METEOROLOGICAL SETTINGS ASSOCIATED WITH SIMULTANEOUS OCCURRENCES OF SEVERE THUNDERSTORMS AND FLASH FLOODS

by

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1. INTRODUCTION

The synoptic and meso-α scale (250-2500 km) aspects of United States flash floods were described by Maddox et al. (3). They developed an event classification scheme, presented mean values for important meteorological parameters and showed typical meso-α scale patterns associated with the floods. For frontal and mesohigh type events, (patterns that frequently affect the eastern United States) they found that severe thunderstorms (i.e., those that produce damaging winds and/or large hail and/or tornadoes) usually did not accompany the heavy rains. However, outbreaks of severe thunderstorms and significant flash floods occasionally do occur simultaneously within the same general area. For example, the May 1978 Palo Duro Canyon storm in west Texas produced large hail, winds of 60-80 knots and four tornadoes in addition to flood-producing rains of more than 10 in. in less than 2 hours (4, 5). Although relatively rare, such events are very important because they represent an extreme challenge to the National Weather Services' operational forecast, watch and warning systems. The meteorological aspects of 11 severe storm/flash flood (SS/FF) situations have been examined and the findings are discussed in the following sections.

2. EVENTS STUDIED AND THEIR CHARACTERISTICS

The NOAA publication STORM DATA was used to identify a number of (SS/FF) events. All of the events (see Figure 1) occurred within a broad region of the central United States from Texas and the lower Mississippi Valley northward to the western Great Lakes. Specific details concerning these events are presented in Table 1 (numbers correspond to those on Figure 1). Nine of the storms occurred during the late afternoon and evening, making them somewhat different than typical flash flood events which tend to occur well after dark. All of the storms produced tornadoes, damaging winds and hail in addition to very heavy rains.

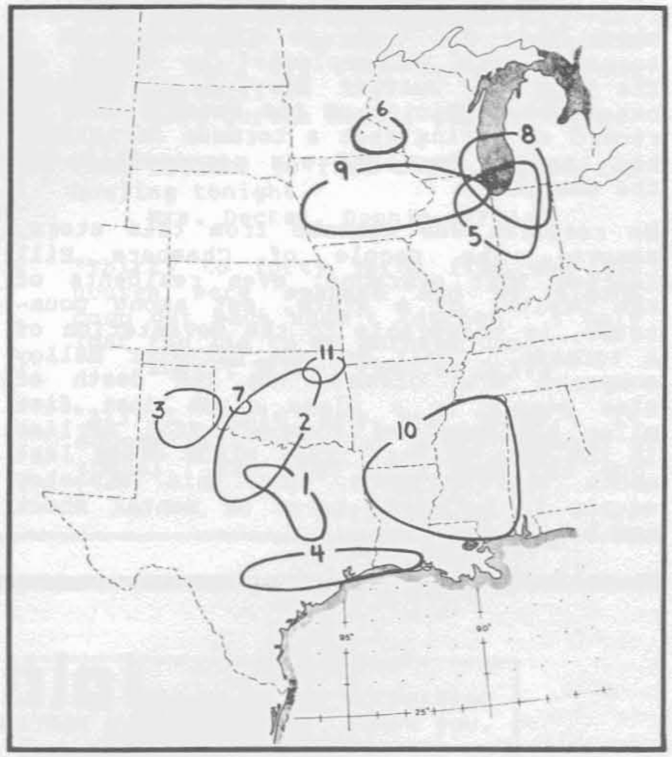

Figure 1. Locations of severe storm/flash flood events.

Map sets (surface, 850, 700, 500 and 200 mb charts) were studied for each event both at 12Z the morning prior to the storms and at 00Z during or just before the events. Careful reanalysis (6) of the charts allowed estimates of representative conditions over the storm region to be made both before and during the events.

