Synoptic Patterns Associated with Flash Floods in Eastern California and Western Nevada

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1. Introduction

Maddox et al. (1980) identified four generalized synoptic patterns to produce flash flooding in the western United States. As valuable as Maddox's study is, it does not completely describe the unique synoptic patterns that produce flash flooding in eastern California and western Nevada (Reno CWA, Figure 1). The Reno CWA presents several difficulties in flash flood forecasting. The complex terrain of the eastern slopes of the Sierra Nevada and mountain ranges in western Nevada provide many possible areas for flash flooding to occur. Steep terrain along most major highways poses a significant rock slide threat, while urban areas in western Nevada are also prone to flash flooding due poor drainage systems. Wildfires can also create an additional flash flood hazard, by greatly reducing vegetation and soil stability (United States Geological Service, 2005).

The purpose of this study is to determine the unique synoptic patterns, and sounding parameters associated with them, that have the potential to produce flash flooding in the Reno CWA. Identifying these patterns and providing a set of key sounding parameters will allow forecasters to improve lead time on heavy rainfall events and alert customers to the potential of flash flooding.

2. Data and Methods

The National Climatic Data Center (NCDC) Storm Event Search Engine (NCDC, 2004) was used to identify all reported flash flood events between 1994 and 2003 for western Nevada and eastern California (Figure 2). The search engine returned 25 days where at least one flash flood occurred in the Reno CWA. July and August had the most events, which coincides with the peak thunderstorm activity in the summer. Three of the 25 days occurred during the winter and early spring months (January, February and March) and were discarded since this study will focus on flash flooding during the summer months.

The summer cases were analyzed using 500 mb synoptic charts of geopotential height and were grouped into patterns with similar characteristics. The synoptic charts were collected from the National Center for Environmental Prediction (NCEP) and National Center for Atmospheric Research (NCAR) Reanalysis project (Kistler et. al., 2001). Three distinct 500 mb patterns were found and each will be discussed in the next section.

Upper air observations play an important role in assessing convective development and heavy precipitation potential. Sounding data from the 00Z and 12Z flights were collected for each flash flood day from observations sites at Winnemucca, for 1994, and Reno, for 1995 through 2003. The following parameters were analyzed: Precipitable Water (PW) in inches, 700 mb Equivalent Potential Temperature (EPT) in Kelvin, K-Index (KI) in degrees C, High Level Total Totals (HLTT, Milne, 2004) in degrees C and Storm Motion (SM) in knots.

Milne defines the HLTT, a modification of Miller's (1972) Total Totals Index, by the following equation,

$$HLTT = 700T + 700Td + (500T * 2)$$

where 700T is the 700 mb temperature in C, 700Td is the 700 mb dew point in C and 500T is the 500 mb temperature in C.

3. Synoptic Patterns and Sounding Data

Individual 500mb synoptic plots of geopotential height from the 22 flash flood days between 1994 and 2003 revealed three distinct patterns can produce flash flooding in western Nevada and eastern California. The patterns are, Four-Corners High (FCH), Great Basin High (GBH), and Upper Low (UL). The FCH is associated with 3 flash flood days, the GBH associated with 6 days, and the UL associated with 12 days.

Sounding data for each event was collected and tables (Tables 1 though 3) were generated for the maximum, minimum and average values for the parameters listed in the previous section. These tables will be used as a guide for NWS Reno forecasters to determine the daily flash flood potential based on the upper air observations. If the average values are exceeded, forecasters should strongly consider issuing a Flash Flood Watch. Values between the minimum and average should increase situational awareness for a heavy rainfall event and use the appropriate wording in text products to alert customers of the threat.

These tables can be used when attempting to project the flash flood potential over the next one to three days based on model output. Caution is required since no evaluation of the accuracy of model forecast for these parameters has been completed. These tables will also be used to improve the Flash Flood Potential Index (FFPI), a graphical product produced within the Graphical Forecast Editor (NWS Reno, 2002) to highlight flash flooding potential in the Reno CWA.

Four Corners High

The FCH is a common synoptic feature in the southwestern United States during the summer months (Figure 3). The anticyclone is usually centered over Arizona or New Mexico, but can be centered as far north as central Utah and Colorado or as far east as west Texas. Flash flood days in this pattern are characterized by PW values of 0.85 inches and higher and 700 mb EPT greater than 335 K. The KI is generally above 27, and the HLTT near 30. Table 1 shows tabulated values of maximum, minimum and average PW, 700mb EPT, KI, HLTT and SM values from the 00Z and 12Z Reno soundings for the three flash flood days in this pattern. A sounding from this pattern is found in Figure 4.

