The White Pine County High Impact Event of 21-22 November 2013

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1. Introduction

A potent winter storm brought moderate to heavy snow to portions of northern Nevada during 21-22 November 2013. The areas that were most heavily affected in WFO Elko's County Warning Area (CWA) included Eureka, White Pine, and northeast Nye Counties (see Figure 1 below).

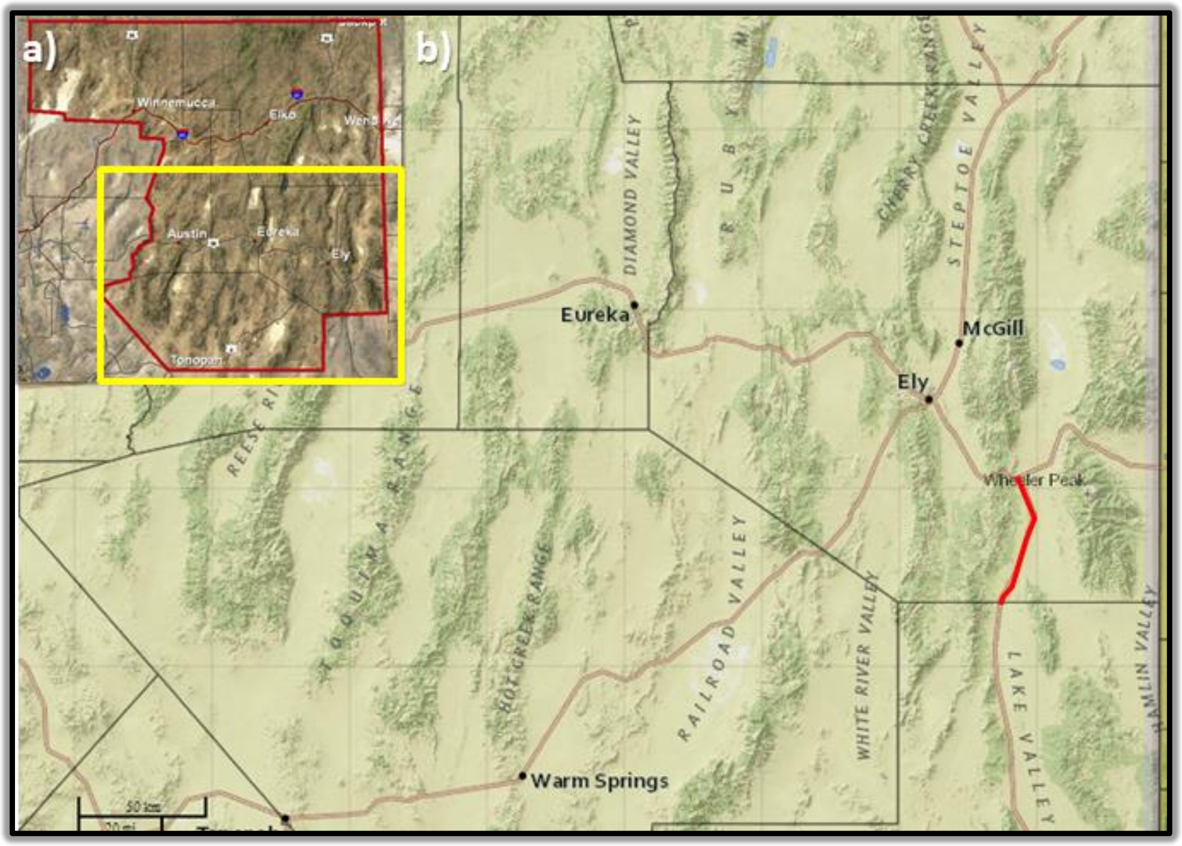

Figure 1 – a) Boundary map of WFO Elko's County warning area outlined in red with b) ESRI National Geographic Map blow-up of the area outlined in yellow highlighting the counties described in the text above. The red line in b depicts the area of U.S. Highway 93 that was closed during the winter storm.

Snowfall amounts in these large counties ranged from 13 to 25 cm (5 to 10 inches) in the valley locations to 25 to 41 cm (10 to 16 inches) in the mountains. Figure 2 below shows these amounts gathered from NWS cooperative observers and SNOTEL sites. In addition, an unusually prolonged and strong east and northeast wind combined with snow fall over this area to create areas of blowing and drifting snow. Wind speeds were generally 11 to 16 m s^{-1} (25 to 35 mph) with gusts to 18 m s^{-1} (40 mph) in a very data-sparse, remote, and unpopulated area of east-central Nevada. Although the area of interest is remote, U.S. Highway 93 is an important travel artery that allows people and commerce to travel from Las Vegas to Interstate 80. During this winter storm, localized blizzard conditions caused 1 to 2 m (3 to 6 ft) high snow drifts to form over this critical section of road in southern White Pine County.

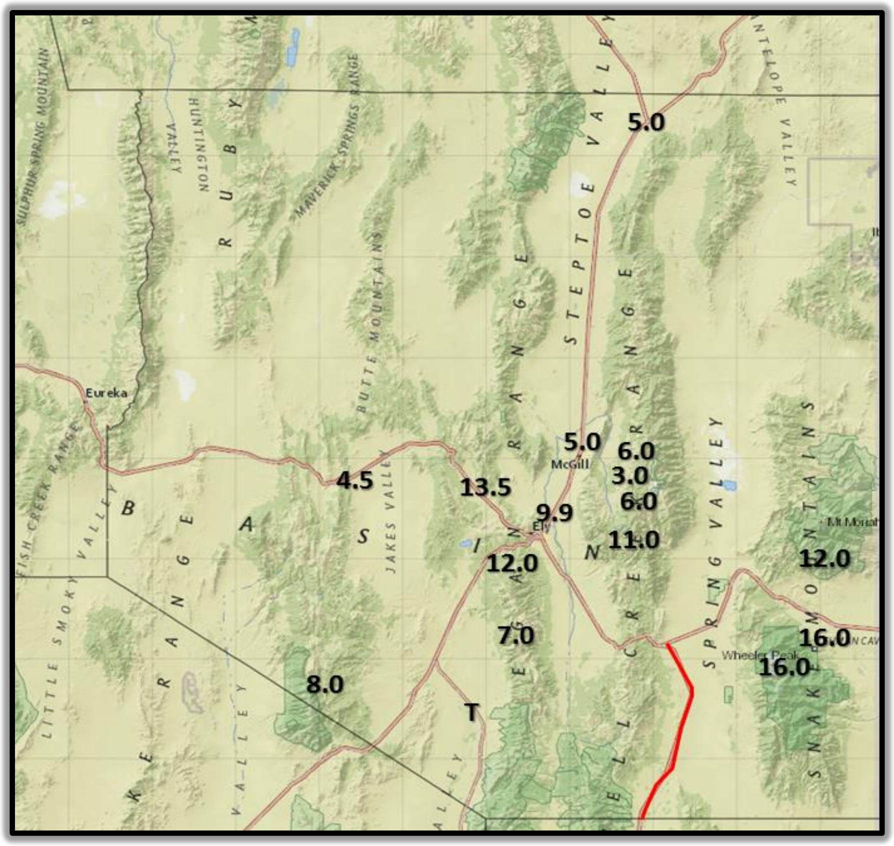

Figure 2 – Storm total snowfall map of White Pine County. Amounts are in inches. The red line depicts the area of U.S. Highway 93 that was closed during the winter storm.

