1. INTRODUCTION

The state capital of Nevada, Carson City, experienced a rare lake-effect snowfall during the early part of November 2000. Within a two-day period, over 53 cm (23 in) of snow fell in Carson City as a result of lake effect from Lake Tahoe, CA. Several areas near surrounding smaller lakes in western Nevada experienced up to 25 cm (10 in) of lake-effect snow during the same time period. Senior forecasters at the National Weather Service (NWS) in Reno, Nevada, some with over 30 years of local experience, had never observed or recalled such an event. The rarity of this type of event coupled with the scarcity of observations, especially around Pyramid and Walker Lakes make this a very unique case. This event was brought about by an unusually cold weather system for early November moving over relatively mild lake surface temperatures.

Lake-effect snow is typical over the Great Lakes, as well as over the Great Salt Lake in Utah. Lake Tahoe and Pyramid Lake are considerably smaller in size, but were able to produce significant snowfall during the two-day period of 10-11 November, 2000. This paper presents the synoptic setting which resulted in the event, compares the Nevada event to classical lake-effect snows, reviews the microphysical processes and reports the observations of snow fall amounts. A companion paper elsewhere in this conference (Huggins et al. 2001) presents the radar characteristics of this event.

2. SYNOPTIC DISCUSSION

Western Nevada experienced a generally warm and dry weather pattern through most of October 2000 and into the first week of November. However, a major change in the synoptic pattern beginning on 8 November set the stage for the lake effect snow event in areas near Lake Tahoe and Pyramid Lake which began on the early morning of 10 November and continued through the afternoon of 11 November.

An unseasonably cold positive-tilt upper trough with 500 hPa heights around 5370 m centered in northern Washington was being driven southward by a northerly jet of 60 ms⁻¹ (125 kt) at 300 hPa over the eastern Pacific Ocean, along the west side of the trough (Fig. 1). A strong surface cold front associated with this trough moved southward across western Nevada during the late afternoon and evening of 8 November. Prior to the passage of the surface cold front, 500 hPa heights over western Nevada ranged from 5500 to 5580 m with 500 hPa temperatures around -20°C and 700 hPa temperatures around -18°C. Maximum surfacetemperatures had reached 14°C (~58°F) in the vicinity of Reno on 8 November. This cold front was accompanied by a narrow band of heavy snow which passed through Reno between 0300 and 0430 UTC on 9 November, and deposited 2-3 cm (about one in) of snow in the foothills around Reno. This frontal snow band continued moving southward across the Truckee Meadows (Reno) and into the Carson Valley. After 06 UTC, the front had stalled out near the Carson City and Douglas county line. Heavy snow continued through the overnight hours with totals by 15 UTC ranging from 12 to 25 cm (5 to 10 in) over much of Carson City, northern Douglas County, and central Lyon County. This narrow area of heavy snow was initially driven by dynamics and frontal lifting in a moist lower atmosphere, but a west wind of 5-10 ms⁻¹ (10-20 kt) across Lake Tahoe likely contributed to enhancing the intensity of the snow band (via the lake-effect process) and slowing its southward progress.

Cold and marginally unstable air continued to pour into western Nevada through 9-10 November as 500 hPa heights dropped to 5390 m, while 500 hPa temperatures over Reno plunged to -12°C and 500 hPa temperatures dropped to -32°C by 1200 UTC on 10 November. This large temperature difference produced a steep 700-500 hPa lapse rate around 8°C/km which continued through the day, with the surface-based lifted index lowering to -1 by 0000 UTC 11 November. Maximum surface temperatures across western Nevada on the 9th and 10th ranged from 0-3°C (32-38°F). Due to the much warmer water temperatures in the 10-13°C range (50-55°F) on Lake Tahoe and Pyramid Lake, actual lapse rates induced by the warm lake water were significantly steeper and much more unstable.

Overnight, a vorticity maximum moved southward across northeast California and advected even colder air into western Nevada, with 700 hPa temperatures bottoming out at -14°C and 500 hPa temperatures down to -33°C (Fig. 2). Winds at 700 hPa gradually shifted to northwest and north with average speeds of 5 ms⁻¹ (10 kt), which resulted in moving the snow band south of Carson City and into northern Douglas County through 1600 UTC, then into South Lake Tahoe before ending by 2000 UTC. As lapse rates decreased, winds...
3. SNOWFALL OBSERVATIONS

Snow began falling over western Nevada during the day on 8 November. By late afternoon, locations in the Carson Valley and east towards Yerrington had received 5.1-7.6 cm (2-3 in) of snowfall. Later that evening, snow showers increased in coverage enveloping much of the urban corridor including the Reno/Sparks vicinity. By the morning of 9 November, many of the western Nevada valleys had accumulated from a trace to 5.1 cm (2 in) of snow. However, to the east of Lake Tahoe, locations received from 12.7-25.4 cm (5-10 in) of snow. Even towns several miles directly to the east of Lake Tahoe, such as Wabuska and Yerrington, had received from 15.2-25.4 cm (6-10 in) of snow.

