



Colorado Climate

Winter 2001-2002 Vol. 3, No. 1

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Colorado Climate

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Cover Photo: Group of spruce and fir trees in Routt National Forest near the Colorado-Wyoming Border in January near sunset. Photo by Chris Hiemstra, Department of Atmospheric Science, Colorado State University.

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Why is the Park Range Colorado's Snowfall Capital?

Matthew D. Parker, University of Nebraska-Lincoln

Most Coloradans who have clicked into a set of ski bindings are aware that Wolf Creek Ski Area, located on Wolf Creek Pass in the San Juan mountains of southern Colorado, advertises "The most snow in Colorado." However, most Coloradans are not aware that, on average, the most winter precipitation in the state falls not at Wolf Creek Pass or in the San Juans, but in the Park Range which rises up just east of Steamboat Springs in north-central Colorado (Figs. 1 and 2). This may seem surprising in light of the fact that the Park Range is not among the tallest mountain ranges in the state, and does not lie within one of the larger massifs of high terrain in Colorado (Fig. 2). This article explores some reasons why a) the Park Range, on average, receives the most winter precipitation in Colorado, and b) the San Juan Range periodically experiences incredibly large winter precipitation amounts, but does not surpass the Park Range in annually averaged precipitation.

Orographic precipitation

In the atmosphere, clouds and precipitation generally form when moist air (air with a high relative humidity) ascends. As the moist air ascends, it cools; if the air cools to a sufficient degree, water vapor in the air is condensed or deposited onto small particles in the atmosphere, thereby forming water droplets or ice crystals (clouds). These droplets and crystals, in turn, can grow and coalesce with one another, eventually becoming quite large and falling from clouds as precipitation.

Precipitation occurs in Colorado's mountains throughout the year. On many days during the summer months, mountains act as elevated heat islands in the atmosphere, producing relatively warm, buoyant air that ascends to form a thunderstorm. However, a preponderance of the precipitation in Colorado's mountains falls during the winter months, between mid-November and mid-May. Most of the winter precipitation episodes in Colorado's high country occur not because buoyant air is ascending on its own, but rather because moist air is forced up the slopes of the mountainous terrain. Rain or snow generated by the mountains in this way is called *orographic precipitation*.

Large annual winter precipitation in Colorado's Park Range

Comparatively moister air

In order to have orographic precipitation in the Colorado mountains, moist air must flow up against and ascend the high terrain. Because the prevail-

(continued on page 2)

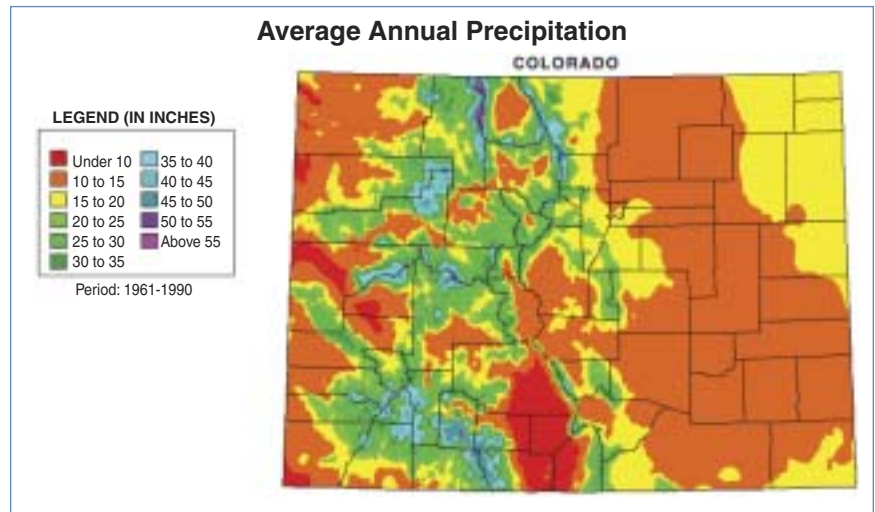


Figure 1: Annually average precipitation for Colorado (in inches).

This map is a plot of 1961-1990 annual average precipitation contours from NOAA Cooperative stations and (where appropriate) USDA-NRCS SNOTEL stations. Christopher Daly used the PRISM model to generate the gridded estimates from which this map was derived; the modeled grid was approximately 4x4 km latitude/longitude and was resampled to 2x2 km using a Gaussian filter. Mapping was performed by Jenny Weisburg. Funding was provided by USDA-NRCS National Water and Climate Center. 12/8/97

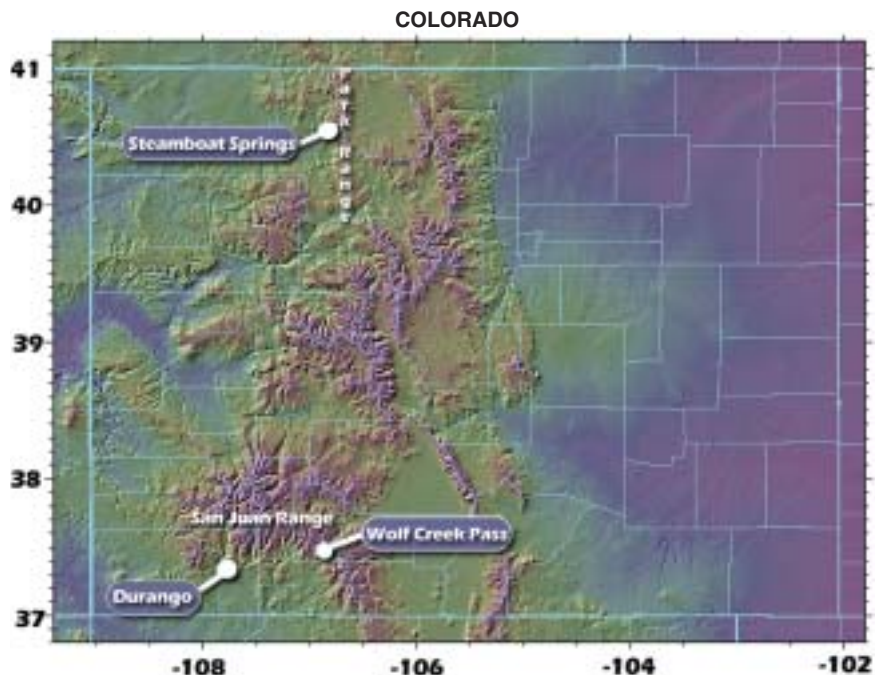


Figure 2: Topographic map depicting the major mountain ranges of Colorado. The Park Range and San Juan Range are labeled, as well as locations referred to in this article.

Colorado's Snowfall Capital *(continued from page 1)*

ing winds in the middle and upper troposphere over Colorado are west-northwesterly (from the west-northwest), the predominant moisture source for winter orographic precipitation in Colorado's high country is the Pacific Ocean (Fig. 3). From Fig. 3, it is evident that there are several major mountain ranges upstream from Colorado, particularly California's Sierra Nevada range, Utah's Wasatch range, and Wyoming's Teton/Wind River/Absaroka complex. As moist air flows up each successive mountain range, some of its humidity is left behind as precipitation that falls out. Accordingly, the fewer mountain ranges that air must pass over, the greater amount of humidity that remains at its final destination.

Skiers and snowboarders have perhaps noticed the symptoms of this phenomenon when comparing annual resort snowfall totals in Colorado (typically around 300 inches) to those in California, Utah, and Wyoming (often exceeding 400 inches). On average, airflow in the middle troposphere follows the white streamlines in Fig. 3, arriving in the Sierra Nevadas, Wasatch, and Wyoming mountains without having previously spent part of its humidity by ascending another large mountain range. The same cannot be said for most of Colorado, which lies in the "shadow" of the California, Utah, and Wyoming mountains. By the time moist air from the Pacific arrives in Colorado, it has already lost a fair amount of its initial water vapor because it precipitated over the upstream ranges. Notably, however, there is a gap of relatively low terrain separating the Wasatch range of Utah from the Teton/Wind River/Absaroka complex in Wyoming. From Fig. 3, it becomes clear that air following the mean streamlines through this gap will likely flow up against the northern Colorado mountains; in particular, the Park Range will receive the brunt of this still-moist Pacific air. So, for the averaged winter winds, the Park Range – unlike most of the Colorado high country – is not in the shadow of upstream mountains, so the air that arrives there is comparatively moist and produces comparatively more orographic precipitation than at other locations in the Colorado mountains.

