AN EXAMINATION OF LOW CAPE/HIGH SHEAR SEVERE CONVECTIVE EVENTS IN THE BINGHAMTON, NEW YORK COUNTY WARNING AREA

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Abstract

A dataset of central New York and northeast Pennsylvania severe weather and flash flood events occurring in environments characterized by small mixed-layer convective available potential energy (MLCAPE) and large 0-6 km bulk shear was examined for the period from 2003 to 2009. A local study of these events is presented, and results from research to discriminate between high-impact and low-impact severe events are shown.

Results from the study indicate that low MLCAPE / high 0-6 km shear (LCHS) events were most often associated with a small number of severe weather and/or flash flood reports. However a subset of more significant LCHS events was identified. These LCHS events most often occurred during the afternoon or evening, and were most often associated with damaging winds. The majority of events occurred during the cool season, though several warm-season events were also identified. High-impact, cool-season events were mostly associated with lines of convection, while the majority of warm-season high-impact events were associated with isolated cells. LCHS events associated with flash flooding tended to be associated with smaller low-level lapse rates, smaller dewpoint depressions and smaller 500-hPa height falls than events that were associated with severe weather, but no flash flooding.

High-impact, warm-season severe events typically occurred in environments characterized by steep low-level lapse rates, deep layers of dry air, and a strong, west-northwest flow aloft. By contrast, most of those characteristics were not found to correlate significantly with number of severe reports during the cool season. Cool-season parameters that exhibited the highest correlation with the number of severe reports were mainly related to wind speed and 12-h 500-hPa geopotential height falls, indicating that the strength and speed of eastward progression of the synoptic-scale forcing is critical for producing major LCHS events during the cool season.

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1. Introduction

The possibility that convective storm structure depends at least partially on the ratio between environmental buoyancy and shear was investigated by Weisman and Klemp (1982), by varying environmental convective available potential energy (CAPE) and deep-layer (0-6 km) shear in an idealized, three-dimensional numerical cloud model. They concluded that storm structure may be dependent on the ratio between CAPE and shear, with large CAPE/shear ratios favoring multicell storms, while smaller ratios favor supercells. The importance of the ratio between CAPE and shear for maintaining severe convective squall lines was subsequently examined in additional, idealized modeling studies, including Rotunno et al. (1988), and Weisman (1992, 1993). These studies indicated that long-lived, convective squall lines are favored in environments where the circulation associated with the storm's cold pool is balanced by the circulation associated with the lower-tropospheric wind shear. Environments with large CAPE and large low-level shear directed perpendicular to the squall line were found to be most favorable for establishing this balance. The resulting structure of convective storms that form in these types of environments promotes strong, persistent lifting on the leading edge of the cold pool, and is also favorable for the development of features that have been observed with damaging winds, such as rear-inflow jets and bookend vortices.

Several subsequent observational studies have also indicated that a substantial subset of well-organized convective storms associated with severe weather occur with large values of CAPE and deep-layer shear. For example, Johns and Hirt (1987) found that warm-season, severe weather-producing derechos typically occur with high values of both CAPE and wind speed. Lapenta et al. (2002) examined the ratio between CAPE and shear for a large collection of storms over the northeast U.S., and found that most "major" severe weather events occurred when both CAPE and shear were large. Cohen et al. (2007) also found that the magnitude of the CAPE and shear, particularly the component of shear perpendicular to the squall line, both correlate strongly to the ability of mesoscale convective systems to produce strong winds.

The aforementioned studies imply an apparent relationship between large CAPE, large shear, and the likelihood of severe weather for a subset of convective event types; however, several other observational studies have indicated that significant severe weather events can occur in a wide range of CAPE and shear environments. For example, Evans and Doswell (2001) examined a collection of severe weather-producing derechos using a dataset of events that occurred during both the warm and cool seasons, and found that these systems occur in a wider range of CAPE/shear environments than what had been suggested by numerical simulations. Specifically, a subset of severe, cool-season derechos was identified that occurred in environments characterized by strong synoptic-scale forcing that developed and persisted in environments with almost no CAPE evident on nearby upper-air soundings. Schneider et al. (2006) and Schneider and Dean (2008) examined mixed-layer CAPE (MLCAPE) and deep-layer shear associated with over 100,000 severe weather reports, and found a wide range of values supportive of all types of severe weather occurrences. More specifically, their work indicated that tornadoes, large hail and significant wind events can occur over very wide ranges of MLCAPE, with large percentages of those events associated with MLCAPE values of less than 1000 J kg^{-1}. Their results did imply some minimum severe-weather thresholds for shear. However there was no indication of a ratio between MLCAPE and deep-layer shear that was favorable for severe weather; in fact environments with low MLCAPE and large deep-layer shear were very frequently associated with tornadoes, large hail and damaging winds.

The observation that significant, severe weather-producing convective storms can occur in environments lacking large CAPE has particular significance in the northeast U.S., since large CAPE values are less frequent in this region than over the central U.S. (Schneider and Dean 2008; Brooks et al. 2003). As a result, forecasters in the northeast U.S. are frequently tasked with diagnosing the potential for severe storms in environments characterized by modest CAPE.

This study will focus on convective storms in environments characterized by low CAPE and high shear. First, a large collection of severe weather and flash flood events that occurred in central New York and northeast Pennsylvania during the period from 2003 – 2009 will be identified. The MLCAPE and deep-layer bulk shear associated with these events will be documented, in order to develop a database of MLCAPE and shear for severe weather and flash flood events in our area. Next, a threshold for "low CAPE / high shear" (LCHS) events will be defined, while the remainder of the study will focus on LCHS events. Moreover, the principal goals of this research are twofold: 1) document the occurrence of LCHS events in central New York and northeast Pennsylvania from 2003 through 2009, and 2) provide insights that allow forecasters to better anticipate and differentiate low-impact vs. high-impact LCHS events.

Section 2 describes the methodology of the study. Section 3 describes the results of the study of LCHS convective events in central New York and northeast Pennsylvania. Section 4 describes some factors that may be used to allow forecasters to anticipate low-impact vs. high-impact events. Section 5 shows two case studies, and section 6 contains a brief summary and discussion.

2. Methodology

The study utilized a locally-developed database comprised of data from 159 days when severe weather and/or convective flash flooding was reported in the National Weather Service Forecast Office (NWSFO) Binghamton (BGM) county warning area (CWA), during the period from 2003-2009. The 159 days represented approximately 80 percent of the total number of severe weather days in the CWA during that time, and approximately 50 percent of the flash flooding days. Events missing from the database were generally minor events that were not always archived, especially prior to 2006. As a result, days with a small number of flash flooding and/or severe reports were likely slightly underrepresented in the database (i.e. most of the missing days were likely days with a small number of severe and/or flash flood reports). The database included 13 events with no severe reports; these were events when the only reports were those of hail with diameters of ¾ of an inch to less than one inch, which was considered severe in the Eastern Region of the National Weather Service (NWS) prior to 2010. The number of severe weather reports in the database based on current NWS severe weather thresholds (hail greater than or equal to one inch in diameter, wind gusts of 50 kt or more, and/or tornadoes) and flash flood reports on these days ranged from zero to 49.

For each day in the dataset, several model forecast soundings were viewed, and a single sounding was chosen as a representative proximity sounding for the event. During the period from 2006-2009, forecasts from the 13-km Rapid Update Cycle (RUC; Benjamin et al. 2004) model were used. During the period from 2003-200, RUC data were not archived locally; therefore, data from the 12-km North American Mesoscale (NAM; Rogers et al. 2001) were used. In order to test whether the change from the NAM to the RUC may have introduced some biases to the dataset, data from the NAM and RUC for 16 events with MLCAPE less than 750 J kg^{-1} from 2006 (the first year when both datasets were locally available) were compared. Direct comparisons from each event between the RUC proximity sounding and the sounding that would have been the proximity sounding, if NAM data were used, produced a median absolute value of 105 J kg^{-1} (NAM – RUC MLCAPE), with a median absolute deviation of 86 J kg^{-1} (Hoaglin et al. 1983). The median value for NAM – RUC MLCAPE was +79 J kg^{-1}, indicating a small high bias for the NAM vs. the RUC. The median absolute value of the NAM - RUC deep-layer shear was 5.0 kt, with a median absolute deviation of 5.0 kt. The median of the NAM – RUC deep-layer shear was 0, indicating no bias in the shear for the NAM vs. RUC. These results indicate that no substantial biases were introduced by changing from the NAM to the RUC between 2005 and 2006. It should also be noted that the horizontal resolution of the RUC changed from 20 km to 13 km in 2005; therefore, some discontinuity in the data for this study would have occurred even if RUC data had been utilized during the entire study period. Thompson and Edwards (2000) compared data from analysis and 1-h RUC-2 forecast soundings with data from observed soundings, and concluded that the accuracy of those soundings was sufficient to allow for their use as severe weather proximity soundings, despite a tendency for the model to slightly underestimate CAPE and bulk shear. Subsequently, numerous studies on environments associated with severe weather have utilized RUC soundings, including Thompson et al. (2003, 2007) and Davies (2004).

