SEVERE WEATHER

ASSOCIATION OF JET STREAKS AND VORTICITY ADVECTION PATTERN WITH SEVERE THUNDERSTORMS IN THE NORTHEASTERN UNITED STATES

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ABSTRACT

The association of 850/300 mb jet positioning and 500-mb vorticity advection with severe thunderstorm events in the Northeastern United States was determined for the period 1980–84. An objective criterion was developed for classifying severe thunderstorm and tornado cases into a four category system using both the frequency (number of severe weather cases) and type of severe weather event. The four non-mutually exclusive categories chosen for this study were called SELS Events, SELS Episodes, Tornado Events, and Tornado Episodes. Each of the jet and advection factors were then analyzed in terms of these four classifications.

The principal results from this study are as follows:

The 850-300-mb jet streak analysis primarily revealed that the right-rear (RR), and secondarily the left-front (LF), quadrants of the 300-mb speed maximum are the most favored for severe weather (i.e., 73% of all events), consistent with divergence considerations, unless cyclonic curvature is present upstream. At 850 mb the only determination which can clearly be made is that the severe weather tends to occur to the left of the 850-mb jet axis (72% of all events).

Average wind speeds in the speed maxima at 850 mb and 300 mb were 40 kt and 95 kt respectively, which are thought to be considerably larger than those of the non-SELS environment of summer, when most SELS events studied here occurred. In only 9% of the events was a 70-kt 300-mb wind lacking in the domain used.

The 500-mb vorticity advection analysis revealed that prior positive vorticity advection was not likely before severe weather occurred in the Northeast, suggesting that some other large-to-medium-scale lifting source is often present before severe weather.

1. INTRODUCTION

Severe local storms (SELS), which are convective storms having a variety of weather elements including rainfall, hail, wind, tornadoes, and lightning, cause human injury and economic dislocation. A severe thunderstorm has been classified by the National Weather Service (NWS) as a storm which produces a tornado, has winds in excess of 25.8 ms^{-1} (57.7 mph), or has hail with a diameter of 19 mm (¾ in) or larger. Diagnosis and forecasting of such storms has obvious importance. Though the majority of SELS in the United States occur in the Great Plains, the Northeast has enough SELS occurrences and resulting property damage/human fatalities to justify their study separately from that of the Midwest, where most of the SELS studies have focused.

During the 1950's, a number of papers by Fawbush and Miller appeared, describing the methods used in forecasting severe storms. They resulted in AWS Manual 105-37 (Fawbush and Starrett, 3). Miller (4), in conjunction with the Air Weather Service (AWS) and National Severe Storms Laboratory (NSSL), conducted a computer study of 328 tornado cases over the entire United States. He found that 14 key parameters (such as 500-mb vorticity, thermal instability, low-level moisture, low level jet (LLJ), upper level jet (ULJ), and height of the wet-bulb-zero (WBZ) above the surface) played a major role in the formation of severe thunderstorms and tornadoes. He further attempted to classify these parameters in terms of weak, moderate, or strong potential for SELS, to serve as a preliminary forecast checklist for less experienced forecasters.

David (5) made use of this checklist to study upper-air parameters at the time of tornadoes. He used an objective analysis routine devised by Endlich and Mancuso (6) to obtain values for various upper-air parameters near the location and time of initial touchdown for tornadoes during the period 1968 to 1974. Tables were constructed which showed the average value and standard deviation for each of the checklist parameters categorized by state and by month. David concluded, based on Miller's (4) assigned values for key parameters, that most tornadoes considered in his study would be associated with weak values of key parameters, except for the mean moisture parameter, which would be graded moderate.

Others have used this concept to predict severe thunderstorm and tornado outbreaks for specific regions of the country. For instance, Gulezian (7) established a severe weather checklist for Maine and New Hampshire to aid forecasters in evaluating the severe weather potential for the two-state area. Some of the most destructive severe weather outbreaks, especially during the late spring and early summer months, are associated with west-northwest or northwest flow in the mid-troposphere [Miller (4)]. Johns (8) did a climatological study of severe weather outbreaks occurring in areas of the contiguous United States between 1962 and 1977 in which the mid-troposphere flow had a north-of-west component. He found that 163 severe weather outbreaks fit the criteria for "northwest" flow (NWF) and occurred along one of two high frequency axes. Johns (9) expanded his earlier study to examine the climatology of meteorological parameters and synoptic patterns associated with NWF severe weather outbreaks. Like Gulezian (7), who developed a severe thunderstorm checklist for New England, Johns used a similar format for NWF outbreaks which included a number of surface and upper-air parameters. Johns found that NWF outbreaks were associated with thermodynamic indications typical of the summer season. In particular, low-level moisture must be widespread and easily advected into areas beneath NWF at 500 mb. He then developed a NWF forecast checklist for the entire United States with threshold values for each parameter.

