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Cover Photo: Pumpkin Patch in October, Photo by © Ronald L. Holle, used with permission.

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Central Colorado's Severe Downslope Windstorms

by John F. Weaver, NOAA Research Meteorologist

Those of us who've lived along the Colorado Front Range for any length of time are aware that the late fall through early spring often brings periods of extremely strong, westerly winds. These winds pummel communities along the eastern foothills of the Rocky Mountains with hurricane force – blowing vehicles off roadways, uprooting trees, damaging structures, and pelting unsuspecting residents with a large assortment of flying objects that are collectively known as debris (Figure 1). The events are called severe downslope windstorms, and they can actually strike the downwind side of mountain ranges anywhere on earth. What causes these winds, and how we predict them in Colorado, is the focus of this article.

In the most general sense, winds are driven by pressure gradients – that is, by air attempting to move from regions with higher pressure to those with lower. Thus, if there were a low pressure center over the Nebraska panhandle, and a region of higher pressure near the Four Corners region in southwest Colorado, air would attempt to move northeast to try to fill the low. The speed that the air moves depends on the pressure difference – the greater the difference, the faster the wind.

Unfortunately, nothing in the atmosphere is quite that simple. There are other factors that alter the speed and direction of the air as it tries to equalize pressure differences. The first of these comes about because the earth is constantly turning on its axis. Thus, as the air moves northeastward toward Nebraska, the earth moves out from beneath it, resulting in a ground relative, eastward "turn" to the flow. This ground-relative drift is formally known as the Coriolis effect. In a frictionless environment, the Coriolis effect is generally sufficient to cause the winds to turn just enough that the air simply circles around low pressure in a counter-clockwise fashion in the Northern Hemisphere (and around high pressure centers in the opposite direction).

But there is another complication due to the fact that the earth's surface is rough. This roughness causes the wind speeds within a few thousand feet of the ground to be reduced by frictional turbulence which, in turn, disturbs the otherwise well-balanced pressure/Coriolis circulation. The effect of friction causes the winds to turn a little, toward the low pressure, and the amount of turning depends on the amount of turbulence. It sounds complex, but the combined effect of all of these various factors ends up causing the winds near the earth's surface to generally *spiral* inward toward areas of low pressure, and spiral away from surface highs. So, in our Nebraska panhandle example, the wind would probably end up blowing from the due west, or even the northwest as it moves across the Front Range.

Figure 1. Tree damage during a severe downslope windstorm that occurred on 3 July 1993 in Fort Collins, Colo., with the arrival of an unusually strong, summertime cold front.

The development of the pressure pattern described here – a pattern that can bring strong airflow near the earth's surface – is a necessary ingredient in developing severe downslope winds. Without that fundamental force, severe winds would not occur. But another important ingredient concerns the winds aloft. In order for a respectable surface windstorm to develop, the winds between about 5,000 to 10,000 feet above ground level must also be strong, and they must be blowing in the general direction of the surface winds. This condition occurs most frequently in the winter or early spring, when the jet stream makes its way across Colorado. The strongest winds in the jet stream are generally found at upper levels of the atmosphere – around thirty-thousand feet, or so – but there is a three dimensional structure to the jet that frequently extends a portion of these stronger winds down to mountain top level. The strong, jet-related, westerly flow at mountain top levels are what typically bring strong winds and blowing snow to the mountains. But for those living along the Front Range, it is the phasing of these jet-related winds with the surface flow that represents the second part of the story for developing severe downslope windstorms.

With everything else in place, there are still local-scale, modifying features to consider. Though larger scale atmospheric patterns generally force the air to begin moving in the first place, the specific nature of an individual wind event depends strongly on the topography of the locale where the winds are taking place. If the local terrain along the eastern slope of the foothills is very steep (in cities like Boulder, Colorado Springs, or Westcliffe, to name a few), and if the air mass is relatively stable, then so-called vertically propagating mountain waves can develop (see Figure 2). These massive waves may have horizontal dimensions on the order of several miles, and can extend upward as far as the lower stratosphere. Think of flood waters splashing up against an obstacle, such as a wall or a dam. The water hits the wall, and – if the flow speed is just right – the water will build up a standing "wave" just above the obstacle. The fluid that courses through this standing wave comes crashing down heavily on the other side. If you were in Boulder, then the Flatirons would be the concrete wall, and you would be at the spot where the fluid comes crashing down. In addition to forcing intense winds at the ground, these stationary waves can also present a significant hazard to aviation by producing severe, or even extreme, clear air turbulence. Sometimes, if there is sufficient moisture in the air, we can actually see the "backwash" from such waves in the form of rotor clouds that form just east of the region where the strongest winds are taking place.

