J7.8 AN ASSESSMENT OF THE USE OF AMBER IN A SEMI-ARID DESERT REGION

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1. INTRODUCTION

Areal Mean Basin Estimated Rainfall (AMBER) program is a new application to the Tucson Weather Forecast Office (WFO) to aid forecasters in the flash flood warning decision making process. The AMBER algorithm is designed to alert forecasters of possible flash flooding events and hopefully improve verification and lead time at WFO's.

Flash floods in southeast Arizona are typically associated with the Type IV event described by Maddox et al. (1980) in which high moisture and instability within the area is associated with the southwest monsoon. The monsoon brings afternoon and evening thunderstorms that include intense rainfall rates with an overall short duration (30 to 60 minutes) and often associated with severe weather. The short duration and non-meteorological variables (Kelsch, 1998) such as urbanization, vegetation, and antecedent moisture make it difficult for forecasters to accurately predict flash flood events.

This paper will examine the effectiveness of the AMBER application in flash flood warning events. Section 2 gives a brief description of AMBER. Three flash flood cases are examined in section 3. Section 4 discusses some limitations of the AMBER application. Finally, section 5 contains general conclusions of AMBER's performance and the verification numbers at the Tucson WFO for the 2001 monsoon season.

2. AMBER OVERVIEW

AMBER uses the Digital Hybrid Reflectivity Scan (DHR) from the WSR-88D radar on a polar grid of 1^{o} x 1 km to compute radar rainfall estimates for small scale drainage basins. AMBER essentially performs the same reflectivity to rainfall accumulation calculations as the WSR-88D precipitation algorithms except the accumulation values from individual range bins are averaged over the basins to compute Average Basin Rainfall (ABR). ABR is computed every volume scan (every 5 to 6 minutes) and then summed to produce running accumulations for six Alert Time Periods (30 min, 45 min, 1 hr, 2 hr, 3hr, and 6 hr). Basin Rate of Accumulation (BRA) for each basin is also calculated and is defined as the volume scan ABR divided by the time between volume scans. AMBER also compares the ABR to Flash Flood Guidance (FFG) values for each time period. The FFG, received from River Forecast Center (RFC), is determined for each county. However in the southwest, the counties are rather large and contain widely varying elevation, slope, and surface characteristics. Thus, the RFC FFG represents the spatially averaged value for the entire county and may not reflect the appropriate value for AMBER basins. The 30 minute ABR is frequently used in Tucson, and the 30 minute FFG for all basins is .65 inches.

Output from AMBER may be viewed by three different methods. The first method is an alert window which displays real time basin Alert Status expressed as ABR/FFG in percent. The alert window is color coded by Alert Status as green (<60% of FFG), yellow (60-90% of FFG), red (90-150%), or purple (>150% of FFG). The display also allows users to see the computed values of BRA and ABR for the six alert periods for each basin. The second method of display is AWIPS D2D. This shows the location and values of the BRA and the ABR for the six alert periods. The third and most commonly used display method at Tucson WFO is ArcView. ArcView provides GIS capabilities and allows a wide range of features such as streets, cities, washes, and rivers to be easily added to the display. The three display methods combined give forecasters the ability to review alerted basins and identify key geographical and geopolitical features near an area of possible flooding (i.e. washes, rivers, towns, and roads).

3. CASE STUDIES

Three flash flood events during the 2001 monsoon season will be examined. The first case (July 5th) involves an event where AMBER was not used and a flash flood warning was verified. Further study suggest that lead time may have been improved by using AMBER. The second case occurred August 14th. It will highlight a flash flood event in which AMBER was used and discuss how it affected the lead time of the warning issued. The final case shows a flash flood event in which no warning was issued and AMBER was not used. This event was the season's largest flash flood event in the Tucson CWA and will indicate how AMBER would have been beneficial to forecasters.

