High Terrain Supercell within a Mid-Tropospheric Ridge on 02 October 2010

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ABSTRACT

During the evening of 02 October 2010 some select atmospheric ingredients conglomerated to form a severe supercell thunderstorm that moved over several high-terrain communities within north central New Mexico. As the storm matured, it impacted some highly-traveled corridors as it crossed two separate interstate highways. Multiple observations of severe hail up to 5.08 cm (2.00 in) in diameter were reported as well as damaging winds up to 31.3 m/s (70 mph). This supercell developed over a geographical area within north central New Mexico, marked by highly variable and elevated terrain. A discussion of the synoptic and mesoscale environment of 02 October 2010 will be given, with intent on raising awareness to both the apparent and seemingly subtle indicators of severe convective potential in a geographical area where supercells seldom occur.

1. Introduction

New Mexico rests in the American Southwest, and hosts a diverse landscape with highly variable terrain and numerous consequent microclimates. Terrain varies from rolling plains near 915 m (3000 ft) in the eastern tier of the state to high mountain peaks in excess of 3960 m (13000 ft) in northern sections of the state. Peaks exceeding 3050 m (~10000 ft) are also common throughout the central to western sections of the state, marking the southern spine of the American Rocky Mountains.

The Jemez Mountains rest in northern New Mexico, and the supercell of 02 October 2010 initiated just after 2200 UTC over the southeastern foothills of this subrange at an elevation of 1798 m (5900 ft) MSL. The storm drifted southward over elevations varying from 1554 to 2313 m (5100 to 7590 ft) MSL within a corridor surrounded by higher peaks of 2400 to 3050 m (~8000 to 10000 ft) MSL (Fig. 1a and Fig. 1b). The storm became supercellular and crossed two separate Interstate highways while producing severe hailstones up to 5.08 cm (2.00 in) in diameter and damaging winds up to 31.3 m/s (70 mph). South of the Interstate 40 corridor, among the foothills of the Manzano Mountains updraft processes were interrupted and the storm finally began to lose intensity and organization at approximately 0205 UTC on 03 October.

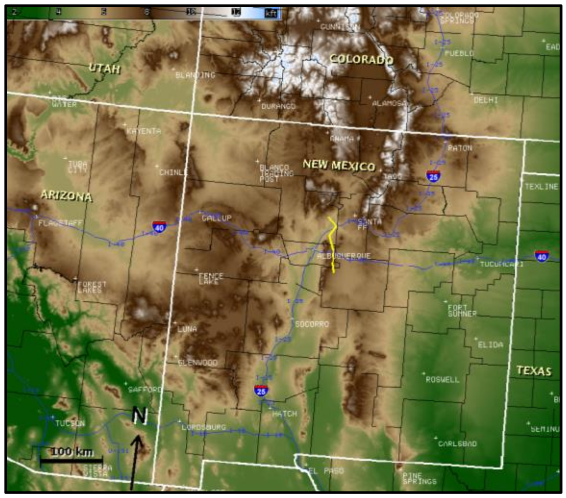

Figure 1a: Topographical map (color scale in kft above) with white lines indicating state boundaries, black lines representing counties, and blue lines marking interstate highways. Storm track is indicated by the thick yellow line within north central New Mexico.

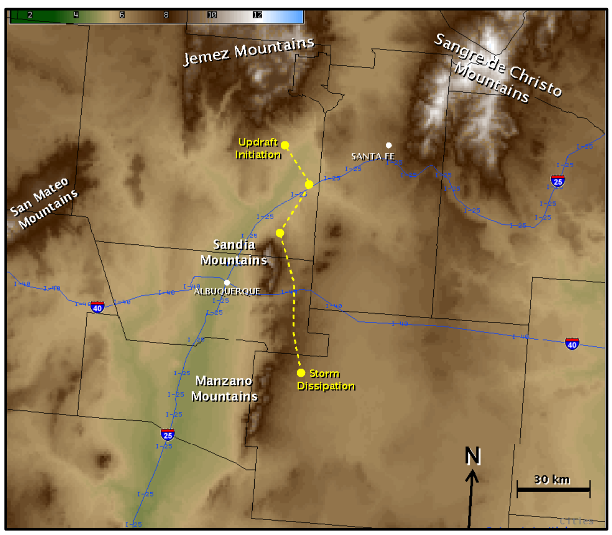

Figure 1b: Same as in figure 1a, but zoomed in to display the storm track and surrounding mountain chains.

Documentation of supercells over high terrain (greater than 1500 m) is relatively scarce when compared to traditional lower elevation supercells on the American Great Plains (Moller et. al. 1994). However, there have been a few select case studies for supercells (and even tornadic ones) over the American Rocky Mountains (Bluestein 2000, Finch and Bikos 2008) and the American Southwest (Perez 1998; Blanchard 2006, 2008, 2011). Jones (1996) also briefly summarized a tornadic supercell in the Sangre de Cristo Mountains of northern New Mexico, and other recent evidence of supercells has been ascertained for high terrain areas of New Mexico using *StormData* (2004, 2008). Supercells are assumed to be quite rare across the highly variable and rugged terrain of north central New Mexico, but a formal climatological record of supercell frequency is not currently available, making it difficult to quantify the rarity of these high impact events. Building a climatological record of supercells for New Mexico is beyond the scope of this writing, but this case study will provide a reference point for future documentation and comparisons of supercell events in north central New Mexico and the greater American Southwest.

The essential ingredients of lift, instability, and moisture for deep, moist convection (Johns and Doswell 1992) are rarely juxtaposed with sufficient deep layer wind shear (Rasmussen and Blanchard 1998) over these high terrain areas of New Mexico. A lack of sufficient moisture is generally the culprit during the meteorological spring months, as robust moisture intrusions within the lower levels of the troposphere typically are impeded by the surrounding mountainous terrain. While increased tropospheric moisture usually infiltrates the state during the latter parts of the meteorological summer season as part of the North American Monsoon (Adams and Comrie 1997), stronger kinematic profiles are absent, and this often hampers deep shear profiles necessary for supercell formation. The 02 October 2010 supercell in New Mexico occurred in a transition period between the warm North American Monsoon season and the cool season, under the presence of a synoptic mid tropospheric ridge of high pressure. This aspect of the synoptic environment differs from many of the aforementioned high terrain cases of supercells and severe convection, however there were other similarities that will be shown as the synoptic and mesoscale environments are analyzed.

Severe hail and winds accompanying a supercell such as that on 02 October 2010 pose a challenge to short term (1 to 6 h) operational forecasters, and timely anticipation of these events is imperative. From the perspective of the author, working as a warning forecaster during this event, the potential for severe convection and supercells on this date was not effectively anticipated. Therefore, a discussion of the synoptic and mesoscale environment of 02 October 2010 will be given, with intent on raising awareness to both the apparent and seemingly subtle indicators of severe convective potential in a geographical area where supercells seldom occur. This review will also reiterate that traditional parameters for forecasting supercells were indeed effective, despite this atypical high terrain setting.

2. Basic Storm Environment

Initial analyses of the synoptic environment for 02 October 2010 began with an interrogation of some fundamental variables such as 500 hPa geopotential height. This synoptic assessment quickly revealed a mid tropospheric ridge of high pressure (Fig. 2) with geopotential heights reaching 591 dam in northwestern New Mexico. The amplification and slow movement of this ridge of high pressure aloft had attributed to a persistent above normal temperature regime over much of New Mexico through late September and very early October. The polar jet remained displaced from New Mexico and the greater American Southwest with no synoptic cold core perturbations over the surrounding region, however a cold core baroclinic wave was observed in the Great Lakes region of the continental United States.

