An Investigation of February 1999 Chinooks

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Abstract: A downslope windstorm event in the Rocky Mountains, referred to as a Chinook occurred in early February of 1999. This paper investigates this Chinook and the high and low pressure systems on the synoptic scale that led to their formation. Cool air pools formed by high-pressure systems to the east and west of the Colorado Rockies led to a mid-level inversion that trapped lee side waves, eventually breaking into winds of more than 100 mph. This also cause a warming to the east in the Denver area and lee cyclogenesis to create a small scale low-pressure system over eastern Colorado.

Introduction

Over the two-day period from February 2-3, 1999 a severe downslope windstorm severely affected a large part of the western part of the United States with major damage occurring in Washington State, Wyoming, and Colorado, and minor power outages and/or damage in western Idaho and eastern Montana. Inversions are either side of the mountains were responsible for inversion formations at mid-levels that led to trapped mountain waves eventually breaking to form downslope wind storms. These windstorms occur all over the world and in the Rockies are given the special name of Chinooks. Chinooks typically occur from December through March due to the strong presence of the jet stream is frequently located directly over the region. A map of Chinook locations in combination with other strong winds found throughout the region is provided in figure 1. Found throughout the Rocky Mountains Chinooks are made of warm, westerly winds, as opposed to the East Winds, North Winds, Wasatch Winds and the Santa Ana Winds, each associated with unique wind directions, locations and temperatures.

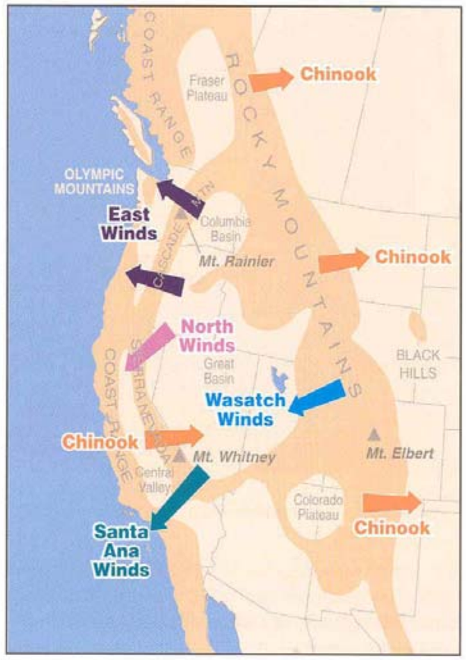

Figure 1: Typical regions affected by downslope windstorms, including Chinooks. Image Source: Jonathan Vigh.

Casualties were solely made up of a litter of puppies who perished in a house fire located in Toppenish, Washington as the "wind blew papers against a heat lamp that was keeping the puppies warm of the back porch of the house," (CNN.com). The storm moved from the Pacific Northwest into the Rocky Mountains bringing down trees power lines and roof materials with wind gusts were reported to have reached over 100 mph at various locations in the Rockies.

Washington State

Sustaining the most damage, Washington State recorded a wind gust of 73 mph at Otis Orchards just east of Spokane. Other gust reports around the state included 53 mph at Spokane International Airport, the highest ever recorded for that location, and 63 mph in downtown Spokane (National Weather Service).

Otis Orchards……………………..73 mph
Spokane International Airport……53 mph
Downtown Spokane………………63 mph

Avalanche control included the closing of U.S. 2 through Stevens Pass and ski resorts were shut down due to the high winds. Thousands of homes in Northwest Washington were without power due to fallen trees; as much as 60,000 home at one point reported by Puget Sound Energy as the high volt transmission line was knocked down (CNN.com).

Wyoming

Far less power outage occurred in Oregon as some trees fell due to the winds in Cheyenne. Wind gusts included a 93 mph report northwest of Rawlins and 71 mph at the Cheyenne Airport (National Weather Service). Sixty miles of Interstate 80 was closed for a period spanning both February 2 and 3 because of blowing snow. Despite the closures, dozens of trailers were blown over along Interstates 80 and 25 (CNN.com).

NW of Rawlins…………………...93 mph
Cheyenne Airport…………………71 mph

Colorado

The strongest gust reported for the state of Colorado was 119 mph at Wondervu, southwest of Boulder, and gusts of 100 to 103 mph were recorded at Longmont, Blue Mountain, and Rocky Flats (National Weather Service, UCAR).

