P 5.1 PRELIMINARY SYNOPTIC CLIMATOLOGY OF COOL SEASON SEVERE WEATHER FOR THE PHILADELPHIA NATIONAL WEATHER SERVICE COUNTY WARNING AREA AND VICINITY

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1. INTRODUCTION

Cool season severe weather occurrence in and near the Philadelphia (PHI) National Weather Service (NWS) in Mount Holly, NJ, County Warning Area (CWA) while rare (e.g., see Kruzdlo and Cope 2005; Brooks et al. 2003) does pose a significant forecast challenge. While most wind events tend to be related to strong pressure gradients given the synoptic forcing common during the cool season, damaging wind events associated with convective systems also do take place. These include reports of hail and tornadoes in the region due to squall lines, bow echoes, or quasi-linear convective systems (e.g., Burke and Schultz 2004; Trapp et al. 2005). These are associated with progressive and/or intensifying weather systems and have no cool season conceptual basis that a forecaster might apply in advance.

The NWS PHI CWA was initially selected for study as it often is depicted as a transition zone of climatic regions in the Mid-Atlantic States given its variations in soil types, elevation, and physiographic features as well as its proximity to and influences from the Atlantic Ocean. In addition, during the heart of the cool season snow cover and soil temperatures may vary tremendously across the region. Anecdotal evidence over the years has also considered it to be a region in which the Atlantic Ocean and Chesapeake Bay region exert a considerable influence with regard to the spatial and temporal distributions of weather conditions throughout the year. Recent investigations in other locations reveal such effects to be multifaceted and common due to complex, and often poorly understood land-surface interactions (e.g., Wasula et al. 2002; Gedzelman et al. 2003; McPherson et al. 2004).

In an effort to better understand and forecast the occurrence of these rare cool season severe weather events a preliminary synoptic climatology was prepared to determine the associated synoptic features. The intent was to provide greater insight to the characteristic nature of these events, their associated attributes and patterns, and to provide some guidance as to what forecasters might look for to recognize the potential for severe weather in advance. In addition, it would assist in identification of what other work may be necessary to improve prediction and lead-time across such a major metropolitan area.

2. DATA COLLECTION & METHODOLOGY

Initial inspection of the storm reports database available online (www.spc.noaa.gov/climo) from the Storm Prediction Center (SPC) for the six year period 2000-2005 revealed that very few severe weather events (four local storm reports) were observed in the PHI NWS CWA during the cool season (traditionally defined as December through February). Therefore, the study area was expanded slightly to include adjoining areas from the Wakefield, Virginia (AKQ) NWS CWA (i.e., five additional counties from Maryland and two in Virginia) and increased in time to include the "cool half" of the year (i.e., October through March).

The resulting enlarged and expanded dataset provided severe weather events (local storm reports) occurring over 12 separate days (see Table 1) out of a possible 1,094 days (i.e., 180 days each year, plus two leap year days), or only 1.1% of the time. These events produced 102 severe weather reports across 32 of the 40 counties (see Table 2), including 5 tornadoes, 15 hail reports, and 82 wind reports as shown in Fig. 1a. Events were observed in all months except February. Of the 12 days with severe weather reports, 10 included wind (83%), 4 tornadoes (33%), and 2 hail (17%).

The storm reports were plotted against the 1997 County Population Statistics via GIS analysis (Chang 2004). Examination revealed very few local storm reports in the Delmarva with many in the vicinity of the Philadelphia metropolitan area (see Fig. 1a). Only seven reports were noted along coastal areas and four in Monmouth and Ocean Counties.

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The lack of local storm reports in the Pine Barrens of New Jersey requires further investigation, but may imply either a lower incidence of events or the lack of eyewitnesses given the physiographic nature of that region.

When separated by severe weather type (i.e., local storm reports of tornado, hail, and wind) there was little spatial coherence, preference, or pattern except for hail (see Figs. 1b, c, and d). Tornado reports were limited to only 4 days with 4 of the 5 storm reports occurring during two separate Octobers (one in 2000 and three in 2003) and one in January (in 2002, reported as a possible waterspout).

Examination of the hail cases revealed that 14 of the 15 hail reports occurred during one day (21 March 2003) and were oriented across the study region from southwest to northeast. The other day, with only one report of hail, occurred 4 October 2000. Wind reports (82 of 102, or 80% of local storm reports during the cool half of the year) were easily the most numerous severe weather reported, occurring in all months (except February) with maxima in October and November.

In order to better understand the dynamics behind all severe weather events, the Daily Weather Map Series available both online and in print form (www.hpc.ncep.noaa.gov/dwm/dwm.shtml) from the NOAA NCEP HPC was accessed in order to depict the basic synoptic weather patterns occurring during each of the 12 days of events. Preliminary analysis focused on surface features in order to allow the events to "self-sort" themselves into the weather patterns associated with their occurrence. This "natural selection" process would allow for distinct patterns to emerge rather than be specified in an arbitrary or preconceived manner.

