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A STUDY OF A "MINOR" SEVERE WEATHER OUTBREAK IN CENTRAL AND NORTHEASTERN PENNSYLVANIA SEPTEMBER 10, 1992

Dean L. Iovino
National Weather Service Forecast Office
Philadelphia, Pennsylvania

1. INTRODUCTION

On September 10, 1992, a "minor" severe weather outbreak occurred in parts of central and northeastern Pennsylvania. Wind gusts, associated with the thunderstorms on that day, downed trees and utility wires at a few locations, but very little property damage was reported. While most severe weather case studies examine events that cause widespread damage, this study focuses on a marginal severe weather outbreak. I will examine the minimal conditions needed for isolated severe weather in central and northeastern Pennsylvania. This should provide forecasters with a better idea of when to expect only isolated severe weather.

2. EVOLUTION

On September 10, 1992 at 1200 UTC, a cold front extended from the eastern shore of Georgian Bay in Ontario, Canada, southwest across northwestern Ohio, to southern Illinois (Figure 1). A surface trough was located to the east of the front, extending from northeastern Ohio to central Kentucky. This trough was what remained of an outflow boundary generated from convective activity, which occurred in Illinois and surrounding states on the evening of September 9. As is often the case with such outflow boundaries, this would provide a focus for the development of thunderstorms during the afternoon of the following day.

During the morning hours, the surface trough continued to move to the east. The 1331 UTC September 10 visible satellite image showed scattered cloud cover over western and central Pennsylvania and West Virginia, the area into which the outflow boundary would move during the next few hours. Abundant sunshine in that region, and the resulting destabilization of the atmosphere, would aid in the development of convection along the trough.

A severe weather checklist is routinely completed each morning (early April through late October) at the National Weather Service Forecast Office in Philadelphia (WSFO PHL). The checklist is used to determine whether (or not) severe weather is to be expected in the office's area of responsibility (eastern Pennsylvania and southern New Jersey) during that day. On the morning of September 10, the checklist did suggest that severe weather was likely within the region (Figure 2).

At 1711 UTC on September 10, the Severe Local Storms (SELS) branch of the National Severe Storms Forecast Center (NSSFC) in Kansas City, Missouri issued Severe Thunderstorm Watch Number 840. The watch, which included all of central and northeastern Pennsylvania, was to be valid from 1745 to 0000 UTC.

At 1800 UTC, the surface trough had moved to a line from Syracuse, New York, to Charleston, West Virginia (Figure 3). In Pennsylvania, this feature extended from northwestern Tioga County to southwestern Somerset County. By 1800 UTC, the convective activity had begun to develop along the trough. This was apparent from the 1731 UTC visible satellite image and from local radar observations. At 1735 UTC, radar observations indicated that maximum thunderstorm tops were near 40,000 feet over southwestern Clearfield County, with a thunderstorm top of 44,000 feet located near Morgantown, West Virginia. Two hours earlier, there were only a few scattered rain showers in the area associated with the surface trough. The cloud tops for those showers were less than 15,000 feet as they moved into western Pennsylvania from eastern Ohio.

The line of convective activity continued to move to the east-southeast at approximately 25 kt, while individual thunderstorms moved to the east-northeast at around 30 kt. The first report of hail (non-severe criteria), came from near the town of Wellsboro (Tioga County), shortly before 1900 UTC. The hail was produced by a cell with a reported top of 43,000 feet. This storm complex went on to generate new thunderstorms resulting in severe weather about an hour later in northern Bradford County (Figure 4).

The first reports of severe weather were received around 2000 UTC from Lycoming and Bradford Counties. Thunderstorms there had produced very strong wind gusts, which downed trees and utility wires. The convection continued to move to the east northeast. The thunderstorms in Bradford County did not produce any additional severe weather in Pennsylvania, but the storm which was over Lycoming County did. (This was likely related to the convection that was over southwestern Clearfield County at 1735 UTC.) After generating new thunderstorms, which produced small hail and heavy rain in parts of Wyoming County, this system produced severe weather in northern and central Wayne County at around 2200 UTC. These thunderstorms downed trees and power lines, produced nickel sized hail, and were accompanied by very heavy downpours. The community of Waymart, in Wayne County, received 1.3 inches of rain in about one hour.

In south central Pennsylvania, a storm complex produced severe weather in Fulton County and in southern Franklin County between 2045 and 2145 UTC. Again, trees and utility wires were downed and pea sized hail was reported. Radar observations indicated maximum tops to 53,000 feet and Digital Video Integrator/Processor (DVIP) levels were as high as 5. (This was likely related to the convection that was near Morgantown, West Virginia at 1735 UTC.)

The third, and final, storm complex to produce severe weather that day, began to strengthen over southern Luzerne County, to the north of Hazleton, at around 2200 UTC. This system moved to the east-northeast producing severe weather in northwestern Monroe and western Pike Counties shortly after 2300 UTC. Radar observations indicated that DVIP levels were up to 5. Tree limbs were downed and nickel sized hail was reported. A wind gust of 60 mph was estimated at Paupack in western Pike County, and several locations in Monroe and Pike Counties reported rainfall totals slightly greater than 2 inches.

The surface trough continued to move to the east, reaching an Albany - Allentown - Richmond line at 0000 UTC on September 11 (Figure 5). The trough would eventually move off the New Jersey coast around 0300 UTC. Meanwhile, the cold front extended southwest from central New York, across central Pennsylvania, to eastern Kentucky at 0000 UTC. It finally moved off the New Jersey coast around 0600 UTC on September 11.

3. ANALYSIS

a) Surface Pressure

For the time period of 1500 to 1800 UTC on September 10, an area of surface pressure falls of greater than 2.5 mb extended from Vermont, southwest across parts of eastern New York and eastern and central Pennsylvania, to northern Virginia (Figure 6). Pressure rises of greater than 1.5 mb for that period covered much of Lake Erie and northern Ohio. The point at which a line of thunderstorms intersects an imaginary line connecting a rise-fall couplet has been shown to be the most likely location to experience damaging winds (Bothwell 1988). An analysis for the time period 1800 to 2100 UTC, indicated that the main pressure rise-fall couplet had passed to the north of the study area (Figure 7). For this period, pressure falls of greater than 2.5 mb extended along the Maine coast and into southern New Hampshire, with another small area of pressure falls located near New York City. Pressure rises of greater than 1.5 mb extended from northern Vermont to central New York.

An examination of the 12-hour surface pressure falls in the study area showed that values generally ranged from -3.5 to -4.5 mb for the time period 0900 to 2100 UTC on September 10. While these values did not imply the development of severe thunderstorms, they did indicate that moderate thunderstorm activity was possible (Henry 1986a).

b) Temperature and Moisture

At 1200 UTC on September 10, surface temperatures were generally in the low to mid 70s (°F) throughout central and eastern Pennsylvania. However, temperatures climbed into the low to mid 80s (°F) by the time the thunderstorms began to move into the region that afternoon, further destabilizing the atmosphere.

At 1200 UTC, the flow at 850 mb over the region was from the southwest (Figure 8). Temperatures over and upstream from the study area ranged from +14 to +16 °C, and changed little between 1200 and 0000 UTC (Figure 9). The same was true at 700 mb, where temperatures remained in the +5 to +8 °C range (Figures 10 & 11). At 500 mb, the temperature also exhibited little change, where readings ranged from -9 to -11 °C at both 1200 and 0000 UTC (Figures 12 & 13). During the morning, dew point temperatures at the surface were high, ranging from 65 to 70 °F. The dew points remained high until the passage of the trough and the accompanying thunderstorms.

