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THE PREDICTION OF THUNDERSTORM WIND GUSTS BASED ON VERTICALLY INTEGRATED WATER CONTENT AND STORM ECHO TOPS

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1. INTRODUCTION

A challenging task for National Weather Service (NWS) meteorologists is the accurate determination of thunderstorm intensity. For example, Doswell (1985) stated that summer time pulse-type thunderstorms (which are generally short lived in nature), do not allow forecasters much time to decide if a severe thunderstorm warning is warranted. Stewart (1991) demonstrated that through the use of the cloud top penetrative downdraft mechanism, in combination with echo top height (TOP) and vertically-integrated liquid (VIL) from digital radar data (WSR-57 RADAP-II), a wind gust potential could be attained for pulse-type thunderstorms in real time.

This technique was tested at various locations across the NWS Southern Region during the summer months of June through September from 1986 to 1990. The locations included Oklahoma City, OK, Nashville, TN, and Ruskin, FL. Following the completion of the testing, it was proposed to further evaluate this technique in the northeastern United States. During the summer of 1992, the National Weather Service Forecast Office (WSFO) in Pittsburgh, PA (PIT) undertook this task by compiling data from RADAP-II. This paper briefly describes the results of this testing.

The results noted in this study, are illustrated by three events (from a total of 18 confirmed cases) that occurred in the WSFO PIT area. It should be emphasized the technique may not always work as well as it did with these cases, and with every pulse-type thunderstorm. In addition to the method presented here, severe pulse-type thunderstorms should be identified by other techniques that make use of atmospheric soundings and both conventional and Doppler radar signatures.

2. PENETRATIVE DOWNDRAFT MECHANISM

For the cloud top penetrative downdraft mechanism, Squires (1958) theorized that within convective type clouds, most of the mixing of air parcels is caused by unsaturated downdrafts created near the cloud top. These downdrafts are accelerated downward in the cloud due to negative buoyancy generated by evaporative cooling.

Emanuel (1981) expanded upon this theory by proposing the similarity theory for unsaturated downdrafts within clouds. This theory suggests that strong downdrafts created by dry air entrained near the cloud top occasionally reach the ground. This process, resulting only from instability at the top of the cloud, could create intense and isolated downdrafts. Srivastava (1985) indicated that larger raindrops versus smaller ones, were more conducive to the intensification of the down draft. Not only would larger drops create more water vapor and negative buoyancy through evaporational cooling, but they would also increase the water loading of the down draft. Larger VIL values are often an indication of greater liquid water content within a convective cell. This high liquid water content increases the potential for a more intense downdraft.

3. POTENTIAL WIND GUST TECHNIQUE

Stewart (1991) defined the following equation from Emanuel's similarity theory (Emanuel 1981) for the production of unsaturated penetrative downdrafts as follows:

$$W = [20.628571 \times \bar{R}_o H - 3.125\times10^{-6}(H)^2]^{1/2}$$

where;

$\underline{W}$ = maximum downward velocity (m/s);
$\bar{R}_o$ = storm averaged liquid water content (g/g); and,
H = height (meters) above m.s.l. of the 18 dBz (VIP 1) echo.

$\bar{R}_o$ is further equated to $\bar{R}_o$ = VIL/TOP, where the assumption is made that 1 m^3 of dry air has a mass of 1 kg in order to obtain the units g/g.

A wind gust potential table based on various VIL and TOP values is illustrated in Table 1. It should be pointed out that with the lower VIL and higher TOP values, the wind gust potential values are below the NWS severe thunderstorm wind threshold of 58 mph. However, higher VIL values such as 60 kg/m^2 and TOP values of 35,000 ft or lower, denote wind gusts strong enough to meet NWS severe thunderstorm warning criteria. In addition to the wind gust potential, Miller (1967) recommended adding one-third of the mean low-level wind speed in the lowest 5,000 ft of the atmosphere to the calculated wind gust potential, in order to obtain the true final predicted wind gust. Adding this value is necessary to account for the low-level horizontal momentum created by the low-level environmental wind. After analysis of the cases at WSFO PIT, it was determined that the entire magnitude of the low-level mean wind needed to be added to the calculated wind gust in order to verify the observed wind gust. An explanation for this difference, based on past case studies, is that thunderstorm radar echo characteristics differ greatly between climatic regimes (Jendrowski 1988). The equation derived by Stewart (1991) is oriented toward the NWS Southern region of the United States where it was developed. The physical characteristics of thunderstorms in the northeastern United States would produce different values for wind gusts when using the same VIL/TOP values.