Wondervu……………….………119 mph
Carter Lake………………...…….107 mph
Rocky Flats…………………...….103 mph
Blue Mountain…….….…………100 mph
Longmont…………….……...……100 mph
CU/Boulder…...…….….…………98 mph
Gunbarrel……...…………………80 mph
Broomfield………...……………...80 mph

Second only to the damage in Washington State, damage for Colorado in and around the Boulder area, reported by the Boulder County Sheriff's Office, included roofs blown off homes, windshields blown out of cars, and trees and power lines knocked down (CNN.com). There were large areas of power losses especially in the western suburbs of Denver. Although the National Center for Atmospheric Research (NCAR) lost its power the battery back up of the automated sensor recorded a four-second average of 93 mph just after 11:30 pm local time, 0630 UTC. This is shown in figure 2 with a meteogram of wind speed and gusts. The peak seen just past 11:30 local time is the 93 mph gust and is the largest recorded for that location throughout the storm. Damage along the front range of the Rockies totaled approximately three million dollars.

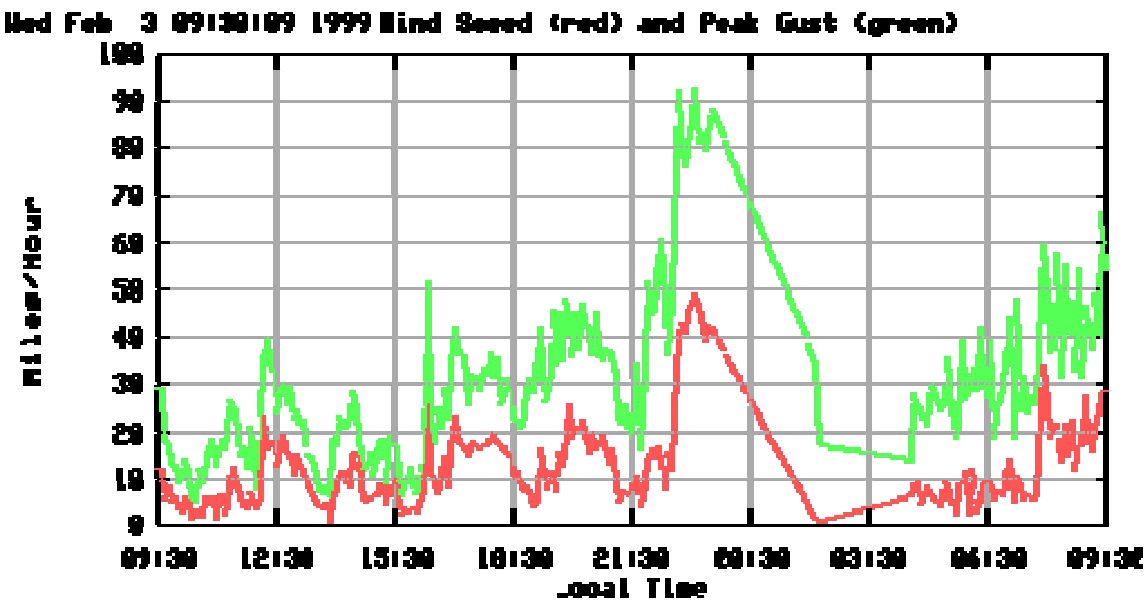

Figure 2: Meteor gram of wind speed and gust speed for the NCAR facility in Boulder, Colorado.

The focus of this paper will be on the downslope windstorm in Boulder County, Colorado, although similar diagnoses may be applied to Washington State as well as Wyoming.

Data

Many sources were used to compile the data needed for this analysis of the February 2-3, 1999 downslope windstorm event in the Rocky Mountains. All map backgrounds and upper air data that are not specifically cited as originating from another source were created using GARP program under the influence of the UW-NMS model. Unysis data was used for surface and upper air maps as individually noted. Soundings were gathered from the University of Wyoming website. Facts on wind totals and damage reports were taken from the National Weather Service and CNN.com, respectively. Individuals giving advice and/or guidance throughout the paper are cited in the section entitled "References and Acknowledgments."

Synoptic Overview

The storms that had formed over the Pacific Northwest and along the west coast of the United States was brought inland by the jet stream leading to the windstorms. These storms were associated with a low-pressure system that moved from west of British Columbia at 12Z on February 2 to north of Montana by 00Z February 3 (figure 3). Also noted is the strong jet that entered the United States in Washington State off the Pacific and extended south west to northern Wyoming and southern Montana by 00Z February 3 (figure 4).