At 850 mb, dew point temperatures indicated by the 1200 UTC sounding were also high (+10 to +14 °C). The 850 mb analysis indicated that a maximum temperature ridge extended from western New York, across central Pennsylvania, to eastern Maryland. The temperature ridge was located downstream from a maximum moisture ridge, which extended from eastern Ohio to south central Virginia. This is the reverse of the conditions which normally promote strong convective development (Henry 1986b). By 0000 UTC on September 11, the 850 mb flow over the region had become more westerly, and dew points began to fall markedly just to the west of the study area. The dew point temperature at Pittsburgh dropped to -16 °C on the evening sounding. At 0000 UTC, high dew point temperatures at 850 mb were confined to areas near and to the east of the convective activity (+13 °C at Albany, +9 °C at Atlantic City, and +16 °C at Dulles Airport near Washington).

At 1200 UTC on September 10, the 700 mb flow over Pennsylvania was from the southwest. Dew point temperatures over the study area generally ranged from -1 to +3 °C. The 700 mb analysis indicated that dry air was located well upstream of the study area over the mid-Mississippi River Valley. There was another area of dry air at 700 mb over eastern North Carolina. By 0000 UTC on the September 11, the dew point temperature spread at 700 mb over the region had increased to include values from -1 to +6 °C. At this time, the dry air which was located to the west of the study area in the morning had begun to move over western Pennsylvania. At the same time, the dry air located to the south had moved up over the Delmarva Peninsula and southern New Jersey.

c) Upper Level Winds

At 1200 UTC on September 10, a 45 kt jet at 850 mb extended from northern Ohio, across western Lake Ontario, to central Quebec Province in Canada. By 0000 UTC on September 11, the jet had shifted to the north and east, extending from central New York to central New England, then northeast to eastern Quebec, Canada. The study area remained to the right of the jet throughout the day, which is not generally a favorable location for the development of severe weather.

During the morning on September 10, the 500 mb flow over the study area was from the southwest at 35 to 45 kt. An 80 kt jet maximum extended from eastern Nebraska to northern Illinois. At 0000 UTC on September 11, the flow at 500 mb over central and northeastern Pennsylvania remained from the southwest and increased slightly to 40 to 55 kt. The 500 mb 80 kt jet maximum, which was located to the west of the study area in the morning, had moved across eastern Ontario and southwestern and central Quebec Province in Canada.

At 1200 UTC on September 10, a 90 kt jet at 300 mb extended from southeastern Iowa to northwestern Lake Huron (Figure 14). Wind speeds of 70 kt or greater, extended as far east as northwestern Ohio. At 0000 UTC on September 11, the jet maximum had increased to 110 kt, and moved to the northeast, to the same area as the 500 mb, 80 kt jet (Figure 15). This placed the study area beneath the right rear quadrant of the upper-level jet during the afternoon, which is generally a favorable region for the development of severe weather.

d) Vorticity

Upper air analyses revealed an additional factor, which may have aided in the development of the isolated severe thunderstorms in the study area. At 500 mb, weak positive vorticity advection was occurring at the time the convective activity began to develop. At 1200 UTC on September 10, a weak vorticity lobe extended across eastern Indiana and central Kentucky. The vorticity lobe moved to the east, passing over the study area between 2000 and 2200 UTC, and became located over western New England and the coastal waters of New Jersey at 0000 UTC on September 11.

e) Soundings

The September 10, 1200 UTC soundings from nearby upper air stations did not appear favorable for the development of widespread severe weather. The Skew-T Hodograph Analysis Research Program (SHARP; Hart and Korotky 1991) indicated Lifted Indices of -3 °C upstream from the study area from the Pittsburgh and Huntington 1200 UTC soundings. Values of Convective Available Potential Energy (CAPE) at those two stations were 1258 and 1185 j/kg, respectively. The Total Totals Indices were 45 and 47. While the Lifted Indices and CAPE values suggested the potential for moderate thunderstorms, the Total Totals Indices implied that only weak convective activity should occur. With the wet bulb zero height at Pittsburgh and Huntington being quite high (11,100 and 11,500 feet), there seemed to be little threat of large hail (Henry 1986a).

Two indices calculated by SHARP, which have only recently been available to the forecasters at WSFO PHL, were very helpful in determining that tornadic activity was unlikely in the study area. These indices are Storm Relative Helicity (0 to 3 km), and the Energy Helicity Index (EHI; see La Penta 1992 for a description of this index). At 1200 UTC on September 10, the Storm Relative Helicity (0 to 3 km) near Pittsburgh and Huntington were 107 and 57 $(m/s)^2$, respectively. These values were relatively low, implying that there would be little potential for rotation in any thunderstorms which did develop in the area (National Weather Service 1991). The EHI, which represents the potential tornadic intensity as a function of CAPE and Storm Relative Helicity (Hart and Korotky 1991), helped to better define the low probability of tornadic activity. EHI values were calculated to be 0.82 at Pittsburgh and 0.57 at Huntington. Both values were below 1.0, which is being used experimentally as a threshold to indicate the possibility of tornado-producing thunderstorms (Mogil et al. 1992). These EHI values suggested that, while the atmosphere was quite unstable, there was not enough of a potential for rotation present to contribute to the development of tornadoes.

In order to approximate atmospheric conditions in the study area during the afternoon of September 10, SHARP was used to create an 1800 UTC sounding for Williamsport, Pennsylvania (Figure 16). The input values used in this estimated sounding were extrapolated from the morning and evening upper air analyses, and from the accompanying soundings from nearby upper air stations. The actual 1800 UTC surface temperature, dew point temperature, and wind at Williamsport were also used.

For 1800 UTC, a Lifted Index of -5 °C and a CAPE of 1821 j/kg were calculated for Williamsport, implying the potential for moderate to strong thunderstorm activity. The estimated sounding also suggested a cap inversion of 1.5 °C, which would not be strong enough to prevent the development of deep convection (Vescio 1991). The Total Totals Index was determined to be 46, which was similar to the values from the 1200 UTC September 10 soundings at both Pittsburgh and Huntington. The Severe Weather Threat Index (SWEAT) was approximately 252. This was below the generally accepted threshold of 300 used to indicate the potential for severe weather (Hart and Korotky 1991). The wet bulb zero height was 11,200 feet, which did not favor the development of large hail. Finally, the Storm Relative Helicity (0 to 3 km) was determined to be low, only 61 $(m/s)^2$. The resulting EHI was 0.69, which was again below the experimental threshold value of 1.0. This indicated that although considerable instability was present, the potential for storm rotation was limited.

The September 11, 0000 UTC sounding from Atlantic City showed a Lifted Index of -5 °C and a Total Totals Index of 46. These values were the same as those estimated for Williamsport at 1800 UTC on September 10. The CAPE was calculated to be 1415 j/kg and the wet bulb zero height was 11,700 feet. While the Lifted Index and the CAPE values implied the potential for severe weather, the Total Totals Index and the wet bulb zero height did not.

Shortly after 2100 UTC on September 10, SELS determined that the axis of greatest instability in the vicinity of the trough extended from eastern Pennsylvania, south into central Virginia. Lifted indices in that area were as low as -7 °C. On the 0000 UTC September 11 Atlantic City sounding, the Storm Relative Helicity was 107 $(m/s)^2$, and the EHI was 0.87. These values were similar to those from the previous soundings taken at Pittsburgh and Huntington, and the estimated sounding for Williamsport.

Along with other information presented, the nearby upper-air soundings showed that the thermodynamic profile of the atmosphere in areas near and to the east of the surface trough had changed little during the day, except for surface heating. Unfortunately, evening soundings were not available from Albany or Dulles Airport. These would have helped to better evaluate the atmospheric thermodynamic conditions.

