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COLD AIR DAMMING IMPACTS ON SNOWFALL DISTRIBUTION ALONG THE EASTERN WIND RIVER MOUNTAINS

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1. INTRODUCTION

The eastern slope of the Wind River Range in central Wyoming is a favored location for upslope snow with northeast low-level flow that develops in the wake of cold frontal passages. Snowfall in the adjacent Wind River Basin and lower foothills shows a marked increase in amounts from Riverton to Lander. Local forecasters are adept at adjusting snowfall forecasts to account for this increase across the basin and into the adjacent east slopes of the mountain range. More interesting, however, are those snow events where locations in the lower foothills around Lander receive snowfall exceeding that of mountain sites. In these events, other basin locations experience snowfall totals that top one-third of their annual average. It is theorized that cold air damming occurs in the Wind River Basin and ultimately serves to generate higher snowfall totals than what might be anticipated in a pure upslope event. Two cases were examined and compared to better evaluate the idea that cold air damming could essentially modify the basin terrain and enhance snowfall.

2. OROGRAPHY OF CENTRAL WYOMING

The Wind River Basin is located in central Wyoming (Fig. 1) with elevation ranging from 1400m to 1850m MSL (all heights hereafter MSL unless otherwise noted). Prominent mountain ranges surrounding the basin include, the Wind River Range (3500-4000m), the Absaroka Mountains (3350-3650m), and the Owl Creek Mountains (2100-2450m). Other features that complete the envelopment of the basin are Beaver Rim (2250m) and Hiland Ridge (1900m). At the southeast extent of the Wind River Range lies another noteworthy feature, South Pass (2250m), which figured prominently as the best route across the Rocky Mountains during the overland migration of the mid-19th century.

Upslope snowfall is a common occurrence in the basin as surface cold fronts sweep south through the basin leaving behind low-level north to northeast flow. This flow direction is nearly orthogonal to the Wind River Range, which favors enhanced snowfall in the range and along the foothills. In fact, 30-year seasonal snowfall averages at Lander (KLND, 1630m) and Riverton (KRIW, 1525m) are about 250cm and 75cm, respectively. Separated by approximately 21 air miles and 100m of elevation, the location of Lander near the range and the impact of upslope snow is notable. Most often, typical cold frontal passage associated with an Alberta Clipper-like system, will generate increasing snowfall from north-to-south across the basin and into the Wind River Range, with the highest snow totals occurring in the higher mountainous terrain.

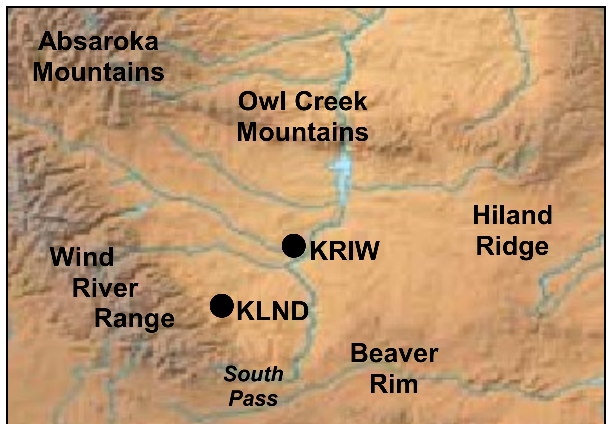

Fig. 1. *The Wind River Basin and surrounding mountainous terrain of central Wyoming. Lander and Riverton are denoted by KLND and KRIW, respectively, and are located within the basin.*

3. COLD AIR DAMMING

Cold air damming has been notably studied along the eastern slope of the Appalachian Mountains (Richwien 1980, Bell and Bosart 1988) and the Colorado Front Range (Dunn 1987). The cold air damming scenario described in these studies included an intrusion of stable, low-level cold air from the north along the east slopes of the higher terrain. Above this shallow layer of cold air lays a strong inversion with warmer air being transported from the east or southeast above the cold dome. The east or southeast flow effectively dams the cold air along the mountain barrier, providing additional lift

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within this narrow zone leading to increased precipitation amounts or a change in phase of the precipitation (i.e. rain to snow).

