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SEVERE WEATHER AS SEEN VIA A PRELIMINARY SOUNDING CLIMATOLOGY AND A WIND ADJUSTED CONVECTIVE INDEX (WACI)

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1. INTRODUCTION

Forecasting warm season (June-September) severe weather and flash flooding in Southern California continues to be a challenge for forecasters as well as researchers. Rugged terrain along with surface heating and moisture from the south and southeast are key components of the forecast problem (Fig 1). Convection over the mountains in Mexico to the southeast can even result in mid level moisture being pushed out over the coastal waters, and finally be brought in from the south and southwest, especially during periods when easterly waves affect the mountains to the south. The heating of the mountain slopes in southern California supplies the elevated heat source for this mid level moisture.

It seems that there is an optimum mid level moisture profile for strong convection that is neither too wet or too dry in southern California. Based on this thinking, a preliminary thermodynamic climatology for the 1998-2000 warm seasons (June through September) was constructed to investigate how convection in southern California is affected by the distribution of moisture in the vertical, the mid level lapse rate, and mid level wind speed. The parameters analyzed were the 750 and 600 mb dew point depressions, the 750 to 500 mb lapse rate, and the 500 mb wind speed. A preliminary "wind adjusted convective index" (WACI) was developed. The WACI assumes that the optimal mid level moisture content is about 75 % relative humidity (a dew point depression of approximately 4 degree C) at 750 mb and 600 mb. Another assumption is that light (10-15 kt) to very light (less than 10 kt) winds at 500 mb are better for updraft strength in an environment characterized by pulse type (or briefly multi-cell type) convection triggered mainly by solar heating. The intent of the index was to target days with the potential for moderate to strong updrafts that may produce severe weather and\or flooding. There was a good match with the 1998-2000 development data. For the 2 highest WACI values, large hail was reported on both days, and of the 6 days with the highest WACI values, large hail was reported on 4 days.

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For WACI values at and above 45 and for days when either severe weather or flooding was reported, the soundings were separated into 4 groups. The 4 distinct sounding types were linked to certain types of convection and will be discussed. The data suggests that WACI values along with sounding types can be used as a first guess in predicting the type of severe weather and/or flooding that is more likely to occur on a given day, and could affect air traffic in and out of southern California. Finally, the original 1998-2000 study was expanded to cover the period 1998-2003. The data will be analyzed to determine thresholds that may be used to forecast severe weather and flash flooding.

2. THE ASSUMPTIONS BEHIND THE WIND ADJUSTED CONVECTIVE INDEX (WACI)

The principle sounding in the WFO San Diego CWFA is the Miramar Naval Air Station sounding (KNKX). The major motivation behind the WACI is the fact that the use of most traditional indices for determining convective character in southern California can be nearly impossible, mainly because of the marine layer at this sounding location. The lowest level of the sounding generally consists of a cool, nearly saturated boundary layer during the warm season. This "marine layer" is capped by a rapidly drying and abruptly warming marine inversion. This layer is around 0.5 km MSL (about 1800 feet) during the period June-September. During much of the summer the dry airmass at the top of the inversion stretches upward throughout much of the troposphere.

At times the dry mid level airmass is replaced with a more moist and unstable airmass. There are 2 common flows that help to moisten the mid levels. Aloft the monsoonal jet advects moisture into southern California at around 650 mb. This moisture generally shows up during the morning hours in the form of dissipating debris clouds from convection to the south and east. Closer to the surface, outflow from the convection pushes into southern California as east to southeast low level flow to moisten the lowest layers, then flows up the mountain slopes to help moisten the mid levels. The thunderstorms generated in southern California during the warm season are largely due to solar heating of elevated sources (mountain slopes).

It seems like the most volatile conditions are when there is just enough drying for most if not all of the high clouds to dissipate, leaving a high amount of moisture aloft and plenty of solar heating. This combines with a moist low level upslope flow, (sometimes in the