The procedure used to select the proximity sounding for each event was as follows. For each day, BUFKIT (a software application toolkit; Mahoney and Niziol 1997) was utilized to view hourly forecast soundings from BUFR data, at grid points closest to Syracuse (SYR), Ithaca (ITH), Binghamton (BGM), Elmira (ELM), and Utica (UCA) in central New York, and Avoca (AVP) in northeast Pennsylvania, valid at times ranging from several hours prior to the event to the occurrence of the event. BUFR data is grid point data with native model horizontal and vertical resolution: 12-km horizontal resolution and 60 vertical layers for data from the NAM and 13-km horizontal resolution with 50 vertical layers from the RUC. Forecast points that were not within at least 100 km of the severe or flash flood-producing convection were eliminated from consideration. Forecast lead times were mostly 0 to 6 hours, with 6- to 12-h forecasts utilized in a few cases due to missing data. The single proximity sounding for the event was the sounding from this group with the highest MLCAPE, which typically occurred just prior to the triggering of the deep convective scheme in the model. The methodology of choosing the sounding with the largest MLCAPE was based on the hypothesis that enhanced low-level convergence typically causes moisture pooling and a CAPE maximum in areas where significant convection occurs. Shear was not a factor in choosing the proximity soundings, since shear typically does not vary as widely as CAPE in model forecasts across areas the size of the BGM CWA.

Once a proximity sounding was selected for each severe weather event, a database was constructed consisting of parameters from each sounding. The thermodynamic parameters were calculated by BUFKIT software, with MLCAPE calculated from a surface-based mixed layer 500 m deep. The 0-6 km bulk shear values were derived by examining plots displayed on NWS Advanced Weather Interactive Processing System (AWIPS) workstations. The database also included the number of severe and flash flood reports from the BGM CWA for each day, derived from local storm reports issued by NWSFO BGM.

In order to further examine characteristics associated with these events, the database also included the type of surface weather pattern and the predominant type of radar reflectivity signature associated with each severe weather day. The types of weather patterns were sub-divided into three categories: 1) progressive cold fronts, 2) warm or stationary fronts, and 3) weak or other. The types of radar reflectivity signatures were also sub-divided into three categories: 1) lines, 2) isolated cells and 3) clusters. Many events featured more than one type of reflectivity pattern; in those cases the reflectivity type for the event was assigned subjectively, based on the predominant storm type indicated from radar reflectivity animations, at the time of the majority of severe or flash flood reports.

A scatter diagram of MLCAPE and 0-6 km shear for all of the events in the database, differentiated by number of severe plus flash flood reports, indicates a wide range of deep-layer shear and MLCAPE values supportive of severe weather and/or flash flooding in central New York and northeast Pennsylvania (Fig. 1a). The data also indicate that the majority of events associated with 15 or more reports were associated with large MLCAPE and/or large 0-6 km shear. The black line on the diagram was drawn subjectively to define a threshold below which there were no events observed with 15 or more reports. The location and orientation of the black line indicates that events associated with 15 or more reports were not associated with environments characterized by low MLCAPE and low shear (located in the lower left portion of the diagram). However, several of these events were associated with LCHS (located in the lower right portion of the diagram).

A scatter diagram (Fig. 1b) showing MLCAPE and 0-6 km shear for all of the events in the database, differentiated by season of occurrence (i.e., red diamond for warm season; blue square for cool season) indicates

Fig. 1(a).

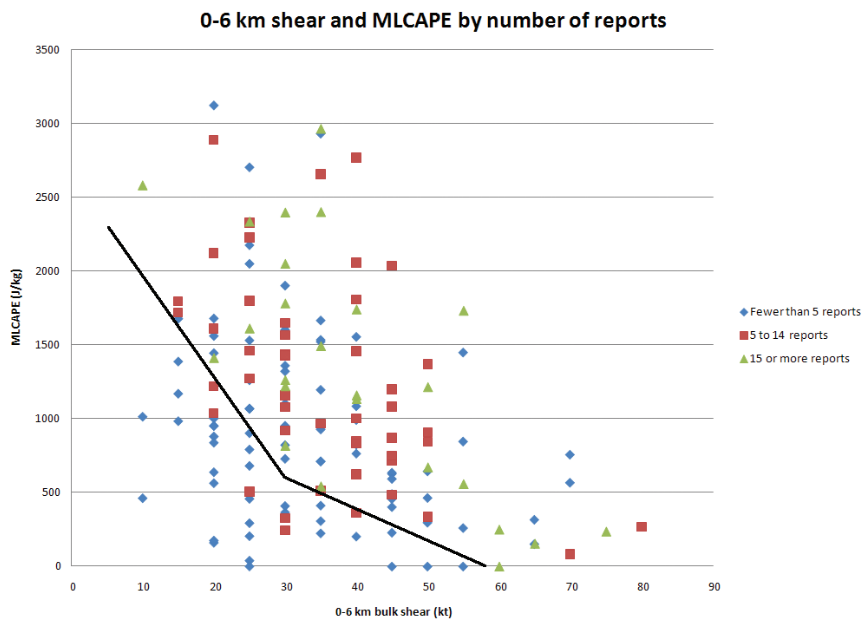

Fig. 1(b).

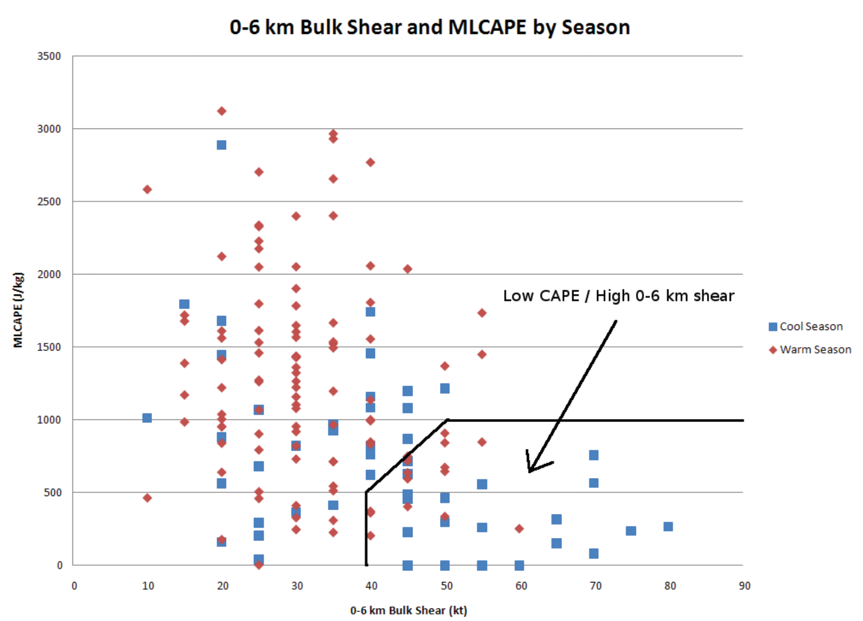

Fig. 1. (a) MLCAPE (J kg^{-1}) and 0-6 km shear (kt) for the severe weather and flash flood events in the database. Events that occurred with 15 or more severe plus flash flood reports are denoted as green triangles; events that occurred with five to 14 reports are denoted as red squares; and events that occurred with fewer than five reports are denoted as blue diamonds. The thick black line marks a threshold below which no events with 15 or more reports occurred. (b) Same as (a) except that events that occurred during the warm season (June – August) are denoted as red diamonds, and events that occurred during the cool season (September – May) are denoted as blue squares. The thick black line marks a subjectively determined threshold for low MLCAPE high shear events defined in this study.

that most of the events occurred during the warm season, defined as June through August. The majority of LCHS events occurred during the cool season (September through May); however, several warm-season LCHS events were also identified. Thresholds of MLCAPE and 0-6 km shear used to define LCHS events were determined subjectively by partitioning the data shown in Figs.1a-b. Those events falling in approximately the lower-right quarter of the scatter diagram chart denote the LCHS events. The black line in Fig. 1b marks the threshold with the 38 events located below and to the right of the line defined as LCHS events. These 38 events will be examined in more detail in the rest of this study.