a. July 5, 2001

On July 5, 2001, a high pressure system was located northeast of Arizona and guiding deep moisture into the area. This moisture combined with daytime heating allowed thunderstorms to initiate. A flash flood warning

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		1127 MST			1133 MST			1150 MST		
Area	Basin	BRA	ABR	Alert	BRA	ABR	Alert	BRA	ABR	Alert
2.3	**2186**	0.82	0.11		1.76	0.28		1.54	0.77	R
6.3	**28984**	2.02	0.38		2.82	0.48	Y	2.35	1.22	P
1.7	**13730**	0.13	0.02		0.61	0.1		3.53	0.87	P
1.3	**9578**	0.3	0.04		1.47	0.18		2.7	1.05	P
1.2	**18184**	2.02	0.28		3.36	0.6	R	3.6	1.62	P
0.5	**19314**	3.56	0.52	Y	4.07	0.91	P	2.83	1.83	P
2.3	**2060**	2.16	0.28		3.19	0.59	Y	2.07	1.2	P
4.3	**9770**	0.7	0.09		1.5	0.24		0.9	0.62	R
3	**5810**	0.45	0.06		0.6	0.12		0.35	0.22	
1	**28952**	2.76	0.42		3.21	0.73	R	1.54	1.2	P
6.3	**28948**	2.02	0.38		2.15	0.58		0.93	0.69	R

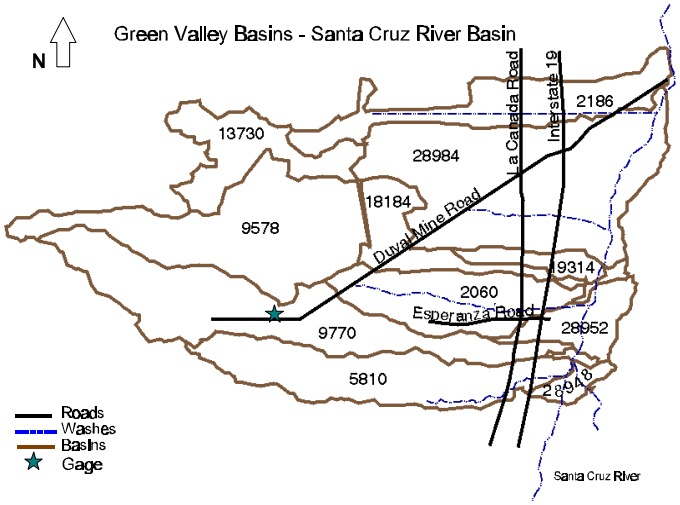

Figure 1. Basins in the Green Valley area are shown on right, which is a portion of the Santa Cruz River Basin. Legend for basin shows primary roads, washes and basins with basin identification numbers. Table to the left shows the area (mi^2) , BRA (in/hr), 30 minute ABR (in), and Alert Status of the basins for July 5, 2001 at 1133 MST and 1150 MST. Alert Status is indicated with a Y for yellow (60-90% of FFG), R for red (90-150% of FFG), and P for purple (>150% of FFG). If Alert Status is not indicated then basin is less than 60% of FFG. Star shows location of gage.

was issued for southeastern Pima County at 1145 MST which included the city of Green Valley. At the time of the warning, a gage on Duval Mine road (Fig. 1) indicated .63 inches in 36 minutes and a spotter reported pea size hail and heavy rain. AMBER was not fully operational at the time, however re-examining the case in playback mode suggests that the lead time could have been increased up to 12 or 18 minutes. Although the basins near Green Valley were a large percentage of FFG at 1046 MST, the BRA for basins near the junction of Santa Cruz River and Old Junction Wash (located 10.4 miles upstream of basin 2060) was ranging from 1.0 to 2.5 in/hr.

At 1052 MST, the first yellow and red alerts appeared in four basins 10.4 miles upstream of basin 2060. The BRA was up to 3.0 in/hr in some of these basins. Two swift water rescues occurred in basins 2060 and 28952 (Fig.1) and the two other basins near the water rescues were 28948 and 19314.

