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TWO CASE STUDIES ILLUSTRATING A METHOD FOR PREDICTING SEVERE WEATHER THRESHOLDS OF VERTICALLY INTEGRATED LIQUID IN WEST VIRGINIA

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1. INTRODUCTION

Previous research has indicated that the vertically integrated liquid (VIL) within a thunderstorm can be an important variable for estimating the severe weather potential of the storm (Devore 1983; Beasely 1986; Davis and Drake 1988; Stewart 1991; Paxton and Shepherd 1993). Typically, high VIL values indicate a high probability of a thunderstorm becoming severe. Previous research has indicated that the severe weather threshold VIL, or the lowest VIL associated with severe weather, may vary in any given area from event to event, depending on the prevailing atmospheric conditions. For example, it has been shown that the highest threshold VIL values are usually found during summer, while a lower threshold VIL occurs during spring and fall (Beasely 1986; Davis and Drake 1988).

Research at the National Weather Service Forecast Office (WSFO) in Charleston, WV (CRW), has determined that local severe weather threshold values of VIL correlate strongly with thermal stability (Evans and Honore' 1994). Specifically, it was found that high thresholds of VIL are associated with unstable conditions, while a lower threshold VIL is associated with a more stable atmosphere. From the results of this research, a simple linear regression equation was derived, which relates threshold VIL to the K-index, the 1000-300 mb lifted index, and the Showalter index. The equation is given as:

$$\mathrm{VIL}(\mathrm{kg\ water/m^2}) = 21.895 + 0.415(\mathrm{KI}) - 0.469(\mathrm{LI}) - 0.998(\mathrm{SI}),$$

where KI = the K-index, LI = the surface to 300 mb lifted index, and SI = the Showalter index.

The purpose of this paper is to illustrate how this regression equation is being used at WSFO CRW in order to assist with the diagnosis and forecasting of severe weather. At this point, it should be noted that the equation was derived from a relatively small data base of only 25 events. In addition, there were no data available on the days when strong thunderstorms occurred, but severe criteria was not reached. Because of these limitations, it should be emphasized that this simple linear regression equation should only be used in combination with other sounding, radar, and RADAP-based identification methods, in order to determine the potential for severe thunderstorms. In this paper, two severe thunderstorm events will be reviewed. For each case, radiosonde soundings will be examined, and the calculation of a severe weather threshold VIL from the simple linear regression equation will be demonstrated. The location and magnitude of the VIL values associated with each event will also be related to the location and strength of the thunderstorms that occurred during the event. (Note: VIL values across West Virginia are currently calculated and displayed at WSFO CRW using the RADAP (Radar Data Processor) II system).

2. CASE 1: JUNE 9, 1993

a. Synoptic Overview

Figures 1 and 2 show the 0000 UTC, June 10, 1993 Nested Grid Model (NGM) analyses for 500 mb geopotential heights and vorticity, surface pressure and fronts, and the 1000-500 mb thickness. A vigorous short-wave trough was indicated at 500 mb over northern Michigan, with a weak low amplitude short-wave trough located further to the southeast, near western Virginia. A 500 mb ridge was located over the south-eastern United States. At the surface, a 994 mb low pressure system was located over central Ontario, with an associated cold front extending to the southwest through Michigan and into Iowa. Except for a weak pressure trough east of the Appalachian mountains, no other organized synoptic scale surface features appeared near West Virginia.

During the late afternoon hours on June 9, thunderstorms with severe characteristics developed along the northern edge of the 500 mb ridge near the Ohio river in northern Kentucky. In this case, the thunderstorms developed well to the southeast of the cold front, which was located over the Great Lakes. Severe thunderstorms moved east through West Virginia between 1800 and 2200 UTC.

b. Soundings

Figure 3a shows the 1800 UTC June 9 sounding from Huntington, WV (HTS) as illustrated by the Skew-T Hodograph Analysis and Research Program (SHARP; Hart and Korotky 1991). Strong insolation was occurring at this time, resulting in a dry adiabatic lapse rate in the lowest level of the atmosphere extending from the surface to around 850 mb. In addition, a layer of dry air was present just above 700 mb. The 1000-500 mb surface based lifted index was -9°C, the Showalter index was -3°C, and the K index was 34. In summary, the thermodynamic structure of the atmosphere was very favorable for the development of strong to severe convection over West Virginia during the afternoon of June 9.

In this case, an estimate of the 1000-300 mb lifted index at 1800 UTC could not be made initially, since the HTS sounding was discontinued above 400 mb. In order to obtain an estimate of the 1000-300 mb lifted index, and therefore, the threshold VIL, an estimate of the temperature structure of the layer above 400 mb was needed. Figure 3b shows the modified 1800 UTC SHARP sounding, where the temperature and moisture profiles above 400 mb were added after examining other nearby soundings, and the 0000 UTC June 10 HTS sounding. (Note, that the winds for the modified sounding are different from the observed 1800 UTC sounding. Since the modification of the upper-levels of the atmosphere had to be performed graphically with a complete sounding, the 0000 UTC June 10 HTS sounding was used as a background chart. The winds that appear on the modified sounding are the winds from the 0000 UTC sounding). The temperature and moisture profiles of the layer from the surface to 400 mb were not changed, except for some minor smoothing of the moisture profile. Therefore, there were no changes in the values of the Showalter or K-indices, which are both a function of variables determined from data at levels from 850-500 mb. The SHARP-calculated 1000-300 lifted index from the modified sounding in Figure 3b was -11°C. The Showalter index was -3°C and the K-index was 34. These values resulted in a calculated threshold VIL of 44.2 kg/m².

c. Relationships between VIL and Severe Weather

Figures 4a through 4f show RADAP-calculated VIL values overlaid on county maps of West Virginia, eastern Kentucky and southern Ohio at: (a) 1836; (b) 1912; (c) 1924; (d) 2012; (e) 2024; and (f) 2101 UTC. All values of 45 kg/m² (or greater) are plotted. In order to reduce clutter on the maps, only a few of the VIL values less than 45 kg/m² are shown. Figure 5 shows locations where severe weather was reported during the event.

