PRELIMINARY SYNOPTIC CLIMATOLOGY OF COOL SEASON CONVECTIVE SEVERE WEATHER EVENTS IN AND NEAR THE PHILADELPHIA NOAA/NATIONAL WEATHER SERVICE FORECAST OFFICE COUNTY WARNING AREA

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Abstract

An examination of the synoptic climatology of convective severe weather occurrences (tornado, hail and damaging wind) during the cool half of the year (October through March) was considered for the Philadelphia (Mount Holly, New Jersey) NOAA/National Weather Service (NWS) Weather Forecast Office (WFO), County Warning Area and vicinity. Using online storm reports from the NOAA/NWS Storm Prediction Center (SPC), a sample of severe weather reports was identified and studied for the five cool seasons of 2000-2001 through 2004-2005. While cool season convective severe weather occurrence was rare in the study area for the five years studied, occurring only approximately one percent of the time, it was found to occur in all cool season months (except February) with maxima in October and March. The severe weather events were dominated by wind damage reports (80%) and occurred on average once each cool season. Hail was relatively rare, occurring only two days, versus tornadoes (four days, most in October,) and there was little evidence of spatial preference in storm locations. Through a self-sorting classification approach, three synoptic patterns were identified that produce convective severe weather during the cool season. Two of the types (North American Trough and Central Trough) illustrated the significance of dynamic forcing and the role of the large-scale synoptic setting. The third synoptic type (Great Lakes Trough) was also a prolific producer of severe weather of all kinds, but differed in its dependence on boundary layer instability and forcing. Null cases were also investigated, based on the very active 2003-2004 season (in which 2% of all days had severe weather), to determine the frequency of the severe weather patterns identified in order to distinguish non-events from those producing severe weather. While the North American Trough, Central Trough, and Great Lakes Trough patterns were observed to occur 15% of the time during the cool season examined, only 14% of these occurrences were associated with severe weather in the study region. Composites of all data sets using the online tools of the provided by the NOAA/Earth System Research Laboratory, Physical Sciences Division, Boulder, Colorado National Oceanic and Atmospheric Administration-Cooperative Institute for Research in Environmental Sciences-Climate Diagnostics Center provided evidence of real synoptic differences that would enable operational forecasters to distinguish between events and non-events in real-time in order to avoid "false alarms". The first half of the 2005-2006 cool season afforded an opportunity to test the results of the investigation and may be used to develop a conceptual model and forecast approach.

1. Introduction

Cool season (October through March) convective severe weather occurrences (tornado, hail and damaging wind), in and near the Philadelphia (PHI) WFO (located in Mount Holly, New Jersey) County Warning Area (CWA), while rare (e.g., Kruzdlo and Cope 2005; Brooks et al. 2003), do pose a significant forecasting challenge. While most severe wind events tend to be related to strong pressure gradients given the synoptic forcing common during the cool season as related to intensifying low pressure systems and strong frontal boundaries; 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.

In order to better understand the problems associated with cool season convective severe weather events, the PHI WFO CWA and nearby area were selected for study. This region is often 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 also considers it to be a region in which the Atlantic Ocean and Chesapeake Bay region exert a considerable modifying 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 because of complex, and often poorly understood land-surface interac-

Table 1. Listing of the 40 counties comprising the study area of concern in and near the Philadelphia (PHI) NOAA/NWS Weather Forecast Office, County Warning Area. Counties are listed alphabetically for each state (beginning with New Jersey with standard state abbreviations) and according to their local NWS Forecast Office alphanumeric identifier. Those counties appearing with an asterisk (*) did not indicate any local storm reports during the period of study.

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. Event dates and storm reports occurring within and near the Philadelphia NOAA/NWS Weather Forecast Office, County Warning Area. Event types and frequencies are summarized for the cool season (October through March) for the period of study 2000-2005. Data with asterisks indicate data later removed and/or modified as explained in the text.

Event Dates	Number of Storm Reports			
Identified	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**

tions (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 synoptic climatology approach is used. The intent is to determine the synoptic features associated with local storm reports occurring over several cool seasons. This provides greater insight as to the characteristic nature of these events, their associated attributes and patterns, and provides some guidance as to what forecasters might look for to recognize the potential for severe weather in advance. Also, in order to distinguish these events from what may be common or recurring patterns during the cool season, null cases are also considered to avoid a high false alarm rate. The identification of these may improve prediction across this major metropolitan area while defining what other work is necessary to understand these cases.

