1.6 A PRELIMINARY METHOD FOR COOL SEASON FLASH FLOOD AND HEAVY SNOW FORECASTING USING A MOISTURE DEPTH/DURATION/FLUX FLASH FLOOD POTENTIAL INDEX (FLINDEX)

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1. INTRODUCTION

Rainfall in southern California is strongly dependent on Pacific storms during the cool season. A variety of scenarios can occur with these Pacific storms. With the stronger, widespread events the heaviest rainfall rates and largest accumulations usually fall during a 4-6 hour period with the low level jet and cold front. Afterward the cool/cold pool and instability can set up convergence zones in a more convective environment behind the front. In these cases, highest post frontal rates are often terrain forced, possibly from either blocked flow, converging flow downstream from terrain, upslope flow, or a combination of those features. Very slow moving upper level lows can result in quasi-stationary cells with even higher rates than the front, and sometimes accumulating hail. Very strong fronts can force the flow and precipitation through the passes into the deserts (especially north of Lytle Creek), otherwise the deserts can remain rather dry. Upper lows, if far enough south, can retrieve warm, subtropical moisture from Mexico (normally untapped except during the summer monsoon season), and deliver heavy rain on the eastern side of the mountains and in the deserts, where flood thresholds are relatively low. Flood events can extend well into the transition season (or "cut-off season" marked by occasional cut-off lows), ending with the tail end of weak fronts that enhanced the marine layer with little accumulation in June. With this in mind, an attempt was made to determine a basic potential for heavy precipitation that could lead to flash flooding and/or heavy snow and will be outlined in this paper. It also seems that the fronts with heavy rain, but embedded in a "consolidated" 35 dBZ radar echo pattern, can deliver almost continuous heavy rainfall, and are very proficient in producing the very big amounts (over about 5 inches, or about 125 mm in the mountains) during a single storm (Fig. 1). To further illustrate these points, indices and parameters will be explored, and a case comparison will be employed, to show some key features of these very heavy rainfall and snowfall events.

2. METHODOLOGY BEHIND THE DEPTH/DURATION DERIVED INDICES

The Pacific Ocean and associated moisture are ever present sources of huge storms with copious moisture. These huge Pacific storms pose several problems:

1. Very high precipitation rates over a short period of time, These events are usually about 1.25 inches in an hour or more (about 32 mm) with strong, frontal passages, or even in a half an hour during the more convective events (especially the very unstable winter patterns). The culprit can be extreme moisture depth associated with cloudy, deep frontal type airmasses, or partly cloudy, but very unstable air mass.

2. Moderate to high rates over very long periods of time (based on moisture not terribly deep, but persistent, for example, shallow, quasi-stationary rain bands or upslope flow).

3. The dreaded "combination thereof", frequently a long period of moderate to heavy rain followed by a burst of heavy to very heavy precipitation with free convection, or forced convection along a strong front. (Negative tilt diffluent troughs or convergence zones that set up late in the event are notorious for this). These events can lead to "wall of water" type flooding.

Some combination of moisture depth, duration, and flux must be determined to formulate guidance. Since many cool season flood events are based on moisture rooted in the boundary layer, boundary layer moisture depth is a good start. Duration of the deep moisture is also critical. Flow speed can help diagnose moisture convergence away from the mountains. If the flow remains onshore zonal or cyclonic, the "lack of ridging" keeps the airmass from drying out and the showers can continue. A parameter that includes this moisture duration aspect can also somewhat address antecedent conditions. Continuous moisture flux leaves the door open for convergent regions to develop, with locally heavy rainfall, even if strong dynamics are not obvious. A level that exceeds 80 % relative humidity ("very wet layer") found somewhere between about 850 and 700 mb seemed to be important for rain to develop, usually along with about 10 to 20 knots (about 5-10 m s^{-1}) of 850 mb flow. Higher amounts of moisture along with stronger flow can result in flash flooding, therefore including this would be a good start for formulating an index. To address this problem, the methodology was to look at 5 consecutive soundings, 12 hours apart, for a number of years, checking to see whether or not "very significant" flooding (basically, significant enough to be

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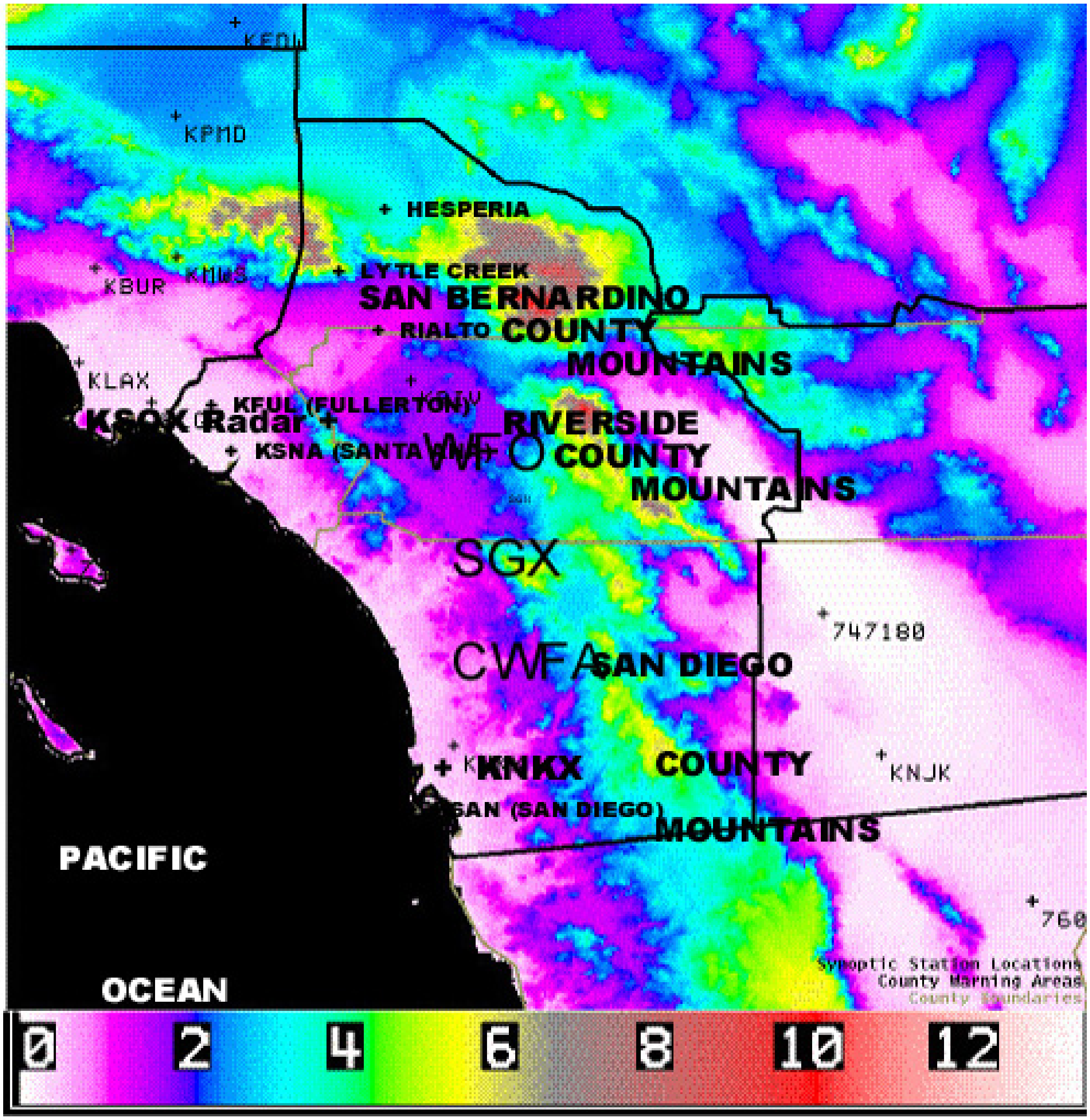