The whiteout conditions, as seen in figure 3, as well as the formation of high drifts made for impossible travel and caused the road to close for approximately 10 to 18 hours (Lincoln County Record, 2013), stranding at least 50 motorists. Images of the snow drifts, stuck vehicles, and rescues are placed at the end of this paper.

Figure 3 – Nevada Department of Transportation (NDOT) heavy equipment removing snow in whiteout conditions along U.S. Highway 93. (Photo courtesy of NDOT)

This paper will investigate the winter storm, highlighting the anomalously long residence time of easterly winds and abundant moisture, which caused U.S. Highway 93 to close in southern White Pine County.

2. Data and Methodology

Model data for this event was gathered from the Storm Prediction Center's (SPC) hourly mesoscale analysis archive (http://www.spc.noaa.gov/exper/ma_archive/). Surface analyses and satellite imagery were retrieved from the Weather Prediction Center (WPC) (www.wpc.ncep.noaa.gov). Snowfall data were collected using NWS trained cooperative observers, as well as the Snowpack Telemetry (SNOTEL) observation sites that are managed and funded by the National Resources Conservation Service (NRCS). The snow-water equivalent measurement was taken from the Automated Surface Observing System (ASOS) in Ely, NV. Wind speeds were obtained from Remote Automatic Weather Stations (RAWS) and Desert Research Institute (DRI) observing sites throughout southern White Pine and northern Lincoln Counties. Standardized climatological anomalies were computed using data from 30-year climatology (1971-2000) and the NCEP-NCAR global reanalysis data (Graham and Grumm, 2010) and were taken from http://cms.met.psu.edu/sref/ensembles/. The image of the LKN sounding was taken from Plymouth State Weather Center's website at http://vortex.plymouth.edu/uacalplt-u.html.

3. Upper Air

a. 300 hPa analysis

Figure 4a is the 300 hPa map just before the heaviest snow began in White Pine County. It shows the subtropical branch of the jet moving across extreme southern Nevada and southern California. A strong area of divergence (shown in pink) is located in the left exit region of a 45 m s^{-1} (90 knots) jet streak. This area of divergence formed over an area of low to mid-level convergence, resulting in strong ascent through a deep layer of the atmosphere. This feature remained nearly stationary and lasted throughout the afternoon of the 21st across White Pine County (Figure 4b).

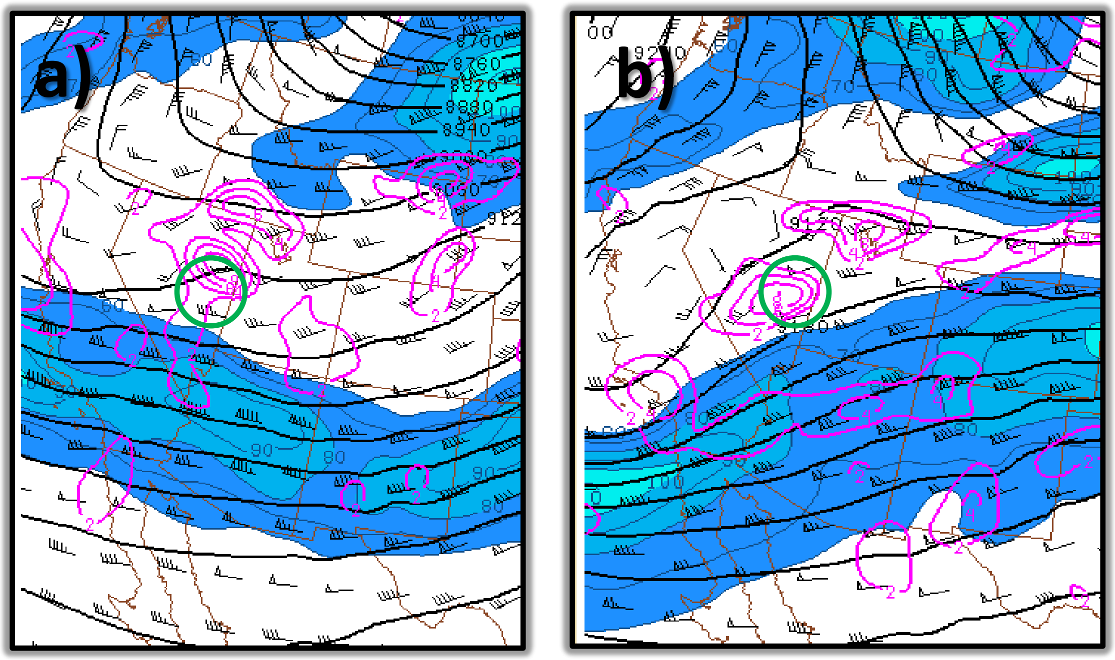

Figure 4: SPC 00-hour analysis showing 300 hPa geopotential height (black, solid lines, in meters)/divergence (pink, solid lines, in units 10^{-5} s^{-1})/wind speed (black, wind barbs) valid at a) 1200 UTC 21 November 2013 and b) 0000 UTC 22 November 2013. For this image and the rest of the images, the colored circles will depict the approximate location of White Pine County.

b. 500 hPa analysis

Figure 5a below depicted a rather broad positively tilted upper level trough that settled across the eastern Pacific at 1200 UTC. By late afternoon, a closed 500 hPa circulation developed across central California, as seen in Figure 5b. Over the area of interest in east-central Nevada, a deformation zone established itself during the afternoon of the 21st.