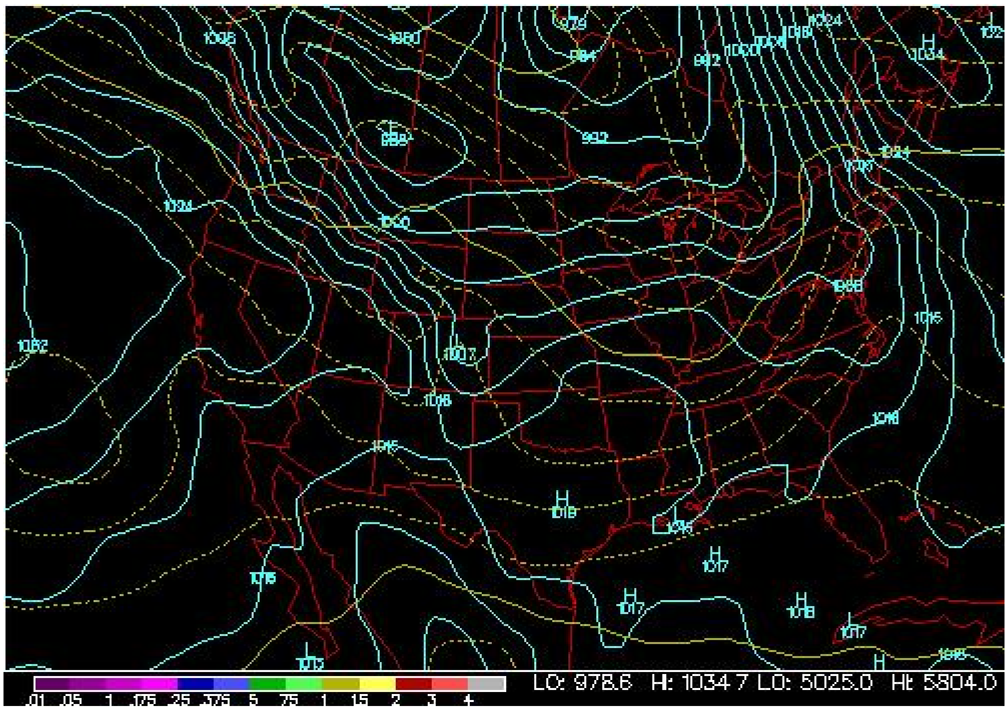

Figure 3: Surface isobars (blue) showing low pressure systems to the north of the Rockies and High pressure to the west and east. Image source: Unisys.

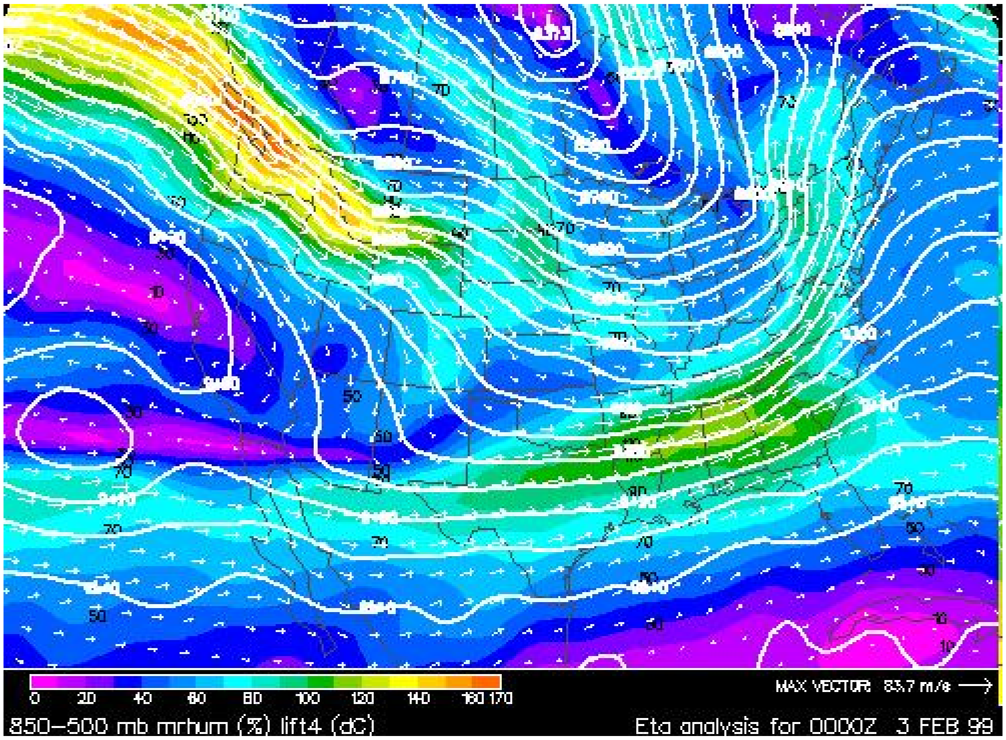

Figure 4: 300 mb heights and wind speed/direction showing jet position. Image source: Unisys.