4. CASE STUDIES

Digital radar products, in addition to storm report data, were collected during the summer of 1992 for western Pennsylvania and eastern Ohio. A window of ± 25 minutes was applied to the digital radar products and the reported severe weather incidents. This was done to account for the temporal resolution of the digital radar and weather reporting limitations by observers. Some wind gust cases were recorded by anemometers, while others were determined from wind damage surveys conducted after the event occurred.

4.1 Case 1: July 10, 1992 - Beaver, PA

The surface analysis for the local area featured a warm front located along the Pennsylvania-Maryland border, that moved northward across Pennsylvania. Temperatures by 1900 UTC had climbed into the mid to upper 80s(°F), with surface dewpoints ranging from the upper 60s to low 70s(°F). Sky conditions were mostly cloudy across the region. The mean wind direction and speed in the lowest 5,000 ft of the atmosphere was 260° at 31 kt, as depicted on the 2200 UTC July 10, 1992 SHARP (Skew-T Hodograph Analysis and Research Program; Hart and Korotky 1991) sounding (Fig. 1a). The Convective Available Potential Energy (CAPE) was 2860 J/kg. Although the winds were stronger than normal for pulse-type thunderstorm development (greater than 30 kt in the lowest 5,000 ft of the atmosphere), the flow was unidirectional (predominately west from the surface to 500 mb). The environmental vertical wind profile did not exhibit any directional shear, which could potentially tear the pulse-type thunderstorm updraft apart. A Severe Thunderstorm Watch was issued during the afternoon hours for eastern Ohio and western Pennsylvania by the National Severe Storms Forecast Center in Kansas City, MO.

Several convective cells that had formed over east central Ohio during the early afternoon hours, moved east across the northern West Virginia Panhandle around 2200 UTC. At 0045 UTC on July 11, a wind gust of 60 kt was observed at the Beaver County airport, about 25 miles northwest of Pittsburgh. At 0036 UTC, the VIL for this cell was 45 kg/m^2 based on digital radar data at WSFO PIT, with a TOP of 50,000 ft for the Beaver County airport location (Fig. 1b). The bin locations (latitude and longitude coordinates with WSFO PIT at the center) were 20°N/3°W for the VIL and 25°N/3°W for the TOP. By summing the downward wind gust of 28 kt (Table 1), plus the mean low-level wind speed of 31 kt, a predicted wind gust speed of 59 kt was obtained. This was 1 kt less than the observed 60 kt wind gust.

4.2 Case 2: July 14, 1992 - Bay Village, OH

The surface temperatures for this day climbed into the upper 80s(°F), while surface dewpoints ranged in the upper 60s(°F). The local surface analysis depicted a warm front moving into northwest Pennsylvania from eastern Ohio. The mean low-level wind direction and magnitude was 250° at 20 kt, as depicted by the 2300 UTC July 14, 1992 WSFO PIT SHARP sounding (Fig. 2a). The CAPE value was 1381 J/kg. Thunderstorm activity developed by 1800 UTC over north central Ohio, and moved across northeast Ohio into northwest Pennsylvania. At 2345 UTC, a wind gust of 60 kt was observed at Bay Village, OH along the Lake Erie shore (just west of

Cleveland). At 2330 UTC, based on the digital radar at WSFO PIT, the VIL for this cell was 35 kg/m^2 with a TOP of 30,000 ft for the corresponding location (Fig. 2b). The bin locations for both the VIL and TOP were 65°N/69°W. The predicted wind gust of 42 kt, plus the mean low-level wind speed of 20 kt, yielded a final predicted wind gust of 62 kt. This was 2 kt greater than the observed wind gust.

4.3 Case 3: September 9, 1992 - Berlin City, OH

The surface analysis for the local area consisted of a warm front initially situated over southern Illinois, moving toward northwest Pennsylvania. A southwesterly flow at the surface advected low-level moisture into the region, in addition to the moisture that was already located over the area from showers that had occurred the previous day. The WSFO PIT SHARP sounding for 2200 UTC September 9, 1992, (Fig. 3a) did not reveal any vertical wind shear in the lower 5,000 ft of the atmosphere. This indicated that the environmental wind conditions were conducive to the development of pulse-type convection. The mean low-level wind direction and speed was 200° at 13 kt. The CAPE value was 2763 J/kg.