Moisture is advected around the anticyclone from the Gulf of California or in some instances the Gulf of Mexico. The residence time of the anticyclone is important to the amount of moisture that is advected northward into Nevada. A short residence time, less than 36 hours, yields enough moisture for thunderstorms, but the thunderstorms may produce little to no rainfall due to a lack of low level moisture, low KI values, and are a threat for a significant number of wildfire starts. A residence time of more than 36 hours allows sufficient moisture to advect northward into central and northern NV and thus produce the threat of flash flooding. Several days of thunderstorms will moisten the boundary layer, produce a higher KI, and lessen the amount of evaporation of rain between the cloud base and the ground. The sounding in Figure 4 was observed after approximately 48 hours of moisture advection, yielding a PW value of 1.33 inches a very high amount for western Nevada.

Thunderstorms from this pattern are generally pulse type storms that develop over the mountains in the early afternoon due to strong solar heating and move over valley locations by late afternoon. Vorticity maxima may be imbedded in the southerly flow can enhance thunderstorm development and increase the threat for flash flooding. This will produce stronger updrafts and increase the precipitation rates from the thunderstorms.

Great Basin High

The GBH is not as common as the FCH pattern, but has caused more flash flood days. The GBH (Figure 5) is centered over NV or UT, but at times can be elongated or ill defined. This pattern can evolve from a FCH, if there is a deepening trough over the eastern US, causing the FCH to retrograde into the Great Basin. The movement of the upper high into the Great Basin shuts off the moisture feed from the Baja, and backs the flow over NV from south to east. This means flash flood days from this type of pattern occur with lower moisture levels than the FCH. The PW values range between 0.50 to 0.85 inches and 700mb EPT values between 325 and 340 K. The KI is also lower, due to less moisture below 700mb, with values generally above 25 C. Table 2 shows tabulated values of maximum, minimum and average PW, 700mb EPT, KI, HLTT and SM values from the 00Z and 12Z Reno soundings for the six flash flood days in this pattern.

Under the GBH, light and variable winds aloft limit the movement of thunderstorms allowing the rain they produce to accumulate over a longer time period. Of the 12 soundings on GBH flash flood days, 10 of these indicated Storm Motion (SM) winds of 10 knots or less. The other two soundings recorded SM of 13 and 14 knots. Figure 6 shows a sounding from a GBH event from 00Z 14 Jul 1999. This sounding clearly shows the light winds from the surface to 300mb. The slow storm motions associated with the GHB provide a longer duration for rainfall events to compensate for the lower amounts of moisture and lower precipitation intensities.

Thunderstorms in this pattern are slow moving pulse type storms that develop from very warm surface conditions. With high pressure over the Great Basin, surface high temperatures during the summer are often above normal with afternoon highs at or above 100 degrees. This provides very steep low and mid level lapse rates favorable for strong convective development which are also present in Figure 6 below 500mb.

Upper Low

This pattern is characterized by a 500mb low or trough in the vicinity of western Nevada, California or the eastern Pacific near the California coast (Figure 7). An upper low at 500mb provides more large scale ascent than the anticyclones in the FCH and GBH patterns, especially in the region of diffluent flow in the northeast quadrant of the low. This large scale ascent can produce organized convection due to favorable shear profiles and additional severe weather threats (Brong, 2004). This leads to thunderstorms with stronger updrafts and high precipitation rates with lesser amounts of moisture, than the pulse type storms in the FCH pattern. Figure 8, shows a sounding from a UL case on 4 Aug 2003. Note the strong veering wind profile below 600mb, high CAPE value near 1500 J/kg and the 0-3 km storm relative helicity of 172 m^2/s^2.

The 500mb flow over NV with this pattern is usually from the south or southwest at speeds higher than 15 kts. This is due to the upper low interacting with an anticyclone centered over Four Corners region. The FCH provides the initial push of moisture, but as the upper low nears western NV the increased southerly flow and large scale ascent can quickly boost the flash flood potential.

Sounding parameters from the UL pattern are similar to the GBH pattern. KI is usually between 25 and 35 C but can be as low as 16 C and can exceed 40 C. HLTT values are generally between 20 and 35 C and the 700mb EPT is 320 to 335 K. However the PW values, 0.55 to 0.90 inches, fall in between the ranges of the GBH and FCH patterns. Table 3 shows tabulated values of maximum, minimum and average PW, 700mb EPT, KI, HLTT and SM values from the 00Z and 12Z Reno soundings for the twelve flash flood days in this pattern.

4. Summary

Between 1994 and 2003, 22 convective flash flood days occurred in the Reno CWA. Three distinct 500mb geopotential height patterns that can produce flash flooding were identified from these 22 days, FCH, GBH and UL. Upper air observations were collected for each of the 22 days and analyzed to determine what parameters can be used as keys to improve flash flood forecasts.

Flash flood thresholds were developed for each of the three patterns based on the PW, 700mb EPT, KI, HLTT and SM from the sounding data on the flash flood days. The FCH pattern had the highest moisture values due to tropical moisture being advected north from the Gulf of California. The GBH pattern has the least amount of moisture, since there is no source of moisture over the Intermountain West. However very low storm motions occur with this pattern allowing thunderstorms to produce rainfall over a location for a longer time duration. The UL pattern contains higher amounts of lift due to cooler air aloft and large scale upper divergence. The UL can also advect moisture from the sub tropics, but only if it is coupled with a FCH.