Figure 4a shows that at 1836 UTC, two distinct thunderstorm cells could be identified by examining the RADAP-calculated VIL value pattern over southwest West Virginia. One cell was associated with a pair of 45 kg/m² VILs located over southern and central Putnam (PU) County. A second cell was evident over southern Jackson (JA) County. Figure 4b indicates that during the period from 1836 to 1912 UTC, both cells weakened as they moved east, with a corresponding decrease in the associated VIL values. Figure 5 indicates that severe weather was associated with both of these cells, before and during the period of collapse. Strong damaging winds and large hail occurred in a line from Cabell (CA) to Kanawha (KA, which contains Charleston) Counties, in association with the southern storm. Strong winds occurred in southern Jackson (JA) and southern Roane (RO) Counties in association with the northern storm. These damage tracks represented the only instances of reported severe weather in West Virginia during this time.

Figures 4c and 4d reveal that by 1924 UTC, the VIL values associated with the northern cell increased, again reaching 45 kg/m² over southern Calhoun (CA) County. By 2012 UTC, the VIL value associated with this cell reached 60 kg/m². Figure 5 shows that damaging winds and hail continued in association with the cell as it moved across southern Gilmer (GI), northern Braxton (BR), southern Lewis (LE), and southern Upshur (UP) Counties. Concurrently, the VIL values associated with storms farther to the south also began to increase, with a VIL of 50 kg/m² appearing over southern Logan (LO) county at 1924 UTC. By 2012 UTC, these storms had moved east into Raleigh (RA), Fayette (FA), and Nicholas (NI) Counties, and continued to maintain top VIL values of 45 kg/m² or greater. Figure 5 shows the reports of severe weather that occurred with these storms as they moved to the east.

Figure 4e and figure 5 indicates that severe weather continued in association with two distinct storms, each with VIL values of 45 kg/m^2 (or greater) through 2050 UTC. The latest severe weather reports, occurring within Pocahontas (PO) County at around 2115 UTC, appear to have occurred as the southern cell was collapsing, with its associated VIL value just under the threshold (Fig. 4f).

3. CASE 2: MAY 18, 1993

a. Synoptic Overview

Figures 6 and 7 show the 0000 UTC May 19, 1993 NGM analyses for the 500 mb geopotential heights and vorticity, surface pressure and fronts, and the 1000-500 mb thickness. A 500 mb short wave trough extended from southern Michigan, southward into eastern Kentucky, while an area of weak positive vorticity advection was located over West Virginia. A well defined quasi-stationary surface baroclinic zone extended from the mid- Atlantic coast, westward across West Virginia, and southwest across the southern Mississippi River valley to Texas. A weak surface low pressure center was located along this baroclinic zone in West Virginia.

Severe thunderstorms developed across West Virginia during the late afternoon, and moved across the state between 2030 and 2230 UTC. Apparently, synoptic scale forcing for upward vertical motion occurred during this time frame. This occurred when weak positive vorticity advection became superimposed above an area of low-level convergence and warm air advection. The quasi-stationary surface baroclinic zone and the approaching surface low pressure center acted as a low-level focusing mechanism for the initiation of convection.

b. Soundings

Figure 8a shows the 1800 UTC, May 18 sounding for HTS. At this time, HTS was just north of the frontal zone, with light easterly surface winds and a low overcast sky condition. Low clouds were also present at CRW, and across most of West Virginia. The HTS sounding exhibited a low-level temperature inversion capped by a thin layer of relatively dry, conditionally unstable air. The surface to 300 mb lifted index was 0°C, the Showalter index was 0°C, and the K-index was 6. These indices indicated that this sounding was not favorable for surface-based convection at that time. The regression equation used in this study yielded a threshold VIL of 24.3 kg/m^2.

During the next 1 to 2 hrs, subsidence ahead of an approaching line of thunderstorms would result in partial clearing across much of West Virginia. The resulting increase in solar heating changed the low-level temperature and moisture profile of the atmosphere so that a more favorable environment for surface-based convection developed. Figure 8b depicts the modified 1800 UTC HTS sounding based on the expected increase in solar heating. The modification resulted in a 1000-300 mb lifted index of -6°C. Since all of the changes made to the sounding were assumed to occur below 850 mb, there was no change in the Showalter or K-index. After these sounding modifications, a threshold VIL of 27.2 kg/m^2 was calculated.

c. Relationships between VIL and Severe Weather

Figures 9a through 9c show RADAP-calculated VIL values overlaid on county maps of West Virginia, eastern Kentucky, and southern Ohio, at (a) 2012, (b) 2112, and (c) 2212 UTC. All VIL values greater than or equal to 25 kg/m² have been plotted. In order to reduce the clutter on the maps, only a few VIL values of less than 25 kg/m² are shown. Figure 10 shows locations where severe weather was reported during the event. Only the severe weather reports received from the WSFO CRW county warning area (boundary highlighted by bold line) are shown.

The VIL values shown in Figure 9a indicate that at 2012 UTC, a strong line of thunderstorms was located over southern Ohio and eastern Kentucky. VIL values as high as 30 kg/m² were indicated across parts of Lawrence and Gallia Counties in Ohio (LA and GA, north of HTS) with values as high as 60 kg/m² throughout Elliott County Kentucky (EL, west of HTS). Concurrently, an isolated cell exhibiting a VIL value of 30 kg/m² was indicated over southern Wayne County (WA) in West Virginia south of HTS. By 2112 UTC (Fig. 9b), the VIL values indicated that some weakening of the storms had occurred. However, storms exhibiting values as high as 25 to 30 kg/m² had moved into the WSFO CRW county warning area. An area of high VIL moved from Ohio east across Jackson (JA) and northern Putnam (PU) Counties, into Roane (RO) County by 2112 UTC. Another storm associated with a VIL of 25 kg/m² moved from Wayne County east into northern Boone (BO) county. Figure 10 shows that both of these high-VIL storms were associated with severe weather, with the northern storm producing high winds in northern Putnam County, and the southern storm producing large hail in Boone County. It should be noted that there were no VIL values greater than or equal to 25 kg/m² observed during this time over the region from southern Putnam County, east into central Kanawha County (KA, containing Charleston). Consequently, there were no reports of severe weather in that area.

During the time from 2112 to 2212 UTC, the storm that was previously located in southern Roane County continued east across Braxton (BR) and moved into Webster (WE) County maintaining a VIL value of 25 kg/m² (Fig. 9c). Figure 10 shows that severe weather continued in association with that storm, as indicated by the reports of strong winds and large hail in Roane, Braxton, and Webster Counties. VIL values of 30 kg/m² to 40 kg/m² also were calculated in association with storms located further to the south over Nicholas (NI) county. VIL values of 25 to 30 kg/m² also continued with a storm moving from northern Boone County, through southern Kanawha County, and into northern Fayette County (FA). Figure 10 shows that localized severe weather was also reported for both of these storms.

