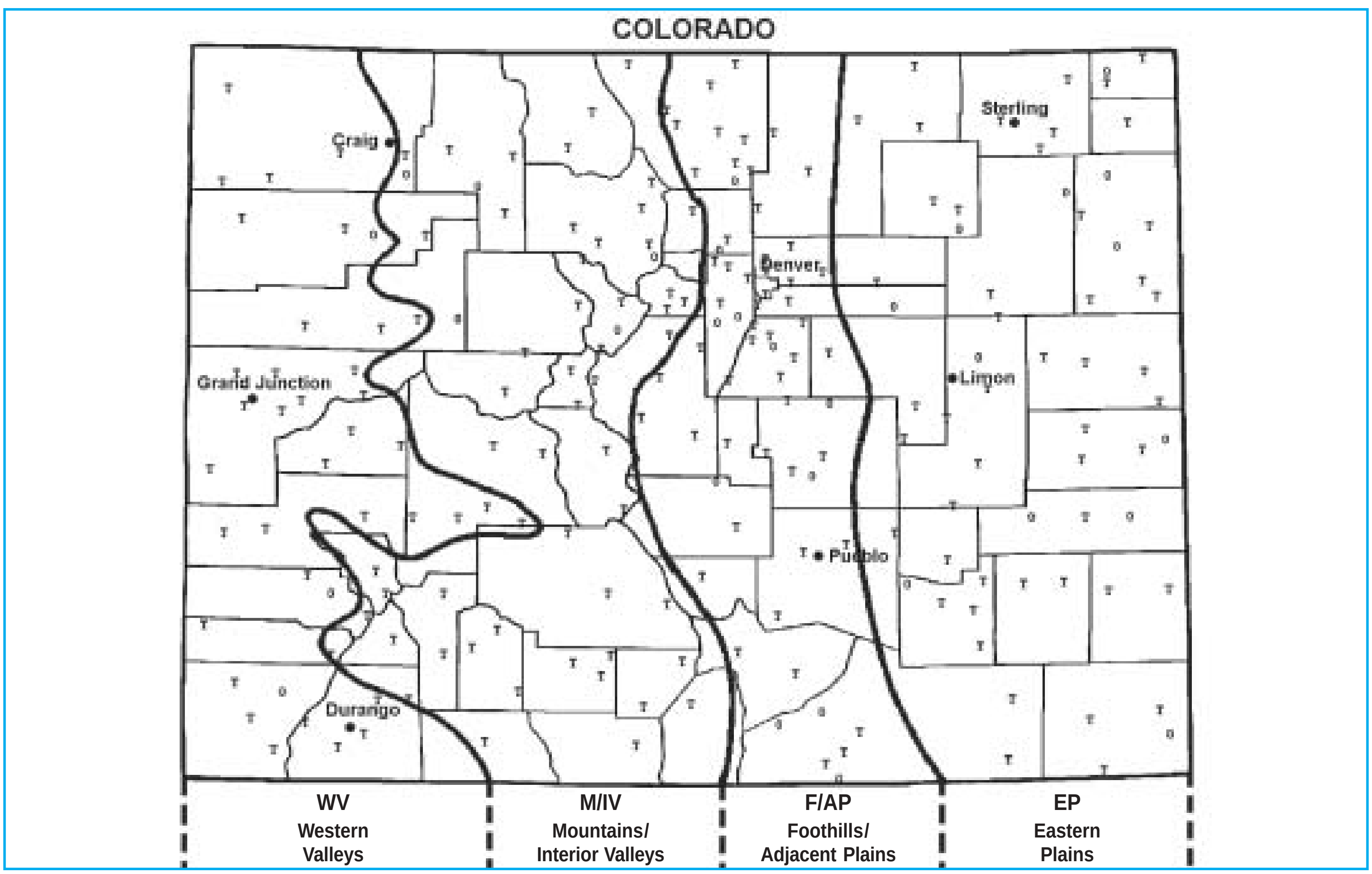
The Cooperative Program has survived more than 100 years and has provided valuable data for applications that those who began this network in the 1800s could never have imagined – information to design the Interstate Highway System, for laying fiber optic lines, and for determining the reliability of microwave communications.

As we end the 20th century (the new millennium actually begins January 1, 2001), the Cooperative Program remains the best source of statewide and nationwide data for monitoring the basic elements of temperature, precipitation, and snowfall on a national scale.

Oh yes, there are some problems. Station locations are not all appropriate. Too often there is missing data. Observers have varied daily observation times which result in data inconsistencies. But even with these problems, there is still no more reliable and accurate measurement of precipitation than what you get from an enthusiastic volunteer weather watcher equipped with one of the National Weather Service's traditional standard high-capacity rain gauges.

We are currently working with the National Weather Service locally and nationally to raise more support for this remarkable network of volunteers. After operating almost 110 years, the program could use some upgrading. There are still thousands of citizens nationwide willing to serve as volunteer weather observers, but people don't stay at home 365 days of the year like they used to. With modern technology, it should be easy to measure and record elements like daily high and low temperatures even when an observer is away for the weekend or for a week. It also needs to be easier and more rewarding for volunteers to report their data to the National Weather Service (and subsequently, to organizations like ours) on a daily basis. However, it is also imperative that the instrumental readings of the future be as accurate as possible and consistent with the measurements taken in the past. This is not as easy as it seems. Few people appreciate that replacing a rain gauge or installing a new thermometer, or moving a weather station from one side of town to another (or one side of a building to another, for that matter), frequently results in an apparent change in the climate. There is more to collecting accurate weather data than most people realize. Much of the value of the Cooperative Observer Program has been the historical consistency of data. We must be careful as we attempt to "modernize."

If you would like more information about the Cooperative Program, or if you would like to help raise support for this incredible nationwide volunteer program, please contact our office. Also, visit the Program's website at: http://www.ccop.nws.noaa.gov




*Cooperative Observer Locations for Colorado. T = Temperature and precipitation stations. O = Precipitation stations only.*

# Climate Data in Use

***Nolan Doesken***

Everyone seems to know and appreciate how fluctuations in daily weather affect business and transportation, but few people stop to think just how important climate information, deduced from weather data collected for many years, really is in conducting business.

In each issue of ***Colorado Climate***, we will briefly describe some of the ways climate data are put to use here in Colorado. You may be surprised. Even after more than 22 years here at the Colorado Climate Center, one of the most interesting parts of my job is answering phone calls and e-mails from businesses needing climate information to do their jobs or to do them better. Every call or e-mail brings a new challenge, and offers a new opportunity to utilize the many years of data we have collected to help make an important decision. It convinces me of the great value in carefully collecting weather data each and every day, even when we're not sure anyone cares. Eventually, if not today, they will.

Let's begin with some of the more common types of questions we receive. This doesn't mean the answers are easy, but these are questions that are asked very often.

- I am planning to move to Colorado from Any Town, USA. Could you tell me how the climate of (where I am moving to) compares to the climate of (where I am moving from)?
- We are considering raising a new crop. Do we get enough precipitation at the most critical times to get a profitable yield, and how often will we be frozen out by short growing seasons?
- I (or a member of my family) have asthma. Where could I live where the climate would be better?
- How often will we experience drought?
- We had a bad flood. How much rain fell to produce that flood? Was it greater than a 100-year storm?
- We are installing a new water line. How deep do we need to bury it to be sure it will never freeze during the winter?
- Our construction company is bidding on a job in Breckenridge (or any other place). How many adverse weather days can we expect that might delay construction?

Now let's get into the fun stuff. Here and in future issues of ***Colorado Climate*** we will describe in brief detail some of the interesting climate applications that we've been involved with.