4. RESULTS AND CONCLUSIONS

As stated earlier, the purpose of this study was to analyze a rather unimpressive severe weather outbreak, which was accompanied by isolated reports of damage. Although most of the study area was unaffected by these severe thunderstorms, and no injuries were reported, two trees fell on houses. One was located in Canton (Bradford County) and the other in Williamsport (Lycoming County). Another tree fell on a trailer in Hepburnville (Lycoming County), and a falling tree landed on a car in Ridgebury (Bradford County).

The data, which were available on the morning of September 10, 1992, strongly suggested that thunderstorms would develop over central and northeastern Pennsylvania later that day. Convective development seemed likely, as an old outflow boundary from the previous day's convection moved into an area with an abundance of low level moisture, strong surface heating and scattered cloud cover. The day's main forecast problem evolved into determining whether any of the thunderstorms would reach severe limits, as suggested by WSFO PHL's severe weather checklist.

It appears that one of the key factors in this case, which determined whether the occurrence of severe weather would be widespread or isolated, was the position of the 850 mb jet. As stated earlier, the study area remained to the right of the 850 mb jet throughout the day. This location is generally not favorable for the development of severe weather. Other factors which may have limited severe weather development were the absence of significant mid-level dry air intrusion and the location of the maximum temperature ridge at 850 mb in relation to the maximum moisture ridge.

Regardless of the unfavorable factors for severe weather development, a few cases did occur. The combination of the other (more favorable) parameters listed in the WSFO PHL Severe Weather Checklist for September 10, 1992 (Figure 2) apparently were sufficient to produce isolated severe weather events.

This case study illustrates the importance of using atmospheric stability indices--in combination with other data sources--for determining the probability and possible extent of severe weather. It also highlights the potential usefulness of Storm Relative Helicity (0 to 3 km) and the Energy Helicity Index in this region of the country. By further studying these "minor" severe weather outbreaks, we may get a better understanding of the minimal conditions needed for the occurrence of severe weather. At the same time, we will also gain a better understanding of when to expect isolated severe weather, or even no severe weather at all.

5. ACKNOWLEDGEMENTS

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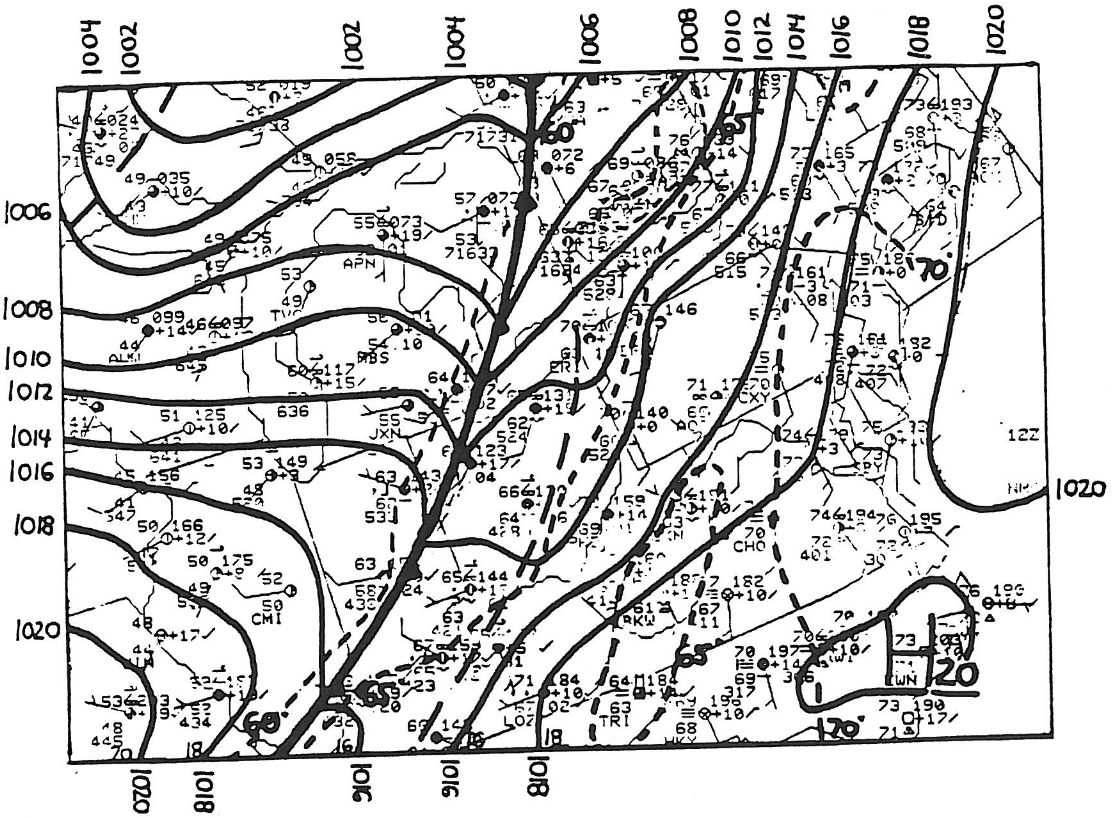


Figure 1. Sept. 10, 1992 1200 UTC surface analysis. Isobar contour 2 mb, isodrosotherm contour 5 °F.

DATE 09/10/92 SEVERE WEATHER CHECKLIST

	FORECAST		OBSERVED	
	YES	NO	YES	NO
PART A				
1. Will synoptic or mesoscale convergence/ confluence affect the area (front, trough, etc.)?	✓	---	✓	---
2. Will the convective temperature be reached and/or will the dynamics be significant enough to induce convection?	✓	---	✓	---
3. Will the 850 mb dew point be +8 C or greater (+6 C or greater for strong dynamics)?	✓	---	✓	---
4. Will the surface dew point be 60 F or greater (50 F or greater for strong dynamics)?	✓	---	✓	---
5. Will neutral or positive vorticity advection occur at 500 mb and/or will the layer between 700 and 500 mb have positive differential vorticity advection?	✓	---	✓	---
PART B				
1. Is there scattered to broken coverage of convective precipitation accompanying the front or trough between midnight and noon?	✓	---	✓	---
2. Are there mostly clear skies or large clear slots during the morning hours and/or is there ACC or CU present in the morning?	✓	---	✓	---
3. Will low level wind speeds be 20 kts or greater (defined as any level between the boundary layer and 7,000 ft)?	✓	---	✓	---
4. Will the surface dew point be 65 F or greater (55 F or greater for strong dynamics)?	✓	---	✓	---
5. Will the forecast area be under or to the left of an 850 mb jet (speed = or > 20 kts) and in the left front or right rear quadrant of a 300 mb jet (speed = or > 70 kts)?	---	✓	---	✓
PART C				
1. Will a 1000 - 500 mb thickness ridge pass through or remain over the forecast area?	✓	---	✓	---
2. Will there be diffluence at 300 mb?	✓	---	✓	---
3. Will there be a 500 mb wind equal to or greater than 35 kts or is the horizontal wind shear equal to or greater than 30 kts/90 nmi?	✓	---	✓	---
4. Is there a 700 mb no change line to the west of the forecast area with the wind crossing it at an angle greater than 40 degrees?	---	✓	---	✓
5. Will there be dry air in the mid troposphere (dew point depressions of 5 C or greater near the 700 mb level or determined by looking at the satellite moisture channel images)? (Do not answer "yes" if the NGM R2 forecast is < 45%.)	✓	---	---	✓
ARCHIVE QUESTION - Is the Energy Helicity Index equal to or greater than 0.5 within 500 miles of the forecast area, in the flow pattern?	✓	---	✓	---

Figure 2. WSFO PHL severe weather checklist for Sept. 10, 1992.

USING THE SEVERE WEATHER CHECKLIST

STEP 1. If the answer to three or more of the questions in PART A is "yes", go to PART B. If not, stop - severe weather will not occur in the forecast area.

