Case Study of a Downslope Windstorm
April 23, 1999
Wasatch Range, UT

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ABSTRACT

An easterly downslope windstorm hit the western side of the Wasatch Range on April 23, 1999. The storm was very damaging to three surrounding counties and winds of up to 113 mph were recorded at the Bringham City Airport. Two factors made this such a damaging storm. Vertically propagating mountain waves hit one of three possible critical levels and returned to the surface with intense winds. The other factor was the strong pressure gradient from Riverton, WY to Salt Lake City, UT that enabled gap flow to be forced through breaks in the range.

1. Introduction

Downslope windstorms can be hazardous to the inhabitants on the lee side of a mountain range. These wind storms have winds in excess of 55 knots, or 34 m/s, with the potential to topple trees, blow tops off buildings, and even cause injury or death. They are also very dangerous to aircraft, with the intense wind creating clear air turbulence at flying altitudes.

The downslope windstorm that occurred between 6 and 12z on the western side of the Wasatch Range in Utah on April 23, 1999 brought gusts of up to 113 mph winds, knocking over trees, power lines, and closing down a highway. The 113 mph winds were recorded at Bringham City Airport, and set a new record for low altitude wind speed in Utah. Throughout three counties, residential property damage cost an estimated $3 to $5 million dollars, with the most damage occurring along the Northern Wasatch Front. Bringham City Airport reported toppled planes and damaged hangars. The wind blew semis over on I-15 between Bringham City and Centerville, closing the highway, and Weber State University reported blown out windows and toppled trees. An estimated 10,000 people lost power due to snapped power poles.

Unlike many of the windstorms that are well documented and studied, this particular windstorm is different because the cross-barrier flow comes from the east, not the west. Figure 1 is a picture from an easterly downslope windstorm in the Sierra Nevadas.

Figure 1 Picture of a downslope windstorm

This wind flow pattern is typical for this area and downslope windstorms on the western side of the Wasatch Mountain Range occur from a variety conditions, ranging from purely gap flow winds, to mountain waves, to a combination of both. The strongest winds tend to happen with mountain waves, but there is almost always some contribution from gap flows, as was the case in the April 23 downslope windstorm. This windstorm was a bora wind scenario, as cold air from the northeast was advected over the mountain barrier, displacing a warmer air mass on the western side of the range.

The downslope windstorm on the western side of the Wasatch Mountain Range was a product of strong mountain waves enhanced by a combination of critical levels, including a mountain top inversion, but the reason extreme winds occurred was due to the aid of a strong pressure gradient over the range. This pressure gradient allowed intense gap flows to occur, which in combination with the mountain waves, produced intense winds of up to 113 mph.

2. Data

Data for this case study was obtained from a downslope windstorm case study of the Wasatch Range by Larry Dunn, as well as the damage reports from NOAA. Data for the Colorado Park Range windstorm came from a publication put out by NOAA's National Weather Service Weather Forecast Office. Papers and publications on downslope windstorms and gap flows were obtained from MetEd at UCAR and Gabersek and Durran of the University of Washington, respectively.

3. Synoptic Overview

On April 23, a cutoff low pressure system was situated in the southwestern U.S, just below Utah, as seen in the model data of Figure 2.

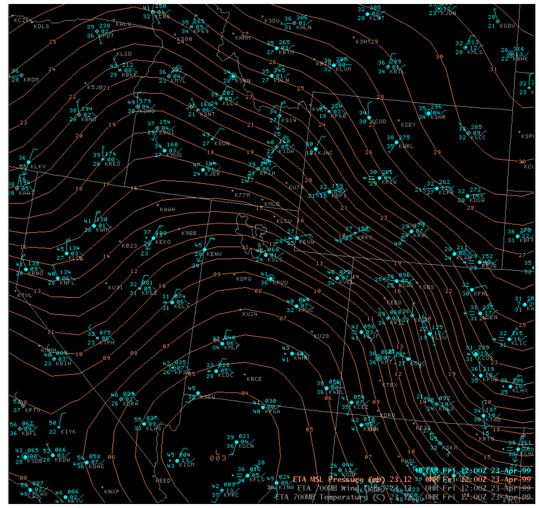

Figure 2 Sea level pressure at 12z 23 Apr 99

A very strong pressure gradient existed in southwestern Wyoming, western Colorado, and into Utah. The cyclonic rotation of the winds from where the low pressure system was located, along with the strong pressure gradient is what caused the easterly cross-barrier winds in northern Utah. Figure 3 shows surface streamlines from 12z on the 23rd.

