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Estimates of Buoyancy, Shear, and Precipitable Water Thresholds for Active Severe Thunderstorm and Active Flash Flood Days in Southeast Arizona

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1. Abstract

The purpose of the study is to determine under what buoyancy and shear conditions severe thunderstorms and thunderstorms that produce flash floods develop in the Tucson County Warning Area (CWA). The conditions were determined by reviewing three atmospheric parameters gathered from soundings and raw mandatory level data: Convective Available Potential Energy (CAPE), precipitable water and wind shear.

Results of this study showed that for active severe thunderstorm and flash flood days, CAPE values varied widely making it difficult to correlate an active day with CAPE. Therefore, relative high, moderate and low CAPE values could not be established. Active flash flood days were most likely to occur when precipitable water was high and the wind shear (average of the 850-500mb and 700-500mb layers) was low. Conversely, active severe thunderstorm days were most likely to occur when precipitable water was low and the wind shear (average of the 850-500mb and 700-500mb layers) was high. All values obtained for this study ended up being lower than the CAPE and wind shear values in the Convective Storm Matrix (Weisman, 2003).

2. Introduction

The idea for this project evolved from the Cooperative Program for Operational Meteorology, Education and Training's (COMET) Convective Storm Matrix (Weisman, 2003). The Matrix is a tool that aids meteorologists in determining thunderstorm structures, their evolution, how they are organized, and the potential for severe weather under certain buoyancy and shear conditions. However, the values for southeastern Arizona may differ from buoyancy and shear values in the Matrix. One possible reason for the difference is the role of large scale dynamics. Although this was not examined in this study, large scale dynamics can alter the environment for thunderstorm development. Another possible reason for this difference is that the Matrix's findings are based on a homogenous and frictionless atmosphere. This assumption cannot be made in Arizona because of its mountainous terrain. Therefore, the parameter values needed for organized severe thunderstorms in southeastern Arizona are likely to vary from the values obtained from COMET's Convective Storm Matrix. Although the Matrix was done under a homogenous atmosphere, the module's author noted that the buoyancy and wind shear values provided by the Matrix could be higher than actual values for a real life thunderstorm event.

3. Data

The parameter data for this study was collected from the University of Wyoming's upper air sounding archive [http://weather.uwyo.edu/upperair/sounding. html]. The collection of data is from 1996 to 2003 for the months of July through September. Since most thunderstorm activity occurs in the months of July, August, and September in southeast Arizona, it was beneficial to perform the study in such a limited time period.

CAPE and precipitable water were derived from the Tucson upper air sounding for 12Z as calculated by the University of Wyoming's website. The formula used to calculate CAPE was:

$$CAPE = Gravity * SUMP \left[DELZ * \frac{(TP-TE)}{TE} \right],$$

where TP is the temperature of the parcel from the lowest 500m of the atmosphere raised dry adiabatically to LCL and moist adiabatically thereafter and TE is the temperature of environment. SUMP is the sum over the sounding layers from the level of free convection (LFCT) to the equilibrium level (EQLV) for which (TP-TE) is greater than zero. The LFCT is the level at which a parcel from the lowest 500m of the atmosphere is raised dry adiabatically to the level above which parcel is positively buoyant . If more than one LFCT exists, the lowest level is chosen. If the parcel is positively buoyant throughout the sounding the LFCT is set to be the same as the pressure at the LCL. The equilibrium level is at which a parcel from the lowest 500m is raised dry adiabatically to LCL and moist adiabatically to a level above which the temperature of the parcel is the same as the environment. If more than one equilibrium level exists the highest one is chosen. DELZ is the incremental depth. Precipitable Water is integrated over the entire sounding. (http://www.weather.uwyo.edu/upperair/sounding.html)

Bulk wind shear was calculated manually using the wind direction and speed provided by the raw mandatory level data. Once the wind data was collected, wind shear was calculated using the Law of Cosines. The wind shear used in this study is the average of the calculated wind shear between the 850-500mb and 700-500mb layers. Statistical analyses were then performed on the collected data in order to determine the average and standard deviation of the CAPE, precipitable water and wind shear.

In order to determine when active severe thunderstorm and active flash flood days occurred, the information provided by the National Weather Services' Extreme Weather and Climate Events (http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwEvent~Storms) was used. This site, based on data from *Storm Data*, allows the viewer to access all weather events that occurred for a specific state. Since the date, time, and location of the events is given, it is easy to determine the events that were reported in the Tucson CWA. An active severe thunderstorm day and active flash flood day were determined by the number of events that occurred in that day. If two or more events occurred within the day then the thunderstorm day was considered an active severe thunderstorm or active flash flood day for the purpose of this study. Events for active severe thunderstorm days included reports of wind greater than 50 knots, wind damage, and ¾ inch hail. Events for active flash flood days included flash flood reports.