FIG 1. Terrain map of the WFO SGX CWFA. Color coding is in thousands of feet MSL (or in meters/0.003281).

reported in Storm Data) occurred with the storm. Moisture depth and duration as well as flow speed was also examined to determine their contribution to flooding. To address moisture "depth", a value of "2" was given to soundings where the deep layer mean relative humidity reaches 80 % (1000-500 mb layer considered to be "deep layer RH" as far as moisture is concerned). A value of "1" was applied to soundings where moisture deepens up enough for the 850-700 mb relative humidity to exceed 80 %, but not deep enough to bring the deep layer RH up to 80 %. To handle the "moisture duration" issue, simply add up the points for the 5 sounding period. This value, by definition, is the moisture depth/duration parameter for the 5 sounding period (since a normal "big" storm has some pre-frontal precipitation, a burst with the front, and possibly additional bursts in post frontal convection lasting a couple of days or so). In a way, it helps address antecedent moisture concerns. To address moisture flux and convergence issues, the top speed of the 850 mb wind during the events was incorporated (MAXH85WS), and thresholds can be based on the data to determine flood potential. The MAXH85WS parameter is the peak 850 mb wind speed for the storm.

3. DATA

The period of development data was 1998-2002 for the months of October through May. All of the flash flood events available in the National Weather Service San Diego Forecast Area during this period occurred with storm depth/duration values of 2 or more, so only days with values of 2 or higher were included. A total of 34 cases were available. 1000-500 mb RH at or above 80% **(very deep moisture)** is a 2 point sounding. The 850-700 mb RH at or above 80 % **(moderately deep moisture)** but 1000 - 500 mb RH ***below 80 %*** is a 1 point sounding. The points are added up for the storm to get the moisture depth/duration parameter for a storm. (For example, a storm which has 2 **"moderately deep moisture**" soundings is the same as a storm with 1 "**very deep moisture"** sounding, since the point total for both is 2). Based on the data, there is a chance of very significant flash flooding when the depth/duration parameter reaches 2 and the wind speed reaches about 25 knots (12.5 m s^{-1}) or more. Looking at depth/duration for 30 knot (15 m s^{-1}) winds or more values of 2, 3, and 4 represent at least 50 percent probability of very significant flash flooding, and nearly 100 % chance of urban/small stream flooding (as well as nearly a 100 % chance of flooding in recently burned areas and low water crossings). Combining the two, a rough estimate of flash flood potential, the depth/duration/flux flash flood potential index (FLINDEX) for a storm can be developed. FLINDEX, the depth/duration/flux flash flood potential index is defined as;

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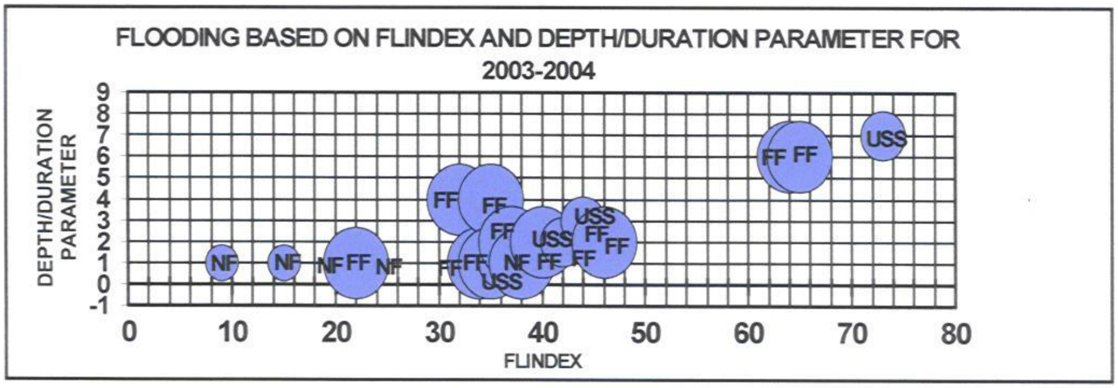
FLINDEX = (depth/duration parameter x 5) + peak storm 850 mb wind speed (1)

FLINDEX becomes FLINDEXS (snow FLINDEX) If only the soundings with 850 mb temperatures below about 6.5 C at KNKX are used. Also, an instantaneous version of FLINDEX, called FLINDEXI can be used to look at only one sounding to get some idea of flood potential, but it is less representative than a 5 sounding FLINDEX value.