4. SUMMARY/CONCLUSION

In order to illustrate the application of a severe weather threshold VIL prediction method developed at WSFO CRW, two case studies have been presented. For both cases, the threshold VIL was first determined by producing a forecasted sounding based on the SHARP workstation. Second, a predicted threshold VIL was calculated by using selected parameters from the forecasted sounding in a predictive equation. For the first case that occurred on June 9, 1993, a threshold VIL of 44.2 kg/m² was predicted. Observations indicate that a threshold of 45 kg/m² was an accurate estimate for the severe weather threshold on that day. For the second case of May 18, 1993, a threshold VIL of 27.2 kg/m² was predicted. Subsequent observations indicated a severe weather threshold of about 25 kg/m².

Again, it should be noted that the equation used for this approach was derived from a very small data set, which contained only 25 events. In addition, no data were available for days when strong thunderstorms occurred, but severe weather criteria was not observed. Because of these limitations, it should be emphasized that this equation probably will not always work as well as it did in these two case studies.

The results from this and other studies show that VIL can be a useful tool for estimating the severe weather potential associated with a thunderstorm. The purpose of this study was to illustrate a recently derived method of applying VIL to severe weather operations. The large difference between the threshold VIL values on the 2 days in question, highlights the importance of utilizing a method that can predict each day's unique threshold VIL. Once the threshold is determined, VIL can be used as an effective severe weather diagnostic tool, in combination with other sounding and radar-based techniques for severe thunderstorm identification, such as the examination of thunderstorm cloud top height, cell structure and cell movement.

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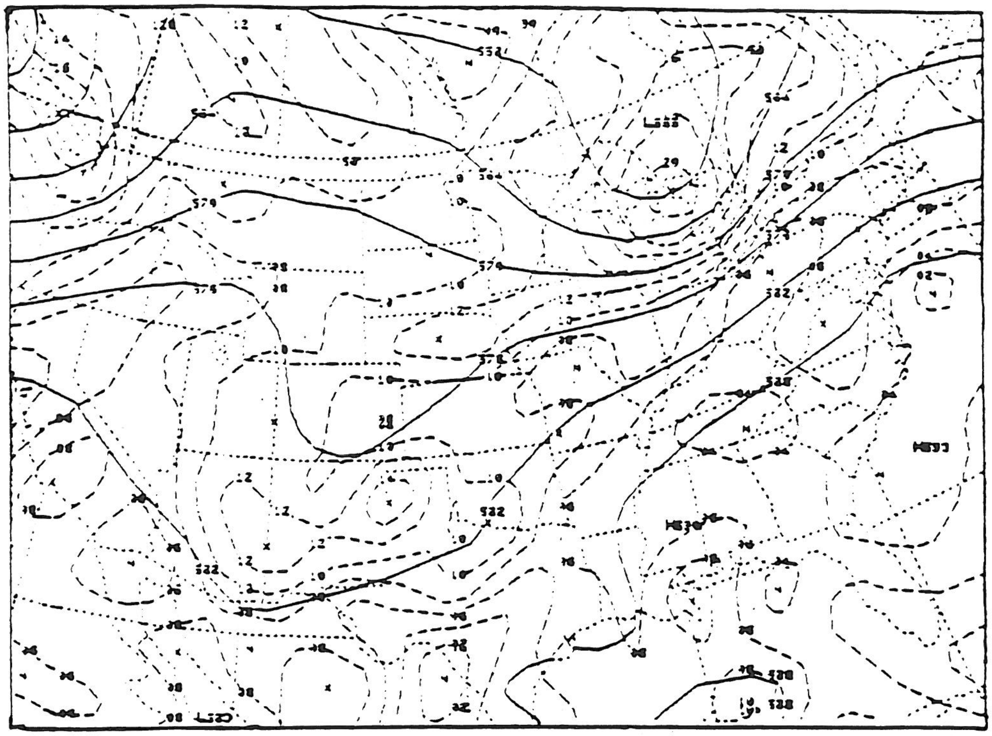


Figure 1. 0000 UTC June 10, 1993 NGM 500 mb height and vorticity analysis.

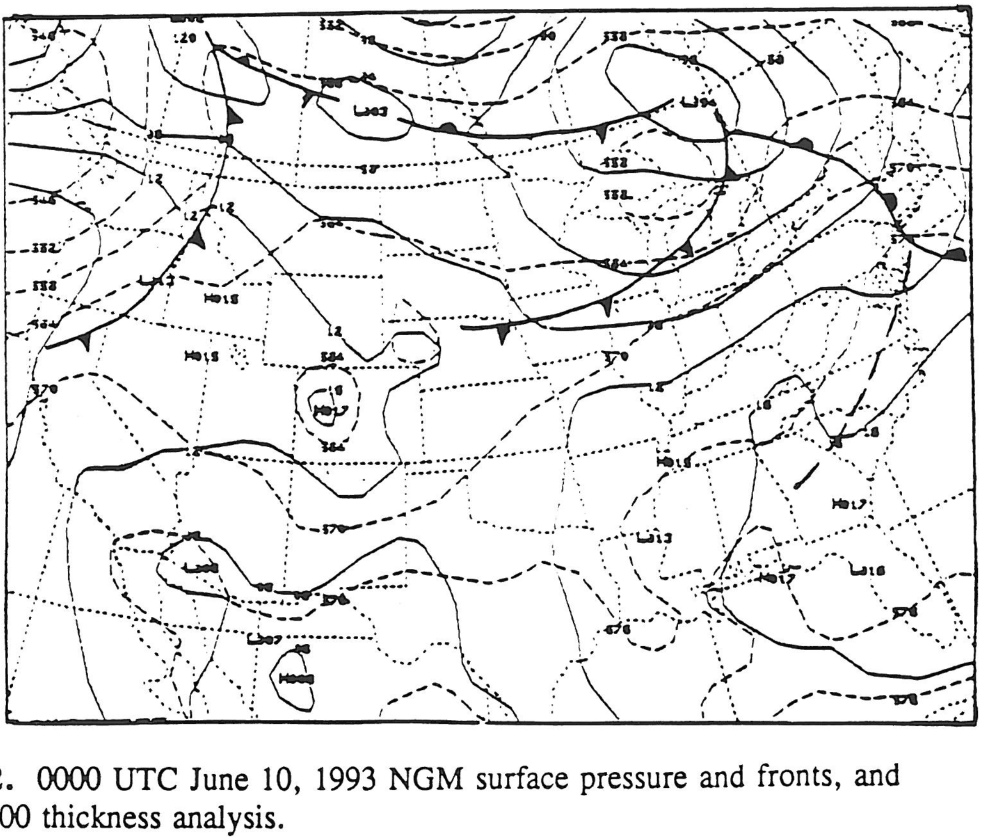


Figure 2. 0000 UTC June 10, 1993 NGM surface pressure and fronts, and 1000-500 thickness analysis.