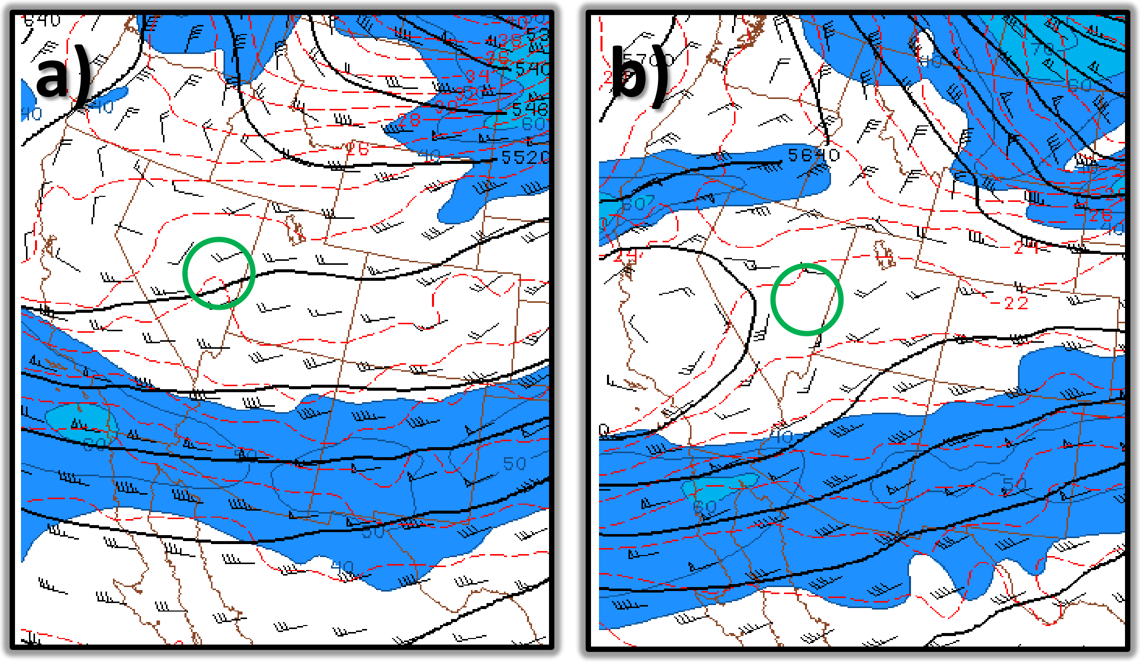

Figure 5: SPC 00-hour analysis showing 500 hPa geopotential height (black, solid lines, in meters)/temperature (red, dashed lines, in ^{o}C)/wind speed (black, wind barbs) valid at a) 1200 UTC 21 November 2013 and b) 0000 UTC 22 November 2013.

In addition to the 500 hPa trough and deformation zone, a modest vorticity maximum was located over extreme southwest White Pine County at 1200 UTC (seen in Figure 6a). This, in association with modest differential vorticity advection, enhanced snowfall rates by providing increased lift. This vorticity maximum increased in strength and remained nearly stationary over Central Nevada through 1800 UTC (seen in Figure 6b), before moving northward and out of White Pine County by 0000 UTC 22 November, not shown.

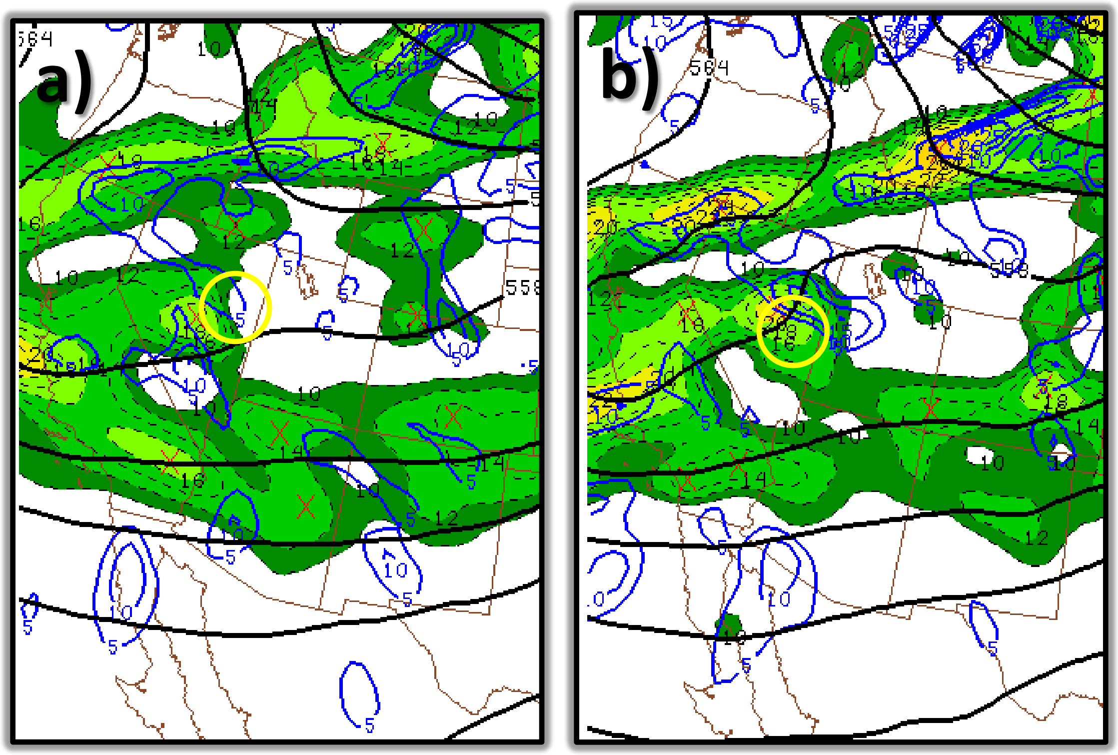

Figure 6: SPC 00-hour analysis showing 500 hPa geopotential height (solid black line) and vorticity (fill, warmer colors represent higher vorticity values) and 700-400 hPa differential vorticity advection (solid blue lines) for a) 1200 UTC 21 November 2013 and b) 1800 UTC 21 November 2013.

c. 700 hPa analysis

Shown below in figures 7a through c are the 700 hPa analyses depicting a closed low located across the mid-western portion of the California coast at 1800 UTC before slowly drifting off the coast of southwest California 18 hours later, as shown in figure 7c. The position of this low set the stage for strong and anomalous north to northeasterly flow by the afternoon and evening hours of the 21st across Nevada. Winds at this level increased to 15 to 20 m s^{-1} (30 to 40 knots), as seen in figure 7b. The initial moisture source of this event was from an antecedent airmass over Utah, before the closed low advected in a sub-tropical fetch of moisture from the south. The long residence time and sub-tropical fetch provided the region with +1 to 2 standard deviation precipitable water values as seen in figures 8a and b. This stream of moisture rotated cyclonically around the closed low into east-central Nevada from the Pacific Ocean and portions of northern Baja.