Knowledge of these patterns and the sounding parameters values that occurred on known flash flood days will improve and increase confidence in flash flood forecasts.

5. References

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6. Figures

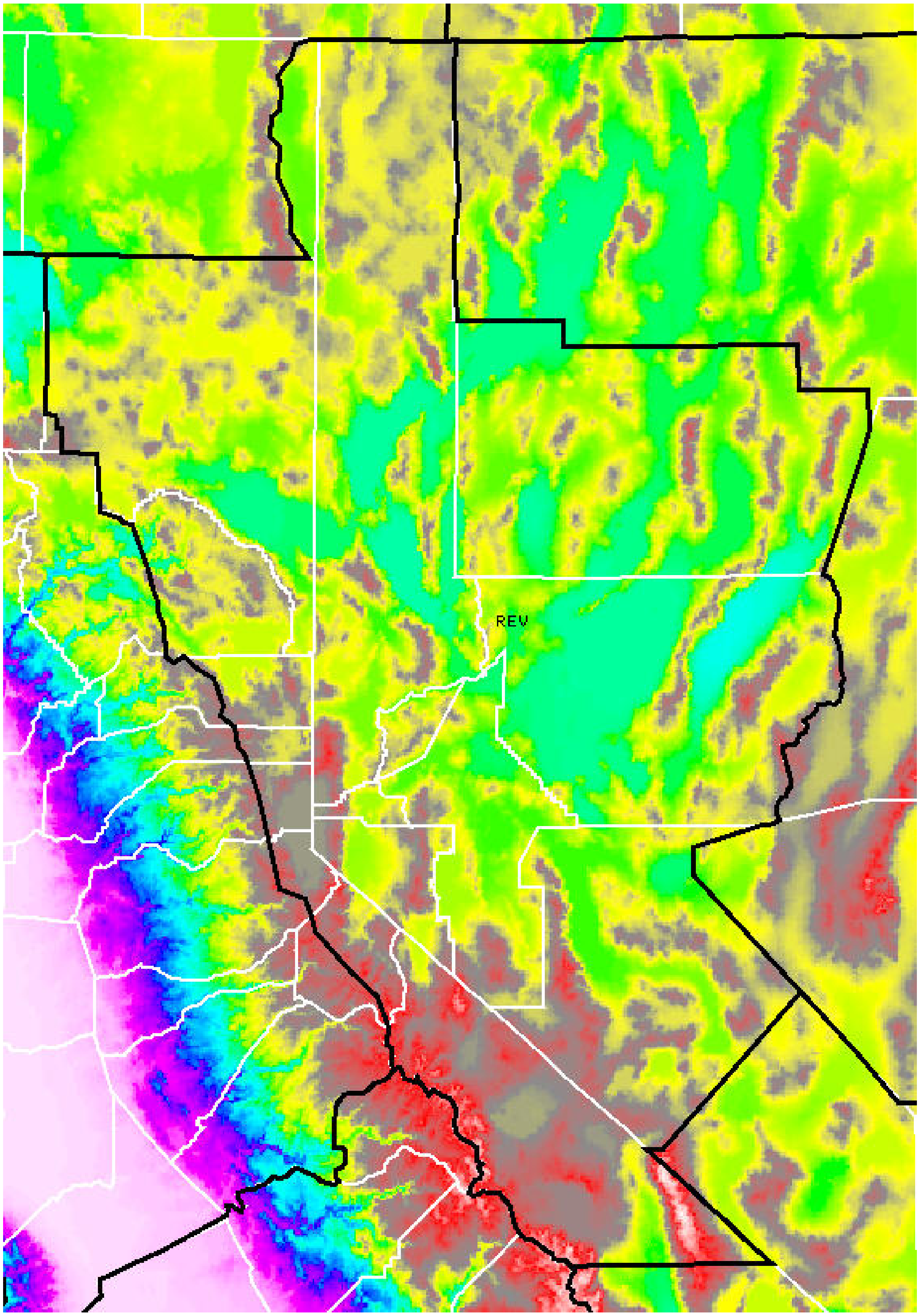

Figure 1: The complex terrain in the NWS Reno CWA (outlined in black with counties lined in white). The light blue shading represents elevations near 4000 feet, red and gray shades are elevations above 8000 feet.