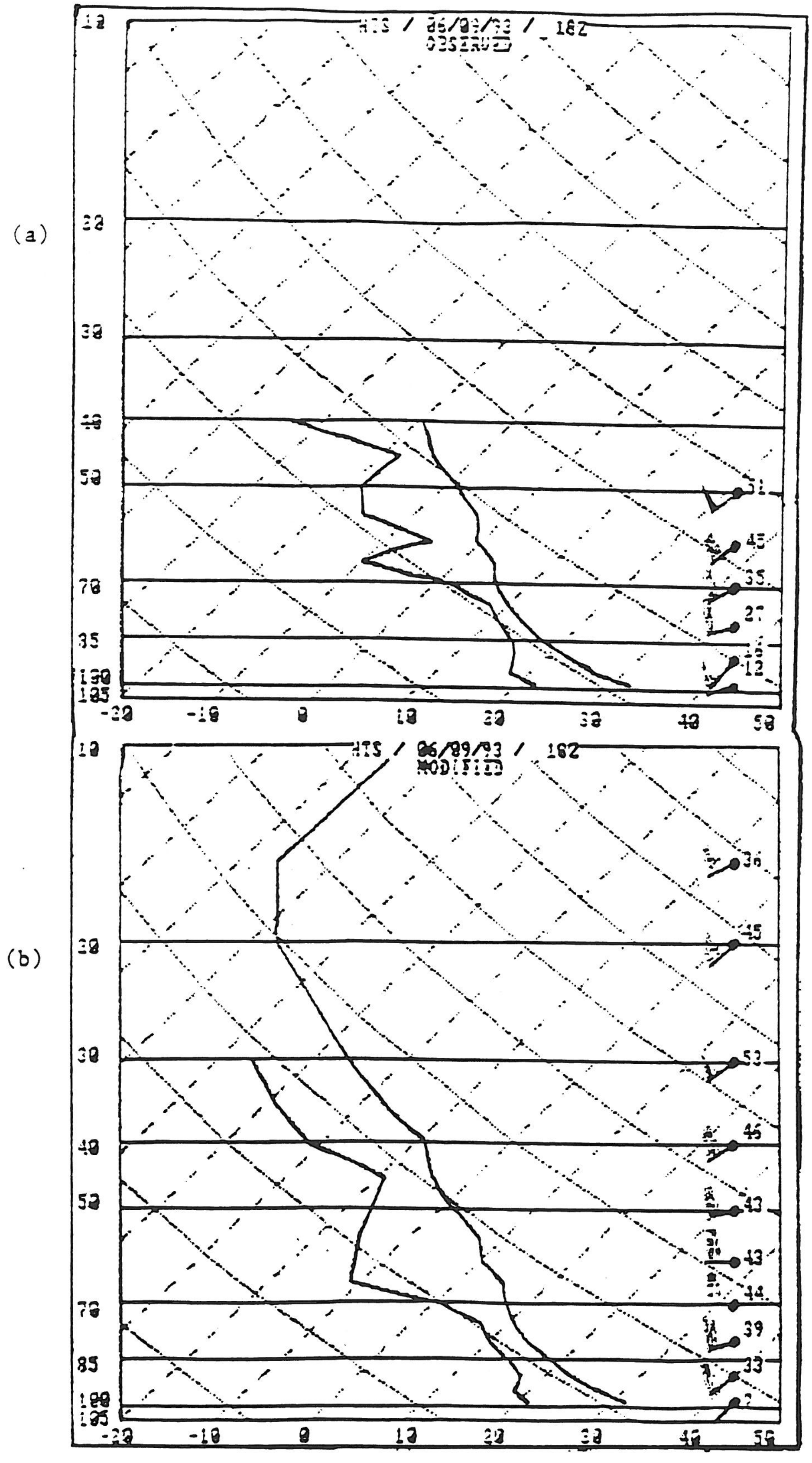
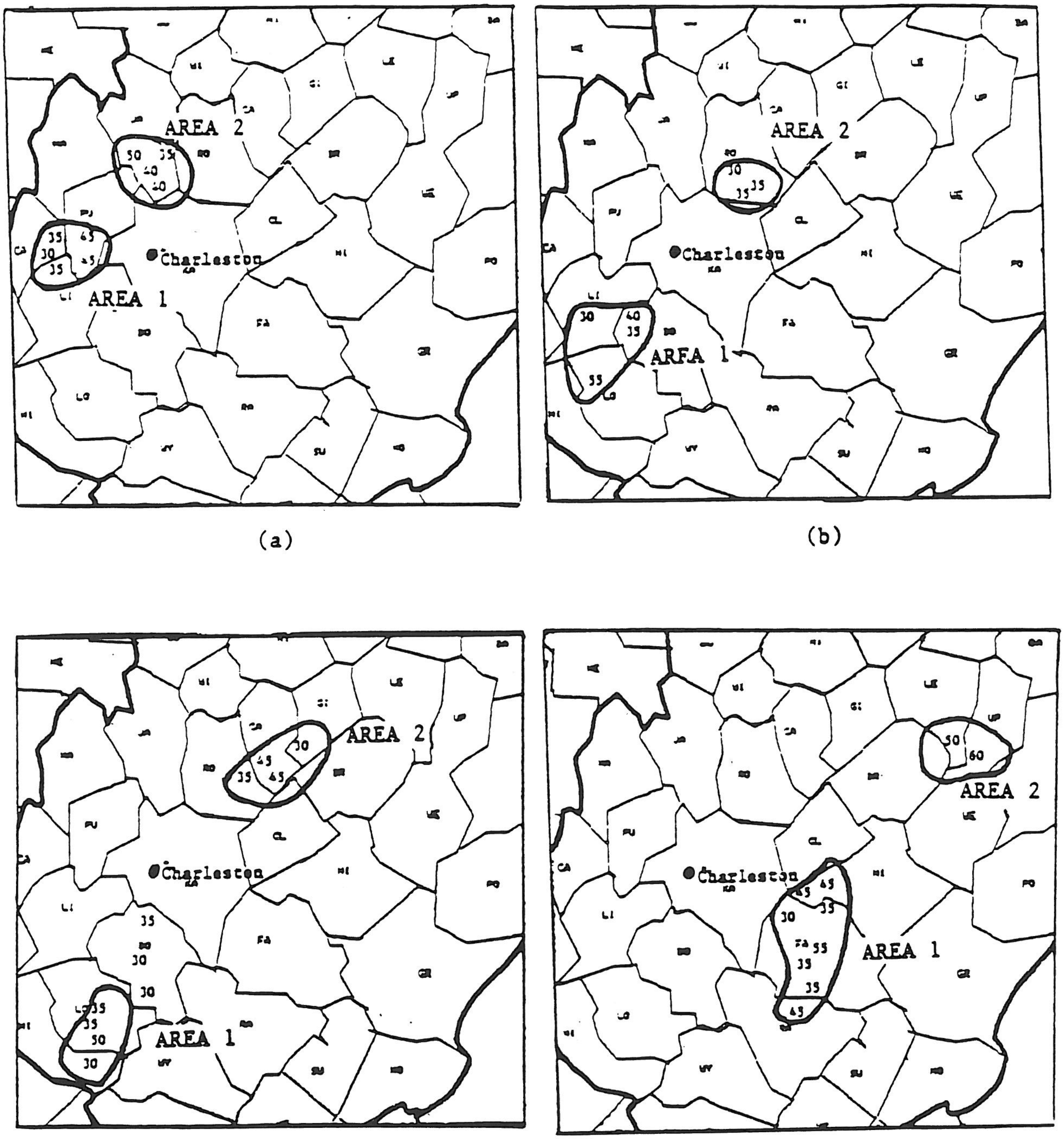


