P1.5 UNIQUE SNOWFALL DISTRIBUTION OVER THE PARK RANGE AND UPPER YAMPA RIVER VALLEY DURING THE LA NIÑA WINTER OF 2007-2008

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1. Introduction

Mountain snowfall forecasting has long been an extreme challenge for forecasters across the globe. These challenges are brought about by the interaction of complex terrain and large scale atmospheric circulations, which tend to perturb large-scale flow patterns through mountainous terrain. The state of Colorado (Figure 1) located in the western United States is home to some of the most diverse topography in the country and will be the focus area for this study.

The 2007-08 winter season brought record snowfall to portions of Colorado (Figure 2), including locations in and around the Park Range near Steamboat Springs, Colorado. While heavy snowfall is common for this portion of Colorado, the pattern in which it fell was unusual in that the mid-mountain and valley locations reported record snowfall accumulations, whereas the higher peaks received amounts closer to seasonal average (Figure 2).

Climate forecasts of a moderate La Niña Event by the Climate Prediction Center (CPC) further supported the idea that heavy snow would be possible across the northern mountains of western Colorado based on previous in-house studies at the Weather Forecast Office (WFO) Grand Junction, Colorado. Typical impacts on western Colorado during a La Niña winter include below normal snowfall across the southwest portions of Colorado with normal to above normal snowfall for the northern mountains of western Colorado.

Three reporting sites were examined across a tight geographical region from the town of Steamboat Springs, to the mid-mountain reporting station at the Steamboat Springs ski area, to a remote sensor located near Buffalo Pass in the Park Range, more commonly referred to as the Tower SNOTEL (Figure 3).

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Figure 1. State of Colorado highlighted from a World View map. Taken from Google Earth[(@)].

After taking a closer look into possible reasons for the abnormally high snowfall across the town of Steamboat Springs and reporting site, it appears that several factors could have come into play to generate the spatial disparity in precipitation. Processes that may have been at least partially responsible for the record snowfall at the lower elevation sites including periods of cold air damming, seeder-feeder processes, orographics and influences from El Niño-Southern Oscillation (ENSO).

2. Site Locations and Topography

The locations of this study lie from the upper end of the Yampa River Valley in north-central Colorado east into the Park Range (Figures 3, 4 and 5). Actual locations that the study will focus on include the cooperative weather observer of Steamboat Springs, Colorado, the mid-mountain reporting station at the Steamboat Springs ski area, and the TOWER SNOTEL site. These three locations are located within 13 kilometers of each other and separated by 1150 vertical meters in elevation.