The events were also studied with regard to their attendant upper air pattern and features. As is typical with any severe weather outbreak in the cool season, strong dynamic forcing often overcomes the lack of sufficient thermodynamics or instability. However, given the preliminary nature of this investigation, no attempts were made to link specific dynamic and thermodynamic attributes directly (e.g., Rose et al 2004; Metz et al 2004); nor were any case studies performed or significant parameter values or radar signatures evaluated (e.g., Kruzdlo and Cope 2005) as the focus of the present study was to better determine the types of synoptic situations (and their features) that lead to severe weather during the cool season.

Each event day was also examined with regard to the time of severe weather reports and the movement of synoptic features from day-to-day. Since the DWM Series includes only an early morning depiction of the synoptic weather pattern, it was important to examine the timing of severe weather reports. Based on this review, one of the event days was removed from further study as it was clearly a high-wind event that caused damage reports due to a strong pressure gradient in association with a deepening low pressure system (13 November 2003).

This led to the removal of 20 of the original 82 wind events leaving 62 and made October the month of most frequent wind events for the cool season. A pair of event days were also merged as it was found that the storm reports were associated with the same synoptic scale event (13-14 January 2003). The remaining data (ten event days) were then analyzed according to their synoptic patterns and features from an operational point of view.

3. ANALYSIS OF EVENTS

The remaining ten event days (Table 3) were analyzed and three distinct surface and upper air synoptic patterns were identified based on an initial inspection of the DWM Series. Five Type "A", two Type "A-2" and three Type "B" events were identified (Table 4) and labeled merely to distinguish one type from another (i.e., "A" versus "B") and to note any similarities between types ("A" and "A-2").

The timing of severe weather reports was found to confined to the period of 1900 through 0000 UTC for both "A-2" (1946-2102) and "B" (1915-0045) but varied from 2100 through 1300 UTC for the "A" events. For the "A" events all but one occurred between 1345 and 2125 (the outlier being reported at 0237). Therefore, while there was a preference for types "A-2" and "B" to follow the diurnal maxima cycle (according to instability), there was only a daytime preference for the first type ("A").

For each synoptic type and for all types combined, summary statistics were also generated of their associated attributes (not shown). These included location and intensity of surface low and high pressure systems and pressure gradients as derived from the DWM Series. The non-occurrence of severe weather reports for these synoptic patterns (i.e., the null case) was not considered in this study. Further, as complete box-and-whisker plots were not possible given the small sample size available for each type, each of these parameters was plotted according to their maxima, minima, and mean values. These were compared to highlight commonalities and differences between the synoptic types (not shown) as well as to verify and confirm distinctions between the synoptic types developed in the study. Key findings from these investigations were that the low intensity was weakest (strongest) for Type "B" ("A") as was the local surface pressure gradient.

Composite maps were generated for the patterns identified using the Climate Diagnostics Center website (http://cdc.noaa.gov/Composites) software, based on the NCEP Re-Analysis (Kalnay et al. 1996), for all cases combined (Fig. 2a) and for each of the synoptic patterns (Fig. 2b, 2c, and 2d) based on the event days available. Composites included geopotential height at 500 mb, omega (through 100 mb), and sea level pressure. These were analyzed with regard to their features, differences, as well as the type and distribution of severe weather reports in the study region.

Review of the DWM Series and the composites indicated that although all types shared a strong southwest flow aloft (500 mb geopotential), Type "A" was characterized by a progressive frontal system associated with a full-latitude trough (and strong flow from the Pacific Ocean) across North America with primary surface low pressure in Canada and the northern Great Lakes. In each case, this led to the passage of a warm frontal feature leaving the entire study area within a warm sector environment prior to cold frontal trough passage and therefore the development of severe weather. The accompanying omega field was very distinct with the advancing shortwave developing a negative tilt.

The influx of warm sector air across the study region with the attendant geopotential pattern allowed for a wider distribution (spatially) of severe weather reports. It is possible that this could allow the distribution of severe weather to be focused according to local physiographic features, but this would require further study of each event date and was not attempted in this study. This synoptic type was also observed in all months except November and February and produced one tornado, 38 wind reports, and no hail on five different days. Given the greater incidence of this type (compared to "A-2" and "B") the overall composite maps share greatest similarity with this pattern. The only type as prolific in generating the same number of severe weather reports ("B") occurred over only three event days in the data sample.

The second synoptic pattern type "A-2" differed in that it included a distinct cold core system aloft (in the Gulf States based on individual cases and the composite mean) that moved in closer proximity to the study area and had its primary surface system located within the conterminous United States (over the Great Lakes region) prior to intensification and movement into Canada. Although the composites for this type were derived from only two cases (one each in January and November), it was characterized by two un-phased progressive systems aloft (separate from the overall flow in Canada), more distinct upper air and surface ridging from the ocean, and a less intense frontal system at the surface as in Type "A" events.

The associated omega field indicated a less focused and more spread-out region of lift (as might be expected based on the upper air pattern) and therefore was a limiting factor for the production of severe weather. This type produced only four reports of severe weather in the study region – three wind and one waterspout moving onshore – that occurred in relatively close proximity to the main height fall center of the progressive system. In these cases there were no reports of hail and there was only a limited influx of a warm sector environment at low or mid-levels. This limited both the number and distribution of severe weather reports across the study region.