*As you know, Colorado has several of the highest elevation heavily-traveled mountain passes in North America. Truckers don't care for these passes, but it's not just the steep roads, the snow and ice, and scary downhill grades that cause problems.*

As you know, Colorado has several of the highest elevation heavily-traveled mountain passes in North America. Truckers don't care for these passes, but it's not just the steep roads, the snow and ice, and scary downhill grades that cause problems. Several years ago a large national trucking company called our office. Some of their shipments of bottled liquids and spray cans from producers in the Midwest were found to be damaged when they reached their destinations in Utah. Quite frankly, some of the containers had exploded in their cases in the trucks. They needed to figure out what happened. Was the trucker negligent, was the product faulty, or did something else happen? With closer scrutiny, it appeared that the containers most likely popped somewhere in Colorado – most likely on I-70 somewhere between Denver and Grand Junction.

By now you've probably already guessed the reason. Between Kansas City and Denver, the actual pressure (not the barometric pressure that you see on TV or hear on the radio, which is corrected to sea level) drops gradually from an average of about 29 inches of mercury at Kansas City (980 millibars) to less than 25 inches of mercury at Denver. This drop is a result of the gradual rise in elevation that occurs. However, from Denver westward, this change is no longer gradual. From Denver to the Eisenhower Tunnel, the average station pressure drops sharply to about 20 inches of mercury at the tunnel and even lower atop Vail Pass. On top of this, passing storm systems impose an additional but relatively minor pressure variation. With the drop of external atmospheric pressure as the trucks climbed the Rockies, the pressurized containers simply popped. It wasn't the trucker's fault.

The solution that this trucking company chose was to route later shipments via I-80 instead of I-70. The shipping route was longer, but the elevations were lower. An alternative solution was a redesign of the containers by the manufacturer so that they could withstand greater variations in outside pressure. That was a more costly solution, since only a small fraction of their product nationally ever had to withstand these lowered pressures. We haven't heard back from them.

# For Teachers: Climatology – It's Perfect for the Classroom

***Nolan Doesken***

It's not surprising, but most students, be they third graders, seventh graders, high school juniors, or even college students (and sometimes even high ranking government officials), think that the only reason we collect weather data is to predict today's and tomorrow's weather. I agree that this is a very important reason for having networks of weather stations. But that is not the only reason. Data, when collected over time, allows us to define and describe our climate. The climate, in turn, plays a large role in determining how we live, where we grow our food, how much energy we consume to keep our homes and businesses comfortable, and much more. I happen to believe that climatology (the study of climate) should have a place in the classroom. Some might call it boring (like my college advisor who tried to talk me out of pursuing a career in climatology), but I disagree. You just have to present it with enthusiasm and real-world applications.

Here in Colorado, every county, every city, and even different parts of some of the larger cities have features of their climate that may differ from nearby areas. For example, south and west Denver routinely get more snowfall than northeast parts of the city. Certain portions of Boulder and Colorado Springs are much more likely to experience very strong winds than others. Any city that occupies both the bottom and the sides of a valley or ridge will likely see dramatic local differences in nighttime temperatures.

Some very simple comparisons of basic climate elements like snowfall, precipitation, or temperature can make a great lesson that can include some math, some geography, and even some history to go along with the science. You can get a little practice on the computer, too, if you want.

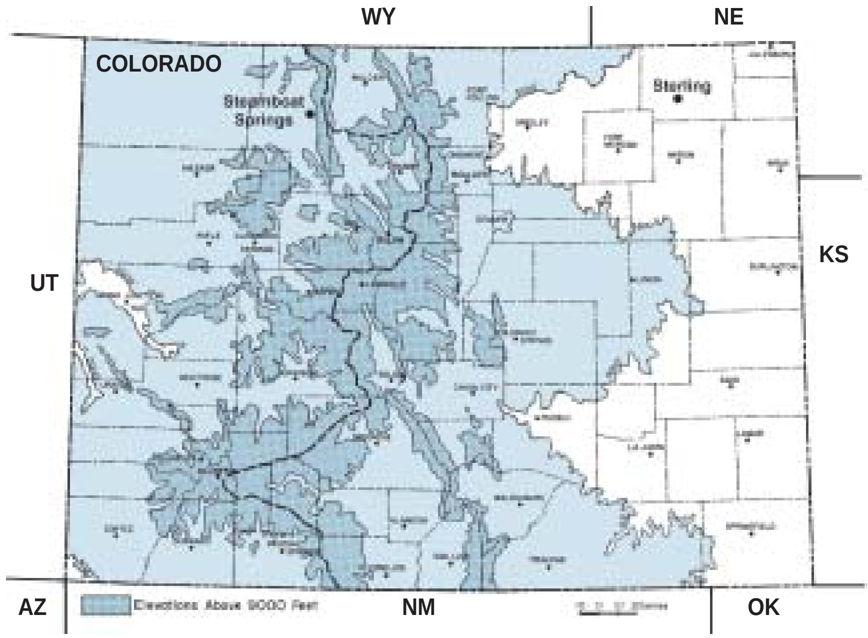
Here's a fun little project. Perhaps you can use or adapt this in your classroom.

### Let's look at two cities in Colorado that are both at about the same latitude – Steamboat Springs and Sterling.

Plot these monthly totals (see table at right) on a bar graph using either graph paper, home-made graph paper, or your computer. Look at the differences and then try to answer these questions.

1) Which location receives the most precipitation over the entire year?

2) Which location gets the most precipitation in winter?




**Average monthly precipitation, 1961-1990, inches.**

*(Remember that precipitation includes both rain and the melted water content of snow)*

| Month | Steamboat Springs (elev. 6,760 Ft) | Sterling (elev. 3,938 Ft) |
|---|---|---|
| January | 2.36 | 0.33 |
| February | 1.99 | 0.22 |
| March | 2.04 | 1.04 |
| April | 2.18 | 1.37 |
| May | 2.11 | 3.16 |
| June | 1.52 | 2.91 |
| July | 1.53 | 2.62 |
| August | 1.48 | 1.87 |
| September | 1.64 | 1.03 |
| October | 1.87 | 0.79 |
| November | 2.09 | 0.49 |
| December | 2.57 | 0.33 |
| Annual Total | 23.38 | 16.16 |

3) Do you think that the precipitation falls as rain or snow?

4) How would you convert these numbers from inches into centimeters? Millimeters?

5) Express as a percentage, how much precipitation Sterling gets compared to Steamboat Springs.

6) What might be different about houses, transportation, occupations, and recreational

*(continued on page 12)*

## For Teachers *(continued from page 11)*

activities between residents of these two Colorado cities?

7) What meteorological explanations can you give for why one city gets much more precipitation during winter and the other gets much more precipitation during summer?

8) What about water resources? What can we learn about Colorado water management from this simple graph?

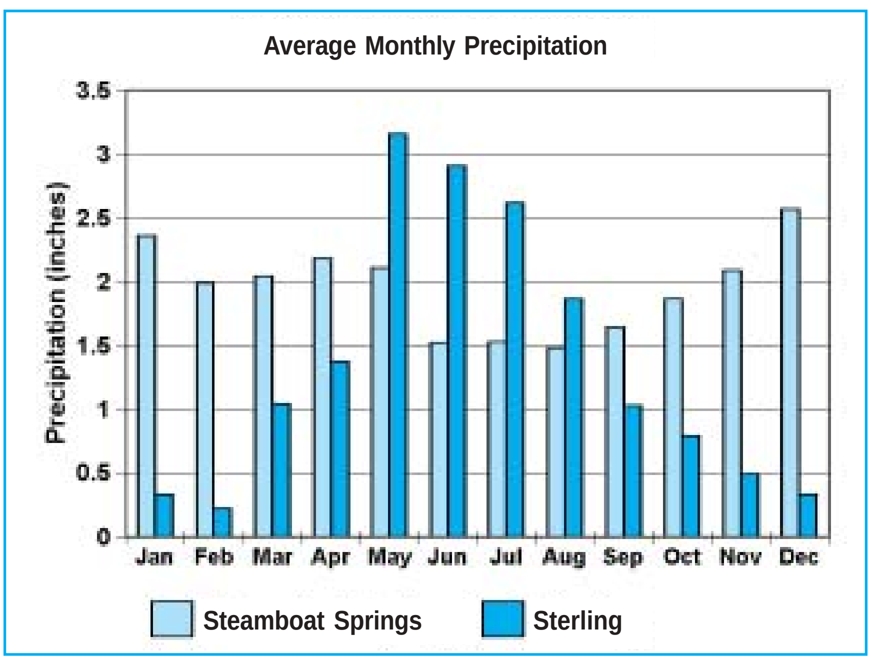
### Here are some answers and some discussion items.