3. Results

Characteristics of the 38 LCHS events in this study are summarized in Tables 1-6. While the majority of LCHS events occurred during the cool season (September to May), a substantial number of events occurred during the warm season (15 out of 38; Table 1). This finding was in contrast to the seasonal distribution of severe and flash flood events from the entire database (Fig. 1a), which indicated that a majority of those events occurred during the warm season (107 out of 159). The majority of warm-season LCHS events occurred primarily during the afternoon through evening (12 out of 15; Table 2). Cool-season events were also more likely to occur during the afternoon and evening; however this diurnal trend was not quite as pronounced as during the warm season (15 out of 23; Table 2). The diurnal signal for events with more than 15 severe plus flash flood reports was stronger than for all events (5 of 6 events with more than 15 reports occurred during the afternoon or evening, compared to 27 out of 38 afternoon or evening events from the entire LCHS dataset). The majority of LCHS events were minor (fewer than five severe plus flash flood reports) in both the warm and cool seasons. However 16 events were identified with five or more reports and six events were identified with more than 15 reports (Table 3). While the majority of the reports associated with LCHS events were reports of high wind, large hail, and flash flooding, even tornadoes have occasionally been observed with these events (Table 4; recall that flash flooding events are somewhat underrepresented in the study).

The characteristics of the reflectivity patterns associated with the LCHS events in this study are summarized in Table 5. Overall, lines were the most common type of observed reflectivity pattern, followed by isolated cells and clusters. Lines were the predominant type of reflectivity during cool-season events, regardless of the number of severe plus flash flood reports (15 out of 23 events). Warm-season minor events (fewer than five severe plus flash flood reports) were also mainly associated with lines (six out of eight events), however, isolated cells were the main type of reflectivity during warm-season major events (five or more severe plus flash

Cool Season (September – May)	23
Warm Season (June - August)	15

Table 1. Number of low CAPE high shear (LCHS) events by time of year.

	Warm Season less than 5 reports	Cool Season less than 5 reports	Warm Season 5 or more reports	Cool Season 5 reports or more reports	Warm Season more than 15 reports	Cool Season more than 15 reports
05z - 15z	1	5	2	3	0	1
15z - 05z	7	9	5	6	2	3

Table 2. Number of LCHS events by time of day and number of reports. Statistics from events when the majority of reports occurred from 05 UTC through 15 UTC are shown in the first row, and statistics from events when the majority of reports occurred after 15 UTC to 05 UTC are shown in the second row. Note that events with more than 15 reports (both warm and cool season) are subsets from the larger number of events showing 5 or more reports.

Less than 5 reports	22
5 to 15 reports	10
More than 15 reports	6

Table 3. Number of LCHS events by number of severe plus flash flood reports.

Flash flood reports	38
Severe wind reports (>50 kt)	203
Large hail (≥1” diameter)	35
Tornadoes	9

Table 4. Number of severe weather reports by type of report.

flood reports; four out of seven events). The strong shear associated with these events resulted in at least some rotation with most of the isolated cells (as determined by WSR-88D storm-relative motion animations), indicating the development of supercells in many of these instances.

The characteristics of the weather patterns associated with the LCHS events in this study are summarized in Table 6. Progressive cold fronts were the primary surface weather pattern category, particularly during the cool season when 16 of 23 events were associated with progressive cold fronts. Cool-season events with five or more reports were even more dominated by progressive cold fronts (eight out of nine events). Just over half of the warm-season events were associated with progressive cold fronts (8 out of 15 events), with the second most common category being "other" (4 out of 15 events). The "other" events occurred with strong flow aloft, but were well to the south and / or east of synoptic-scale frontal boundaries.

A comparison of the characteristics of LCHS events associated with flash flooding (nine events) vs. events that were not associated with flash flooding (29 events) is shown in Table 7. The non-flash flood events were found to be associated with stronger 500-hPa 12-h height falls, steeper low-level lapse rates, and larger dewpoint depressions. The differences in the mean values of these

	Warm Season less than 5 reports	Cool Season less than 5 reports	Warm Season 5 or more reports	Cool Season 5 or more reports
Lines	6	8	2	7
Isolated Cells	0	4	4	2
Clusters	2	2	1	0

Table 5. Number of LCHS events by dominant reflectivity type. Number of reports include flash flood and severe reports.

	Warm Season less than 5 reports	Cool Season less than 5 reports	Warm Season 5 or more reports	Cool Season 5 or more reports
Progressive Cold Fronts	4	8	4	8
Warm / Stationary Fronts	1	3	2	1
Weak / Other	3	3	1	0

Table 6. Number of LCHS events by pattern type.

	Max Tdd sfc – 700 hPa	Max Tdd 700-500 hPa	Sfc-700 hPa Lapse Rate	500-hPa 12-h Ht falls	Progressive cold fronts / all forcing types	Lines / all reflectivity types
Flash Floods (9 events)	**3.9(3.5)**	**4.8(2.0)**	**5.8(5.8)**	**18(10)**	3 / 9	4 / 9
No Flash Floods (29 events)	**6.6(6.0)**	**10.0(7.0)**	**7.0(7.0)**	**55(50)**	21 / 29	19 / 29

Table 7. Mean (median) values of several parameters associated with LCHS events that included flash flooding (second row) and events that did not include flash flooding (third row). Parameters shown from left to right: maximum dewpoint depression between the surface and 700 hPa (° C), maximum dewpoint depression between 700 hPa and 500 hPa (° C), lapse rate from the surface to 700 hPa (°C km^{-1}), 500-hPa geopotential height falls [m $(12\ h)^{-1}$], ratio between progressive cold fronts and all forcing types, and ratio between convective lines and all reflectivity types. Mean values associated with flooding events that are statistically significantly different than corresponding mean values associated with non-flooding events are displayed in bold font.

parameters between the flood and non-flood events were found to be significant at the 0.90 level using a Kruskal-Wallis statistical test (Gibbons 1976). Non-flash flood events were also much more likely to be associated with progressive cold fronts and lines of convection than flash flood events.

4. High-Impact vs. Low-Impact Severe Events

In order to study differences in the environments associated with high-impact LCHS severe events vs. low-impact LCHS severe events, high-impact events were defined as events associated with five or more severe weather reports, while low-impact events were defined as events associated with fewer than five severe weather reports. Flash flooding reports were included in the first half of the study to demonstrate that flash flooding can occur with LCHS events; however flash flooding reports were not included in this part of the study, since sounding characteristics of flash flood events are fundamentally different than characteristics associated with severe weather. Therefore, including both flash flood and severe reports in this part of the study would only serve to confuse the results. Flash flood events were not studied separately, as there were not enough flash flood events in the database to yield statistically meaningful results. In order to study differences associated with warm-season vs. cool-season events, characteristics of high-impact vs. low-impact events were examined within three datasets: one dataset contained all 38 LCHS events; the second dataset contained the 15 warm-season events; and the third dataset contained the 23 cool-season events. Some of the differences in the environmental parameters associated with "low-impact" vs. "high-impact" events for the entire database, as well as by season, are summarized in Table 8.

For each of the three datasets, Table 8 lists the average value of each meteorological parameter for low- and high-impact events, followed by the correlation coefficient between the value of the meteorological parameter and the number of severe reports. Statistically significant correlations are displayed in bold font. The correlation statistic used in the study was the Spearman coefficient of rank statistic, since the data in this study were not normally distributed, and the number of reports was a non-continuous variable (Gibbons 1976). A confidence level of 0.95 was used to determine the significance threshold for the correlation statistic. Correlations above the threshold implied a statistically significant relationship between the meteorological parameter and the number of severe reports in the study, indicating that the apparent correlation did not occur by chance, and that a real relationship exists between the parameter and the number of reports.

The number of severe reports was positively correlated to both the 0-6 km maximum wind speed

	Average Values All Events (correlation with number of reports)		Average Values Warm Season Events (correlation with number of reports)		Average Values Cool Season Events (correlation with number of reports)	
0-6 km max wind speed (kt)	54 / 71	**(0.51)**	49 / 53	(0.45)	58 / 84	**(0.67)**
0-6 km bulk shear (kt)	50 / 58	**(0.54)**	45 / 51	**(0.50)**	54 / 63	**(0.55)**
MLCAPE (J kg^{-1})	408/423	(0.07)	530/627	(0.09)	330/287	(0.14)
0-3 km CAPE (J kg^{-1})	83 / 83	**(0.29)**	106 / 109	(0.14)	69 / 66	(0.33)
1000-700 hPa lapse rate (°C km^{-1})	6.5 / 7.2	**(0.42)**	6.0 / 7.9	**(0.82)**	6.7 / 6.6	(0.07)
700-500 hPa max Tdd (°C)	8.2 / 9.9	(0.22)	3.0 /13.0	**(0.75)**	11.6/7.5	(-0.21)
Sfc – 700 hPa max Tdd (°C)	5.8/ 6.3	(0.17)	3.2 / 9.2	**(0.83)**	7.5 / 4.1	(-0.28)
3-km wind direction (°)	232/252	(0.12)	234/271	**(0.60)**	249/238	(-0.19)
12- hr 500- hPa height falls (m)	39 / 57	**(0.41)**	13 / 22	(0.44)	56 / 81	**(0.46)**

Table 8. Average values of environmental parameters for low impact (fewer than 5 reports) / high impact (5 or more reports) events and (Spearman correlation coefficients between the parameter values and number of reports). Data is for all 38 LCHS events in column 2, the 15 warm-season events in column 3, and the 23 cool-season events in column 4.

and the 0-6 km bulk shear, in all three datasets. The correlations between number of reports and 0-6 km maximum wind speed were only statistically significant in the datasets containing all LCHS events, and the dataset containing only cool-season events. The correlations between number of reports and 0-6 km bulk shear were found to be statistically significant in all three datasets.