The standard level temperatures and dewpoints are shown for all 11 SS/FF events, both before and during, in Table 2 along with two familiar stability indices (the Totals as described by Miller (7) and the K Index developed by George, (8)). The primary difference between results reported for general flash flood storms (3) is that surface temperature and dewpoints are considerably higher. This is especially

TABLE 1. EVENTS STUDIED

NO.	DATE	PERIOD OF HEAVIEST RAINFALLS	MAXIMUM REPORTED RAINFALL	DEATHS/ INJURIES
1	25/26 MAY 1976	18-21 Z/25th	6"+	0/1
2	30/31 MAY 1976	01-04 Z/31st	14"	5/10
3	26/27 MAY 1978	00-03 Z/27th	10"+	7/15
4	6/7 JUNE 1978	01-04 Z/7th	11"+	0/3
5	25/26 JUNE 1978	23-02 Z/25&26	4-8"	2/5
6	5/6 JULY 1978	23-02 Z/5&6th	6"	5/2
7	26/27 JULY 1978	21-00 Z/26&27th	2-5"	0/1
8	18/19 AUGUST 1978	06-09 Z/19th	4-9"	0/14
9	13/14 JUNE 1976	21-00 Z/13&14th	6-7"	3/46
10	7/8 MAY 1978	04-07 Z/7th	10"	2/11
11	8/9 JUNE 1974	00-03 Z/9th	10"	26/517

true at 00Z when the average surface dewpoint is a tepid 71°F. The indices indicate significant conditional instability with the most interesting characteristic being the large increase in the K Index from 12Z to 00Z. This change is due to the increase in dewpoint at 700 mb which occurs during the day. The increase (note that it is also evident at 500 mb) is probably due to lifting of higher mixing ratio air by large and medium scale vertical motion fields and perhaps by thunderstorms. At 00Z the mid-level environment (700 and 500 mb) is slightly drier than that of the typical flash flood situation.

Table 3 presents the standard level winds for all 11 events. The lower-level (surface to 850 mb) winds are stronger and more southerly than for the typical mesohigh and frontal flash flood patterns documented by Maddox (3), indicating a greater flux of warm humid air into the storm region. The winds veer strongly within the lower half of the troposphere but speeds increase only slightly with height. The winds in mid-levels are quite light considering that severe thunderstorms are also occurring.

The general patterns attending the SS/FFs are similar to those described by Maddox (3) for frontal and mesohigh flash floods. Ten of the storm areas were located near the mid-tropospheric, large-scale ridge position. These events typically occurred within outwardly benign large-scale settings (i.e., not associated with intense synoptic weather systems). The data of Tables 2 and 3 do indicate that events 9, 10 and 11 occurred within patterns characterized by moderately strong winds aloft. Events 9 and 11 also occurred within the southeast sectors of intense surface lows.

Two of the SS/FF events exhibited classic severe storm/upper-level jet stream relationships (9, 10). Upper-level jet stream structure was poorly defined and/or exhibited little apparent relationship to the storm area for the remainder of the SS/FF events. Maddox and Doswell (11) have recently shown that this is not unusual for organized, long-lived convective events.

Miller ((7) see his page 5-2) presented a ranked (weak, moderate, strong, table of key parameters for forecasting severe thunderstorms. For the 11 SS/FF events the low-level (850 mb) jet would be considered weak to barely moderate; the mid-level (500 mb) jet and the upper-level (200 mb) jet also would be ranked weak to barely moderate. Thus the kinematic environment attending these SS/FF events is apparently quite different (much weaker winds) than that associated with the severe storm patterns described by Miller. However, if the thermodynamic factors of Table 2 are similarly evaluated, it is found that instability is moderate to very strong and low-level (surface and 850 mb)

TABLE 2. STANDARD LEVEL TEMPERATURES BEFORE AND DURING THE STORM EVENTS.