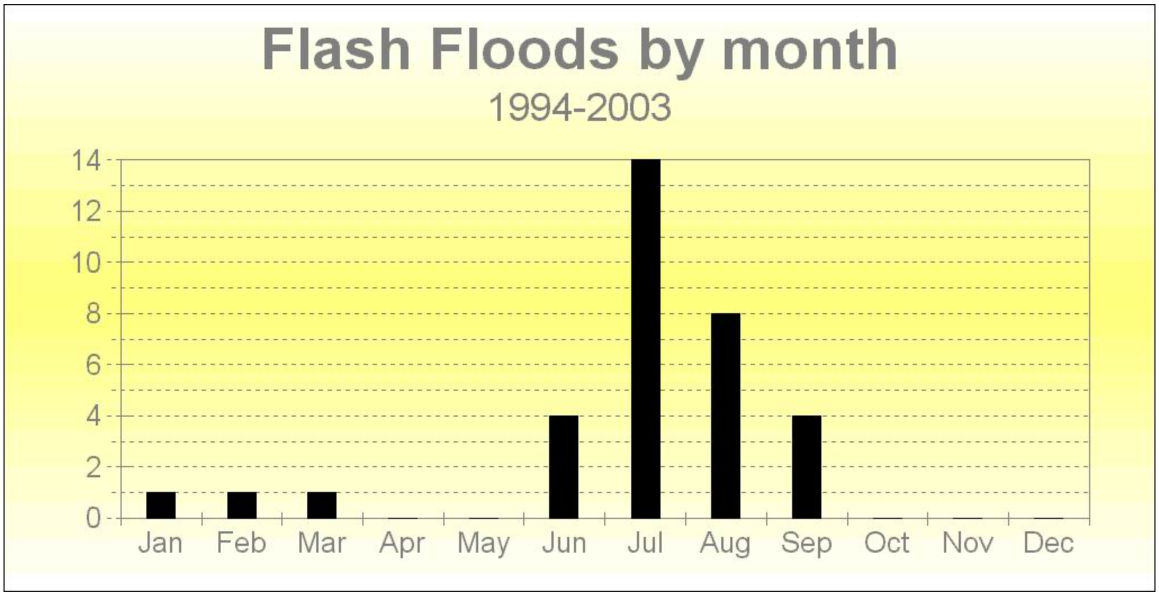

Figure 2: Flash Flood events by month in the Reno CWA from 1994-2003.

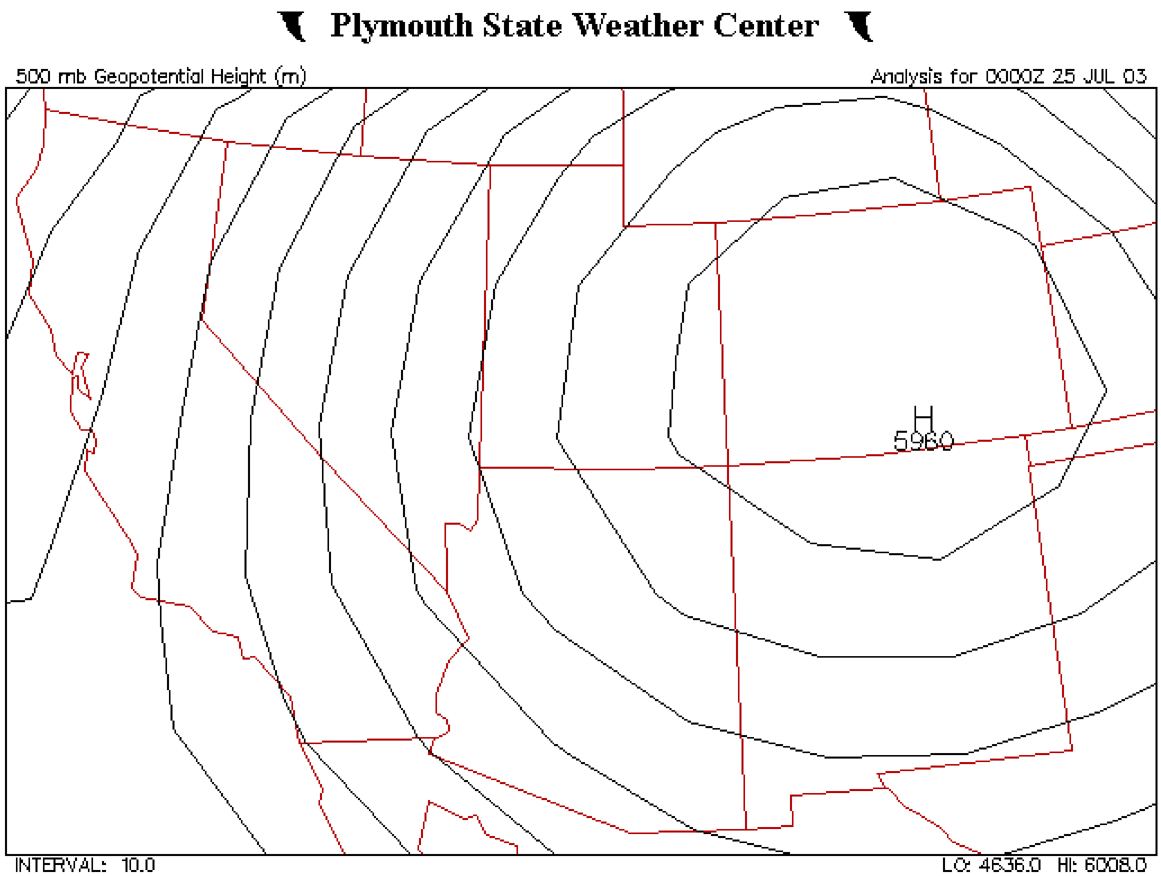

Figure 3: FCH 500mb pattern from 00Z 25 Jul 2003.