Type "B" systems were different from the two "A-types" being characterized by the presence of quasi-stationary boundaries at the surface under a strong southwest flow aloft from Mexico. The upper air flow indicated that although a broad full latitude trough was evident over North America, there was both a progressive northern stream system in the northern Great Lakes and a positively tilted trough from Texas to the southern Great Lakes region. This created a stretched and diffuse area of omega centered in the vicinity of the study region that, although weaker, effectively produced more severe weather reports per event date than the other synoptic types.

This pattern was consistent with a relatively broad and diffuse surface system undergoing decay and thus less significant dynamic forcing as compared to "A" and "A-2". The isobaric field suggests also an east-west oriented boundary (or northeast-southwest) existing under a strong parallel flow aloft (and streamwise vorticity) to aid in the generation of severe weather. Type "B" events occurred on three separate days, during two different Octobers and during one March, and produced all of the observed hail reports as well as three tornadoes (both Octobers) and 21 wind reports (both Octobers). These cases were characterized by an unstable boundary layer and focusing given the weakness of the low pressure and gradient fields.

In order to further consider any spatial patterns of these severe weather occurrences, storm reports were also plotted by synoptic type (Fig. 3) to determine features specific to the severe weather occurrences, and by time of year to identify any trends. Type "A" events (3a), in which the primary system moves from the Great Lakes region into Canada and which have the strongest pressure and gradients indicated the majority of wind reports occurred inland away from the immediate coast. This type was dominated by wind reports and suggests a greater synoptic scale role of dynamic forcing in the production of severe weather.

Synoptic Type "A-2" (3b) showed storm reports oriented from south to north in the vicinity of the Chesapeake Bay region into southeastern Pennsylvania. This type produced very little severe weather (three wind reports, one waterspout) which was focused along and/or in the vicinity of the upper center as well as the best region for an influx of a maritime air mass (and/or low level instability). The Type "B" events (3c), in which pressure values and gradients were the weakest, indicated that all severe reports were located in the northern half of the study region suggesting some frictional and elevation effects within the local storm environment. This was the only synoptic type which produced all severe weather types (i.e., tornado, hail, and wind) and was as prolific in generating severe reports as Type "A" (see Table 4).

4. CONCLUSIONS

A preliminary examination of the synoptic climatology of severe weather occurrence during the cool half of the year was considered for the PHI NWS CWA and vicinity. Through an examination of online storm reports from the Storm Prediction Center, a small sample of severe weather reports was identified and studied. Although their occurrence is rare (approximately one percent of the time) the events are dominated by wind damage reports and occur on average once each cool season. Reporting of events did not appear to be a function of population density or distribution.

Severe weather events did not exhibit any significant patterns until they were examined with regard to the synoptic weather type associated with their occurrence. Two of the types ("A", "A-2") illustrate the significance of dynamic forcing and the role of the large scale synoptic setting. These dictate the amount and distribution of severe weather reports across the study region. The third synoptic type ("B") however is also a prolific producer of severe weather of all kinds but differs in its dependence on boundary layer instability and forcing (particularly aloft) that is fundamentally different from the other two synoptic types.

In fact three of the five tornadoes occurred with Type "B" as well as all of the hail cases which imply that the more traditional severe weather environment associated with quasi-stationary boundaries helps to focus and maintain surface parcel advection and lift with moisture convergence. This in association with an upper core passing to the west of the region provides for enhancement of lapse rates to increase the instability. Therefore, unless this synoptic type is present there should be little or no expectation of hail or tornado in the forecast region in a cool season severe weather episode.

Given these preliminary findings, it would be of value to determine a list of synoptic precursors for each event type and to examine the null case events for comparative purposes. Distinguishing these would be useful to operational and short-term forecasting and provide greater insight to the nowcasting of cool season severe weather in the PHI NWS CWA and vicinity. Other efforts might also include an examination of population density and physiographic features on a county by county basis through the application of GIS methods and datasets.

Further efforts might focus on expanding the study period to generate a larger sample size to better understand the cool season severe weather population parameters. In addition, consideration of the placement and/or expansion of spotter networks where gaps appear may be of interest to investigate in terms of their impacts on reporting of severe weather. The application of alternative techniques, for example the categorization of cold period weather types (Cartalis et al. 2004) or standardized anomalies (Grumm and Hart 2001) might also provide greater insight and direction for further study.