By 1127 MST, basin 19314 turned to a yellow Alert Status. At this time basin 2060 showed a BRA of 2.16 in/hr and a 30 minute ABR of .28 inches. Basin 28952 showed 2.76 in/hr BRA and .42 inches for the 30 minute ABR. Surrounding basins indicated 1.6 to 3.56 in/hr BRA. With similar values of BRA and 30 minute ABR from the previous volume scan, some additional basins alarmed by 1133 MST. Basin 2060 indicated a yellow alert, while basins 28952 and 19314 indicated a red and purple alert (Fig. 1).

At 1150 MST the BRA for basin 2060 was 2.07 in/hr and had a 1.20 inches for the 30 minute ABR. Basin 28952 showed 1.52 in/hr BRA and 1.20 inches for the 30 minute ABR. The first report of flash flooding was at 1200 MST by Pima County dispatch with two swift water rescues. One rescue was along La Canada and Esperanza Blvd and the other on Esperanza near Interstate 19 (Fig. 1). Also at 1200 MST, La Canada Road was closed due to the flooding. The Duval Mine road gage reported 1.34 inches in 1 hour with .63 inch of that occurring between 1109 and 1145 MST.

This case demonstrates that AMBER may have nearly doubled the lead time to possibly 27 or 33 minutes. Indication of possible flooding was seen as early as 1127 MST.

b. August 14, 2001

The second case looks at a flash flood event where AMBER input was used in the warning decision process. Thunderstorms started developing over the Santa Catalina mountains (north of Tucson) and later developed over the Tucson mountains (northwest side of Tucson).

The first indication of strong convection occurring over the Tucson mountains was at 1657 MST, when basins in northwest Tucson showed BRA of .25 to 1.0 in/hr. The following volume scan showed increasing BRA values with 1.68 in/hr in basin 5604 and 2.92 in/hr in basin 29332 (Fig. 2). The 30 minute ABR also increased to .17 inches and .34 inches in basins 5604 and 29332 receptively.

By 1707 MST, the first red alert appeared in basin 5604 and a yellow alert in basin 29332. Forecasters on shift were monitoring the AMBER Alert Status and continued to closely watch the BRA and 30 minute ABR values.

At 1728 MST, many of the basins (5604, 11768, 29332, and 13018) on the northwest side of Tucson had a purple alert status (Fig. 2). Basin 5604 indicated BRA values of 3.93 in/hr and 30 minute ABR values of 1.43 inches (a basin in which a swift water rescue would be reported later). With a large area of alerted basins indicating high 30 minute ABR and higher BRA, a flash

		1728 MST			1733 MST			1758 MST		
Area	Basin	BRA	ABR	Alert	BRA	ABR	Alert	BRA	ABR	Alert
2.3	**2028**	1.09	0.69	R	0.44	0.63	R	0.1	0.11	
2.2	**29332**	1.78	1.52	P	1.55	1.4	P	0.16	0.44	Y
6.1	**13018**	3.02	1.24	P	2.34	1.36	P	0.24	0.53	Y
1.5	**29340**	1.8	0.48	Y	1.48	0.59	Y	0.16	0.43	
3	**5604**	3.93	1.43	P	3.64	1.56	P	0.24	0.79	P
5.3	**11768**	3.87	1.02	P	3.64	1.28	P	0.65	1.15	P
5	**11082**	2.99	0.51	Y	2.85	0.74	R	2.3	1.39	P
3.2	**29352**	1.26	0.21		0.77	0.27		2.57	0.89	P
2.5	**7562**	2.29	0.33		2.27	0.51	Y	2.31	1.5	P
2.6	**3806**	0.26	0		0.54	0.1		2.12	1.17	P
5.3	**29594**	0.18	0		0.78	0.1		1.03	0.61	R