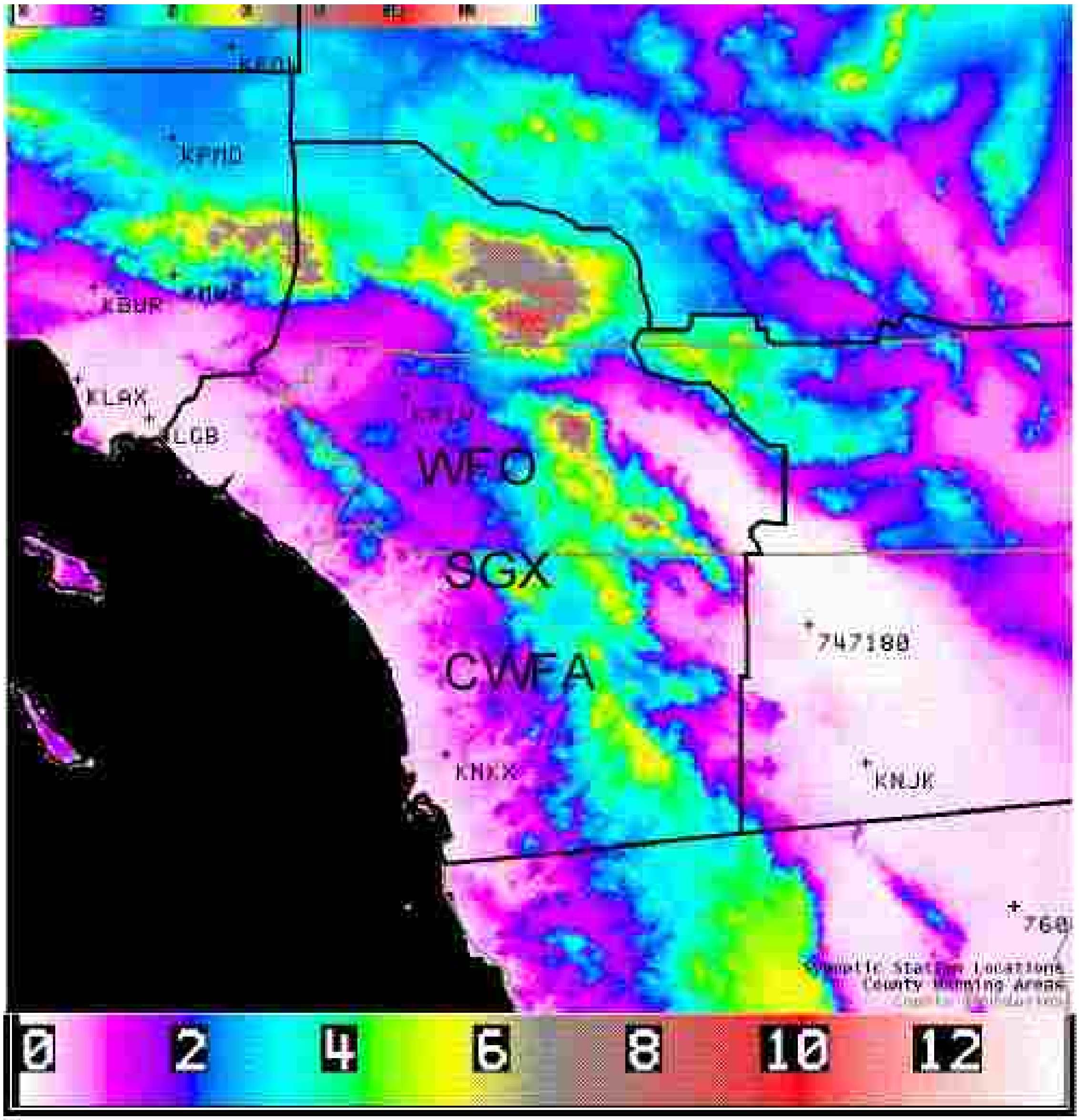


FIG 1. Terrain map of the WFO SGX CWFA. Color coding is in thousands of feet MSL (or in meters/0.003281).

form of an outflow boundary from convection to the south and southeast). Another ingredient is the surface heating on mountain slopes and convergence zones at the mountain ridge lines.

It was decided that to best reflect the character of the convection, an index should consider several factors.

1. The 750 mb dew point depression, which indicates the amount of moisture near the elevated heat source (mountains).

2. The 600 mb dew point depression (the amount of moisture in the layer that the parcel is traveling through as it rises, and also a rough indicator of the amount of mid/high cloudiness).

3. The temperature difference between a parcel lifted moist adiabatically from 750 mb to 500 mb and the 500 mb temperature to represent instability.

4. The wind speed at 500 mb, which helps determine how fast the parcel is being sheared apart, or removed from its initial source of heating (and possibly its source of mountain top convergence and/or upslope flow).

The mountaintop heating is around 850 - 700 mb, or about 1.5 - 3.0 km MSL (5000-10,000 feet MSL). Because the base of the moist mid level flow and the top of the subsidence dried low level airmass is also around 750 mb, an index base of 750 mb was decided upon .

2.1 Definition of the "Wind Adjusted Convective Index" (WACI)

WACI = [(-1) x (Lifted Parcel Parameter)]
x (Moisture Modifier)
- wind adjustment
+ constant **(1)**

The goal of the first 2 components (the lifted parcel parameter and the moisture modifier) is to multiply a "lifted index" type term by an "optimum moisture" type term in order to obtain large values for optimal updraft conditions. The moisture modifier is to be a multiplicative factor for the lapse rate parameter. The end result is a big moisture modifier multiplied by a large lapse rate parameter results in a large WACI value.

The Lifted Parcel Parameter (LPP), which is shown as the "lapse rate code" in figure 2a, is a simple concept. It measures instability by taking a parcel on the temperature portion of the sounding at 750 mb and raising it along a moist adiabat to 500 mb. This 500 mb temperature is then subtracted from the ambient (sounding) 500 mb temperature. (This is basically the lifted index of a saturated 750 mb parcel). The LPP is not allowed to drop below -8 degrees C to keep the index from becoming too skewed by heating (since very large lapse rates can occur with strong mixing to as high as 500 mb in the west with little moisture). The LPP is also not allowed to climb above -1 otherwise the index can yield a value of 0 or less, even when there is sufficient moisture for convection. Thus LPP values are always between -1 and -8.

LPP = lifted index of a saturated 750 mb parcel
with values limited to between -1 and -8 **(2)**

The moisture modifier is based on the 600 mb dew point depression code plus two times the code based on the 750 mb dew point depression, all divided by 3 (since the 750 mb dew point depression is assumed to be twice as important as far as convection is concerned). The 600 mb moisture is needed as a check to see how "wet" the airmass that the parcel is traveling through is. This gives some idea of buoyancy reduction due to cloudiness and/or entrainment of dry air. The codes for the 600 and 700 mb dew points can be calculated using figure 2b. Figure 2b shows that a code is a maximum of 10 at a dew point depression value of 4. (A dew point depression of 4 is assumed to be the optimal moisture value for strongest updrafts).