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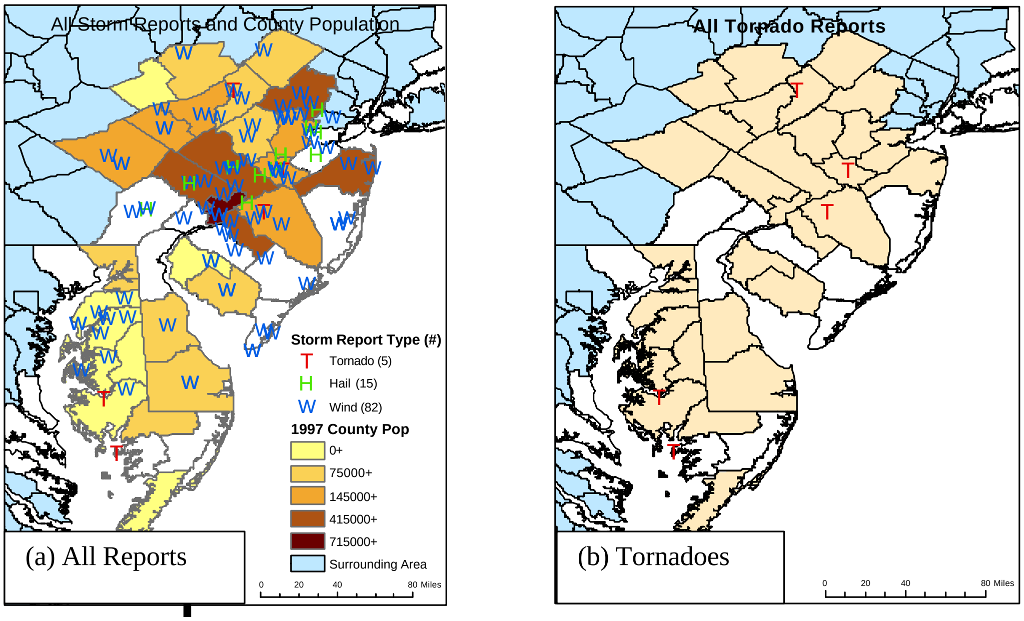
Event Dates Identified	Number of Storm Reports			
	Tornado	Hail	Wind	Total
4 October 2000	1	1	7	9
17 December 2000			3	3
6 January 2002	1			1
9 March 2002			9	9
21 March 2003		14		14
14 October 2003	1		17	18
27 October 2003	2		14	16
13 November 2003			20	20
19 November 2003			3	3
6 March 2004			2	2
13 January 2005			6	6
14 January 2005			1	1
Total	5	15	82	102

Table 1. Event dates and reports occurring within and near the Philadelphia (Mount Holly) National Weather Service County Warning Area. Event types and frequencies are summarized for the cool season (October through March) for the period of study 2000-2005.

Atlantic, NJ – PHI	Morris, NJ – PHI	Delaware, PA – PHI	Cecil, MD – PHI*
Burlington, NJ – PHI	Ocean, NJ – PHI	Lehigh, PA – PHI	Dorchester, MD – AKQ
Camden, NJ – PHI	Salem, NJ – PHI	Monroe, PA – PHI	Kent, MD – AKQ
Cape May, NJ – PHI	Somerset, NJ – PHI	Montgomery, PA – PHI	Queen Anne’s, MD - PHI
Cumberland, NJ – PHI	Sussex, NJ – PHI	Northampton, PA – PHI	Somerset, MD – AKQ
Gloucester, NJ – PHI	Warren, NJ – PHI	Philadelphia, PA – PHI	Talbot, MD – PHI
Hunterdon, NJ – PHI	Berks, PA – PHI	Kent, DE – PHI	Wicomico, MD – AKQ*
Mercer, NJ – PHI	Bucks, PA – PHI	New Castle, DE – PHI*	Worcester, MD – AKQ*
Middlesex, NJ – PHI	Carbon, PA – PHI*	Sussex, DE – PHI	Accomack, VA – AKQ*
Monmouth, NJ – PHI	Chester, PA – PHI	Caroline, MD – PHI*	Northampton, VA – AKQ*

Table 2. Listing of the 40 counties comprising study area of concern in and near the Philadelphia (Mount Holly) National Weather Service County Warning Area. Counties are listed alphabetically for each state (beginning with New Jersey with standard state abbrevations) and according to their local National Weather Service Forecast Office (as identified in text). Those counties appearing with an asterisk (*) indicate no local storm reports during the entire period of study.