The magnitude of the MLCAPE exhibited a very small (insignificant) correlation to number of severe reports in all three datasets. The magnitude of the 0-3 km (low-level) CAPE exhibited somewhat higher but still rather weak correlations, with a statistically significant positive correlation indicated for the dataset containing all of the events. Meanwhile, the 1000-700 hPa lapse rate exhibited a statistically significant correlation of 0.82 with number of severe reports during the warm season, and a much lower, insignificant correlation during the cool season. One explanation for the fact that the low-level lapse rate appeared to correlate much more strongly to number of severe reports in the warm season than low-level CAPE is that the high-impact warm-season events tended to be associated with significant dry layers in the lower troposphere. Specifically, both the surface-700 hPa and 700-500 hPa maximum dewpoint depressions had relatively high correlations (0.83 and 0.75 respectively) with number of severe weather reports during the warm season. The dry air at low levels in those cases would sometimes result in reduced low-level MLCAPE values (when the dry air was in the boundary layer). Dry air and steep low-level lapse rates are suggestive of strong cold pools, which may be necessary to balance strong environmental shear, especially during the warm season when large-scale dynamical forcing may be limited. In addition, midlevel dry air is indicative of potential instability, which would be realized locally in cases where convective storms develop. Meanwhile, much weaker correlations were found between the number of severe weather reports and low-level lapse rate during the cool season, and weak, negative correlations were found between number of severe weather reports and dewpoint depression. This indicates that cold pool strength or the release of potential instability may be less of a factor during the cool season, when strong large-scale dynamical forcing for upward motion can act to maintain convection in an environment characterized by weak, mainly elevated instability, but lacking an optimal balance between low-level cold pool circulations and low-level environmental shear.

Another parameter that appears to behave differently between the warm and cool seasons is the 3-km wind direction. During the warm season, a significant, positive correlation was found between number of severe reports and 3-km wind direction, implying that a westerly flow at mid-levels is more favorable for severe weather than a southwesterly flow. This finding is related to the observation that such flows frequently bring dry air and steep lapse rates into the area from the Northern Plains during the summer (Ekster and Banacos 2010). Meanwhile, only a small, negative correlation was found between 3-km wind direction and the number of severe weather reports during the cool season.

In order to test the hypothesis that strong dynamical forcing is critical for producing major severe weather events in LCHS environments, especially during the cool season, 12-h 500-hPa geopotential height tendency was calculated for each event in the database, based on data derived from archived upper-air maps from the Storm Prediction Center (available online at http://www.spc.noaa.gov/obswx/maps/). Modest, yet positive, statistically significant correlations were found between 500-hPa geopotential height falls and observed number of severe reports in both the full and cool-season datasets. The correlation during the warm season was also positive, but was small enough so as to not be statistically significant.

Composite analysis (available online at http://www.cdc.noaa.gov/data/composites/hour/, and derived from the National Center for Environmental Prediction/National Center for Atmospheric Research Global Reanalysis data) of environments associated with low-impact vs. high-impact events during the warm season indicated a westerly flow aloft during the high-impact events, compared to a southwesterly flow for the low-impact events (Figs. 2a-b). The mean position of the 500-hPa trough was farther east for the high-impact events. Composite analysis of low-impact vs. high-impact events during the cool season indicated strong 500-hPa troughs with their axes over the central Great Lakes for both types, with deeper troughs during the major events (Figs. 2c-d).

5. Case Study Examples

In this section, two case studies are shown to illustrate some of the findings from sections 3 and 4. Low- and high-impact cases were chosen to highlight the differences between the environments of each event type.

a. *21 June 2007*

The flow pattern on 21 June 2007 was characterized by a northwest flow across Ontario and the northeast U.S., with a surface cold front (not denoted) moving southeastward across the eastern Great Lakes and a pre-frontal surface trough extending from central New England to northeast Pennsylvania (Figs. 3a-d). A short wave trough moving southeast from southern Canada toward New England was associated with moderately strong 500-hPa height falls (approximately 50 gpm over central New York) during the 12-h period from 1200 UTC 21 June to 0000 UTC 22 June. The RUC 3-h forecast valid at 2100 UTC 21 June 2007 (Fig. 4) indicated a large area characterized by 45-55 kt of deep-layer shear across upstate New York and northern Pennsylvania. MLCAPE values across that area ranged from 400 to 700 J kg^{-1}. The 1-h RUC forecast sounding for SYR valid at 1900 UTC 21 June (the time when the MLCAPE was maximized at the onset of model convection) indicated a weakly veering profile from the surface through 700 hPa, with wind speeds increasing from around 5 kt at the surface to around 40 kt at 700 hPa. From 700 hPa to 400 hPa, the flow was nearly unidirectional, with wind speeds increasing from 40 kt to 78 kt. The 1000-700 hPa lapse rate was forecast to be in excess of 8.0° C km^{-1}, and substantial dry layers can be seen near the surface and around 500 hPa (Fig. 5a). The 1800 UTC 21 June 2007 BUF observed sounding (Fig. 5b) also indicated a strongly sheared wind profile, culminating in a 70-kt northwesterly flow at 400 hPa, along with steep lapse rates and a dry layer extending through a deep layer of the troposphere. Geostationary Operational Environmental Satellite (GOES) visible satellite imagery animations (not shown) indicated scattered cloud cover across upstate New York, just prior to the onset of convection early in the afternoon.

In summary, this event matched the profile of a high-impact, warm-season LCHS event: 1) 12-h 500-hPa height falls were moderately strong, 2) low-level lapse rates were steep, 3) a deep layer characterized by low relative humidity was evident on area model and observed soundings, as well as GOES water vapor satellite imagery, and 4) the midlevel flow was from the northwest with a

Continued page 140

Fig. 2(a).

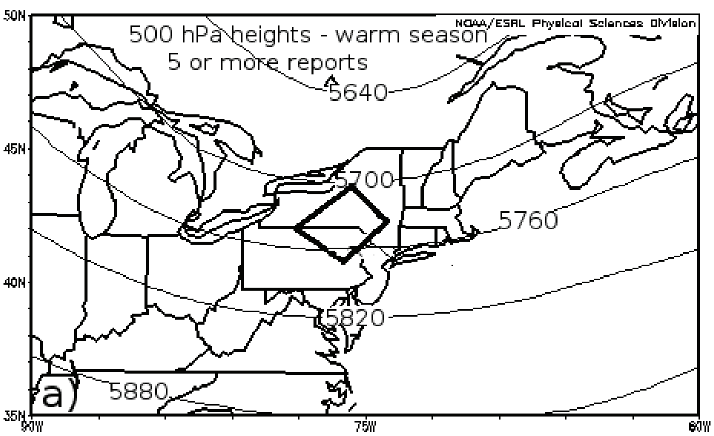

Fig. 2(c).

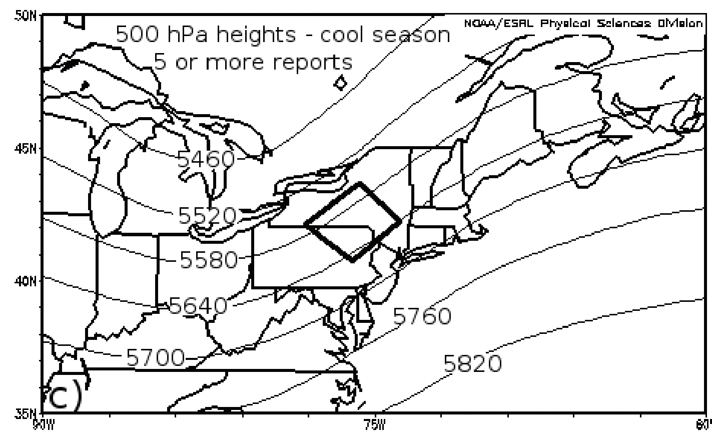

Fig. 2(b).