McNulty (10) used 28 cases of severe weather during March 1976 and examined the 850-mb and 300-mb jet axis positions to see which jet streak pattern was associated with the greatest frequency of severe weather outbreaks. He found that the largest number of severe weather events occurred in the right-rear quadrant of the 300-mb jet streak and left-front quadrant of the 850-mb jet streak.

The literature documents the fact that a number of synoptic features and fields (analyzed and derived) have a physical and/or empirical relationship with SELS [see, for example, Barnes (11)], but the purpose here is not to summarize SELS forecasting or study each factor. The present study was designed to be limited in scope, focus on the Northeast, and have practical usefulness; and to investigate a few widely used relationships such as that between SELS and tropospheric jet streaks on the one hand and between SELS and vorticity advection at 500 mb on the other, *to quantify frequency of associations*. The relationships examined pertained only to upper-air data (850-300 mb), utilizing mandatory level information, and focusing on some features and fields which have been discussed previously with regard to severe weather. In most instances these relationships have been inadequately justified in terms of the number of cases studied, therefore, the reliability of the relationship for SELS forecasting purposes is unknown. By using a large number of cases this situation has been rectified for two associations, both of which were chosen because: 1) they are used as forecast aids currently, 2) there is a physical justification for the relationship examined, and 3) they can be examined using published weather maps/data and easily analyzed features without recourse to the use of gridded data sets. It was felt that because this study was planned as the first in a series on this subject, the procedures would emphasize some basic concepts first, before increasing the complexity by introducing gridded data, finite-difference formulas, and significant levels into the procedures.

2. DATA COLLECTION

From previous studies and physical reasoning it is apparent that there are many variables and features which may be used to predict convection and severe weather. The present study examined a few of those upper-air synoptic features which may be important for severe weather formation and which could be quantified from published weather maps and data. The raw data (observations and features examined) used were: the temperature, dew point, wind direction, and wind speed for the 850-mb, 700-mb, and 500-mb levels; inferred 500-mb vorticity advection; and jet stream axis/streak positions for the 850-mb and 300-mb levels. Some stability indices were also computed: the K Index, Showalter Index, Total-Totals Index, and the Air Force SWEAT Index; however, these results are not noteworthy and are not included in this paper. In cases where data were missing, the values were obtained from a visual analysis (interpolation) of the data field. However, this was not done for the jet stream analysis where certain minimum values were needed for jet maxima to be designated at 850 mb and 300 mb.

The severe weather cases for the present study were collected from the National Climatic Data Center's (NCDC) publication *Storm Data* for the period 1980 to 1984. *Storm Data* lists the location, date, duration, and character of storm for all known destructive storms. The cases selected had to meet the NWS criteria for a severe thunderstorm. The "observed" surface wind speeds were often inferred from the listed structural damage as to whether the "severe" wind criteria was met. The "Northeast" region was defined for this study as extending from central Maine to Maryland and westward to (but not including) western New York, western Pennsylvania, and western Maryland.

The *NMC Constant Pressure (850-10 mb) Charts* were used to analyze for jet stream axis/streak position at the 850-/300-mb levels and the NMC 500-mb Vorticity and Vertical Velocity charts (PE model) were used to analyze vorticity advection patterns.

3. CLASSIFICATION OF SEVERE THUNDERSTORMS AND TORNADOES

An objective criterion was developed for classifying severe thunderstorm and tornado cases. Initially a single all SELS event category was used, but later three subset categories were defined. The four-category system has categories called SELS Events, SELS Episodes, Tornado Events, and Tornado Episodes.

A SELS Event was classified as any storm that met the NWS definition of a severe thunderstorm. Further, a single SELS Event had to be separated from a similar type event (wind, hail, or tornado) by more than 15 minutes or 18.6 km (10 nmi) within the same county to be classified as two separate events [Doswell *et al.,* (12)]. In addition, the time of *initial* occurrence reported for an event had to be at least 6 hr *after the last occurrence* reported of a prior event (within the same state) to be considered a separate event.