1) Steamboat Springs receives the most precipitation.

2) Steamboat Springs receives the majority of its precipitation during the winter months at the same time that Sterling receives very little precipitation.

3) You cannot tell just by looking at these graphs whether the precipitation falls as rain or snow. However, from what we know about geography and temperature, we know that most precipitation in Steamboat Springs for about half the year (late October into mid April) falls as snow. Sterling also receives some of their precipitation in the form of snow, but very little moisture falls in Sterling during those months when it is cold enough to snow. The majority of Sterling's annual precipitation falls as rain.

4) There are 2.54 centimeters (approximately) in one inch. There are 10 millimeters in one centimeter, which means that there are 25.4 millimeters in one inch. To convert inches to centimeters or millimeters, multiply the number of inches for any month by the unit multiplier.




For example, if May precipitation averages 3.16 inches in Sterling, this means that the May precipitation in Sterling averages 3.16 inches times 25.4 millimeters/inch = 80.264 millimeters (you can also practice your rounding). There is usually no reason to report precipitation to increments of less than 1 millimeter or less than 0.01 inches.

5) Sterling Precipitation/Steamboat Springs Precipitation times 100% = 69.1189.

You will get the same answer regardless of the units you are using. You will get a different answer, however, for each month. Annually, Sterling receives 69% as much precipitation as Steamboat Springs. However, in July, Sterling receives 171% as much as Steamboat Springs. You could also say that Sterling averages 71% more precipitation than Steamboat Springs in July.

6) The precipitation graphs alone do not provide enough information to answer these questions, but they can serve as the beginning of the discussion. More geographic information is needed to round out this discussion. Residents of Steamboat Springs are accustomed to deep snow, while Sterling residents expect dry winters. Houses and businesses in the Steamboat Springs area are built with stronger roofs to withstand the weight of the snow. The Steamboat Springs economy is based on the winter recreation industry and some remnants of the cattle ranching business that still exist. Sterling remains an active agricultural economy. Since most of Sterling's precipitation falls during the growing season, many crops can be grown. Livestock are also important to the economy.

7) We could teach a whole class on weather and climate as we try to answer this question. To put it simply, the reason is "mountains" and "air masses." Here in the mid latitudes, the air up at mountain-top level and higher moves primarily from west to east. It moves faster in the winter when the temperature differences are greatest between the equator and the north pole, and much slower in the summer when temperature variations are small. The air moving from the west to the east crosses the Pacific Ocean bringing plentiful moisture into the West Coast during the winter. These Pacific air masses drop much of their moisture in the mountains of Washington, Oregon, and California, but still have enough moisture to drop more snow as the air is forced to rise and cool as it encounters the Rocky Mountains. Steamboat Springs sits at the base of a mountain range that stands perpendicular to these winter winds. This is why Steamboat Springs gets so much winter precipitation. The same air masses continue eastward towards Sterling, but after rising over the continental divide, the air descends, warms, and dries rapidly. Areas east

of the mountains are "downwind" of the Pacific moisture source and are normally very dry in the winter.

During the spring and summer, the weather patterns change as the westerly winds aloft weaken. Moist air from the Gulf of Mexico and the southern and central plains states occasionally drifts westward into eastern Colorado. This moisture fuels large thunderstorms that can drop heavy rains in short amounts of time. But this moisture is blocked by the Rocky Mountains and usually does not reach the Steamboat Springs area in quantity. The result is that Sterling receives much more summer rainfall than Steamboat Springs. Storms can be so heavy as to cause major flash flooding near Sterling. Summer storms west of the mountains usually do not produce such heavy downpours.

8) Again, this could be an entire class period or more. This would be a good opportunity to contact a local water official – someone from a local water conservancy district or someone with the State of Colorado or one of the federal agencies like the U.S. Bureau of Reclamation. There are many water officials in Colorado – many more than climatologists. Try to get one to visit with your class. Water resources issues in Colorado are absolutely fascinating, and what we have done to provide water for agriculture and urban development may amaze your students and give you a whole lot to talk about – including environmental issues and endangered species. The sky's the limit on this topic.

## What have you accomplished?

- Learned to access data on the web.
- Learned to make graphs by hand or by computer.
- Learned to interpret graphs and apply the information.
- Opportunity to discuss precipitation processes and air motion.
- Chance to talk about geography, economy, and water resources.

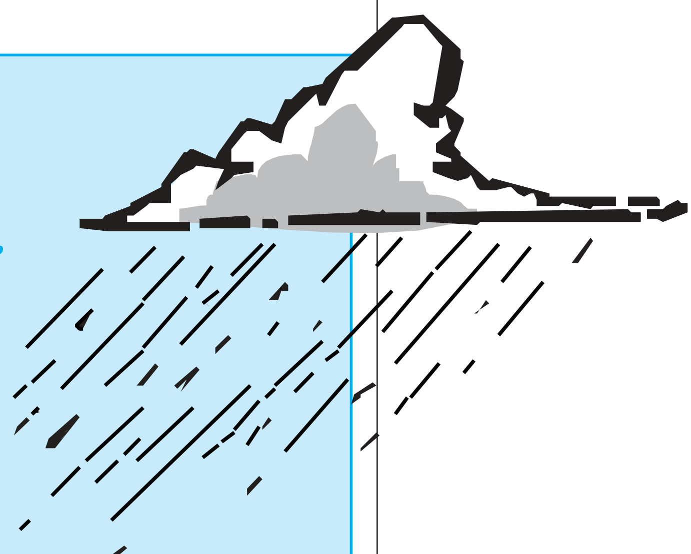
This very simple exercise could be adapted to almost any age group. If you want to do more, or give motivated students special science projects, you could dig into the Colorado Climate Center data archives on the Web to extract year-by-year data for these two stations. Ask students to see how much precipitation varies from year to year and if precipitation totals have been changing over time. You could even explore known flood or drought periods and determine how much precipitation fell then.

## Folklore

*"A cold April the barn will fill*
*A dry April not the farmer's will"*

*"Snow in April is manure"*

*"April cold and wet fills barn and barrel"*

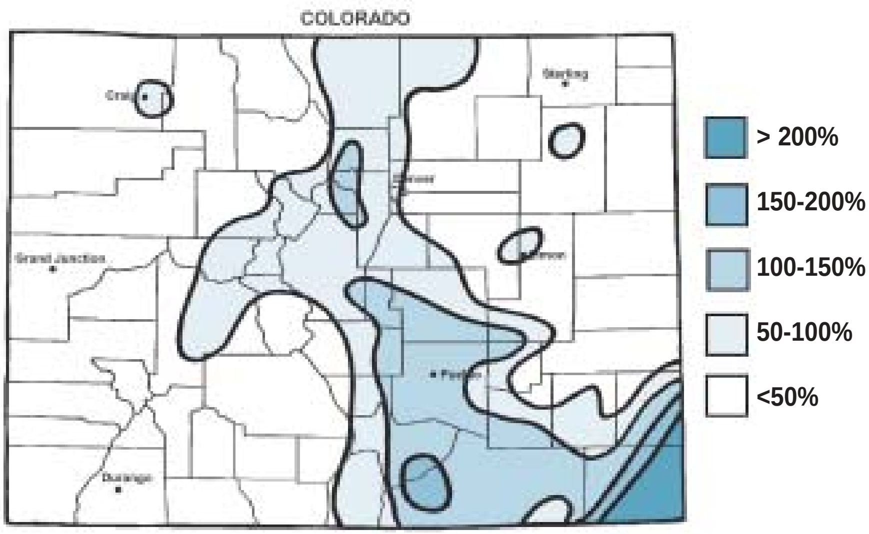


*Taken from "Weather Proverbs" Signal Service Notes No. IX by H.H.C. Dunwoody, U.S. Government Printing Office, Washington, DC, published in 1883.*