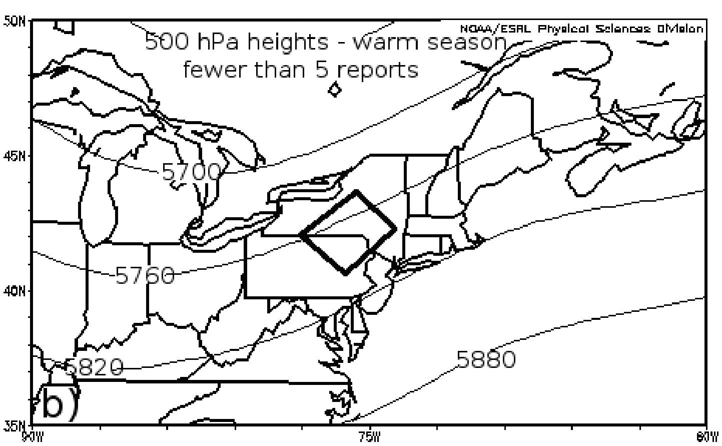

Fig. 2(d).

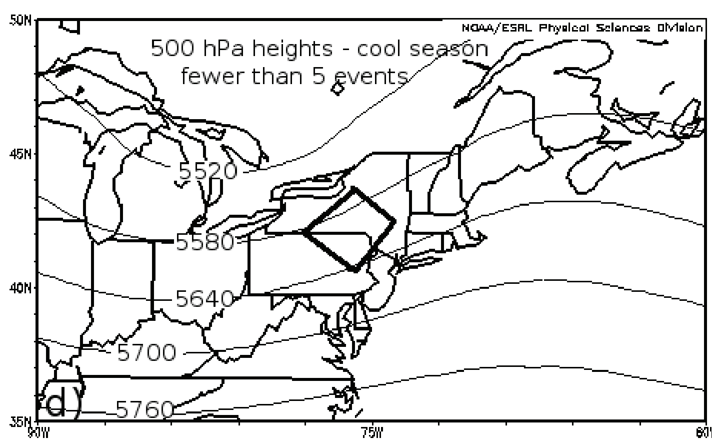

Fig. 2. Composite analysis of 500-hPa geopotential heights (gpm) from NCEP/NCAR reanalysis data for: (a) warm-season LCHS events that occurred with five or more reports (six events); (b) warm-season LCHS events with fewer than five reports (nine events); (c) cool-season events with five or more reports (nine events) and (d) cool-season events with fewer than five reports (14 events).

Fig. 3(a).

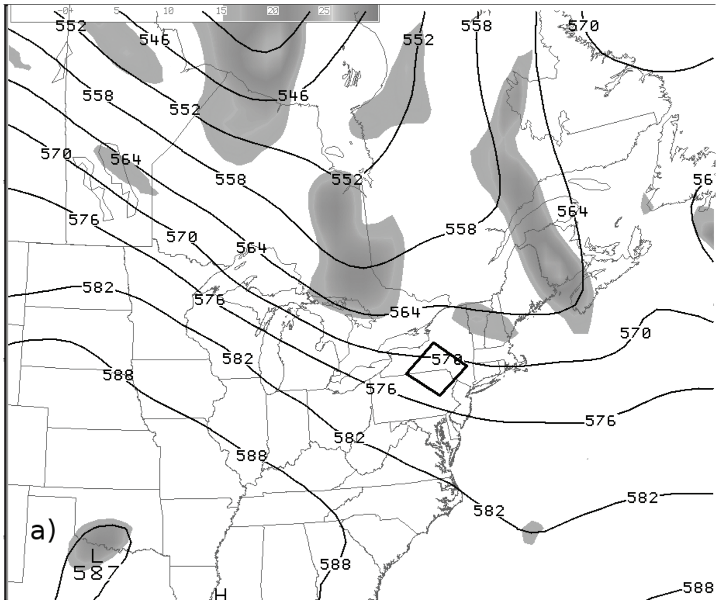

Fig. 3(c).

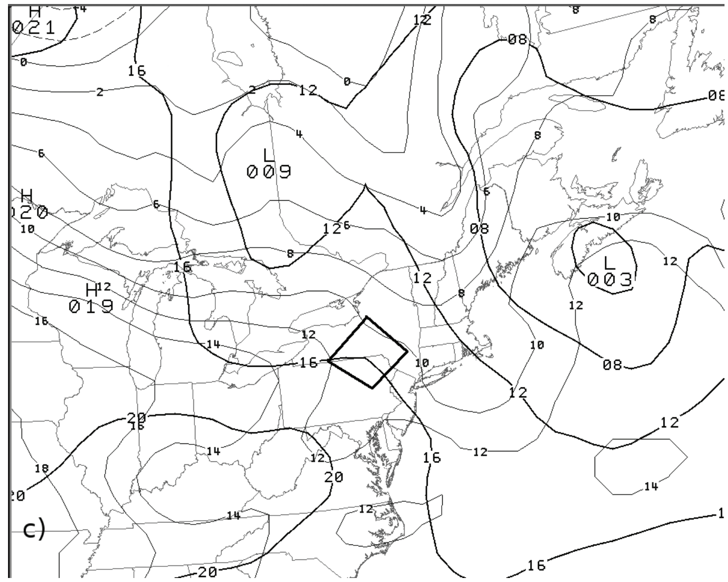

Fig. 3(b).

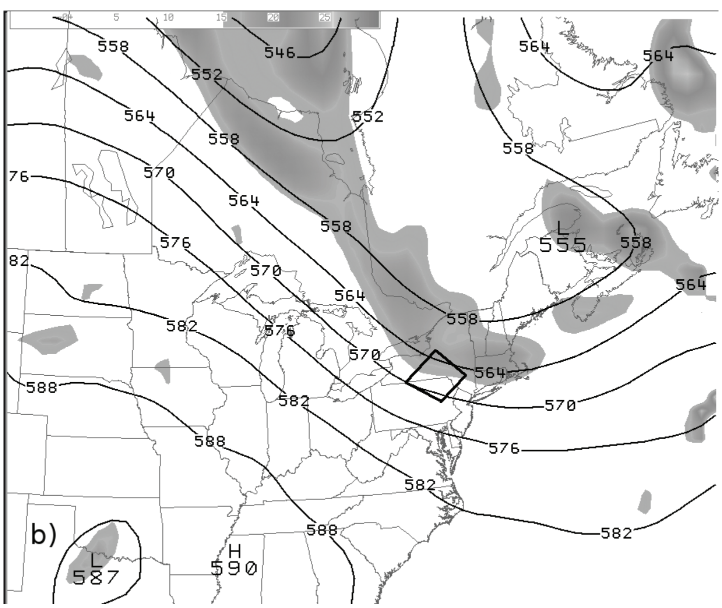

Fig. 3(d).

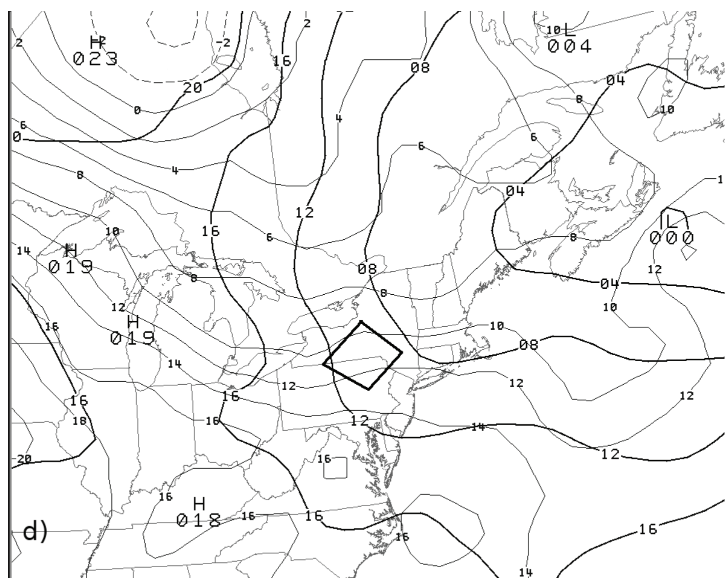

Fig. 3. Analysis and forecast fields as initialized by the 1200 UTC 21 June 2007 NAM model. (a) 500-hPa geopotential heights (solid, dkm) and absolute vorticity (shading > 15 x 10^{-5} s^{-1}) valid at 1200 UTC 21 June 2007; (b) as in (a), but valid at 0000 UTC 22 June 2007; (c) sea-level pressure (heavy solid, hPa) and 850-hPa temperature (thin solid, ° C) valid at 1200 UTC 21 June 2007; (d) as in c), but valid at 0000 UTC 22 June 2007. The rectangular box marks the approximate location of the BGM CWA.