Accumulations remained light during the day of the 9th but increased once again overnight. By the morning of the 10th, additional accumulations east of Lake Tahoe ranged from 10.2-22.9 cm (4-9 in). At this point, parts of Carson City and south to Minden had snow depths in excess of 30.5 cm (12 in).

The final wave of heavy snow occurred late on 10 November into the morning of the 11th. Heavy snow overnight brought accumulations ranging from 7.6-22.9 cm (3-9 in) throughout the Carson Valley. Also, towns located to the south of some other area lakes reported unusual snowfall. South of Walker Lake, Hawthorne received 17.8 cm (7 in) and south of Pyramid Lake, the Palomino Valley received 15.2 (6 in). No additional valley snow accumulations were reported after the morning of the 11 November. Figure 3 presents a graphical summary of total snowfall for the period of 8-11 November.

4. COMPARISONS TO OTHER LAKE EFFECT EVENTS

Lake-effect snows are frequently observed on large lakes throughout the United States, in particular the Great Lakes and the Great Salt Lake in Utah. Numerous studies have been produced, and were reviewed for comparison. We wanted to discover if the western Nevada lake-effect snows had similar characteristics. Lake-effect snow events were reviewed (Steenburgh et al. 2000; Wilken 1997) with several common factors noted which influence lake-effect snows. These included: 1) synoptic influences; 2) instability; 3) wind shear; and 4) fetch.

4.1 Synoptic Influences

The lake-effect snow event of western Nevada showed the same basic synoptic features as events in other areas of the country. A post cold-frontal airmass was in place with an upper trough and associated cyclonic flow over the area. Cold advection in this pattern continued from the afternoon of 9 November through 11 November.

4.2 Instability

According to Bluestein (1993), one of the necessary conditions for lake-effect snow is a nearly dry-adiabatic boundary layer at least 1 km deep, capped by an inversion. To approximate this condition in the Great Lakes region, the temperature difference between the water surface and 850 hPa of 13°C is required. This figure is adjusted for higher lake elevations in the western U.S.. In this study a lake surface-700 hPa temperature difference was used with 17°C needed to approximate a dry-adiabatic lapse rate. Data from 0000 UTC 10 November through 0000 UTC 12 November showed a lake surface-700 hPa temperature difference at Pyramid Lake exceeding 23°C, indicating a very unstable airmass in the boundary layer. Lake Tahoe was also unstable with a lake surface-650 hPa difference exceeding 26°C.

Lake-modified soundings for the period showed extremely large convective available potential energy (CAPE) values (over 2000 J kg⁻¹) on Pyramid Lake, along with lifted indices of -10 or lower. Similar values were derived for Lake Tahoe. As with Steenburgh et al. (2000) in the study of the climatology of lake-effect snowstorms of the Great Salt Lake, the surface parcel characteristics used in the calculations were based on an average of the lake-land temperatures with the
surface dewpoint set equal to the temperature.

Observed soundings from Reno, NV (REV) were stable to slightly unstable (lifted indices of +2 to -1) with low CAPE values (0 to 200 J/kg). Figure 4 shows the dramatic differences of CAPE and lifted indices between the observed and lake-modified soundings at Pyramid Lake. None of the soundings from 0000 UTC 10 November through 0000 UTC 12 November showed a capping inversion, although one sounding (1200 UTC 11 November; Fig. 5) showed a shallow isothermal layer just above 500 hPa. This does not appear to fit the “ideal” lake-effect snow sounding, however Steenburgh et al. (2000) found approximately half (15 of 29) of rawinsonde observations in the Great Salt Lake study to be without significant capping inversions or stable layers.

Figure 4. Comparison of CAPE and lifted indices between observed REV soundings and lake-modified soundings at Pyramid Lake, NV.

4.3 Wind Shear

Steenburgh et al. (2000) reported that low-level flow typically needs to be oriented along the major axis of a lake for intense snow bands to develop. Winds oriented along the minor axis of a lake typically produces multi wind-parallel snow bands that are less intense. In addition, strong snow bands appear to intensify during periods of unidirectional low-level flow.