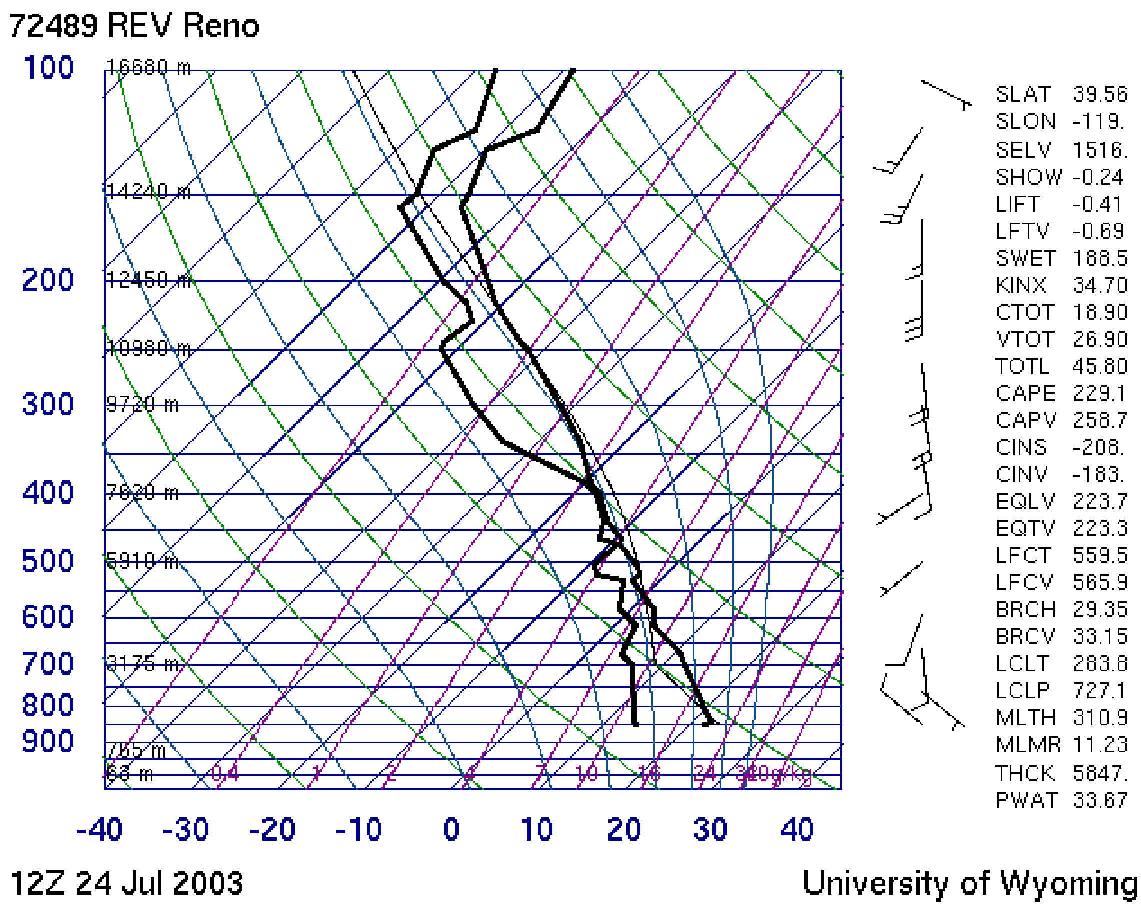

Figure 4: FCH sounding from Reno, NV, 12Z, 24 Jul 2003.