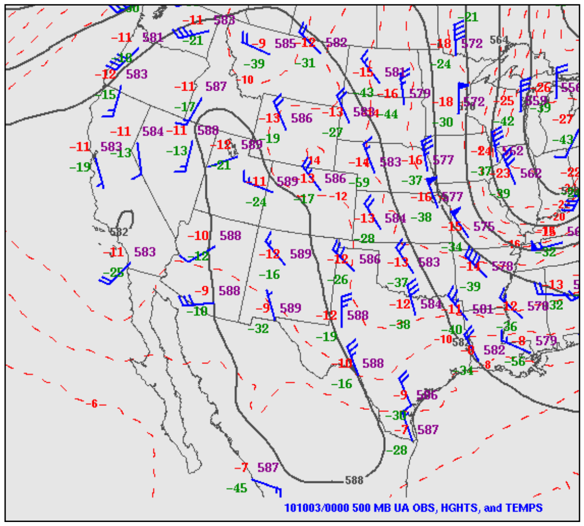

Figure 2: Objective 500 hPa analysis from Weather Prediction Center (formerly Hydrometeorological Prediction Center) at 0000 UTC on 03 October 2010. Geopotential height contours (black) are drawn every 6 decameters; temperatures are plotted in °C (red) with isotherms as dashed red contours; dewpoint temperatures in °C (green); wind barbs drawn so that a half barb represents 2.6 m/s (5 kt) and a full barb represents 5.2 m/s (10 kt).

Representative precipitable water data can be ascertained from the 03 October 2010 0000 UTC upper air sounding conducted by the nearby Albuquerque weather forecast office which revealed a value of 20.41 mm (0.79 in) as seen in Fig. 6. This value would fall within the 80th to 85th percentile for all early October precipitable water values analyzed from Albuquerque upper air soundings from 1948-2012 (Bunkers 2013). It should also be noted that precipitable water values did undergo an increase from 14 mm to 20.41 mm in the 24 hour period from 0000 UTC on 02 October to 0000 UTC on 03 October 2010.

An east southeast surface wind component was noted at many observation sites surrounding the storm environment and the areas to the lee of the central mountain chain of New Mexico. These east southeast winds near the storm environment were induced by a synoptic cold front that had backed into New Mexico the previous day on 01 October 2010. The favorable east southeast surface flow coincides with the eastern periphery of the upper level ridge where ground-relative winds were veering more northwesterly at heights of 500 hPa and above. Objective analysis (Fig. 3) of Mean Sea Level Pressure (MSLP) would also reveal a synoptic area of higher pressure values oriented northeast of New Mexico with another synoptic cold front approaching the state from the northeast. This regime would keep the east southeast surface winds prevailing in and near the storm environment. The absence of a synoptic mid tropospheric cold pool makes this case different from the episode of severe storms in northern Arizona in October 2005 that Blanchard (2006) reviewed or even the warm season event in August 2003 that was documented (Blanchard 2011). However, this northern New Mexico event does share some environmental similarities to the warm season tornadic supercell that impacted Divide, Colorado in 1996 (Bluestein 2000). The Divide, CO supercell environment was also characterized by persistent east southeasterly upslope flow associated with a synoptic cold front; a lack of upward synoptic-scale forcing was also noted.

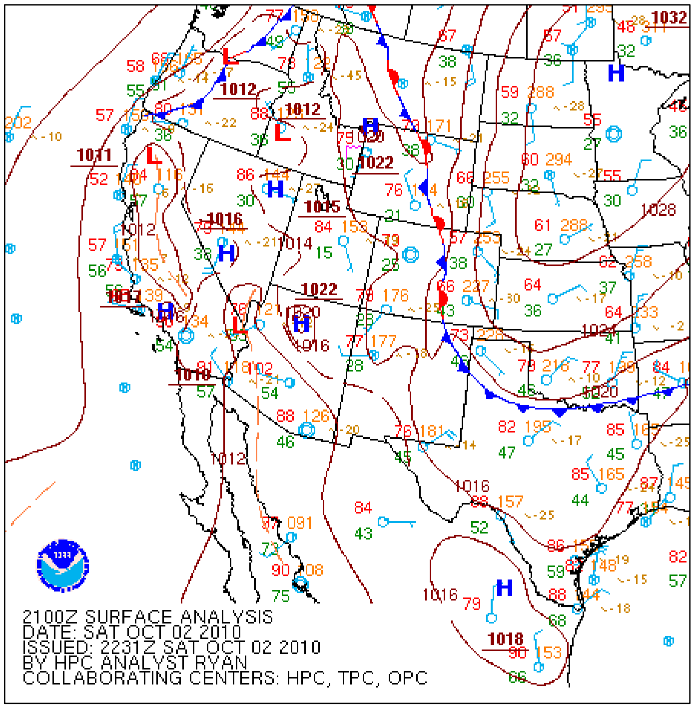

Figure 3: Objective Surface Analysis across the western United States on 02 October 2010 2100UTC.

Surface observations were analyzed at 2200 UTC, just 20 minutes prior to the first detections of precipitation echoes on radar with this particular storm of interest. These observations revealed dewpoint temperatures ranging from 2.7 to 7.2ºC (upper 30s to the mid 40s ºF) within the vicinity (less than 110 km or ~60 n mi) of the initial storm updraft (Fig. 4). Surface temperatures were shown to range from the upper teens to upper 20s ºC (mid 60s to the lower 80s ºF) within this vicinity, however it should be noted that the closest observing site, KLAM (Los Alamos), had become rain-cooled and contaminated from other nearby convective cells, rendering it unrepresentative of the inflow and updraft region of the soon-to-become severe cell.

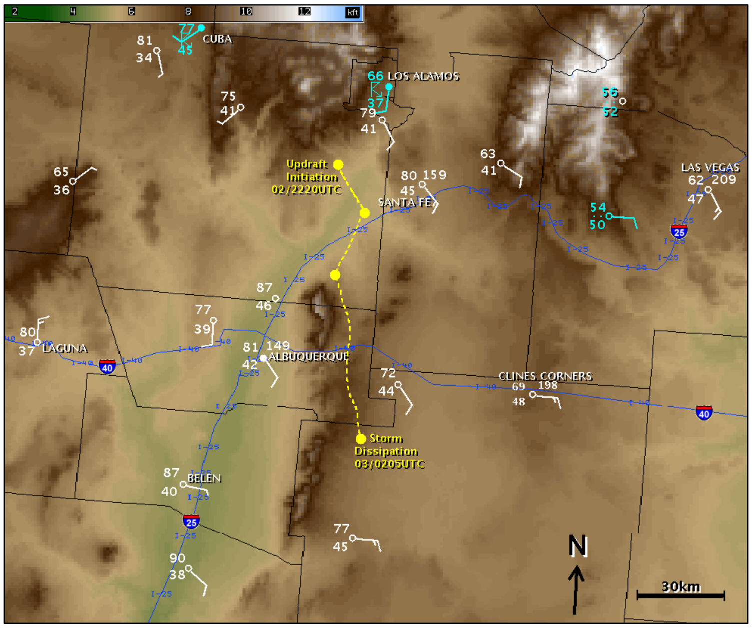

Figure 4: Surface observations in north central New Mexico 02 October 2010 at 2200 UTC. Temperature (°F) is denoted in upper left, dewpoint temperature (°F) in lower left, and sea level pressure in upper right where available (dPa with first two digits omitted, i.e. 149 represents 1014.9 hPa). Background image is topography (scale in kft above), blue lines are interstate highways, black lines are New Mexico county boundaries, and the storm track is annotated in yellow.