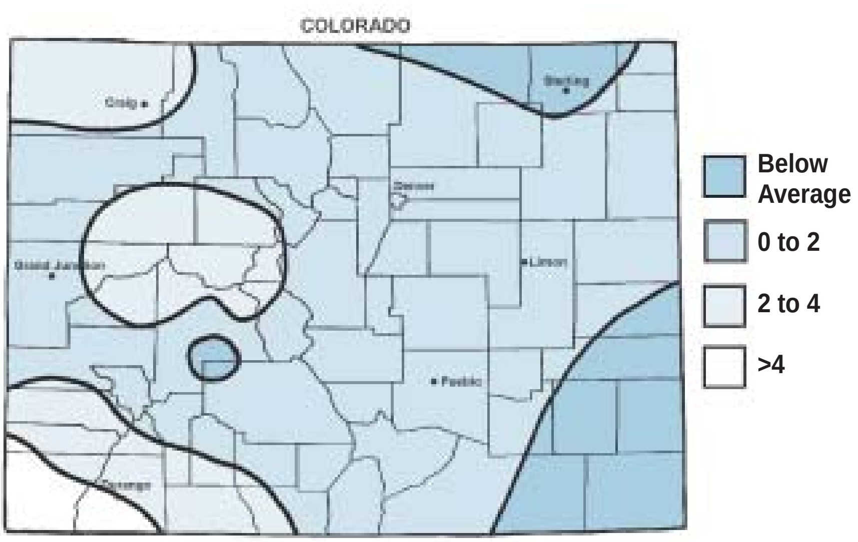
A cool wet spring means good crops ahead. This was more an observation than a forecast – and there was a lot of truth to it and still is. Delaying fruit tree blossoming spares early freeze damage. Cool, damp weather results in better soil moisture reserves to carry through dry summer periods. Farmers for centuries have witnessed the advantages of cool, wet springs. While it kept them from getting into the field as early as they may have liked, it paid off at the end of the season more often than not. Spring 2000 is off to a warm start. If you believe the old-timers, this does not bode well for Colorado agriculture this year.

# Quarterly Climate Review

Here is a review of the first three months of the 2000 water year: October, November, and December, 1999. In each future issue of "Colorado Climate" we will review recent months in terms of precipitation patterns and temperature anomalies. By the time you get this publication, these months will be long gone and fading from your memory. But hopefully these brief narratives with accompanying graphs and maps will serve to document interesting climate features for posterity.




**October 1999 precipitation as a percent of 1961-1990 average.**




**October 1999 temperature departures from 1961-1990 average, degrees F.**

## October 1999

### Climate in perspective:

October weather was truly delightful. There were an abundance of warm, sunny days, deep blue skies, dry air, light breezes and cool, crisp nights. The predominantly dry weather made it a great month for late-season golfing, mountain hiking, biking, or outdoor projects at home. Huge day-night temperature variations made it very interesting to figure out how to dress. Forty to fifty degree (Fahrenheit) daily temperature swings were common. On October 1, the Pueblo airport started the day at 31° F but managed to reach 90° F by afternoon, only to drop back to near freezing that night. Gunnison saw the temperature drop from a high of 64° down to a morning low of +9° F on October 25.

### Precipitation:

Most of Colorado was much drier than average in October with many areas well below 50 percent of average. Little or no precipitation fell across southwest Colorado at a time of year that is sometimes quite wet there. Northeastern Colorado was also very dry in October. The only relatively wet areas of the state were found along the Colorado Front Range, the urban corridor, and southeastern counties. Extreme southeast Colorado received more than double the average precipitation with most of this coming in one storm October 7-8.

### Temperature:

October temperatures ended the month near to a little below average over eastern Colorado while western Colorado was a little to as much as four degrees Fahrenheit above the 1961-1990 averages.

### Daily Highlights

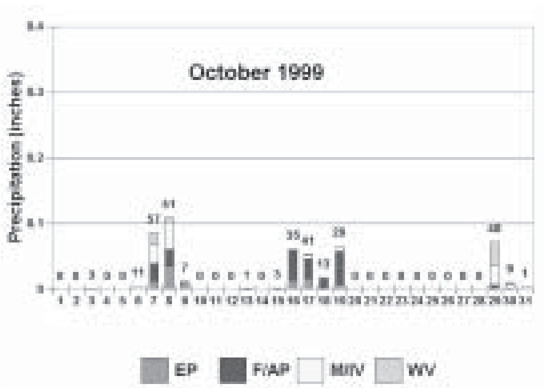
1 Dry and warm with increasing clouds. Turning cooler over northeastern counties.

2-3 Warm and dry over western Colorado, but sharply cooler east of the mountains with some low clouds and fog patches on the 2nd.

4-5 Warm and dry again, but with increasing clouds from the southwest on the 5th.

**October 1999**

| Description | Station | Extreme | Date |
|---|---|---|---|
| Precipitation (day): | Walsh | 2.60" | Oct. 8 |
| Precipitation (total): | Walsh | 3.70" | |
| High Temperature: | Stratton & | 94 F | Oct. 14 |
| | Las Animas | 94 F | Oct. 14 |
| Low Temperature: | Hohnholz Ranch | -9 F | Oct. 17 |




6-8 A significant storm system with a generous moisture supply approached from the southwest on the 6th. Fairly lively thunderstorms for so late in the season developed on the afternoon and evening of the 6th and moved northeastward. Thunderstorms continued into the morning of the 7th in northeast Colorado. Later on the 7th, moderate to heavy rains moved across southeast Colorado with very heavy rains over Baca County. 3.50 inches of rain were reported at the Walsh weather station.

9-14 Sunny, dry and warm weather statewide.

15-19 Cool and unsettled. Western Colorado missed out on much precipitation, but easterly "upslope" winds helped generate widespread precipitation along the Front Range in two separate surges. The first event began on the 15th in northern Colorado and spread southward, eventually ending over southern Colorado early on the 17th. Six inches of wet snow fell in Boulder on the 16th. Rain and wet snow developed in the same areas again on the 18th ending on the 19th with the heaviest amounts falling southwest of Pueblo.

20-27 Sunny with warm, lovely days but cold nights. Nighttime temperatures dropped into the single digits in some high mountain valleys.

28-29 Windy and cooler as a Pacific storm system spread precipitation across parts of north-western Colorado.

30-31 Sunny and pleasant.