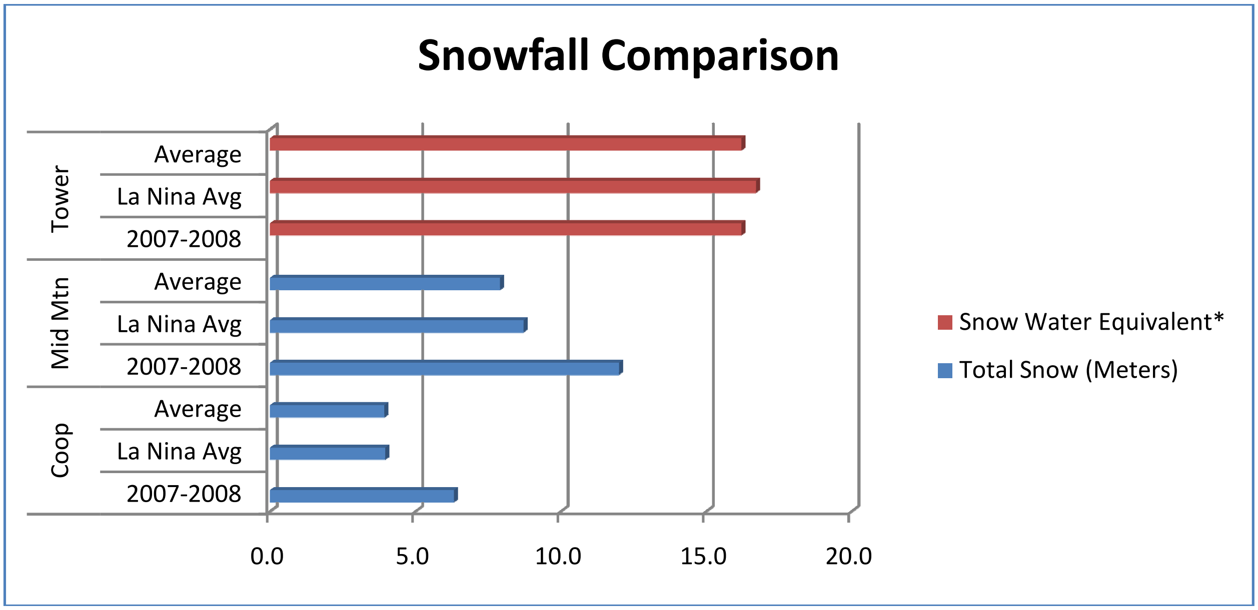


Figure 2: Graph of snowfall in meters comparing the 2007-08 winter to an average winter and to that of a typical La Niña Winter. *Note: The Tower SNOTEL data was coverted from snow water equivalent (SWE) using a 14:1 ratio (Judson and Doesken 2000)

The Park Range is aligned in a north to south orientation with a slight northwest curve near the Colorado and Wyoming state lines. The orientation of these mountains makes them favorable for significant orographic precipitation events, especially in westerly flow patterns.

The cooperative weather observing site in Steamboat Springs is located near an elevation of 2040 meters. This particular location has been taking observations since 2004.

The Steamboat Springs ski area takes and reports snowfall measurements at a mid-mountain site located at 2765 meters. Observations from this site have been ongoing for over 25 years.

The third and final location is what is referred to as a SNOTEL (for SNOwpack TELemetry) site. This SNOTEL site is part of the Natural Resources Conservation Service (NRCS), who are responsible for installing, operating, and maintaining the extensive, automated system. The SNOTEL's are used to collect snowpack and related climatic data in the western United States. More information of SNOTEL's can be found on the NRCS Website at: http://www.wcc.nrcs.usda.gov/factpub/sntlfct1.html

This study focuses on the Tower SNOTEL site which is located at 3200 meters near the top of the Park Range east of Steamboat Springs, Colorado. This site routinely records some of the highest snowfall totals for the entire state of Colorado.

Figure 3. Photograph depicting area of focus for this study. Location S denotes the town of Steamboat Springs, Colorado, M is the approximate location of the mid-mountain snow measurements at the Steamboat Springs Ski Area, and T is near the Tower SNOTEL site.