Significant directional shear was not observed on soundings during this study. Shear between the lake surfaces and 700 hPa (650 hPa for Lake Tahoe) did not exceed 60 degrees (40 degrees for Lake Tahoe) from 10-12 November. It should be noted that on the morning of 11 November during the time when steering winds brought the flow parallel to the major axes of most area lakes, the directional shear at Lake Tahoe was only 10 degrees while 20 degrees was observed at Pyramid Lake.

4.4 Fetch

Bluestein (1993) studied lake-effect snow in the Great Lakes area, and determined that a fetch of at least 80 km was necessary for lake-effect snowstorms. A fetch is defined as the length of area in which waves are generated by the wind, in the direction of the wind over the lake water. Steenburgh et al. (2000) in studies of the Great Salt Lake showed that significant snowfall is possible when this criteria is met. In the case of the Great Salt Lake the flow would be oriented along or near the major axis to produce a fetch of 80 km. Lakes in western Nevada and eastern California are much smaller and could not meet the fetch criteria mentioned by Bluestein. Pyramid Lake is approximately 40 km long at it’s longest point, with a width ranging from 7 to 16 km. Lake Tahoe is approximately 35 km long and 14 km wide.

Radar loops (Huggins et al. 2001) over Pyramid Lake on the morning of 11 November showed strong reflectivity over the southern portion of the lake and several kilometers inland, oriented along the major axis of the lake as low level wind shifted to the north. The strongest reflectivity observed was 40-45 dBZ around 1330 UTC. Although sparsely populated, reports from south-southwest of the lake indicated snowfall of up to 15 cm (6 in) between 1430 UTC and 1830 UTC. Low level wind shifted to the northeast by that time and a well-defined mid-lake band formed that extended approximately 30 km southwest of the lake. This band showed possible orographic enhancement and was similar to that described by Steenburgh et al. (2000) except that the precipitation axis was no longer parallel to the major axis of the lake. Snowfall totals were not available over this mostly uninhabited area. A similar band was observed on Lake Tahoe, but with much lower radar reflectivity. The weaker reflectivity returns on Lake Tahoe were likely due to the greater distance from the radar and the resulting over-shooting of the radar beam.

5. MICROPHYSICAL PROCESSES

The unusual circumstances on 10-11 November 2000 which lead to lake effect snow on western Nevada lakes can be attributed to many factors. The mild lake temperatures were reflective of a relatively warm October compared to average (Fig. 6). On 10 November the air temperature plummeted to 0°C (32°F) at Sutcliffe, Nevada at Pyramid Lake while the lake water temperature was measured at 12.7°C (55°F). As -14°C
air at 700 hPa moved over the area on 11 November the lake surface-700 hPa lapse rate was 26°C compared to the dry adiabatic lapse rate of 17°C through the same layer. When adjusted for altitude these conditions rated extreme on the Collier Index for severity of lake-effect snowfall. [The Collier Index was developed from a local study at the Buffalo, New York NWS. No documentation is available on this Index, though it is used frequently in the Great Lake weather offices.]

As with most lake effect events, the most important factor was the low level instability due to very cold air (-14°C) at 700 hPa over a relatively warm lake surface (11.7°C). The flux of water vapor from the lake into cloud could be visualized as fog lifting off the lake surface into a deep convective cloud up to the equilibrium level. On the morning of 11 November the 1200 UTC sounding at REV (Fig. 5) showed an equilibrium level of 5.67 km (18,600 ft) or 480 hPa. Within this relatively deep moist layer, microphysical processes were occurring to enhance snow fall productions. Ice crystal growth by deposition occurs primarily between -10°C and -20°C and reaches a maximum around -15°C. The number of active ice crystal nuclei per liter do not become significant until temperatures of -15°C or colder are reached. Growth by aggregation occurs and is maximized when ice crystals of different shapes and terminal velocities collide in layers with temperatures between 0°C and -10°C. Figure 5 also indicated that most of the saturated airmass below the equilibrium level was within the temperature ranges favorable for all the preceding types of microphysical processes leading to snow production.

6. CONCLUDING REMARKS

Western Nevada experienced a rare lake-effect snow in the early part of November 2001. Forecasters at the NWS office in Reno had never experienced a similar event in over 20 years. This paper presented the review of the synoptic conditions which produced this rare snow event. Forecasters working on this case have discovered similar traits of the larger lake-effect snows compared to the Great Lakes, and the Great Salt Lake. It is hoped that this event will be considered "lessons learned"; the remaining forecast staff will be trained on the characteristics of this event in hope that future events will be well-forecast.

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8. REFERENCES