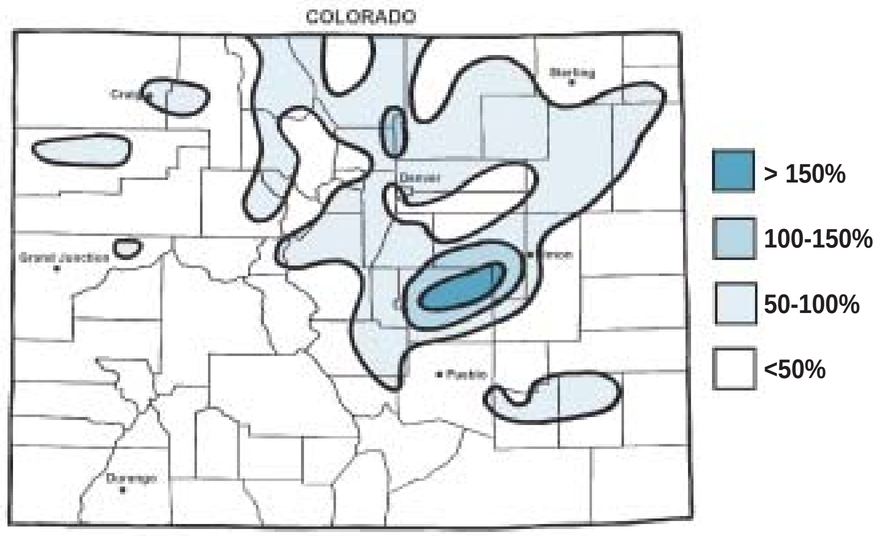
### November 1999

| Description | Station | Extreme | Date |
|---|---|---|---|
| Precipitation (day): | Ruxton Park | 1.00" | Nov. 21 |
| Precipitation (total): | Ruxton Park | 1.25" | |
| High Temperature: | Las Animas | 87 F | Nov. 8 |
| Low Temperature: | Walden | -23 F | Nov. 24 |

# November 1999

## Climate in perspective:

Winter was slow to get started as unseasonably warm temperatures that felt more like September persisted almost to Thanksgiving. The state was free of any precipitation for the first 16 days of the month. Finally, a taste of winter arrived on the 21st in the form of sharply colder temperatures and a significant snowstorm.




**November 1999 precipitation as a percent of 1961-1990 average.**

## Precipitation:

Almost all of Colorado was drier than average in November, with the majority of the state receiving less than 50 percent of the 1961-1990 average. Many

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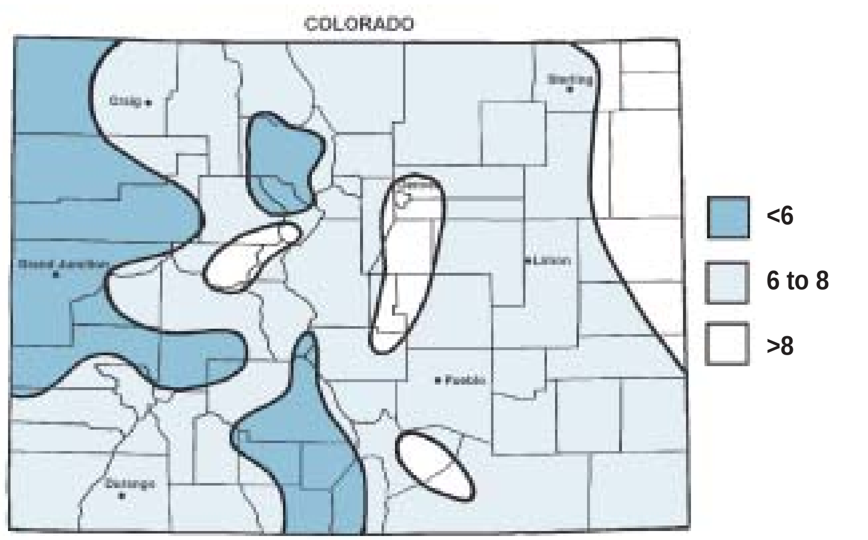
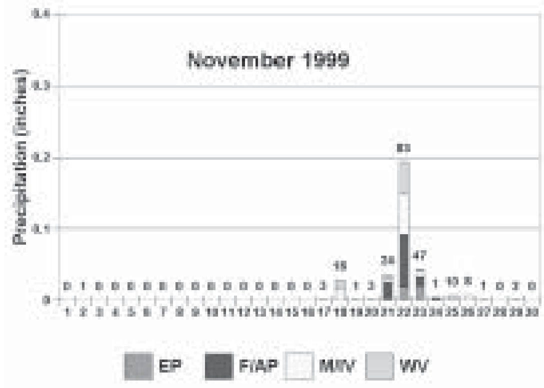



**November 1999 temperature departures from 1961-1990 average, degrees F.**




weather stations in eastern, southern, and western Colorado totaled just a few hundredths of an inch for the month. The only areas approaching average precipitation for the month were found in north central Colorado and near Colorado Springs. These areas were particularly hard hit by the Nov. 21-22 storm. The Colorado Springs airport reported 1.01 inches of moisture from 10.6 inches of snowfall.

### Temperature:

November temperatures for the month as a whole were much above average statewide ranging from about five degrees F warmer than average on the Western Slope to more than eight degrees above average in some areas east of the mountains (one of five warmest Novembers on record at several locations).

### Daily Highlights:

1-17 Dry, sunny, and unseasonably warm with light winds – a remarkable stretch of warm, dry weather for so late in the fall. Daily maximum temperatures passed the 70-degree mark in Denver 13 days during this period, while temperatures soared into the 60s high in the mountains. New daily record highs were set in some cities, especially on the 8th. There was no sign of mountain snows, and it was even difficult for ski areas to effectively use their snowmaking facilities.

18 Windy and cooler as a Pacific cold front finally reached Colorado. Some valley rains and mountain snows in northern Colorado.

19-20 Dry but seasonally cool as a new storm system developed.

21-22 The only winter storm of the month. 4-12" of snow fell along the northern Front Range with the heaviest amounts near Colorado Springs.

23-25 Dry but cold, with some morning fog, especially over snow covered areas. Lows finally dipped below zero in the mountains with single digits over portions of northeastern Colorado.

30-30 Warm and dry again, with melting snow. Not so warm as earlier in the month.

## December 1999

### Climate in perspective:

The stable and persisting weather pattern of November gave way to more changeable, faster moving systems in December, more typical of the season. Pacific moisture made its way into Colorado's northern and central mountains on several occasions bringing small doses of much welcomed snowfall. However, very little of this moisture extended southward into the mountains of southwest Colorado. Prevailing westerly winds aloft also helped generate downslope winds east of the mountains that helped raise temperatures and reduce humidity. One storm system managed to drop heavy snows east of the mountain crest in southern Colorado early in the month.

### Precipitation:

December precipitation totals were again below average over most of Colorado. Areas of southwestern and eastern Colorado were particularly dry with almost no precipitation for the month at places like Durango and Lamar. While Colorado's northern and central mountains fared better, only a small area near Ouray and in the mountains near Meeker were actually above average for the month. The storm of Dec. 3-4 targeted a few areas along the Colorado Front Range leaving above average precipitation amounts for December over areas south and west of Denver and along the east slopes of the Sangre de Cristo and Wet Mountains southwest of Pueblo.

### Temperature:

No true arctic air masses reached Colorado in December. Relatively cold Pacific air masses dominated December weather patterns bringing seasonally cold temperatures to the central Rockies but with no dramatic extremes. East of the mountains, temperatures ended up above average again, with some stations in northeastern Colorado at least six degrees Fahrenheit above average. Many stations in northeast Colorado had no low temperatures below +10° F all month.

**December 1999**

| Description | Station | Extreme | Date |
|---|---|---|---|
| Precipitation (day): | Ruxton Park | 2.60" | Dec. 2 |
| Precipitation (total): | Ruxton Park | 4.46" | |
| High Temperature: | Kim & Pueblo | 74 F | Oct. 14 |
| | Reservoir | | Dec. 1 |
| Low Temperature: | Sargents | -28 F | Dec. 14 |

## Daily Highlights

2-2 Still quite warm but with increasing clouds and moisture. Mountain snows began on the 2nd spreading to the Front Range.