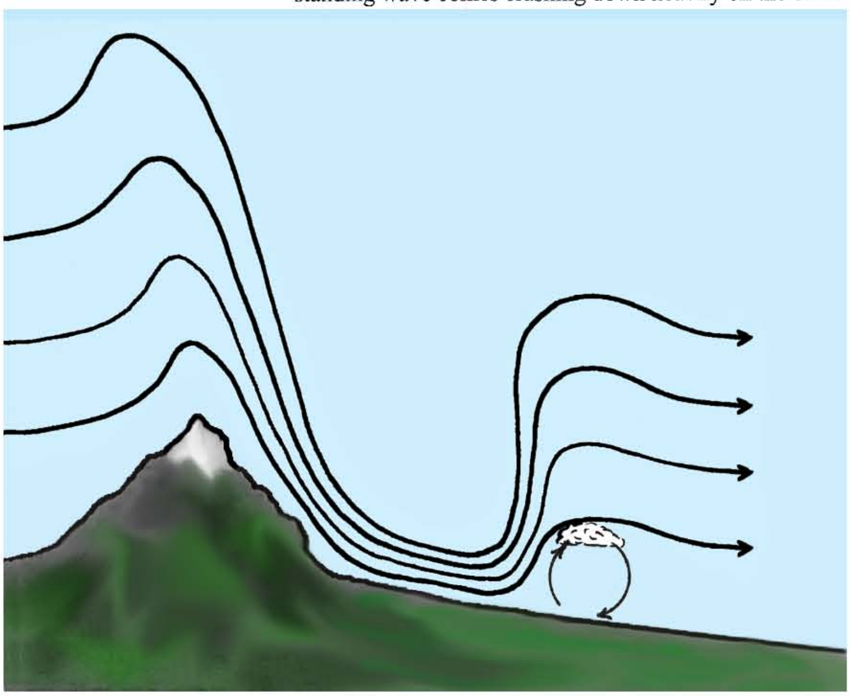

Figure 2. Diagram illustrating some idealized streamlines associated with a vertically propagating wave-type of downslope windstorm that occurs downwind from stark terrain barriers.

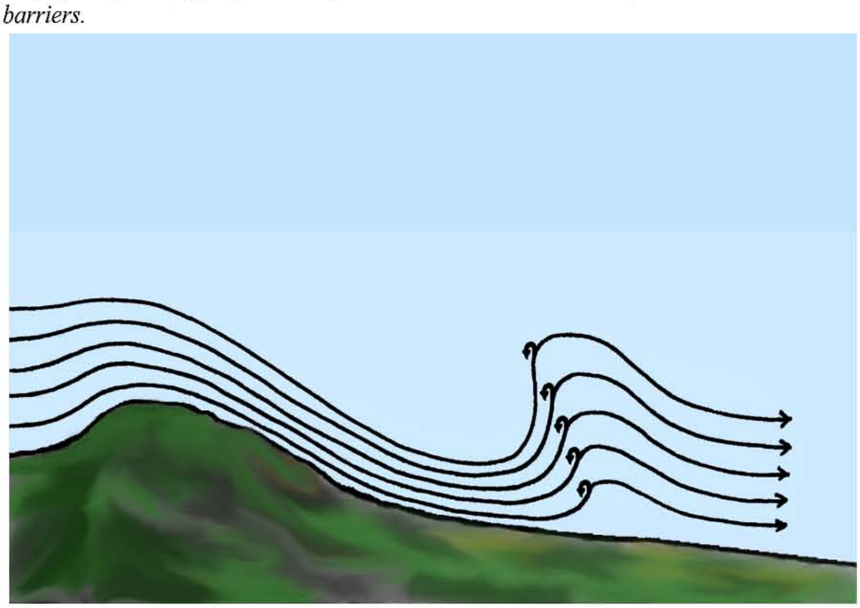

Figure 3. Diagram showing some idealized streamlines associated with a modified hydraulic jump, Bora-driven downslope windstorm that occurs downwind from areas of moderate-profile terrain.

In spots along the Front Range where the terrain to the west is less steep (in cities like Fort Collins or Longmont, for example), severe downslope windstorms can also develop (Figure 3). Such events are most likely to occur if the westerly flow is accompanied by cold air advection – that is, if a cold front tries to move in from the mountains along with the winds. This type of event is known as a "Bora." With shallower terrain, there is no steep "barrier," and vertically-propagating waves cannot set up as easily. Also, the eastward moving air tends to warm by compressional heating (remember the Ideal Gas Law) as it moves down the eastern slopes. This warming causes turbulent vertical motions within the flow, because warm air tends to try to rise. The result is a dampening of the wind speed. The cold air that accompanies a Bora event can offset the compressional heating, allowing the approaching stream of fast moving air to remain shallower – more contained. In fact, since cold air is heavier than warmer air, gravity can often play a role in accelerating the air on its way out of the mountains. Often these severe wind events lead to a so-called "hydraulic jump" just east of the Front Range. The eastward rushing air, out on the flatter terrain to the east of the mountains no longer has as much gravitational acceleration, so it will move slower. At some point (usually out near I-25 in Fort Collins), the current of air will suddenly transition from a shallow, fast moving stream, to a deeper and much slower moving one. The change in wind speed can be dramatic when you cross between the two. Notice that the vertically propagating mountain waves described in the previous paragraph also develop a hydraulic jump out to the east. In the case of Boulder's windstorms, this jump is often found over the western suburbs of Denver. The dramatic backwash, beneath the rotor cloud shown in figure 2, can sometimes result in severe dust devils that form at spots where intense shears between east and west winds develop. A series of very dramatic spin-ups occurred on January 17, 1982. They produced tornado-like damage at the Jefferson County airport – damage which included the upending of several planes that had been tied down with steel cable.