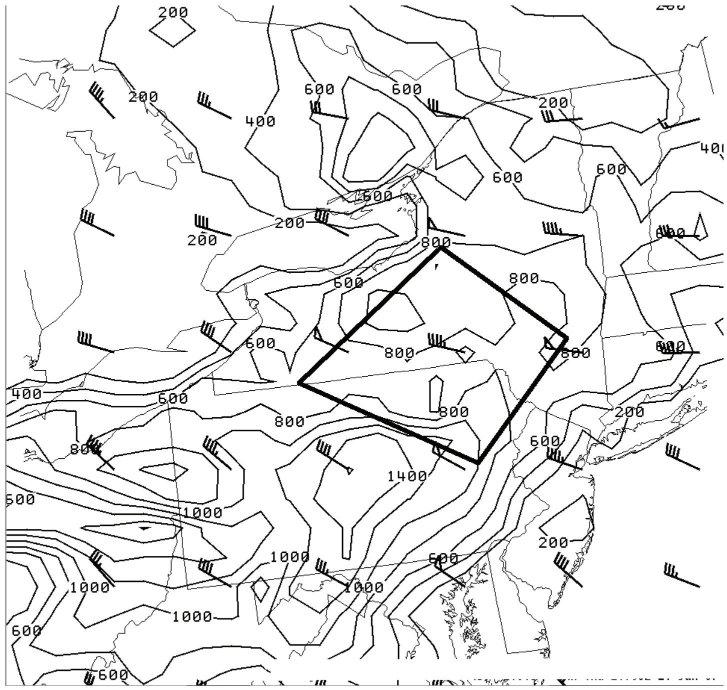

Fig. 4. 3-h RUC forecast 0-6 km bulk shear (kt) and MLCAPE (J kg^{-1}), valid at 2100 UTC 21 June 2007. The rectangular box marks the approximate location of the BGM CWA.

Fig. 5(a).

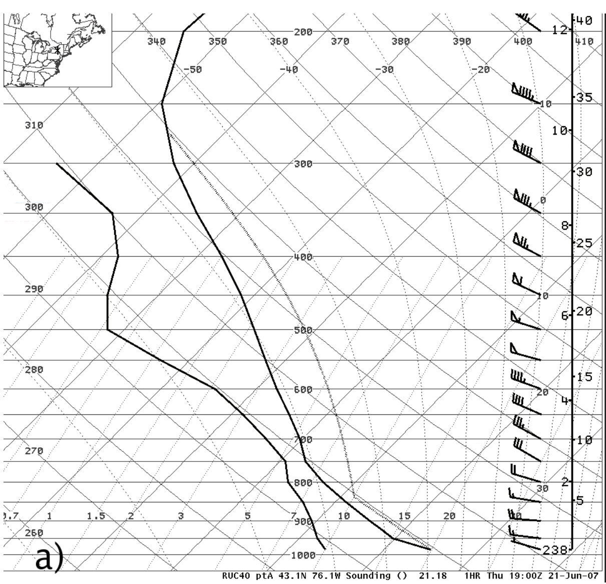

Fig. 5(b).

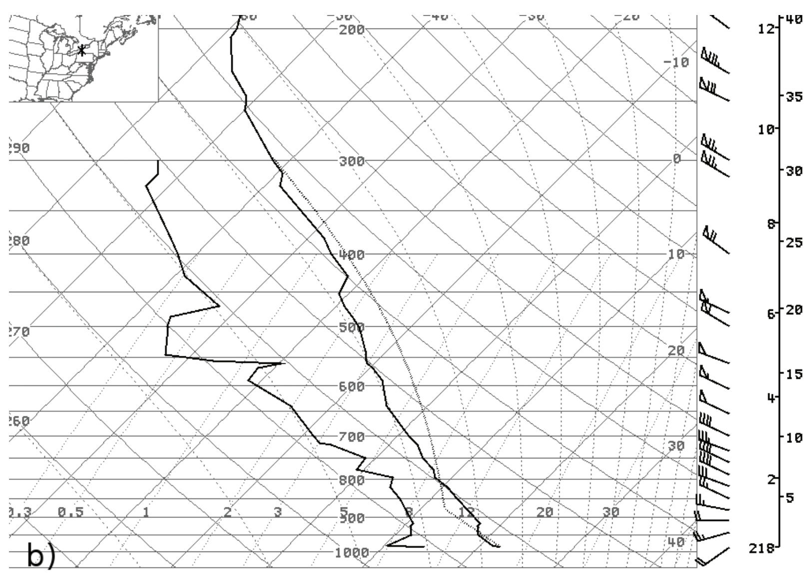

Fig. 5. (a) 1-h RUC model forecast sounding at SYR, valid at 1900 UTC 21 June 2007. (b) 1800 UTC June 21 2007 observed sounding at Buffalo, NY.

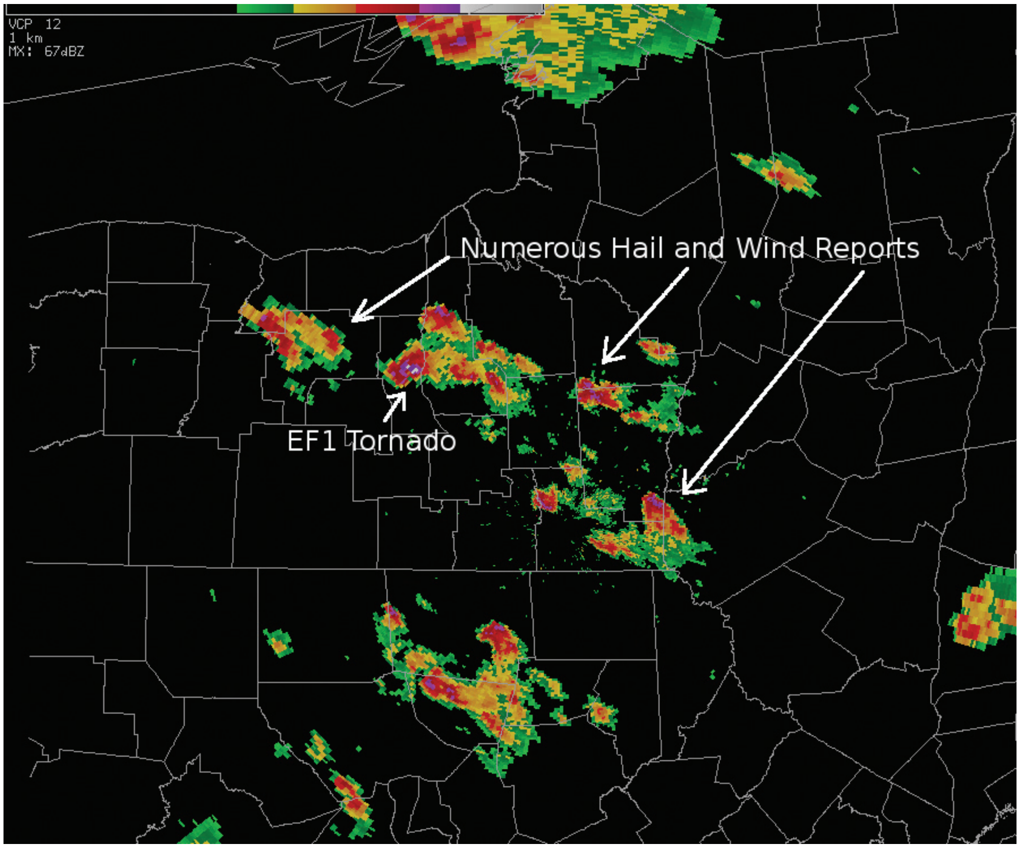

Fig. 6. KBGM 0.5° base reflectivity image at 1932 UTC 21 June 2007.

maximum wind speed below 6 km of 55 kt. This event produced an outbreak of small supercell thunderstorms across central New York with 24 severe weather reports: 18 reports of large hail, five reports of damaging winds, and an EF1 tornado (Fig. 6).

b. 13 July 2008

The flow pattern on 13 July 2008 was characterized by a 500-hPa trough advancing slowly eastward across the central Great Lakes with a surface cold front (not denoted) moving eastward across the eastern Great Lakes, and a prefrontal trough moving eastward across central New York and central Pennsylvania. (Figs.7a-d). 500-hPa 12-h geopotential height falls (from 1200 UTC 13 July to 0000 UTC 14 July) across central New York were approximately 20 gpm. The RUC 2-h forecast valid at 2000 UTC 13 July 2008 indicated a large area characterized by 30 to 45 kt of 0-6 km bulk shear over central New York and northern Pennsylvania, and a southwest-northeast axis of MLCAPE values with maximum values ranging from 300 to 500 J kg^{-1} (Fig. 8). The BGM sounding from the 2100 UTC RUC analysis (Fig. 9, just prior to the triggering of convection in the model) indicated a veering wind profile from the surface to 700 hPa with wind speeds increasing from around 4 to 34 kt. Above 700 hPa, the flow was unidirectional from the southwest, increasing gradually from 34 to 44 kt at 400 hPa. Low-level (1000-700 hPa) lapse rates were around 6.0°C km^{-1}, and the sounding was quite moist from the surface through 200 hPa. MLCAPE was 371 J kg^{-1}. In this case, the flow had a strong southerly component, so that neither the 1200 UTC observed soundings at Buffalo, New York or Pittsburgh, Pennsylvania were likely representative of the sounding at BGM at 1800 UTC; therefore, no observed sounding is shown. GOES visible satellite imagery (not shown) indicated a slow-moving, north-south band of clouds covering the area. Some dry air was evident on water vapor imagery (not shown) to the west of this cloud band; however, animations indicated that the dry air was not making rapid eastward progress.