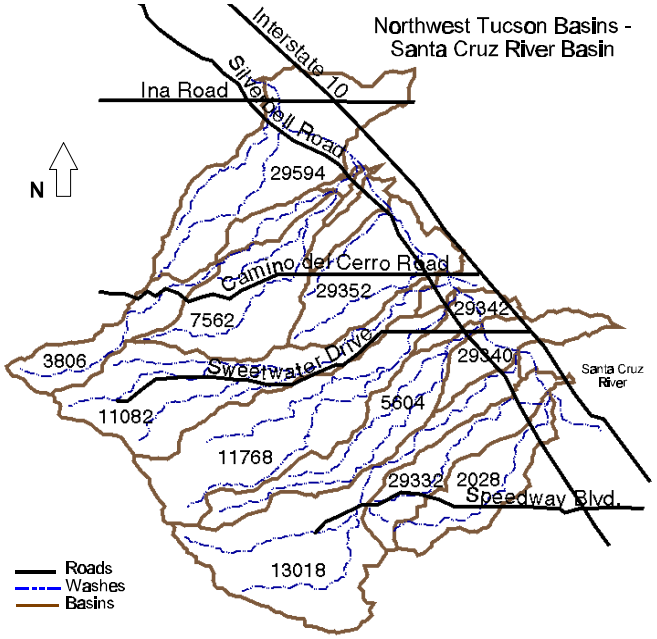

Figure 2. As in Figure 1 but for basins in the northwest Tucson area on August 14, 2001 at 1728 MST, 1733 MST, and 1758 MST.

flood warning was issued at 1730 MST

At 1733 MST, basin 5604 had a 3.46 in/hr BRA and a 1.56 inches for the 30 minute ABR with the heaviest precipitation occurring from Speedway Blvd. north to Camino del Cerro road (Fig. 2). The following volume scan indicated that the BRA and 30 minute ABR increased northward to include areas up to Ina Road.

The first report of flooding came in at 1815 MST by a spotter using a cell phone. The driver had to pull over at Camino del Cerro road due to the wash flooding the road. Near this time (1813 MST) AMBER indicated that many of the basins BRA decreased with values ranging from .50 to .75 in/hr and 30 minute ABR at 1.0 inch from Sweetwater to Ina roads. However, the purple Alert Status remained over most of the basins in the area.

After 1815 MST numerous flash flood reports were received by the Tucson WFO. There was a swift water rescue reported at 1820 MST when a driver drove into a flooded wash. At 1845 MST, police officials closed several roads between Ina and Camino del Cerro. Also, a spotter on Sweetwater Drive reported 1.98 inches in one hour (basin 11082).

In this flash flood event forecasters successfully used AMBER to issue a flash flood warning on the northwest side of Tucson. The lead time for this event was 45 minutes.

c. July 24, 2001

This late afternoon flash flood event in Douglas, AZ was the largest flooding event of the 2001 monsoon season in the Tucson WFO county warning area (CWA). This case will examine the missed flash flood event and demonstrate how AMBER may have helped the forecasters in the warning decision process.

On the afternoon of July 24th, isolated to scattered thunderstorms had already developed across Tucson's CWA. Forecasters noticed a thunderstorm over the Pierilla Mountains moving south-southeast toward Douglas. Phone calls were made to the Cochise County dispatch between 1630 and 1700 MST and there were no reports of flooding and a decision was made not to issue a flash flood or severe thunderstorm warning. Instead a strongly worded short term forecast (NOW) was issued for the thunderstorm. Although AMBER was not used in this event, monitoring of the BRA and 30 minute ABR could have led to a decision to issue a warning.

At 1544 MST, AMBER indicated no alerts among the basins within the Douglas area (basin 7276, Fig. 3). However, there were basins 8.4 mi northeast of downtown Douglas that were indicating 30 minute ABR values of .10 inches and BRA of .25 in/hr.