		SFC (°F)	850 (°C)	700 (°C)	500 (°C)	200 (°C)	Totals/KI
1	12Z	70/65	16/13	8/-2	-11/-20	-58	51/30
	00Z	75/66	15/13	6/4	-8/-15	-59	44/34
2	12Z	68/63	16/13	11/4	-14/-35	-59	57/28
	00Z	79/70	19/18	10/5	-13/-38	-58	63/35
3	12Z	63/61	18/16	10/-5	-11/-41	-58	56/30
	00Z	82/66	21/14	8/2	-12/-13	-55	59/40
4	12Z	77/75	17/15	7/4	-8/-25	-54	48/37
	00Z	83/76	18/15	10/4	-7/-10	-54	47/34
5	12Z	76/67	18/11	9/-1	-10/-12	-57	49/29
	00Z	86/73	20/16	10/2	-9/-9	-54	54/37
6	12Z	71/68	19/11	10/-15	-10/-18	-54	50/15
	00Z	85/75	21/15	11/-6	-9/-14	-54	54/28
7	12Z	78/65	24/12	9/-2	-7/-37	-53	50/32
	00Z	90/70	25/14	10/5	-7/-37	-54	53/41
8	12Z	73/70	18/12	9/2	-10/-40	-56	50/33
	00Z	86/73	20/12	10/3	-10/-15	-54	52/35
9	12Z	73/68	18/12	6/-15	-13/-36	-53	56/22
	00Z	84/64	20/16	8/6	-12/-42	-52	60/46
10	12Z	65/62	17/13	10/-20	-10/-40	-59	50/10
	00Z	74/70	16/15	8/3	-10/-28	-58	51/36
11	12Z	68/65	18/17	8/6	-9/-15	-57	53/42
	00Z	85/74	20/18	10/2	-6/-36	-55	50/36
Ave.	12Z	71/66	18/13	9/-5	-10/-29	-56	51/27
	00Z	83/71	20/15	9/2	-9/-23	-55	53/37

moisture is very strong. Therefore, when compared to Miller's typical severe thunderstorm settings, the SS/FF event is characterized by relatively weak tropospheric winds and vertical wind shears (for the layer 850 to 200 mb) but is distinctive because of its greater instability and lower-tropospheric moisture contents.

3. CASE EXAMPLES

A number of analyses for events 5 and 2 illustrate (see Figures 2 and 3) "typical" characteristics of the SS/FF meteorological setting. The case of 25/26 June 1978 (Figure 2) has been discussed in considerable detail by Agee (12, 13). The morning surface map (Figure 2a) indicates thunderstorm activity just north of the flash flood area (cross-hatched region over Illinois and Indiana) with a larger region of thunderstorms far to the west over the northern Plains. These storms dissipated during the morning and did not influence the flood area. Note the large region over which dewpoints exceed 70°F. By evening (Figure 2b) the surface pattern has

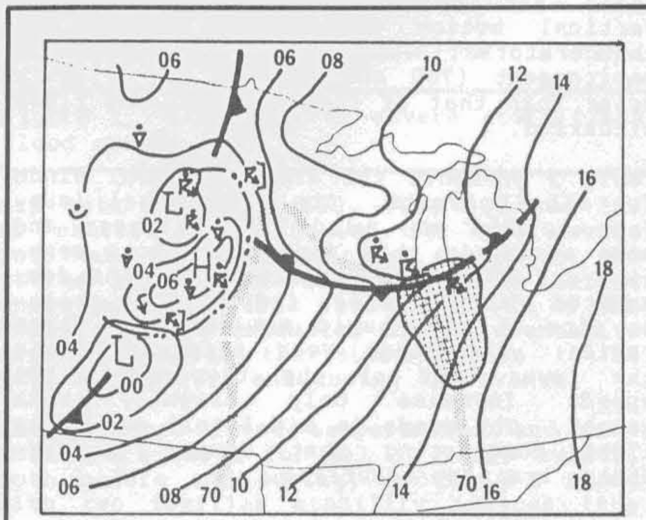

Figure 2a. Surface analysis for 12Z 25 June 1978. Storm area is cross-hatched and 70°F dewpoint isoline is stippled.

