The Utility of a High Level Most Unstable CAPE (HLMUCAPE) and a High Level Lifted Index (HLLI) for Forecasting Elevated Convection in Southwestern California

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1. INTRODUCTION

The Total Totals Index, which is used extensively to predict the occurrence and severity of thunderstorms in the plains, was modified for the higher elevations of the Intermountain West. Milne (2004) replaced the 850 mb level with the 700 mb level in his calculation of the Total Totals Index and renamed it the High Level Total Totals Index (HLTT). His motivation stems from the fact that the 850 mb level is often at or below the surface in the western United States and therefore fails to account for the moisture necessary for thunderstorm development. Strong correlations were found between the HLTT index and thunderstorm development, the severity of thunderstorms, and the probability of precipitation. He also found that the HLTT index should be used with caution when unseasonably cold upper lows move through the Intermountain West as the 500 mb temperature can lead to an overestimated value of the HLTT index. He concluded that the HLTT index should primarily be used during the summer season, when 500 mb temperatures are usually -15EC or above.

2. ELEVATED INDICES IN SOUTHERN CALIFORNIA

In southern California (Fig.1) there are also shortcomings with the Total Totals index because sometimes the moisture does not dip down to the 850 mb level. Small (2004) created the Wind Adjusted Convective Index (WACI) to address the issue of strong convection when optimal moisture and instability only falls as low as around 750 mb, which can still generate flash floods, large hail, damaging winds, or a combination thereof. The WACI is mainly geared toward the more "pulse type" severe thunderstorms that develop in weak dynamic regimes (mainly summer monsoon type events) with light winds aloft, and weak if any large scale lift from upper lows or easterly waves. Thunderstorms can develop during these weaker dynamic conditions if the 50 percent relative humidity contour dips down to around 650 mb level. The WACI can also be used effectively in windy, dynamic conditions if the wind component of the equation is ignored, and only the moisture and lapse rate portions are used.

With upper lows, the 50 percent relative humidity can sometimes fall only as low as the 650-700 mb level or so, but parcels lifted from as low as 700 mb can be unstable, even though parcels lifted from below 700 mb might still be stable. Traditional indices that look below 700 mb may not detect this elevated moisture source. In some of these cases, rather impressive lightning outbreaks can occur.

One way to tackle this problem is by using an elevated lifted index, for example, lifting parcels from 700 or 650 mb. Even then, sometimes the instability is higher still, so an elevated Most

Unstable CAPE (an elevated MUCAPE calculated via the lifting of a parcel from between 700 and 500 mb) can be employed. Tardy (2002) looked at elevated CAPE for an event with the greatest moisture confined between 600 and 500 mb. A Most Unstable Elevated CAPE method can also be used when dynamics are sufficient for strong convection, and the problem of the convection being torn apart by strong winds as in the “pulse thunderstorm type cases” is minimal. The elevated Theta-e lapse rate is also a promising parameter when looking for upper level convection, but will not be examined here. For our purposes, the High Level Lifted Index (HLLI) will be defined as the same as the standard Lifted Index, except the parcel is lifted from 700 mb. The High Level Most Unstable CAPE (HLMUCAPE) will be defined as the CAPE of the most unstable parcel in the 700 to 500 mb layer. These parameters should continue to work under the conditions associated with cold upper level low pressure systems [which includes the events where the HLTT begins to overestimate (below -15 C 500 mb temperatures)].

At the National Weather Service Forecast Office in San Diego the AWIPS volume browser has been modified to calculate elevated convective parameters. [The Advanced Weather Interactive Processing System (AWIPS) is the main computer system used by forecasters in the National Weather Service. The volume browser is a tool to manipulate and view various weather parameters].

The HLTT appears to be useful for events with 500 mb temperature of about -15 degrees C or higher. Also, modifications were made to calculate the Lifted Index based on parcels lifted from 700 mb (HLLI) and 650 mb, as well as the HLMUCAPE for parcels lifted from a level between 700 and 500 mb. We will look at two cases of significant elevated convection in order to get a very preliminary evaluation of the effectiveness of these parameters for diagnosing and predicting significant elevated convective events.