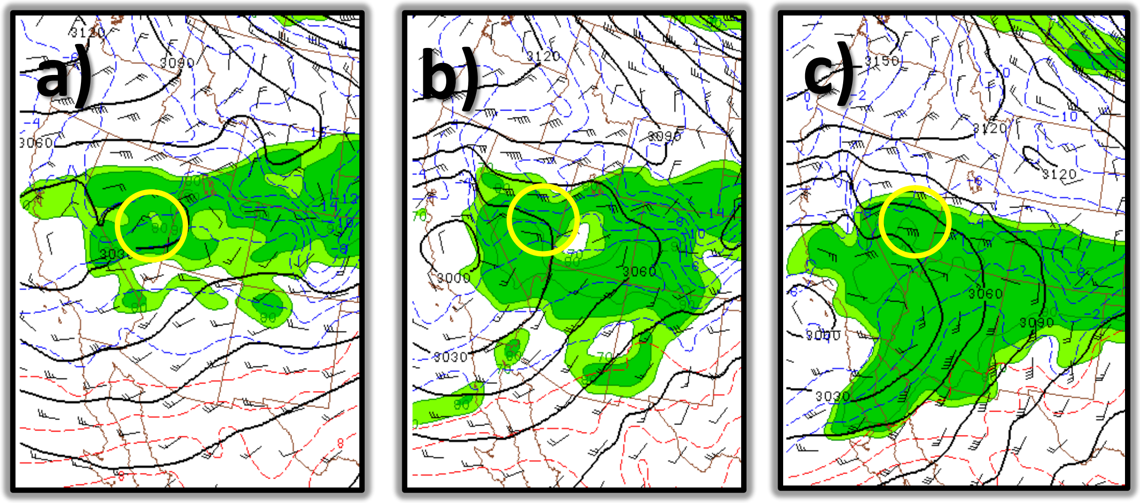

Figure 7: SPC 00-hour analysis showing 700 hPa geopotential height (black, solid lines, in meters) / temperatures (blue and red, dashed lines, in ^{o}C) / wind speed (black, wind barbs, full barb, and half barb denote 50, 10, and 5 kts, respectively) / 700 hPa-500 hPa mean relative humidity (green shading) valid at a) 1800 UTC 21 November 2013; b) 0000 UTC 22 November 2013; and c) 1200 UTC 22 November 2013.

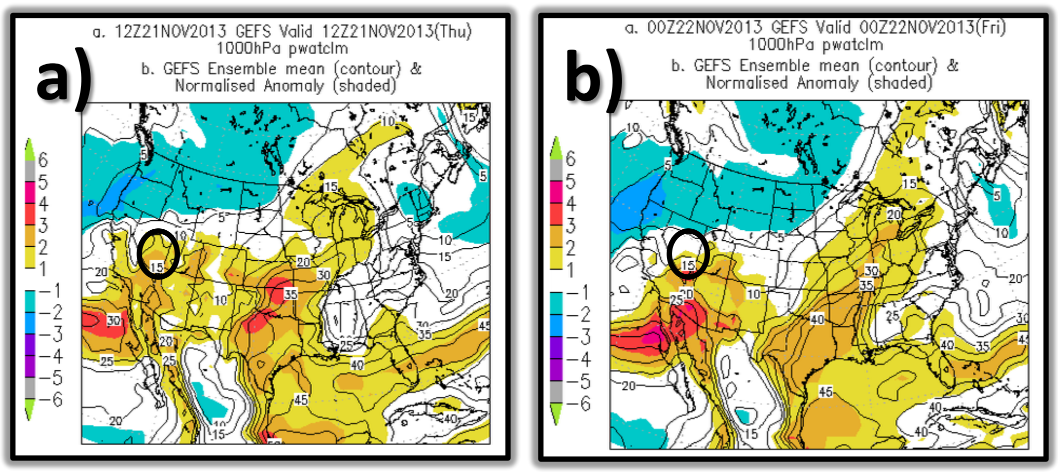

Figure 8: NCEP GEFS 00-hour forecasts showing precipitable water values (in mm) and anomalies valid at a) 1200 UTC 21 November 2013 and b) 0000 UTC 22 November 2013. Precipitable water contours every 5 mm, anomalies in standard deviations from normal (warmer colors represent higher anomalies).

4. Surface and Satellite Analysis

Figures 9a through c highlight the surface features and infrared satellite imagery (IR) during the early morning and afternoon hours of the 21st. Cold clouds tops are evident across east-central Nevada during the aforementioned time frame. Based on surface observations taken from the Ely ASOS, the heaviest snow fell between 1500 UTC and 2200 UTC (not shown). The cold front's forward motion decreased significantly across central and south-central Nevada. Dry, low-level Arctic air from southern Idaho and Oregon advected into portions of Elko's northern CWA, but due to the front's slow forward progression, the moist air mass had a residence time of 18 hours over southern White Pine County, causing enhanced snowfall.

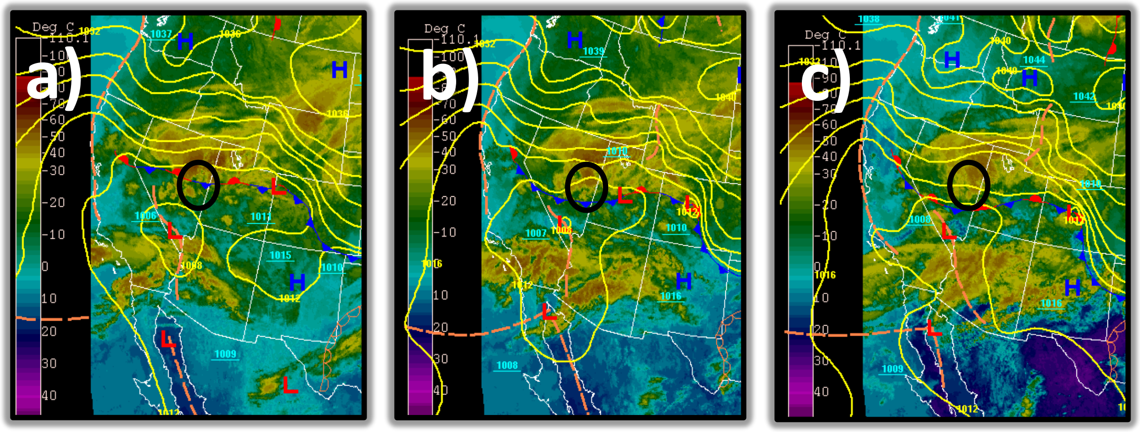

Figure 9: WPC IR composite satellite imagery and surface analysis valid at a) 1200 UTC 21 November 2013; b) 1500 UTC 21 November 2013; and c) 1800 UTC 21 November 2013. Isobars (solid lines, yellow) are in hPa.

Strong high pressure located over the northern Rockies, coupled with a surface low over the Desert Southwest, created a strong pressure gradient over central Nevada. This resulted in anomalously strong north to northeasterly winds over White Pine County. The strong winds led to blowing and drifting of snow and greatly reduced the visibility to near zero at times along U.S. Highway 93.

Table 1 below shows the hourly wind observations from five automated sites that were working at the time; Figure 10 shows the locations of the automated stations. Looking at these observations, wind speeds were near blizzard criteria at KELY after the frontal passage on the afternoon of the 21st. In addition, the COYN2 RAWS (mid-slope site location) site in northern Lincoln County showed the most impressive wind speeds from the evening of the 21st through the night into the 22nd. The two closest observation sites to the closed portion of U.S. Highway 93 were DNEP1 and DNEP4, which are both located at the west facing foothills of the Snake River Mountain Range, east of the highway. It is not known how representative these observing site conditions were to what occurred on the highway, but accounts and visual pictures clearly show ground blizzard conditions in the basin. It is possible that orographic (mountain) waves were occurring, due to the erratic behavior of the wind speeds at these two locations. One can see that both sites had winds increasing at 2000 UTC on the 21st, blowing through the night of the 22nd. Maximum gusts were peaking in the 9 m s^{-1} (20 mph) range through most of the night at DNEP4, while winds were 4.5 to 9 m s^{-1} (10 to 20 mph) lower at DNEP1. This could possibly mean turbulent eddies were occurring on the west side of the Snake Mountain Range.