TABLE 3. STANDARD LEVEL WINDS (kt) BEFORE AND DURING THE STORM EVENTS

		SFC	850	700	500	200
1	12Z	100/10	160/20	240/25	270/35	280/100
	00Z	090/10	160/25	250/20	260/40	265/80
2	12Z	150/10	200/35	240/25	220/30	270/20
	00Z	090/10	190/30	240/25	260/40	220/20
3	12Z	150/15	170/35	215/20	230/30	250/60
	00Z	140/20	140/25	180/25	250/35	250/75
4	12Z	180/15	180/20	200/10	250/20	260/50
	00Z	170/15	190/15	220/20	240/40	250/35
5	12Z	150/10	210/20	250/20	280/30	320/60
	00Z	120/10	220/30	250/40	270/35	320/20
6	12Z	120/10	210/25	270/20	270/30	270/35
	00Z	170/15	240/25	260/25	280/30	240/50
7	12Z	180/10	240/10	330/5	030/10	320/30
	00Z	150/10	180/10	140/10	360/15	340/35
8	12Z	170/15	210/20	240/25	250/15	280/40
	00Z	170/10	210/25	230/35	250/45	260/40
9	12Z	180/15	240/15	250/25	250/40	260/65
	00Z	140/20	190/30	240/40	250/50	260/70
10	12Z	100/10	180/30	200/30	240/25	270/120
	00Z	120/10	190/30	210/25	210/40	260/80
11	12Z	140/10	180/35	210/45	260/30	260/90
	00Z	180/15	190/50	220/50	220/50	250/40
Ave.	12Z	147/12	198/24	240/23	265/27	276/61
	00Z	140/13	190/27	222/29	257/38	265/49

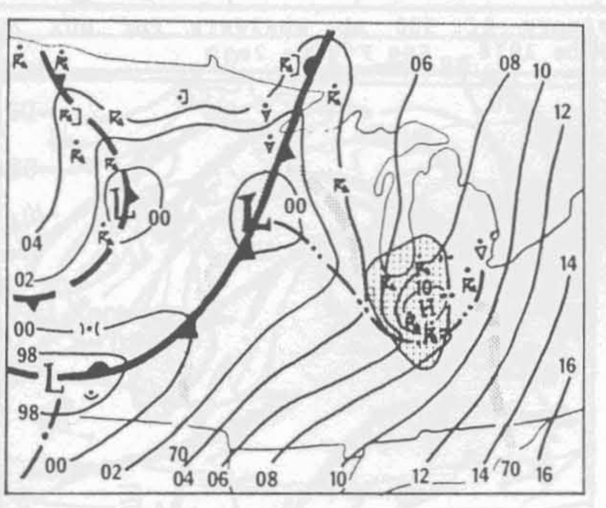

Figure 2b. Surface analysis for 00Z 26 June 1978. See Figure 2a.

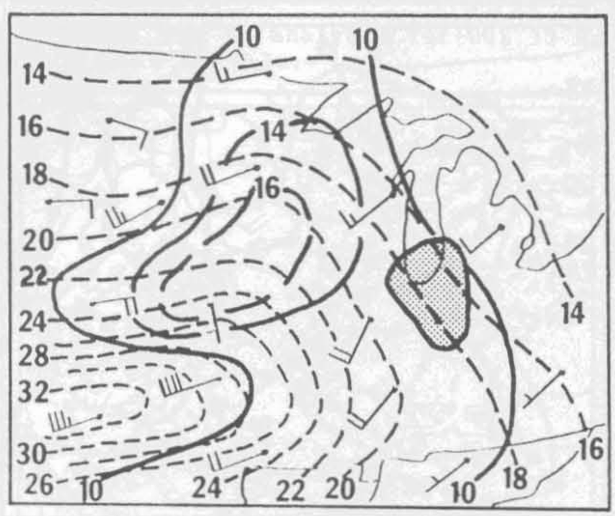

Figure 2c. 850 mb analysis for 12Z 25 June 1978. Isotherms (°C) are dashed and dewpoints (°C) are solid. Winds are in knots (full barb equals 10 knots).

become very complicated over the Plains. A pronounced thunderstorm mesohigh and outflow boundary has developed over the storm area (the presence of an easily detectable mesohigh and outflow boundary was noted at both 12 and 00Z in 8 of the 11 events studied).