By 1900 UTC, surface temperatures ranged in the lower 80s(°F), while surface dewpoints were in the upper 60s(°F). At 2315 UTC, a report of large trees being blown over was received at WSFO PIT from Berlin City, OH (just west of Youngstown). At 2320 UTC, the corresponding WSFO PIT digital radar data indicated a VIL of 50 kg/m^2 and a TOP of 45,000 ft (Fig. 3b). The bin locations for both the VIL and TOP were 25°N/29°W. The predicted wind gust of 41 kt (Table 1), in addition to the mean low-level wind value of 13 kt, resulted in a final wind gust predicted value of 54 kt. Wind gusts of this speed are capable of producing damage to large trees such as that observed in Berlin City, OH.

5. CONCLUSION

Forecasting wind gusts with the technique presented in this paper is dependent upon three variables. These include: 1) the vertically-integrated liquid (VIL) content of the convective cell; 2) the echo top height (TOP); and, 3) adding the mean low-level wind speed to the predicted wind gust.

The encouraging results illustrated in this paper indicate that this type of severe weather predictor may be useful to forecasters in the northeastern United States. However, it should be noted that this technique probably will not work with every pulse-type severe thunderstorm. This is due to a number of factors which include erroneously large VIL values due to hail contamination, thunderstorms that are too close to the radar site causing truncation of storm heights during tilt scans, and thunderstorms at a distance greater than 125 miles from the radar causing an error in storm top measurement.

Another reason that this technique should be used with caution is insufficient confirmed severe weather reports for every severe threshold VIL and TOP that were computed by RADAP-II, on the days when severe convective weather occurred. While utilizing this technique as a forecasting tool, it is critical that other types of data (e.g., atmospheric soundings and conventional radar signatures) are examined in order to determine if the pulse-type thunderstorm may reach severe criteria.

With a few minor differences, the results of this study agree with the findings of Stewart (1991). The main difference between the two studies is the percentage of the mean low-level wind which was added to the predicted wind gust. Whereas Stewart added one-third of the mean low-level wind value to the wind predicted by the VIL and TOP, the findings of this study indicate that the entire value of the mean low-level wind should be added for the wind gust forecast to be accurate.

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Table 1. Wind gust potential (m.p.h) as a function of VIL and echo top height (TOP) for the National Weather Service Southern Region. VIL is in units of kg/m^2, TOP is in thousands of feet. From Stewart 1991.

		VIL								
		30	35	40	45	50	55	60	65	70
	60						18	27	33	39
	59						21	29	35	41
	58						24	31	37	42
	57						27	33	39	44
	56						29	35	40	45
S	55				14	24	31	37	42	46
T	54				18	26	33	38	43	48
O	53				21	29	35	40	45	49
R	52				23	31	36	41	46	50
R	51				26	32	38	43	47	51
M	50			19	28	34	39	44	48	52
	49		10	22	30	36	41	45	49	53
E	48		14	24	31	37	42	46	50	54
C	47		17	26	33	38	43	47	51	55
H	46		20	28	34	40	44	49	52	56
O	45	11	23	30	36	41	46	50	53	57
	44	15	25	32	37	42	47	51	55	58
T	43	18	26	33	38	43	48	51	55	59
O	42	20	28	34	40	44	49	52	56	59
P	41	22	30	36	41	45	49	53	57	60
S	40	24	31	37	42	46	50	54	58	61
	39	26	33	38	43	47	51	55	58	62
	38	27	34	40	44	48	52	56	60	62
	37	29	35	40	45	49	53	56	60	63
	36	30	36	41	46	50	54	57	60	64
	35	31	37	42	47	50	54	58	61	64
	34	33	38	43	47	51	55	58	62	65
	33	34	39	44	48	52	56	59	62	65
	32	35	40	45	49	53	56	60	63	66
	31	36	41	45	50	54	57	60	63	66
	30	37	42	46	50	54	57	61	64	67