STEP 2. If the answer to three or more of the questions in PART B is "yes", go to PART C. If not, stop - severe weather is not likely to occur, however, continue to monitor conditions for any significant change.

STEP 3. If the answer to three or more of the questions in PART C is "yes", be prepared for the occurrence of severe weather in the forecast area.

IMPORTANT NOTES

1. All questions (except B1 and B2) must be answered for the afternoon and evening for the entire forecast area. Notations should be made on the checklist if only part of the forecast area is affected.
2. If convection is expected, forecast where clear/cloudy boundaries will be (ie. boundaries between areas with fog and without fog). Convection will often develop along these boundaries due to differential heating.
3. For question C5, if it appears as though there will be moisture at 700 mb, but dry air just above, answer this question "yes", especially if this is supported by the satellite moisture channel images.
4. Remember to look at all other thermodynamic indicators, as well.
5. Fill out the "observed" part of the checklist completely if strong or severe thunderstorms occur. Also complete the entire "observed" part of the checklist if no strong or severe thunderstorms occur, but you can still reach PART C.

Figure 2. (continued)

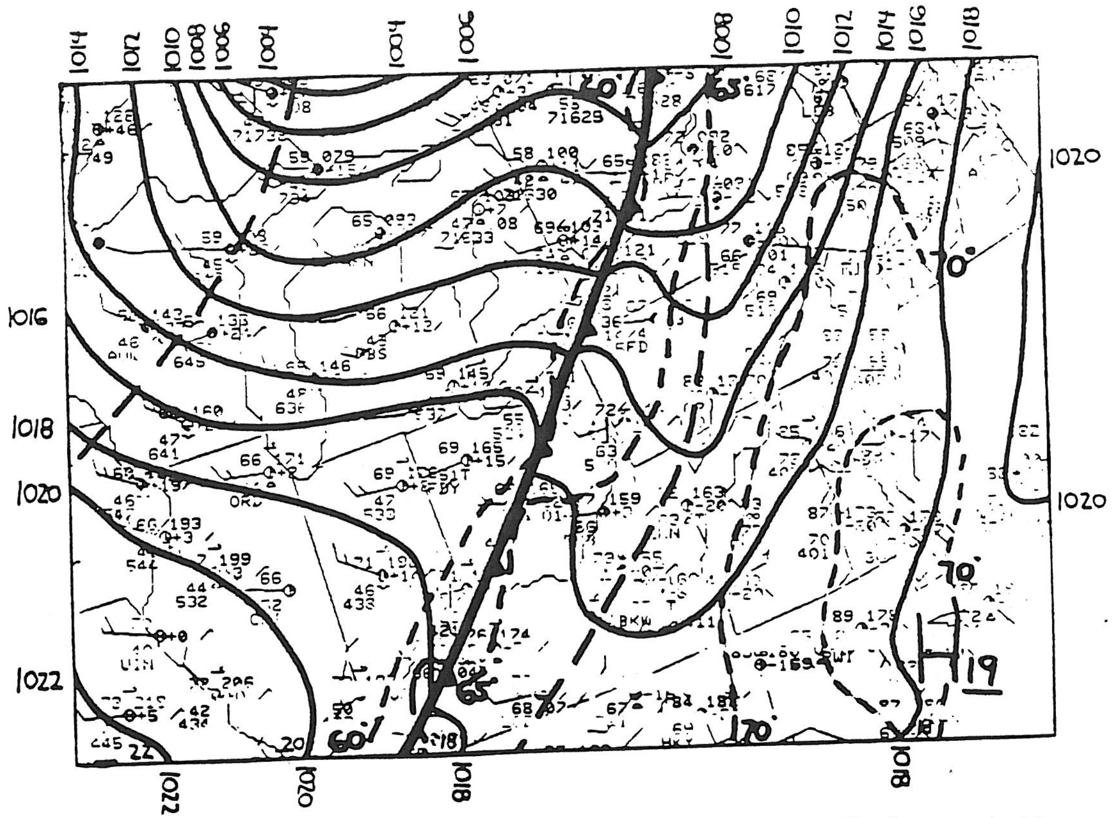


Figure 3. Sept. 10, 1992 1800 UTC surface analysis. Isobar contour 2 mb, isodrosotherm contour 5 °F.

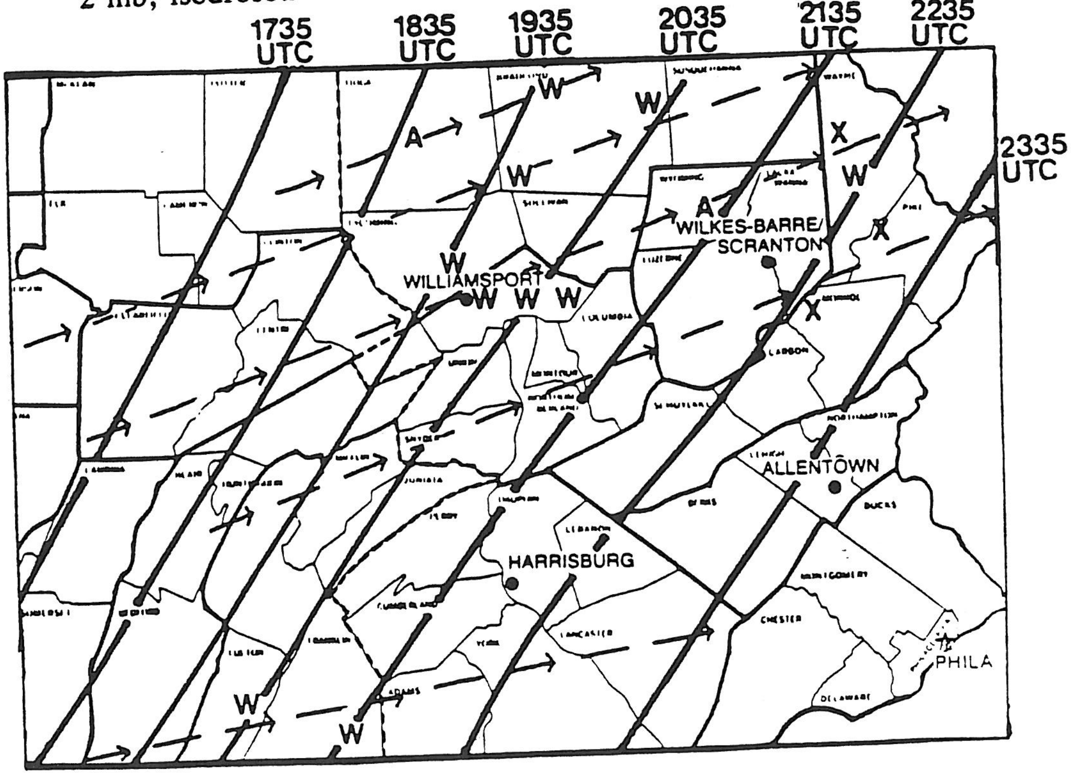


Figure 4. General progress of thunderstorms on Sept. 10, 1992. Dashed lines indicate the strongest storms which generated new convective activity throughout the afternoon and evening. X = hail and wind damage, W = wind damage and A = hail less than 3/4 inch in diameter.