Orientation of the range

If the ridge of a mountain range is perpendicular to the airflow, moist air will be forced upward by the slope of the terrain, which favors the formation of precipitation. In contrast, if the ridge of a mountain range is parallel to the airflow, much of the moist air will simply flow along-side the range, not being forced upward and hence not favoring the formation of precipitation. For the most part Colorado's central mountain massif can be thought of as a north-south barrier of high terrain (Fig. 2), which is beneficial for

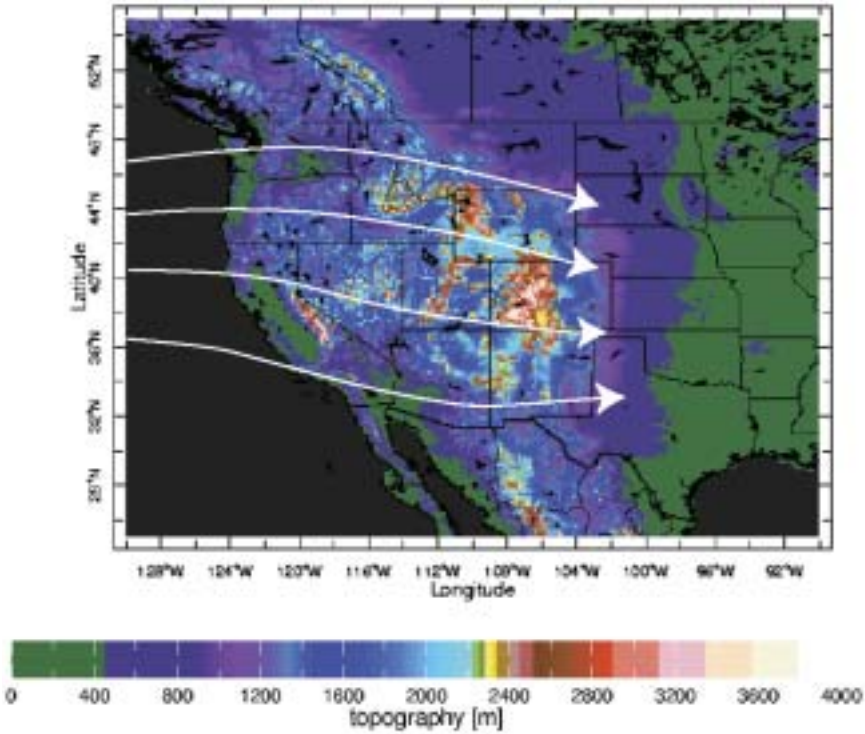


Figure 3: Surface elevation (in meters) of the western United States, with the mean middle tropospheric streamlines for November-May shown as white arrows.

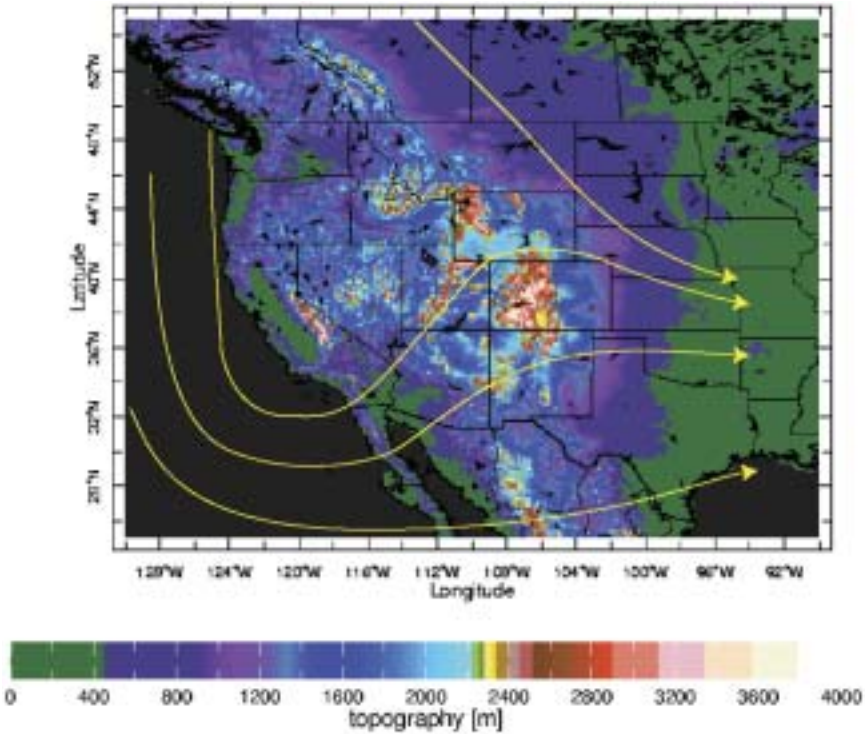


Figure 4: Surface elevation (in meters) of the western United States, with middle tropospheric streamlines from 26 January 2001 shown. This pattern is typical for large snows in Colorado's San Juan Range.

orographic precipitation because it is nearly perpendicular to the prevailing west-northwesterly winter winds (Fig. 3). The Park Range not only helps to compose the north-south Colorado mountain massif, but itself is also oriented roughly north-south (Fig. 2). Accordingly, not only does especially moist air flow into the Park Range (as described above), but it is also forced up dramatically because the Park Range is roughly perpendicular to the airstream. The orientation of the Yampa River Valley and the higher ground north and south of the valley also help funnel moist air towards the Park Range.

For the averaged winter west-northwesterly winds, no other location in Colorado enjoys such a favorable superposition of comparatively moist air (owing to the Park Range's location with respect to the upstream terrain) and orientation (nearly perpendicular to the mean flow).

Winter precipitation in Colorado's San Juan Range

The air streams shown in Fig. 3 are averaged over the entire winter snowfall season (November through May). However, large temporary deviations from this average happen throughout the season. Occasionally, when strong storms develop along the west coast of the U.S., a highly curved airflow pattern occurs in which Wolf Creek Pass and the San Juans receive tremendous amounts of snowfall. You may have noticed on Fig. 3 that there aren't any large, high mountain massifs to the southwest of Colorado. This suggests that, if a southwesterly (from the southwest) airstream could occur over the western United States, moisture from the Pacific Ocean and Gulf of California could flow into Colorado and rise up the San Juan range without having had to ascend over much high terrain upstream. Furthermore, the southern edge of the San Juan range extends roughly from northwest to southeast (from the vicinity of Durango southeastward toward Santa Fe, New Mexico, see Fig. 2). Therefore, a moist southwesterly airflow would be forced to rapidly ascend the steep southwest-facing (flow-perpendicular) slopes of the San Juans. In such a situation the San Juan range, and particularly Wolf Creek Pass, enjoys a juxtaposition of advantages similar to that described above for the Park Range. One example of this, in Fig. 4, occurred on January 26, 2001; approximately 20 inches of snow fell at Wolf Creek Pass in 24 hours from this airflow regime. Some of Colorado's largest single-day snow totals are received in the San Juan Range when the atmospheric flow pattern produces southwesterly winds across the western U.S. For this reason, Wolf Creek Ski Area is renowned for its deep powder skiing.

The Park Range versus the San Juan Range: A study in variability

The difference between the annually averaged precipitation totals for the Park Range and the San Juans has to do with the magnitude of typical snow events and the frequency with which they occur. Snowfall totals for individual storms in the San Juan Range tend to be large, but the annual snowfall totals in this range are quite variable. The frequency with which snow occurs in the San Juans varies widely from month to month and from year to year because of the special pattern needed to produce big snow events there (Fig. 4). In some years, moist southwesterly airflow patterns are scarce and annual snowfall totals in the San Juan Range are extremely low, even though one or two events in that year might produce very large daily totals. In other years, moist southwesterly airflow patterns are abundant, and the San Juan Range leads the state in annual snowfall by a healthy margin. By contrast, snowfall in the Park Range is much less variable. Over the course of most winters, the mean flow pattern shown in Fig. 3 prevails for much of the season. Unlike the San Juans, the Park Range does not receive many prolific single-day snows; however, snow falls more regularly throughout the winter and is more consistent from winter to winter in the Park Range because the average winter airflow pattern is favorable for it. In fact, not only does the Park Range lead Colorado in average annual precipitation, but it is also less variable from year to year than anywhere else in the state. Accordingly, if you had to book a ski vacation one year in advance, you might consider the reliability of large annual snowfall in the Park Range (i.e. Steamboat) to be very attractive; however, if you wished to ski in waste-deep snow and could leave at a moment's notice, the San Juan Range might be a better choice.