A SELS Episode was classified as two or more SELS Events occurring on the same day over four or more counties, not in a straight line with regard to storm movement. This requirement was specified in order to ensure that a single thunderstorm cell was not counted more than once.

A Tornado Event was classified as any storm that had at least one reported tornado. The Tornado Events were separated from the SELS Events to examine if some factors were better than others for predicting tornado occurrences.

A Tornado Episode was classified as two or more Tornado Events. The reason only two or more Tornado Events were used to classify a Tornado Episode was that occurrences of tornadoes in the "Northeast" are quite uncommon [Galway, (13)].

These four categories were then used as a basis for averaging and compositing indices and synoptic variables. In summary, the four categories are not mutually exclusive. The last three categories are subsets of the first and the 'episode' category is a subset of the 'event' category under the SELS and tornado designations. The first category was the starting point for this study and its use encompasses the main objectives desired, while the additional three categories were used to help answer secondary questions regarding synoptic relationships for differing coverage/intensity of severe weather cases.

4. METHODS OF DETERMINING SOME SYNOPTIC ASSOCIATIONS WITH SEVERE WEATHER OCCURRENCE

The development of precursor upper air conditions for severe weather cases is made inherently difficult by the fact that upper-air weather observations are taken only at selected stations twice a day (0000 GMT and 1200 GMT). Some of the past studies have used a 3-hr window either side of the 0000 GMT or 1200 GMT upper-air weather observations to associate those severe weather events which occurred near observation time with the concurrent upper-air data. To allow results of the present study to be part of a forecast guide and to increase the sample size, synoptic charts and upper-air weather observations were used for the period 3 to 15 hours prior to the time of initial convection reported for a severe weather cluster. Thus, 1200 GMT (0700 EST) upper-air weather observations were used for storms occurring between 1000 EST and 2200 EST, and 0000 GMT upper-air weather observations were used for storms occurring between 2200 EST and 1000 EST. This time lag is realistic in practical applications of upper-air charts to forecasting because users do not have NMC charts in hand much before 3 hr after observation time.

a. Jet Streaks

To determine how jet streak maxima influence the "Northeast" region, a spatial domain bounded by 60°–90°W longitude and 30°–55°N latitude was constructed for this analysis. This domain was constructed with the 3–15 hr lead-time window in mind. All jet axes were analyzed from the *NMC Constant Pressure (850-10 mb) charts* for the lower- (850 mb) and upper-tropospheric levels (300 mb). Minimum values for designating jet axis positions were established for each level: 850 mb—20 kt and 300 mb—70 kt. Averages and standard deviations of jet streak maxima speeds for each severe weather classification were computed for each level. In addition, the distance and compass direction to the closest speed maxima from initial convection was determined at both levels.

A further analysis was performed using the 850-mb and 300-mb jet streak position similar to that of McNulty (10). McNulty's analysis involved associating the jet axes and streak at 850-mb and 300-mb levels with the region where severe weather occurred. Further, McNulty's analysis was designed to illustrate that severe weather activity occurred under areas of upper-level divergence (i.e., left-front and right-rear jet streak quadrants). It should be noted that there are 16 combinations formed by the 850-mb and 300-mb jet axis streak maxima (see Fig. 1), of which McNulty found only four associated with severe weather in his limited study.

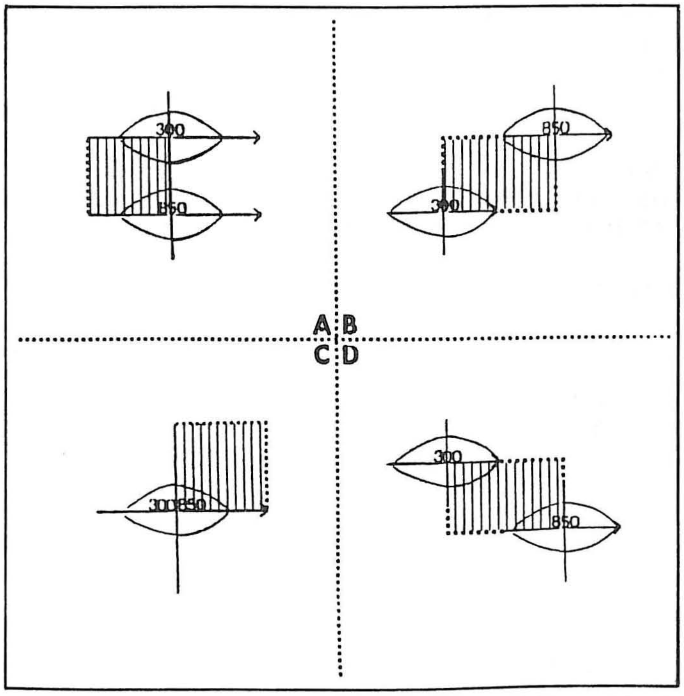

Fig. 1. Relationships between the 850 mb and 300 mb jet axes/streak maxima and severe weather occurrence (hatched area) found in this study. The north/south (solid) lines were drawn to be perpendicular to the jet axis through the isotach maxima to delineate quadrants.