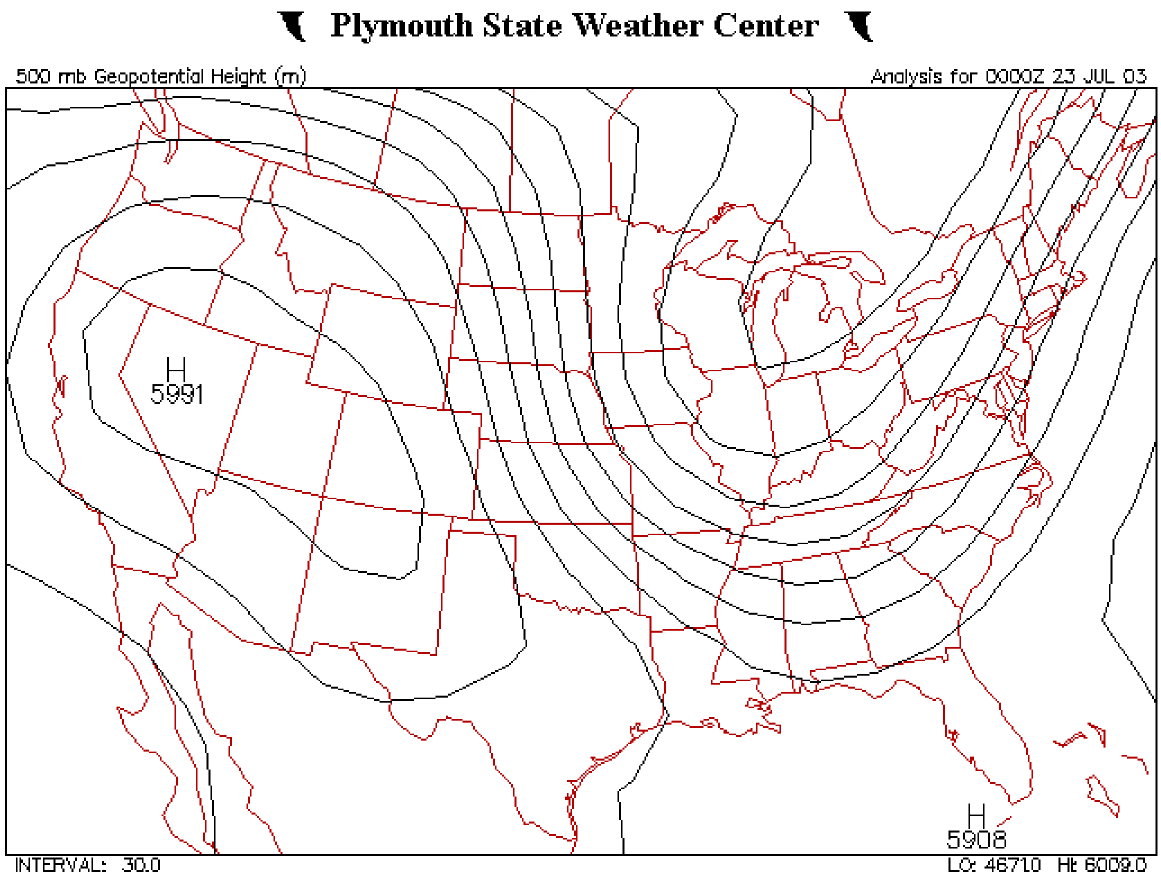

Figure 5: GBH 500 mb pattern from 00Z 23 Jul 2003.