3. CASE I. THE 3 JUNE 2009 LIGHTNING AND SEVERE WEATHER OUTBREAK

The period of late May through early June is no stranger to severe weather. On 22 May 2008, 4 tornadoes were reported in southern California due to a late season, very strong upper level low pressure system (Small et al., 2009). The 3 June 2009 event in this study occurred during the same time of year, almost exactly 1 year after the 22 May 2008 event, supporting this point. During the 3 June 2009 event an unseasonably strong upper level low pressure system moving eastward from the Pacific brought high based thunderstorms, locally gusty winds, and large hail. There were around 1500 lightning strikes, with about 70 lightning caused fires, mainly in the mountains. There was one lightning fatality. The first lightning strike was around 0900 UTC, with the activity increasing in intensity and coverage through the midday hours.

Rainfall reports were mainly less than a tenth of an inch as there was still a deep dry layer in the lower-mid levels. One-inch diameter hail was reported. The transition from a mainly “lightning” event to a low end severe weather event was the result of the “top-down” moistening of the sounding that thickened the moist layer aloft enough to support severe hail.

The 0000 UTC 4 June 2009 12 hour forecast of the 500 mb heights and HLLI from the 1200 UTC 3 June 2009 NAM80 run is shown in Figure 2. Notice the HLLI value of just below zero, showing a forecast of very marginal instability. The 0000 UTC 4 June 2009 12 hour forecast of the 500 mb heights and HLMUCAPE from the 1200 UTC 3 June 2009 NAM80 run is shown in Figure 3. Notice the HLMUCAPE is forecast to be near zero.

Based on the KNKX soundings (Fig. 4) the 700 mb and 500 mb temperatures changed very little from 1200 UTC 3 June 2009 to 0000 UTC 4 June 2009, however the 700 mb dew point increased substantially from -21.4 degrees C to 1.6 degrees C, showing that the huge increase in instability was largely due to the increase in mid level relative humidity. Lift associated with the diffluent region of the low likely added to the instability and thunderstorm development. The 0000 UTC 4 June 2009 HLMUCAPE was 501 J/kg, and the HLLI was -3.2 degrees C, far more unstable than was forecast by the NAM 80 model.

Apparently the destabilization shown by the models was much less than the destabilization that actually occurred. Figure 5 shows the 2027 UTC 3 June 2009 composite reflectivity from the KNKX radar. The 3 pixels of 65-70 dBZ near the time of the reported 1 inch diameter hail (near Solana Beach) can be seen.

4. CASE II. THE 21 SEPTEMBER 2005 LIGHTNING OUTBREAK

From about 0200 UTC 20 September 2005 through 1630 UTC 20 September 2005 another unseasonably strong upper level low pressure system drifted over southern California. Widespread thunderstorms resulted in numerous small fires, power outages, and property damage. The storms were strongest early morning on 20 September 2005. A few homes were damaged due to the lightning.

The 1200 UTC 20 September 2005 12 hour forecast of the 500 mb heights and HLLI from the 0000 UTC 20 September 2005 NAM80 run are shown in Figure 6. Notice the HLLI value of around -2 degrees C shows a large amount of instability, considering that the distance that the parcel is lifted (700 mb parcel lifted to 500 mb) is only 200 mb. The 1200 UTC 20 September 2005 12 hour forecast of the 500 mb heights and HLMUCAPE from the 0000 UTC 20 September 2005 NAM80 run are shown in Figure 7. Notice that the HLMUCAPE value of around 200 J/kg is showing a large amount of instability, considering that the parcel is lifted from such a high level (between 700 and 500 mb).

Based on the 1200 UTC 20 September 2005 KNKX sounding (Fig. 8), the 700 mb and 500 mb temperatures changed very little from 0000 UTC 20 September 2005 to 1200 UTC 20 September 2005, however, the 700 mb dew point increased substantially to 7.5 degrees C, showing that the huge increase in instability was largely due to the increase in mid level relative humidity. Lift associated with the diffluent region of the low likely added to the thunderstorm development. The HLMUCAPE was 724 J/kg, and the HLLI was -2.4, quite a bit more unstable than forecast by the model (approximately 200 J/kg and -2 degrees C). Again, moisture increase seems to be the destabilizing factor. Apparently the destabilization shown by the models was again less than the destabilization that actually occurred. Figure 9 shows the thunderstorms on the 1046 UTC 20 September 2005 composite reflectivity from the KNKX radar.