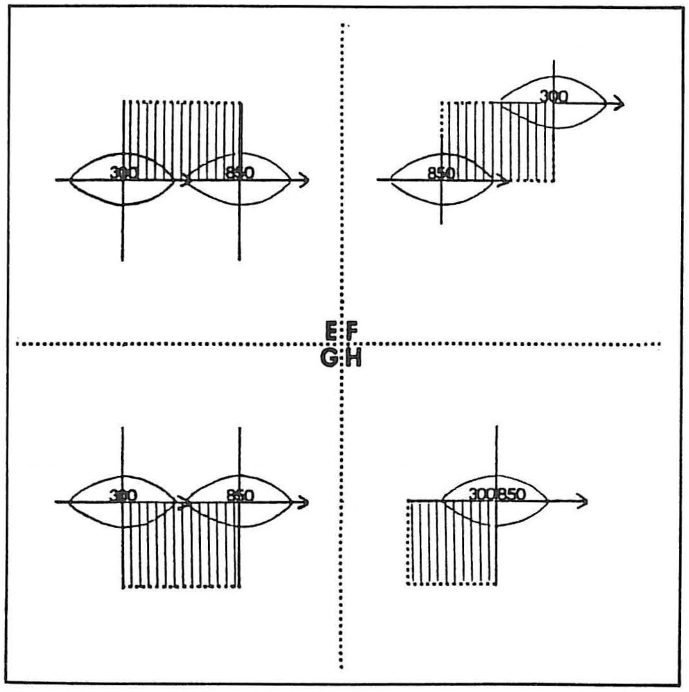

Fig. 1. Continued.

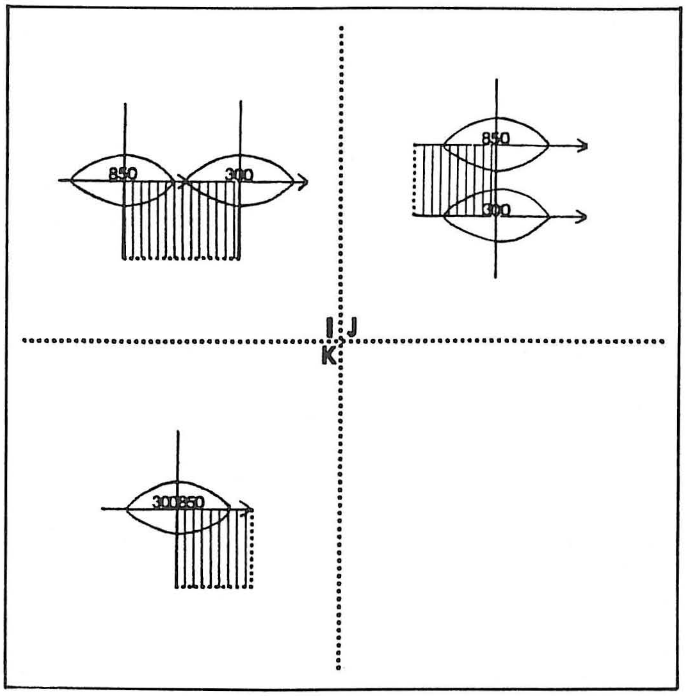

Fig. 1. Continued.

b. Vorticity Advection Analysis

Another feature which has been suggested to be associated with the formation of severe thunderstorms and tornadoes is the presence of moderate to strong positive vorticity advection (PVA) in the middle troposphere. Since mid-tropospheric PVA normally contributes to lower tropospheric upward vertical motion (unless PVA is decreasing upwards), Miller (4) emphasized positive advection in the vorticity field more than the actual numerical value of vorticity for triggering severe weather outbreaks.