4. HEAVY SNOW

Many heavy snowstorms are troughs deepening into cut-off lows in a "Northwest Express" or "Aleutian Express" type of pattern [a nearly north-south (or "meridianal") jet stream flow just downstream of a high amplitude ridge], and may collide with subtropical air. The heavier snow events [about 8 inches (210 mm) or more at the "resort levels" near 6000 foot (1800 m)] generally occur when the trough line and low center are about 500 miles west of southern California. This is offshore enough so that the northerly flow around the bottom of the trough becomes south to southwest flow, especially near 850 mb. This results in enough over-water trajectory to destablize and moisten the cold airmass at the bottom of the trough in the warmer waters off the coast. Then it bring in this moist, unstable modified maritime polar airmass (now even more moist and unstable) in south to southwest flow. Next, the cold pool, oftentimes a large area of 500 mb temperatures between -25 and -30 C, moves over for additional, largely convective, snowfall. These heavier snow events are almost always accompanied by funnel clouds and waterspouts. Sometimes severe winds, large hail, and tornadoes develop. If the trough line and cut-off low initially cut off too close to the coast, or even slightly inland, the trough picks up less moisture, and there is usually less snow. Cold, windy conditions can develop during these "Aleutian Express" patterns.

This direction of reasoning used for rainfall can also be applied to snow. The "cold depth/duration parameter" is defined as the normal depth duration parameter, except moisture is evaluated for a freezing level around 6000 feet or lower (basically after the cold pool has arrived), and its use changes FLINDEX to FLINDEXS, for evaluating snow potential. These values correspond to a temperature of about 6.5 degrees C at KNKX in order for the temperature to fall to about 5 C in the mountains to the north for snow. In other words, if a storm has a total of 4 depth/duration points, but the freezing level was at or below 6000 feet for only 2 of the four points, then the normal depth/duration parameter is still 4, but the "cold depth/duration parameter" is only 2. If the cold pool arrives after the moisture becomes very shallow, then little snow is possible since the moisture and cold air must first "phase" for maximum snowfall.



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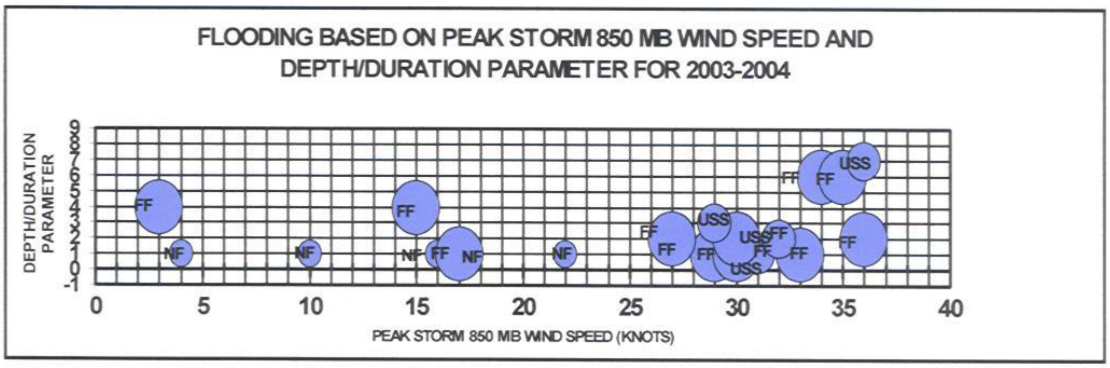

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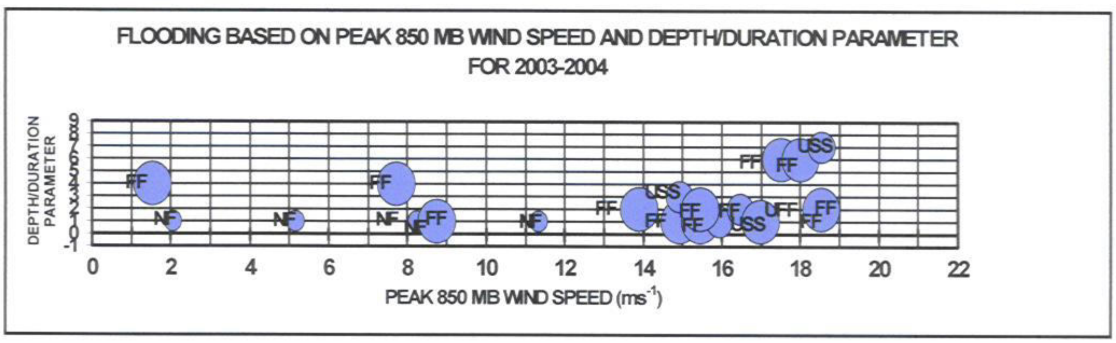

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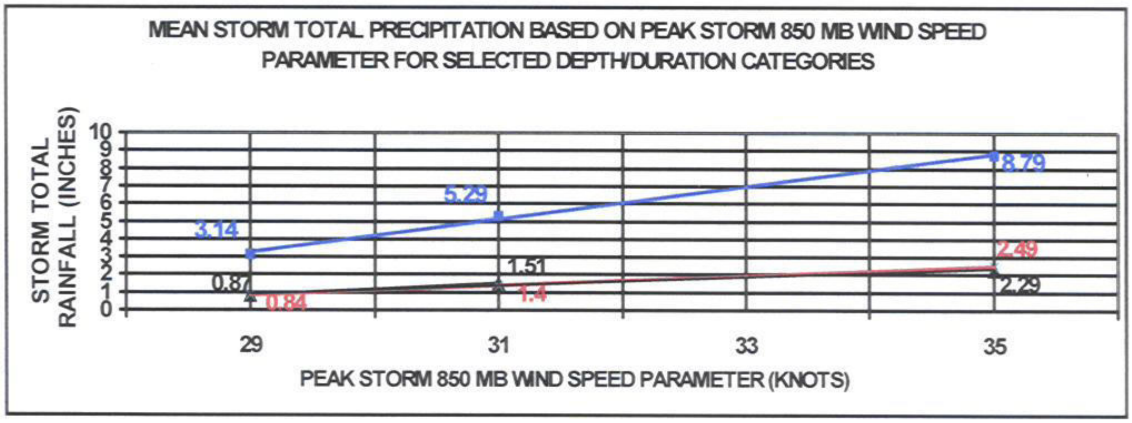
Figure 2. Graphs of flood parameters for 2003-2003 with NF, USS, and FF representing days with no flooding, urban and small stream flooding, and flash flooding respectively. (a). Graph of FLINDEX versus the depth/duration parameter showing a large increase in flood days for FLINDEX values in the 30s. (b). Graph of peak storm 850 mb winds in knots versus depth/duration parameter showing a huge increase in flood days for peak storm 850 mb wind speeds in the mid 20s with depth/duration parameters of 2 or more, and/or when the depth/duration parameter reaches 4. (c). Same as b, except wind speed is in meters per second.