By 1614 MST, the BRA for the basins north of Douglas increased dramatically with 1.33 in/hr in basin 18552 and .54 in/hr in basin 9482 (Fig. 3). The first yellow alert appeared in basin 18552 which had a BRA of 2.5 in/hr. Basin 7276 only received .10 inches for the 30 minute ABR at the same time. The following volume scans showed more basins to the north of basin 7276 indicating yellow alerts and by 1634 MST there were three basins to the north of downtown Douglas with purple alerts. The downtown Douglas basin (7276) showed a BRA of 2.13 in/hr and 30 minute ABR of .26 inches. Basin 21582 (north of 7276) showed a BRA of 3.97 in/hr and a 30 minute ABR of .51 inches.

Several basins in the Douglas area had a purple Alert Status by 1644 MST, with BRA values ranging from 1.22 in/hr to 4.03 in/hr and 30 minute ABR values of .81 inches to 1.33 inches. Given the very high BRA and rapidly increasing ABR, a flash flood warning would now be prudent. By 1715 MST, seven basins over Douglas

		1634 MST			1654 MST			1714 MST		
Alert	Basin	BRA	ABR	Alert	BRA	ABR	Alert	BRA	ABR	Alert
5.3	**11654**	0.77	0.4	Y	0.69	0.37	R	0.08	0.22	
3.2	**6594**	1.79	0.52	Y	0.84	0.62		0.13	0.2	
5.3	**11646**	2.25	0.76	R	0.57	0.79	P	0.13	0.23	
0.7	**18552**	3.76	0.99	P	2.64	1.8	P	0.37	0.8	P
4	**20796**	3.4	0.83	P	1.33	1.32	P	0.3	0.43	R
1	**28716**	4.04	0.98	P	1.03	1.24	P	1.16	0.51	Y
3.9	**28744**	2.53	0.42	Y	0.97	0.88	P	1.29	0.53	Y
1	**20364**	1.67	0.22		2.85	1.32	P	0.72	0.99	P
4.2	**9482**	3.46	0.77	R	2.94	1.69	P	0.33	0.84	P
12.6	**18412**	0.98	0.15		1.62	0.65	R	0.42	0.56	R
2.1	**714**	1.68	0.19		4.06	1.46	P	0.96	1.25	P
1.8	**21582**	3.97	0.51	Y	3.28	1.76	P	0.69	1.28	P
1	**28792**	4.04	0.66	R	0.93	1.32	P	0.71	0.62	R
3.4	**7276**	2.13	0.26		3.44	1.42	P	1.28	1.3	P
8	**15414**	0.93	0.1		1.95	0.67	R	1.2	0.89	P
2.2	**1638**	0.21	0.1		1.69	0.36		0.75	0.71	R

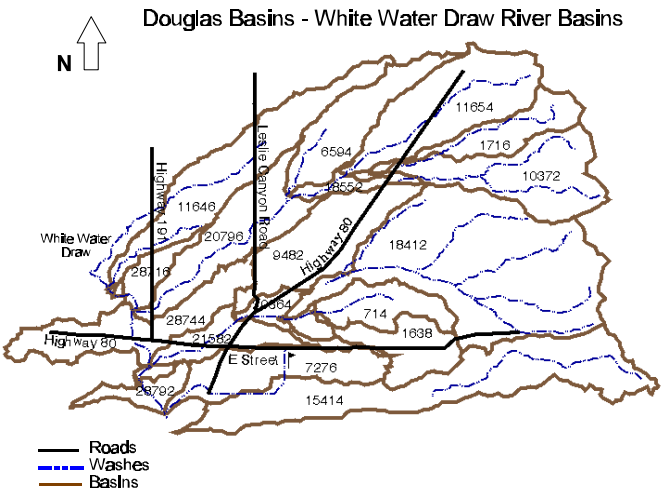

Figure 3. As in Figure 1 but for basins in the Douglas area on July 24, 2001 at 1634 MST, 1654 MST, and 1714 MST. Flag shows location of levy and retention pond.

and surrounding areas indicated a purple Alert Status and another four basins showed a red Alert Status indicating a large area of probable flooding. The BRA values ranged from .33 in/hr to 1.28 in/hr and the 30 minute ABR values indicated .80 inches to 1.30 inches. Also at this time, the radar indicated one hour precipitation total of 2.3 to 2.5 inches over the Douglas area.