In the present study vorticity advection patterns were analyzed for all severe weather outbreaks from *NMC 500 mb Vorticity and Vertical Velocity* charts. Vorticity advection patterns were analyzed both prior to and after the time of initial convection of the severe weather outbreaks from the 0000 GMT and 1200 GMT charts. This was done because it was impossible to tell, in general, what the vorticity advection pattern looked like at the time of initial convection. Vorticity advection categories were then constructed based on the vorticity advection patterns. The weak vs. strong vorticity advection categories were decided by angle (between the 500-mb height field and the vorticity field) only, although the gradient of vorticity and height are also important. The original five vorticity advection categories were collapsed into three categories by putting all the weak (angle less than 30 degrees) and neutral vorticity advection patterns into one category. By examining synoptic times before and after initial convection a 3 × 3 contingency table was constructed for each severe weather classification.

c. Seasonal Stratification

A seasonal stratification was performed on all factors used in this study to evaluate their validity at different times of the year. For the 5 yr examined (1980–1984) in this study, severe weather cases were found to occur only during March through October. Thus the convective period was divided into two distinct seasons—spring and summer. The spring season was chosen to include the months of March through May, while the summer season was represented by the months from June through October. These classifications were chosen based on judgements made at NSSFC that the months of September and October were more closely tied to the synoptic characteristics of summer than that of spring (Sammler, 1986, personal communication). In most instances, the results of this stratification are not shown since little seasonal differences were found here, however mention of them is made as appropriate.

5. RESULTS

a. Temporal Climatology of Cases in the Present Study

The peak month of occurrence for SELS Events was July and the period June–August accounted for 81% of all cases. However, the Tornado Events also exhibited a relative maximum during May. By comparison, the peak months of severe weather occurrence in the Midwest are May, June, and July, while the peak months of tornado occurrences are May and June.

In terms of diurnal variation, 81% of all severe weather cases began between 1200 and 1800 EST with the time of highest frequency of occurrence being between 1600 and 1800 EST. Further, it appears that the SELS Episodes had a tendency to occur earlier in the afternoon (peak initiation period 1200 to 1400 EST).

b. Jet Streak Position

Figure 1 shows 11 of 16 possible relationships between the 850-mb and 300-mb isotach maxima and the quadrant of severe weather occurrence (hatched area). There are 16 possible relationships, based on four quadrants of severe weather occurrence in relation to the isotach maxima at each level, of which 11 relationships were found for the 165 cases studied here.

Table 1 shows the number of cases for each relationship for each of the severe weather classifications. In the present study, relationships A and F accounted for 47% of all cases, while relationships C, E, and G accounted for another 30%. A seasonal stratification of the relationships was performed; however, no apparent pattern emerged to indicate that any of the relationships were more important during the spring than during the summer.

Table 2 shows the number and percentage (in parentheses) of cases by quadrant for each of the four severe weather classifications. In each classification it is apparent that the left quadrants of the jet streak maxima at 850 mb is the most important (with a slight preference for left-rear), while the right-rear (rr) quadrant of the jet maxima is the most important at 300 mb. The left-front quadrant at 300 mb assumes greater importance (higher percent of cases) for tornado cases than for non-tornadic SELS based on this analysis. Overall this analysis illustrates, as expected, that apparent upper-level divergence (300 mb) associated with the left-front (lf) and right-rear (rr) quadrants of jet maxima is important for severe weather in the Northeast. Among the 14 Tornado Episodes there were no exceptions. This analysis serves to quantify these relationships so the forecaster can know, at least for the Northeast, how reliable the most common association is and how often and in what fashion exceptions have occurred.

Table 1. The number of cases for each 850-to-300-mb-jet-axis relationship (shown in Fig. 1) in each of the four severe weather classifications.

Relationship	SELS Events	SELS Episodes	Tornado Events	Tornado Episodes
A	30	15	07	03
B	10	04	05	01
C	12	02	04	01
D	08	01	01	00
E	18	08	09	04
F	40	16	15	04
G	15	03	01	00
H	10	04	03	01
I	01	00	00	00
J	02	01	00	00
K	03	00	00	00
—	15	05	03	01
M	01	00	00	00
Total	165	59	48	15

Note:—denotes no jet maxima present at either 850 mb or 300 mb.

M denotes missing 300 mb constant pressure map for 1200 GMT, MON 04 JUNE 1984.

Table 2. The number and percentage (parentheses) of cases by quadrant in each of the four severe weather classifications.