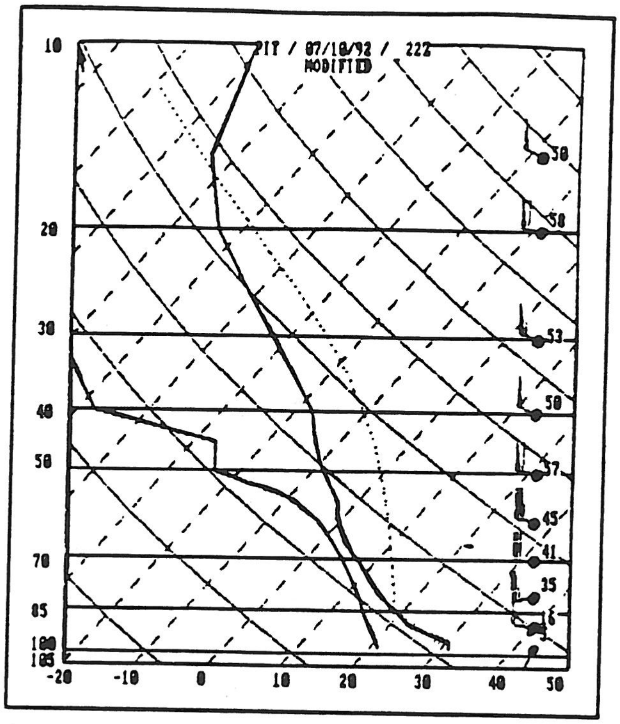

Figure 1a. 2200 UTC, July 10, 1992 modified SHARP sounding for WSFO Pittsburgh, Pennsylvania.

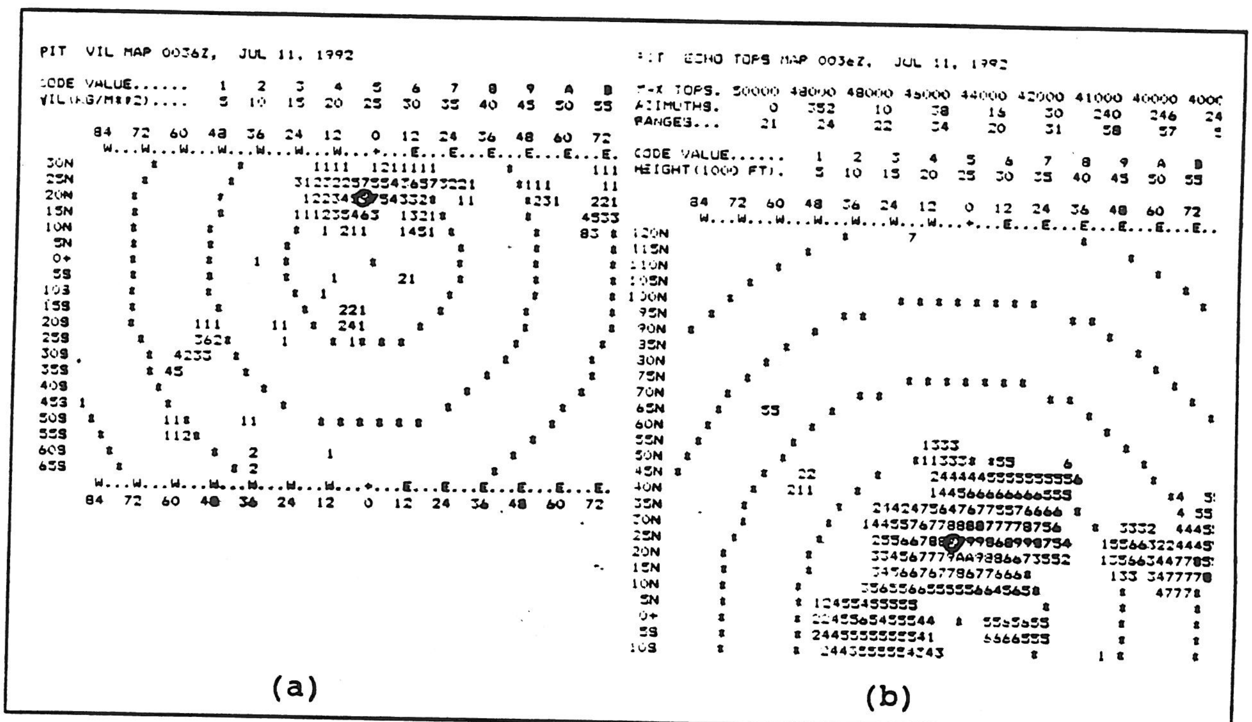

Figure 1b. 0036 UTC, July 11, 1992 VIL (a) and TOP (b) analysis generated by WSFO Pittsburgh, Pennsylvania RADAP-II digital radar. Small circle denotes location where severe weather was observed.