Code = 10 **(3)**

Code values decrease at a 1 to 1 ratio for dew point depression values less than 4. (Drops off to reflect the likelihood of increased cloudiness and its negative effect on heating and convection). Code values fall from 10 to 6 as the dew point depression approaches 0 to reflect the possibility that there is little solar heating for air masses that are saturated at the mid levels.

Code = 10 + (dew point depression - 4). **(4)**

Code values decrease at a 2 to 1 ratio for dew point depression values between 4 and 8. Code values fall from 10 to 2 to reflect the negative effects of entrainment.

Code = 10 -
(2 x (dew point depression - 4)). **(5)**

Code values decrease at a 1 to 1 ratio for dew point depression values between 8 and 9.5. Code values fall from 2 to 0.5 to reflect the negative effects of entrainment.

Code = 2 - (dew point depression - 8) **(6)**

Code values hold steady at 0.5 for dew point depression values between 9.5 and 15 degrees C.

Code = 0.5 **(7)**

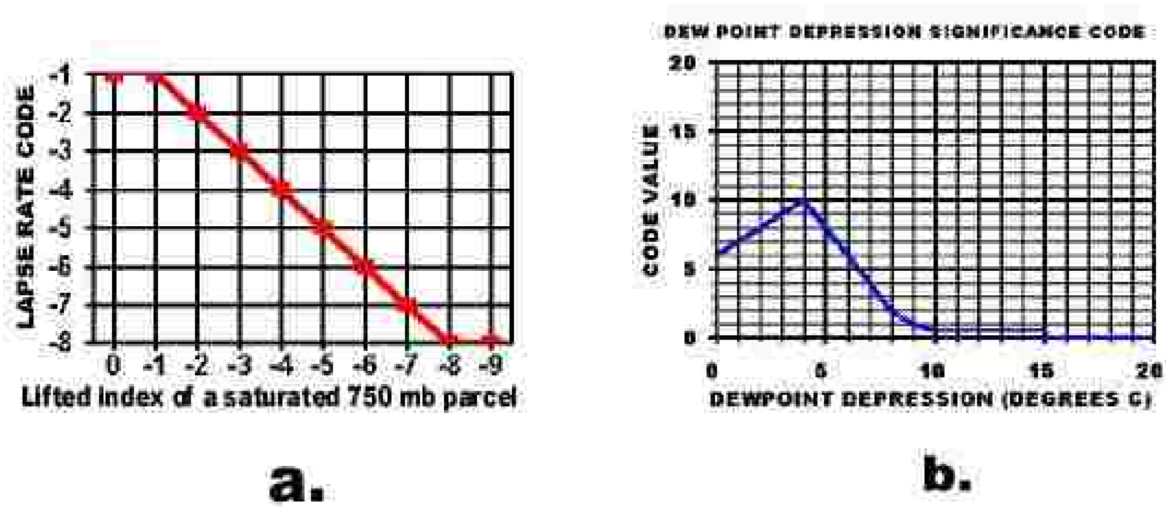


FIG. 2. Tables for calculation of the codes based on (a) the lifted 750 mb parcel and (b) the moisture profile.

Code value is 0 for dew point depressions drier than 15 degrees C (basically too dry for much convection).

Code = 0 **(8)**

Based on the code calculated for the 600 and 800 mb dew point depressions, the

moisture modifier =
(600 mb code + 750 mb code + 750 mb code) / 3 **(9)**

The wind adjustment is simply half of the 500 mb wind speed

wind adjustment = 500 mb wind speed / 2 **(10)**

A constant of 30 is added so that values of WACI resemble values of the TT index

constant = 30 **(11)**

3. COMPUTING THE INDEX

The first chart (Fig. 2a) is used to determine the value of the lifted parcel parameter (the lapse rate code). Notice that if the difference between the moist adiabatic lapse rate and the environmental lapse rate drops below -8, the chart will not assign a value less than -8, since the lapse rate would "overpower" the index. The upper end is capped at -1.

The second chart (Fig. 2b) shows how a dew point depression value is converted to a code. The maximum value of 10 is achieved for dew point depressions equal to 4 degrees C (assumed to be the optimal value for strong updrafts).

During the warm seasons of 1998-2003 there were 11 days with WACI values of 62 or higher. There was large hail reported on 6 of the 11 days. This gives a POD of 0.55 (6/11) a FAR of 0.45 (5/11) and CSI of 6/(11+ 5) = 0.38. Therefore it does show some skill for detecting large hail days.

The chart in figure 3 is a graph of the number of days flooding and/or large hail occurred within about 5 units of the plotted WACI value, divided by the number of days such WACI values occurred. [For instance, for the 59 days with WACI values between 45 and 54, there were floods reported on 20 of those days. The probability of detection (POD) was 20/59, or 34 %. The value of 34 is assigned to the midpoint of this interval (50 in this case) on the thick red curve with red squares, which is a plot for weak wind days (500 mb winds less than 15 knots). The thin blue curve with blue diamonds is the plot for days with any wind speed]. The red curve seems to indicate that conditions are more favorable for large hail and flash flooding with light winds (500 mb winds less than 15 knots), especially for higher WACI values. As for severe microbursts, they were rather spread out as far as WACI values were concerned. This is probably due to the possibility that wet microbursts can occur at large WACI values, dry microbursts can occur at small WACI values with large lapse rates, and a blend of the 2 can occur for values in between.