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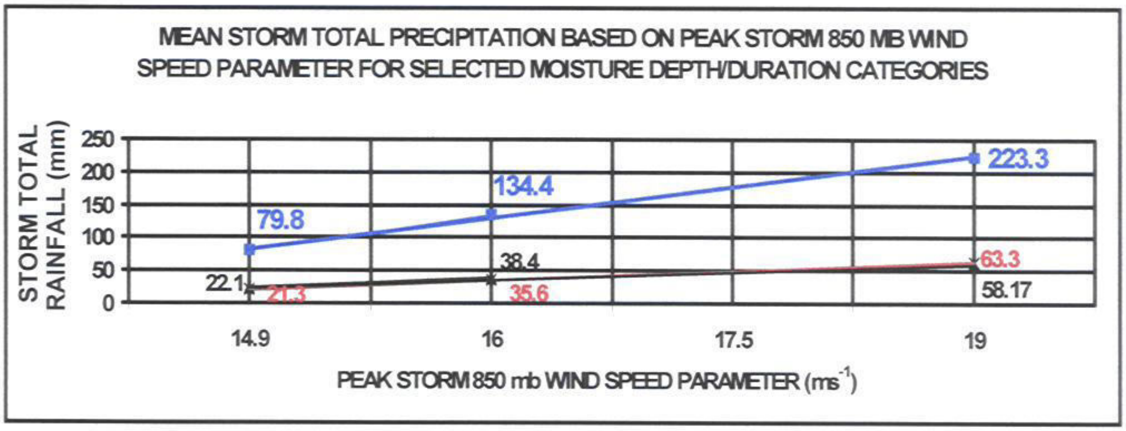
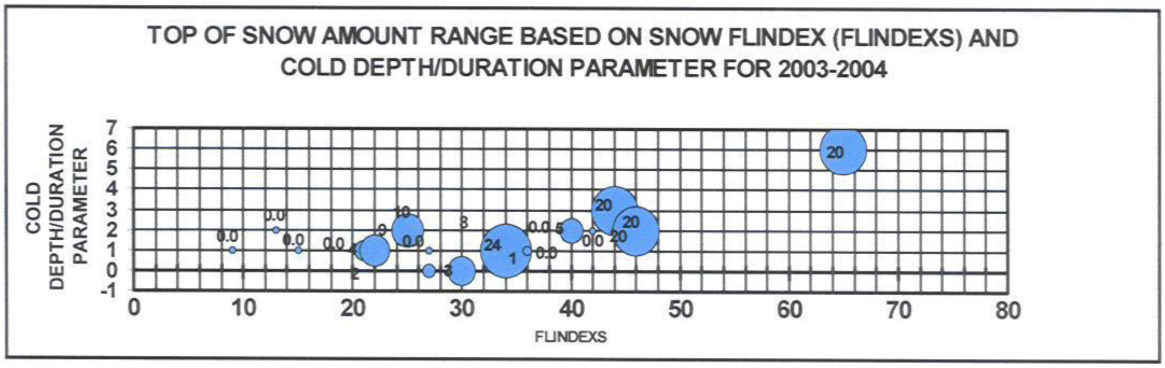


b.

Figure 3. Mean storm total precipitation (rainfall) based on peak storm 850 mb wind speed parameters of 20 knots or more for 2003-2004. For example, the thick blue curve shows average rainfall for Lytle Creek for depth/duration value categories of 0-1, 2-3, and 6-7 respectively along with the average peak storm 850 mb wind speed for those depth/duration categories. There were no storms with depth/duration values in the 4-5 range with peak storm 850 mb wind speeds of 20 knots or more. (a) Storm total rainfall in inches at Lytle Creek (blue), Rialto (black) and Santa Ana (KSNA, in red). (b) Same as for a, using mm and meters per second.



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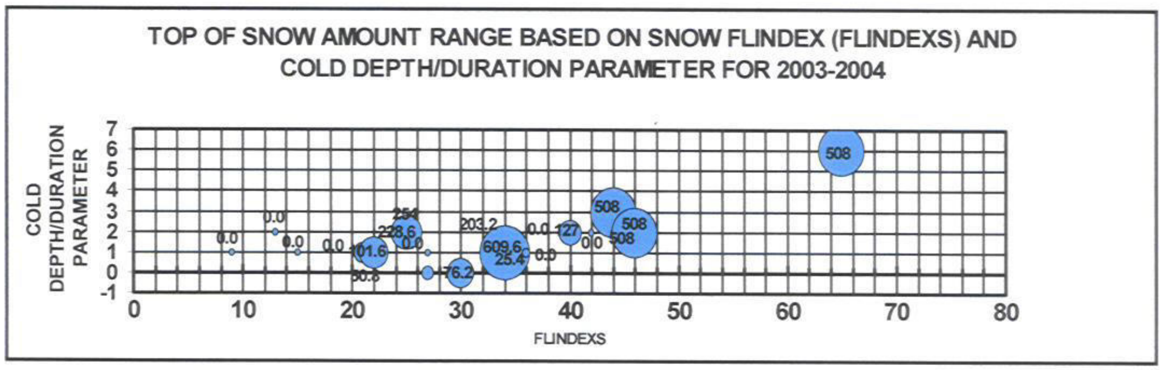