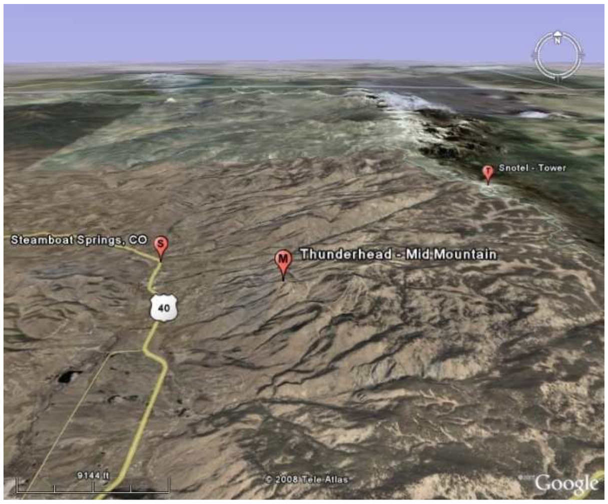


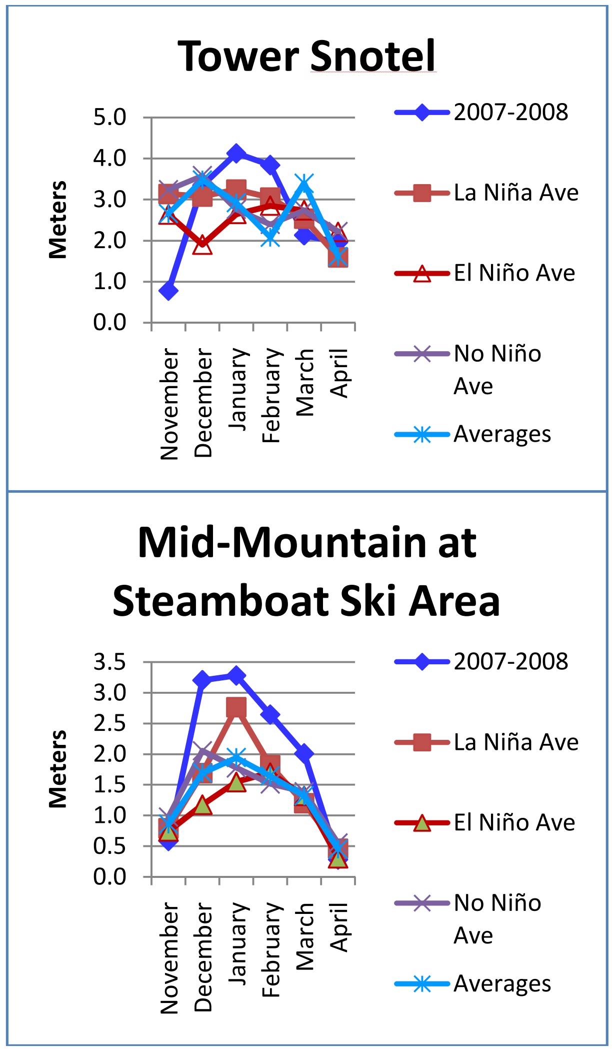
Figure 4 (top) is an aerial view looking north taken from Google Earth. Labels correspond to labeling in Figure 1. Figure 5 (bottom) looks east and displays the topography and spatial distribution of the sites. Image was taken from Google Earth(@).

3. Preliminary Results

3.1 La Niña Impacts

A typical La Niña impact on this region results in heavier snowfall near mountain ridges based on previous in-house studies. However, the 2007-08 La Niña pattern remained progressive late into the winter months, resulting in the failure of our "normal" dry ridging pattern in the months of January and February. Possible explanations for the failure of the ridge to form include a disruption of the low-level wind fields over the equatorial pacific due to activity associated with the Madden-Julian Oscillation (MJO). This disruption in the wind fields may have played a vital role in the failure of the dry ridge to develop, thus leading to a more progressive and active pattern across the Colorado Rockies.

Actual climatic comparisons of the sites showed that the Tower SNOTEL experienced average snowfall when compared to previous seasons and previous La Niña episodes. However, the mid-mountain and valley sites both reported record snowfall which started off strong in December 2007 and continued through March 2008 (Figures 6, 7 and 8).



Figures 6 & 7: Graphs represent seasonal snowfall in meters under different climate regimes for the Tower SNOTEL and mid-mountain reporting sites.

3.2 Cold Air Damming

Stable, low-level westerly flow was present for a number of the winter events that impacted the Park Range during the 2007-08 winter season (archived model data and personal observance). This stable flow was blocked by the north to south oriented mountain range, resulting in a deceleration of the wind field.

Strong surface-based inversions were present on a number of days with cold air trapped in the valleys. Observational data from the cooperative weather observer in Steamboat Springs showed daytime maximum temperatures running well below seasonal averages and even below the typically cooler La Niña averages when compared to past La Niña events (Figure 9).

Throughout the course of the winter season, moist Pacific storms continually overran this cold trapped air, resulting in optimal conditions for the generation of persistent precipitation events.

3.3 Seeder Feeder and Orographic Processes

Stable, ascending air motion into the Park Range often produces orographically generated clouds, especially near the Desert Research Institutes Storm Peak Laboratory (SPL), which is a high altitude atmospheric physics lab located near the summit of Mt. Werner (~3210m MSL) near Steamboat Springs, Colorado (Borys and Wetzel, 1997). The orographic clouds extended further down the mountain, encompassing much of the Steamboat Springs ski area during the 2007-08 winter season. This low stratus field was, at times, fed by hydrometeors associated with higher seeder clouds aloft resulting in ample riming of cloud droplets in the lowest 2km (Saleeby et al., 2006; Rauber et al., 1986; Reinking et al., 2000). The low level riming enhanced the precipitation resulting in more efficient production of snowfall at the mid-mountain site and into the town of Steamboat Springs itself.

The enhanced riming increases the mass of the snow crystals as well as the fall speed and increases the likelihood of higher snow accumulations along the windward slopes (Hindman, 1986).

In addition, the blocking pattern likely resulted in a shift in the heavier orographic precipitation upwind of the Park Range, focusing heavier snowfall across the lower elevations.