4. SOUNDING TYPES

The are certain types of soundings that accompany days with certain types of weather. Figure 4 shows the 4 major sounding types. Figures 5-9 show the soundings for days that flooding, large hail, microburst winds, or some combination thereof occurred for the period 1998-2000. The soundings are grouped based on the weather that occurred. The sounding chosen to represent each weather day is the sounding with the highest WACI value for that day.

4.1. Large Hail Soundings.

The large hail soundings (fig. 5) are for days when large hail was reported (flash flooding and/or severe wind gusts may have also occurred). For the large hail examples there is a shallow marine layer topped by a layer of drying. Above the drying layer the monsoonal moisture rapidly moistens up the airmass, with most 850 mb dew points in the teens, most 750 mb dew points around 10 degrees C, and even 700 mb dew points above 0 degrees C. The mid-level portion of the soundings shows the “not too wet and not too dry” near optimum profile. There is a pronounced drying at about 500-550 mb on most of the soundings.

4.2. Flood Soundings

The flood soundings in figure 6 and figure 7 are for days when flash flooding occurred but no large hail or severe wind gusts were reported. The base and mid levels of the flood soundings are very similar to those of the large hail soundings, except the dew point depression is smaller, indicating a wetter sounding. Unlike the large hail cases, the airmass generally remains very wet above 500 mb, with dew point depressions mainly below 10 degrees C up to at least 500 mb in most cases. This is similar to a Miller “Type II” sounding, which is also known as a tropical sounding. (Miller, 1972)

4.3. Combined Flood/Severe Microburst Soundings

The combined flood/severe microburst soundings shown in figure 8 are for days when wind gusts 50 knots or more were reported along with flooding (but no large hail). The 850-700 mb lapse rate has increased in comparison to those seen on the “flood only” soundings. Overall, based on figure 4c, it seems to be a composite of the upper portion of a tropical flooding sounding, combined with the lower portion of an inverted V microburst sounding. Soundings 8a and 8b are more “wet microburst” types of soundings with relatively low 850 mb temperatures (only in the 20-25 degree C range). Soundings 8c and 8d have much larger lapse rates and the 850 mb temperatures exceed 25 degrees C, which lean toward a more “dry microburst” type of sounding. It is the light (less than 15 knots) 500 mb wind speeds that helps to allow some flooding in these combined flood/severe weather examples.

4.4. Severe Microburst Soundings

The severe microburst soundings are for days when wind gusts 50 knots or more were reported, but no flooding or large hail reports (fig. 9). These soundings are essentially the classic “inverted V” type soundings (Beebe, 1955). These are more along the lines of a nearly saturated mid level layer capping a very steep, nearly dry adiabatic lapse rate. In these cases the temperature near the base of the steep lapse rate results in an 850 mb temperature approaching 30 degrees C, and a 900 mb temperature in excess of 30 degrees C. It dries out rapidly from the nearly-saturated layer aloft to a near 15 degree C dew point depression around 850 mb. These days are generally days with high temperatures well above normal in the coastal zones (for example, at least in the 90s), which is where the KNKX sounding is located. One such pattern where these conditions can develop fairly easily is during “monsoonal/offshore flow patterns”. These patterns are characterized by offshore pressure gradients to the interior along with monsoonal flow. (This scenario can generate pass/canyon winds in the valleys, and occasionally as far west as the coastal areas for huge temperature lapse rates). Microbursts can fairly easily develop in the highly populated coastal valleys under these conditions.

5. Discussion and Conclusion

Although the data set is somewhat limited, some relationships can still be made. The wind adjusted convective index (WACI) seems to show some skill in detecting which days have a significant flood threat, especially for the light wind cases (500 mb wind speed less than 15 knots). The flood threat seems to reach about 30 percent when WACI values approach 50, with the threat increasing for higher values. It also seems to indicate the days when large hail may be a significant threat. It hints at about a 30 percent or higher probability of large hail in the WFO SGX CWFA for WACI values in excess of 60. The reduction in hail probability with increasing wind speed and wind shear is in stark contrast with much of the U. S., where the more prolific hail producing scenarios involve supercells forming in environments characterized by strong winds and strong wind shear. This may be due to the fact that the updrafts of these mainly pulse thunderstorms are relatively weak compared to the organized supercells common to much of the U. S.,