A high-pressure system followed the storms just east of California. The isobars between the two systems, over Washington, Oregon, Idaho and Wyoming were closely packed at all pressure levels indicating strong wind speeds with northwesterly flow. The jet max was approximately 84 m/s or close to 170 mph over northwestern Washington State at this time. The pressure difference from 1024 mb on the western side of the mountains to 1007 mb on the lee side of the mountains leads to gap flow as the high pressure forces air through the mountain passes, enhancing the windstorm on the lee side.

There is also a small low-pressure system in eastern Colorado that will be further explained in the mesoscale discussion. Collocated with this small low is a warm temperature anomaly that will also be discussed further in the next section.

Mesoscale Discussion

Streamlined winds, shown in figure 5, are representative of the typical situation favorable to Chinooks. These winds are westerly, described above in the Introduction as a quality of Chinooks.

Also seen by analyzing these streamlines is the cyclonic curvature associated with the now Canadian low-pressure system to the north of the Rockies and anticyclonic curvature off to the west of the Rockies as there is high pressure located there as noted above (figure 3).

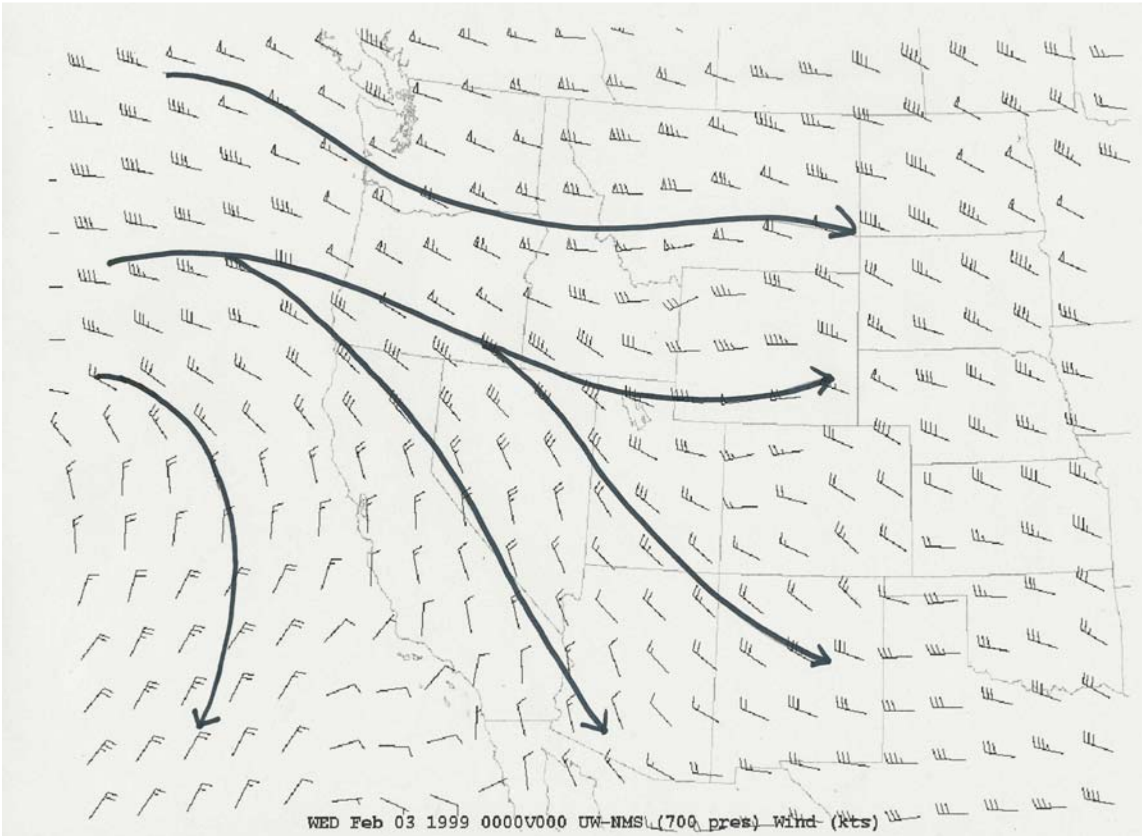

Figure 5: Streamlines depicting westerly flow of Chinooks.