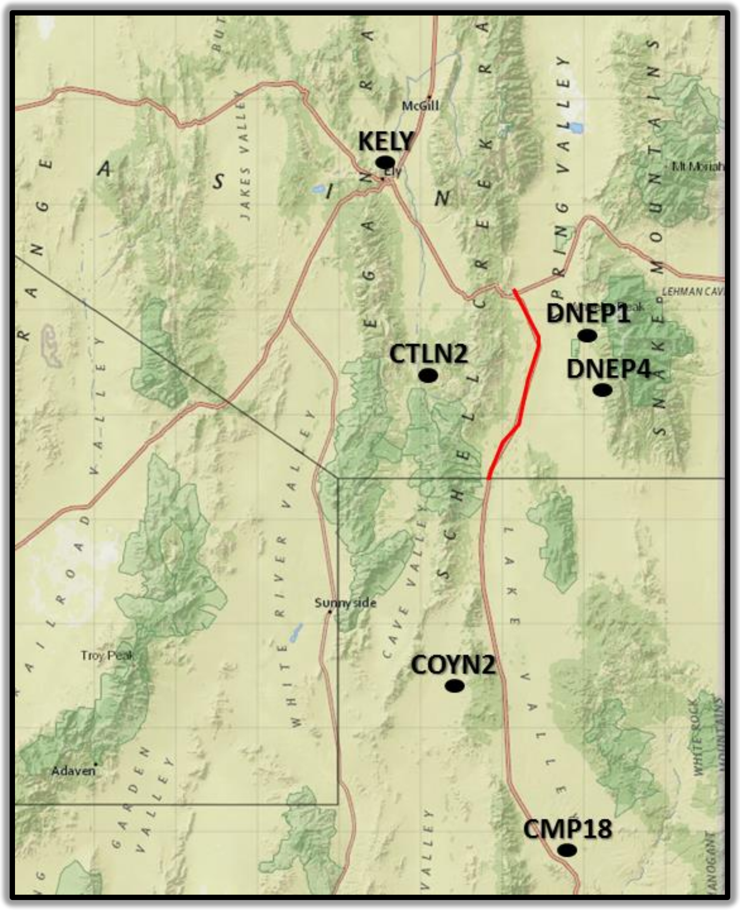

Figure 10: Location of automated weather stations referenced in Table 1. The red line depicts the area of U.S. Highway 93 that was closed during the winter storm.

Date and Time	KELY	CTLN2	DNEP1	DNEP4	COYN2
21-Nov					
12Z	NNE08	E0G2	SSW2G5	SW4G10	N3G6
13Z	NNE14	NNW1G3	ESE2G4	S2G5	ENE2G6
14Z	NNE13	N3G7	NW2G5	ESE2G4	N3G5
15Z	NNE22G27	NNW2G7	*	SE2G4	NNE6G11
16Z	N16G24	N4G9	*	SSE1G3	N5G9
17Z	N21	N5G10	*	SE2G6	NNW7G14
18Z	N24G30	NNE7G13	N6G13	E3G6	N5G11
19Z	N27G35	N9G17	NNW11G17	E3G5	N3G8
20Z	N29G36	NNE9G18	N15G24	ENE5G9	NE6G22
21Z	N27G41	NNE11G18	N21G28	NE12G20	N13G21
22Z	N29G38	NNE11G19	N17G27	NE9G16	N13G26
23Z	N25G36	N12G22	N15G21	NE10G17	NNE13G28
22-Nov					
00Z	NNE22G30	NNE11G19	N11G16	NE13G25	N18G33
01Z	NNE21G30	SE10G21	N14G22	NE14G27	N22G35
02Z	NNE28G33	N10G21	SE9G12	ENE10G22	N17G35
03Z	NNE22G35	NNE7G20	E5G10	NE12G21	N21G36
04Z	NNE21G32	NNE9G16	ESE2G6	NE12G24	N20G42
05Z	NNE24G33	NE8G14	SSE3G7	ENE10G19	NNE19G38
06Z	NNE21	NNE8G15	SSE6G10	NE13G26	N19G40
07Z	NNE18G28	NNE9G17	NW4G9	ENE13G30	NNE17G32
08Z	NNE23	NNE8G15	S3G4	NE10G24	N21G36
09Z	N20G27	NNE9G25	SE2G3	ESE11G26	NNE23G56
10Z	N16G25	NNE9G22	SSE4G8	E8G19	NE17G39
11Z	NNE23G29	NNW4G15	SSE5G7	ENE7G16	NNE20G32
12Z	NNE20G28	NE7G13	SSE6G8	ENE8G20	N20G45

Table 1: Hourly wind speeds and gusts (in mph) during the winter storm. Red text highlights sustained wind speeds greater than 20 mph and gusts greater than 30 mph.

Figures 11a and b depict a significant departure in the 850 hPa wind speeds of -2 to -3 standard deviations from normal. Due to the high elevation across Elko's CWA, 850 hPa can be used as the surface of most valley and basin floors, even though across White Pine County 825-800 hPa would be more representative.

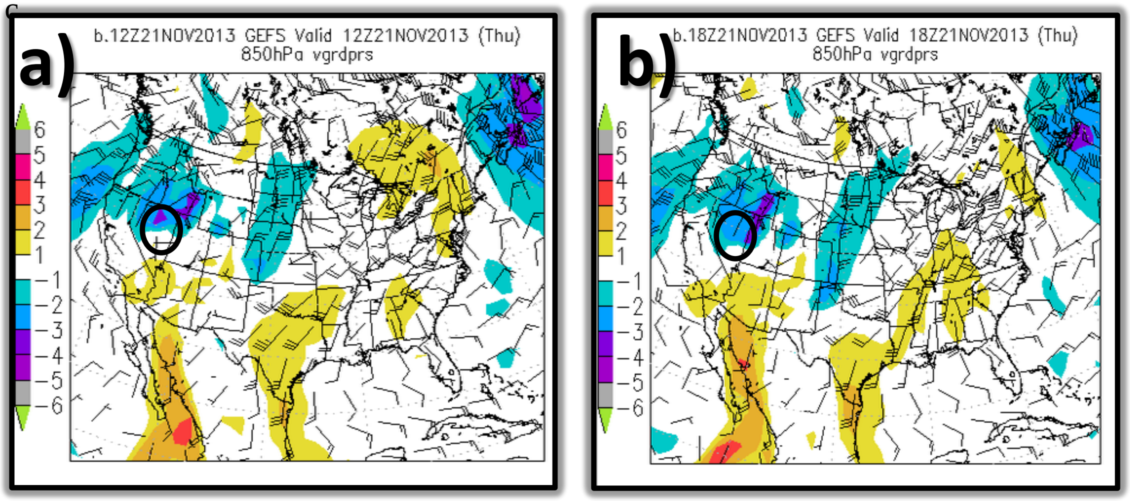

Figure 11: NCEP GEFS 00-hour forecasts showing 850 hPa wind speeds (black wind barbs) and anomalies valid at a) 1200 UTC 21 November 2013 and b) 1800 UTC 21 November 2013. Anomalies are in standard deviations from normal, with warmer colors representing positive anomalies.