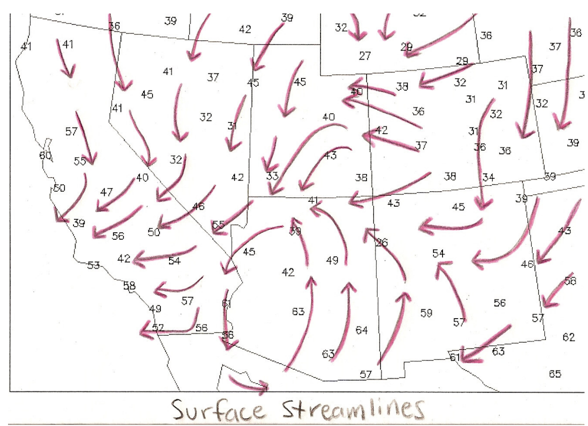

Figure 3 Surface streamlines and temperatures in degree F at 12z 23 Apr 99

Cold air from the northeast, namely Montana, was being advected into northern Utah, replacing a warmer air mass on the western side of the Wasatch Range. All of this was fueled by cyclogenesis in a trough centered over the Great Basin area on the morning of April 22. An upper level jet positioned in the base of this trough helped to turn the trough into a strong, closed low pressure system. As the low pressure system became cut-off, intensified by cyclogensis, the easterly cross-barrier flow at 700 mb strengthened and the cross-barrier sea level pressure difference between Riverton, WY and Salt Lake City, UT was over 19 mb. The importance of the strong pressure gradient will be discussed in the mesoscale analysis.

4. Mesoscale Analysis

As mentioned before, in a downslope windstorm, there is almost always some contribution from gap flow. The contribution from gap flow in this case was enhanced by both the synoptic and mesoscale pressure gradients that were present. The synoptic closed low pressure system with a strong pressure gradient over southwestern Wyoming, as well as the pressure gradient created from blocking of the wind by the topography at low levels created an ideal situation for strong gap flow. Gap flow is sometimes referred to as pressure driven channeling, so as the easterly winds found gaps or channels through the Wasatch Mountain Range, the high pressure on the east side of the range forced the wind through the gaps at high speeds.

The major mesoscale events in this case study were the lee side mountain waves caused by the upslope flow. The atmosphere surrounding the Wasatch Mountain Range was very stable on April 23. When the strong winds from the east went up and over the mountain barrier, the restoring force on the lee side of the mountain was strong, causing buoyancy oscillations. Vertically propagating waves from the upslope flow hit one of several possible critical levels which were at about 650mb-400 mb, sending the waves and all their energy back toward the surface where they amplified the downslope windstorm. The critical level at 500 mb occurred where stable air met less stable above it and the wave were not able to propagate vertically any longer. Figure 4 is the cross section from Lander, WY to Michael, UT which shows the region of less stable air above 500 mb where the isentropes are farther apart.

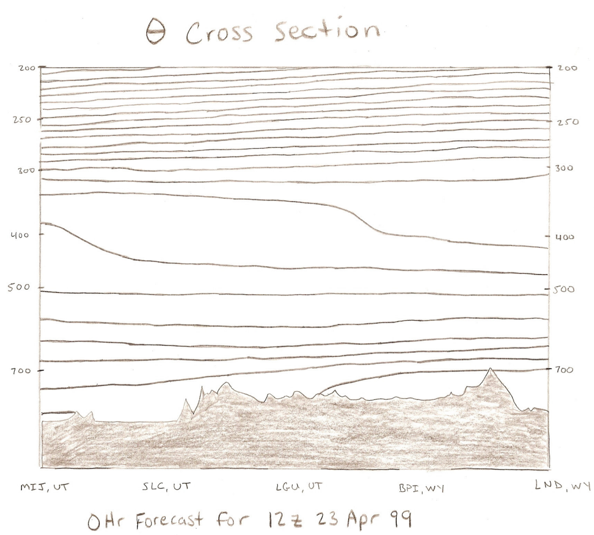

Figure 4 Theta cross section from Eta model data, 0hr forecast for 12z 23 Apr 99

Downslope wind storms are often compared to the flow of water over a rock. The wave-breaking that occurs in whitewater rapids is similar to the wave-breaking process that happens in downslope windstorms. With the breaking of the mountain wave, there is also a possibility that a self-induced critical level was also present. This means that when the mountain wave broke, it created turbulence and a reversal of the wind direction in the atmosphere, which also acted to deflect the energy from the wave back towards the surface. This self-induced critical level can be seen in Figure 5 at about 400 mb on the skew-t diagram taken from Salt Lake City.

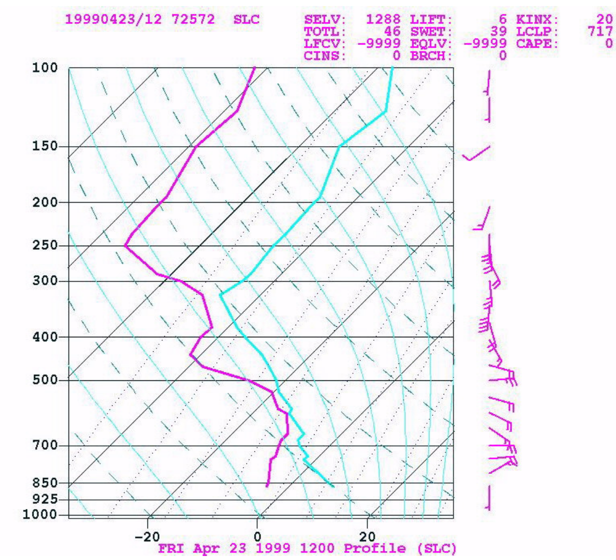

Figure 5 Skew-t from Salt Lake City, UT at 12z 23 Apr 99

Notice the reverse wind shear at this level, with the wind speed dropping to 15 knots.