4. WIND RIVER BASIN COLD AIR DAMMING

The damming of cold air that occurs in the Wind River Basin is different in several ways from that described in classic literature. First, the typical cold pool depth of 1-1.5 km AGL is much deeper and less stable in the Wind River Basin case. The basin acts as a bowl where cold air spills into and fills, different from the coastal plain east of the Appalachians or the sloping plains of Colorado. Lower inversions in the basin are typically noted with arctic high pressure in the absence of cyclogenesis. Next, overrunning flow from the east or southeast is rare and would not be perpendicular to the blocking terrain feature, the northwest-southeast oriented Wind River Range. Therefore, the overrunning upper-level flow (above about 600hPa) for Wind River Basin cold air damming is generally from the south or southwest (Fig. 2). This favorable flow regime occurs in advance of a trough or closed low to the southwest of Wyoming.

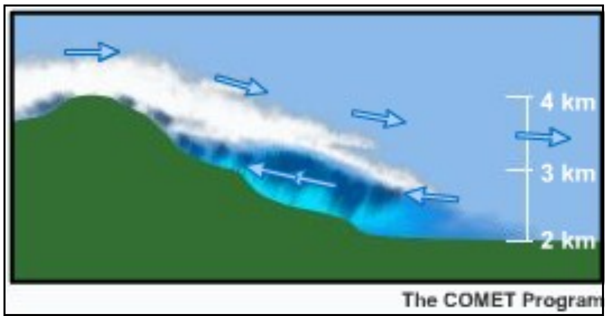

Fig. 2. *Schematic of cold air damming occurring with overrunning upper level flow from the opposing direction. In the Wind River Basin, low level flow in the shaded blue area is from the northeast with upper level flow from the south or southwest. (Courtesy of The COMET Program)*

Evidence of the cold air accumulating along the east slopes of the barrier can be seen in the automated surface observations at Lander and Riverton during a damming event. Frequently, north to northeast surface flow of 8-15 ms^{-1} at Riverton will decelerate to less and 3 ms^{-1} and in many cases be calm. This deceleration occurs as the low-level flow is unable to rise and cross the barrier.

5. CASE STUDY COMPARISON

Two October cold air damming episodes (2003 and 2008) were examined and compared to evaluate synoptic scale flow, thermodynamic, and snowfall similarities. By identifying similarities, local forecasters could thereby adjust snowfall forecasts to account for higher amounts away from the typically upslope-favored locations.

Synoptically, in both cases, a surface cold front moved south along and east of the Continental Divide (not shown) providing the necessary cold air for damming to occur. Following frontal passage, surface observations at both KRIW and KLND indicated north to northeast wind, the favored upslope direction. At 500 hPa, south or southwest flow provided the requisite overrunning flow (Fig. 3), albeit with a closed low