On January 26, 2001, about 20 inches of snow fell at Wolf Creek Pass.

About the author: Matt Parker was a graduate student in the Department of Atmospheric Science at Colorado State from 1996-2002, during which time he completed his M.S. and Ph.D. degrees and developed a fondness for Colorado's snowy slopes. He is now an assistant professor of meteorology/climatology at the University of Nebraska-Lincoln.



Wolf Creek 1E Weather Station Closes

Colorado Climate Center Staff

We regret to inform you that the Wolf Creek Pass 1E weather station closed November 30, 2001. This station has been a cooperative station for the National Weather Service taking temperature and precipitation data since December 12, 1957. The personnel of the Colorado Department of Transportation (CDOT) supported it. They actually lived year round at East Side Camp at an elevation of 10,640 feet. This location is 1 mile east of the summit of Wolf Creek Pass. This station began as a replacement for an earlier

cooperative station that was four miles west of Wolf Creek Pass. Because there are not many high elevation stations in the cooperative program, losing this station is what makes it so difficult.

Over the years many CDOT employees have helped take weather observations, but the most recent observer, Daniel Goldsberry, has been enthusiastically taking weather observations since March 1990. He and his wife, Linda, did an exemplary job for the past twelve years taking quality observations in a difficult and challenging environment. Thank you so much for your time and commitment!

As we say goodbye to the Wolf Creek Pass 1E station, we thought we would share with you some of what we learned in the past 44 years.

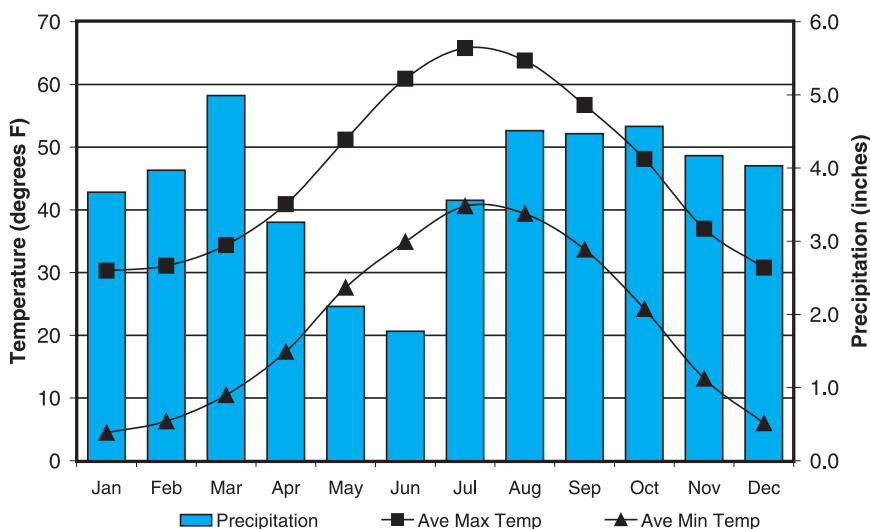
Wolf Creek Pass 1E holds the state record for the most snowfall during a winter season – a whopping 837.5 inches during the winter of 1978-79 (a heckuva way to end the drought of 1974-77).

Some other highlights include:

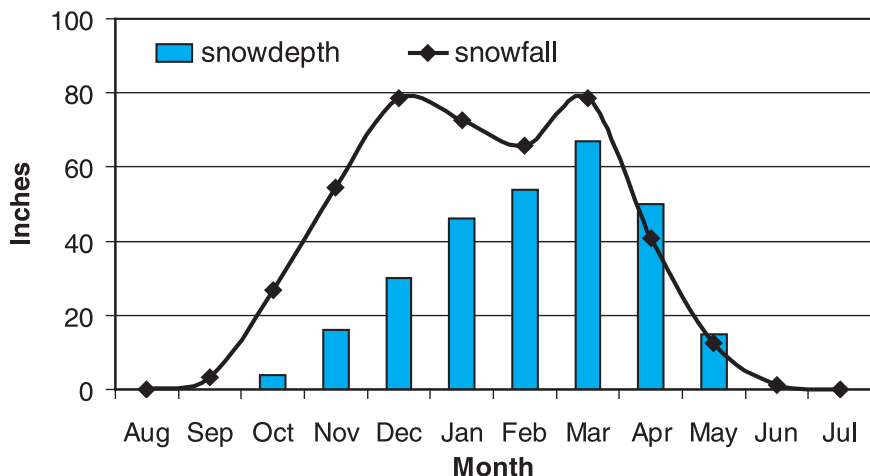
1. Warmest day on record was 80°F on June 28, 1990 and July 6, 1989.
2. Coldest minimum temperature was -40°F on February 5, 1982.
3. During the winter of 1992, Wolf Creek Pass enjoyed a very mild winter while only a short distance east, Alamosa and the San Luis Valley suffered through one of their coldest winters on record. There were 29 days that winter when Alamosa was at least 20 degrees F colder than Wolf Creek Pass. On January 3, 1992 Wolf Creek Pass 1E had a high of 39°F and a low of +14°F. That same day in Alamosa the high was +2°F and the low was -27°F.

4. During the late summer, moist air moves up from old Mexico as a part of the “Southwest Monsoon” wind circulation. As a result, very heavy rains are possible. During August of 1993, 10.89 inches of rain fell. September 1970 brought 11.25 inches and 14.45 inches of rain and wet snow came down in October 1972.

**Wolf Creek Pass 1E
Precipitation and Temperature Averages, 1957-2001**



**Wolf Creek Pass 1E
Average Snowfall and Snowdepth Averages, 1957-2001**



Colorado Climate in Review

by Nolan Doesken

October 2001

Climate in Perspective

October brought a little bit of everything. There were some very hot days early in the month. There were some thunderstorms with hail and strong winds. There were some heavy rains and a few heavy, wet snows. There were cloudy days and there were sunny days. But while the weather was changeable, it was no more so than usual. For the month as a whole, sunny and dry weather dominated and there were more warmer than average days than there were cool days.

Precipitation

Precipitation fell somewhere in Colorado on nearly half the days in October. Most precipitation was light, however, with only two storm systems bringing widespread rain or snow to at least half the state. The greatest precipitation totals for the month were observed in portions of Colorado's northern mountains where close to 2.5" of water content were reported. Precipitation was least east of the mountains, particularly east from Pikes Peak where several stations reported no measurable moisture for the month. The majority of the state received less than half the average October precipitation. Above average moisture was limited to areas of western Colorado between the Colorado and White Rivers and in northeastern Colorado.

Temperature

Temperatures oscillated all month, especially east of the mountains, as a series of autumn cold fronts crossed the state. The hottest temperatures occurred early in the month. Some stations in southeastern Colorado hit 90 degrees F on the 2nd and again on the 7th. Pueblo reached the 80-degree mark on 9 days in October. There were chilly days as well, but for the month as a whole most Colorado weather stations ended up warmer than average. October mean temperatures ranged from near to slightly above average over the Eastern Plains to nearly 4 degrees F above average in southwestern Colorado.

October Daily Highlights

- 1-3 A very warm air mass was in place over Colorado on the 1st with high temperatures in the 80s at lower elevations and a few mountain clouds and sprinkles. Upper level northwesterly winds increased 2-3rd, and much cooler air reached northeastern Colorado by the 3rd. The rest of the state remained warm and dry.
- 4-6 A shallow layer of much colder air surged into eastern Colorado on the 4th accompanied by low clouds. Rain turned to wet snow over extreme northeastern Colorado where up to

4" accumulated near Sedgwick. The cold air spread into the foothills and mountains on the 5th along with clouds and a little snow while western Colorado remained mild and dry. Skies cleared on the 6th as the cold air mass retreated quickly to the east.

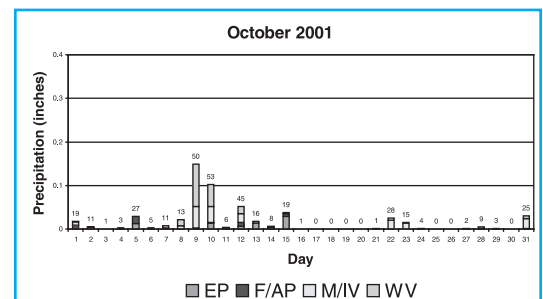


October 2001 precipitation as a percent of the 1961-1990 average.