4. Results

Table 1 represents the data for active severe thunderstorm days and table 2 represents the data for active flash flood days. These tables were used to derive figures 1 and 2. Looking at figure 2, CAPE is significant for active severe thunderstorm or flash flood days to occur but the wide range of values makes it difficult to categorize what is high, moderate, or low CAPE. However, figure 2 does show that it is unusual for southeastern Arizona to have a CAPE value above 1500 J/kg at 12Z.

Since the range for precipitable water and wind shear was not as large as CAPE, it was easier to assign relative high, moderate and low values to precipitable water and wind shear. High precipitable water and wind shear were defined as one standard deviation above the mean, moderate precipitable water and wind shear were defined to be the range between one standard deviation above and below the mean, and low precipitable water and wind shear were defined to be one standard deviation below the mean.

Figure 1 showed that for an active flash flood day high precipitable water was 43mm to 48mm (1.70in. to 1.90in), moderate was 32mm to 43mm (1.30in. to 1.70in.), and low was 24mm to 32mm (0.90in. to 1.30in.). High wind shear was 26 knots to 46 knots, moderate was 8 knots to 26 knots, and low was 3 knots to 8 knots. From Figure 1, active flash flood days were most likely to occur when precipitable water was high and wind shear was low. For active severe thunderstorm days figure 1 showed that high precipitable water was 40mm to 46mm (1.60in. to 1.80in), moderate was 29mm to 40mm (1.10in. to 1.60in) and low was 26mm to 29mm (1.00in. to 1.10in.). High wind shear was 27 knots to 35 knots, moderate was 12 knots to 27 knots, and low was 4 knots to 12 knots. Active severe thunderstorm days were most likely to occur when precipitable water was low and wind shear was high.

Comparing these values to the Matrix under moist conditions, it can be seen that the values above for southeastern Arizona are considerably lower than CAPE and wind shear values in the Convective Storm Matrix. Moist conditions for the Tucson CWA occurred when the precipitable water range was about 25mm to 48mm (0.98in to 1.90in.). This can be seen in figure 1. Under moist conditions in the Matrix (Weisman, 2003), high CAPE is 3123 J/kg, moderate CAPE is 2300 J/kg and low CAPE 1243 J/kg. In the Matrix (Weisman, 2003), strong shear is considered to be 90 knots and up, moderate shear is 60 to 80 knots and low shear is equal to and less than 50 knots of wind shear. As expected, one does not need as much CAPE and shear in southeastern Arizona to produce either severe thunderstorms or flash floods compared to the Convective Storm Matrix.

5. Discussion

Although the data did produce some identifiable trends over the seven year period, there are uncertainties that must be considered. In this study, the soundings and use of the two event criteria could all lead to uncertainties.

Soundings are usually taken twice a day at 12Z and at 00Z. In between those times the sounding profile can change drastically, especially when thunderstorms alter the environment. Thunderstorms occurring at the time of release can also affect the data the sounding provides. Due to these disadvantages, soundings can be unrepresentative of the atmosphere, especially during or immediately after a thunderstorm passage. Since thunderstorms frequently occur before the 00Z sounding in Tucson, 00Z data was not used for this study.

Two events were a low number to consider a day "active", but in order to obtain a suitable data set it was necessary to set the range at two or more events to define an active severe thunderstorm and active flash flood day. Results were inconclusive when using a larger number of events per day because the sample set was too small. Also, using two events or more to define an "active day" can lead to a bias against single yet potent thunderstorms. For example, a very active supercell may have occurred on a particular day but it may have been neglected in this study because only one event was reported. Although the two event or more criteria excludes less numerous yet important severe thunderstorms and flash flood occurrences, it did provide a way to better distinguish active severe thunderstorm or active flash flood days. Usually, with some exceptions such as the example given above, the more events that occur, such as wind greater than 50 knots, wind damage, and ¾ inch hail, the risk of an active day is generally higher.

Another problem with using "events" is that severe thunderstorms and flash floods do not always occur where they can be verified. This is because thunderstorms can develop in locations where no one lives or an event is simply not reported. Thus, the right conditions for severe thunderstorms may exist, but with no events to verify it, it did not show up in this study's data set.