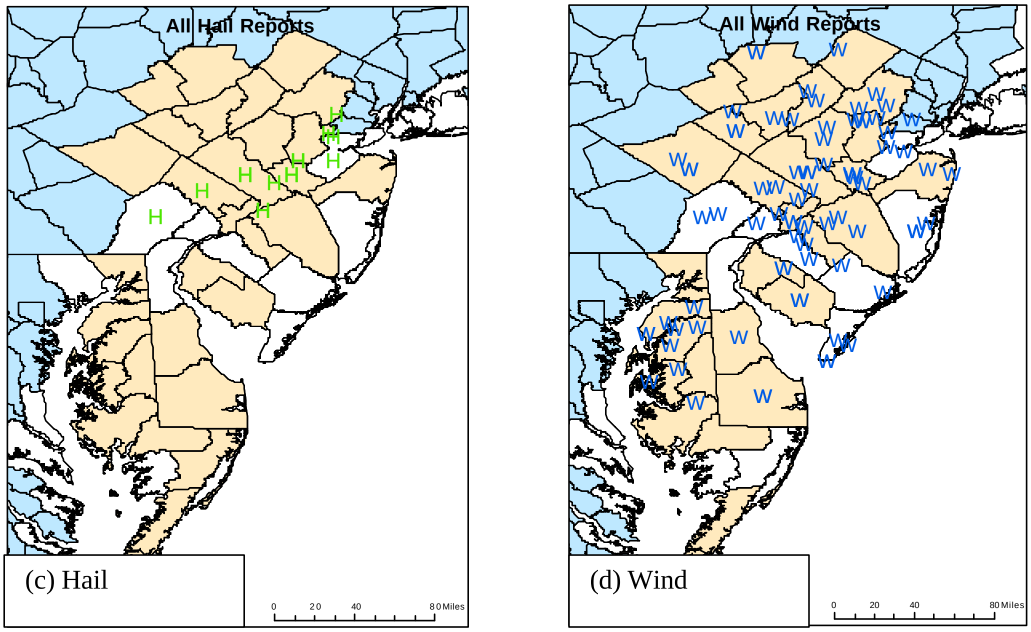
Figure 1. Study area showing (a) all storm reports across all event days (with county population statistics from 1997 as per text); and then according to location of reports of severe weather types (b) tornadoes, (c) hail, and (d) wind.


All Storm Reports and County Population

All Tornado Reports

(a) All Reports

(b) Tornadoes


All Hail Reports

All Wind Reports

(c) Hail

(d) Wind

Event Dates Remaining	Number of Storm Reports			
	Tornado	Hail	Wind	Total
4 October 2000	1	1	7	9
17 December 2000			3	3
6 January 2002	1			1
9 March 2002			9	9
21 March 2003		14		14
14 October 2003	1		17	18
27 October 2003	2		14	16
19 November 2003			3	3
6 March 2004			2	2
14 January 2005			7	7
Total	5	15	62	82

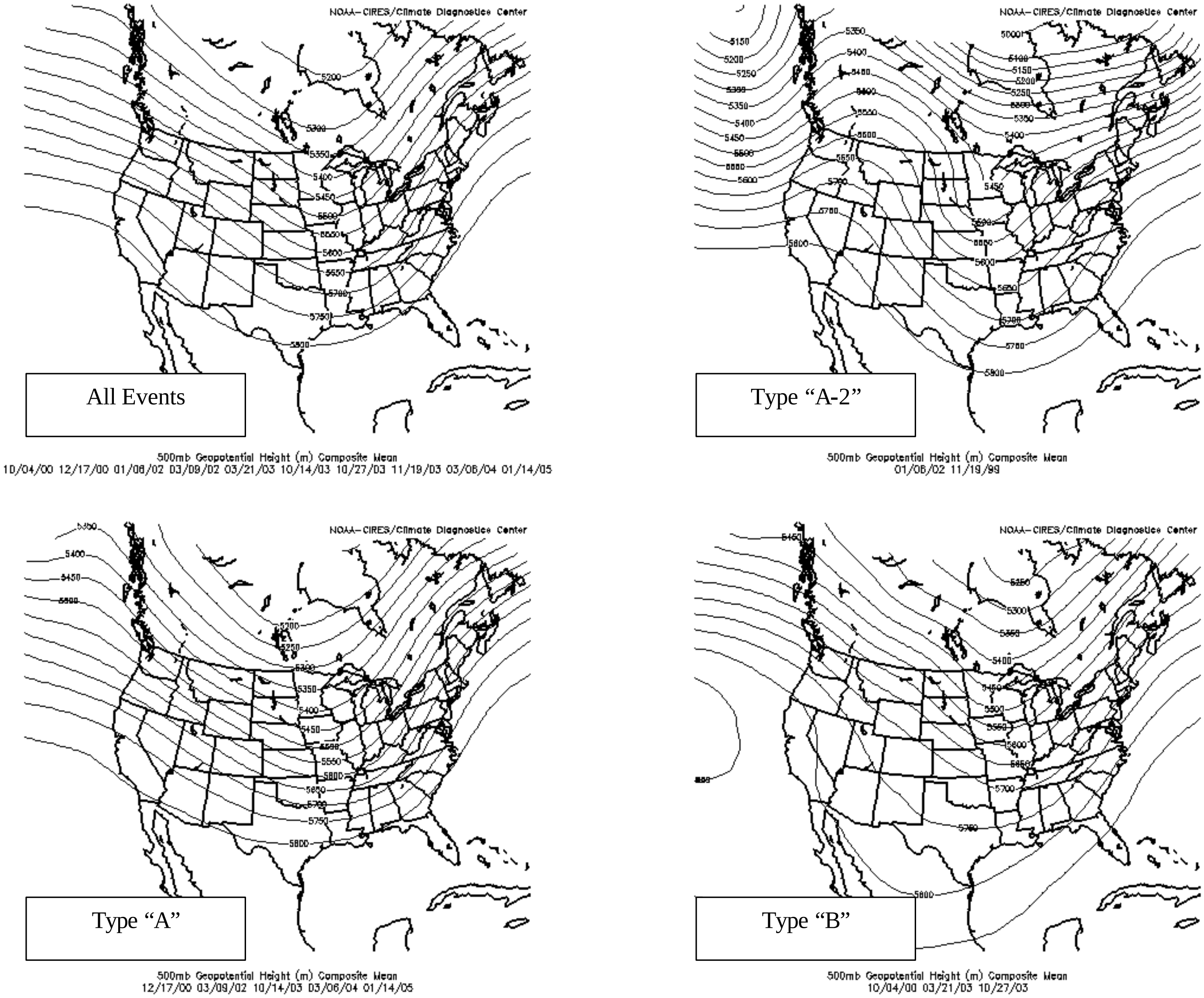
Table 3. Same as Table 1 except for ten case days retained (as per text discussion).