The winds flowing down the mountain slope creates a dip in the isentropic surfaces along the lee side of the mountain range (figure 6a). Max winds associated with this are also located on the lee side of the mountain where the max horizontal gradient in theta is found, shown here as 55 m/s, or 110 mph in figure 6b.

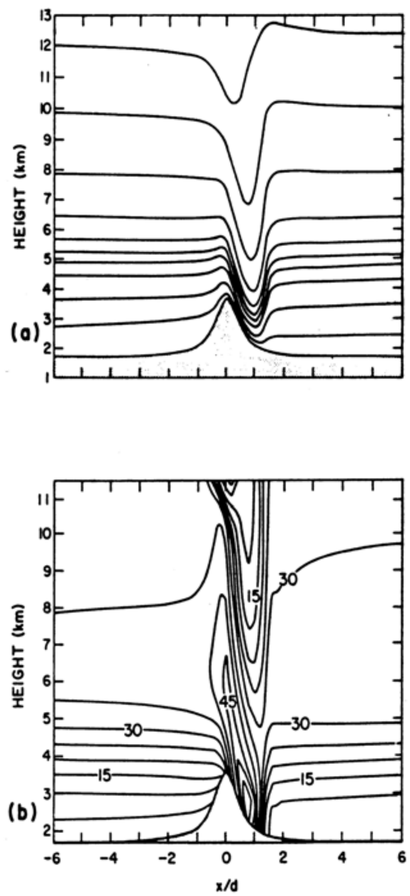

Fig. 12.10. Numerical simulation of 11 January 1972 case. (a) Displacement of potential temperature surfaces; (b) contours of west wind component (m s^{-1}). Maximum surface velocity lee of the mountain is 55 m s^{-1}. [From Klemp and Lilly (1978).]

Figure 6: a. Potential temperature contours. **b.** Wind speed contours. Image source: Greg Tripoli.

There is a mid level inversion to both the east and west of the Colorado Rockies, seen in the soundings below (figures 7 & 8) at approximately 600-700 mb. Cool pools of air to the west and east create this with a high-pressure system on each side of the Colorado Rockies. These highs are seen in figure 3.