The buoyancy and shear values were found to be lower than the values in the Matrix. The lower values may be a result of two different effects on the environment in which thunderstorms are developing. These two possible effects are large scale dynamics and mountainous terrain. According to Banta (1990), "the major direct role of mountains in thunderstorm occurrence is in the triggering or initiation process. Most of the upward air motion is driven by terrain or thermally induced flows. Flow in the vicinity of mountains provides initiation mechanisms, or flow configurations that produce updrafts and initiate thunderstorms." This can explain why the buoyancy and shear values in Arizona are much lower than the values obtained from the Matrix. Since southeast Arizona includes mountainous terrain, less CAPE and large-scale wind shear is apparently needed to produce and organize thunderstorms because mountains help to increase instability through orographic and thermal lifting. Meanwhile, the terrain-induced flows locally alter the actual wind shear profile where thunderstorms initiate and propagate.

6. Conclusion

This study provides forecasters with a range of values to consider when forecasting an active storm day. Active flash flood days were most likely to occur when precipitable water was high and wind shear was low. Active severe thunderstorm days were most likely to occur when precipitable water was low and wind shear was high. Even if this study did not provide a concrete range of values, it can aid forecasters of the National Weather Service in Tucson in determining the relative threat of organized severe thunderstorms or flash floods. Not only does this study aid forecasters, it also provides an incentive for others to perform the same study in other parts of the United States. The more knowledge that is gained about thunderstorm development the more effectively forecasters can prevent the loss of life or damage to property.

7. References

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National Weather Services' Extreme Weather and Climate Events [Available online at http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwEvent~Storms].

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Weisman, M., 2003: The Convective Storm Matrix: Buoyancy/Shear Dependencies. [Available online at http://meted.ucar.edu/convectn/csmatrix/].

8. Figures and Tables

Table Key
tw = thunderstorm wind
ff = flash flood
h = hail

Table 1: Active Severe Thunderstorm Day Data for 1997-2003 during Monsoon Season

12Z Tucson Date	Cape	PW(mm)	Shear 850&500	Shear 700&500	Average 850&500/700&500	Weather	Events
7/7/97	954	25.6	12.2	14.7	13.5	h/tw	2E
7/28/97	29.2	27.8	19.8	14.5	17.1	h/2tw	3E
8/8/97	877	38.2	27.8	14.7	21.3	3tw/3ff/h	7E
9/21/97	723	40.1	30.1	33.5	31.8	2h/ff	3E
7/31/98	342	43.6	0.18	7.15	3.67	tw/h	2E
8/5/98	225	29.2	14.3	15.9	15.1	h/ff/tw	3E
8/28/98	0.00	32.0	14.8	19.2	17.0	4tw	4E
9/5/98	91.2	33.4	22.5	46.9	34.7	2tw	2E
7/7/99	13.5	40.4	20.6	40.3	30.5	2tw	2E
8/16/99	23.3	33.8	25.8	16.9	21.3	2tw	2E
8/19/99	37.6	34.2	12.5	9.53	11.0	tw/2h	3E
8/23/99	21.3	31.9	16.0	9.16	12.6	2tw	2E
8/31/99	850	40.0	16.3	15.3	15.8	h/2tw/ff	4E
9/15/99	6.13	25.4	15.1	37.1	26.1	tw/h	2E
9/19/99	39.3	25.9	24.9	38.4	31.6	h/tw	2E
8/13/00	469	35.1	12.2	4.07	8.16	4tw	4E
8/28/00	857	40.1	13.3	14.2	13.7	h/tw	2E
9/10/00	1985	34.6	28.0	6.39	17.2	tw/2h/ff	4E
7/2/01	35.4	27.8	7.81	33.9	20.9	2tw	2E
7/5/01	1472	38.0	5.84	9.08	7.46	ff/tw/h	3E
7/24/01	89.6	28.5	12.6	19.9	16.2	2tw/ff	3E
8/5/01	326	33.5	11.1	9.11	10.1	tw/h	2E
8/16/01	872	38.7	8.97	20.9	15.0	tw/h	2E
8/17/01	332	32.4	20.2	22.5	21.4	ff/2tw/h	4E
7/8/02	0.00	27.3	23.4	39.7	31.5	3tw	3E
7/12/02	60.4	31.8	23.8	28.7	26.3	3tw	3E
7/14/02	1296	34.0	31.7	20.7	26.2	3tw/h	4E
8/18/02	761	36.5	7.59	8.44	8.01	3tw	3E
8/28/02	3655	45.6	25.5	35.7	30.6	ff/h/tw	3E
9/6/02	28.1	32.4	21.4	21.7	21.6	2ff/3tw	5E
7/11/03	885	33.8	22.2	23.8	23.0	2tw/2h	4E
7/12/03	47.4	30.4	30.2	24.8	27.5	tw/h/ff	3E
7/13/03	87.2	27.8	20.8	17.5	19.1	6tw	6E
7/20/03	91.4	34.6	3.12	23.9	13.5	3h/tw	4E
7/25/03	784	38.3	28.4	24.8	26.6	5tw/2ff/2h	9E