Event Dates Remaining	Synoptic Types		
	“A”	“A-2”	“B”
4 October 2000			9*
17 December 2000	3		
6 January 2002		1	
9 March 2002	9		
21 March 2003			14
14 October 2003	18		
27 October 2003			16
19 November 2003		3	
6 March 2004	2		
14 January 2005	7		
Total	39	4	39

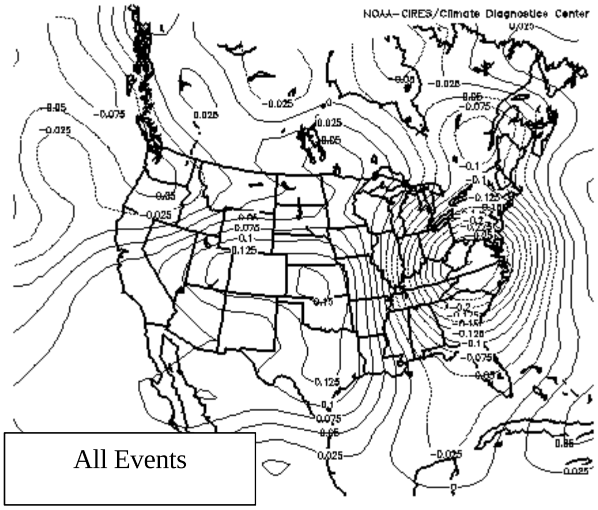
Table 4. Synoptic types identified (as per text discussion) according to event days with number of storm reports received across the study region for each event day. Values with an asterisk (*) indicate all severe weather types occurred (i.e., tornado, hail, and wind).

Figure 2. Three synoptic patterns identified from Daily Weather Map Series based on surface and upper air patterns and features as analyzed through Climate Data Center compositing website. Plots are provided of (a) geopotential height (500 mb), (b) omega (through 100 mb), and (c) sea level pressure for all events combined and types "A", "A-2", and "B".

(a)

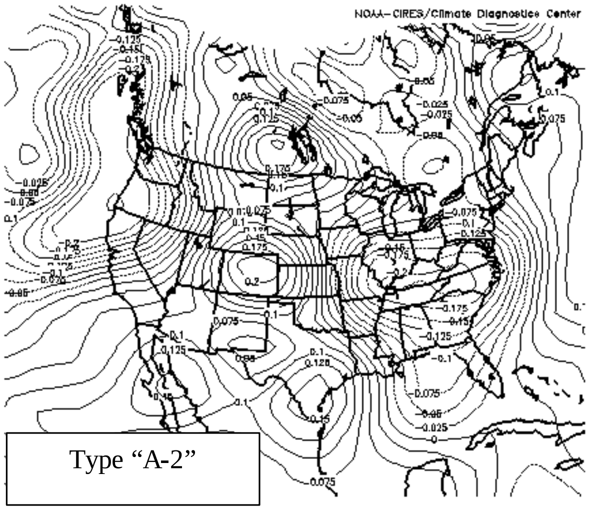


(b)



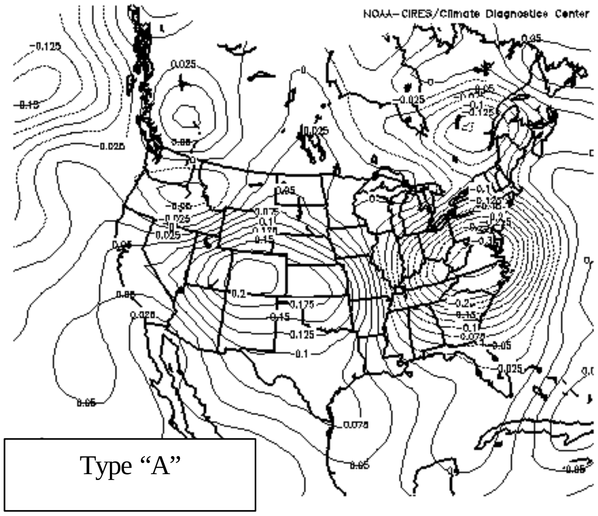
All Events

500mb Omega (Pa/s) Composite Mean
10/04/00 12/17/00 01/08/02 03/09/02 03/21/03 10/14/03 10/27/03 11/19/03 03/06/04 01/14/05