Significant 1000 hPa surface anomalies were evident in Figures 12a and b. Standard deviations of 2 to 3 above normal were located across the Pacific Northwest, while anomalies of -1 to -2 were evident across the Desert Southwest. This is just another indicator of the strong pressure gradient forcing that led to the persistent long duration of strong winds across central Nevada on the afternoon of the 21st through the 22nd.

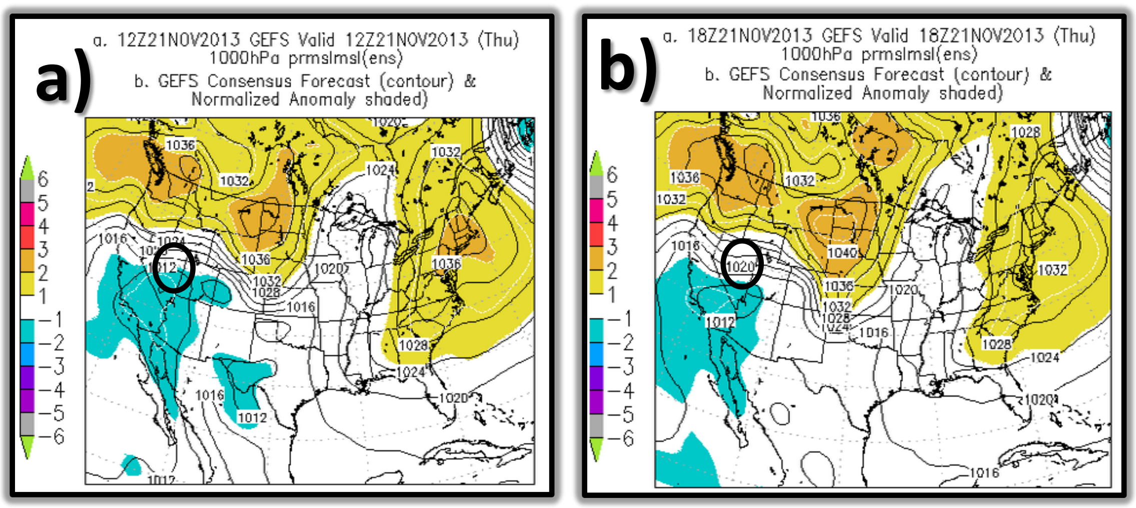

Figure 12: NCEP GEFS 00-hour forecasts showing mean sea level pressures (solid black lines, every 4 hPa) and anomalies valid at a) 1200 UTC 21 November 2013 and b) 1800 UTC 21 November 2013. Anomalies are in standard deviations from normal, with warmer colors representing positive anomalies.

5. Mesoscale Features

Frontogenetic forcing (seen in Figures 13a and b) across the area was modest, but due to the coarse nature of the archived mesoanalysis, pockets of moderate to strong frontogenesis likely existed. At 1200 UTC, a maximum in frontogenesis was located in southern Elko and White Pine Counties. This feature provided focus and enhanced lift; these ingredients were sustained through the afternoon of the 21st.

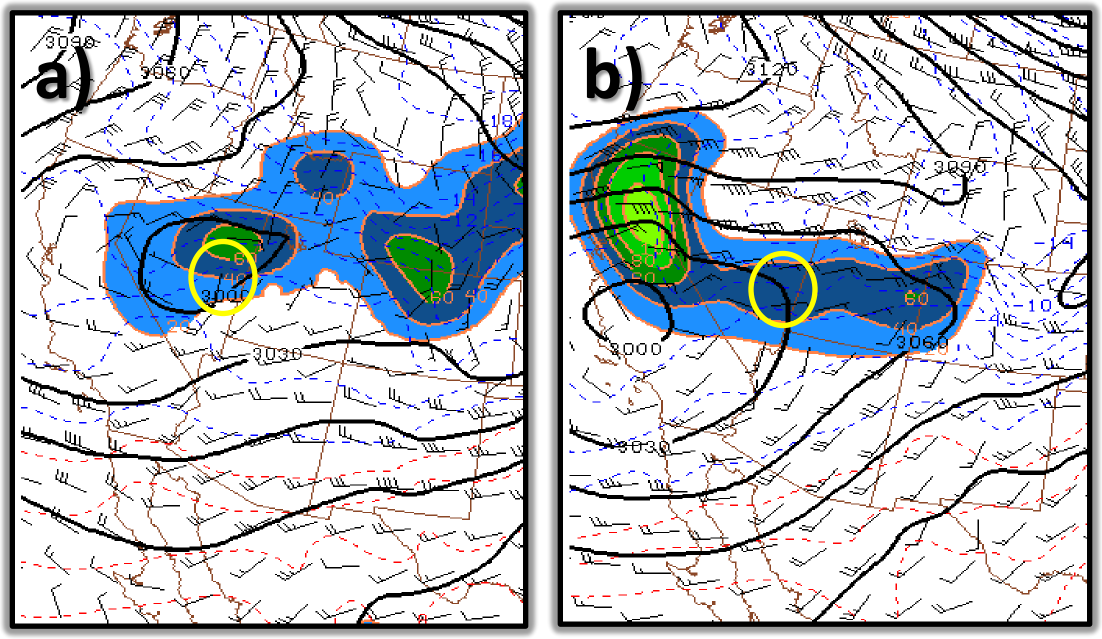

Figure 13: SPC 00-hour analysis showing 700 hPa geopotential height (black, solid lines, in meters)/temperatures (blue and red, dashed lines, in ^{o}C)/wind speed (black, wind barbs)/700 hPa Pettersson frontogenesis (shading, warmer colors represent stronger forcing) valid at a) 1200 UTC 21 November 2013 and b) 0000 UTC 22 November 2013.

a. Observed and Forecast Soundings

The 1800 UTC GFS BUFR forecast sounding, seen in Figure 14, showed a saturated column, with a maximum of omega located in the dendritic growth zone. This allowed for optimal dendritic growth, which enhanced snow ratios and led to significant amounts of snow. In addition, note the moist northeast flow in the low levels advecting in the moist antecedent airmass from Utah.