No. and % of SELS Events (149 Events)

Quadrant/ Jet Level	LF	LR	RR	RF
850 mb	52 (35)	56 (38)	37 (25)	04 (03)
300 mb	40 (27)	02 (01)	81 (54)	26 (17)

No. and % of SELS Episodes (54 Episodes)

Quadrant/ Jet Level	LF	LR	RR	RF
850 mb	18 (33)	24 (44)	12 (22)	00 (00)
300 mb	14 (26)	01 (02)	35 (65)	04 (07)

No. and % of Tornado Events (45 Events)

Quadrant/ Jet Level	LF	LR	RR	RF
850 mb	19 (42)	17 (38)	09 (20)	00 (00)
300 mb	18 (40)	00 (00)	25 (56)	02 (04)

No. and % of Tornado Episodes (14 Episodes)

Quadrant/ Jet Level	LF	LR	RR	RF
850 mb	05 (36)	07 (50)	02 (14)	00 (00)
300 mb	06 (43)	00 (00)	08 (57)	00 (00)

c. Other Jet Streak Characteristics

Table 3 displays the results of calculations regarding the distance and compass direction from SELS location to jet streak location, and the maximum wind speed in the jet streak.

At 850 mb the average distance to the speed maxima is 517 to 639 km with the tornado categories having the smaller distances. Examination of the frequency distributions (not shown) revealed that the tornado cases had a much less flat distribution; for example, 48% of the Tornado Events had distances concentrated in the 300- to 500-km range. In terms of compass direction to the speed maxima from the SELS location, the distribution tends to peak in the westerly direction (261 to 280 degrees), especially for the tornado categories. Lastly, for the 850-mb jet-streak maximum wind speed, the average speeds range from 37 to 41 kt. The tornado categories had slightly higher average maximum 850-mb wind speeds. For tornado events, 26% of all cases had speeds greater than 40 kt, while for the overall sample (SELS Events) there were 21% with these wind speeds.

Table 3. Characteristics of jet streaks associated with types of SELS cases. B: Most frequently observed direction from SELS occurrence to speed maxima position; d: average distance between the same two locations; and JS: average wind at speed maxima.

	SELS Events	SELS Episodes	Tornado Events	Tornado Episodes
850-mb cases	160	58	48	15
B(deg) interval	261–280	261–280	261–280	241–280
d(km)	639	585	586	517
JS speed(kt)	37	38	42	41
500-mb cases	162	59	48	15
JS speed(kt)	59	61	64	63
300-mb cases	153	55	45	14
B(deg) interval	301–320	021–040	241–260	261–280
d(km)	960	993	964	985
JS speed(kt)	95	98	98	92

At the 300-mb level, the distance distribution is very flat over the range 700 to 1400 km, with this range having 73% of all SELS Event cases. The average distance for all categories is 900 to 1000 km. The direction distribution is bimodal, with jet streaks most likely to be located to the northeast (021 to 040 degrees) or to the west-southwest/west-northwest (241 to 320 degrees), depending on category, from the SELS location. The westerly direction frequencies were slightly higher than the northeasterly ones. The 300 mb maximum wind speeds average 90 to 100 kt, with about half of the SELS Events having maximum winds 60 to 90 kt. Little difference was seen between SELS categories.

d. Vorticity Advection Analysis

Table 4 shows the 3 × 3 contingency table constructed for each of the four severe weather classifications. The contingency table was constructed using the vorticity advection prior to the time of the initial convection and the vorticity advection pattern after the time of the initial convection for each severe weather case. In other words, the vorticity advection patterns which were used to construct the contingency table were 12 hr apart. From Table 4 it is apparent that the weak PVA-neutral-weak NVA category prior to and after the time of initial convection clearly dominates the contingency table for each severe weather classification.

Table 5 shows the numbers and percentages (in parentheses) of cases for which PVA occurred prior to or after the time of initial convection of the severe weather outbreak. It should be kept in mind that the analysis technique used is not generally able to establish the vorticity advection pattern present at the time of initial convection. However, it is surprising that 33% of all SELS events did not have even weak PVA prior *or* after severe convection, which suggests that warm thermal advection or mesoscale triggering of severe

Table 4. The 3 × 3 contingency table of vorticity advection patterns prior to and after the time of initial convection in each of the four severe weather classifications.