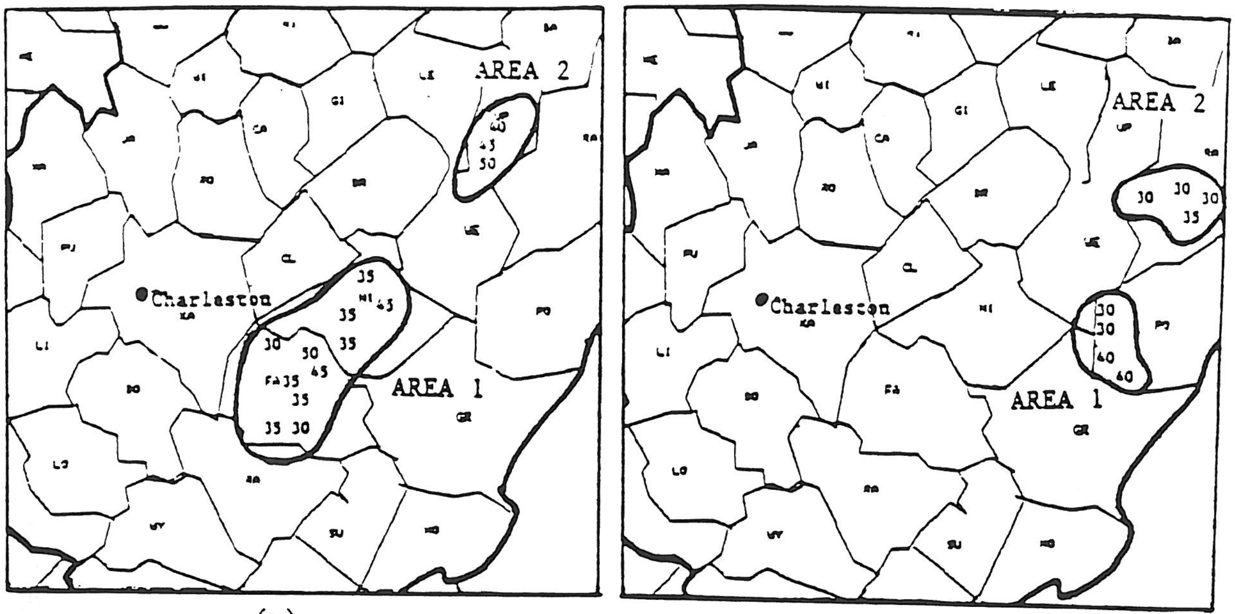
Figure 3. 1800 UTC June 9, 1993 observed (a) and modified (b) sounding for Huntington, WV (HTS). From the SHARP Workstation (Hart and Korotky 1991).



(a) (b)

(c) (d)

Figure 4. June 9, 1993 RADAP-calculated VIL over West Virginia at: (a) 1836; (b) 1912; (c) 1924; (d) 2012; (e) 2024; and (f) 2101 UTC.



(e)

(f)

Figure 4. Cont.