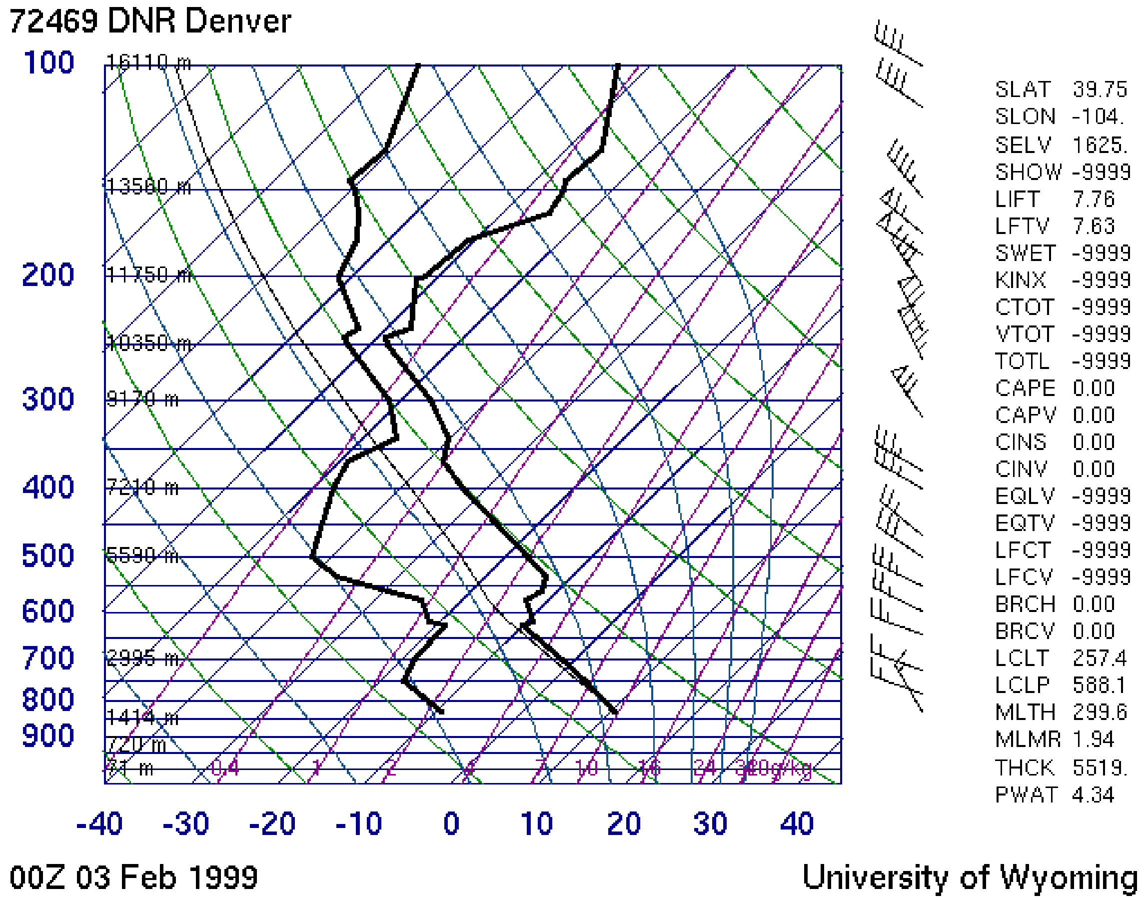

Figure 7: Vertical profile of temperature and dew point in Denver, Colorado. Image source: Univeristy of Wyoming.

The Denver sounding (figure 7) shows an inversion at approximately 625 mb. This inversion traps the waves until they break, creating the severe damaging winds. The Grand Junction/Walker sounding (figure 8) shows the inversion at 700 mb. This inversion forms the critical level and traps wave energy below and allows the amplification to take place until that wave breaks. This is the cause of the downslope wind storms; the breaking waves. The inversions on either side of the mountain range can also be seen in a cross section of temperature (in degrees Celcius, figure 9) taken perpendicular to the mountain ridge.

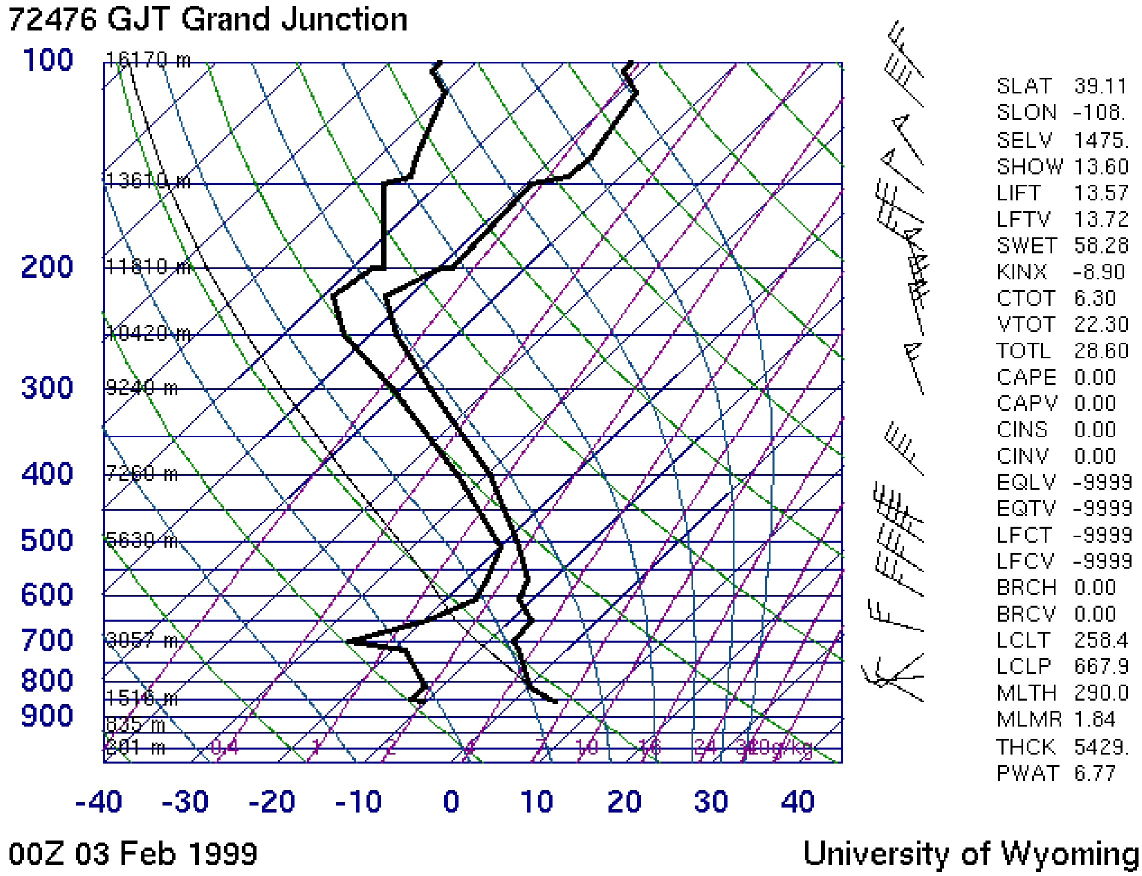

Figure 8: Vertical profile of temperature and dew point in Grand Junction/Walker, Colorado. Image source: Univeristy of Wyoming.