SELS Events

Vorticity Prior:	Strong PVA	Weak-Neutral-Weak	Strong NVA	Total
Vorticity After:				
Strong PVA	16	15	08	39
Weak-Neutral-Weak	19	82	06	107
Strong NVA	13	03	03	19
Total	48	100	17	165

SELS Episodes

Vorticity Prior:	Strong PVA	Weak-Neutral-Weak	Strong NVA	Total
Vorticity After:				
Strong PVA	07	08	06	21
Weak-Neutral-Weak	06	21	05	32
Strong NVA	03	01	02	06
Total	16	30	13	59

Tornado Events

Vorticity Prior:	Strong PVA	Weak-Neutral-Weak	Strong NVA	Total
Vorticity After:				
Strong PVA	06	06	02	14
Weak-Neutral-Weak	07	22	01	30
Strong NVA	03	00	01	04
Total	16	28	04	48

Tornado Episodes

Vorticity Prior:	Strong PVA	Weak-Neutral-Weak	Strong NVA	Total
Vorticity After:				
Strong PVA	03	02	02	07
Weak-Neutral-Weak	00	06	00	06
Strong NVA	01	00	01	02
Total	04	08	03	15

Table 5. Numbers and percentages (parentheses) of cases for which PVA occurred prior to and/or after the time of initial convection of the severe weather outbreak in each of the four severe weather classifications.

Classification	Prior Strong PVA	Prior Strong-Weak PVA	Prior-After Strong PVA	Prior-After Strong Weak PVA
SELS Events (165 Events)	48 (29)	72 (44)	71 (43)	110 (67)
SELS Episodes (59 Episodes)	16 (27)	24 (41)	30 (51)	42 (71)
Torn. Events (48 Events)	16 (33)	28 (58)	24 (50)	37 (77)
Torn. Episodes (15 Episodes)	04 (27)	08 (53)	08 (53)	11 (73)

Table 6. The number of cases for each vorticity advection pattern for SELS in the 3-hr window around 0000 GMT in each of the four severe weather classifications.

Classification	Strong PVA	Weak PVA	Neutral	Weak NVA	Strong NVA	Total
SELS Events	14	15	18	16	08	71
SELS Episodes	04	04	03	01	01	13
Tornado Events	04	04	05	02	01	16
Tornado Episodes	02	00	01	00	01	04

weather may have been the primary forcing mechanism. PVA appears to be slightly more important in tornado cases.

To see if at least slight PVA existed near the time of initial convection, a selected subsample was used. Table 6 uses a 3-hr window either side of 0000 GMT for severe weather cases. It is apparent that, at least for the Northeastern United States, PVA is not generally necessary for the occurrence of severe weather events, as 42 of the 71 cases (59%) in the 3-hr window did not have it.

6. DISCUSSION

As noted in the previous section, the results obtained indicate some useful relationships between severe weather and prior upper air synoptic conditions in the Northeast. The most useful result involves the 850–300 mb jet streak positioning. The vorticity advection results indicate that it should not be included as a primary forecast indicator. Certainly, the use of each of the aforementioned factors for forecasting severe thunderstorms could be improved upon by comparing the results to those determined for ordinary thunderstorm and/or non-thunderstorm days. This is particularly important when the results of this study are used as a forecast guide because without a more complete analysis, over-forecasting of severe weather may occur.

A useful tool for forecasting severe weather in the Northeast is the use of jet-streak positioning. On average the 850-mb speed maxima is found about 500 to 650 km to the west of SELS initiation, while the 300-mb speed maxima is found about 1000 km to the west or northeast of SELS initiation. Representative maximum wind speeds at these two levels are 40 kt at 850 mb and 95 kt at 300mb. Also, it was found that severe weather occurred predominantly in the right-rear (RR) quadrant of a 300 mb speed maximum (49% of events) and secondarily so in the left-front (LF) quadrant (24% of events), which are the expected quadrants based on divergence considerations at 300 mb. In addition, in a right vs. left analysis using the 300-mb jet axis, it was found that 72% of all severe weather outbreaks occurred to the right of the 300-mb jet axis (Table 2). This latter point is essentially in agreement with Miller (4), who used mainly Midwest cases. It is less clear if severe weather occurs in the region of 850-mb convergence, as divergence computations were not made. However, in a simplistic way one would expect to find convergence at 850 mb downstream of the speed maximum (i.e., speed convergence region). In this study severe weather occurred more often in the left rear (LR) quadrant of the 850-mb speed maximum, and secondarily in the left-front (LF). In addition, in the right vs. left analysis, 72% of all severe weather events occurred to the left of the 850 mb jet axis, also in essential agreement with Miller (4). The dominance of the left region at 850 mb increases from 'event' to 'episode' classification and from severe thunderstorm to tornadic classification, while the dominance of the right region at 300 mb decreases when comparing results similarly across classifications. One difficulty inherent in using the jet-streak analysis is being able to incorporate the correct jet streak for cases where more than one jet streak is found.