October 2001 temperature departure from the 1961-1990 average, degree F.

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.



- 7-15** Four storm systems crossed Colorado in rapid succession. The first system on the 7th brought cooler temperatures but only a few scattered showers to western Colorado. At the same time, temperatures shot up to near 90 degrees over portions of southeastern Colorado. The second system moved in quickly on the 8th and crossed the state on the 9th. This storm brought widespread rain and some high-mountain snow to all areas west of the Continental Divide. A few showers and thunderstorms developed east of the mountains. The heaviest rains fell across northwestern Colorado. More than an inch of moisture fell over a sizeable area from Rifle, Meeker and Craig west to the Utah border. The 10th brought chilly temperatures but a lot of sunshine, but by the 11th the next disturbance approached from the northwest with precipitation developing late in the day over western Colorado. Most of the mountains picked up 1-4" of snow by midday on the 12th. Rye, on the east face of the Wet Mountains southwest of Pueblo, picked up 6" of wet snow. Little moisture fell east of the mountains with the exception of the Burlington area where 0.75" of rain was reported. Very strong northwesterly winds aloft then developed, with gusts exceeding 60 mph in the eastern foothills and high mountains 12-14th. The last in this series of storm brought several hours of cold rain turning to snow over northeastern Colorado while the rest of the state remained dry. Holyoke picked up 0.53".
- 16-20** A dry period with seasonal temperatures but some strong winds in the mountains.
- 21-23** Some moist Pacific air reached Colorado bringing valley rain and mountain snow showers. Most showers were light but Crested Butte totaled 0.41 inches. Eastern Colorado remained mild, dry but windy.
- 24-25** Clearing and cold. The low temperature at Antero Reservoir in South Park dipped to 5 degrees F on the morning of the 25th.
- 26-29** A ridge of high pressure over the Rockies brought dry weather with above average temperatures to the state.
- 30-31** A Pacific storm crossed California on the 30th but only scattered rain and snow showers remained by the time it reached Colorado on Halloween. Strong winds were widespread, however, and gusts exceed 70 mph in wind prone areas of the Front Range.

Month: October 2001

Precipitation (day): Shoshone, 1.42", 10/9/01
Precipitation (total): Shoshone, 2.10"
High Temperature: Fruita, 93°F, 10/1/01
Low Temperature: Climax, 4°F, 10/26/01

November 2001

Climate in Perspective

A series of storms in late November brought much needed and much appreciated snows to the Colorado mountains. This got the 2001-2002 winter recreation season off to a reasonably good start despite the nation's economic downturn and travel anxiety resulting from the September 11 terrorist attacks. But the first three weeks of November kept snow lovers very nervous as extremely mild temperatures prevailed and the only storm that hit the state brought mostly rain.

Precipitation

November storms deposited a total of more than four inches of water content on the Grand Mesa of western Colorado and in other mountainous areas. Low elevations both east and west of the mountains also received generous precipitation. The majority of the state ended up wetter than average for the month with substantially above average moisture in northwestern Colorado, the western slopes of the San Juan mountains, and over the central and northeastern plains. Holyoke totaled 1.75" of rain and melted snow, nearly three times the average. Not all areas benefited, however, and November ended up drier than average over much of southern Colorado and much below average in South Park and the Collegiate Valley from Salida to Buena Vista. Southeastern Colorado from Cheyenne Wells southward to Lamar and Holly also received less than 50% of the average November precipitation.

Temperature

Cold air with some subzero readings arrived in late November but not before Coloradoans had enjoyed an unusually mild November. The first three weeks of the month were consistently warm. For the month as a whole, temperatures ended up three to five degree Fahrenheit above the long-term averages in all areas of the state. With little snowcover until the last few days of November, Crested Butte ended the month more than six degrees above average.

November Daily Highlights

- 1-6** November got off to a dry and unseasonably warm start with daytime temperatures in the 60s and 70s at lower elevations
- 7-8** A vigorous, moisture-laden storm brought widespread precipitation in the form of both rain and snow to most of Colorado. Not much cold air accompanied the storm, so snow melted quickly. Precipitation totals ranged from a trace to a few hundredths over most of southern Colorado to 0.95" at Joe's in eastern Colorado. Montrose, Gunnison, Aspen and Crested Butte all got over 0.50" of water content, but even in

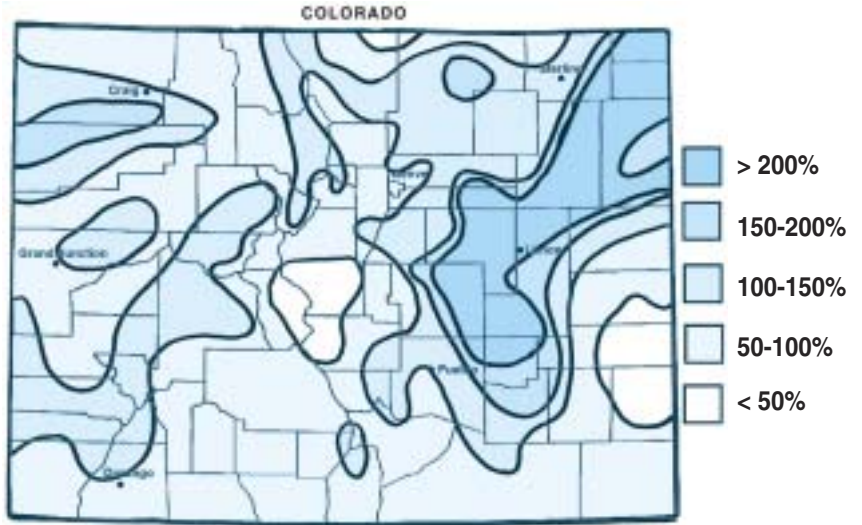
the mountains the snow melted soon from roads and open areas.

9-17 Nine consecutive days of unseasonably warm and dry weather just before the Thanksgiving holiday made for a nervous winter recreation industry. Temperatures climbed into the 60s and low 70s each day at lower elevations, although clouds and cooler temperatures were reported over southern Colorado 15-17th, as an upper level low pressure area skirted just south of the state. Ski area snowmaking efforts were hampered by warm temperatures as well, with daily highs in the 50s.

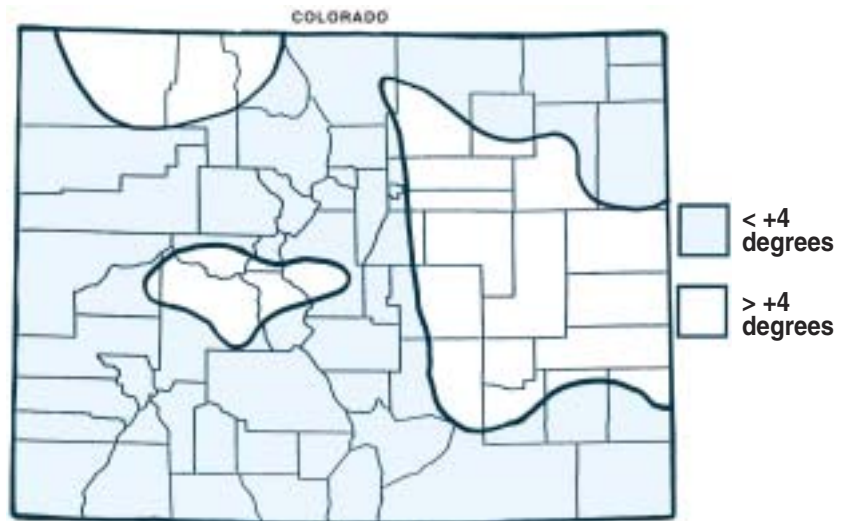
18-21 At last, a bit of a storm took aim at Colorado on the 18th bringing cooler temperatures closer to the averages for mid November, and a few hours of snow (some rain east of the mountains). Most mountain weather stations reported less than 3" – pretty puny – but Walsenburg had 4" and Climax measured 5 inches. Southwest and northeast Colorado missed out on most of the precipitation, and southwest Colorado continued having much warmer temperatures than average. Precipitation ended on the 19th, but some fog lingered. Skies cleared on the 20th bringing the first subzero temperatures of the winter to a few high mountain valleys. Daytime temperatures warmed quickly, and Canon City hit 73°F on the 20th. Mild, dry weather continued on the 21st, but clouds increased in advance of a developing storm system along the Pacific Coast.