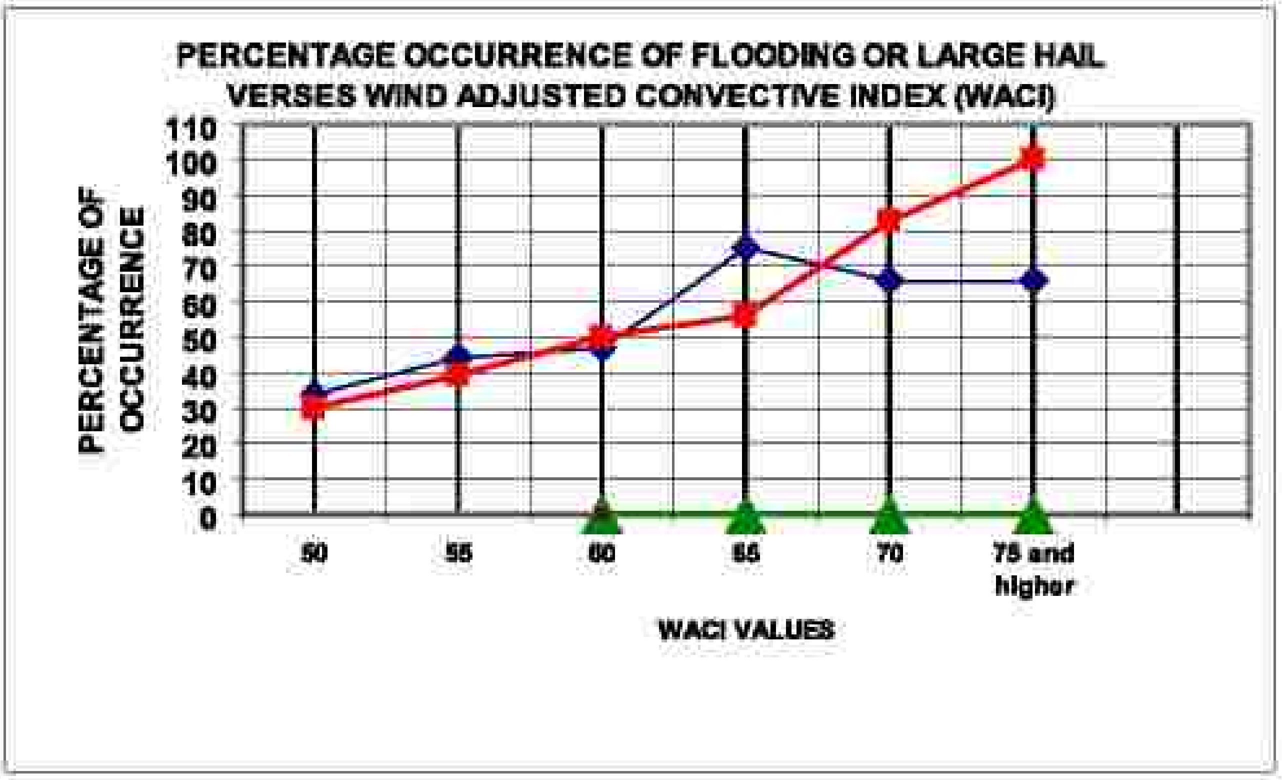


FIG. 3. Percentage of warm season (June - September) days that large hail or flooding occurred based on WACI values for the years 1998-2003.
The blue curve with diamonds is for all days when flooding and/or large hail occurred for all 500 mb wind speeds. The red curve with squares is the same as the blue curve, except only for days with light 500 mb winds (less than 15 knots). The green triangles are under the region where large hail was reported at least 30 percent of the time.

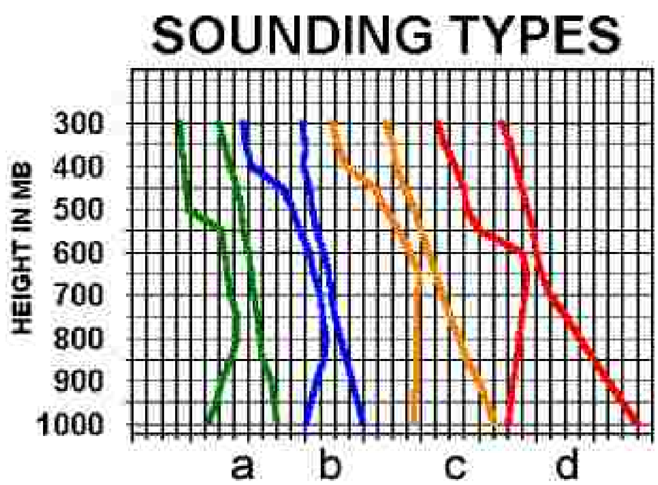
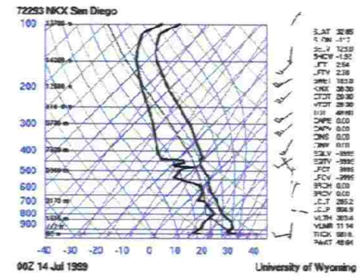
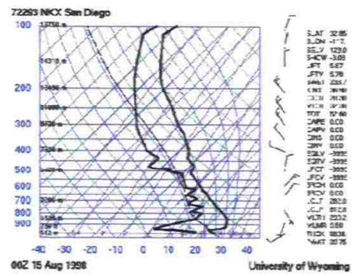


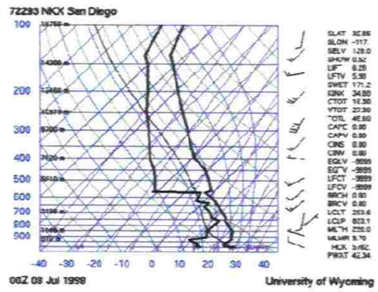
FIG. 4. Sounding profiles common to the 4 types of events. The green sounding (a) is common for large hail days. The blue sounding (b) is common for flood days with no large hail and no severe wind gusts. The orange sounding (c) is common for days with flooding, severe wind gusts, but no large hail. The red sounding (d) is common for days with severe winds, but no large hail and no flooding (dry microbursts).



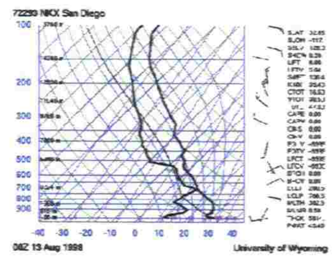
a.



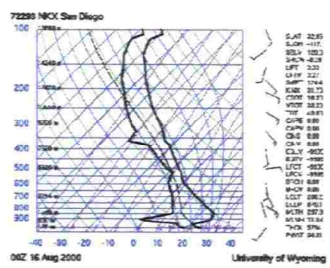
b.