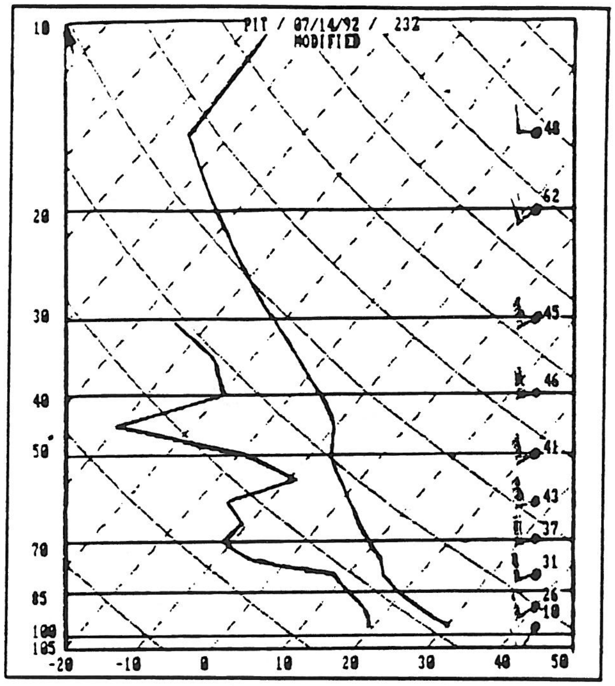

Figure 2a. Same as Figure 1a except for 2300 UTC, July 14, 1992.

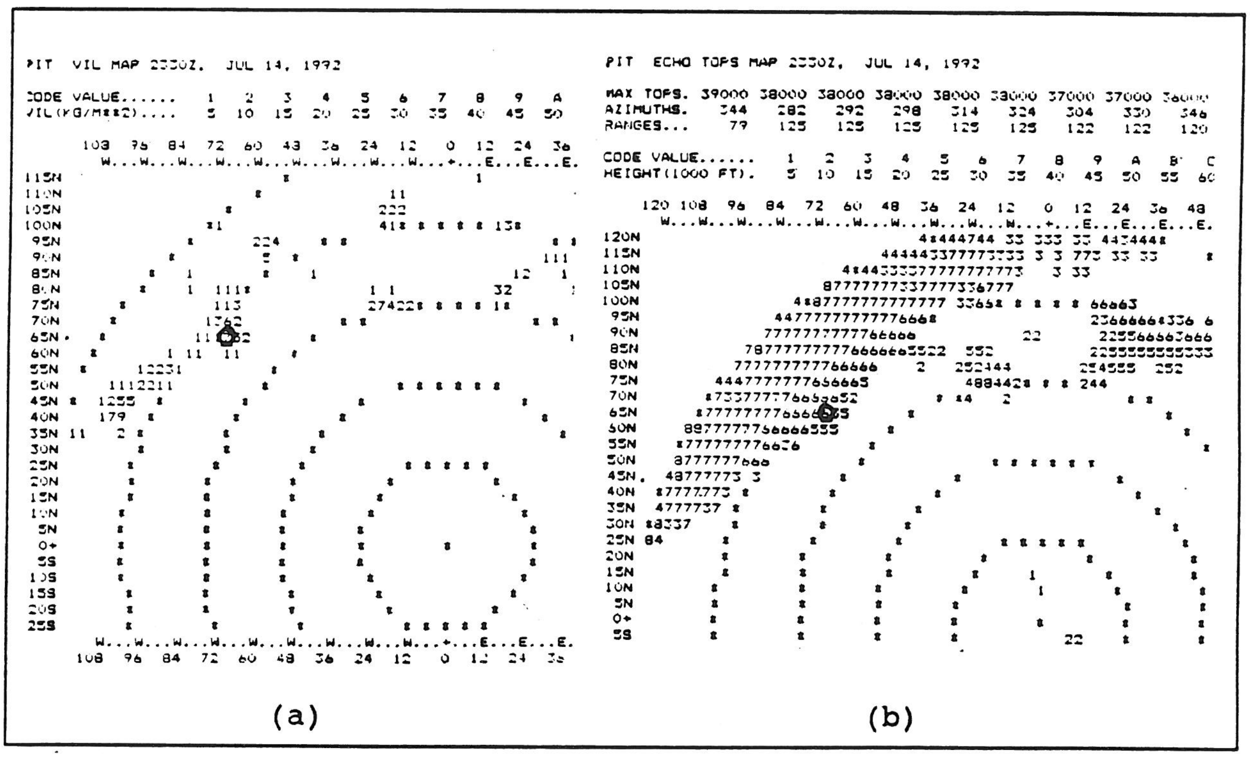

Figure 2b. Same as Figure 1b except for 2330 UTC, July 14, 1992.