Discrepancies among the observations of MSLP within mountainous terrain are notorious (Pauley 1998), and thus emphasis will be shifted to other aspects of available surface observations within the area of interest. The high variability in terrain will also lead to numerous microclimates which are unable to be adequately sampled with such a relatively low resolution surface observation network as that in New Mexico. Still, careful scrutiny of these observations failed to reveal any mesoscale surface boundaries close to the storm origin. While daytime convection was noted around the region the previous day on 01 October 2010, storms remained sparse and localized while exhibiting short life spans. Therefore, no remnant mesoscale cold pools or outflow boundaries were believed to have existed from earlier convection.

While no blatant mesoscale surface boundaries were found among surface observations, nearby convection should be mentioned. Prior to the development of the initial updraft of the severe cell of interest (approximately 2220 UTC), a separate convective cell had already matured approximately 29 km (15.7 n mi) to the north, hereafter referred to as CEL1 (Fig. 5). Attendant precipitation and the gust front from this storm steered north and east of where the new storm would soon form, along the southeastern foothills of the Jemez Mountains. This allowed east southeast surface winds to prevail without interference toward the southeastern Jemez Mountains where genesis of the new severe supercell would occur. Surface winds from the east southeast also provided an upslope component over the southeastern foothills of the Jemez Mountains where the storm originated, and initial updraft processes likely benefited from this.

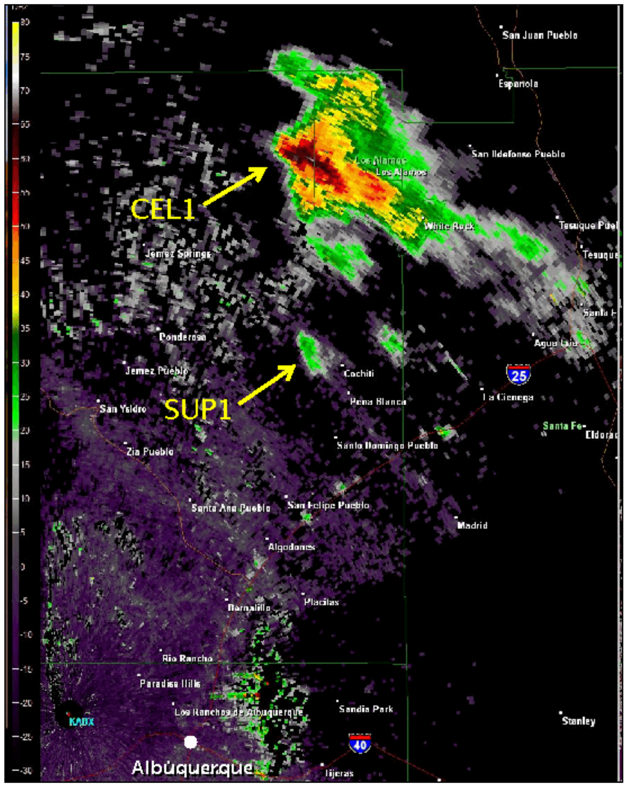

Figure 5: 0.5 Degree Reflectivity from ABX (Albuquerque) at 02 October 2010 2220 UTC displaying an ongoing convective cell (CEL1) and the first echoes of the soon to develop supercell (SUP1).

It was initially inferred from the mid tropospheric ridging signal that wind speeds were relatively light throughout the tropospheric column, and this was confirmed from the Albuquerque afternoon upper air sounding. The Albuquerque (ABQ) sounding released at 03 October 2010 0000 UTC coincided with the mature stage of the thunderstorm, and is believed to provide a reasonably representative sample of atmospheric conditions given that the radiosonde was released ~69 km (37.3 n mi) from where the initial updraft developed. It should be noted, however, that the radiosonde balloon was released at an elevation of 1620 m (5300 ft), approximately 183 m (600 ft) lower than the location of updraft initiation. As indicated in the ABQ sounding, light wind speeds of 17 m/s (33 kt) or less existed between the surface and 300 hPa, however ground-relative winds were veering in the lower levels of the troposphere. The 0–6 km layer mean wind was calculated to be only 2.6 m/s (5 kt) from the west (286º) by AWIPS (Advanced Weather Interactive Processing System) or 3.4 m/s (6.8 kt) from the west northwest (291º) when calculating a 0.5 km interval average through a 0-6 km above ground level (AGL) layer.

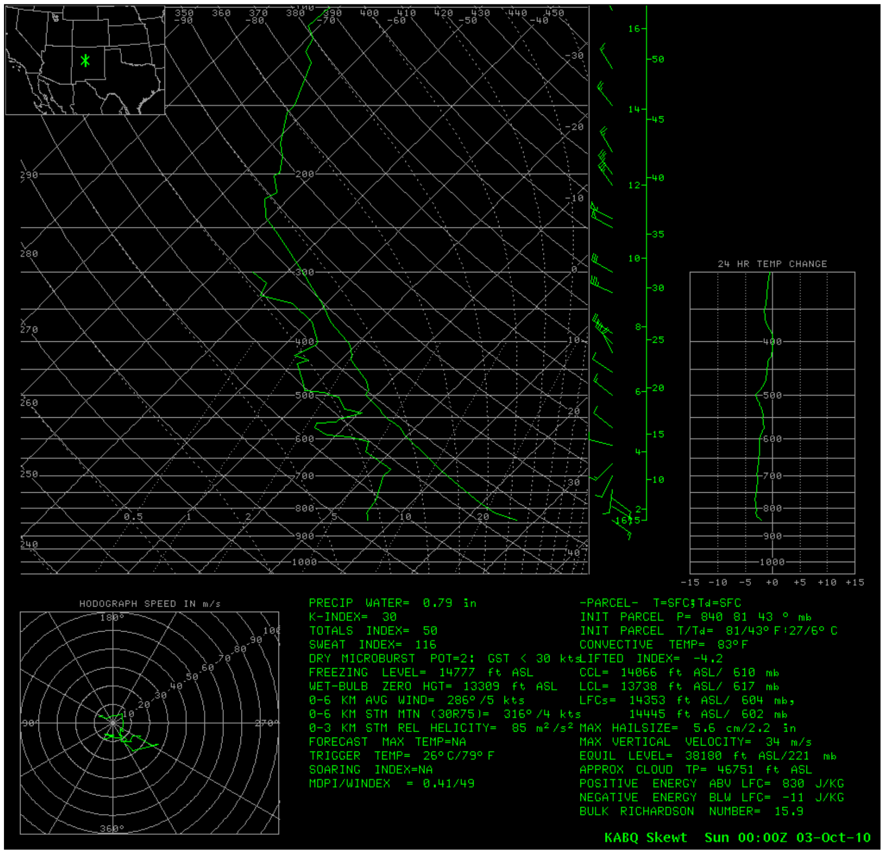

Figure 6: Atmospheric sounding released at Albuquerque (ABQ) on 03 October 2010 0000 UTC.