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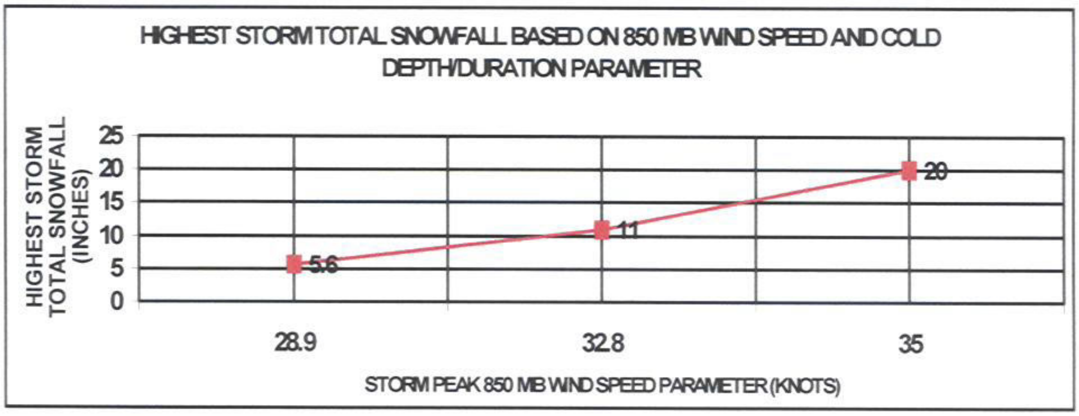
Figure 4. Top of the snow amount range based on the "snow FLINDEX" (FLINDEXS) which uses only cold depth/duration parameter values defines as depth/duration values calculated only for KNKX 850 mb temperatures at or below 6.5 C. Snowfall is for regions near resort levels (around 6000 feet msl, or about 1800 meters msl). (a). Snow amount values in inches. (b). Snow amount values in mm.



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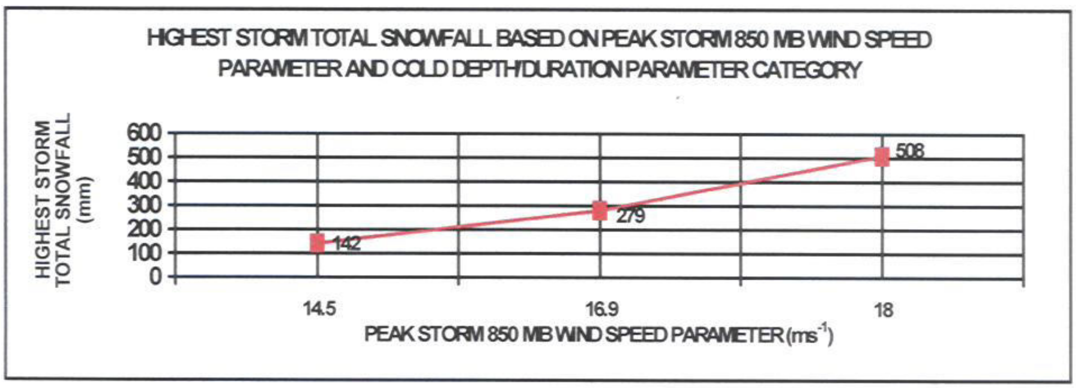


b.

Figure 5. Top of reported storm total snowfall range for peak storm 850 mb wind speed parameters of 20 knots or more and cold depth/duration parameters of 0-1 for the far left point, 2-3 at the middle point, and 6-7 at the far right point. Snowfall is for regions near resort levels (around 6000 feet msl, or about 1800 meters msl). (a). Graph indicates up to about 20 inches of snow for peak 850 mb wind speeds at about 35 knots with a depth/duration parameter of 6-7, about 12 inches for 850 mb winds around 33 knots and a depth/duration parameter value of 2-3, and about 5 inches for 850 mb winds around 29 knots and a depth/duration value of 0-1. There were no storms with depth/duration values in the 4-5 range with peak storm 850 mb wind speeds of 20 knots or more. (b). Same as a, except in mm and meters per second.

The indices can give an overview of the type of weather problems a storm may bring. Based on the 1998-2002 development data, a cold depth/duration parameter of 2 with 30 knot winds generally results in a moderate probability of flash flooding at the low elevations, at least ½ a foot of snow in the higher mountains, wind gusts with the front to 30 knots (15 m s^{-1} at the coast), twice as high (about 60 knots, or about 30 m s^{-1}) in the mountains, and usually a thunderstorm or two if the 500 mb temperatures approach -20 C. Oftentimes at the end of a rain event the 850-700 mb relative humidity falls to about 60-70 percent, usually good for scattered to widespread showers if there is still about 100 mb of 80 % relative humidity in the critical 850-700 mb zone, Figures 2-5 show various relationships between indices and actual rainfall and snowfall in 2003 and 2004.

5. CASE COMPARISON

During this study, it was found that the character of the rainband is likely to be more significant than just the FLINDEX, depth/duration parameter, and MAXH85WS parameters alone. A solid, wedge-shaped wide cold frontal rain band seem more likely to consistently generate widespread heavy (especially heavy orographic) precipitation than disjoint line segments in other fronts. The following 2 examples, both with depth/duration parameters of 1 and MAXH85WS values of near 30 at KNKX, but vastly different rainfall totals helps to illustrate this point.