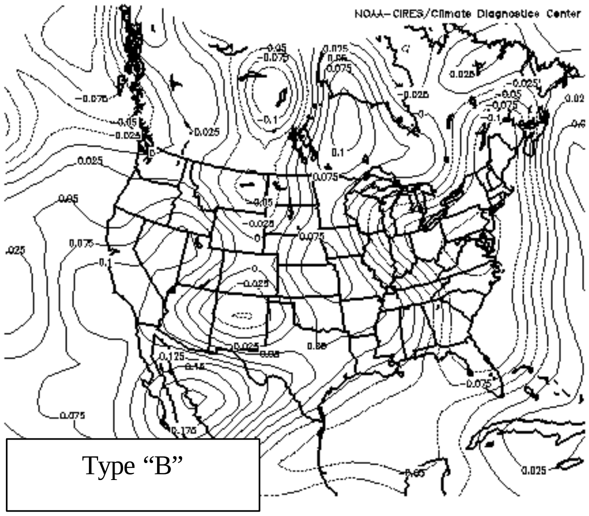
Type “A-2”

500mb Omega (Pa/s) Composite Mean
01/08/02 11/19/99



Type “A”

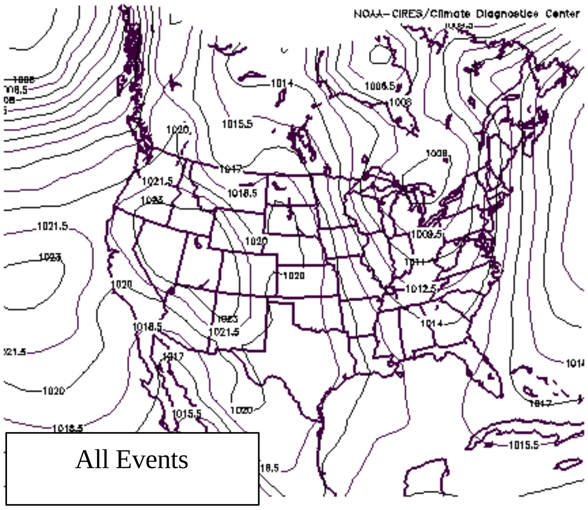
500mb Omega (Pa/s) Composite Mean
12/17/00 03/09/02 10/14/03 03/06/04 01/14/05



Type “B”

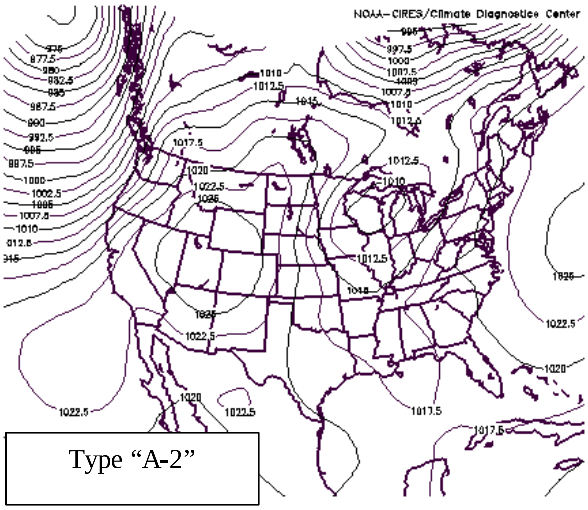
500mb Omega (Pa/s) Composite Mean
10/04/00 03/21/03 10/27/03

(c)



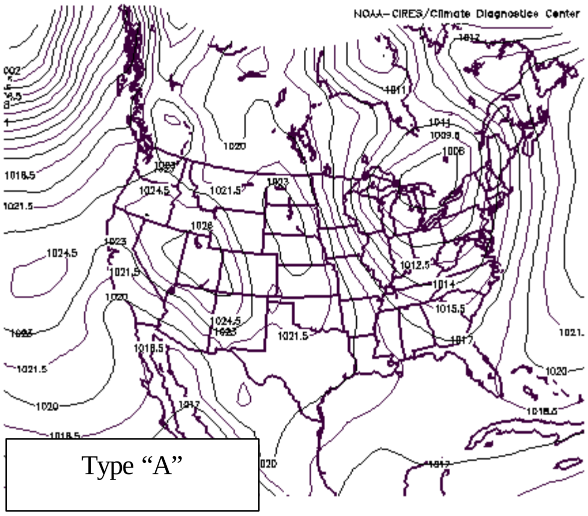
All Events

Sea Level Pressure (mb) Composite Mean
10/04/00 12/17/00 01/06/02 03/09/02 03/21/03 10/14/03 10/27/03 11/19/03 03/06/04 01/14/05