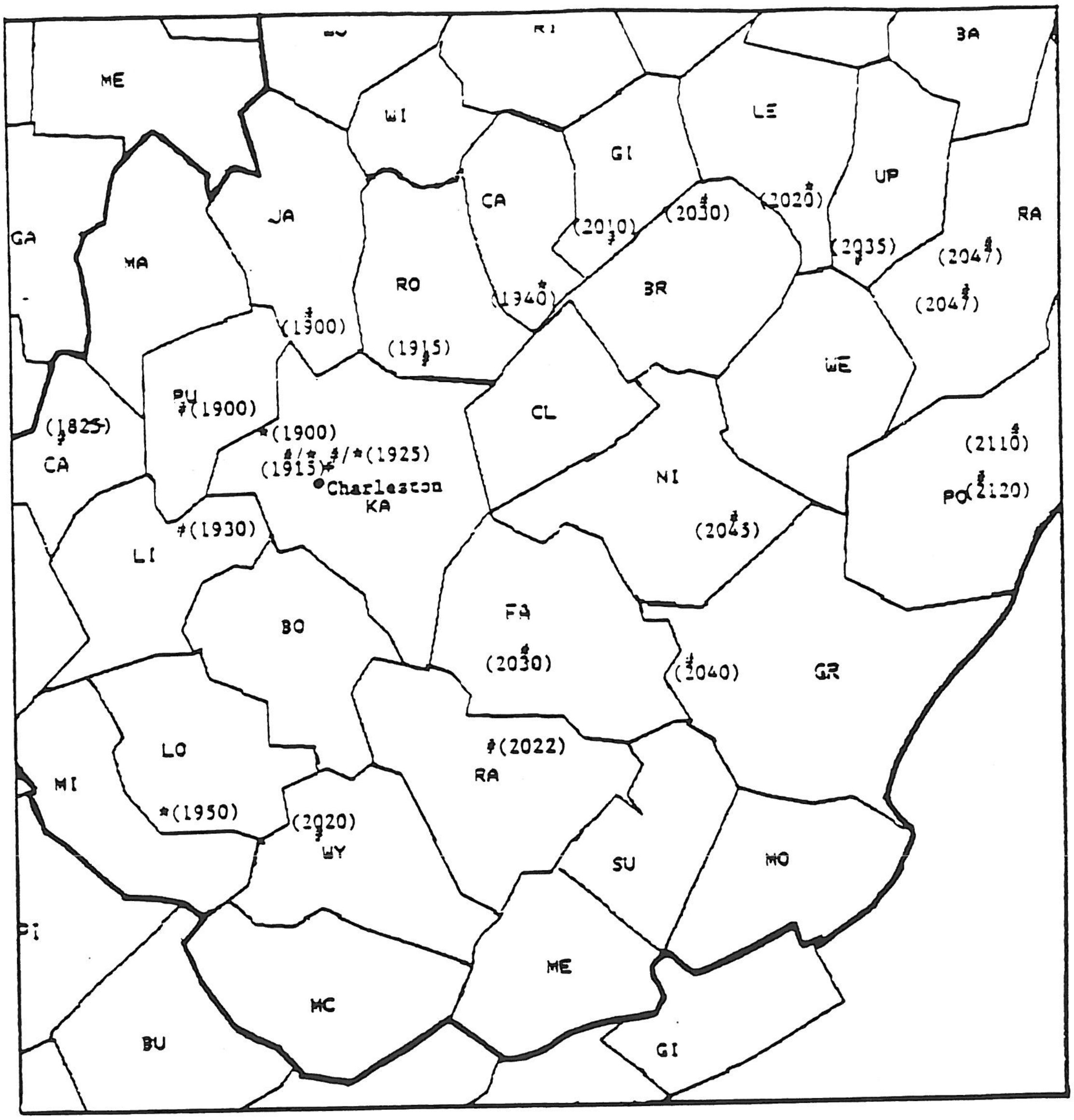


Figure 5. June 9, 1993 locations and times of severe weather reports within West Virginia. Asterisks (*) indicate severe criteria hail, while pound signs (#) indicate severe criteria wind gusts.

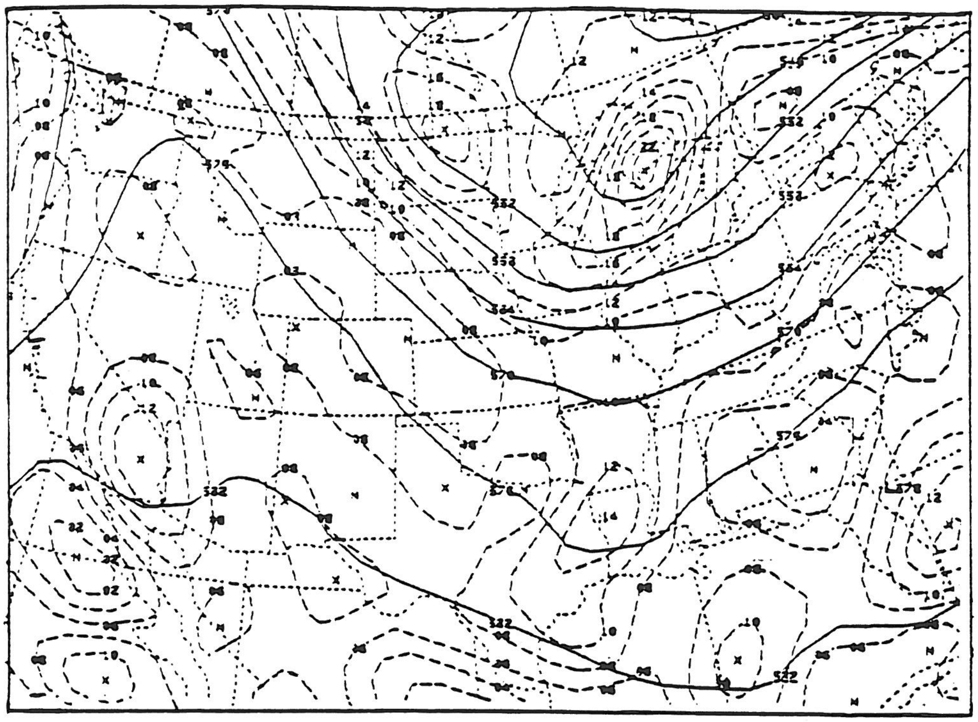


Figure 6. Same as Figure 1 except for May 18, 1993.