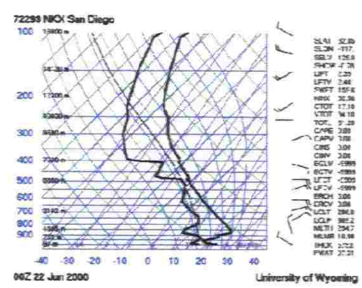
c.



d.



e.



f.

Figure 5. Figures a-f are for days with WACI values at or above 45 with large hail (possibly accompanied by flash flooding, urban and small stream flooding, and/or severe wind gusts). WACI values are 73, 70, 65, 64, 47, and 45 respectively.

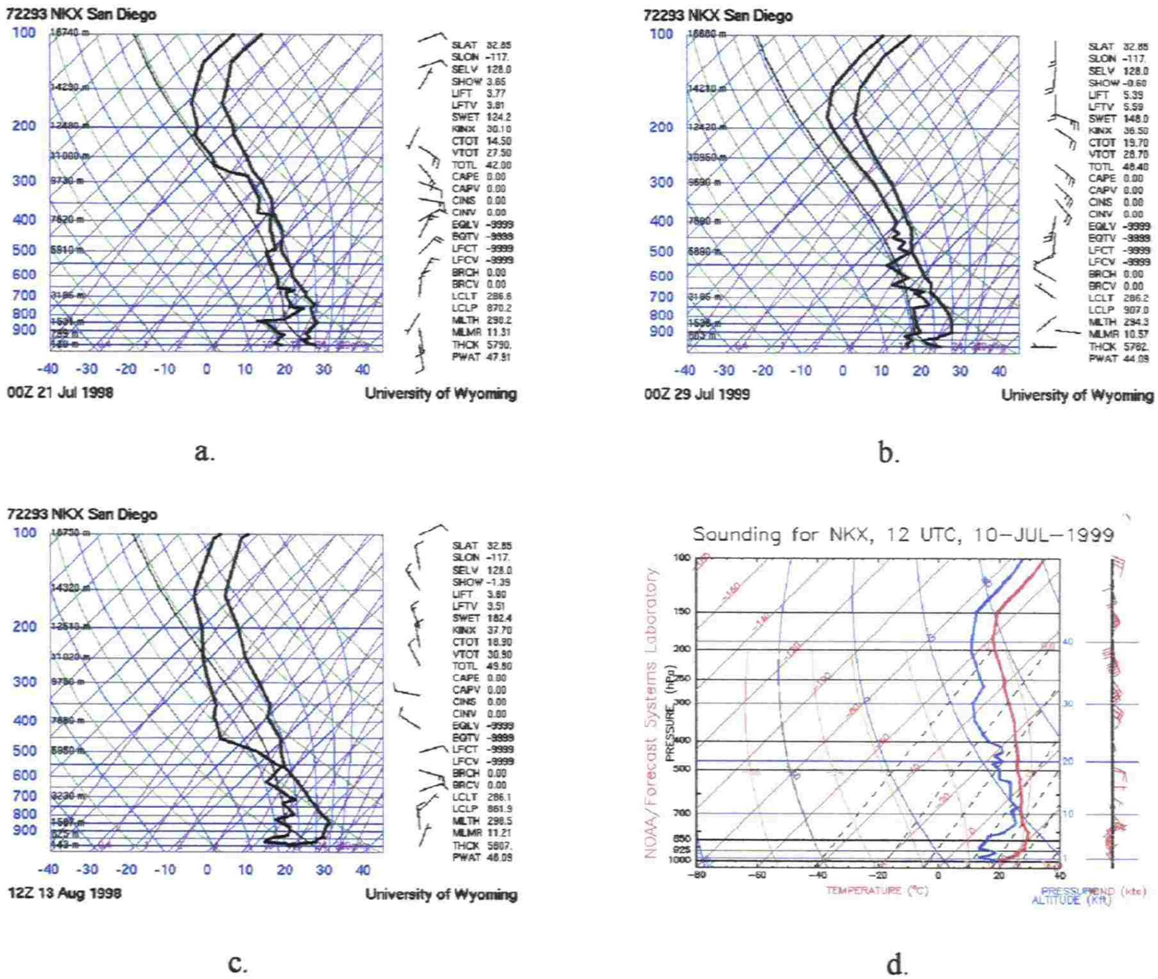
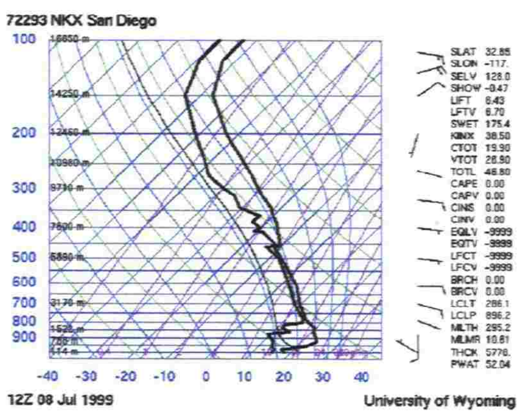
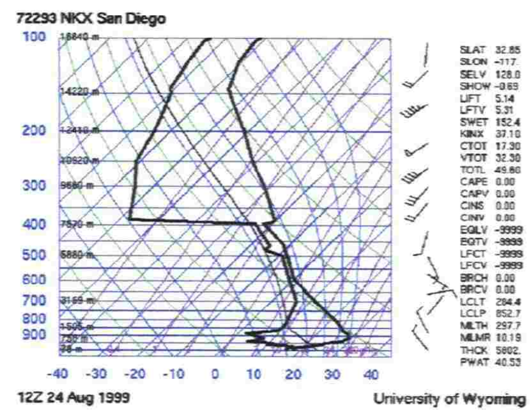


Figure 6. Figures a-d are for days with WACI values at or above 45 when flash flooding or urban/small stream flooding was reported, but no large hail and no severe wind gusts were reported. WACI values are 68, 62, 56, and 53 respectively



a.