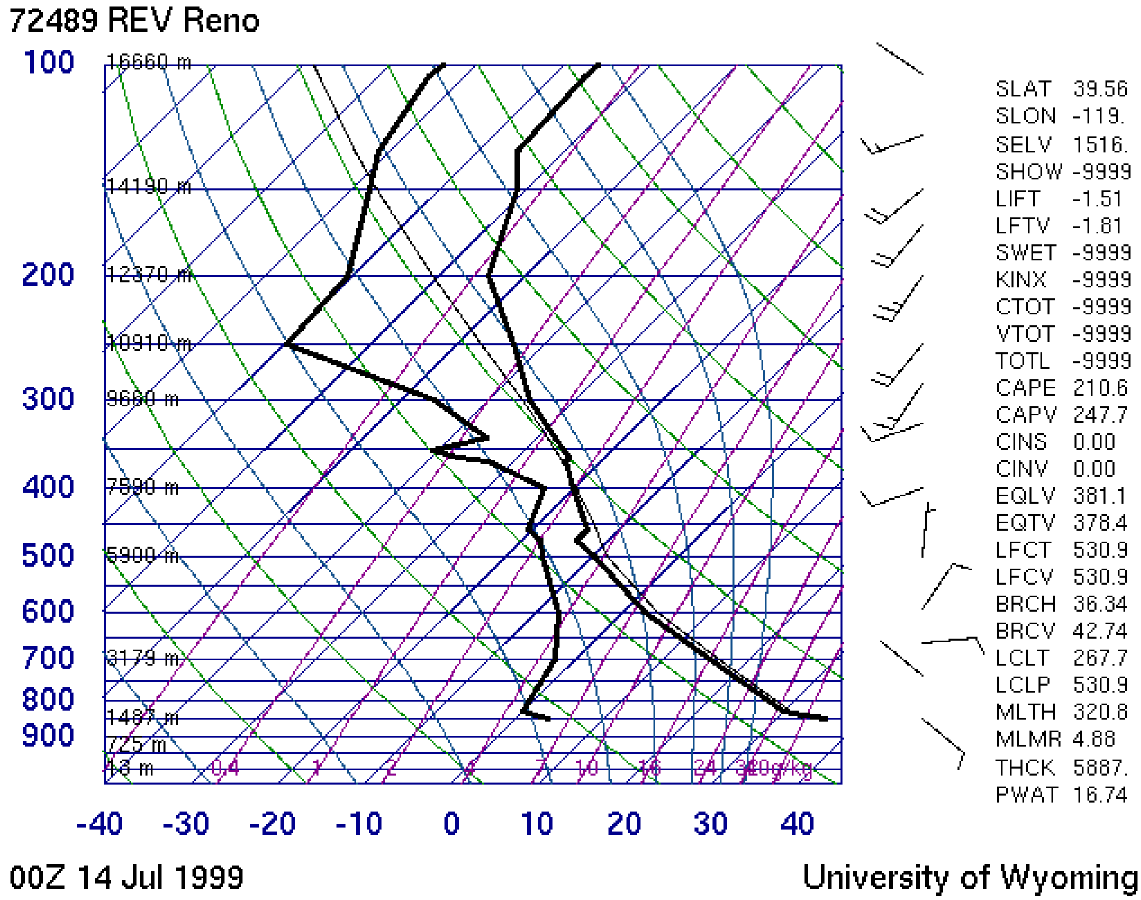

Figure 6: GBH sounding from Reno, NV, 00Z 14 Jul 1999.

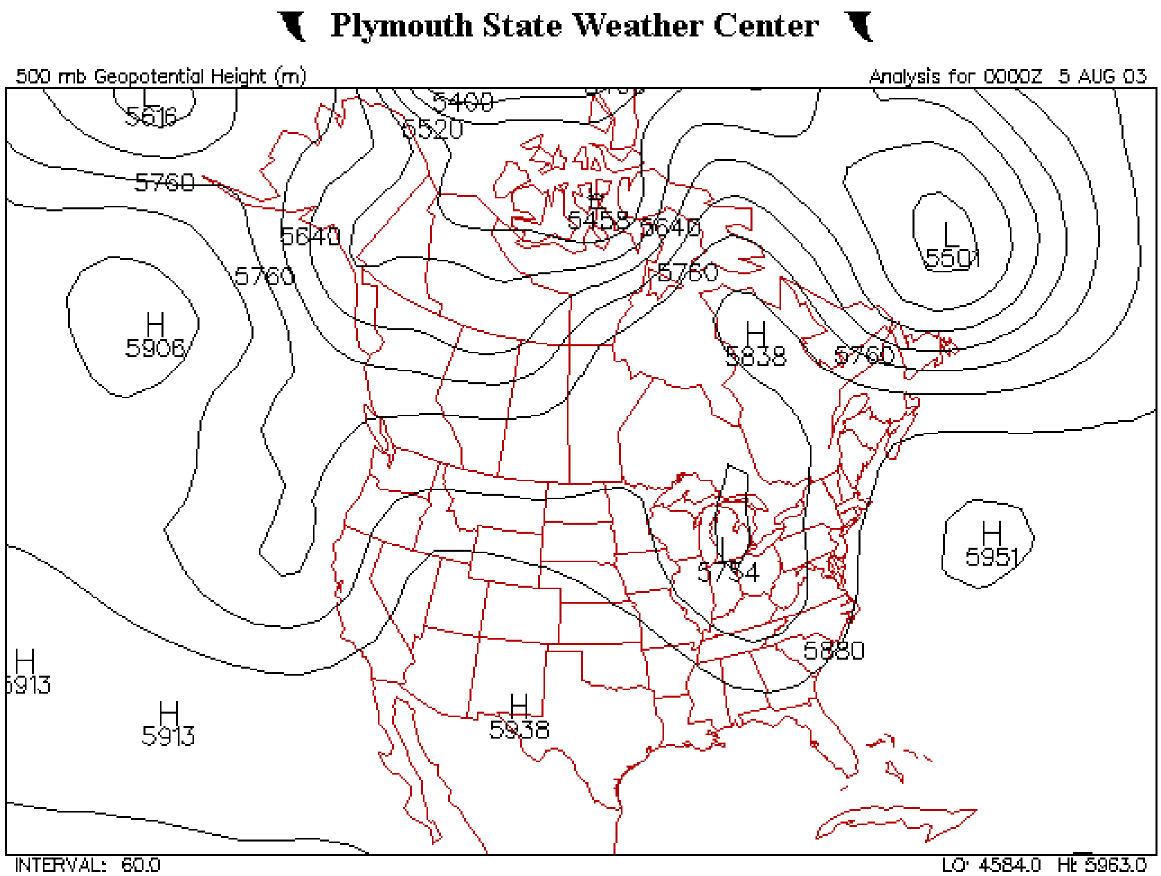

Figure 7: UL 500 mb pattern from 00Z, 5 Aug 2003.