Temperature lapse rates favorable for convection were also observed across north central New Mexico. From Fig. 6, a lifted index of -4.2ºC was calculated on the observed ABQ sounding along with a surface-based CAPE (Convective Available Potential Energy) value of 830 J/kg. Minimal surface based CIN (Convective Inhibition) was noted at only 11 J/kg, and upslope wind components likely supplemented vertical motions with observed surface heating to overcome this inhibition. Other notables within the analyzed temperature profile include the freezing level at 4504 m (14800 ft) MSL and a -20 ºC level at 7315 m (24000 ft) MSL.

A plan view, or two-dimensional view of CAPE was also available utilizing the Local Analysis and Prediction System (LAPS) data. Estimates of CAPE are calculated within LAPS by lifting a surface parcel taken from locally observed surface temperature and dewpoint fields, as well as LAPS surface (terrain following) pressure. In addition, a model background and available radiosonde data are combined to construct LAPS 3-dimensional temperatures that are utilized to calculate CAPE. As noted in Fig. 7, the LAPS analysis of CAPE showed approximately 800 J/kg just southeast of the intersection of Interstate 25 and 40, which correlates well to the observed CAPE values from the 0000 UTC ABQ sounding. An area of increased CAPE is also noted along the Interstate 25 corridor between Santa Fe and Albuquerque where the storm propagated; CAPE values of 1400 J/kg were analyzed here by the LAPS.

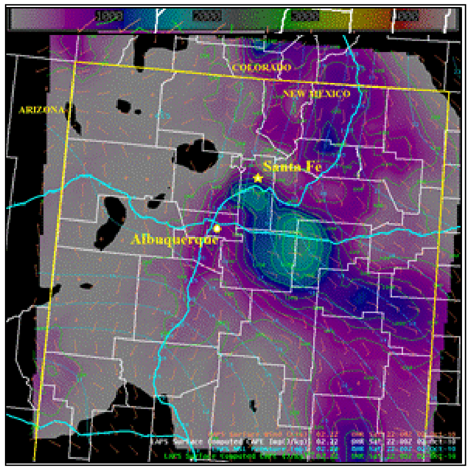

Figure 7: Local Analysis and Prediction System (LAPS) objective analysis of CAPE at 2200 UTC on 02 Oct 2010 (green contours and colored image) and surface winds (orange barbs). Approximately 800 J/kg of CAPE was analyzed near the ABQ sounding release point and up to 1400 J/kg over portions of Interstate 25 (south southwest of Santa Fe) where the storm later tracked.

3. Genesis, Characteristics, and Associated Severe Weather

The first echoes, associated with this particular storm of interest, appeared on the Albuquerque (ABX) Weather Surveillance Radar 1988 Doppler (WSR-88D) at 2220 UTC on 02 Oct 2010, with reflectivity values ranging between 30 and 35 dBZ on the 0.5 degree elevation slice. This signified updraft development just west of Cochiti Lake, New Mexico, or about 27.4 km (14.8 n mi) south southwest of Los Alamos. As was alluded to in previous sections, an unrelated mature convective cell, CEL1, was already underway west of Los Alamos, New Mexico (north of the developing supercell of interest). At a mature state, CEL1, remained intact until 2320 UTC when the southern storm became the dominant cell, depriving the northern cell of southeasterly upslope flow. This newly developing and soon to become supercell will hereafter be referred to as SUP1 (Refer to Fig. 5). Through 2320 UTC, CEL1 quickly began to weaken as evidenced by reflectivity and lightning data, while the SUP1 flourished with a rapidly increasing reflectivity core aloft and pronounced reflectivity gradient evident at the 0.5 degree radar slice.

Banta and Schaaf (1987) reviewed thunderstorm genesis over the Rocky Mountain zones of Colorado utilizing geosynchronous satellite imagery, and found several occurrences of storm initiation on the eastern or southeastern slopes and foothills in association with upslope flow and opposing northwesterly flow aloft. Later, Fosdick and Watson (1995) found coincident zones of convective initiation to the east and southeast of many New Mexico mountain ranges, including the Jemez where SUP1 developed. While SUP1 shares a similar origin with pronounced directional veering of the ground-relative winds, it also continued to move into an area where surface winds remained mostly from the east southeast, even over the variable terrain. This gave SUP1 a prolonged environment of veering (ground-relative) winds with height.

By 2326 UTC reflectivity in excess of 50 dBZ was observed among the core of SUP1, as high as the 8.0 degree elevation slice on the ABX radar (Fig. 8). With the core of the storm 60 km (32.4 n mi) away from the ABX radar on the 8.0 degree elevation slice, the beam centerline would have been 8626 m (28300 ft) above radar level or 10455 m (34300 ft) MSL (factoring in the 5,950 ft site elevation of the

ABX radar). Here, environmental temperatures were observed to be -45 ºC according to the 0000 UTC 03 October Albuquerque upper air sounding. It has been empirically shown over the upper Midwest, central plains (Donavon and Jungbluth 2007), and southern high plains (Porter, et. al. 2006) of the continental United States that such high reflectivity values sampled at these altitudes can be an excellent indicator of severe hail (greater than or equal to 2.54 cm in diameter) given the cold environmental temperatures that would support the growth of hail. Operationally, this theorem has been utilized not only over the high plains of eastern New Mexico, but also over the more mountainous terrain in central and western portions of the state. Several high terrain hail events in New Mexico (since 2006) have successfully validated the utility of a hail size prediction tool that Porter et. al. introduced, and additional documentation of these events is underway. On 02 October 2010 the hail size indicator tool revealed that hail in excess of at least 2.54 cm (1.0 in) could be expected from reflectivity exceeding 50 dBZ at an altitude of 9937 m (34.6 kft), and numerous hail reports associated with SUP1 would later validate the tool's prediction. Shortly after the high altitude reflectivity core of SUP1 was sampled, a severe thunderstorm warning was issued and subsequent warnings would remain in effect until 0245 UTC 03 October 2010 for this storm.

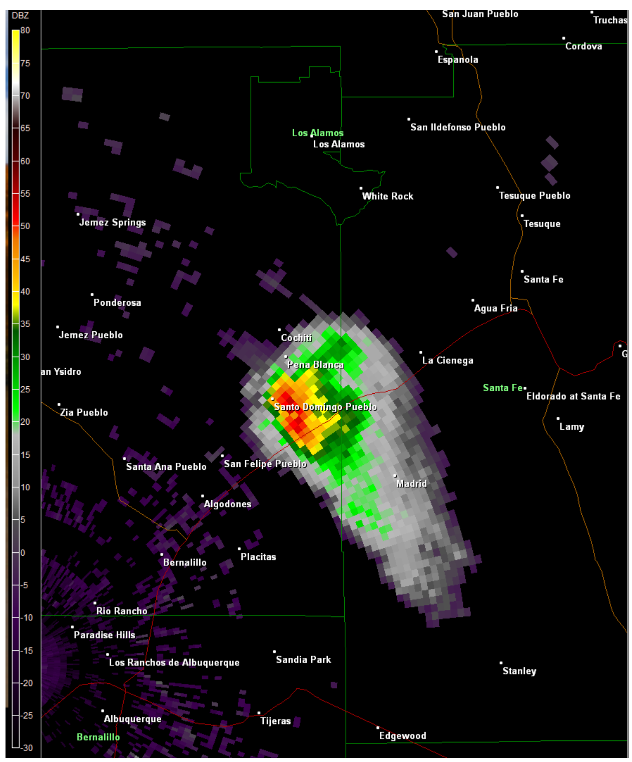

Figure 8: The 8.0 degree elevation cut of the ABX radar at 2326 UTC on 02 Oct 2010 revealed a 50 dBZ echo at 8626 m (28300 ft) above radar level (34300 ft MSL) where temperatures were observed to be -45 °C.