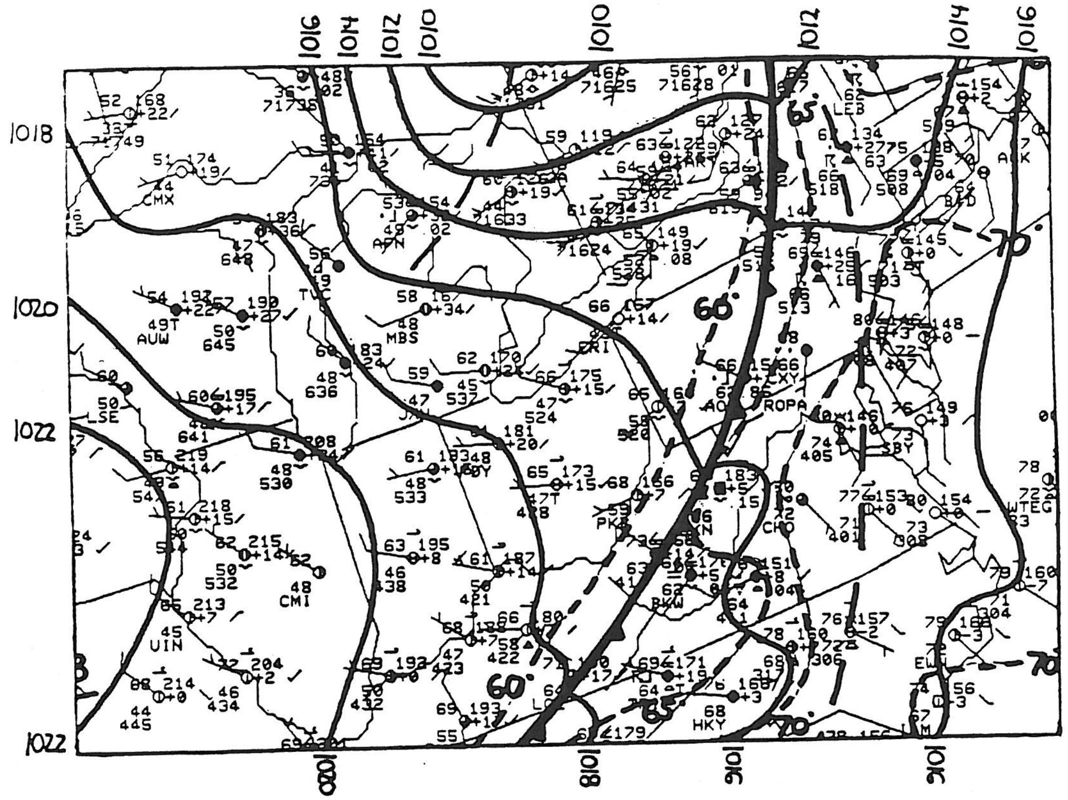


Figure 5. Sept. 11, 1992 0000 UTC surface analysis. Isobar contour 2 mb, isodrosotherm contour 5 °F.

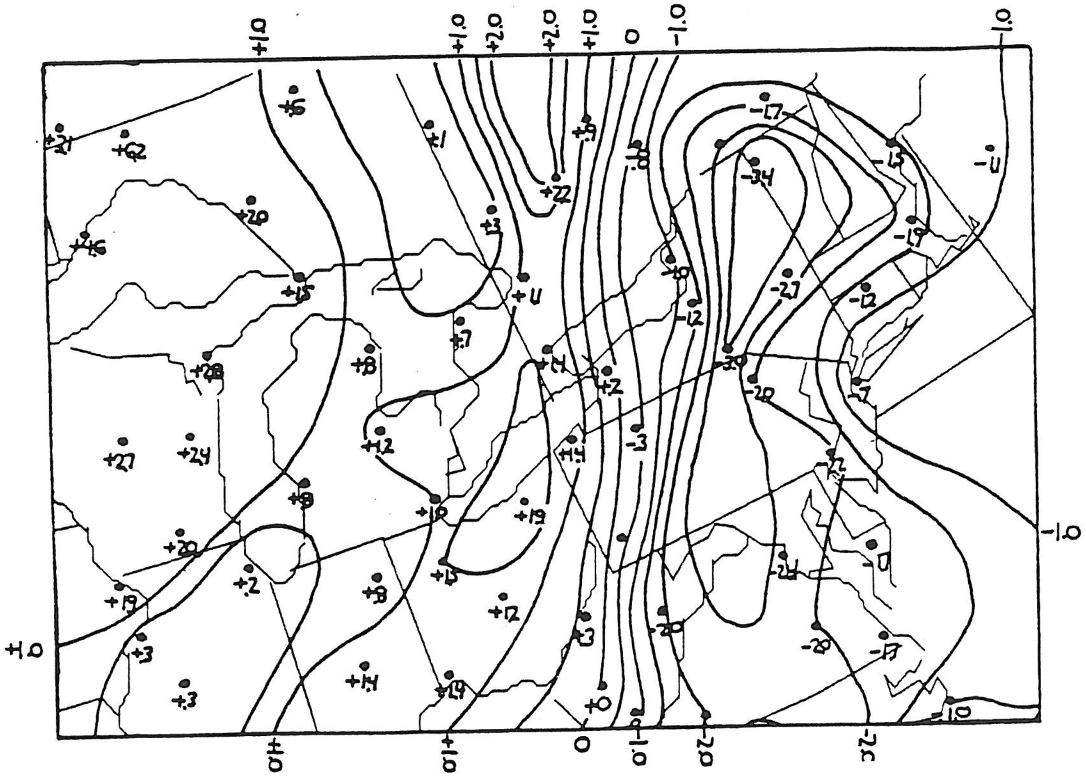


Figure 6. Three hour surface pressure change analysis for the period 1500 to 1800 UTC Sept. 10, 1992. Isallobar contour 0.5 mb.

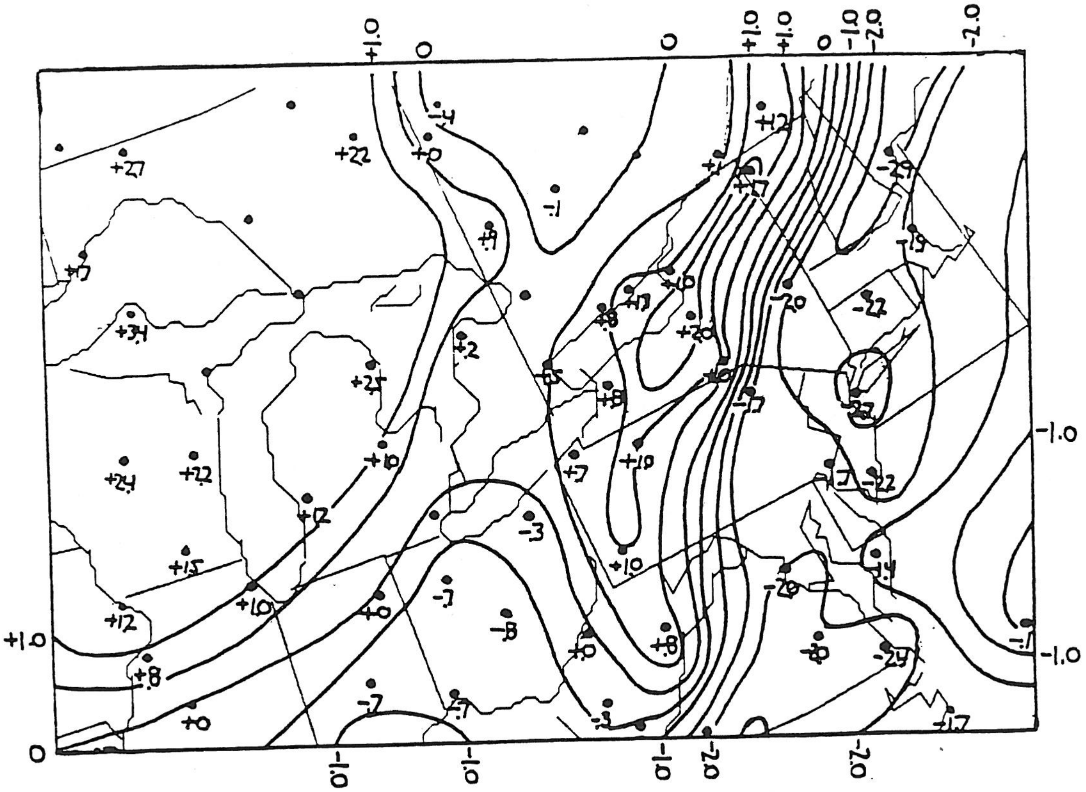


Figure 7. Three hour surface pressure change analysis for the period 1800 to 2100 UTC Sept. 10, 1992. Isallobar contour 0.5 mb.