A slight inversion was present at about 650 mb on the 12z skew-t diagram, Figure 6, from Riverton, WY, which was just above the top of the mountain.

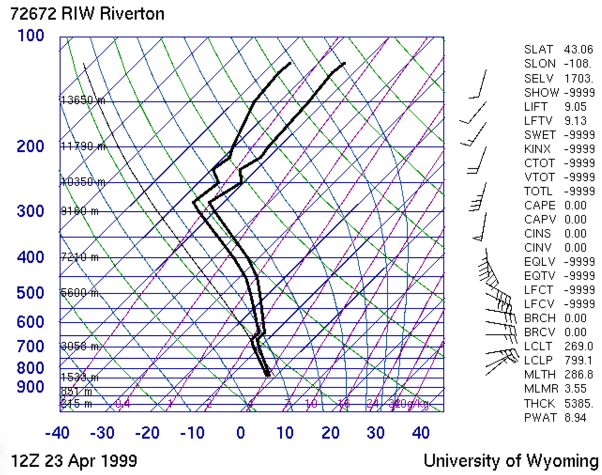

Figure 6 Skew-t from Riverton, WY at 12z 23 Apr 99

An inversion just over the height of the mountain aids in wind flow over the mountain because it too acts as a critical level. Once again there is less stable air above stable air which stops the mountain waves from propagating vertically. Assuming this inversion was present over the whole Wasatch Range, it also acted to accelerate the mountain waves downward towards the surface. The buoyancy oscillations, wave breaking, blocking, and a mountain top inversion are all shown in Figure 7, a conceptual model of a downslope windstorm. The region of strongest wind is also indicated.

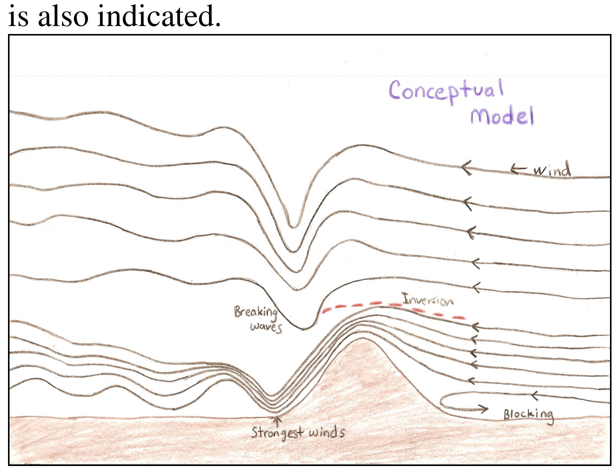

Figure 7 Conceptual model of a downslope windstorm

It is interesting to note that a similar downslope windstorm event happened on the same day in north central Colorado. While it is fairly common to have easterly winds over the Wasatch Range, it is very rare to have easterlies over the Colorado Park Range. The Colorado event happened a few hours earlier than the Utah event, at about 8z, and was affected by the same cut-off low pressure system that caused the easterly winds in Utah. Also similar to the Wasatch Range case, the cross-barrier difference in sea level pressure was 16.8 mb, enabling gap flow to occur, and there was a critical level at about 500 mb where winds changed direction to blow parallel to the ridge. The wind storm produced wind speeds of 89 mph, toppling trees and damaging several homes.

5. Conclusion

One of the most intense downslope windstorms of the decade in Utah occurred on April 23, 1999. With wind gusts of up to 113 mph recorded at the Bringham City Air Port, this windstorm did $3-$5 million dollars worth of residential damage over three counties, as well as additional damage to airports, power lines, and semis. The easterly winds in this case were not so a-typical for this region, but they were very rare for the windstorm that occurred on the western side of the Colorado Park Range that very same day.

The synoptic set-up was the cause of the easterly winds, with a large cut-off low pressure system sitting just to the south of Utah. A very strong pressure gradient from higher pressures in Wyoming towards the lower pressures in Utah also aided in speeding up the winds as they crossed the mountain barrier.

The two main elements that aided in creating this downslope windstorm were the mountain waves created from the upslope flow and the gap flow. The mountain waves that were vertically propagated met with one of three possible critical levels. At about 650 mb, an inversion was present just above the mountain to halt the vertical propagation of the mountain waves and send them back towards the surface. At 500 mb, a layer of stable air met with a layer of generally less stable air, once again not allowing the vertical waves to propagate any further, but enhance the downslope wind. At 400 mb, a reverse shear was present in the winds, indicating a self-induced critical level by the wave breaking in the wind itself. The gap flow in this case was enhanced by a pressure difference of 19 mb between Riverton, WY and Salt Lake City, UT. This pressure difference acted to force the wind through low areas and breaks in the mountain range at high speeds.

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