2. Data Collection and Methodology

The local storm reports database available online (http://www.spc.noaa.gov/climo) from the SPC was examined for each of the five cool seasons of 2000-2001 through 2004-2005 to determine the type and frequency of severe weather events (or cases) for the study region. Reports of severe weather (tornado, large hail, and damaging wind) were collected for the immediate PHI WFO CWA as well as the surrounding area (see Fig. 1) including adjoining counties from the Wakefield, Virginia (AKQ) WFO CWA (i.e. five additional counties from Maryland and two in Virginia; see Table 1) so as to capture as many event reports as possible. The study region represents a large portion of the Washington, D.C. to Boston megalopolis that includes varied climatic zones, diverse physiographic features, and high population density areas subject to damage and injury.

a. Severe weather events

Severe weather events (local storm reports) occurred over 12 separate days (see Table 2) out of a possible 911 cool-season days (i.e. 182 days each year, plus one leap year day), or only 1.3% of the time. These events produced 102 severe weather reports across 32 of the 40 counties, including five 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, ten included wind (83%), four tornadoes (33%), and two hail (17%) and these were retained for investigation. Two of these dates were eventually "removed" from consideration as described later in this section.

The storm reports were plotted against the 1997 County Population Statistics via Geographic Information Systems (GIS) analysis (Chang 2004). Examination revealed very few local storm reports in the Delmarva Peninsula, but 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. 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 (or survey teams) 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 apparent except for the hail events (Figs. 1b, c, and d). Examination of the hail cases revealed that 14 of the 15 hail reports occurred on 21 March 2003 and were oriented across the study region from the southwest to northeast. The other day, with only one report of hail, was 4 October 2000.

Tornado reports were limited to only four days in three months: October 2000, January 2002 (reported as a possible waterspout), and October 2003. 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 types reported, occurring in all months (except February) with maxima in October and November, and the most widespread across the study area.