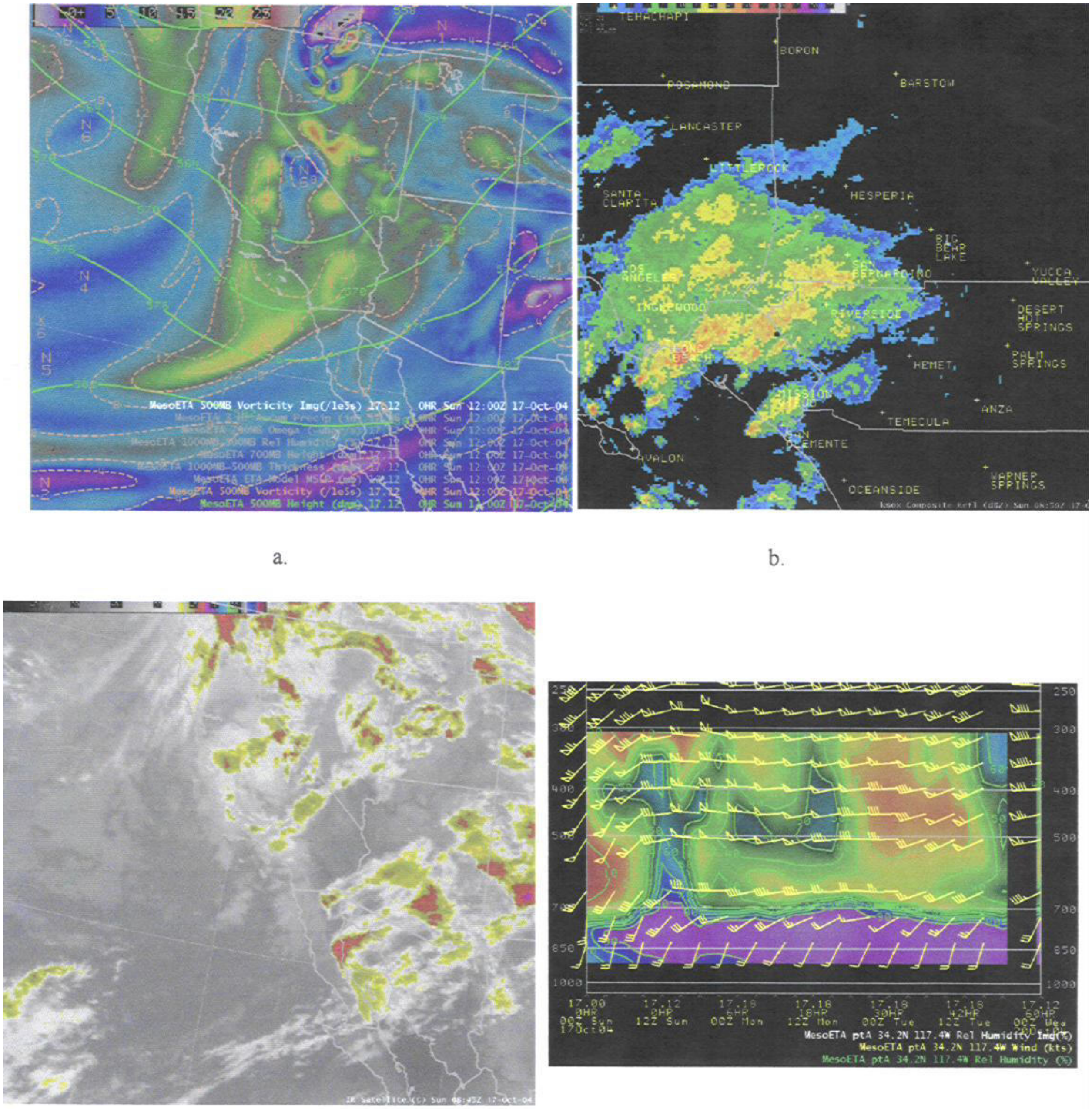
5.1 CASE 1

On 16-17 October 2004 (Fig 6a) after stalling off the coast, an upper level low lifted northeast over the area with showers and thunderstorms. (Upper lows, even if there is no 50 % 700-500 mb relative humidity layer in the sounding, can still seem to generate showers and thunderstorms with 700-500 mb relative humidity in the 40s, since they somehow "find the moisture" within isolated pockets of uplift).

About 26.9 mm (1.06 inches) of rain fell at Santa Ana (KSNA), about 55 ft msl. This was a "fractured" front (Fig 6b), with cores of 35 dBZ radar return separated by much lighter rainfall. The rainfall was mainly in loosely organized line segments. In this case, there was some minor "single segment training" (individual segments oriented in such a way that the mean flow carries much of the segment over the same location, for enhanced accumulations). This results in large variations in rainfall totals over short distances. However, this front did not deliver the 25 to 64 mm (about 1.00 to 2.50 inch) accumulations in one hour seen in the past by single segments of forced convection training over isolated locations. About 1.87 inches (about 47.5 mm) fell at Lytle Creek, at 2792 feet msl (about 850 meters msl) on the lower coastal slopes of the mountains. Satellite shows what appears to be a low topped heavy precipitation event with minimal enhancement noted in the imagery over southern California (Fig. 6c). This is also seen in the time-height cross section taken near Lytle Creek (Fig 6d). However, the low level moisture is extreme. An 80 % core somewhere between 850 and 700 mb is usually enough for some measurable precipitation. This front is nearly saturated (above 90 %) from the surface to near 700 mb. The airmass dries out rapidly above 700 mb.

5.2 CASE 2

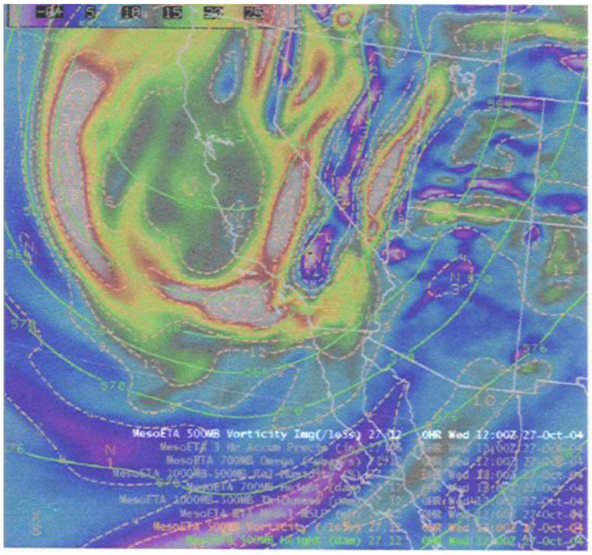
Unlike the first case the 26 - 27 October 2004 case showed the characteristics of a classic southern California heavy rain and flash flooding event. About 2.12 inches (53.8 mm), exactly twice the amount that fell in the case 1, was recorded at Santa Ana. A whopping 8.98 inches (about 228.1 mm) fell at Lytle Creek. There was an upper level trough over the west coast with regions of strong vertical vorticity and vertical velocity moving through southern California (Fig. 7a). In this case, there is a consolidated area of 35 dBZ or higher (Fig 7b), which is much different than the un-consolidated 35 dBZ returns associated with the 16 - 17 October 2004 case. These types of wedge shaped events are often accompanied by precipitable water approaching twice normal (exceeding 1 inch, or 25.4 mm), and there is often transverse banding along the front. This resulted in a more continuous heavy rain event, and much higher and more widespread accumulations, even in regions without orographic enhancements. A classic feature is the wedge shaped enhanced cirrus deck, trailing off to a wedge shaped, very wide and strong surface cold front extending well into the Pacific. Conveyor belt activity is evident. This setup shows strong difluence aloft most likely fueling a thick, solid frontal rain band. (Fig. 7c). Well developed comma clouds are another classic feature, one of which is approaching and strengthening the front. As is typical for this type of event, rainfall averaged about ½ to 1 inch per hour (12.7 - 25.4 mm per hour) around the time that the main portion of the band went through. On the lower coastal slopes of the mountains a peak of about 1.18 inches (30.0 mm) fell in 1 hour, much higher than the peak hourly rainfall of 8.0 mm (about 0.32 inches) that fell on the 17th. There were also very strong winds, gusting to near the 850 mb wind speed in the coastal areas, which is usually damaging around 20-25 knots or more (10-12 m s^{-1}). There were reports of downed trees and power lines. There was around 2 feet of new snow in the mountains above 6000 feet as the cold air filtered in. The time height cross section showed very deep moisture, extending to around 600 mb, with 35 knot 850 mb winds (Fig 7b). Ridging, with higher pressure over KTUS, (in Arizona, not shown) can result in precipitation that is especially heavy if the 850 mb height gradient between KNKX and KTUS approaches 60 meters, or the 850 mb height gradient between KTUS and KDRA, (in Nevada, not shown) approaches 75 meters. This generally indicates a blocked, slow moving front with a very strong low level jet. Blocking between KNKX and KTUS reached 64 meters in this case.