The storm survey following the event estimated 100,000 to 200,000 dollars in damage from this flash flood. Several residents with rain gages across downtown portions of the city received a total storm precipitation of 4.0 inches. A basin graph of the downtown Douglas area (7276) at 1709 MST indicated a peak in the BRA of nearly 4.0 in/hr and a 30 minute ABR of 1.5 inches (Fig. 4). It can be seen that the FFG was exceeded for the 30, 45, 60, and 120 minute alert time periods. After discussion with city officials, the heaviest rainfall occurred between 1630 and 1700 MST. Some homes on the northwest side of Douglas had 10 inches of water inside the homes, with a few evacuations. The downtown area had water overflow the curbs and into front doors of businesses causing damage. In addition, a levy on the east side of town (flag in Fig. 3) broke, which was 2 feet below 100 year flood plain requirements and included an undersized retention pond that overflowed. There were four swift water rescues on the northwest side of the city when drivers attempted to drive through the washes. Also, the Port Authority closed at the international border for 75 minutes as there were two inches of standing water at the entry point. This thunderstorm also produced severe winds that caused windows to break in some downtown businesses and lifted a small utility shed from a backyard and onto a neighbors fence.

In this flash flood event, AMBER indicated a very high BRA and 30 minute ABR for several basins indicating likely flooding at 1634 MST (a lead time of 26 minutes). The monitoring of AMBER in addition to the storm total precipitation, would have determined that the storm was producing basin average rates and accumulations that caused several basins to flow toward the city of Douglas.

4. AMBER LIMITATIONS

Although AMBER appears to be extremely useful in identifying possible flash flooding there is at least one limitation of the application. Since AMBER uses only the data from a single radar, the program will have the same weaknesses of the radar. In particular, the radar coverage does not reach the far western and the

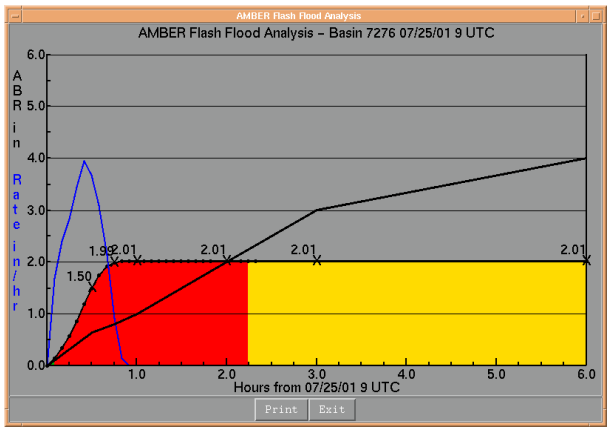

Figure 4. Basin graph for downtown Douglas area (7276) on July 24, 2001 at 1709 MST. The x-axis shows current time (0.0) going back 6 hours to the right. The y-axis shows average basin rainfall (ABR) and basin rate of accumulation (BRA). ABR is the dotted black line. BRA is the solid line that peaks near 4.0 in/hr. Heavy line is the FFG.