In summary, this event matched the profile of a low-impact, warm-season LCHS event: 1) a slowly moving midlevel trough was associated with modest 12-h height falls; 2) low-level lapse rates were modest; 3) no deep dry layers were evident on model soundings or on GOES water vapor imagery; and 4) the midlevel flow was from the southwest with a maximum wind speed below 6 km of under 50 kt. This event produced a weak line of showers and thunderstorms, with two isolated damaging wind reports in the BGM CWA (Fig. 10).

Continued page 143

Fig. 7(a).

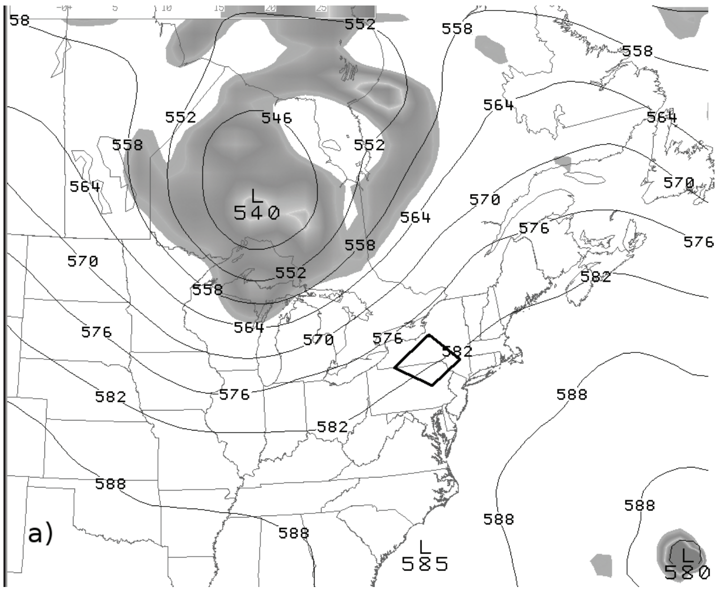

Fig. 7(c).

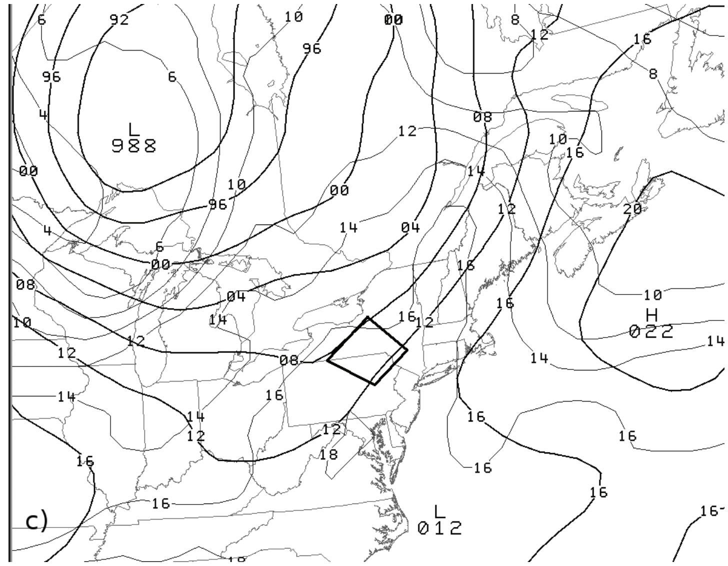

Fig. 7(b).

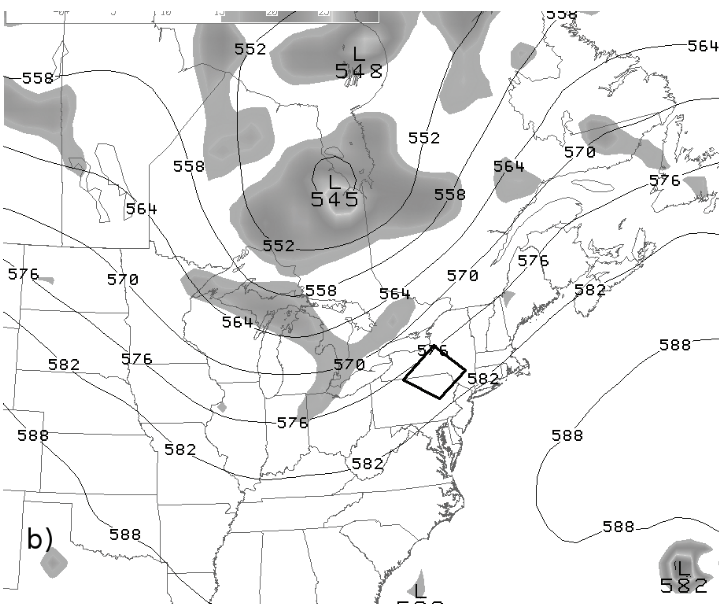

Fig. 7(d).

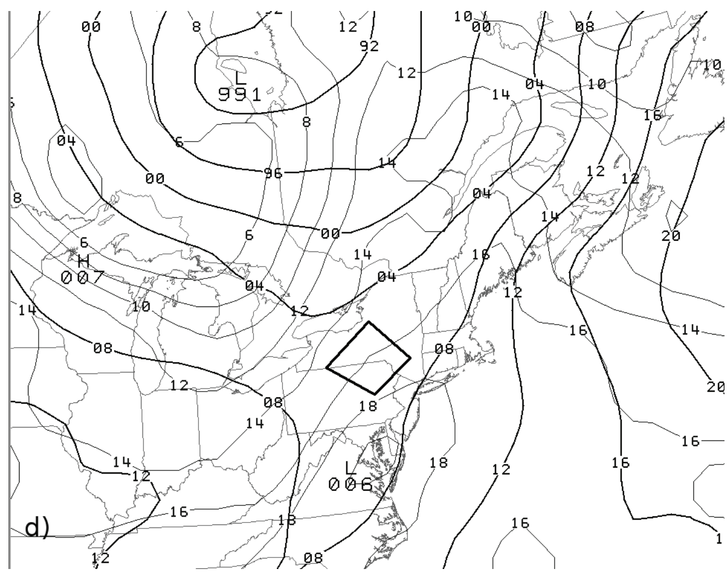

Fig. 7. Analysis and forecast fields as initialized by the 1200 UTC 13 July 2008 NAM model. (a) 500-hPa geopotential heights (solid, dkm) and absolute vorticity (shading > 15 x $10^{-5}s^{-1}$) valid at 1200 UTC 13 July 2008; (b) as in (a) but valid at 0000 UTC 14 July 2008; (c) sea-level pressure (heavy solid, hPa) and 850-hPa temperature (thin solid, ° C) valid at 1200 UTC 13 July 2008; (d) as in (c), but valid at 0000 UTC 14 July 2008. The rectangular box marks the approximate location of the BGM CWA.