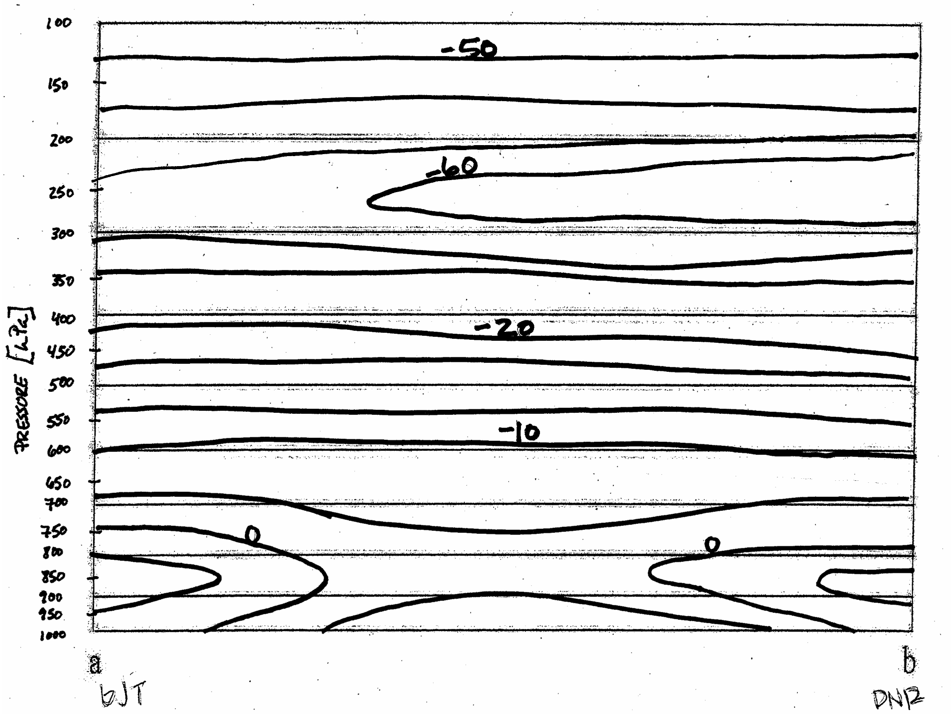

Figure 9: Cross Section of Temperature (degrees Celcius) Grand Junction/Walker to Denver, Colorado. Data compiled from UW-NMS.

The small low-pressure system in eastern Colorado is a result of lee cyclogenesis resulting from the waves produced from the broad mountain range. Waves are created from the constant adaptation of the streamlines to the pressure level including over and undershoots. This is modeled conceptually in figure 10 in which the streamlined winds attempt to reach the pressure level by rising or sinking but over and undershoots this pressure level creating a wave on the lee side of the mountain. This is extended to higher and lower levels.

This eastern part of Colorado is also affected by a warm temperature anomaly. Seen in figure 11, these warmer temperatures come from the sinking Chinooks on the lee side of the Rockies. The air is allowed to warm either adiabatically or through latent heat release. A maximum of 9.8 degrees Celcius per km is possible through each of these warming techniques.