The sharp reflectivity gradient persisted along the southern flank of the storm, and by 2345 UTC, ground-relative velocities in excess of 31 m/s (70 mph) were measured from the level 2 velocity data near the Interstate 25 corridor (Fig. 9). The first Local Storm Report to validate these measurements came in at 0010 UTC October 03 with an estimated 70 mph gust from a local storm spotter at the San Felipe Casino, located along Interstate 25 at mile marker 259.

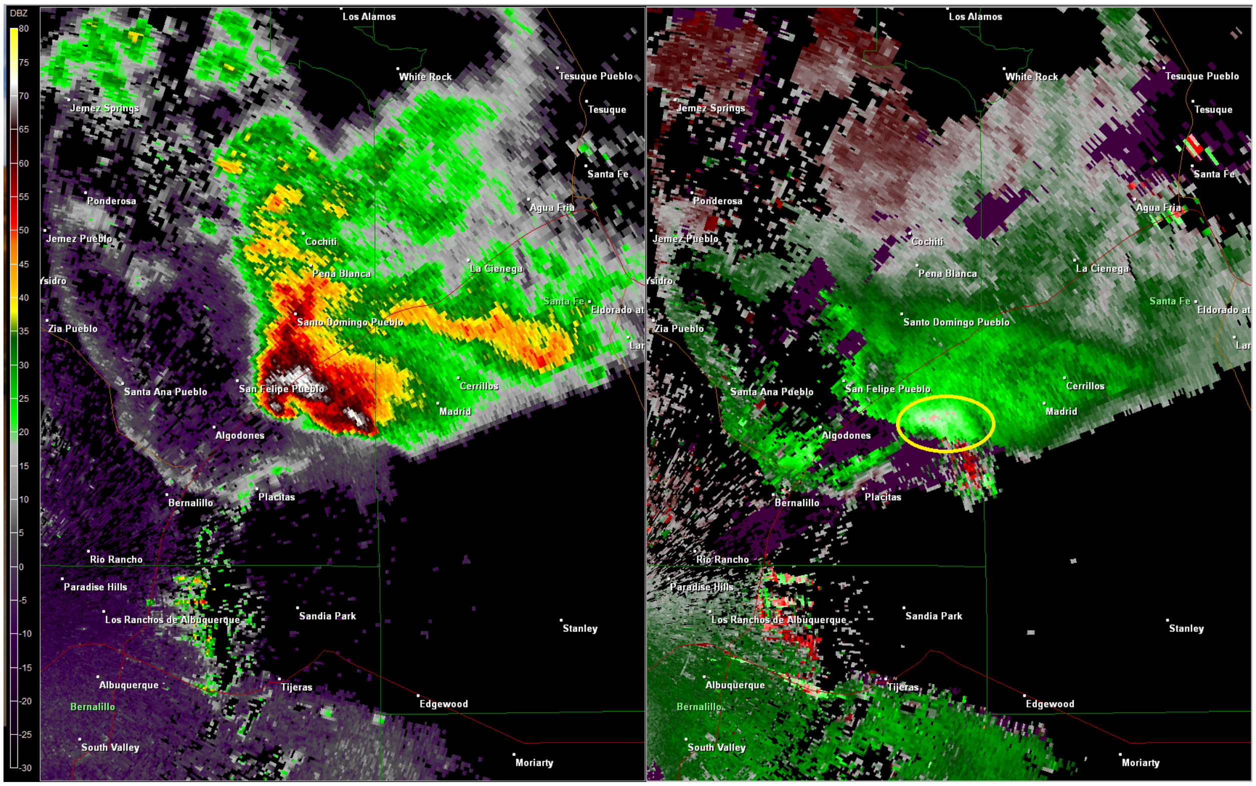

Figure 9: This 2 panel, side-by-side image of the 0.5 degree elevation cut of the ABX radar at 2359 UTC on 02 Oct 2010 displays reflectivity as high as 70 dBZ (left) and ground-relative velocities in excess of 36 m/s or 70 kt (right, circled in yellow).

Again, much of the low level (0–1 km) inflow of the storm was from the east southeast, and the storm moved against this with the support of northwesterly winds in the mid to upper levels (5–10 km) of the cell. By 0030 UTC the trajectory of the supercell carried it east of the Sandia Mountains, a range residing to the east of the Albuquerque metropolitan area hosting peaks as high as 8 to 10.0 kft MSL. The Sandia Mountains present a substantial barrier to the ABX WSR-88D radar, and consequently the beam from most of the lower tilts of the radar volume coverage pattern were blocked before reaching the lower portions of SUP1. Due to this dilemma of beam blockage during the convective event, operational forecasters were relegated to use of the higher elevation tilts of the ABX radar. Aside from the ABX radar, the closest practical radar was far away in the eastern plains of New Mexico, the FDX WSR-88D at Cannon Air Force Base near Clovis. Unfortunately, SUP1, at this stage in its lifecycle, was still located 256 km (138 n mi) from the FDX radar. This would place the 0.5 degree beam centerline 5791 m (19000 ft) above radar level or 7224 m (23700 ft) MSL (factoring in the 4,697 ft site elevation of the FDX radar) when passing through the core of the storm between 0030 and 0200 UTC on 03 Oct 2010. Both the beam blockage from the ABX radar and the unfavorable distance from the FDX radar (and consequent beam height) left the lower levels of SUP1 undetected. A few small villages lay to the east of the Sandia Mountains in the path of the storm. Along with several reports of large hail (greater than or equal to 5.08 cm diameter), some reports of cloud lowerings, rotating wall clouds, and even brief funnel clouds were received (Fig. 10 and Table 1).