22-30 Winter eased its way into Colorado as the jet stream strengthened and moved southward bringing a series of storms and progressively colder temperatures to the Rockies. The first system developed rapidly on the 22nd over Colorado and became a very deep low pressure area over Kansas on the 23rd. Widespread precipitation accompanied this storm with cold rains over portions of eastern Colorado and wet snows in the mountains. The heaviest rainfall total was 0.70" at the Karval station in southern Lincoln County. 4-8" of snow was common throughout the mountains but with more than a foot of new snow in the southwestern mountains. The Telluride weather station west of town picked up nearly 20" of snow with a water content of 1.31". After a short respite on the 24th, and second storm moved in on the 25th. This time, arctic air joined forces to help create a dangerous situation. Substantial snows fell in the mountains, but an area of heavy snow also developed east of the mountains extending from east of Denver northeastward to Akron, Yuma, Holyoke and Julesburg. Holyoke and Julesburg both measured close to one inch of water content from 10 inches of windblown snow.

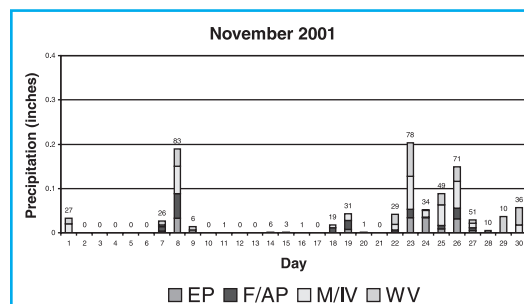
The storm moved away from Colorado on the 26th, but cold air lingered. Subzero nighttime temperatures were widespread in the mountain and over portions of northeastern Colorado. Walden, Hohnholz Ranch (Larimie River) and Crested Butte all had low temperatures below -20° F on the morning of the 28th. November



November 2001 precipitation as a percent of the 1961-1990 average.

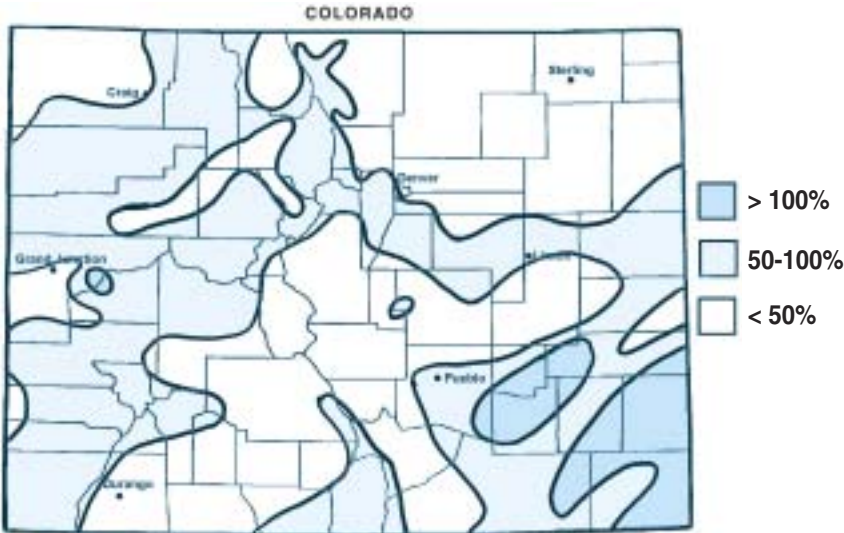


November 2001 temperature departure from the 1961-1990 average, degree F.

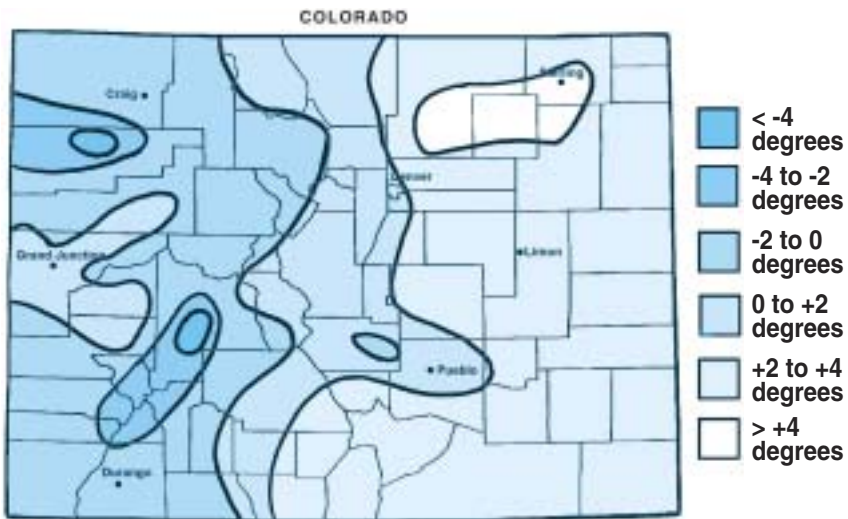


ended with more cold and snow as yet another storm crossed the Rockies 29-30th with several more inches of snow. The timing of this snow could not have been better for Colorado's winter recreation industry.

Month: November 2001
Precipitation (day): Hamilton, 1.55", 11/23/01
Precipitation (total): Wolf Creek Pass 1 E, 3.77"
High Temperature: Springfield 7 WSW, 86°F, 11/1/01
 Walsh 1 W, 86°F, 11/1/01
 John Martin Dam, 86°F, 11/1/01
 Holly, 86°F, 11/1/01
Low Temperature: Hohnholz Ranch, -21°F, 11/28/01
 Walden, -21°F, 11/1/01



December 2001 precipitation as a percent of the 1961-1990 average.



December 2001 temperature departure from the 1961-1990 average, degree F.

December 2001 Climate in Perspective

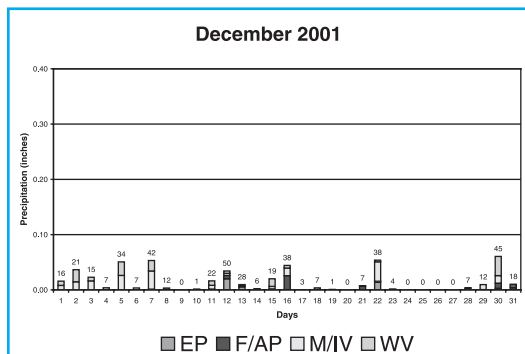
December weather patterns provided many opportunities for significant winter snowfall. At least eight definable storm systems approached Colorado in the first three weeks of the month. Several were predicted to be major snowstorms. Most storms fizzled as they crossed the Rockies leaving only a few inches of snow in some areas. East of the mountains, most storms just “blew over” dropping little or no moisture. The frequent snows and fairly cold temperatures in the mountains provided acceptable skiing conditions for most of Colorado's large resorts. The water content of the snow, however, lagged behind what would normally be expected for early winter.

Precipitation

Despite the many opportunities, December precipitation totals were below average over most of Colorado. Totals exceeded three inches in the higher elevations of the northern and central mountains and were relatively close to average. But adjacent valley areas were drier than average. As is often the case during midwinter, little moisture fell east of the mountains. Many stations in northeastern Colorado reported less than 0.05" of water content all month. The exception was the southeastern plains where a few of the storms dropped some snow. Rocky Ford, La Junta, Lamar and Walsh were wetter than average for December, but their monthly totals were only about 0.50 inches.

Temperatures

Subzero temperatures were common in December in the mountains and high valleys of western Colorado. Fraser dropped below zero on 22 nights during the month. Most of western Colorado ended up one to three degrees F below average. With fresh snow cover, Gunnison's temperatures were seven degrees below the long-term average making this their coldest December since 1978. East of the Continental Divide was markedly warmer with most stations two to four degrees above average.



December Daily Highlights

1-7 Dry and warm east of the mountains with occasional gusty “downslope” winds. Near Westcliffe in southern Colorado winds gusts of 87 mph were registered the night of December 5th. Mostly cloudy across the mountains and western valleys with periods of snow, as mild, moist Pacific air masses moved inland. With fairly warm temperatures, snow accumulation in the valleys was limited. But higher in the mountain this was one of the snowiest weeks of the year. Steamboat Springs totaled 9" 1-2nd. Crested Butte piled up 8" 2nd-3rd. Aspen reported 6" the morning of the 5th. The heaviest burst of snow came overnight on the 6th. Vail reported nearly a foot of new snow at their observation on the morning of the 7th with a water content of 1.30".