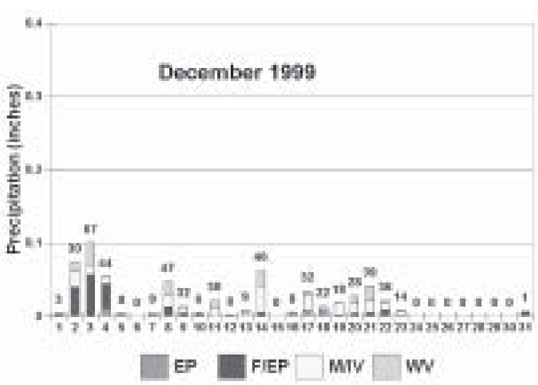
4-4 A major Front Range storm developed with strong winds and blowing snow in some areas. The heaviest snow fell south and west of Denver on the 3rd, with heavy snows continuing from Pikes Peak southward to Raton Pass into the day on the 4th. Snowfall totals exceeded two feet in some areas, with locally more than three feet near Cuchara.

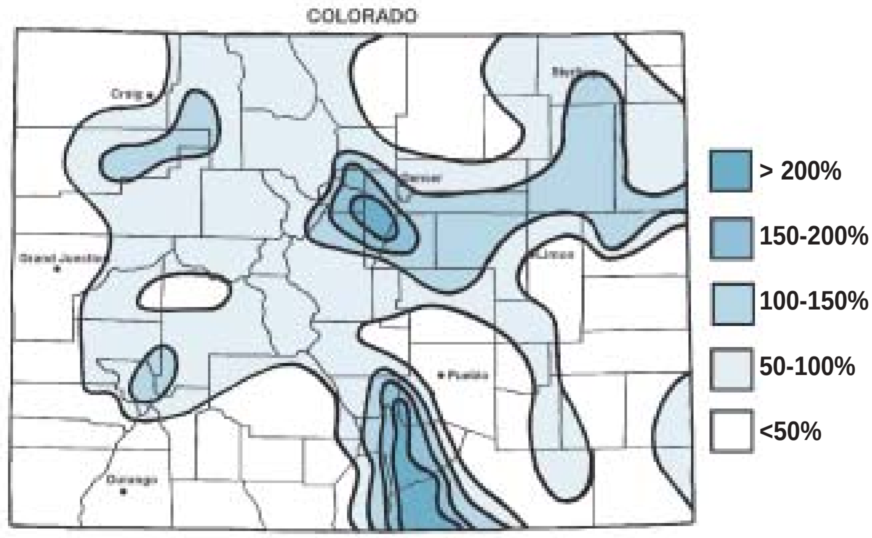
6-6 Mild and dry, but with cold nights in the mountains.

10-10 A cold front approached on the 7th accompanied by light snow producing icy roads late on the 7th and early on the 8th. Skies then cleared and temperatures dropped. Many locations had their coldest temperatures of the month early on the 9th. Walden dropped to –21° F while Antero Reservoir recorded –23° F.

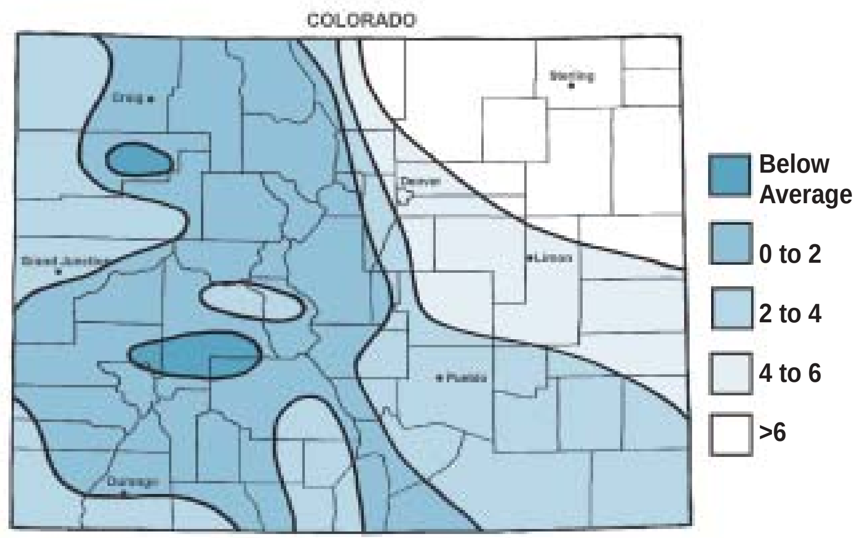
11-22 West northwesterly winds aloft pushed a series of weakening Pacific storm systems toward Colorado. Snows, mostly light, fell intermittently accompanied by normal ranges of temperature. The coldest days were the 14th and 15th when daytime highs only climbed into the teens in some mountain communities. Most snowfall was limited to the northern and central mountains, but flurries and sprinkles spilled out onto the plains, especially 17-21st. Strong downslope winds blew periodically through the period along and east of the mountains.

23-31 Clear skies with pleasant temperatures and clear holiday driving conditions. However, cold air settled into some of the broad snow-covered mountain valleys. Kremmling, for example, had daily high temperatures only near 20° F each day with overnight lows well below zero.




**December 1999 precipitation as a percent of 1961-1990 average.**




**December 1999 temperature departure from 1961-1990 average, degrees F.**

## Water Year Precipitation, October through December 1999

For the first three months of the 2000 water year, precipitation totals are well below average over practically all of Colorado. Some locations in southwestern Colorado have received less than 0.25 inches of precipitation in these 3 months, making this an even drier start to the water year than what they experienced in the severe drought winter of 1976-77. Precipitation totals are much better over the northern and central mountains although all stations are still below the 1961-1990 average. East of the crest of the mountains, accumulated precipitation patterns are highly variable, reflecting the patterns from four storm systems that have contributed most of the precipitation so far this winter. While most areas remain dry, above average

*(continued on page 18)*

precipitation has been observed southwest of Denver, in the Colorado Springs area, and along the eastern slopes of the Wet and Sangre de Cristo Mountains south and southwest of Pueblo. Extreme southeastern Colorado also continues to show well above average precipitation totals as a result of a single large storm dropping more than three inches of rainfall in early October there.

## Colorado's Climate, April-June – A look ahead

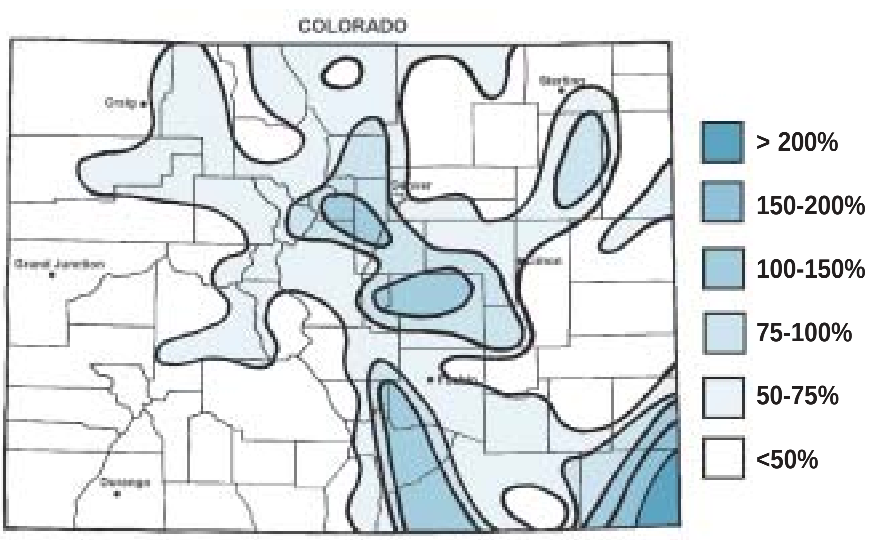
Every season in Colorado has its special features and memorable aspects. But there is no season like spring to point out the dynamic nature of the climate in the mid latitudes and in the middle of a continent. If you have lived in Colorado even just a few years, I don't have to tell you any of this, because you've likely already learned it on your own. Springtime is the most changeable, the most exciting, the most hazardous, and probably the most important season of the year to the health and growth of all forms of life in Colorado. Even the slow steps of geologic processes quicken for a time in the spring as wind erosion, soil erosion, freeze-thaw processes, rock slides, and sedimentation all speed up, only to slow again later in the summer and fall.