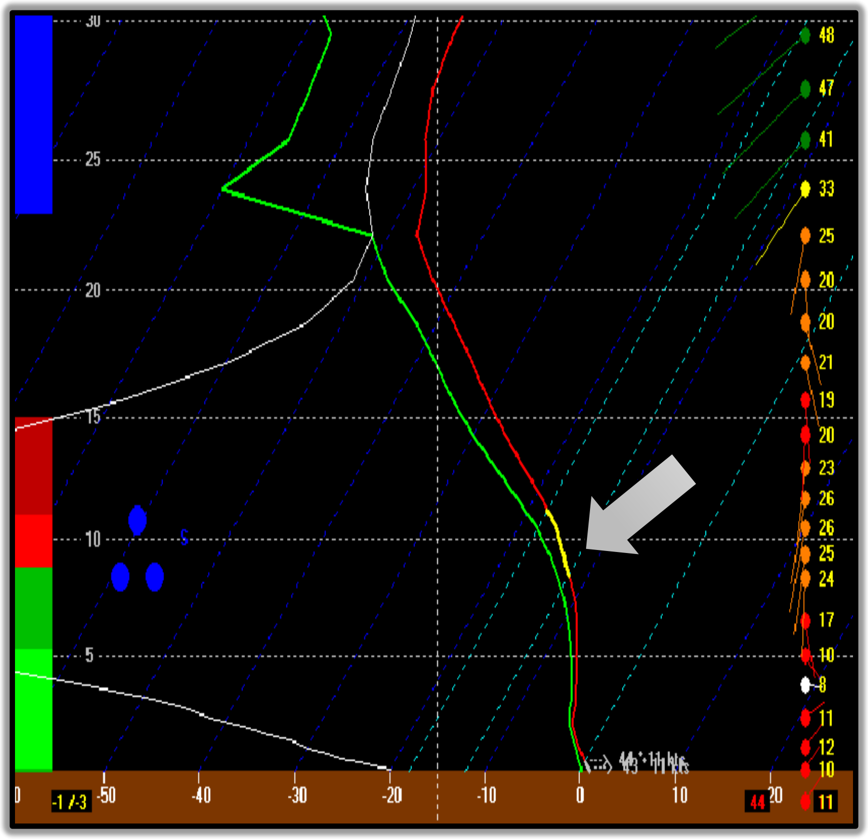

Figure 14: 0600 UTC NCEP GFS BUFR data for point KELY (Ely, Nevada) valid at 1800 UTC 21 November 2013 depicting temperature (red solid line), dew point (green solid line), omega (white solid line), and wind speed and direction (right side using wind vectors in knots). Dendritic growth zone (DGZ) (-12C to -18C) indicated by the yellow line on the temperature profile line. Note the location of the area of maximum omega coincident with the DGZ.

The GFS BUFR forecast sounding for 2100 UTC, (seen in Figure 15), depicts the northeast component of the wind from the surface to 1829 m (~6000 ft) AGL. With north to south orientated mountain ranges, a downslope wind component likely formed. According to Clark and Peltier (1984), this is an example of flow reversal, which can be seen in the 1524 to 3048 m (~5000 ft to 10000 ft) AGL layer. This is also collocated with a layer of near neutral or weakly stable air seen at 914 to 2134 m (3000 to 7000 ft) AGL. One can hypothesize this increased the potential for mountain wave activity, further enhancing the strong winds seen at the surface. The north-south orientated mountain barriers in central Nevada are steep and tall, which further increase the chance for mountain waves to form. Due to the limited number of observations, this cannot be confirmed.

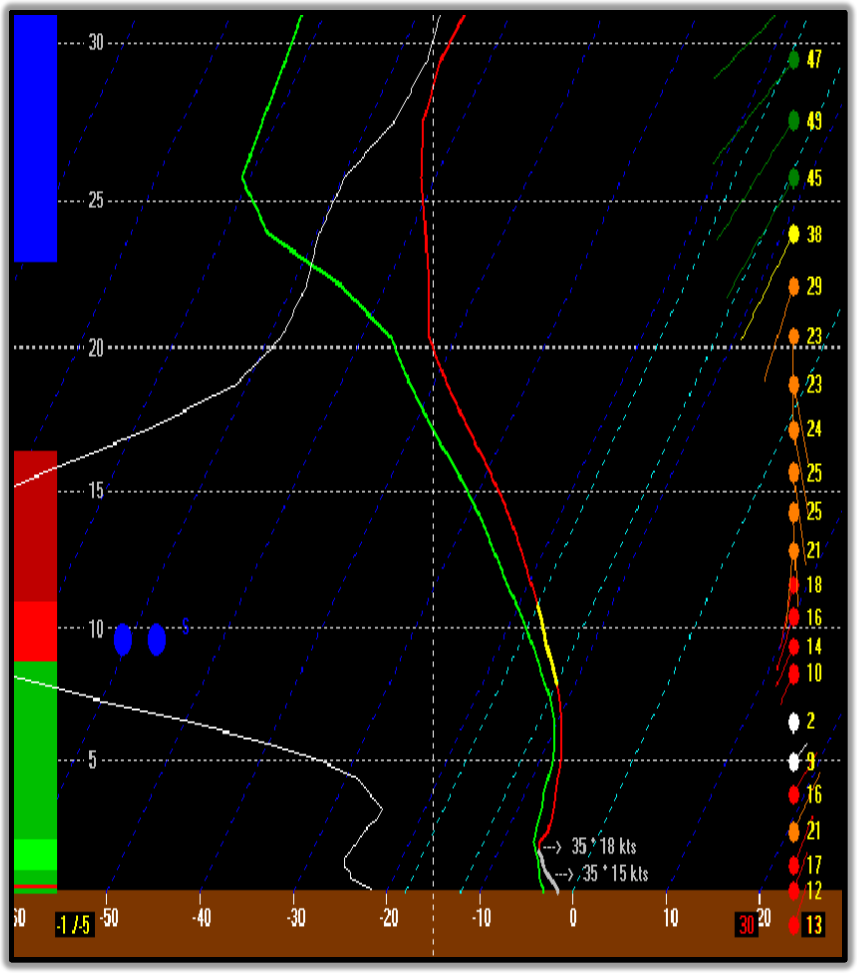

Figure 15: Same as Figure 14, except valid at 2100 UTC 21 November.

6. Radar Observations

Archived radar images during the period of heaviest snow can be seen in Figures 16 and 17. The usefulness of radar is very limited during the winter months in White Pine County. The two servicing radars, KLRX (Elko) and KICX (Cedar City) are both approximately 269 and 293 km (145 and 158 nmi) from Ely. Even with using the lowest 0.5 degree slice, KLRX's beam heights range from 3658 m (12000 ft) MSL across the northwest corner of the county to approximately 10688 m (35000 ft) MSL in portions of southeast White Pine County. In the winter, these challenges are exacerbated due to lower clouds tops associated with winter precipitation regimes.