Forecasters have many tools available to identify situations in which severe downslope wind conditions are setting up. But a lot of this information comes from computer models which – though noticeably better in recent years – can easily make an error of twenty or thirty degrees in their predictions of wind direction at both the surface, and aloft. Such small changes in direction can affect the intensity of the surface event, its specific location, and the type of storm that is going to occur. Plus, there are other local-scale complications that can alter the forecast. For example, if a very cold air mass were to be situated over an area where severe winds are trying to develop, it may take a while for the flow to "break through" the colder, more dense dome of air, and reach the surface. Sometimes the air can be so cold and so deep that the predicted wind event never comes to pass. Nevertheless, forecasting success for severe downslope windstorms has been improving routinely as newer and more complex computer products come on line. Highway officials and emergency responders concerned with high profile vehicles on the Colorado roadways, building contractors who find themselves at wind-sensitive stages in their construction, light and power companies worried about power poles blowing over or trees falling onto wires, can all plan for, or plan around, these uniquely localized windstorms with an increasing degree of confidence.

About the author: John Weaver is a NOAA research meteorologist working at the Cooperative Institute for Research in the Atmosphere (CIRA) at Colorado State University. He specializes in severe weather research and satellite meteorology.

Colorado Climate in Review

by Nolan Doesken

July 2002

Climate in Perspective

July was a month of heat, drought, smoke and fire. Wildfires that had ignited in June continued to burn into early July. New fires were ignited over western Colorado, many caused by lightning. Overall, thousands and thousands of acres burned as Colorado suffered through the worst drought period in recent memory. Crop conditions also continued to deteriorate as a combination of heat, low humidity, lack of precipitation and inadequate irrigation water plagued Colorado farmers. Water levels on rivers, streams and reservoirs usually drop quickly during July, but this year there was little to start with, and many rivers were at record low levels. July was not bone dry, however. Several stormy periods brought heavy rains to some areas. Higher humidity along the Front Range helped slow the spread of the huge Hayman fire southwest of Denver, and it was eventually controlled. Tropical moisture associated with the North American Monsoon did fuel numerous afternoon showers over the mountains and temporarily quieted the wildfire outbreak later in July. However, local flash floods occurred over several of the recently burned areas.

Precipitation

July was another dry month for most of Colorado. Precipitation was scant and widely scattered across the eastern plains and Front Range. Most areas east of the mountains ended up with less than half the July average. A few areas missed out on nearly all the storms. For example, Fort Collins only received 0.07" for the month and Boulder was right behind with only 0.09". Idalia, north of Burlington, reported only a trace of precipitation all month. Akron totaled just 0.10", 4% of average. Rocky Ford received only 0.06" of moisture while temperatures soared to 100 degrees or higher on 13 days. Western Colorado fared a bit better, although some areas received less than half of average. Afternoon thundershowers were generally light but fairly numerous over the mountains, and most of the mountains got 50 to 80% of their long-term average. There were several heavy storms, however, that helped lift localized areas above average for the month. Two storms late in July dropped heavy rains near Trinidad. Trinidad Lake ended up with 4.08" or rain for the month, 154% of average. Heavy rains also fell near the Hayman fire in Douglas County. The Sedalia weather station totaled 3.96" in July.

Temperature

Hot weather was again the rule over Colorado in July. Temperatures climbed into the 90s and low 100s most days at lower elevations, while 80s were common in the mountain valleys. Crested Butte, known for pleasant summer temperatures, saw the mercury climb into the 80s on 17 days during July. For the month as a whole, July temperatures were one to three degrees Fahrenheit warmer than historic averages while across north central, northwest and extreme southwestern Colorado, temperatures were four to as much as six degrees above average.

July Daily Highlights

1-3 Forest fires burned, smoke filled the skies, and temperatures set new records. Larkspur in Douglas County, not far from the huge Hayman fire, hit 101°F on July 1, the hottest temperature ever recorded there. The downtown Denver cooperative weather station at the Denver Water Department hit 105°F. Temperatures remained very hot 2-3rd , but humidity increased and some isolated severe thunderstorms with high winds and hail developed. Parts of Weld County were pelted by storms on the 3rd with hail and heavy