7/28/03	209	37.4	24.2	27.9	26.1	2tw/2ff/h	5E
7/29/03	650	37.1	25.5	17.1	21.3	4tw/4ff/h	9E
8/14/03	274	43.2	17.0	19.8	18.4	3ff/tw/h	5E
8/22/03	559	40.2	9.20	23.4	16.3	h/tw	2E
8/25/03	54.0	37.7	12.0	17.3	14.6	h/2ff/tw	4E
Average	503	34.5	18.0	21.2	19.6		
St. Dev.	697	5.22	8.02	10.6	7.72		

Table 2: Active Flash Flood Day Data for 1997-2003 during Monsoon Season

12Z Tucson Date	Cape	PW(mm)	Shear 850&500	Shear 700&500	Average 850&500/700&500	Weather	Events
8/8/97	877	38.2	27.8	14.7	21.3	3tw/3ff/h	7E
8/12/97	0.25	33.2	9.00	12.0	10.5	2ff	2E
8/13/97	192	38.0	10.0	11.6	10.8	2ff/tw	3E
8/28/97	610	34.5	25.9	17.0	21.4	2ff/tw	3E
9/13/97	847	33.3	20.4	1.94	11.2	tw/2ff	3E
7/6/98	588	48.1	7.53	9.52	8.52	2ff	2E
7/7/98	244	46.2	13.8	16.7	15.3	2ff	2E
7/21/98	114	44.6	16.0	12.1	14.0	tw/2ff	3E
7/22/98	935	46.8	4.65	2.03	3.34	2ff	2E
7/23/98	503	44.6	7.79	5.23	6.51	2ff	2E
8/11/98	1121	35.2	16.2	10.3	13.2	tw/2ff	3E
8/17/98	211	35.9	17.8	1.80	9.81	2ff	2E
7/26/99	464	31.9	9.41	10.4	9.91	2ff	2E
8/8/99	0.00	23.7	16.0	15.6	15.8	2ff	2E
8/6/00	93.9	35.2	27.4	27.9	27.7	tw/2ff	3E
8/17/00	603	34.1	19.1	6.69	12.9	4ff	4E
8/13/01	1417	41.7	5.47	86.7	46.1	3ff/tw	4E
8/5/02	454	39.0	22.4	13.2	17.8	2ff/tw	2E
9/6/02	28.1	32.4	21.4	21.7	21.6	2ff/3tw	5E
7/22/03	437	37.2	26.6	24.5	25.5	2ff/tw	3E
7/25/03	784	38.3	28.4	24.8	26.6	5tw/2ff/2h	9E
7/28/03	209	37.4	24.2	27.9	26.1	2tw/2ff/h	5E
7/29/03	650	37.1	25.5	17.1	21.3	4tw/4ff/h	9E
8/14/03	274	43.2	17.0	19.8	18.4	3ff/tw/h	5E
8/25/03	54.0	37.7	12.0	17.3	14.6	h/2ff/tw	4E
Average	468	37.9	17.3	17.1	17.2		
St. Dev.	377	5.55	7.59	16.3	8.94		