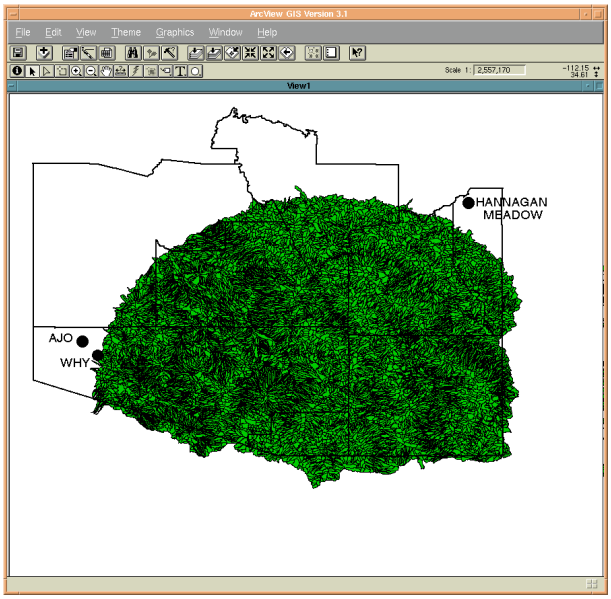

Figure 5. The towns of Ajo, Why, and Hannagan Meadow are shown with the counties and basins in ArcView. The towns area not within the basin area.

far northeast portions of the CWA (Fig. 5). There were three particular flash flooding events (one event east of Why, one event in Ajo, and another event in Hannagan Meadow) in which AMBER was unable to assist in the possible flooding situation. Also like the radar, there will be beam blockage issues due to the mountainous terrain. AMBER's limitations are far outweighed by the several occasions that AMBER has helped in detecting flash flooding before the event occurs during the summer of 2001.

5. CONCLUSIONS

In the Desert Southwest, most flash flooding events occur during the monsoon season. The purpose of this study was to examine the performance of AMBER in the Tucson WFO county warning area and determine if there was any improvement of the flash flood verification scores and lead time. The three cases examined showed that information provided by AMBER is extremely useful to a forecaster making a decision on issuing a flash flood warning.

On July 5th in Green Valley, a warning was issued with a 15 minute lead time. Although the flash flood event was not missed, further review suggests that using AMBER could have doubled the lead time.

During the flash flood event of August 14 in northwest portions of Tucson, AMBER indicated high value of BRA and 30 minute ABR by 1728 MST. Forecasters on shift were using AMBER as well as other valuable information before issuing a flash flood warning at 1730 MST. The first report of flooding came in at 1815 MST, giving forecasters a 45 minute lead time for the event. Without the basin averaged rainfall it is likely forecasters would not have had the confidence to issue the warning so early.

	1996	1997	1998	1999	2000	2001
FAR	0.66	0.63	0.47	0.71	0.52	0.55
POD	0.74	0.72	0.87	0.79	0.85	0.91
CSI	0.32	0.34	0.5	0.28	0.44	0.44
Lead time	21.5	35.8	14.4	20.4	24.7	39.6

Table 1. The false alarm ratio (FAR), probability of detection (POD), critical success index (CSI), and lead time in minutes for years between 1996 and 2001.

Finally, the third case examined a flash flood event that occurred in Douglas on July 24th. Forecasters on shift were watching the thunderstorm moving into the area and called county dispatch for any information of heavy precipitation or severe weather. The final decision was not to issue a flash flood or severe thunderstorm warning. Had forecasters been using AMBER, its positive indicators may prompted them to issue a warning for what turned out to be the largest and costliest flash flooding of the 2001 season.

For the monsoon season of 2001, the flash flood verification scores for the Tucson WFO increased considerably in term of POD and lead time (Table 1). The largest increase appears to be in the lead time which increased to 39.5 minutes (2000 lead time=25 minutes, average 1996-2000 lead time=23 minutes) and the POD of .91 (which was the highest score in the last 5 years). It is impossible to attribute all the improvement in flash flood verification statistics to AMBER. However, it is believed that AMBER positively contributed to the verification scores and lead time in its first test season in Tucson. In addition, it's the authors hope that further use and study of AMBER data will lead to more realistic flash flood guidance for the basins in Tucson CWA, and thus, even better verification scores.

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