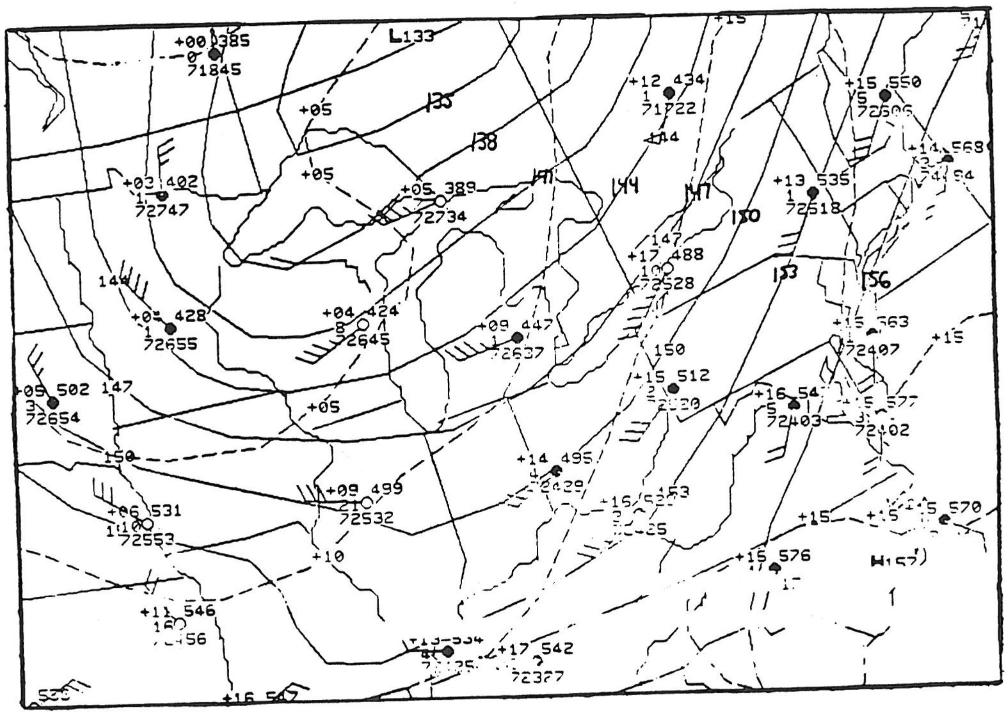


Figure 8. Sept. 10, 1992 1200 UTC 850 mb analysis. Height contour 30 gpm, isotherm contour 5 °C.

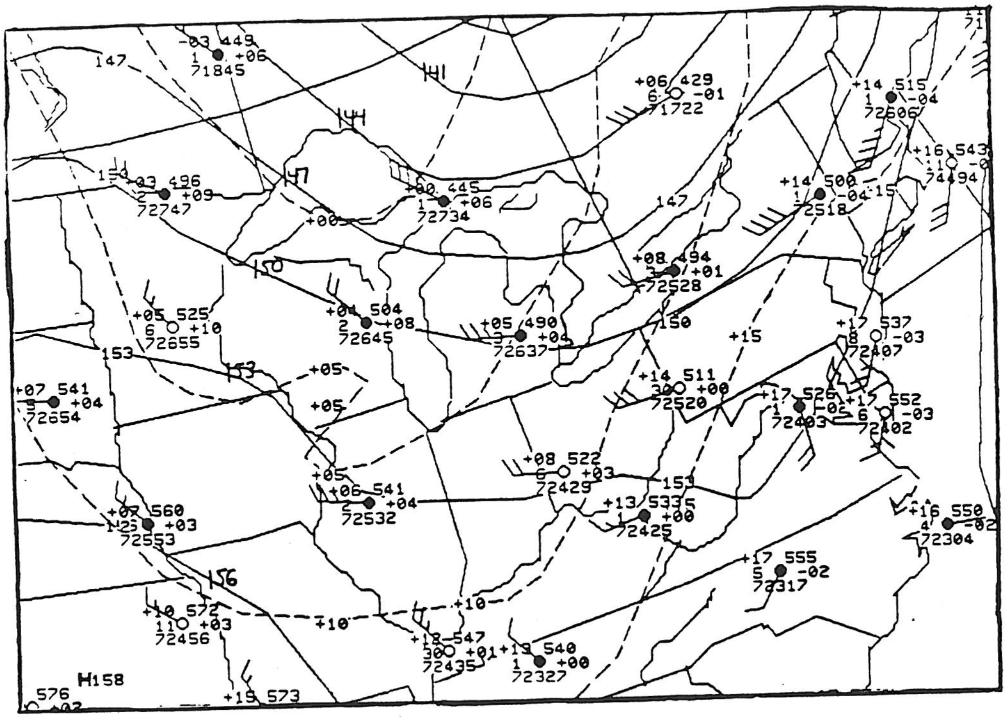


Figure 9. Sept. 11, 1992 0000 UTC 850 mb analysis. Height contour 30 gpm, isotherm contour 5 °C.

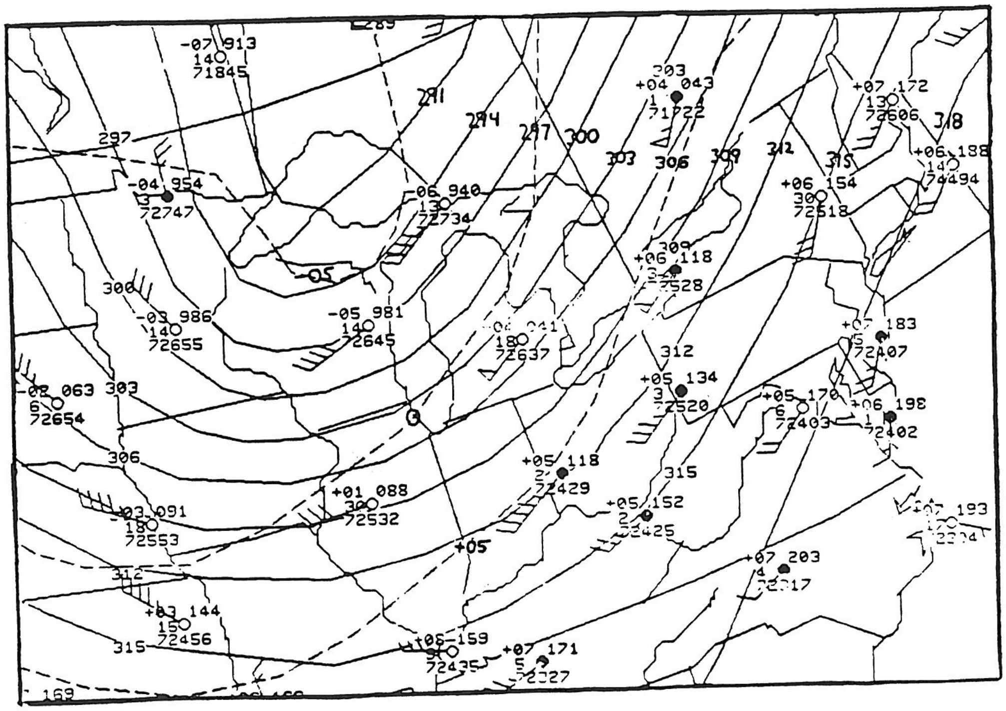


Figure 10. Sept. 10, 1992 1200 UTC 700 mb analysis. Height contour 30 gpm, isotherm contour 5 °C.