The morning 850 mb analysis (Figure 2c) shows very warm air over the Plains to the west southwest of the storm area while moisture contents are highest to the northwest. A widespread region of apparent warm advection is evident over the central Plains and western Great Lakes region. By evening (Figure 2d) winds had increased over the storm area as had dewpoints (notice the large area in which dewpoints exceed 18°C). These high dewpoints reflect the lifting of more moist air to the 850 mb level, since they exceed any values present on the morning map. A 30-40 knot low-level jet intersects the storm region and pronounced warm advection is indicated.

At 500 mb the 12Z analysis (Figure 2e) indicates a broad, low-amplitude ridge over the analysis region with a weak short-wave trough approaching from the west. Warm advection is also apparent at this level. By 00Z (Figure 2f) the short-wave trough had weakened dramatically as it moved eastward through the mean ridge; however, it appears that the southern end of the short-wave is affecting the storm area.

Figure 2g shows the 12Z 200 mb wind analysis. Two jet streaks, or speed maxima, are indicated; however, the upper flow has probably been affected by the storms that

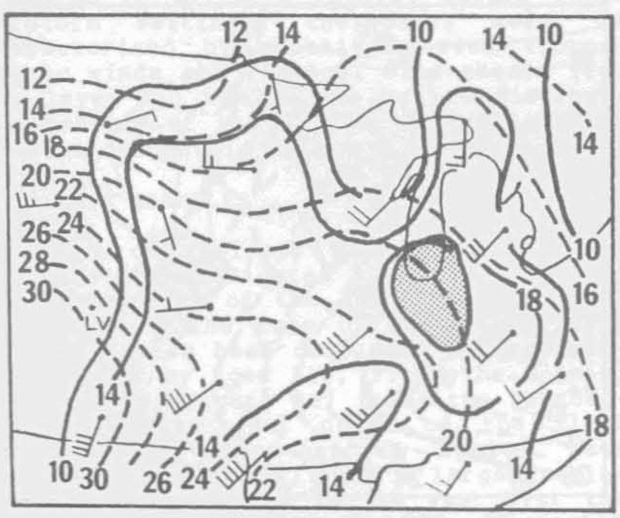

Figure 2d. 850 mb analysis for 00Z 26 June 1978. See Figure 2c.

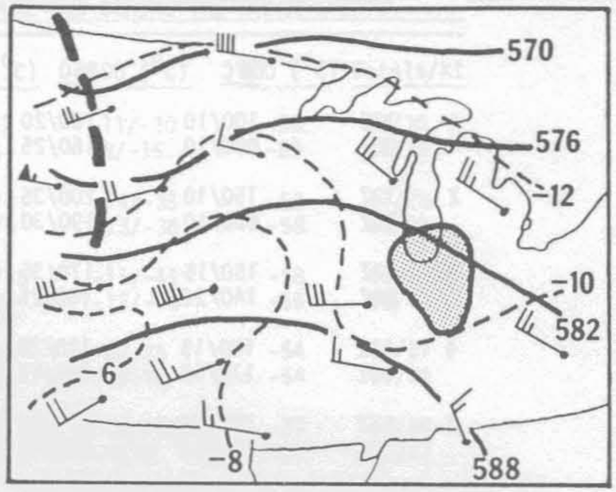

Figure 2e. 500 mb analysis for 12Z 25 June 1978. Isotherms (°C) are dashed, heights are in decameters (dam) and winds are in knots (full barb equals 10 knots, flag equals 50 knots).