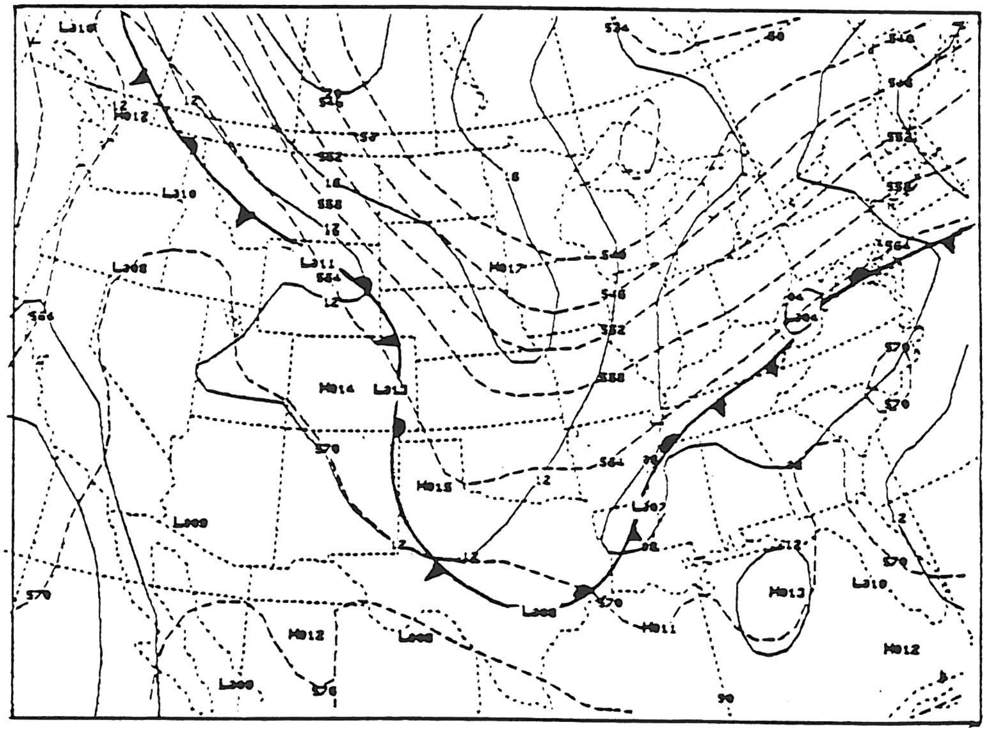


Figure 7. Same as Figure 2 except for May 18, 1993.

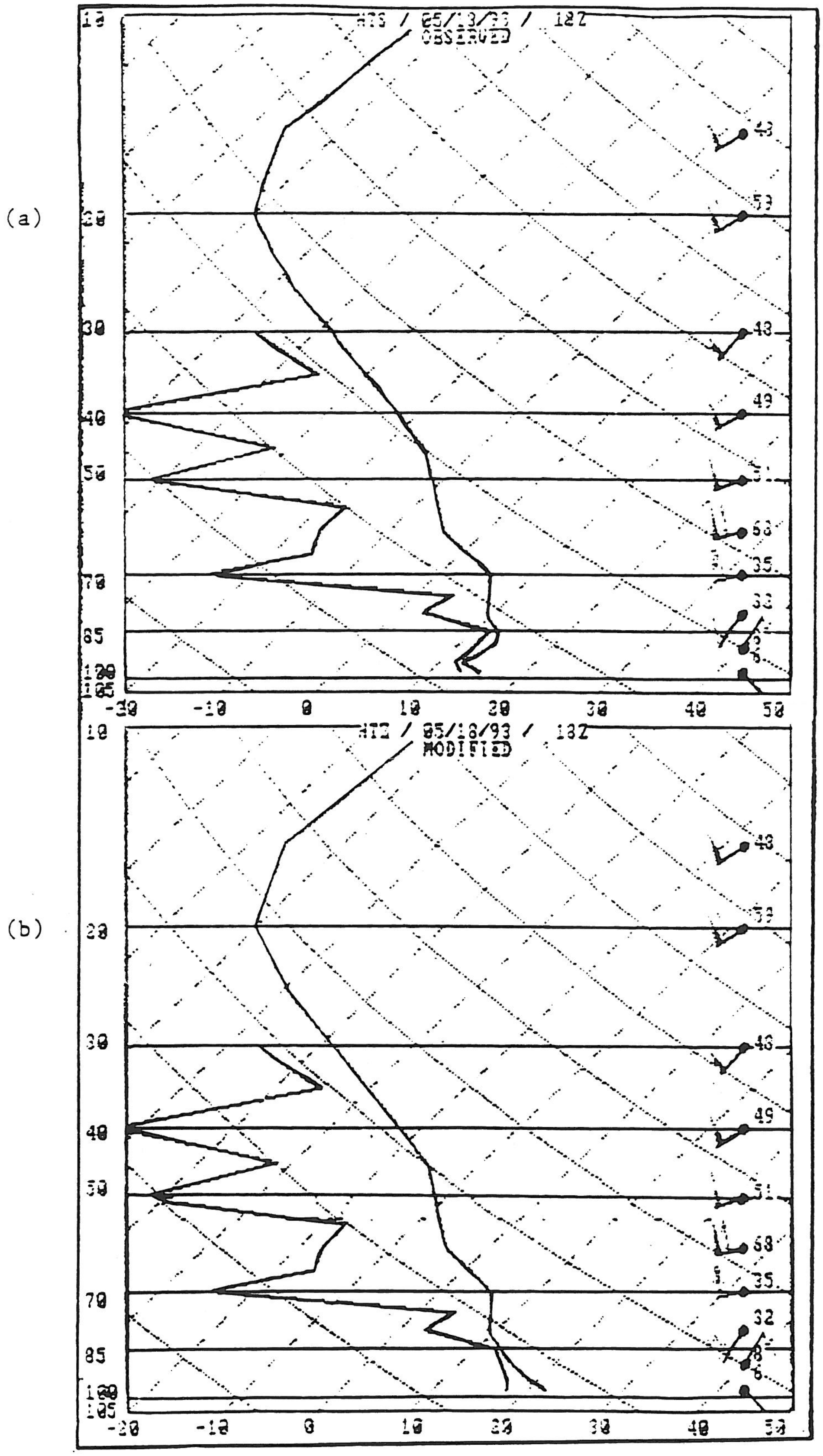
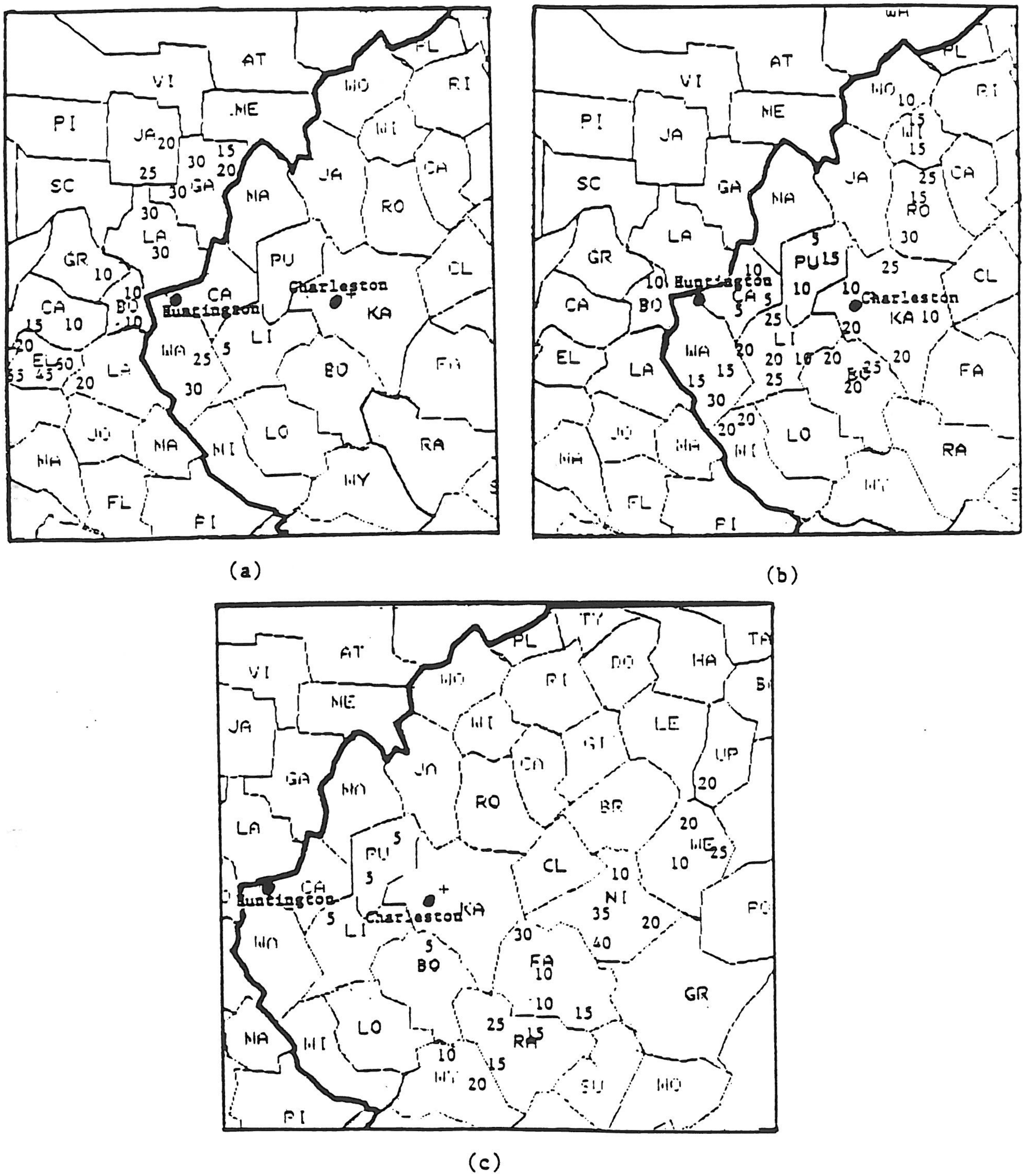