The jet-streak analysis turned up 28 severe weather events for which upper-level (300 mb) divergence was apparently lacking based on theoretical considerations. Table 7 lists the four relationships (D, G, J, and K; shown in Fig. 1) and number of cases apparently lacking upper-level divergence in each of the four severe weather classifications. In 20 of the 28 cyclonic curvature was present near the location of the 300-mb jet streak. Because cyclonic curvature was increasing upstream in those cases (i.e., PVA in all quadrants more likely), the LF and RR quadrant regions are less preferentially favored for severe storm occurrence as the divergence difference between quadrants may be reduced. Seven of the remaining eight cases could be explained by having above classification average stability index values. Despite these plausible explanations, it is difficult to say with any certainty from these limited analyses what caused individual severe weather events.

Table 7. The four 850- to 300-mb jet-axis relationships and number of cases for which upper-level (300 mb) divergence was apparently lacking in each of the four severe weather classifications.

Relationship	SELS Events	SELS Episodes	Tornado Events	Tornado Episodes
D	08	01	01	00
G	15	03	01	00
K	03	00	00	00
J	02	01	00	00
Total	28	05	02	00

The study performed by McNulty (10) showed four relationships of the 850- to 300-mb jet-streaks to the area of severe weather occurrence. In the present study these four relationships (A, C, E, and F) accounted for 67% of all cases. Clearly McNulty's four relationships are not the only four relationships associated with severe weather occurrence, not surprising because he examined only 28 cases of severe weather during one month (March, 1976). The time lag between analyses used and SELS occurrence in this study could explain some of the differences in results as well.

The vorticity advection analysis indicated that PVA [which was Miller's (4) most important factor] is not critical for severe weather in the Northeast. However, this does not mean that large-scale upward vertical velocity is not important as a trigger mechanism, as warm thermal advection may be a contributor as shown in case studies (for example Maddox and Doswell, 14). Of course mesoscale forcing is often significant as well.

Surface variables and features which were not examined in this study are likely to further elucidate precursor conditions for SELS. The next step in this research will be to incorporate surface data and examine non-SELS days for analysis.

7. SUMMARY AND CONCLUSIONS

An attempt was made in this study to examine a few associations between synoptic features and severe weather events 3 to 15 hr later in the northeastern United States. This study made use of severe storm reports gathered from *Storm Data* for the Northeast region extending from Maine to Maryland for the period 1980–1984. The cases pertained to the convective season only, which is defined as beginning in March and ending in October.

The raw data used (observations and features examined) were the inferred 500-mb vorticity advection and jet-stream axis/streak positioning for the 850-mb and 300-mb levels, including maximum wind speeds. An objective criterion was developed for classifying severe thunderstorm and tornado cases into a four category system using both the frequency (number of severe weather cases) and type of severe weather event. The four categories chosen for this study were called

SELS Events, SELS Episodes, Tornado Events, and Tornado Episodes. Each of the aforementioned factors were then analyzed in terms of these four classifications.

The principle findings resulting from this study are as follows:

1. The 850- to 300-mb jet-streak analysis primarily revealed that the right-rear (RR), and secondarily the left-front (LF), quadrants of the 300-mb speed maximum are the most favored for severe weather (i.e., 73% of all events), consistent with divergence considerations, unless cyclonic curvature is present upstream. At 850 mb the only determination that can clearly be made is that the severe weather tends to occur to the left of the 850-mb jet axis (72% of all events).
2. Average wind speeds in the speed maxima at 850 mb and 300 mb were 40 kt and 95 kt respectively, which are thought to be considerably larger than those of the non-SELS environment of summer, when most SELS events studied here occurred. In only 9% of the events was a 70 kt 300-mb wind lacking in the domain used.
3. The 500-mb vorticity advection analyses revealed that prior positive vorticity advection was not necessary for severe weather to occur in the Northeast, leading one to believe that some other large to medium scale lifting source is often present when severe weather develops.

ACKNOWLEDGMENTS

New Jersey Agricultural Experiment Station Publication No. D-13507-5-88 supported by State funds.

The authors wish to thank Mr. William Sammler, Dr. Charles Doswell III, and Mr. Chet Henricksen for their critiques of this manuscript.

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