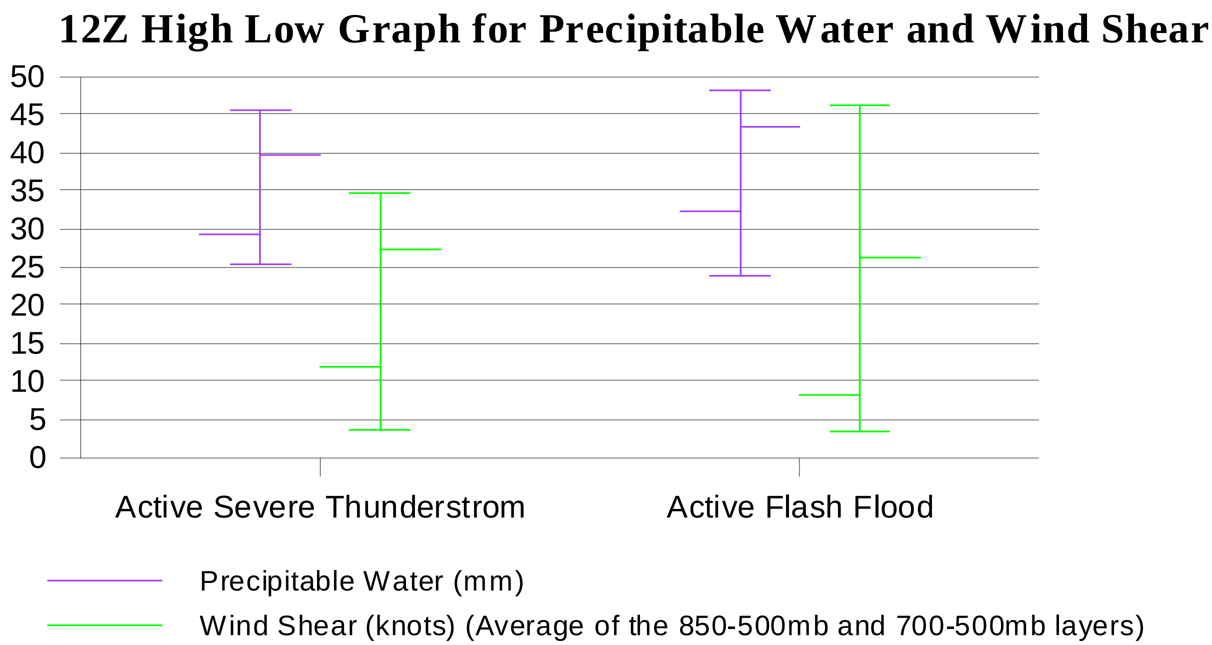

Figure 1: High Low Graph for precipitable water and wind shear. The topmost barb represents the highest value of precipitable water and wind shear in the dataset and the lowest barb represents the lowest value of precipitable water and wind shear in the dataset. The barb below the topmost barb is one standard deviation above from the average and the barb above the lowest barb is one standard deviation below from the average. The center of the standard deviation barbs is the average.

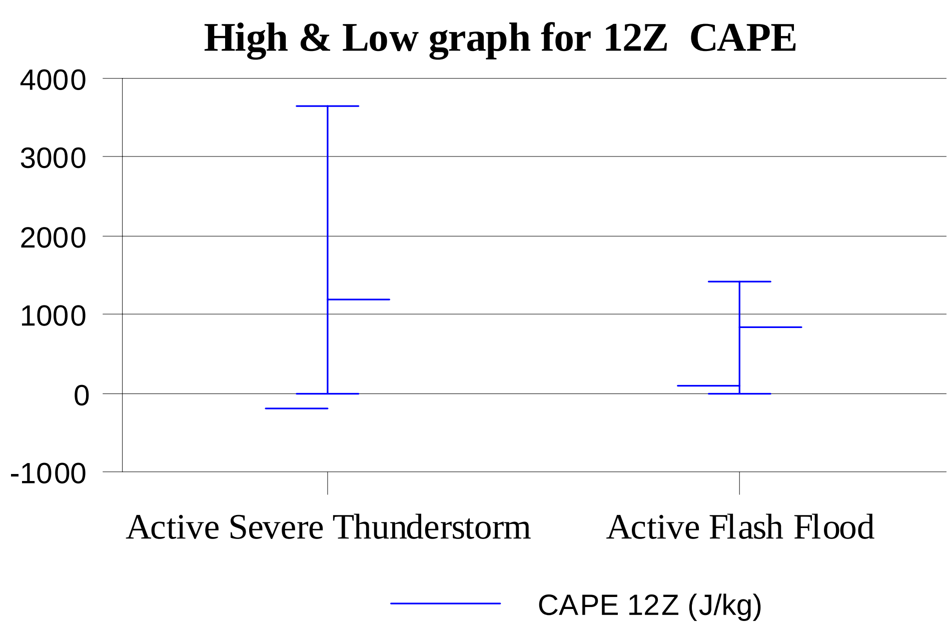

Figure 2: High Low Graph for CAPE. The barbs represent the same as in Figure 1. For active severe thunderstorm days, the lowest barb represents one standard deviation below the average and the barb at zero represents the lowest value of CAPE.