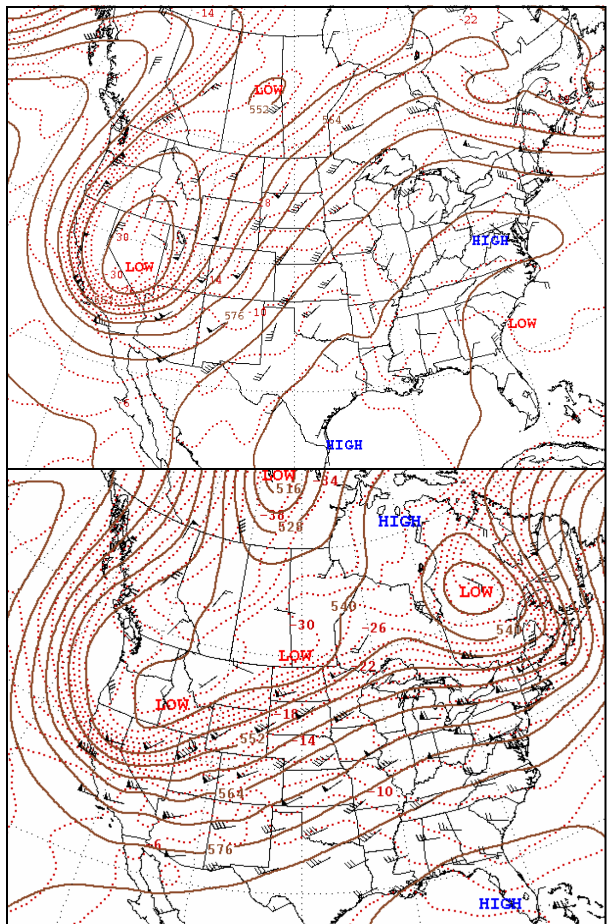

Fig. 3. *500 hPa height, temperature, and wind for 1200 UTC 11 October 2008 (top) and 1200 UTC 30 October 2003 (bottom). Cold air damming and heavy snowfall was underway by this time in both instances.*

in one case and an open wave in the other. This fact may further demonstrate that while dynamics can certainly play a role in enhancing snowfall, the predominant factor is likely the overrunning of the dammed cold air region.

Thermodynamic (Skew-T) profiles of these two cases (Fig. 4) clearly showed the dammed region below a mountain-crest level inversion (around 650hPa) with strong overrunning above this level. Unlike cold air damming described in classic literature, the inversion in the Wind River Basin cases is much higher and the layer below better mixed. The well-mixed boundary layer is consistent with the thought that the basin, like a sink, fills with cold air through the depth of the basin, rather than a shallow surface layer.

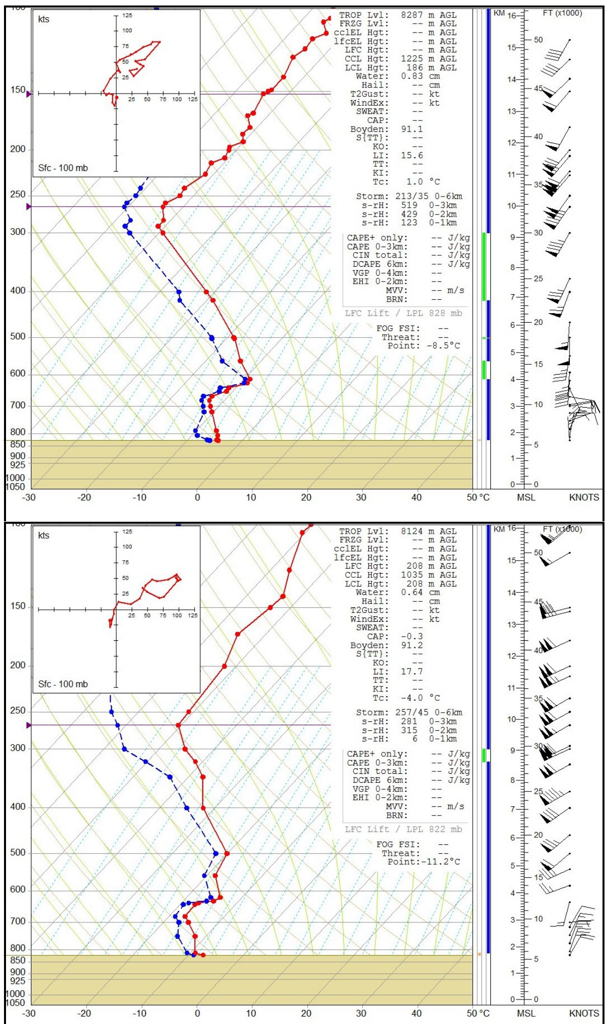

Fig. 4. *KRIW Skew-T plot from 1200 UTC 11 October 2008 (top) and 1200 UTC 30 October 2003 (bottom). Note inversion around 650 hPa in both plots and overall similarities between these two mid-storm soundings.*

The dammed cold air in these examples essentially served to modify the terrain in the Wind River Basin. In doing so, the overrunning south to southwest flow above 600 hPa was able to generate heavier precipitation away from the mountain slopes and over the interior of the basin. In the October 2008 case, interior locations measured snowfall of 30cm to nearly 50cm. The average was around 40% of the annual snowfall in these locations. Snowfall amounts within the dammed region around Lander were 30-50% greater than what was measured and estimated in the mountains. Total snowfall in Lander and the immediate foothills ranged from about 55cm to 75cm. During the October 2003 event, snowfall in the basin interior was 25cm to 30cm. Similar to the 2008 event, a 2:1 ratio was found in the amounts measured at KLND and KRIW.