5. DISCUSSION AND CONCLUSIONS

As seen above, HLMUCAPE and HLLI values can be quite useful in the west for diagnosing the instability of not only the current sounding, but that of the forecasted air mass. This gives the forecasters better information than just looking at the traditional indices at the traditional levels (below 700 mb). Fairly simple modifications in AWIPS allows forecasters at WFO SGX to calculate the MUCAPE of layers at 700 mb or higher, and LI values from parcels lifted at 650 and 700 mb. The HLTT (Milne, 2004) is also quite handy, as long as the air mass is warm enough. Although upper level vertical motion has not been assessed, it is somewhat implied by the diffluent regions in the upper level data, and will be a topic of later studies. HLMUCAPE values of 200 J/kg or more and HLLI values of around -1.5 degrees C or lower appear to be significant values, which makes sense since the values are reached using a much smaller layer in the atmosphere than those of the traditional CAPE and LI.

Burger (2008) looked at a lightning outbreak in the Pacific Northwest on 20-21 June 2008. A review of the data and consultation with the SPC regarding the event strongly suggest that the numerical forecast models greatly understated atmospheric instability. Although only 2 events were treated here, based on the southern California cases the underestimation of the instability was again seen, and supports their findings. Burger also stated that there were a number of observational clues to suggest in advance that an unorthodox event was a possibility. They included lightning offshore many hours before commencing over land, a widespread ACCAS cloud field observed the morning of the event, two moisture sources…Hawaii and offshore Baja California, strong upper level diffluence, and an unseasonably strong jet. This would also be true over southern California, except the moisture feed from Hawaii is not a necessary factor. Using the above clues, along with the information supporting a possible underestimation of the instability by the models, forecasters should be able to adjust the instability upward, watch for the clues, and use the HLMUCAPE and HLLI to produce a better forecast for this type of event.

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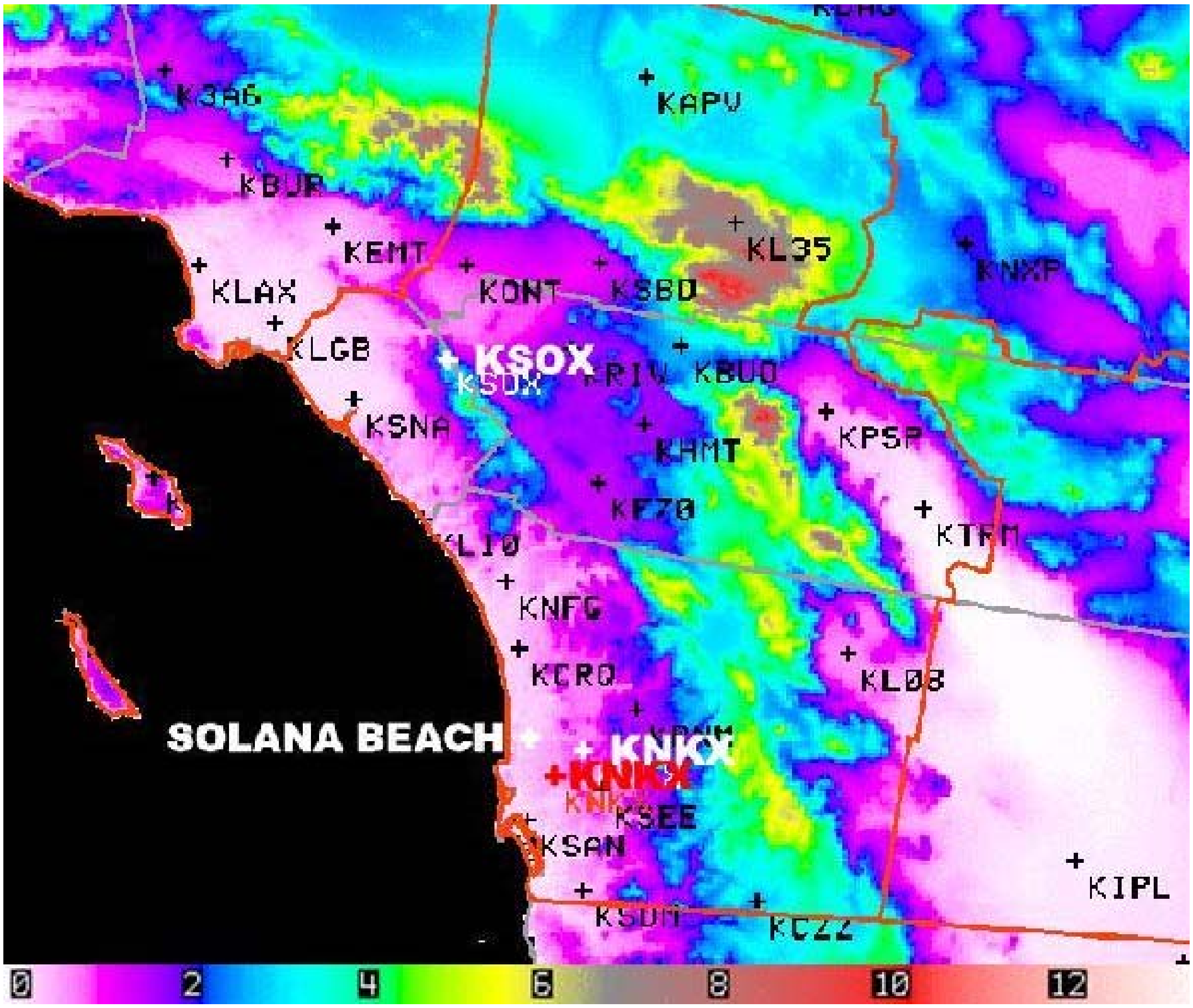