April, for all practical purposes, is still a winter month in the mountains of Colorado. Snow continues to fall, and sometimes in huge quantities. In particular, the eastern slopes of the Front Range can expect very heavy snows in April. Towns like Cripple Creek, Bailey, and Estes Park receive more snowfall in April, on average, than any other month. The only other portions of the U.S. where April is the snowiest month of the year are some of the eastern slopes of mountains in central Montana and eastern Wyoming such as the Big Horns near Sheridan, and the higher peaks of the Black Hills in South Dakota. A snowstorm dropping two to three feet of new snow in 24 hours or less occurs about every other year along the Colorado Front Range. Almost every decade there is at least one storm dropping four feet or more in one day. Colorado holds very few national climate records, but the amazing 76 inches of snowfall in 24 hours recorded at Silver Lake, Colorado (in the Boulder watershed just west of Boulder) back in April 1921 still stands as a North American 24-hour snowfall record. It has been challenged a time or two by storms in the Sierras, the Pacific Northwest, the Alaska panhandle, and the snow belts of Lake Ontario, but more than six feet of snow in one day is a tough record to beat.

By late April, the snowpack at high elevations typically reaches its greatest depth of the season. Skiers and snow boarders are still traversing the highest slopes while flowers and fruit trees are blossoming in the surrounding lower valleys. April is a very critical month for Colorado's Western Slope fruit industry as growers revel in the warm sunshine but fear the dreaded late frost that can end the entire fruit season in one cold night. Meanwhile in eastern Colorado, freezing nighttime temperatures are still fairly common, but daytime temperatures are plenty warm for fieldwork. Mile upon mile of wheat shows steady growth. Rain showers with occasional lightning and thunder become more numerous as the month goes on. But on occasion, the spring rains can turn to wet snow and sudden blizzards. Some of the spring storms may last for several days dropping widespread moderate precipitation that replenishes soil moisture reserves. Between storms, drying winds sweep across the plains and the mountain valleys, especially on sunny afternoons.

April and early May are especially known for sudden changes. Bright warm sunshine in the afternoon can quickly turn to evening thunder and cold winds. By morning, the ground can be covered by deep snow. Strong winds associated with passing storm systems can pick up clouds of dust. This is a time of year to be prepared for just about anything.

As we move later into May, the sun climbs still higher in the sky, and temperatures warm gradually. Winter-like storms become increasingly rare, especially over the southern mountains. Occasional episodes of hot, summer-like weather occur, during which mountain snows begin to melt rapidly. As water levels begin to rise, kayakers and rafters migrate toward their favorite rivers, although these




**Water Year 2000 (October through December 1999) as a percent of the 1961-1990 average.**

waters are icy cold, even on hot, sunny days. Thunderheads become a frequent afternoon visitor to the skies east of the continental Divide. Later in May, thunderstorms increase in both frequency and severity, often tossing huge quantities of hail stones to the ground. A few of these storms may produce a tornado or two, but most Colorado tornadoes in May are fairly small and short-lived. Closer to Kansas, tornadoes and severe weather are greater hazards, since these tornadoes may be quite large. Over portions of northeastern Colorado, May is the wettest month of the year, and rainfall probabilities are higher in late May than any other time of year. Widespread soaking rains are quite common. Approximately once every 10-20 years, a large May storm will produce heavy rains that combine with melting snows to produce flooding over portions of eastern Colorado.

As we move into June, winds at mountain-top level become noticeably lighter as the jet stream weakens and drifts northward into Canada. Large storm systems become infrequent, and instead localized thunderstorms become the dominant rain maker. Severe thunderstorms are most common in early June over eastern Colorado. Almost every year, tornadoes are spotted on at least one day during the June 1-14 window. Meanwhile, western Colorado sees little precipitation and many hot, clear days in June. High mountain snowpack melts rapidly, and many of Colorado's largest rivers reach their peak flows for the year in early June. Reservoirs are filled during this very important time of year.

An abrupt change from cool, changeable spring weather to persistent sunshine and intense heat takes place in the middle of June. The last half of June is almost always hot and dry in Colorado with only widely scattered thundershowers. These storms can produce large hail and heavy rains in eastern Colorado, but heavy precipitation is normally quite localized. By the end of June, the most of the snowpack is gone, and summer access to the Colorado high country can begin.

***Thunderheads become a frequent afternoon visitor to the skies east of the continental Divide.***

# Are There Urban Heat Islands in Colorado?

*Nolan Doesken*

For four years during college, I was fortunate to have a great summer job working with a large crew of scientists from several institutions studying the St. Louis, Missouri area. The project, known as METROMEX (METROpolitan Meteorological EXperiment), was trying to discover if that large urban area was affecting the summertime climate of the agricultural areas of southern Illinois downwind (east) of the city. We collected all sorts of data ranging from rainfall and rain chemistry data from hundreds of locations upwind, in, and downwind of the city, to surface temperature readings and much more. Later, several important conclusions were reached. St. Louis was found to be hotter and drier than surrounding forested or cultivated lands during the summer months. Also, the air over the city, not surprisingly, was found to carry more particles and pollutants. With the buoyancy of the hotter air over the city, that urban air tended to rise, causing rural air to be drawn inward towards the city (convergence). Finally, it appeared that these factors all worked in combination to enhance thunderstorm development and severity such that areas downwind from the city appeared to receive more rain and more severe weather than areas immediately over or upwind of the city. The differences were not dramatic, but they did appear to be detectable and non-random.


*Denver's urban heat island in degrees Fahrenheit (with respect to Stapleton airport temperatures) for extreme low winter temperature days. Taken from Rocky Mountain Chapter of ASHRAE, 1976, "Climate Data for Air Conditioning Design Rocky Mountain Chapter Region Colorado, Wyoming, Montana, and Environs."*

This wasn't the first time that scientists and other observant people noticed that the climate of cities differed from the climate of nearby rural areas. Beginning in the 1920s, airports were constructed in the rural areas just outside of most U.S. cities. From the 1930s and continuing into the 1950s, many of the nation's weather stations were moved from downtown locations, where they had been since government weather offices were first established in the U.S. beginning in the 1870s, out to each city's airport where weather observations were critical for airport operations and aviation safety. Climatologists quickly noticed that the airports were typically cooler than the inner city where the stations had previously been. Even before that, the idea that densely populated urban areas were warmer places than the surrounding countryside had been shown in Europe early in the 19th century. Around 1947 the phrase "urban heat island" was coined to describe this phenomenon.

Are there urban heat islands here in Colorado? This hasn't been studied in much detail. A 1976 publication of the Rocky Mountain Chapter of the American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE) contained a map of Denver's "heat island" which is shown at left. Assuming that the data they found then were accurate and representative, it showed a profound difference in extreme cold winter temperatures between Denver Stapleton airport and the center of the city. A difference of 8 degrees Fahrenheit on extremely cold days, along with reduced urban wind speeds caused by the friction from many large buildings and urban landscaping, is significant. The effect is large enough that urban furnaces and heating systems can be smaller and use less fuel than heating systems for rural and suburban structures.

It should be very easy to look for urban heat islands in Colorado. All you do is find weather stations that have been in cities or have had the city grow up around them. Then compare their temperatures to that of nearby weather stations that have always remained in a rural location. That's a good idea, but the reality is there are hardly any weather stations that meet these simple requirements. One of the best examples may be in Fort Collins. The weather station has always been on the campus of Colorado State University, and the city has grown up around it. The bulk of the urbanization in Fort Collins has occurred since the 1950s. The bad news is there aren't many nearby choices of rural stations for comparison. The best choice may be Waterdale just west of Loveland. While it is close in distance, its foothill location means that much of the difference in temperature between the two sites may be due to topography, not urbanization. For that reason, we also selected Akron, Colorado for comparison. The Akron 4E (4 miles east of the Akron Post Office) is 100 miles away but is free of dramatic topographical effects and has excellent data quality.