6. POSSIBLE BARRIER JET EXISTENCE

Whiteman (2000) described how a barrier with an edge or low pass on its left side, relative to the low-level wind flow, can be suitable for the formation of a barrier jet. As the low-level flow approaches the barrier, it turns left and blows parallel to the mountain range. This is exactly the set-up in the cold air damming situation along the east slopes of the Wind River Range. South Pass provides the low pass to the left of the range when the low-level flow is north to northeast, which is common to the Wind River Basin cold air damming scenario.

As discussed in section 4, observations from KRIW and KLND indicate the low-level north to northeast wind decelerates over time as it nears the barrier. Parish (1982) described how this deceleration can lead to damming of the cold air and eventually the development of a barrier jet. With these considerations along with the set-up of local topographic features, it can be theorized that the development of a barrier jet could occur along the east slopes of the Wind River Range. However, sampling this feature would be difficult since the orientation of the jet would be orthogonal to the beam of the KRIW WSR-88D radar.

Some of the heaviest snowfall observed in the cold air damming cases often occurs on the low benches and in Sinks Canyon southwest of Lander. Besides the dynamic impacts of cold air damming, it has been theorized by local and regional meteorologists that a barrier jet could also be responsible for enhancing snowfall in this region. If it does, the protruding Table Mountain (Fig. 5) could play a role in snowfall enhancement by creating a localized upslope region around Sinks Canyon. Preliminary research of a 2003 blizzard along the Colorado Front Range shows that a localized maxima and minima of snowfall can occur in the upslope and downslope regions relative to small-scale features like that of Table Mountain. Similarly, Nieman et al. (2010) noted enhanced precipitation along a localized bend in the northern Sierra Nevada due to the west-east oriented sierra barrier jet.

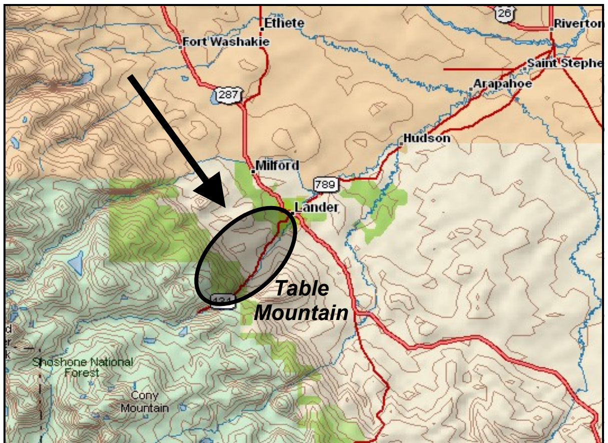

Fig. 5. *Area of enhanced snowfall (shaded circle) southwest of Lander in the vicinity of Table Mountain. A barrier jet parallel to the Wind River Range (dark arrow) would be oriented northwest-southeast and could possibly cause orographic enhancement within this region.*

In the Wind River Basin case, future research would focus on generating a dense network of snow observers upstream and downstream of Table Mountain to further investigate and assess the role of a barrier jet in snowfall enhancement.

7. SUMMARY

Cold air damming along the east slopes of the Wind River Range in central Wyoming commonly enhances snowfall across lower elevations of the Wind River Basin. Following cold frontal passage, low-level north to northeast flow is unable to cross the range and flow deceleration and subsequent damming of the cold air against the barrier occurs. This dammed cold dome acts to modify the local terrain in such a way that overrunning south to southwest flow above about 600 hPa generates increased snowfall over the interior of the basin away from the barrier. Total snowfall across interior basin sites can approach 40% of the seasonal average. Snowfall in the vicinity of Lander can exceed that of mountain locations 600m to 1300m higher. These are important considerations for local forecasters to consider in cold air damming scenarios. It is important to note that in the absence of cold air damming, the prevailing upper-level south to southwest flow would generate downslope flow and dry and warmer conditions in the lee of the Wind River Range.

8. REFERENCES

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