FIG. 1. Terrain map of the WFO SGX CWFA. The location of the KNKX sounding is indicated in red type. The locations of the KSOX and KNKX radars are shown in white type. The terrain color coding is in thousands of feet MSL.

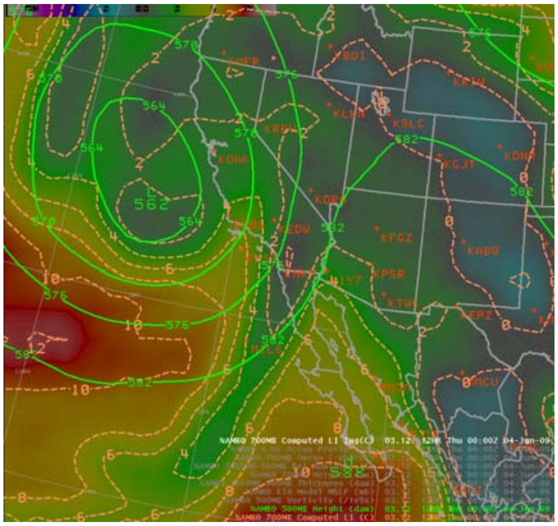


FIG. 2. The 12 hour forecast of the NAM80 500 mb heights (solid green contours in intervals of 60 meters) and HLLI (dashed orange contours in intervals of 2 degrees C, and shaded) valid at 0000 UTC 4 June 2009. Notice the HLLI value of just under zero near KNKX showing a forecast of very marginal instability.

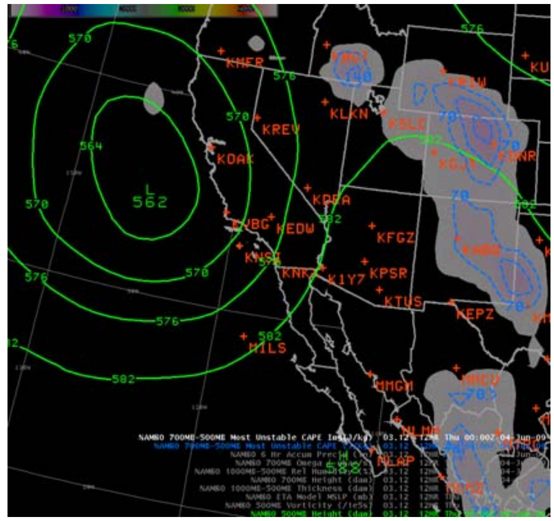


FIG. 3. The 12 hour forecast of the NAM80 500 mb heights (solid green, contours in intervals of 60 meters) and HLMUCAPE (dashed blue contours in intervals of 70 J/kg, and also shaded) valid at 0000 UTC 4 June 2009. Notice the HLMUCAPE is near zero over KNKX.