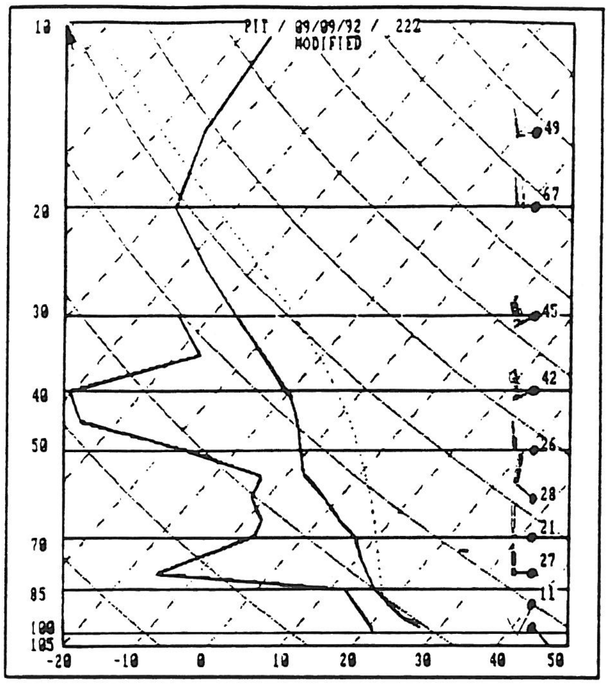

Figure 3a. Same as Figure 1a except for 2200 UTC, September 9, 1992.

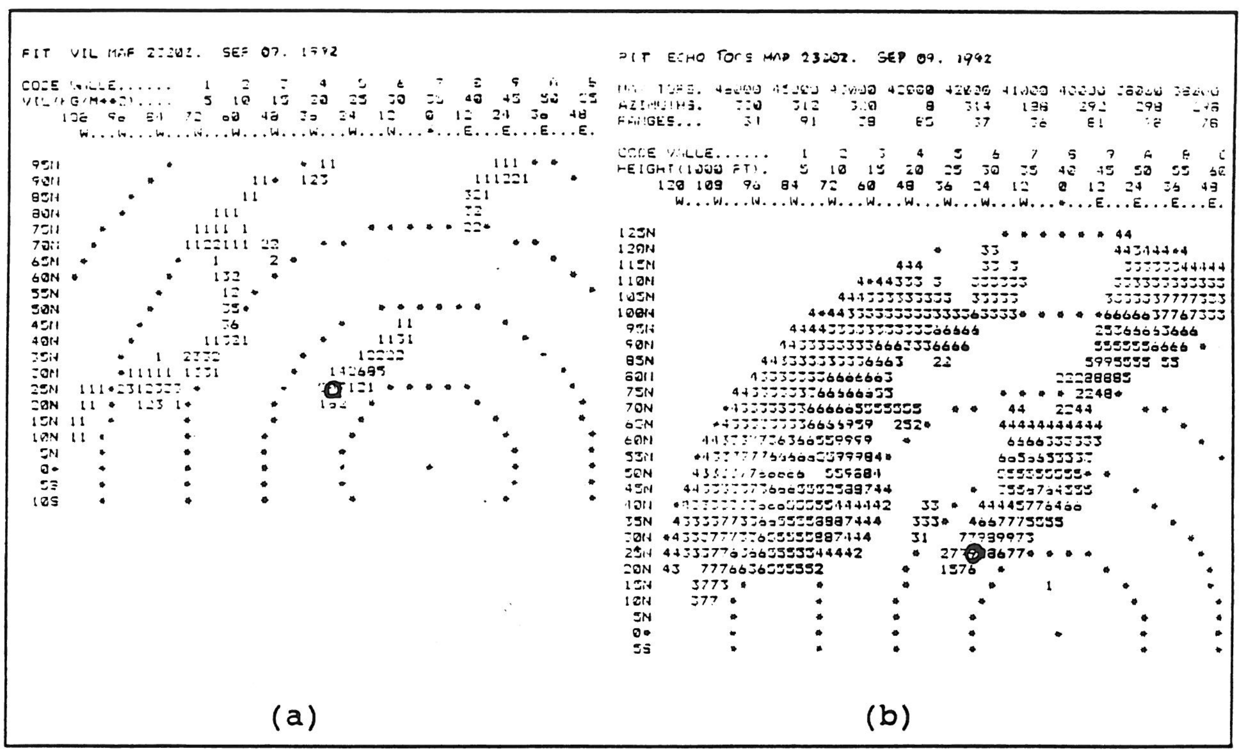

Figure 3b. Same as Figure 1b except for 2320 UTC, September 9, 1992.