8-9 A break between storms with clearing skies. Cold nighttime temperatures over the fresh mountain snows. Crested Butte reported -8°F on the 8th.

10-13 Clouds and light snow spread into Colorado from the SW on the 10th as a low-pressure trough approached. Low pressure developed over the Eastern Plains on the 11th. Areas of rain and snow developed on the 12th followed by much colder temperatures. Burlington measured 4 inches of snow with 0.51" of water content. Rocky Ford picked up 6" of new snow, but most of the plains got just a light dusting. The storm weakened on the 13th, but cold temperatures prevailed, especially in the mountains. Crested Butte reported a low of -24°F on the 13th.

14-16 A Pacific storm moved inland with a push of moist air into the Rockies. Several inches of snow fell in some areas with close to a foot of new snow in a few exposed portions of the San Juan mountains. The Front Range foothills also received snow with 5" at Conifer, Evergreen and Estes Park. Little or no snow reached eastern Colorado.

17-20 A dry period for most of the state with some strong westerly winds aloft and just a few mountain snow showers. Daytime temperatures were quite warm, especially east of the mountains. Pueblo hit a high of 67°F on the 17th after a morning low of just 12 degrees.

21-22 A fast moving storm crossed Colorado. A little snow fell in the mountains, but parts of SE Colorado also received beneficial moisture. Lamar, for example received 0.30" of water content including 2" of snow.

23-28 Dry with lots of sunshine and seasonal temperatures as a high pressure ridge remained nearly stationary over the northern Rockies 23rd-27th.

Clouds increased on the 28th in advance of an approaching storm.

29-31 Mild and moist Pacific air moved into western Colorado, while a shot of arctic air moved down from Canada into eastern Colorado. The southern mountains picked up a few inches of much needed snow, and the southern Front Range also got some moisture. Walsenburg reported 5" of fresh snow on the 30th. Most of northern Colorado remained dry and only a few flurries fell on the eastern plains.

Month: December 2001

Precipitation (day): Vail, 1.20", 12/7/02

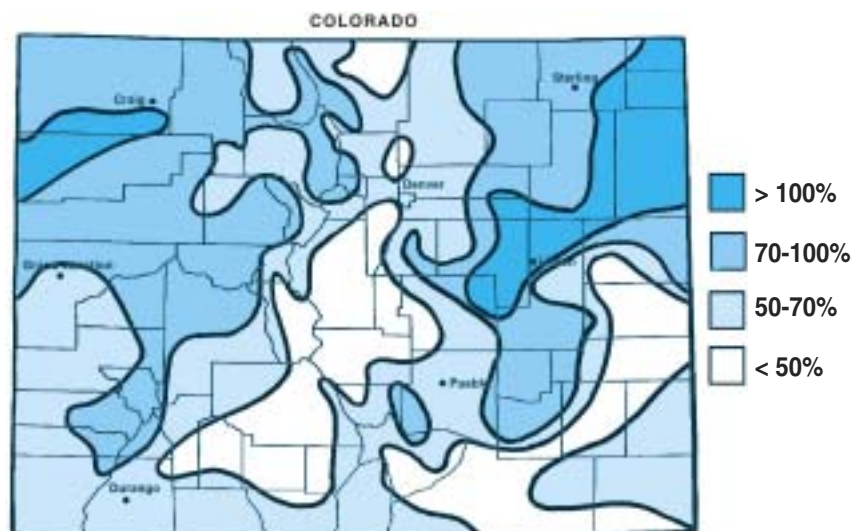
Precipitation (total): Vail, 3.03"

High Temperature: Campo 7 S, 79°F, 12/4/02

Low Temperature: Crested Butte, -24°F, 12/13/02
Gunnison 3 SW, -24°F, 12/25/02

Water Year in Review Through December 2001

The first three months of the 2002 water year left most of Colorado with less than average precipitation. Thanks to a few fall storms, the area from northeast El Paso County northeast through Limon into Yuma, Phillips and Sedgwick Counties were above average as was a small area of northwestern Colorado. All other areas of Colorado were dry with substantial portions of central Colorado totaling well below 50% of the October-December average. The driest area was Park County with only about 25% of average. Larimer and Boulder counties in northern Colorado, and portions of several counties in southeastern and south central Colorado were also far below average.



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

Stump the Climatologist

Question: Why is it so windy in Huerfano County?

Submitted by Jim Conley, Huerfano County Cooperative Extension Office

Answer: Episodic strong winds are a part of life for all areas in the immediate lee (just east of) the high Rocky Mountain chain. Most of these strong winds are relatively brief but severe associated with rapidly descending air cascading over the crest of the Rockies and racing out to the plains.

These “Down-Slope Wind storms” are most common from late autumn into spring and accompany travelling upper level disturbances in the strong wintertime jet stream. Fort Collins, Boulder, Denver, Colorado Springs and Pueblo are all prone to these windstorm events.

There are a few “preferred” areas that see strong winds much more commonly. Particular topographic features along the Front Range of the Rockies make certain areas more prone to strong winds than others. Portions of Huerfano County are in one of those wind zones.

There are three topographic features of your area that work together to produce a “wind tunnel.” A clue to this tunnel is the location of the Great Sand Dunes. The long, relatively straight and broad valley of the Huerfano River happens to run parallel to the strongest upper level winds that blow over the Rockies in the winter. The bend in the Sangre De Cristo Mountains (and the protruding Blanca Peak massif) channels

the winds toward Mosca Pass. Mosca Pass provides a low pass for the concentrated winds to blow through. Then, on the eastern side is a long, broad and straight valley headed straight for the open plains. And that’s she blows!

This is not a year-round wind tunnel. From late spring through mid autumn when upper level winds are light, the Huerfano County winds are not strong. But as long as the upper-level “Westerlies” are blowing, your wind tunnel will often be working. One of the benefits of these winds are markedly warmer winter temperatures. Compare temperatures at Westcliffe to those of Gardner on a breezy winter morning. The difference can be huge – as long as you don’t consider the wind chill effect.

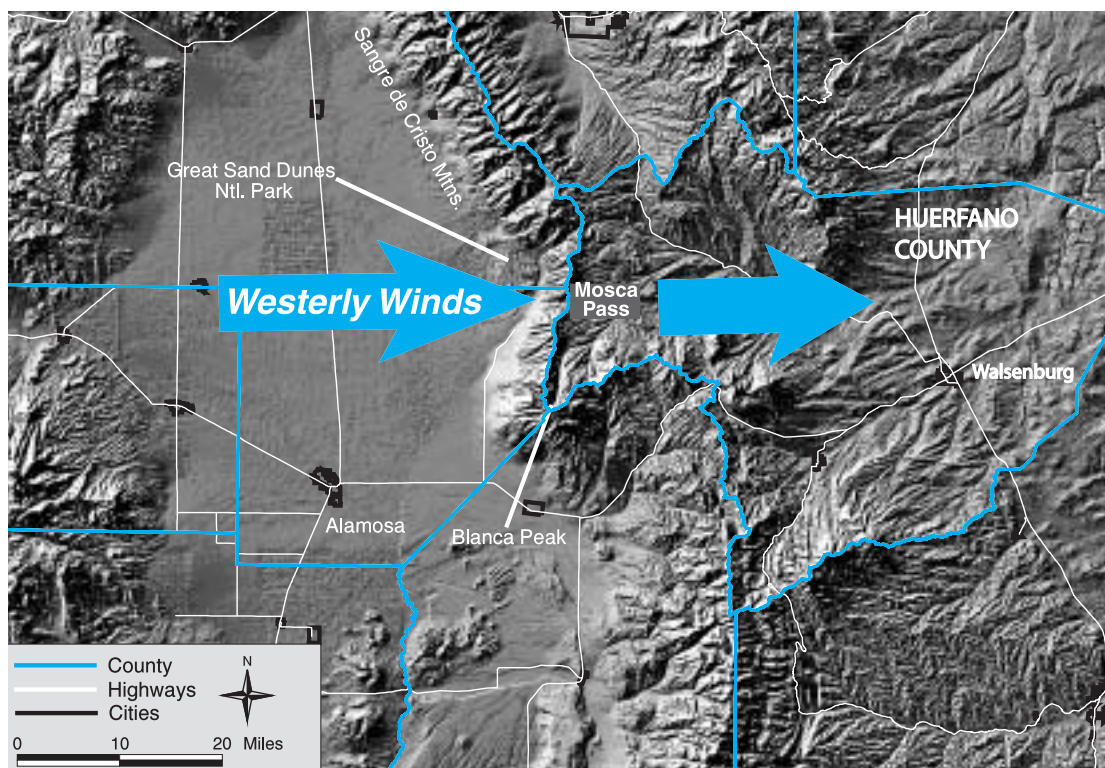
Under certain circumstances winds can reverse and blow up the valley. When easterly “upslope” winds blow, the Huerfano valley becomes a preferred location for heavy snows. In the summer, upvalley winds create preferred locations for thunderstorm development. The wettest areas in Colorado in July and August are often found in the Wet and Sangre de Cristo Mountains where these upslope easterly daytime winds converge with monsoonal winds blowing up from the south or southwest at mountain top level.