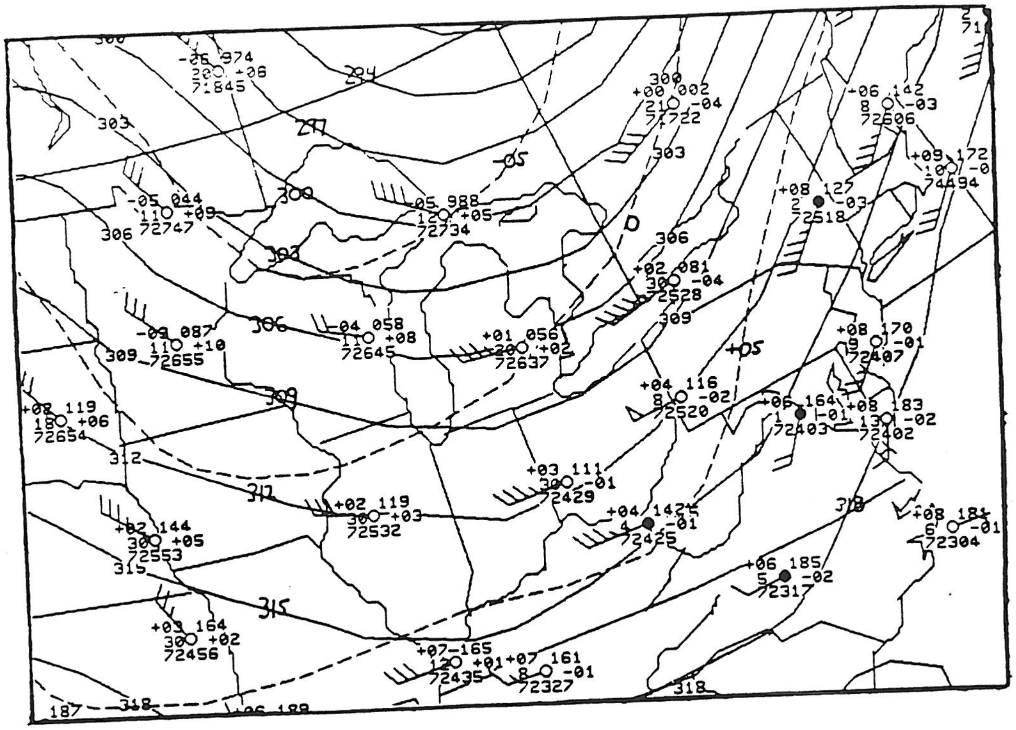


Figure 11. Sept. 11, 1992 0000 UTC 700 mb analysis. Height contour 30 gpm, isotherm contour 5 °C.

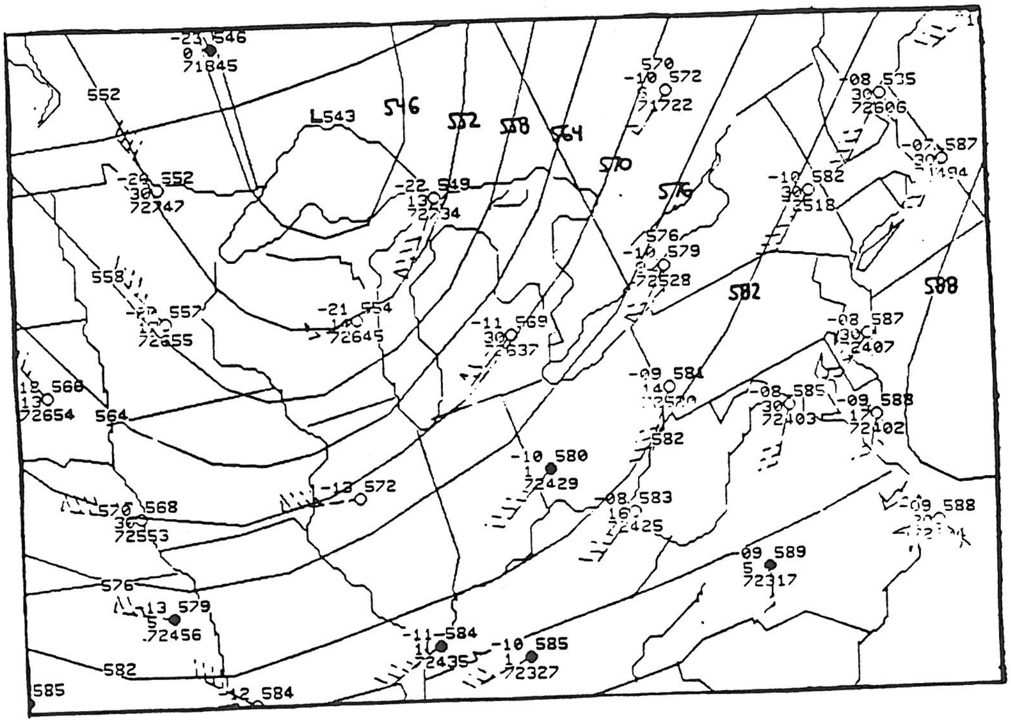


Figure 12. Sept. 10, 1992 1200 UTC 500 mb analysis. Height contour 60 gpm.

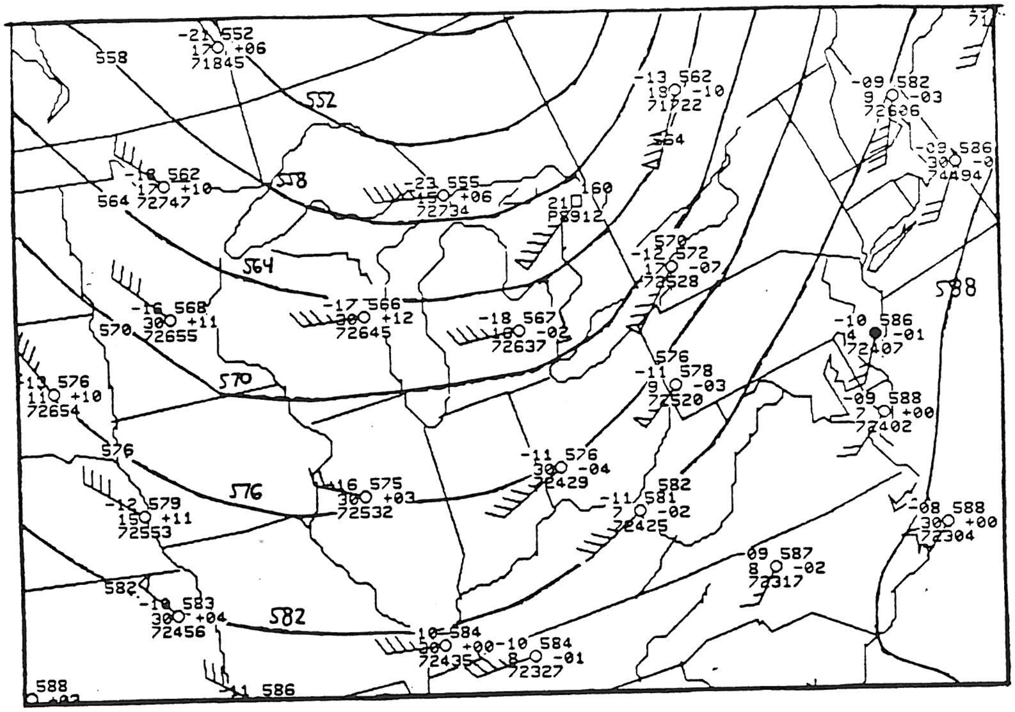


Figure 13. Sept. 11, 1992 0000 UTC 500 mb analysis. Height contour 60 gpm.