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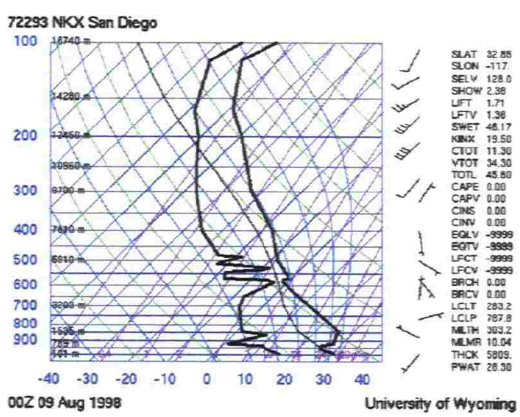

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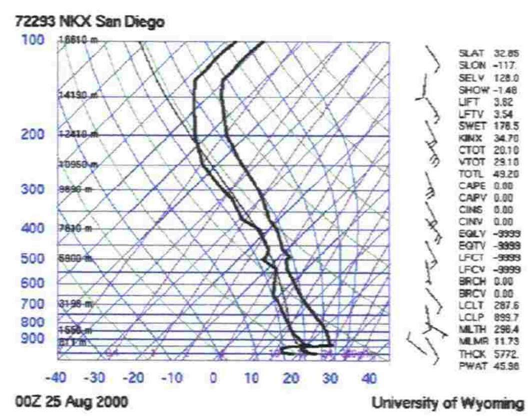

d.

Figure 7. Figures a-d are for days with WACI values at or above 45 when flash flooding or urban/small stream flooding was reported, but no large hail and no severe wind gusts were reported. WACI values are 52, 51, 51, and 47 respectively

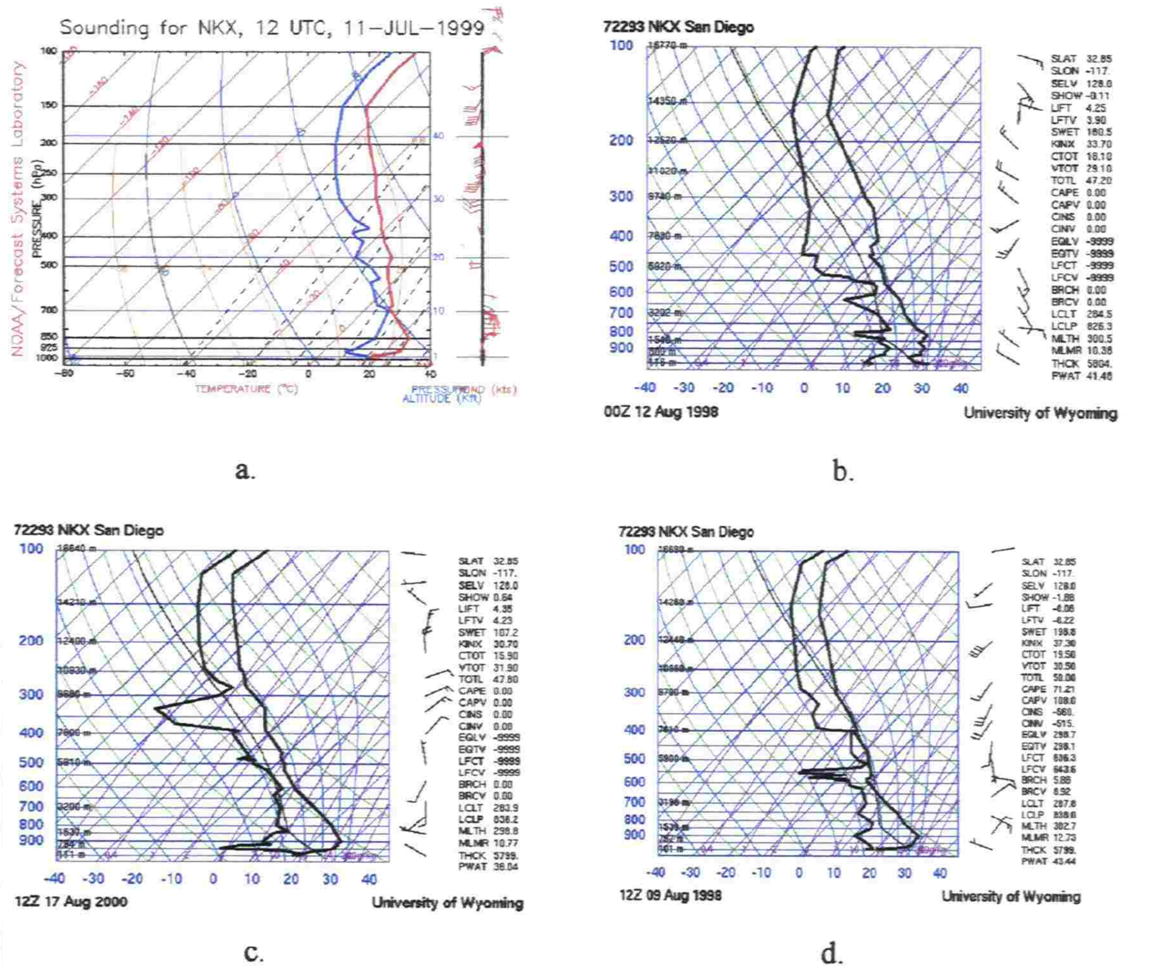

Figure 8. Figures a-d are days with WACI values at or above 45 and flash flooding along with wind gusts of 50 knots or more, but no large hail. WACI values are 69, 58, 55, and 45 respectively.