Thanks for a good question.

Nolan Doesken

If you would like to submit a question for the Climatologists to answer, send it to odie@atmos.colostate.edu

Topographic view of Mosca Pass in the Sangre De Cristo Mountains. Drawing courtesy of Christopher Hiemstra.



The Cold-Land Processes Field Experiment: North-Central Colorado

By Glen E. Liston, Department of Atmospheric Science, Colorado State University;
Don Cline, NOAA, NWS, National Operational Hydrologic Remote Sensing Center;
and Kelly Elder, USDA Forest Service, Rocky Mountain Research Station

Introduction

During the winters of 2001-2002 and 2002-2003, there is a Cold-land Processes Field Experiment taking place in Colorado (Figure 1). This experiment is designed to advance our understanding of the terrestrial cryosphere – cold areas of Earth’s land surface where water is frozen either seasonally or permanently. These areas, where snow, ice, and frozen soils and vegetation are common, have a large influence on global water, energy, and biogeochemical cycles. The storage of large amounts of fresh water in seasonal snow covers is a critical element of Earth’s hydrologic cycle. On average, over 60% of the northern hemisphere land surface has snow cover in midwinter, and over 30% of Earth’s total land surface has seasonal snow.

In many high-latitude and mountainous regions of Earth, the majority of total annual precipitation occurs as snowfall, and snowmelt is responsible for most of the total annual streamflow. Seasonal snow-covers are a large energy sink in Earth’s energy cycle, and through their effects on land surface albedo, the net radiation balance, and boundary layer stability, have profound effects on weather patterns over large areas. Frozen soils also have large effects on Earth’s water and energy cycles.

Seasonally and permanently frozen soils occur throughout higher latitudes and at high elevations; they are thought to occur over at least 35% of Earth’s land surface, including approximately 50% of northern hemisphere land areas. Seasonal and permanent frost in soils, reduce both infiltration into and migration of water through soils, and severely reduce the amount of water that can be stored in soils. By reducing infiltration, frozen soils can dramatically increase the runoff generated from melting snow. An estimated 7.2% of the world’s organic carbon resides in the annually thawing surface layer of tundra soils alone. In these environments, vegetation growing seasons are determined primarily by the thawed period. In turn, the timing of the spring thaw and the duration of the growing season are strongly linked to the carbon balance of seasonally frozen ecosystems. The influence of seasonally and permanently frozen land surfaces extends to engineering in cold regions, trafficability for humans and other species, and a variety of hazards and costs associated with living in cold lands.

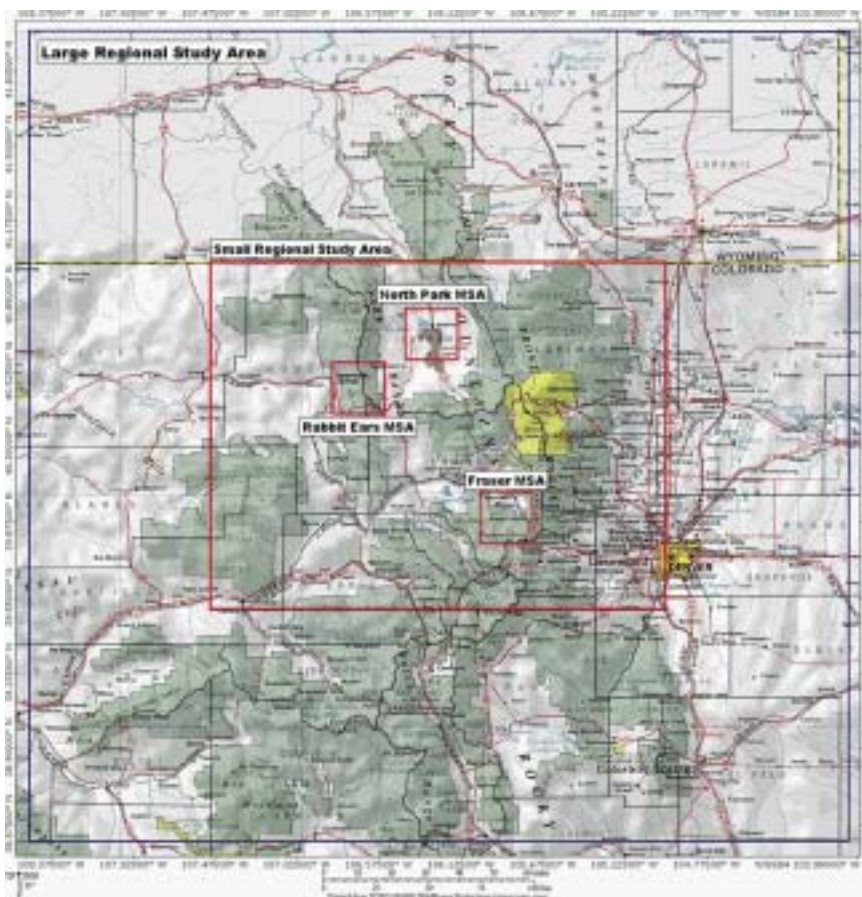


Figure 1. Nested study areas for the Cold Land Processes Field Experiment. The map limits depict the Large Regional Study Area (4.5 x 3.5 degrees) in north-central Colorado and south-central Wyoming (blue boundary). The Small Regional Study Area (2.5 x 1.5 degrees) boundaries are shown in red. Within that area are the three 25-km x 25-km study areas: North Park, Rabbit Ears, and Fraser. Each of these three areas contains three 1-km x 1-km Intensive Study Areas (not shown) where most of the field observations are being collected.

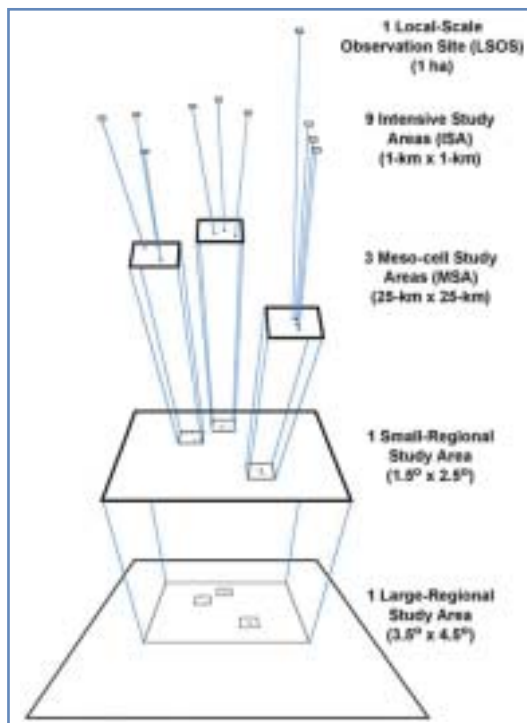
Scientific Objectives

To advance our understanding of the terrestrial cryosphere, the Cold Land Processes Field Experiment (CLPX), largely funded by NASA, has been designed and implemented. Complete details of the Experiment can be found at the web site: <http://nohrsc.nws.gov/~cline>. Developing a more complete understanding of fluxes, storage, and transformations of water and energy in cold land areas is a critical focus of the NASA Earth Science Enterprise Research Strategy,

(continued on page 12)

The Cold-Land Processes Field Experiment *(continued from page 11)*

Figure 2. Schematic diagram of the nested study areas for the Cold Land Processes Field Experiment.



the NASA Global Water and Energy Cycle (GWEC) Initiative, the Global Energy and Water Cycle Experiment (GEWEX), and the GEWEX Americas Prediction Project (GAPP). The movement of water and energy through cold regions, in turn, plays a large role in ecological activity and biogeochemical cycles.