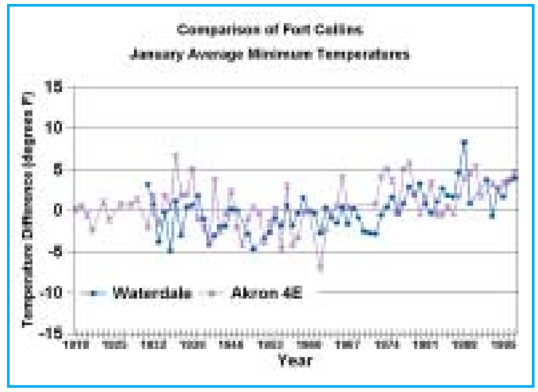
Let's look at average minimum temperatures for January, the time when the heat island effect is believed to be greatest. The graph of temperature differences does seem to show a long-term warming trend for Fort Collins with respect to the two rural stations. While there are large year-to-year differences in the relationship, Fort Collins has been systematically warmer than these rural sites since the early 1970s. Since the early 1950s, the Fort Collins station has warmed about three degrees Fahrenheit compared to these two rural stations.

What about other cities? It turns out that Fort Collins is one of the only weather stations in an urban area of Colorado that has not been modified, frequently relocated, terminated, or otherwise greatly disrupted. The only other reasonable choice for a long-term urban weather station is the old U.S. Weather Bureau Denver station that resided on the roof of the Post Office in downtown Denver from January 1916 until that weather station was terminated in the early 1970s. While its rooftop location was not compatible with weather station exposure guidelines, it was otherwise a consistent and high quality climate record. For comparison, temperature data from the Kassler Water Treatment Plant southwest of Denver was used. Like Waterdale, Kassler temperatures are not an ideal match since the station lies in complex topography at the mouth of the Platte Canyon where the South Platte River exits the mountains. We will also compare Denver to the Akron 4E temperature records.

As the graph clearly shows, downtown Denver temperatures are much warmer than the rural stations almost every year – typically four to five degrees warmer than Kassler and six to ten degrees F warmer than Akron 4E. Over the 1931 to 1972 period there may have been a slight warming of Denver compared to Kassler, but no obvious trend is evident with respect to Akron. Keep in mind that the area near the Denver Post Office has been fully urbanized for the entire century so there may be no reason to expect an ongoing upward trend with respect to the rural sites.

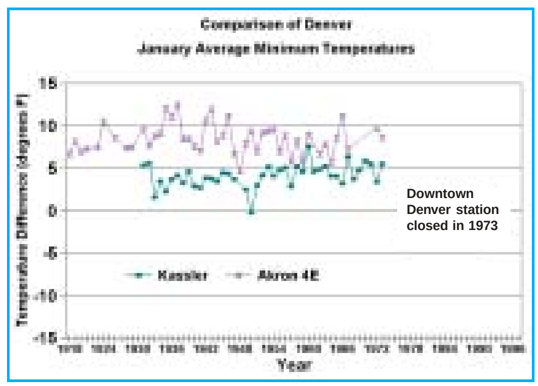
Yes, urban heat islands do appear to exist in Colorado. Some analysts believe that even small towns may be slightly warmer than surrounding countryside due to roads, buildings, waste heat from buildings and vehicles, and vegetation differences. However, the combination of complex topography and irrigation complicate the picture. Colorado's largest cities reside along the eastern base of the Rocky Mountains. Even without urbanization, this area is often warmer than surrounding regions during the winter months as a result of downslope winds that warm by compression as air descends the Front Range of the Rockies. Vegetation also plays an interesting and important role in defining temperature patterns around cities. Unlike the cities of humid climates, portions of Colorado cities may be greener and lusher than surrounding rural areas during the summer months due to the large extent of irrigated landscapes that have accompanied urbanization. During daylight hours, surrounding unirrigated rural areas may heat up more than the moist vegetated urban landscape.

This is the "urban oasis" phenomenon that helps explain why many western cities do not have the same urban heat island characteristics as midwestern, eastern, and southern cities in the U.S.




*Temperature differences between Fort Collins and two rural stations.*

A neat way to learn about the nature of Colorado urban temperature patterns is to compare minute by minute the daily temperature cycle between nearby urban and rural weather stations. In Fort Collins, comparable electronic weather stations have been maintained for several years on the CSU Main Campus and four miles northwest at Chrisman Field on the CSU Foothills Campus approximately 0.5 miles beyond the edge of the city. These stations record temperatures every few minutes. Clear days during the past year were selected during January, July, and October. Temperature differences were calculated with respect to the Main Campus station. Sure enough, the main campus "urban" station is cooler during the day – a daytime oasis. A rapid shift from cooler to warmer takes place within one hour and occurs at sunset. Throughout the evening and into the early morning hours, the urban site averages about two degrees F warmer than the nearby rural site – a nighttime heat island. After sunrise, the rural site warms more quickly than the urban site and the "urban oasis" returns. The maximum daytime difference occurs mid morning when the main campus station averages over one degree F cooler than the rural site. The relationship is similar in all seasons, but the magnitudes vary. During the winter, nighttime temperature differences were greatest averaging about 3 degrees warmer in the city with very little urban-rural daytime temperature differences. Daytime differences were greatest in late summer when urban vegetation was still very green, but grasslands near the foothills had turned brown.




*Temperature differences between downtown Denver and two rural stations.*

It is also well known that urbanization affects runoff from rainfall and snowmelt. But is urbanization also affecting precipitation and storm severity? Recent scientific papers by Stohlgren et al (1998) and Chase et al (1999) suggest

*(continued on back cover)*

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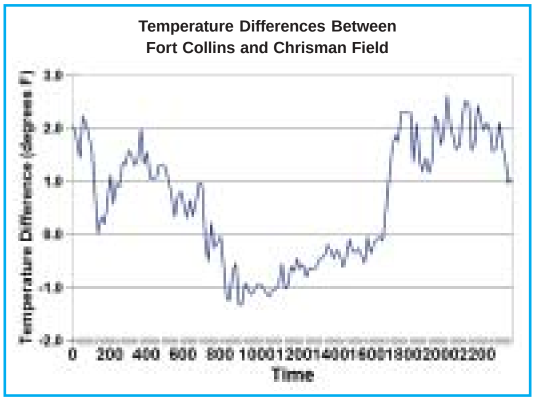
## Urban Heat Islands in Colorado? *(continued from inside back cover)*

that irrigated croplands along the Front Range may contribute to more summer thunderstorms. Some have speculated that severe weather has become more frequent in Aurora and further east in Adams County in recent years. But others have pointed out that severe weather there has always been common but until recently few people lived there and those that did simply took it in stride. We simply do not have enough long-term weather stations east and northeast of Denver or Colorado Springs know for sure. Perhaps we can explore this in more detail in a future issue.




*Daily cycle of temperature differences in degrees F between an urban weather station (Fort Collins, CSU Main Campus) and a rural station (Chrisman Field, CSU Foothills Campus) for selected days in 1999. Positive values are indicated when the urban site is warmer than the rural site.*


References: Chase, T.N., R.A. Pielke, Sr., T.G.F. Kittel, J.S. Baron, T.J. Stohlgren, 1999: Potential impacts on Colorado Rocky Mountain weather due to land use changes on the adjacent Great Plains. *J. Geophys. Res.* in press.

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### Next Issue:

- Fall frost dates
- Climate extremes
- The Colorado Agricultural Meteorology Network, Co Ag Met
- Learning about hail
- STEPS – The Severe Thunderstorm Electrification and Precipitation Study
- Cloudiness trends in Colorado – an update