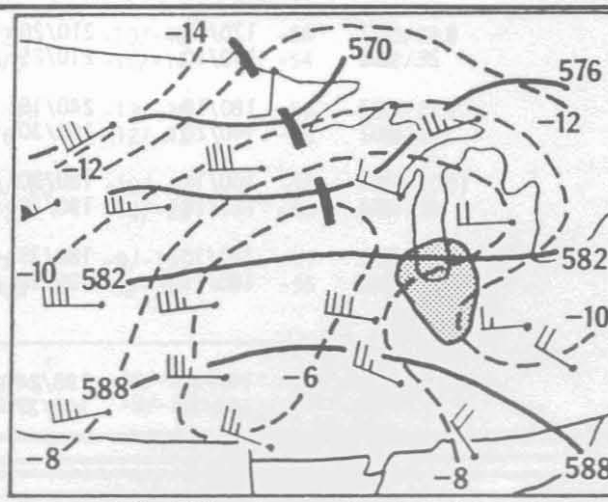

Figure 2f. 500 mb analysis for 00Z 26 June 1978. See Figure 2e.

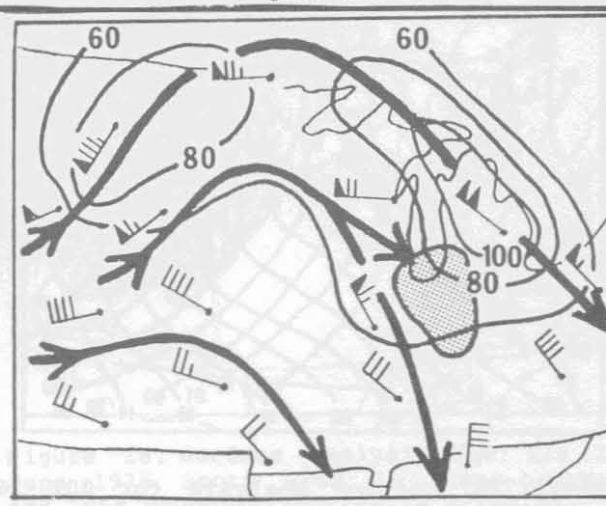

Figure 2g. 200 mb analysis for 12Z June 1978. Isotachs are in knots.

are in progress. Upper-tropospheric flow is difluent over a large region of the central United States. By 00Z (Figure 2h) upper-level flow was more poorly defined. The storms in Illinois and Indiana had strongly perturbed the winds with strong, anticyclonic outflow indicated over the storm area. This is a common characteristic of organized convective storm complexes (14).

The case of 30/31 May 1976 is illustrated in Figure 3. Weaver (15) has discussed the structure and behavior of several severe thunderstorms that occurred during this particular SS/FF event. The morning 850 mb analysis (Figure 3a) shows a pronounced temperature gradient over the southern Plains with a strong jet and warm advection in the storm region. By evening (Figure 3b) the 850 mb data indicate continued strong southerly inflow of warm, very moist air and warm advection. Once again the evening dewpoints are <u>much higher</u> than any values observed at 12Z. The morning 500 mb analysis (Figure 3c) shows the storm region located between short-wave troughs. Height gradients are slight and warm advection is indicated over the storm area. By 00Z (Figure 3d) the pattern has changed little with a very weak short-wave <u>ridge</u> over the storm area.

The 500 mb maps for these two events are quite different (much weaker synoptic setting) than those typically considered to be associated with severe thunderstorms (7, 16). However, pronounced lower-tropospheric warm advection is a common feature. Maddox and Doswell (11) have discussed the important role that low-level warm advection plays in forcing regions of upward motion, thereby triggering signifi-

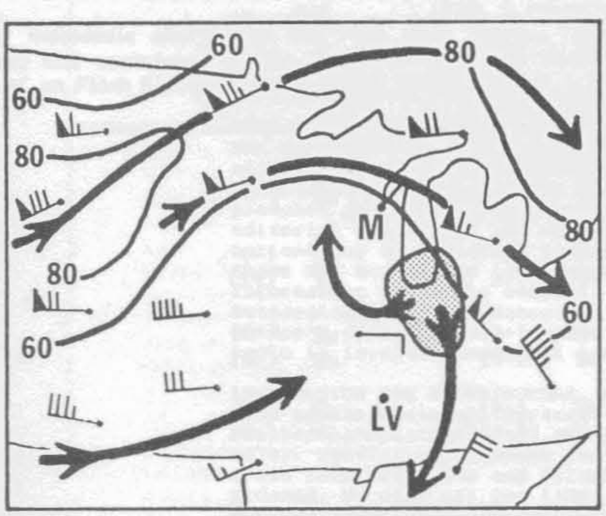

Figure 2h. 200 mb analysis for 00Z June 1978. See Figure 2g.