The Cold Land Processes Field Experiment focuses on developing the quantitative understanding, models, and measurements necessary to extend our local-scale understanding of water fluxes, storage, and transformations to regional and global scales. The experiment emphasizes developing a strong synergism between process-oriented understanding, land-surface models, and remote sensing.

Quantitative understanding of cold-land processes over large areas requires the following four major science questions to be addressed together:

1. Process Understanding. How do the extent and evolution of snow and frozen landscapes affect fluxes, storage, and transformations of water, energy, and carbon?

2. Spatial Variability. At what scales does the spatial variability of key state variables in the terrestrial cryosphere, including snow characteristics, soil moisture, the extent of frozen soils, and the transition between frozen and thawed conditions, control fluxes and transformations of water, energy, and carbon, and can remote sensing resolve this variability at these scales?

3. Temporal Variability. What are the rates of change of the dominant cold land processes, and can remote sensing resolve these with sufficient accuracy to diagnose and improve land surface models?

4. Uncertainty. How do the various uncertainties associated with remote-sensing observations and models of cold land processes constrain/affect data assimilation and the ability to improve forecasts?

The Cold Land Processes Field Experiment is designed to help answer these important scientific questions.

Experimental Design

The experimental design for CLPX is a multi-sensor, multi-scale approach to providing the comprehensive data set necessary to address the general science objectives of the Experiment. A set of nested study areas, ranging from 1 ha to 160,000 km², provides the framework necessary to permit a detailed examination of cold land processes, modeling, and measurement over a wide range of physiographic conditions and spatial scales (Figures 1 and 2). Within this framework, intensive ground, airborne, and spaceborne observations are being collected, and land surface model data sets generated, to produce a comprehensive data base sufficient to meet the science objectives.

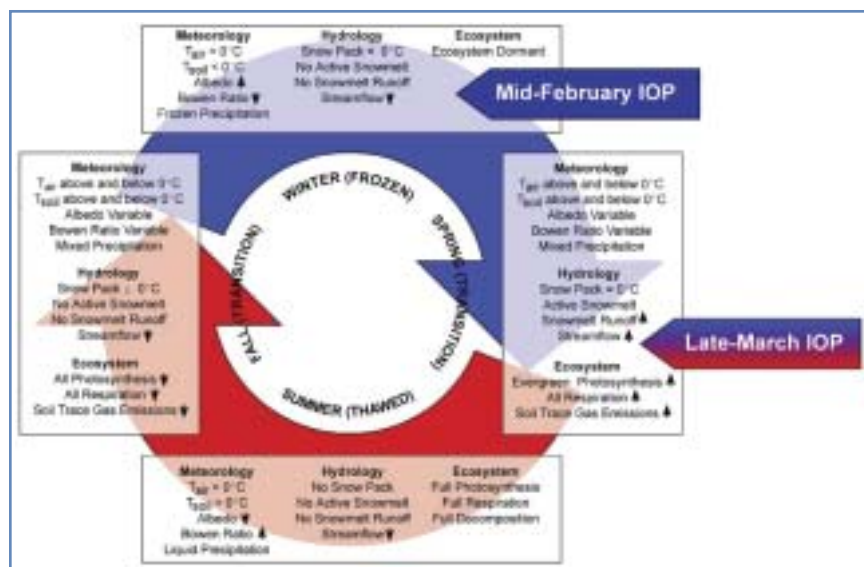


Figure 3. Schedule for Intensive Observation Periods (IOP) for the CLPX program, in the context of seasonal meteorologic, hydrologic, and ecological variations.

The experiment study sites and schedule have been designed to efficiently provide a wide range of snow and frozen soil, topography, and vegetation conditions, with strong consideration given to winter accessibility and safety issues. The experiment is being conducted in the complex terrain of north-central Colorado (Figure 1), where elevation gradients and slope/aspect variations provide a wide range of conditions over relatively short distances. Study sites have been selected that range from low-relief (flat topography), unforested areas with shallow snow covers, to high-relief (complex topography), densely forested areas with deep snow covers. The experiment will also exploit seasonal variations in snow and frozen soil conditions. Field campaigns are being conducted in late winter (mid-February), when predominantly frozen conditions and dry snow covers are expected, and in early spring (late-March), when transitional (e.g., frozen and thawed) conditions and predominantly wet snow covers are expected (Figure 3). The field campaigns were conducted in 2002 and repeated in 2003 (see the previously-listed web site).

Data collection during the experiment is focusing on 1) active- and passive-microwave remote sensing observations from ground, aircraft, and satellite platforms (Figure 4), 2) intensive in situ observations of snow and soil characteristics (Figures 5 and 6), and 3) in situ meteorological observations.

CLPX is likely the largest and most comprehensive field experiment to be implemented with such a major focus on snow and other cold-related processes. The data sets collected as part of this effort are expected to have an important impact on our understanding and ability to model and forecast weather and hydrologic processes in cold, snowy regions such as Colorado.



Figure 4. The NASA DC-8 on a high-altitude (39,000' MSL) AIRSAR, POLSCAT, and PSR flight line over North Park. Inset, upper left: AIRSAR antenna (upper structure) and PSR instrument (lower drum-shaped instrument) mounted on the DC-8. Inset, lower right: NASA flight crew at work. (Inset-photos credit: Koni Steffen).



Figure 5. Denny Hogan (Colorado Avalanche Information Center) and Steve Muller make snow measurements at the Alpine Intensive Study Area.



Figure 6. Gus Goodbody (Colorado State University, left) and John Fitzgerald in a snow pit at the Buffalo Pass Intensive Study Area. The photo illustrates the replicate snow density sampling protocol used in all CLPX snow pits. Snow depth here is about 2.2 meters.

*Floods, Hail, Drought, Blizzards,
Lightning, Tornadoes*

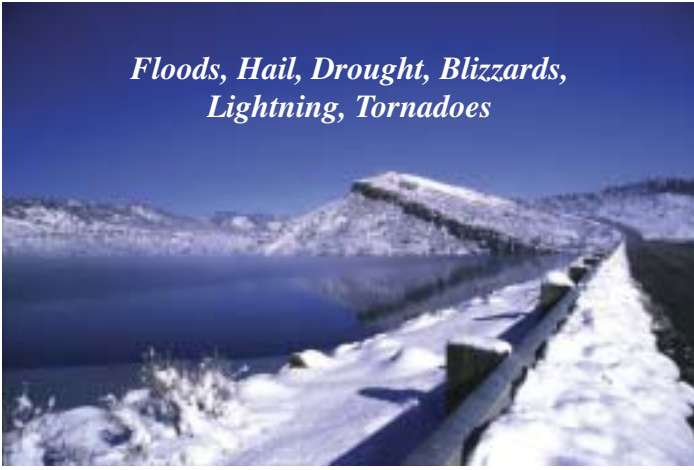


Photo by Ian Wittmeyer, Horsetooth Reservoir.

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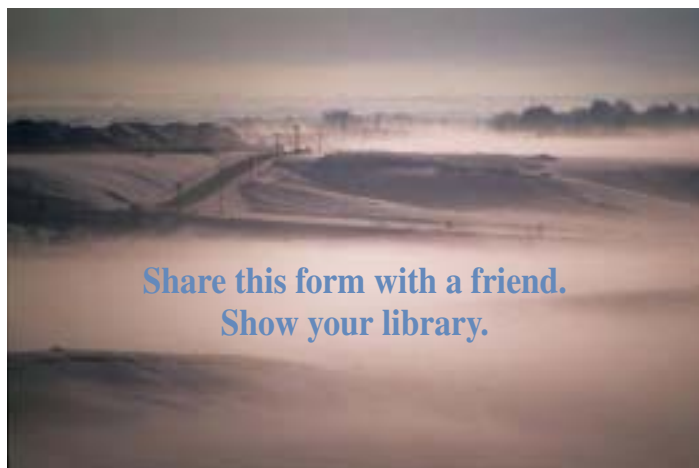
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