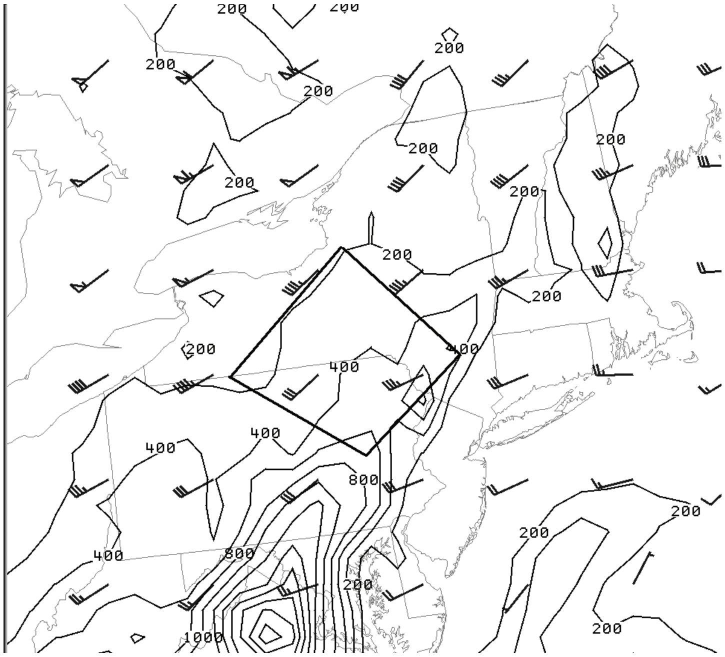

Fig. 8. 2-h RUC forecast of 0-6 km bulk shear (kt) and MLCAPE (J kg^{-1}), valid 2000 UTC 13 July 2008. The rectangular box marks the approximate location of the BGM CWA.

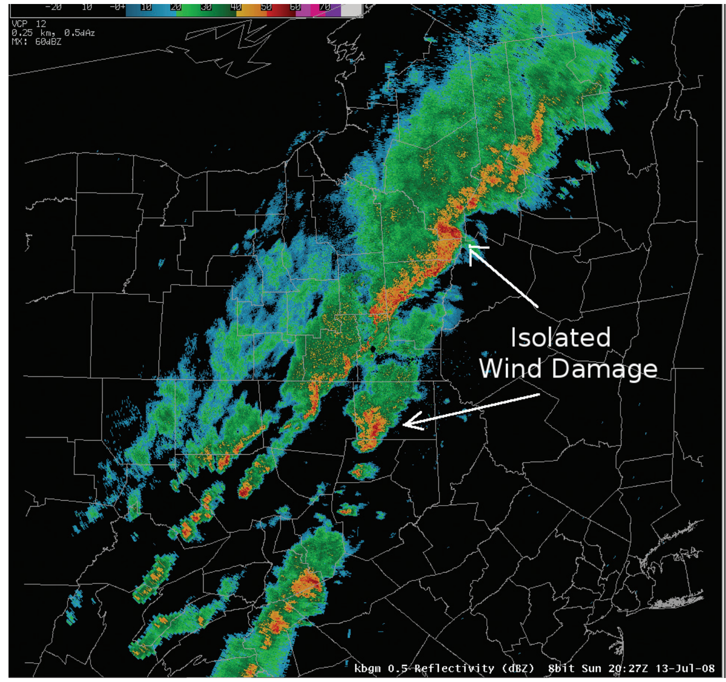

Fig. 10. KBGM 0.5° base reflectivity image at 2027 UTC 13 July 2008.

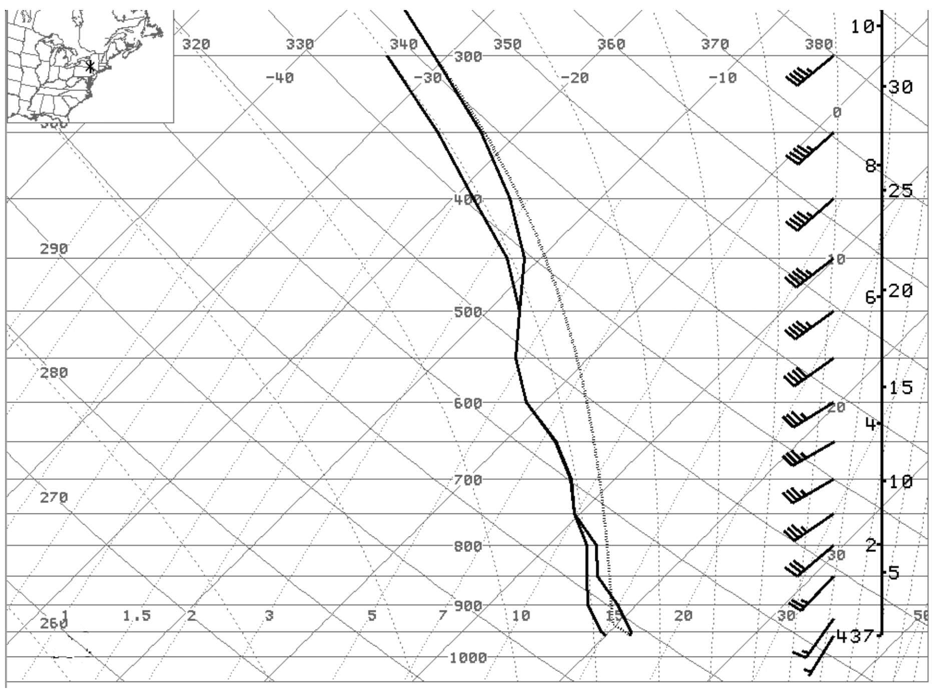

Fig. 9. 0-h RUC model forecast sounding at BGM, valid at 2100 UTC 13 July 2008.

Acknowledgments

The author would like to thank the forecast staff at WFO BGM for numerous discussions and input on this topic. Discussions and reviews by Justin Arnott, Science Operations Officer at the WFO in Gaylord, Mich., and Dave Radell at NWS Eastern Region SSD also improved the manuscript. Finally, the author would like to thank 3 reviewers from the NWA – Tom Salem, Steve Weiss and Scott Rochette.

6. Summary

This study identified and examined a subset of severe weather and flash flood-producing events that occurred in the NWS Binghamton, New York (BGM) CWA from 2003 through 2009 that were characterized by low mixed-layer conditional available potential energy (MLCAPE), and high deep-layer bulk shear (LCHS). The 38 LCHS events made up approximately one quarter of the total number of severe weather and flash flood events that affected our area during that time.

The majority of LCHS events were minor events, occurring in conjunction with fewer than five severe and or flash flooding weather reports. However, a substantial percentage of LCHS events occurred with five or more reports, and six events were identified that occurred with more than 15 reports. It was found that LCHS events associated with many reports ("high impact" events) are most likely to occur during the afternoon or evening. During the cool season, LCHS events with the largest number of severe reports tend to occur in lines, while isolated cells were the dominant reflectivity mode during warm-season events with a large number of severe reports. LCHS events are most often associated with progressive cold fronts; however a large subset of events were found to occur with other types of patterns, especially during the summer season. LCHS events associated with no flash flooding occur in environments characterized by steeper lapse rates, less moisture and larger 500-hPa height falls than LCHS events that occurred with flash flooding. Non-flash flood producing environments are also more likely to be associated with progressive cold fronts, and lines of convection.

A comparison of LCHS events containing few severe weather reports with LCHS events containing many severe weather reports revealed some significant differences between their associated environments. During the cool season, LCHS events associated with the most reports occurred with stronger maximum winds, stronger deep-layer shear, and larger 500-hPa height falls than in more modest events. During the warm season, the correlation between 500-hPa height falls and 0-6 km maximum wind speed with number of reports was not statistically significant; however statistically significant correlations with number of reports were found for low-level lapse rate (steeper lapse rates more favorable for a large number of reports), maximum mid-level dewpoint depression (dryer air more favorable for a large number of reports), and 3-km wind direction (westerly flow more favorable for a large number of reports than southwesterly flow). The relationship between number of reports, lapse rate and dewpoint depression implies that strong cold pools are required to balance strong environmental wind shear for the development of major warm-season LCHS severe weather events. Meanwhile, the relationship between number of reports, 500-hPa height falls and 0-6 km mean wind speed implies that strong dynamical forcing can produce major events in the absence of a favorable cold pool–shear balance during the cool season.

Finally, the reader should keep in mind that the dataset used for this study included no events when no convection occurred. This fact should be considered carefully when applying some of the findings of this study operationally. For example, warm-season LCHS environments with weak dynamical forcing, steep low-level lapse rates, and very dry air frequently produce no convection when capping is sufficient to severely inhibit convective cloud growth. These types of events were not included in the study. As a result, the results of this study are best applied once the operational meteorologist concludes that some type of convective storm will occur.

Author

Michael Evans received his Bachelor of Science degree at Penn State in 1985. After working for 3 years at Accu-Weather, he received a Master of Science degree at SUNY Albany in 1992. Michael began his career in the NWS as a Meteorologist Intern in Charleston, WV in 1992. He worked as a Journeyman Forecaster in Detroit, Michigan, a Lead Forecaster in State College, Pa, and has been the Science Operations Officer in Binghamton, NY since 2002. Michael has published studies on topics including lake effect snow, meso-scale snow bands, and precipitation type forecasting.

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