a. b.

c. d.

Figure 6. Graphics from storm on 16-17 October 2004. (a) 1200 UTC 17 October 2004 MesoEta 500 mb Heights (green solid, decameters) and Vorticity (imagery, and orange dashed lines). (b). 0859 UTC 17 October 2004 KSOX Composite Reflectivity. (c). 0845 UTC 17 October 2004 infrared satellite imagery. (d). 1200 UTC 17 October 2004 time height cross section of relative humidity (imagery, and green contours in intervals of 10%) and wind barbs (knots) at Lytle Creek.



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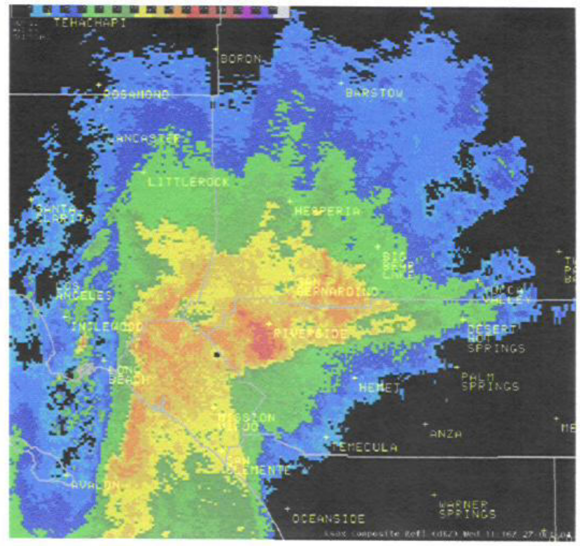

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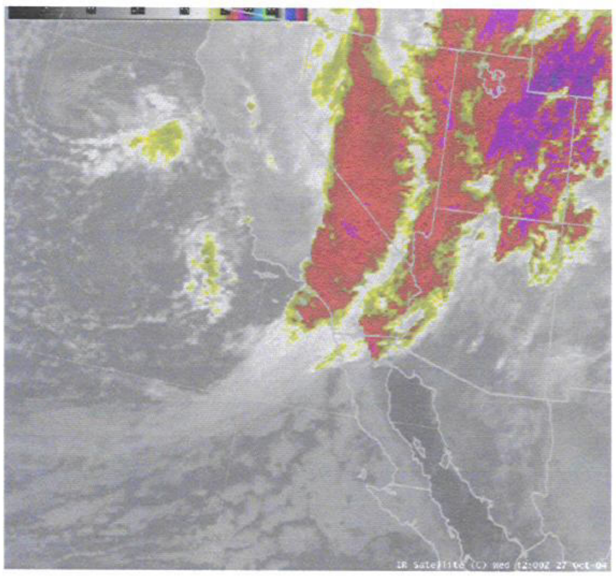

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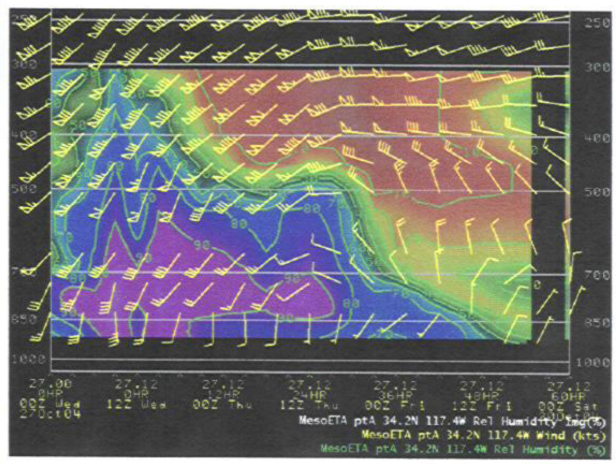

d.

Figure 7. Graphics from storm on 26-27 October 2004. (a) 1200 UTC 27 October 2004 MesoEta 500 mb Heights (green solid, decameters) and Vorticity (imagery, and orange dashed lines). (b). 1116 UTC 27 October 2004 KSOX Composite Reflectivity. (c). 1200 UTC 27 October 2004 infrared satellite imagery. (d). 1200 UTC 27 October 2004 time height cross section of relative humidity (imagery, and green contours in intervals of 10 %) and wind barbs (knots) at Lytle Creek.

6. DISCUSSION AND CONCLUSION

Based on the 1998-2002 development data, events with a depth/duration parameter value of at least 2 and a peak storm 850 mb wind of around 25 knots (12 m s^{-1}) usually result in flash flooding in vulnerable areas (for example, recent burn areas, low water crossings, vulnerable intersections, and some desert areas), with urban and small stream flooding in less vulnerable areas. This can be satisfied by a 2 point sounding (1000-500 mb relative humidity 80 % or more), and result in an instantaneous FLINDEX value of 5 times the depth/duration parameter added to the storm peak 850 mb wind parameter in the 30s.. For a wind speed of 25 knots, the FLINDEXI value is 35. By the time winds reach 35 knots, there is usually widespread flash flooding, with a FLINDEXI value of 45. If 5 soundings are interrogated, the FLINDEXI by definition becomes FLINDEX. The 1998-2002 development data showed that for depth/duration values of 4 or more, for any wind speed, flash flooding was reported 63 % of the days ("likely" flash flooding), targeting duration of deep moisture as a strong factor in flash flooding since mesoscale features can take advantage of this deep and/or long duration moisture. In the 2003-2004 data, the probabilities were even higher for the same index values. Although flooding can occur at lesser values, these parameters can help support the idea of flash flooding at the higher values. The indices and parameters discussed in this paper can go a long way in helping the forecaster anticipate the upcoming weather threat. For example, an upcoming storm with multiple periods of 850-700 and 1000-500 mb mean relative humidity exceeding 80 % with a storm peak 850 mb wind of 25 knots or more should alert the forecaster to possible flooding.