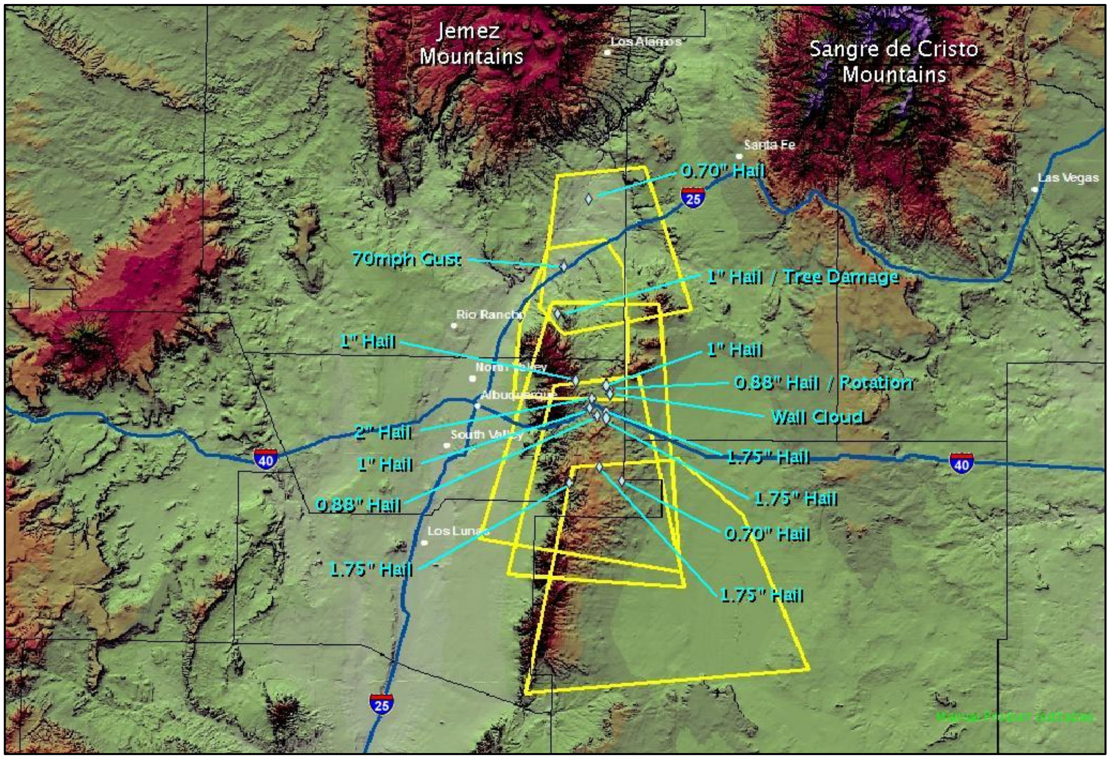

Figure 10: Map of severe thunderstorm polygons issued on the evening of 02 October 2010 (yellow) and local storm reports (gray diamond icons).

Table 1

No.	Report	Time UTC	Location
1	1.78 cm (0.70 in) diameter hail	2330Z	Pena Blanca
2	1.27 cm (0.50 in) diameter hail	0010Z	2SE San Felipe Pueblo
3	31.3 m/s (70 mph) wind gust	0010Z	2SE San Felipe Pueblo
4	24.6 m/s (55 mph) wind gust	0013Z	3E Bernalillo
5	2.54 cm (1.00 in) diameter hail	0018Z	1NE Placitas
6	5.08 cm (2.00 in) diameter tree limbs down	0018Z	1NE Placitas
7	2.54 cm (1.00 in) diameter hail	0050Z	Sandia Park
8	wall cloud with weak rotation	0053Z	3NNE Sedillo
9	clouds lowering w/ rotation	0100Z	Sandia Park
10	2.24 cm (0.88 in) diameter hail	0100Z	Sandia Park
11	1.78 cm (0.70 in) diameter hail	0101Z	3NNE Sedillo
12	5.08 cm (2.00 in) diameter hail	0102Z	4NE Tijeras
13	4.45 cm (1.75 in) diameter hail	0105Z	5E Tijeras
14	2.54 cm (1.00 in) diameter hail	0105Z	5E Sandia Park
15	4.45 cm (1.75 in) diameter hail	0110Z	Sedillo
16	2.24 cm (0.88 in) diameter hail	0115Z	3NNE Sedillo
17	2.24 cm (0.88 in) diameter hail	0120Z	1WSW Sedillo
18	4.45 cm (1.75 in) diameter hail	0120Z	5E Tijeras
19	2.54 cm (1.00 in) hail	0120Z	2WNW Sedillo
20	4.45 cm (1.75 in) diameter hail	0127Z	10S Tijeras
21	4.45 cm (1.75 in) diameter hail	0140Z	Ponderosa
22	1.78 cm (0.70 in) hail	0200Z	3ESE Miera

Table 1: Local Storm Reports acquired throughout north central New Mexico on 02 Oct 2010.

4. Shear, Storm Motion, and Storm Relative Helicity

As alluded to earlier, the synoptic mid tropospheric ridge pattern hosted a light wind environment (0–6 km mean wind of 5 kt from 286º), however postmortem analysis of the 03 October 2010 0000 UTC sounding at ABQ indicated 0–6 km bulk shear of 21 m/s (41 kt) due to substantial ground-relative veering of the winds with height. Thus, vertical wind shear was supportive of rotating storms (Rasmussen and Blanchard 1998). The 0–6 km bulk shear prognosis was viewed as a near real-time forecast via the North American Mesoscale (NAM) model; the model displayed 15–18 m/s (30–35 kt) of 0–6 km bulk shear at 0000 UTC on 03 October 2010 (Fig. 11). There is a low bias to this range forecasted by the model when compared to observed sounding data, and better sampling and assimilation of boundary layer winds might have resulted in higher values, closer to what was observed via the sounding data.

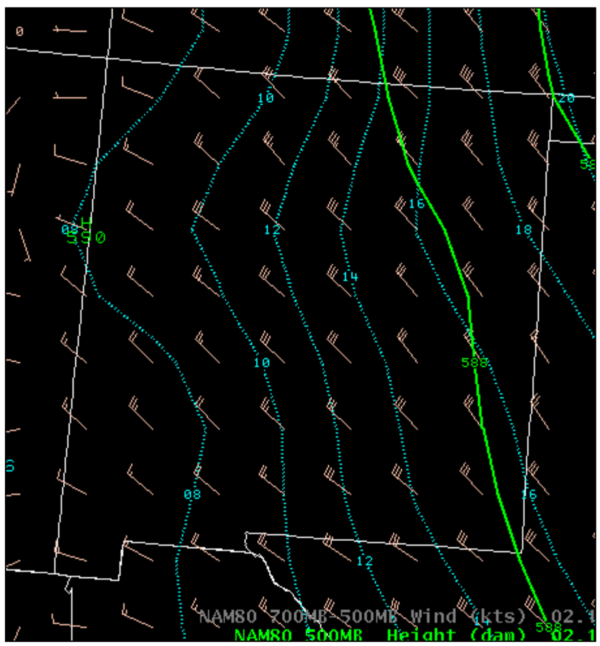

Figure 11: North American Mesoscale model depiction of 0–6 km Bulk Shear (tan barbs) along with Mean Sea Level Pressure (blue dotted), and 500 hPa geopotential height (green). Valid 03 October 2010 0000 UTC.

The observed storm exhibited cyclonic rotation through much of its lifecycle, consistent with a right-moving supercell. Utilizing the hodograph from the ABQ sounding data, the Internal Dynamics method (Bunkers et al. 2000, Zeitler and Bunkers 2005) was applied for a postmortem estimate of the supercell's motion. The Bunkers ID method gave an estimated storm motion from north to south (016º) at 7.0 m/s (14 kt) for right-moving cells. Once the mesocyclone developed, storm motion was calculated to be from 006º at approximately 7.7 m/s (15 kt) between approximately 02/2340 UTC and 03/0010 UTC. At this time the storm was moving over the Rio Grande valley, where terrain lowers to 1585 m (5200 ft), and this variation in terrain could account for some of the subtle motion deviation from the Bunkers ID estimate.

The higher based nature of the storm could have also been a potential factor that led to the storm slightly deviating from the highly proven Bunkers ID method. A relatively high lifting condensation level (LCL) and arid environment were analyzed with this case when compared to many other plains and

Midwest supercell cases (Rasmussen and Blanchard 1998). From the sounding at ABQ, the environmental lifting condensation level was estimated at 4.2 km MSL (approximately 2.2 km or 7200 ft AGL), and again the precipitable water was only 20.41 mm (0.79 in), implying a high-based storm with echo tops of 13.7 km (45000 ft) MSL still rivaling or exceeding supercells common on the lower elevation plains. Further evidence of the high lifting condensation level can be seen in the form of a pronounced gust front, seen in Fig. 9 on the southern flank of the storm. This gust front may have also induced a deviation from the Bunkers ID projection of storm motion.