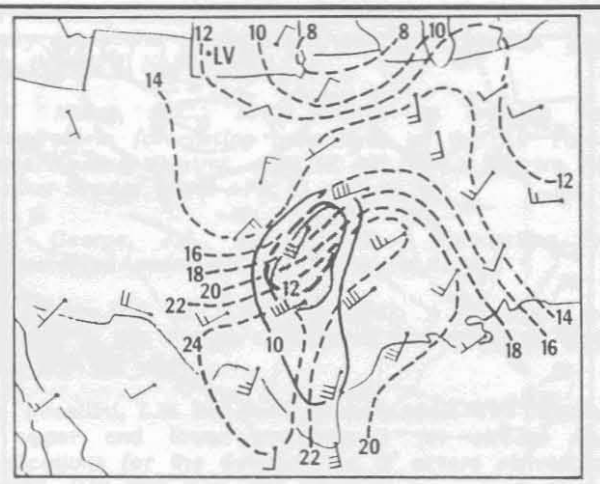

Figure 3a. 850 mb analysis for 12Z 30 May 1976. Isotherms (°C) are dashed and dewpoints (°C) are solid. Winds are in knots (full barb equals 10 knots.) Storm area is shaded.

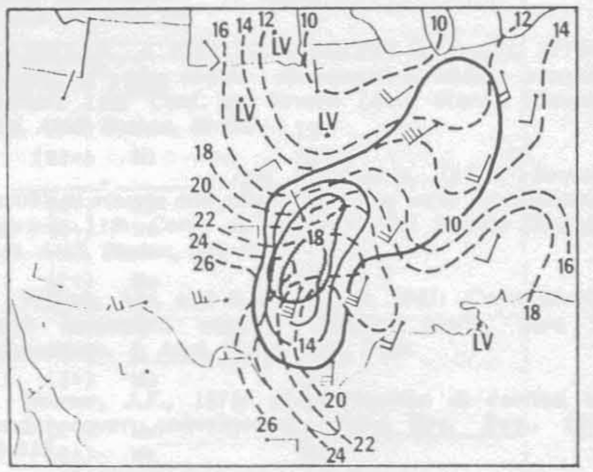

Figure 3b. 850 mb analysis for 00Z 31 May 1976. See Figure 3a.

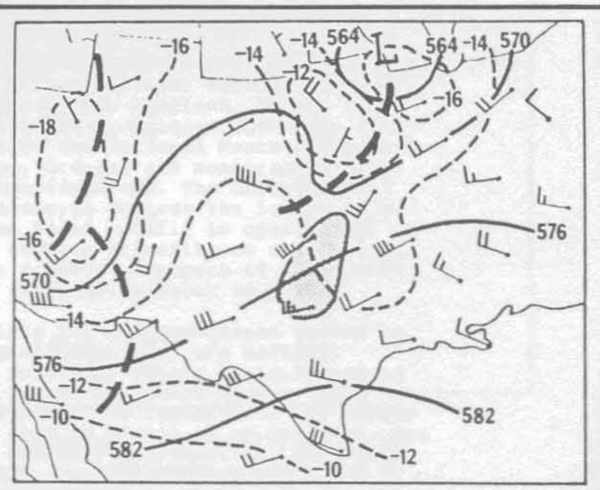

Figure 3c. 500 mb analysis for 12Z 30 May 1976. Details as in Figure 2e.