It is noted that purely orographic clouds can often seed themselves (Colle and Zeng, 2004). And Roe (2005) argues "there is not a clear distinction

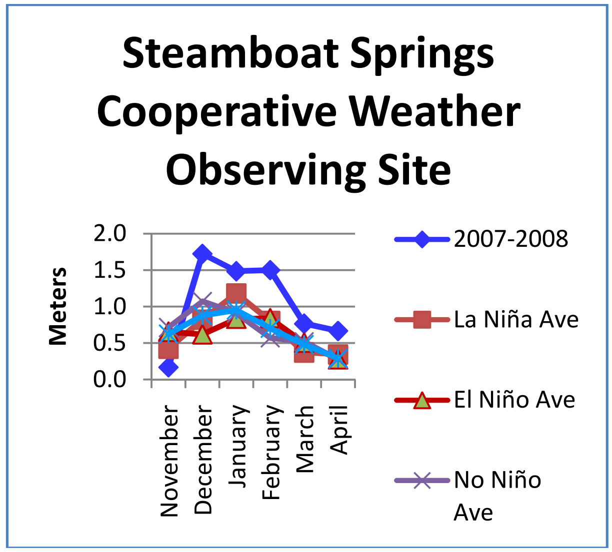


Figure 8: Graph represents seasonal snowfall in meters under different climate regimes for the Steamboat Springs cooperative weather observing site.

between upslope ascent and seeder-feeder, and the differences are perhaps somewhat semantic."

However, the mechanisms associated with cold air damming and the persistent winter pattern that allowed a constant stream of moist Pacific storms to pass through the region offer an explanation for the heavier snowfall based on seasonal averages for the lower elevation sites.

4. Conclusions

This study will be continued into the winter season of 2008-09 and likely beyond as we build a stronger case history. Although La Niña conditions are not expected at this time based on the latest forecast from the Climate Prediction Center, a baseline needs to be established. A more robust look at the impacts of cold air damming, orographics and the seeder-feeder process impacting the mid-mountain and lower valley sites in and around the Steamboat Springs area will be closely examined.

Additional data expansion and spatial separation will also be introduced to determine a more defined impact region. It is expected that with a few more years of research, we will be able to build tools that will allow the operational forecasters to predict with greater accuracy the probability of seasonal winter forecasts.

Even with the guidance provided by the Climate Prediction Center, it remains important for the

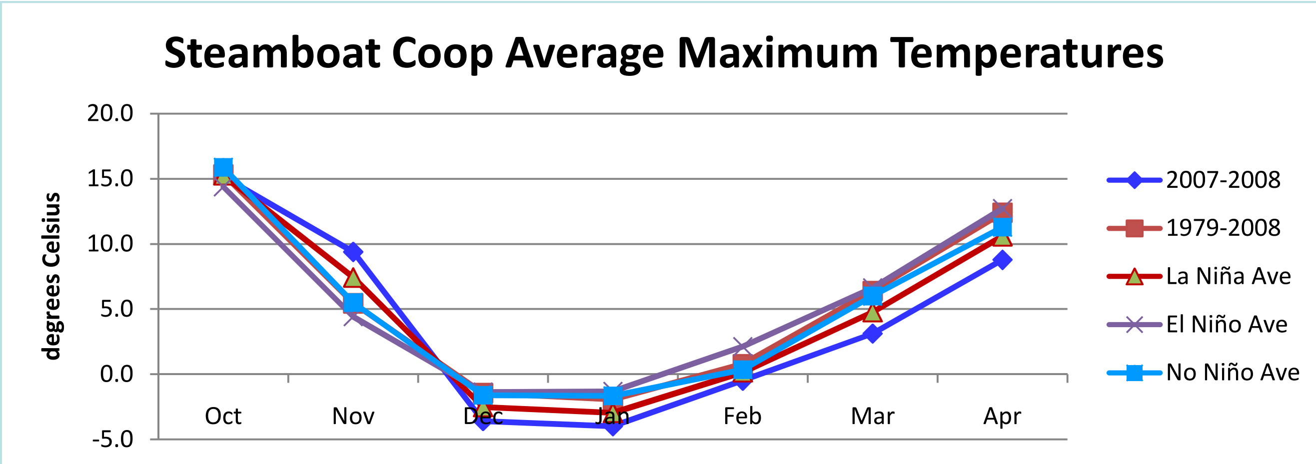


Figure 9: Graph of Maximum Temperature in degrees Celsius for the Steamboat Springs cooperative weather observing site during different climate regimes. Note the colder than normal 2007-2008 winter.

local forecasters to have a strong understanding on seasonal impacts on their local area.

6. Acknowledgements

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