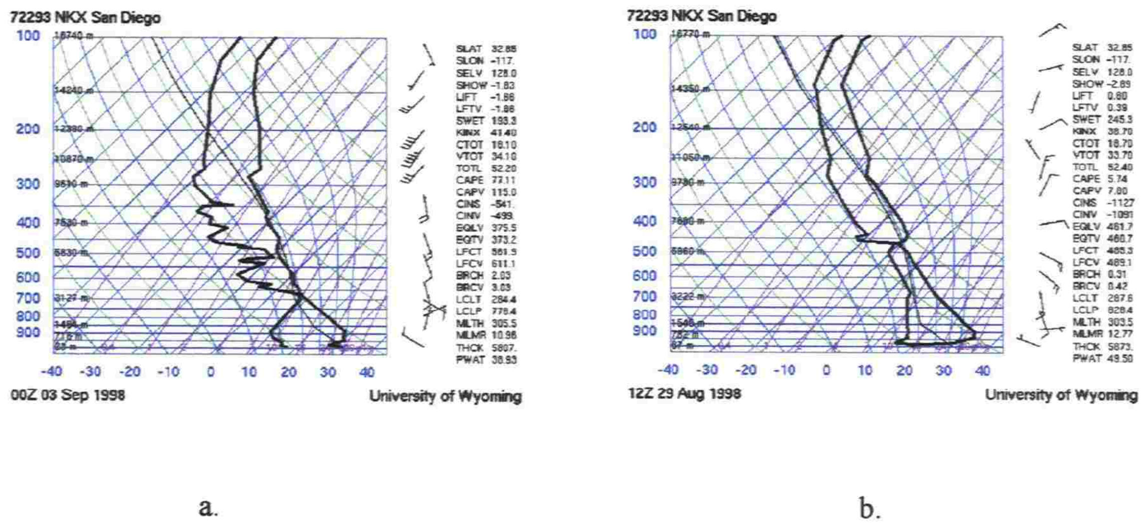

Figure 9. Figures a and b are days with WACI values of 45 or more, wind gusts of 50 knots or more, but no urban/small stream flooding, no flash flooding, and no large hail. WACI values were 53 and 45 respectively.

and are more readily sheared apart. Removal from the upslope forcing or the heat source by strong wind may also serve to generate unfavorable conditions for strong updrafts.

Of course, there are limitations with the WACI. For instance, it uses selected levels which may not accurately represent the overall airmass in order to calculate the index. The thresholds should be treated as suggested values that the forecaster should be aware of when analyzing the problem of the day. Based on the 1998-2003 data a WACI value of 50 is approximately a “30 percent chance of flooding” and a value of 60 is approximately a “30 percent chance of large hail”. A forecaster would have had good success, especially in the 2000-2003 summer convective seasons using these thresholds based on the data.

An attempt was made to diagnose the type of airmass that the parcel would be surrounded by while making the index. Interrogation of the airmass away from mountains may be a better gauge of the overall airmass that a parcel is flowing upwards in. Mountaintop convection may locally generate very high WACI values, but measurements over the mountains may not accurately diagnose the overall environment well since it is only a local increase in WACI values. So mountaintop convection may contaminate the index. The sounding prototypes can help guide the forecaster toward the most likely convective scenario, especially on days that match the more classic profiles.

Occasionally upper level lows enhance the vertical motion over the area and may result in severe convection and/or flash flooding, regardless of what the index indicates. This is especially true if there is overnight or early morning convection in the mountains and deserts. The more volatile patterns are when low level upslope flow develops. This can occur with flow from the south or east. The flow can come from a gulf surge (Brenner, 1974), or an outflow boundary from convection to the south and east. The low level moisture can sometimes be seen as low clouds on the eastern slopes of the mountains in the morning. It is usually accompanied by dew points at desert stations in the 70s and 80s, and even mountain dew points and /or relative humidities in the 50s and 60s. The morning low clouds in the deserts is a good guage of the depth of the moisture layer and strength of the upslope flow (there is also some natural mountain/valley circulation that can pull the moisture upslope as well).

Days with WACI indices that are above 50 can severely hamper air traffic in and out of southern California. On such days the convection can begin quite early. Occasionally, showers develop before 1800 UTC. These days can be a sign of some kind of dynamic forcing, a very unstable airmass, or both. Days with morning convection have been good predictors of afternoon severe thunderstorms and flash flooding in the past. When the cloud tops reach about 18,000 feet (about 5.5 km) then air traffic over the local mountains can be adversely affected. Noting how high the morning WACI value is can help determine whether the tops will exceed 5.5 km during the late morning, or remain below this level until sometime during the afternoon.

Finally, as a follow-up to this study, another local study (Small, 2002) and ongoing research indicates that there is a good relationship between the maximum precipitable water of the day (max pw method) and its associated 500 mb wind speed for determining flood potential (and to an extent severe hail and downburst winds). Preliminary data shows that for values that are above about 38 mm (about 1.50 inches or about 150 % of normal) with 500 mb winds less than 15 knots, there is at least a 30 percent chance of flooding. This is high enough to at least consider a flood watch. There were also some relationships to severe weather. Future study will be conducted to compare these and other tools.

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