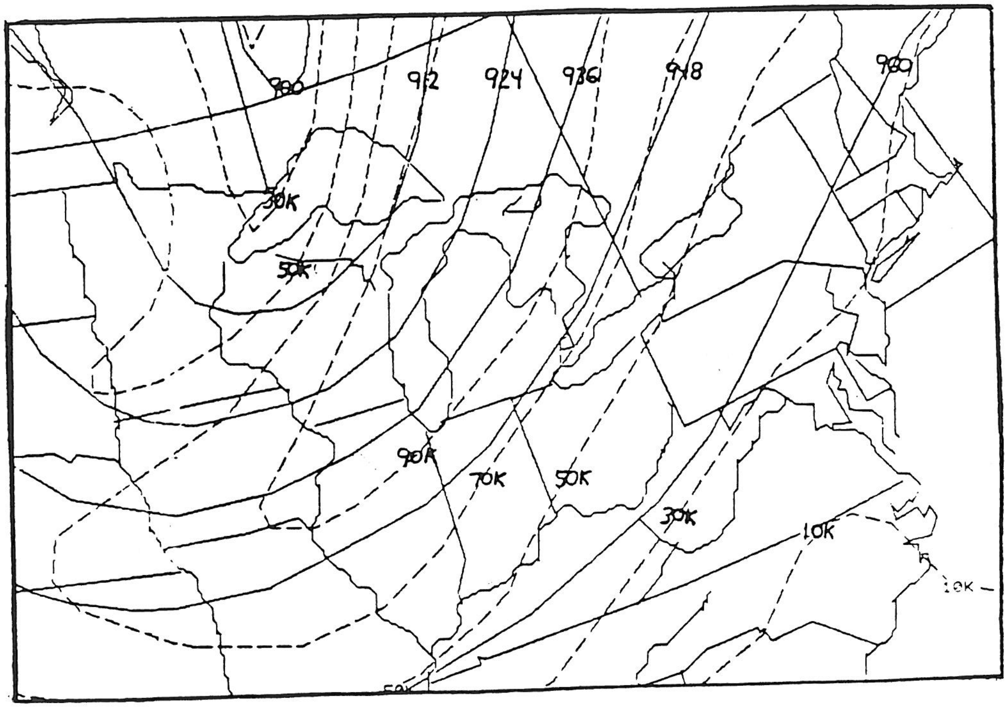


Figure 14. Sept 10, 1992 1200 UTC 300 mb analysis. Height contour 120 gpm, isotach contour 20 kts.

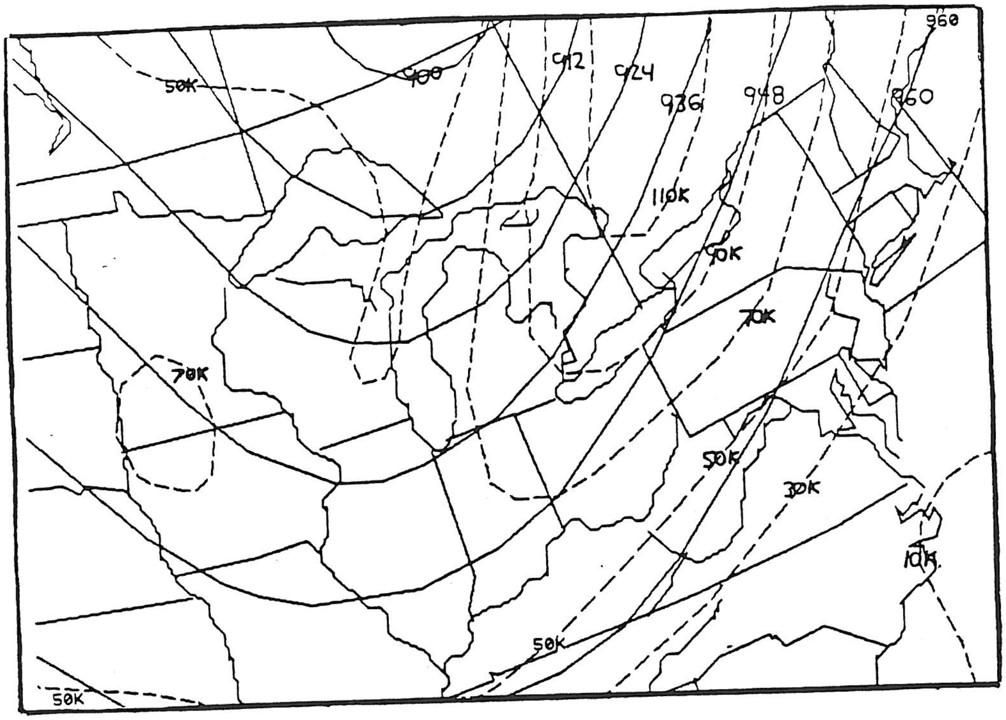
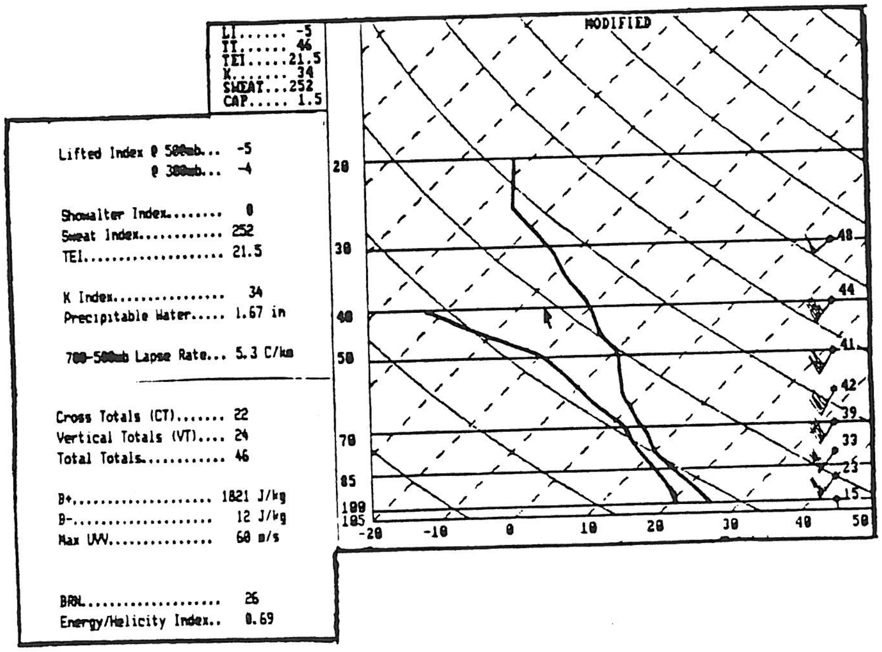


Figure 15. Sept 11, 1992 0000 UTC 300 mb analysis. Height contour 120 gpm, isotach contour 20 kts.



LI...... -5
TT...... 46
TEI.....21.5
K....... 34
SWEAT...252
CAP..... 1.5

Lifted Index @ 500mb... -5
@ 300mb... -4

Showalter Index........ 0
Sweat Index............ 252
TEI.................... 21.5

K Index................ 34
Precipitable Water..... 1.67 in

700-500mb Lapse Rate... 5.3 C/km

Cross Totals (CT)....... 22
Vertical Totals (VT).... 24
Total Totals............ 46

B+..................... 1821 J/kg
B-..................... 12 J/kg
Max UVV................ 60 m/s

BRN.................... 26
Energy/Helicity Index.. 0.69

Figure 16. 1800 UTC estimated sounding using SHARP for Williamsport, PA., Sept. 10, 1992.