An attempt was made in this paper to determine a basic potential for heavy precipitation that could lead to flash flooding and/or heavy snow. About 60 % 850-700 mean relative humidity points toward a very slight chance of getting rain in many cool season cases, and usually some rain with an 80 % core in the layer. With 80 % mean 850-700 mb relative humidity or higher, some locally heavy rain generally occurs. The depth of the "very wet" layer, (for example, 80 % relative humidity from the surface to above 600 mb) may generate flooding, and will be investigated more thoroughly in the future.

Although these indices and parameters can give an idea of what the moisture and wind profile indicate as far as rainfall and flooding potential are concerned, the key to the very heavy amounts being realized seems to be the character of the front. If there is a wide, continuous area of 35 dBZ radar return with embedded widespread 40-50 dBZ, then widespread and continuous heavy rainfall can occur. This is often associated with the diffluent zone of a Pacific storm, consisting of a wide, often wedge-shaped region of high clouds above a wedge shaped, wide cold frontal rain band. On radar the precipitation shows up as a wide, wedge shaped region of strong radar return. These frontal regions impinging upon the mountains, and often generate strong orographic precipitation, especially for the more "tropical" airmasses (850 mb dewpoints above about 5 C). In extreme cases, the echoes associated with the wide cold frontal rainband may be strong enough to obscure the imbedded narrow cold frontal rainband, with hours of rainfall at about 1 inch per hour (25.4 mm per hour) or more and almost certain flooding. Sometimes, a wide area of precipitation is actually a strong, or strengthening front catching up to another weakening front.

If the front is more of a "narrow cold frontal rainband" type, and is broken up into cores, it is more difficult to obtain the heavy, sustained amounts seen with wide cold frontal rainbands. This is because the motion of the individual cores results in a core moving across a location at an angle, delivering intense rainfall, but with a short duration. However, if a strong, single line segment training event occurs, where the segment moves over an area in a lengthwise fashion, there is intense, long duration very heavy rainfall with huge rainfall amounts where it occurs, including the orographic regions. These "narrow cold frontal rain band events" have been seen to be less conducive to widespread heavy orographic rainfall in the mountains in comparison to "wide cold frontal rain band events. Unless a series of precipitation cores moves over the same area, or the rain bands become nearly stationary the lack of continuous heavy rain can result in reduced rainfall totals in the mountains since there is a chance that the heaviest precipitation cores will miss the favored upslope flow regions.

During these heavy rain events, areas recently burned by wildfires must be closely watched. Rates resulting in mud and/or water over roads are about 1/3-1/2 of that in less "flood - prone" areas. The rates are basically about 0.40-0.50 (10 to 12.5 mm) in an hour or less in burn areas and vulnerable flood areas such as low water crossings and the desert areas, about 1.00 to 1.25 inches (about 32 to 38 mm) in one hour or less for the less vulnerable areas, and just about anywhere for amounts over 1.25 inches in one hour or less, even in well drained areas. This makes rainfall rates and amounts that are generally insignificant in most parts of the country into flash flood/mudslide threats in southern California.

With approximately a 3.5 to 1 ratio of rainfall between Santa Ana at 55 ft msl (about 17 meters msl) and Lytle Creek at 2792 feet msl (about 850 meters msl) based on the 2003-2004 events, rainfall is strongly magnified, even in the foothills below 3000 feet msl, further worsening the flooding problem. Figure 3. showed that depth/duration values in the 6-7 range with 35 knot peak storm 850 mb winds, on average, produced about 2 ½ inches (76 mm) of rain in the coastal areas, but nearly 9 inches (229 mm) of rain near the foothills, showing very strong orographic enhancement below 3000 feet msl (about 900 meters msl). During some of these bigger events, the rainfall can exceed ½ inch (about 12.5 mm) per hour for 6 to 10 hours with 6 hour amounts in the 4 to 6 inch range (102 to 152 mm).

With some storms, it seemed that rather than using an 80 % threshold to determine depth/duration, maybe a sounding with 1000-500 mb mean relative humidity of only 70 or 75 % might be wet enough to justify a depth/duration value of 2. The FLINDEX and FLINDEXI should be used for depth/duration parameters of 1 or more, (but best at 2 and above), otherwise values would be too dry for flooding. One variation that would result in a continuum of values, as well as reduce the index for dry airmasses, is an estimate of FLINDEXI called FLINDEXE. It can give a quick estimate of flood potential using raob (or model) data. Basically, the equation is altered by a combination of 850-700 mb relative humidity and 1000-500 mb relative humidity values. Developing a continuum of values for depth/duration, rather than using the discrete values of 1 and 2 is fairly simple. If A = 850-700 mb relative humidity and B = 1000-500 mb relative humidity, then the depth/duration portion of FLINDEXI now becomes C = (A + B)/60. The 850-700 mb relative humidity divided by one hundred results in a value of 1 for 100 % 850-700 mb relative humidity, and a number approaching zero for a very dry airmass. This value, D = 0.01A, makes an excellent multiplier for reducing index values for dry airmasses. The following equation is the result.

FLINDEXE = D(5C + 850 mb wind speed) **(2)**

This would allow for a continuum of flood values that are very close to the “single raob” values of FLINDEXI. Future work to explore adjustments due to the capacity of the airmass to hold moisture are planned.

Even without moisture, the peak storm 850 mb wind speed parameter (a reasonable estimate for the low level jet) can give a good estimate for maximum wind gusts near frontal passage. Coastal wind gusts are approximately equal to the peak 850 mb wind speed. Highest wind gusts in the mountains are oftentimes about 2 times the peak 850 mb wind speed approaching those mountains (a sort of “Small’s mountain wave wind gust estimate technique” which works reasonably well in many of the stronger wind events in southern California).