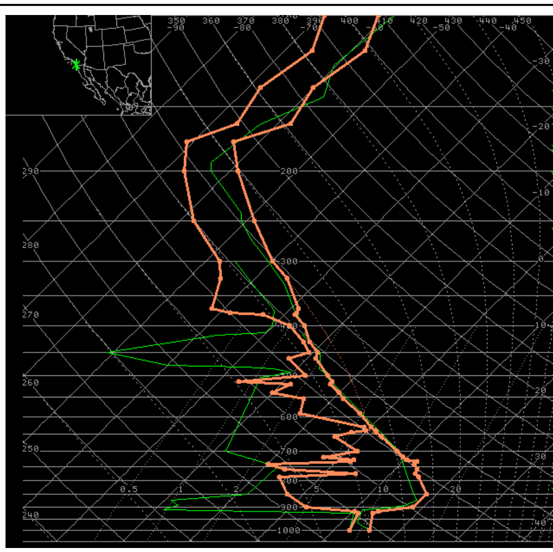


FIG. 4. The 1200 UTC 3 June 2009 KNKX Sounding (thin, green contours) overlaid with the 0000 UTC 4 June 2009 KNKX Sounding (thick, orange contours with circles). The HLMUCAPE was 501 J/kg, and the HLLI was -3.2, far more unstable than forecast by the model. Moisture increase seems to be the destabilizing factor.

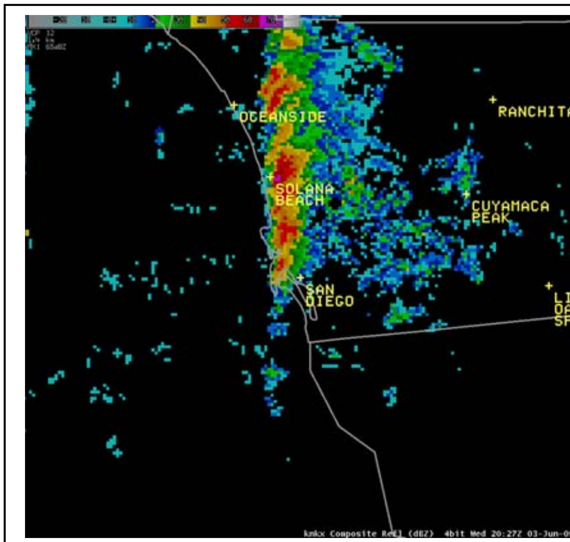
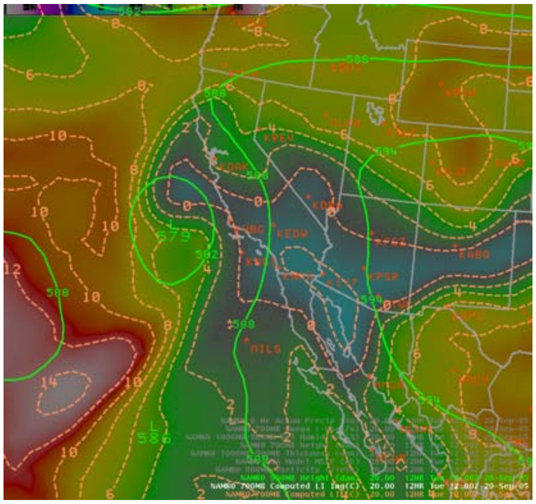


FIG. 5. The 2027 UTC 3 June 2009 composite reflectivity from the KNKX radar. Notice the 3 pixels of 65-70 dBZ near the time of the reported 1 inch diameter hail (near Solana Beach).