Figure 8. Same as Figure 3 except for May 18, 1993.



(a) (b) (c)

Figure 9. May 18, 1993 Radap-calculated VIL within West Virginia at: (a) 2012; (b) 2112; and (c) 2212 UTC.

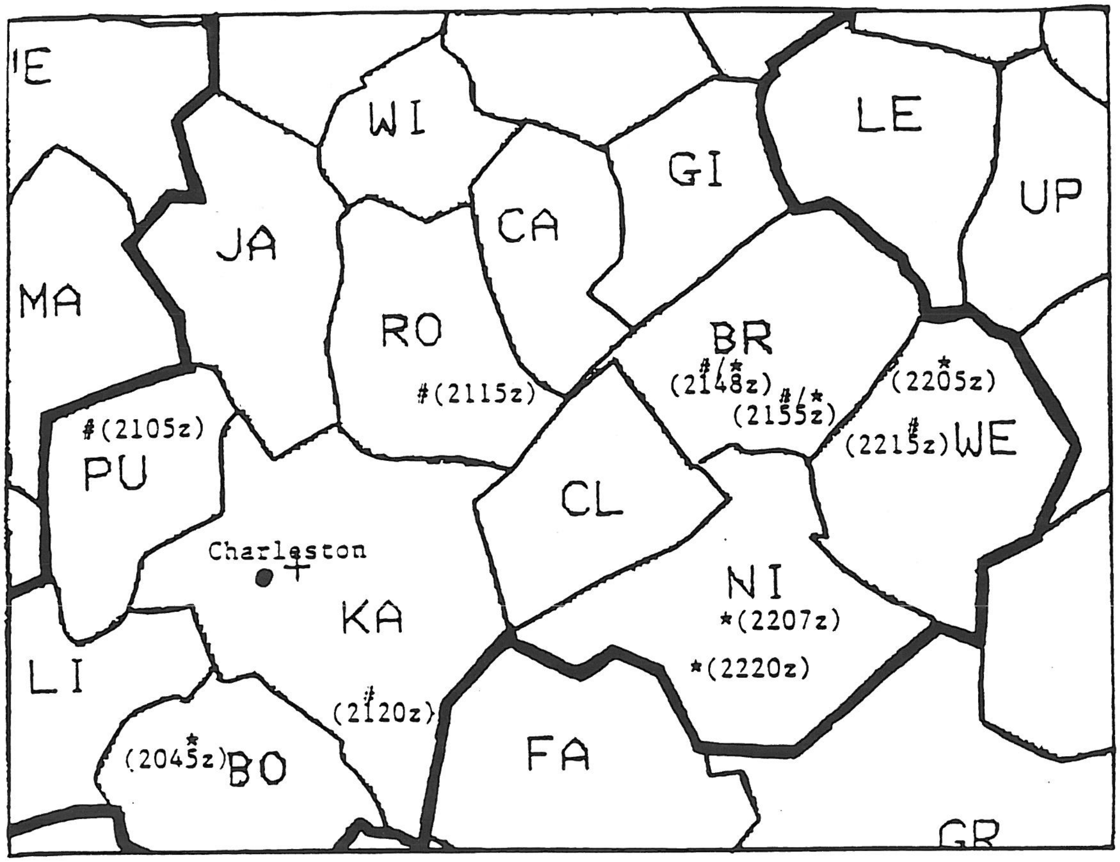


Figure 10. May 18, 1993 locations and times of severe weather reports within West Virginia. Asterisks (*) indicate severe criteria hail, while pound signs (#) indicate severe criteria wind gusts.