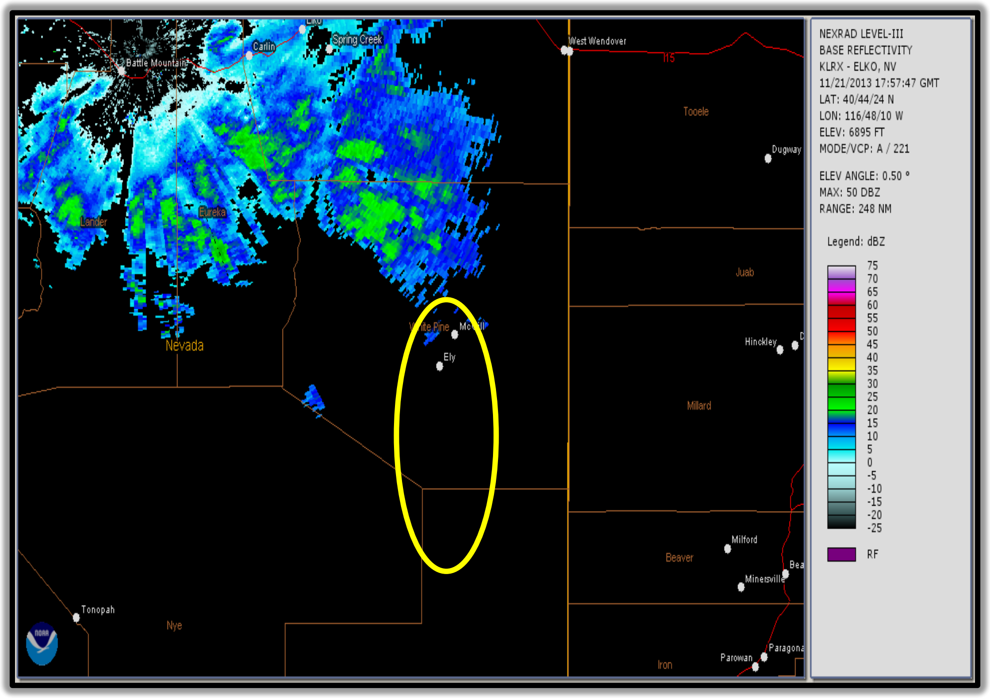

Figure 16: KLRX WSR-88D 0.5 degree reflectivity image valid at 1757 UTC 21 November 2013. Note the absence of reflectivity returns over southern White Pine County and northern Lincoln County. Yellow circle is approximate location of U.S. Highway 93.

KICX has the same radar sampling issues as KLRX, (seen in Figure 17). Elevations of the 0.5 degree reflectivity slice across White Pine County are similar to KLRX. This makes forecasting and monitoring precipitation extremely difficult in regions that have a limited observation network and that are sparsely populated.

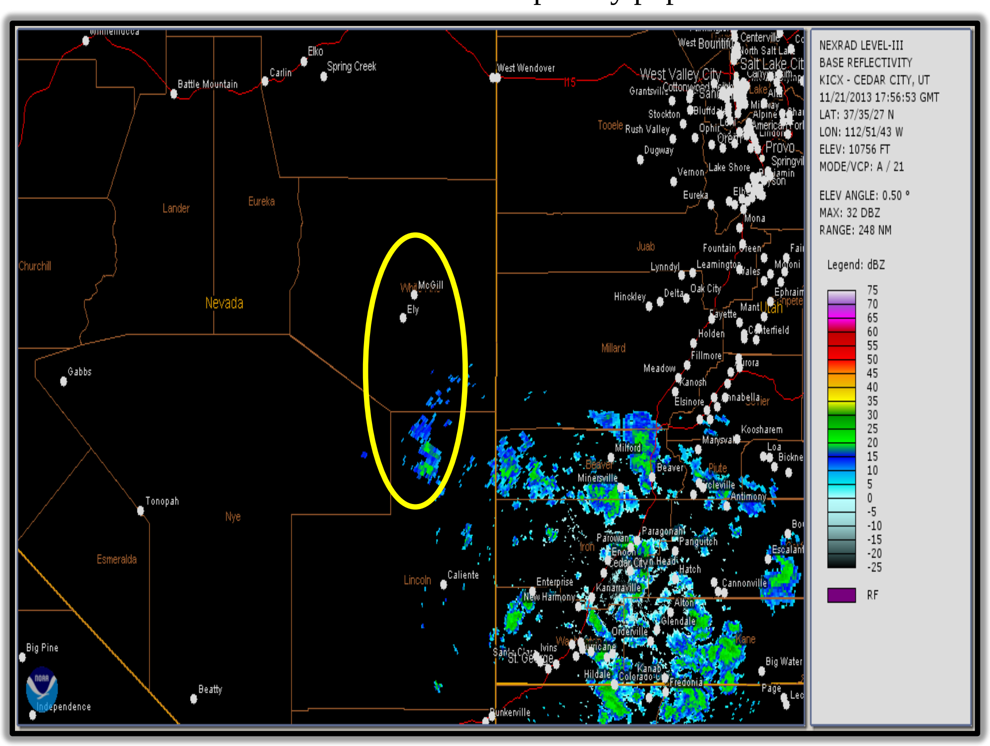

Figure 17: KICX WSR-88D 0.5 degree reflectivity image valid at 1756 UTC 21 November 2013. Note the absence of reflectivity returns over southern White Pine County and limited reflectivity returns across northern Lincoln County. Yellow circle is approximate location of U.S. Highway 93.

7. Conclusions and Operational Rules of Thumb

This area of the CWA is normally impacted by strong cold fronts that bring a 6 to 8 hour period of snow and localized blowing snow. There were two interesting aspects about this event. First, on the meteorological side, a prolonged period of strong winds, possibly enhanced by mountain wave activity, led to localized ground blizzard conditions. The second aspect deals with the societal impacts in a rural or desolate location of a CWA. The location of this event shows that even in areas of the country that have little to no population, but with a major travel corridor, a high impact event can still occur. During the period of 21 to 22 November 2013, approximately 50 individuals were stranded throughout the night on U.S. Highway 93. This is an excellent case for forecasters to recognize that even in some of the most unpopulated regions of the country, a high impact event can still occur and Impacted-based Decision Support Services to local officials is imperative to mitigate impacts.

Operational forecasters should be aware of the following:

1. Strong MSLP gradient situated north to south that will cause anomalous north to northeast winds over east-central Nevada.
2. Use of anomaly maps – these clearly showed a higher probability for strong V component winds at the surface. Higher than normal moisture levels were clearly evident in the precipitable water maps.
3. Increased awareness of easterly wind mountain wave events, along westward facing slopes, concurrent during moderate to heavy snow. This will bring significant blowing and drifting snow across U.S. Highway 93 in southern White Pine County.

8. Acknowledgments

The authors would like to thank Donald Dumont, Science Operations Officer, WFO - Elko for his assistance in providing crucial comments and guidance that made this paper better. We would like to send a special thank you to Deborah Block, Ely, NV NDOT Manager for providing information and images on the U.S. Highway 93 closure.

9. References

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Graham, Randall A., and Richard H. Grumm, 2010: Utilizing Normalized Anomalies to Assess Synoptic-Scale Weather Events in the Western United States. *Wea. Forecasting,* **25**, 428-445.

Lincoln County Record, 2013: Winter Storm Strands Travelers.

Figure 18: NDOT heavy equipment removing snow from U.S. Highway 93, along with helping stranded motorists. (Photo Courtesy of Nevada Highway Patrol - Elko)

Figure 19: Emergency vehicles assist a tractor-trailer that went off U.S. Highway 93 during the 21 November 2013 snowstorm. (Courtesy, Nevada Highway Patrol, Elko)

Figure 20: NDOT heavy equipment clears snow from U.S. Highway 93. (Courtesy, Nevada Highway Patrol, Elko)