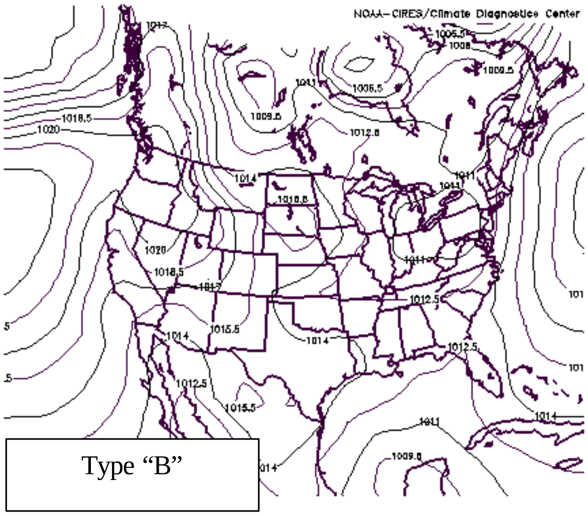
Type “A-2”

Sea Level Pressure (mb) Composite Mean
01/06/02 11/19/99



Type “A”

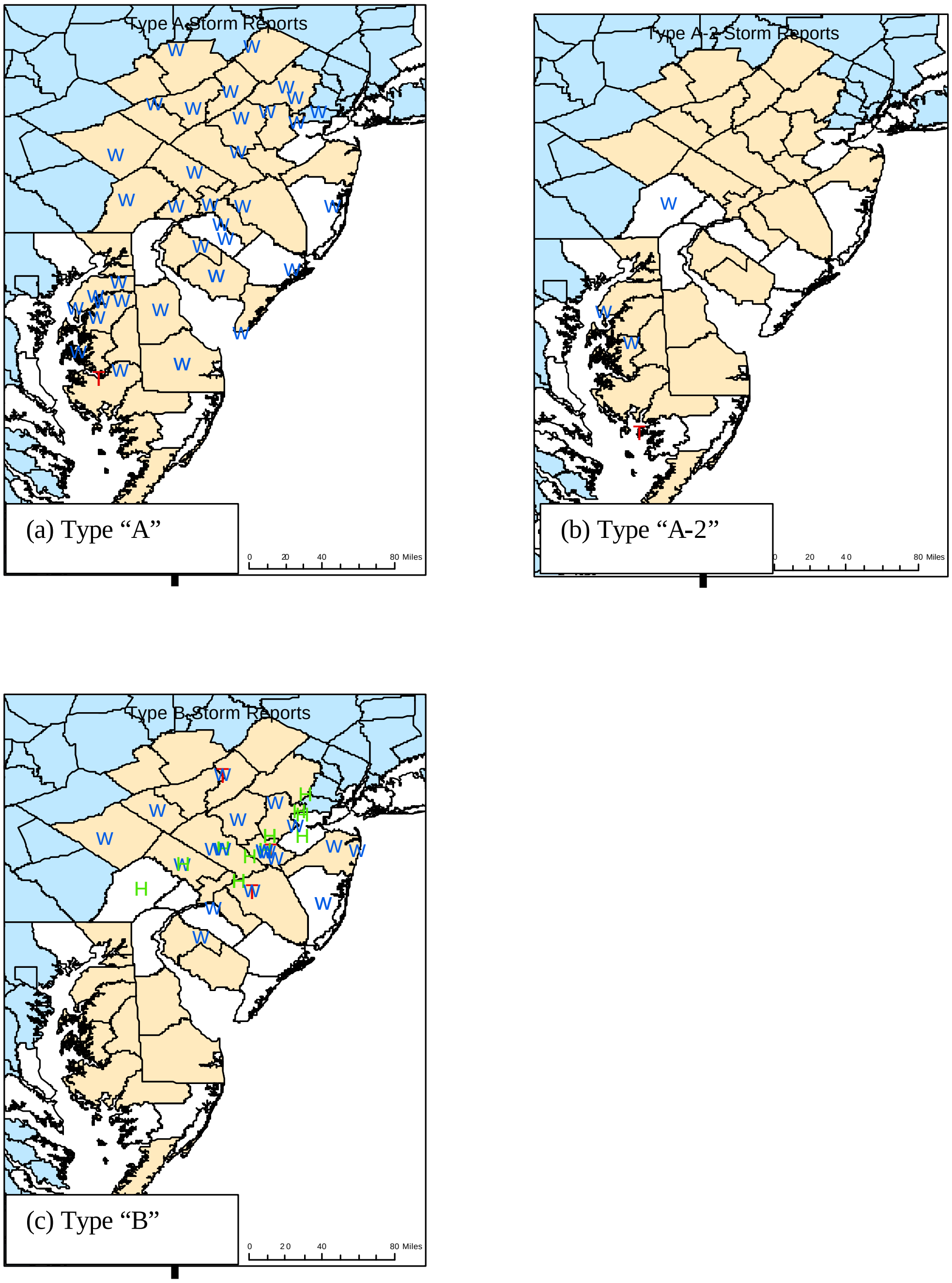
Sea Level Pressure (mb) Composite Mean
12/17/00 03/09/02 10/14/03 03/06/04 01/14/05



Type “B”

Sea Level Pressure (mb) Composite Mean
10/04/00 03/21/03 10/27/03

Figure 3. Distribution and type of storm reports within the study area according to synoptic types (a) “A”, (b) “A-2”, and (c) “B” as defined in the text.



(a) Type “A”

(b) Type “A-2”

(c) Type “B”