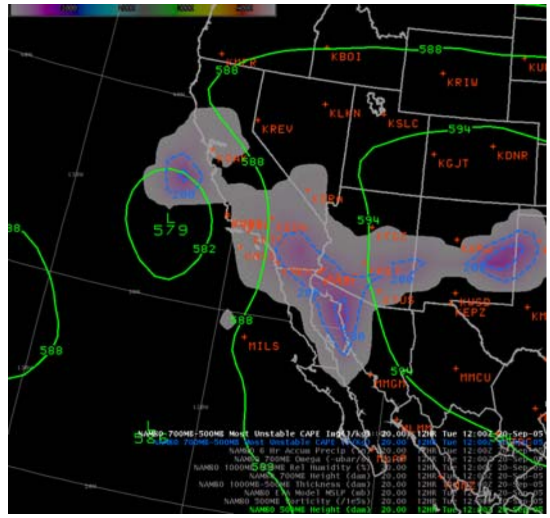
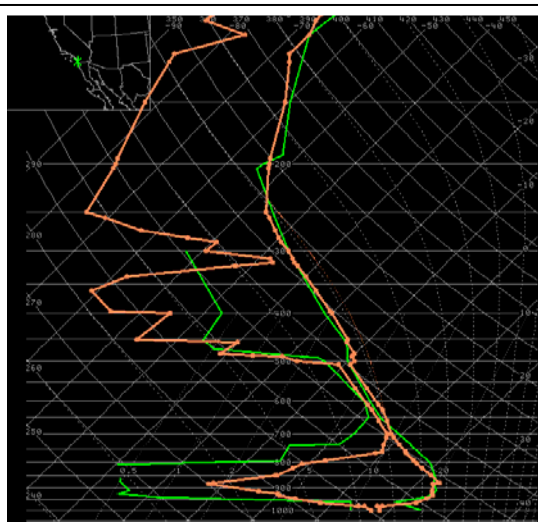


FIG. 6. The 12 hour forecast of the NAM80 500 mb heights (solid green contours in intervals of 60 meters) and HLLI (dashed orange contours in intervals of 2 degrees C, and shaded,) valid at 1200 UTC 20 September 2005. Notice the HLLI near KNKX was forecast to be just under 2 degrees C.

FIG. 7. The 12 hour forecast of the NAM80 500 mb heights (solid green contours in intervals of 60 meters) and HLMUCAPE (dashed blue contours in intervals of 200 J/kg, and shaded) valid at 1200 UTC 20 September 2005. Notice the HLMUCAPE value was forecast to be around 200 J/kg at KNKX.



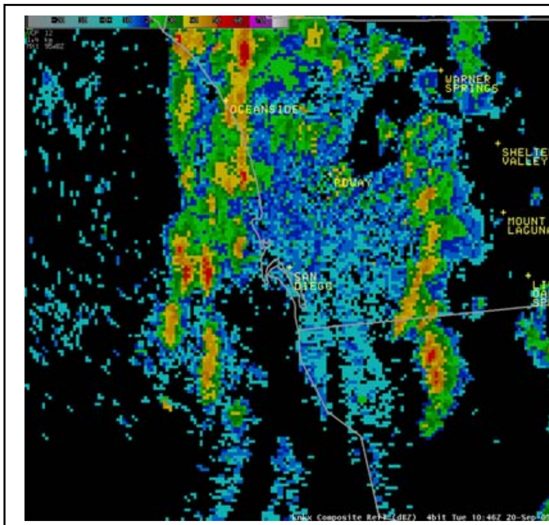


FIG. 8. The 0000 UTC 20 September 2005 KNKX Sounding (thin, green contours) overlaid with the 1200 UTC 20 September 2005 KNKX Sounding (thick, orange contours with circles). The HLMUCAPE was 724 J/kg, and the HLLI was -2.4 degrees C, far more unstable than forecast by the model values of approximately 200 J/kg and -2 degrees C. Again, moisture increase seems to be the destabilizing factor.

FIG. 9. The 1046 UTC 20 September 2005 composite reflectivity from the KNKX radar.