By 03/0010 UTC the supercell began to accelerate faster with less rightward movement, approximately 350º at 9.8 m/s (19 kt). This motion was observed as the storm began to move within close proximity to the Sandia Mountains where peaks rise to 2400 to 3050 m (~8000 to 10000 ft) MSL. The storm also moved directly over higher terrain from 1.5 to 2.1 km (5200 to 7000 ft) MSL between 03/0010 UTC and 03/0200 UTC with the higher Sandia Mountains to its west, a topographical setting that would reasonably alter the propagation component of the storm's motion. As mentioned earlier the lower levels (0–1.5 km AGL) of SUP1 were not sampled by radar due to beam blockage from the Sandia Mountains, thus it is unknown the character of the gust front during this phase of the storm. Caveats that have been found to lead to deviations from the Bunkers ID method include topographical variance and outflow-shear interactions such as gust fronts (Bunkers 2000), factors that were observed with SUP1. The Bunkers ID method was based on analyses of 260 right moving supercells, largely found over the domain of the lower elevation plains and Midwestern states, but despite the atypical high terrain setting of SUP1 the motion prediction method still provides effective utility as long as the aforementioned caveats are considered.

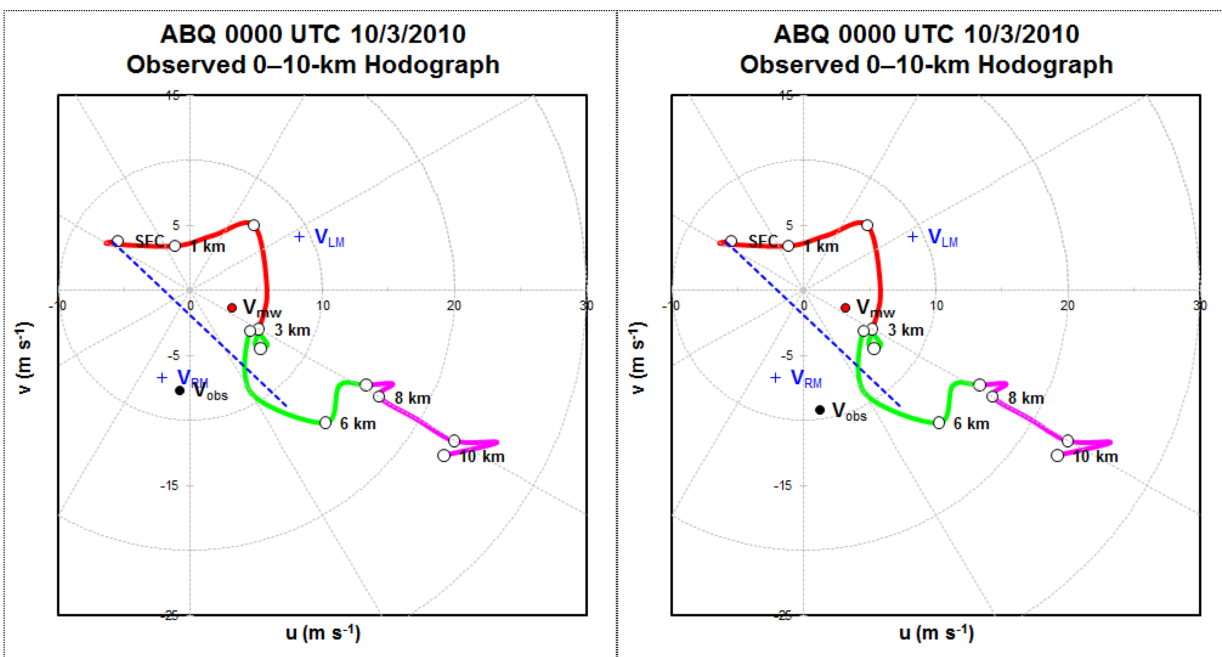

Figure 12: Hodographs for ABQ 03 October 2010 0000 UTC. The blue dashed line indicates the 0–6 km bulk shear vector while the red dot from 291° at 3.5 m/s (6.7 kt) represents the 0–6 km mean wind. The Internal Dynamics method (Bunkers et al. 2000) was applied by drawing a line (not shown) from the red dot and making it orthogonal to the dashed blue line. From 7.5 m/s of this intersection the vector for right moving cells is acquired and indicated by the blue cross Vrm (016° at 7.0

m/s or 13.6 kt). The left image shows observed motion of 006° at 7.7 m/s (15 kt) between 02/2340 UTC to 03/0110 UTC. The right image shows a comparison with the observed motion of 350° at 9.8 m/s (19 kt) that occurred between 03/0010 UTC and 03/0200 UTC. Hodograph images courtesy of Bunkers.

A backed surface flow and high values of storm relative helicity (SRH) have been documented with many supercells and especially tornadic supercells (Rasmussen and Blanchard 1998), but this parameter is seemingly neglected often times during analyses and forecasting of convective weather in mountainous regions. As is the case with many other meteorological variables, quality analysis of SRH often proves difficult in mountainous regions. Low resolution observation networks and poor sampling of the highly variable boundary layer conditions existing over uneven terrain can lead to significant errors in the estimates of boundary layer winds, storm motion, and consequently the quantitative analysis of SRH. Therefore, the assumption is often made by operational forecasters within the intermountain western United States that real-time estimates of SRH are inaccurate during convective events, especially when examining the 0–1 km above ground level (AGL) layer. On the rare occasions that higher SRH environments do actually develop, this parameter can seemingly be neglected during analysis and short term forecasting. The Rocky Mountains often pose a barrier effect, inhibiting the advection of moist air from the Gulf of Mexico, and as a result high SRH environments seldom occur to the west of the barrier. The central mountain chain within New Mexico (southern Rockies) fits within this conceptual model. However, on the rare occasions when boundary layer moisture intrusions are able to penetrate beyond the mountain barriers, they will usually establish veering wind profiles in the lower layers (0–3 km) of the troposphere. The 03 October 0000 UTC ABQ sounding indicated 0–3 km SRH of 85 m^2/s^-2 west of the central mountains of the state, and while this value falls within a range supportive of supercells and even weak tornadoes (Rasmussen and Blanchard 1998, Kerr and Darkow 1996) it should be noted that this calculation was performed in AWIPS (Advanced Weather Interactive Processing System). The calculation of SRH in AWIPS is based on a storm motion of 30 degrees to the right and 75 % of the 0–6 km density weighted average wind (30R75). The 30R75 estimate of storm motion has been shown to be inferior to other methods such as the Bunkers ID method (Bunkers et al. 2000), and the actual observed storm motion indeed differed significantly from the 30R75 estimate (the observed motion was from 350º at 9.8 m/s (19 kt) in contrast to the 30R75 estimate of 046º at 4.9 m/s or 9.5 kt). Calculations of SRH based on the true observed storm motion of 350º at 9.8 m/s (19 kt) indicated a value of 188 m^2s^-2, a significant difference that would suggest much higher likelihood of updraft rotation (Rasmussen and Blanchard 1998). It seems prudent to reiterate this to operational meteorologists utilizing SRH calculations from AWIPS generated skew T diagrams.