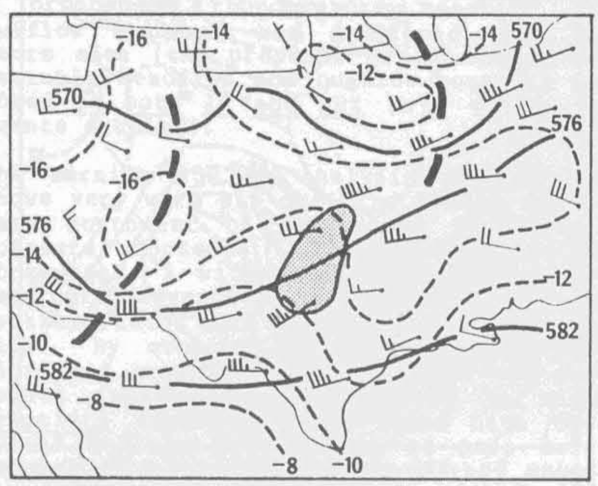

Figure 3d. 500 mb analysis for 00Z 31 May 1976.

cant outbreaks of thunderstorms within weak synoptic patterns. Table 4 shows the temperature advection patterns associated with the SS/FF events. The warm advection nature of these phenomena is striking - occasionally even at 500 mb!

4. SUMMARY

An examination of eleven SS/FF events has illustrated a number of common meteorological characteristics. The general pattern that produced the storms were similar to those described by Maddox et al. (3) for frontal and mesohigh type flash floods. The events typically occurred within outwardly benign large-scale settings very close to a mid-tropospheric ridge position. This characteristic complicates the forecast problem and stresses the need for early recognition of developing SS/FF situations.

TABLE 4. TEMPERATURE ADVECTION BEFORE (12Z) AND DURING (00Z) THE STORM EVENTS

		850 (^{o}C/12 h)		700 (^{o}C/12 h)		500 (^{o}C/12h)	
1	12Z	wW	(+4)	sW	(+9)	N	(-)
	00Z	sW	(+19)	sW	(+8)	N	(-)
2	12Z	sW	(+9)	sW	(+7)	wW	(+2)
	00Z	sW	(+8)	wW	(+2)	wW	(+3)
3	12Z	wW	(+3)	wW	(+2)	N	(-)
	00Z	wC	(-2)	wW	(+4)	wC	(-2)
4	12Z	N	(-)	wW	(+1)	N	(-)
	00Z	wW	(+5)	wW	(+4)	N	(-)
5	12Z	wW	(+5)	sW	(+9)	wW	(+1)
	00Z	sW	(+9)	sW	(+12)	sW	(+6)
6	12Z	sW	(+7)	wW	(+1)	wW	(+3)
	00Z	sW	(+10)	wW	(+2)	N	(-)
7	12Z	wW	(+3)	sW	(+6)	wC	(-3)
	00Z	wW	(+1)	N	(-)	wC	(-4)
8	12Z	sW	(+10)	sW	(+6)	N	(-)
	00Z	sW	(+7)	sW	(+12)	sW	(+8)
9	12Z	wW	(+4)	sW	(+6)	N	(-)
	00Z	wW	(+3)	sW	(+6	wW	(+2)
10	12Z	sW	(+7)	sW	(+6)	wW	(+2)
	00Z	wW	(+5)	sW	(+8)	sW	(+6)
11	12Z	sW	(+26)	sW	(+9)	sW	(+8)
	00Z	sW	(+23)	sC	(-16)	sW	(+12

sW = significant warm advection ($\geq + 6^{o}$C/12 h)
wW = weak warm advection ($< + 6^{o}$C/12 h)
N = neutral temperature advection
wC = weak cold advection ($> - 6^{o}$C/12 h)
sC = significant cold advection ($\leq - 6^{o}$C/12 h)

Although the typical SS/FF event is characterized by relatively weak tropospheric winds and vertical wind shear, conditional instability and lower-tropospheric moisture contents are very high. A well-defined low-level jet provides a continuing supply of this unstable air to the thunderstorm area. Since the large-scale setting is typically weak, the forecaster should focus upon lower-troposheric features and closely monitor regions in which pronounced warm advection and unusually high moisture contents and instability coexist or are forecast to coexist.

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1. Robert A. Maddox has worked with the NWS, AWS and ERL during his career. He has spent a number of years as a weather forecaster and continues to be interested in studies designed to improve operational meteorology and in the actual implementation of new forecast techniques.

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