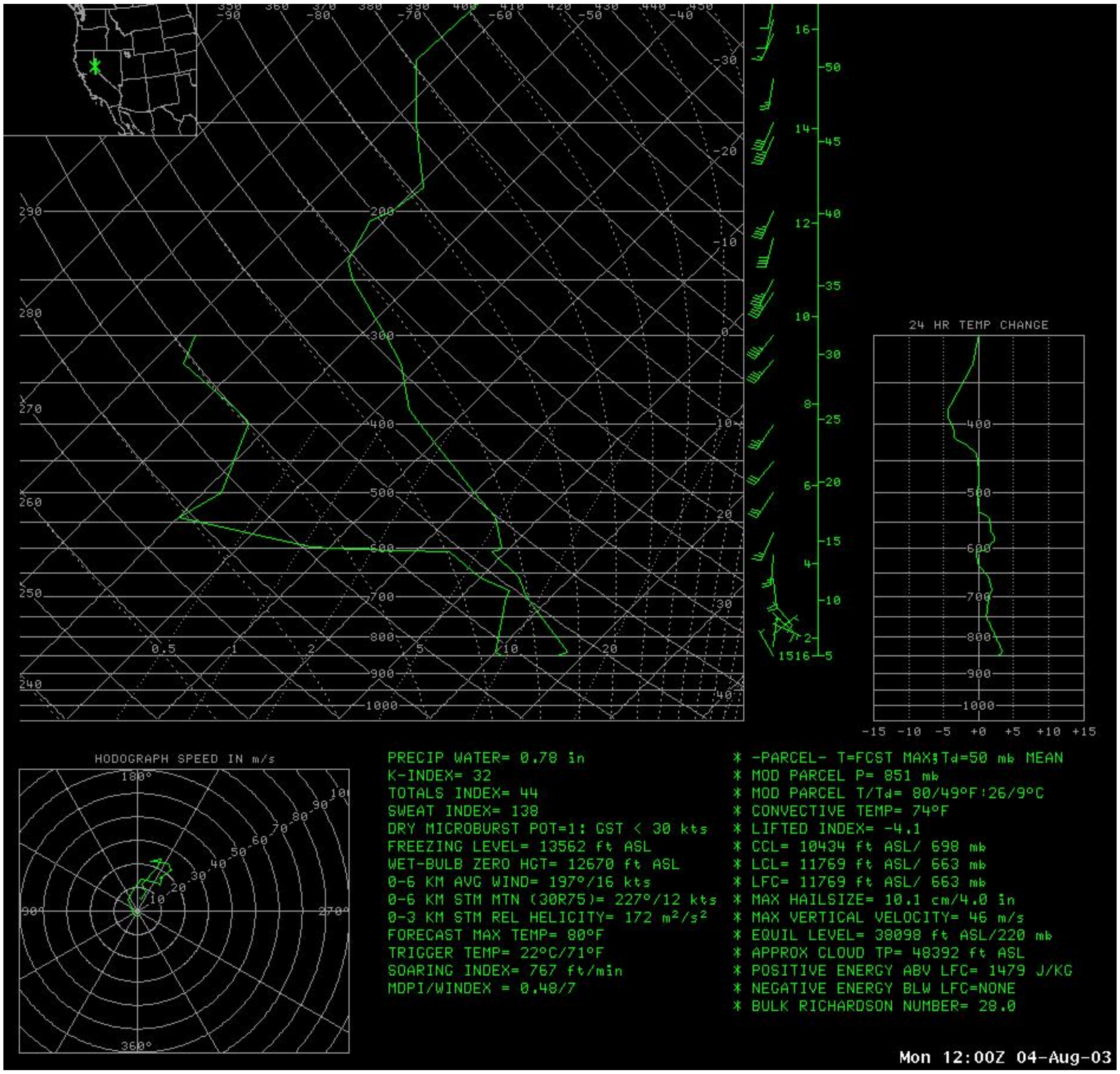

Figure 8: UL sounding from Reno, NV, 12Z, 4 Aug 2003.

7. Tables

	Maximum	Minimum	Average
PW	1.31	0.87	1.04
KI	37	27	32
HLTT	31	29	30
700 mb EPT	345	337	340
SM	15	6	10

Table 1: Maximum, minimum and average values from the FCH sounding data. Precipitable Water (PW) in inches, 700 mb Equivalent Potential Temperature (EPT) in Kelvin, K-Index (KI) in C, High Level Total Totals (HLTT) and Storm Motion (SM) in knots.

	Maximum	Minimum	Average
PW	0.84	0.48	0.67
KI	38	21	28
HLTT	34	29	31
700 mb EPT	338	327	333
SM	14	4	8

Table 2: Maximum, minimum and average values from the GBH sounding data. Precipitable Water (PW) in inches, 700 mb Equivalent Potential Temperature (EPT) in Kelvin, K-Index (KI) in C, High Level Total Totals (HLTT) and Storm Motion (SM) in knots.

	Maximum	Minimum	Average
PW	0.90	0.56	0.70
KI	44	16	30
HLTT	35	19	30
700 mb EPT	335	319	328
SM	19	4	11

Table 3: Maximum, minimum and average values from the UL sounding data. Precipitable Water (PW) in inches, 700 mb Equivalent Potential Temperature (EPT) in Kelvin, K-Index (KI) in C, High Level Total Totals (HLTT) and Storm Motion (SM) in knots.