Spatiotemporal analysis of mountainous surface observations can prove to be difficult in real-time due to the limitations of observation networks and variable terrain, and consequently the calculations of SRH suffer. This dilemma is also carried over into numerical weather prediction models, especially considering the low resolution surface terrain built into most forecast models. Despite this shortcoming, the North American Mesoscale (NAM) model still indicated SRH values of approximately 135-195 m^2/s^-2 across the storm environment with higher values shown in the northeastern quadrant of the state of New Mexico (Fig. 13). Although there are limitations with forecasted SRH values from this model, the NAM model does incorporate the Bunkers ID method into the calculations of storm motion and SRH, giving a more accurate representation than the 30R75 method.

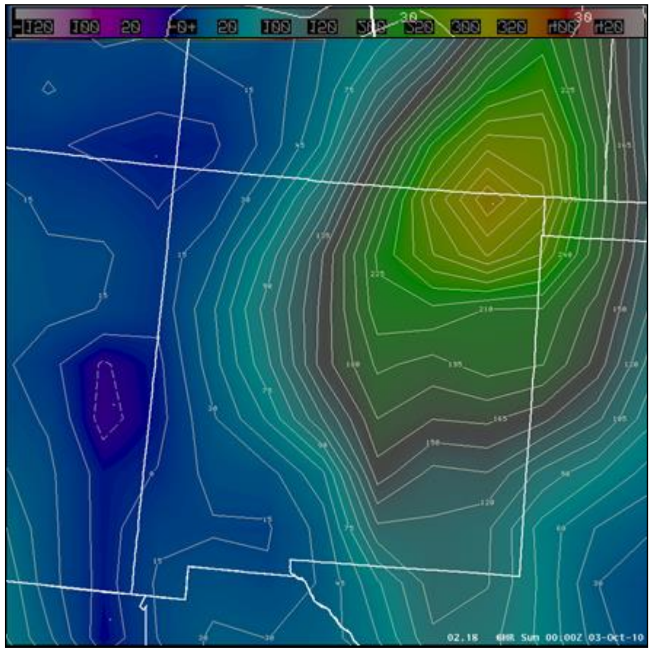

Figure 13: North American Mesoscale 80km resolution model depiction of 0–3 km Above Ground Level Storm Relative Helicity (SRH) over New Mexico. Valid 03 October 2010 0000 UTC.

5. Evaluation of Equivalent Potential Temperature

Similar to the discussion above of SRH, absolute values of equivalent potential temperatures are also often overlooked during short term forecasting of deep convection in mountainous terrain. Finch and Binkos (2008) discussed the importance of analyzing equivalent potential temperature θ_e, potential temperature θ, and mixing ratio w when assessing potential instability over variable and high terrain areas. It was reiterated that equivalent potential temperature θ_e is dependent on both potential temperature θ and mixing ratio w, and these variables were shown to give much more revealing assessments of convective instability (in high terrain areas) rather than traditional analyses of surface temperature and dewpoint. These findings were built on fundamental principles regarding potential temperature and mixing ratio; when two areas at different elevation have the same dewpoint, the higher elevation area will yield a higher mixing ratio w. This will ultimately lead to higher equivalent potential temperature θ_e. To demonstrate this, the chart below breaks down four different automated observation sites closest to the storm environment, including temperature, dewpoint temperature, station pressure, mean sea level pressure, mixing ratio, potential temperature, and equivalent potential temperature.

Table 2

Observation Site	**Elevation MSL**	**Temperature / Dewpoint (T/Td)**	**Station Pressure**	**Mean Sea Level Pressure (MSLP)**	**Mixing Ratio (w)**	**Potential Temperature (θ)**	**Equivalent Potential Temperature (θ_e)**
Los Alamos*	2186 m (7172 ft)	18.9ºC/2.8ºC (66 ºF/37 ºF)	787.7 hPa	1008.5 hPa	5.95 g/kg	312.6 K	331.5 K
Santa Fe	1935 m	26.6ºC/7.2ºC	803.4 hPa	1015.9	7.96 g/kg	319.8 K	344.8 K

	(6348 ft)	(80ºF/45ºF)		hPa			
Albuquerque	1620 m (5315 ft)	27.2ºC/5.6ºC (81ºF/42ºF)	841.0 hPa	1014.9 hPa	7.22 g/kg	315.8 K	338.9 K
Clines Corners	2164 m (7100 ft)	20.6ºC/8.9ºC (69ºF/48ºF)	783.8 hPa	1019.8 hPa	9.17 g/kg	314.9 K	343.8 K

Table 2: Automated observations closest to the storm environment at 2200 UTC on 02 Oct 2010. *Denotes observation was rain-contaminated from other nearby convective cells.

The observation at Los Alamos was considered to be rain-contaminated from unrelated cells, and thus it was not reflective of the inflow environment of the high terrain supercell. Focusing on the remaining three observations, θ_e ranged from approximately 339–345 K, and these values have been associated and documented with destructive and even tornadic supercells across the continental United States. The benefits and importance of assessing *w* and θ_e, as opposed to simply analyzing temperature and dewpoint has been emphasized with other high terrain supercell cases (Finch and Bikos 2008). This particular north central New Mexico supercell case conceptually demonstrates the significance of thorough analyses of *w* and θ_e, especially since dewpoints in the 40sºF may have been overlooked as being too low when forecasting deep, moist convection.

6. Summary

Because of their rarity, analysis and documentation of high terrain supercells has remained minimal over the past few decades. However, the supercell case over north central New Mexico on 2 Oct 2010 provides an excellent cornerstone sample for modern day investigation and review. A postmortem dissection of the existing environment during this case revealed some common and widely accepted indicators of supercell potential.

- Many variables mimicked those found with lower elevation supercell cases such as the unstable temperature profile, convective available potential energy (CAPE), and veering wind profile with significant directional shear. Other atmospheric parameters associated with this high terrain supercell would contrast with many commonly accepted conceptual models of lower elevation or high plains supercells.
- These conflicting variables include low dewpoint temperatures in the single digits °C (40s °F), a high lifting condensation level of 2.2 km (7200 ft) AGL, precipitable water values less than 20 mm (0.80 in), as well as the inhabitance of a mid-tropospheric ridge of high pressure.

Storm propagation was evaluated and tested against the Bunkers ID motion prediction method to assess how this high terrain case performed with counterparts on the lower elevation plains.

- The Bunkers ID method proved far superior to the 30R75 technique for this high terrain supercell case.
- A more representative estimate of storm motion was also found when the height of the advection (mean wind) and shear components in the Bunkers ID equation were expanded to include a deeper layer of 0–8 km rather than 0–6 km.
- The importance of accurate storm motion estimates was then discussed with an emphasis placed on Storm Relative Helicity and its dependence on a reliable storm propagation vector. This

discussion carries key weight for operational radar forecasters during the rare instances that supercellular storms develop in high terrain areas.

- Operational forecasters are reminded of the discrepancies between the calculations of SRH from an AWIPS skew-T plot (based on the 30R75 storm motion) and those from mesoscale models (based on Bunkers ID method for storm motion).

Other vital principles were reiterated for the sake of short term forecasting, especially when related to operational radar warning meteorology.

- This particular north central New Mexico supercell case demonstrates the significance of thorough analyses of w and θ_e, two variables that can be much more divulging than just dewpoint alone.

Although this writing has reviewed many facets about the high terrain supercell that impacted north central New Mexico on 02 October 2010, further examination and comparisons of this event with other supercells in high elevation environments would be highly beneficial for the operational meteorology community, including the weather forecast offices of the western United States where these events would be most prone to occur. Additional documentation, analysis, and collaboration of these findings seems paramount given the high impact these destructive storms pose to life and property whether on the plains or in higher mountainous landscapes.

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