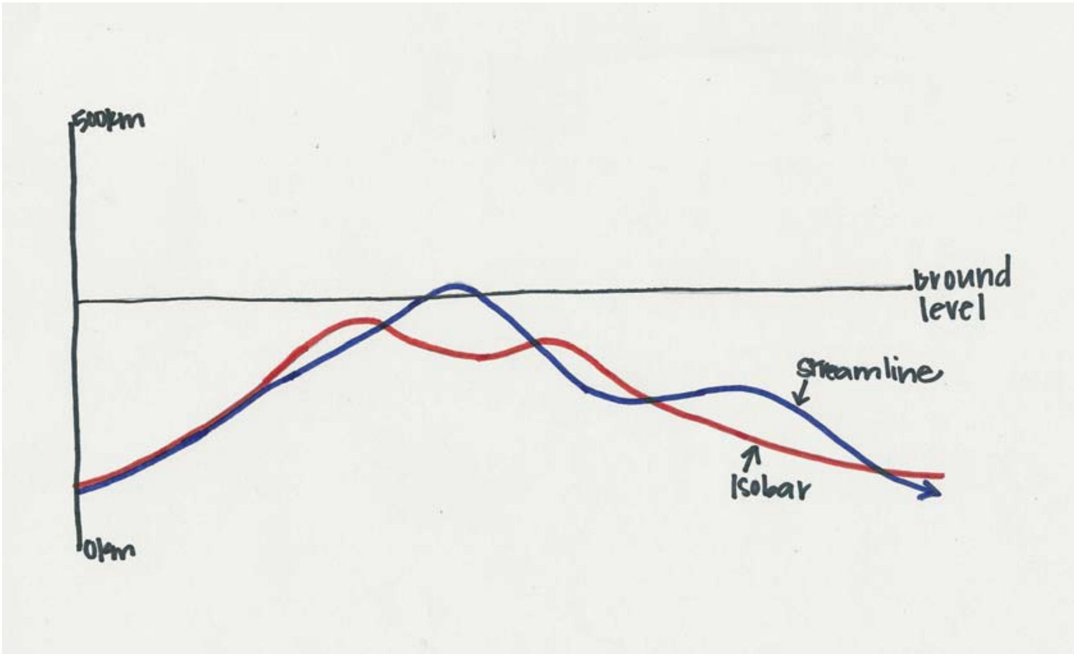

Figure 10: Conceptual model of streamlined flow adjusting to pressure creating waves. Image adapted from figure used by Greg Tripoli.

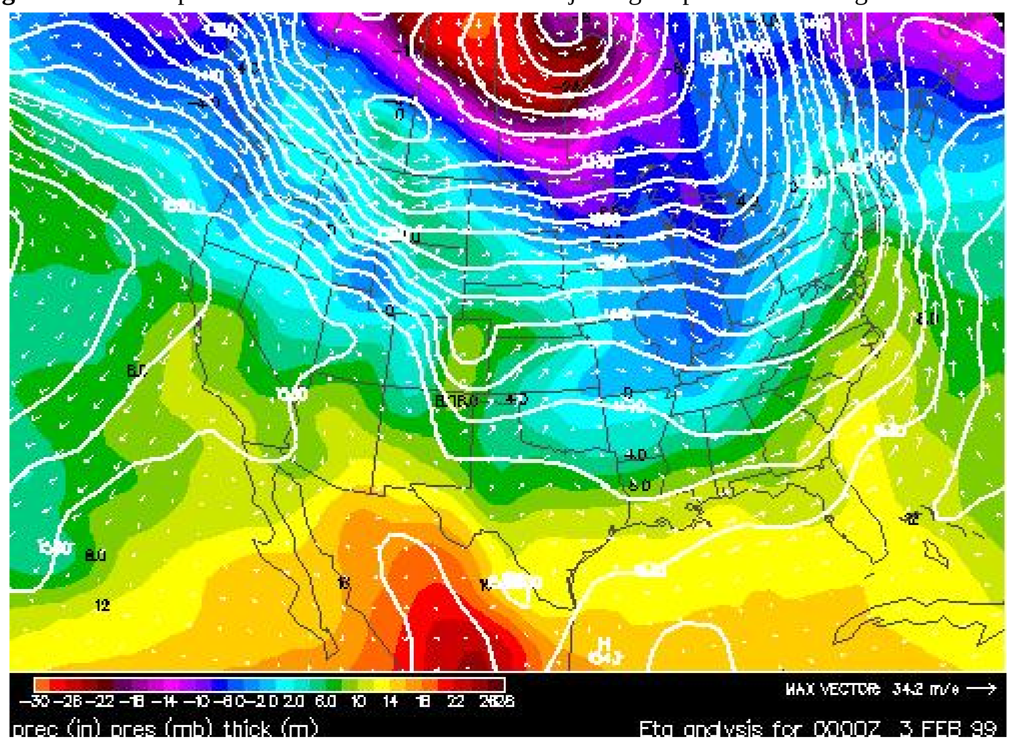

Figure 11: 850 mb temperatures depicting the warm air anomaly in eastern Colorado. Image source: Unysis.

Conclusion

The downslope windstorms affecting the Rocky Mountain region were associated with the jet stream located right over the region, leading to strong winds aloft. High pressure to the east and west of the Colorado Rockies led to cool pools and mid-level inversions. It was these inversions that trapped lee side mountain waves to the point where they broke to create the 100+ mph downslope windstorm event in Boulder County Colorado. The warm anomaly and small scale low-pressure system located in eastern Colorado was a direct result of lee cyclogenesis formed form these waves.

References and Acknowledgments

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