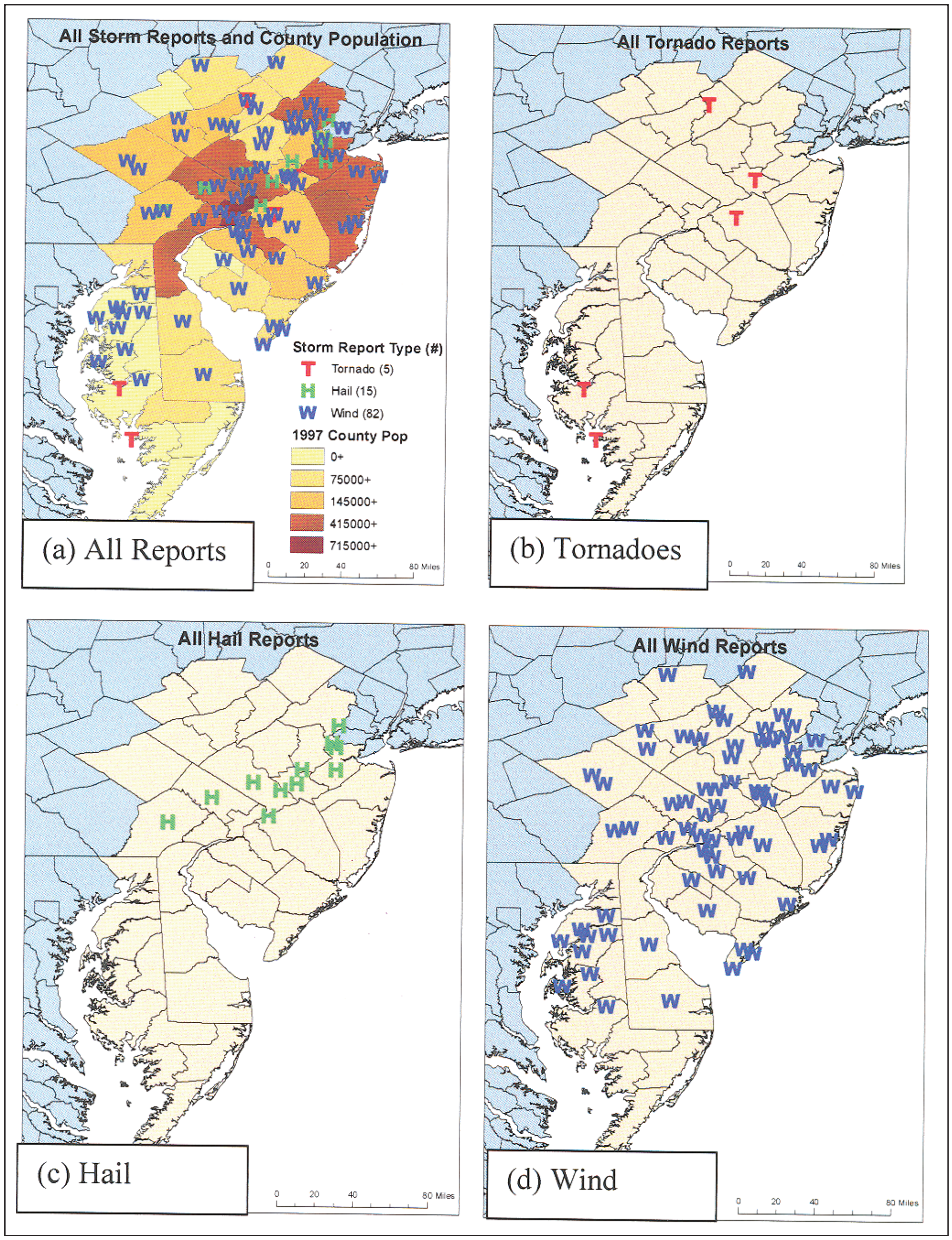

Fig. 1. Study area showing (a) all storm reports across all event days (with county population statistics from 1997); and, according to location of reports of severe weather types (b) tornadoes, (c) hail, and (d) damaging winds.

b. Synoptic setting

While strong dynamic forcing often overcomes the lack of sufficient thermodynamics or instability in cool season severe weather outbreaks, no attempts were made in this study to link specific dynamic and thermodynamic attributes directly (e.g., Rose et al. 2004; Metz et al. 2004). There were also no attempts to perform case studies or consider significant parameter values or radar signatures (e.g., Kruzdlo and Cope 2005) of any one event or to identify specific cases of high- shear low- topped convection or similar attributes. 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. This would allow for the development of a predictive conceptual model to improve understanding of the dynamics behind all events.

Therefore, the Daily Weather Map Series (DWM), available both online and in print form, were obtained (http://www.hpc.ncep.noaa.gov/dwm/dwm.shtml) from the NOAA/NWS National Oceanic and Atmospheric Administration's National Centers for Environmental Prediction (NOAA NCEP) – Hydrometeorological Prediction Center (HPC) to depict the basic synoptic weather patterns occurring during each of the 12 days of events identified. 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

Table 3. Same as Table 2 except for the ten case days retained and the synoptic weather type identified. Each synoptic type produced the following number of days of severe weather: NAT – five, CNT – two, and GLT – three.

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

DWM Series includes only an early morning depiction of the synoptic weather pattern (i.e. at 1200 UTC).

Analysis focused on determining the surface and upper- air (500 mb) features occurring in order to allow the events to "self-sort" themselves into the weather patterns (or types) found to be associated with the occurrence of severe weather. This method of classification provides information about the population of weather regimes and their features, occurring in the study region, and is often applied in the development of contingency or conditional probability tables.

The premise of the method is based upon relating observed synoptic patterns to the occurrence of specific phenomena and has its roots in dynamic climatology (Glickman 2000) as formally developed by Bergeron, and later referred to as physical or synoptic climatology. Initial applications were made with regard to air mass frequencies (Bergeron 1930) and their source regions which then served to identify the synoptic patterns that were associated with various weather regimes. This sort of classification, or self-sorting approach, has its basis within sampling theory (Stringer 1972) when attempting to identify populations and the characteristic features of these distributions. It also serves as the basis for various data mining and other classification techniques, for example the decision-tree diagram, and many of these which are used (Earickson and Harlin 1994) in operational contexts.

This "natural selection" process allowed distinct patterns to emerge rather than be specified in an arbitrary or preconceived "a priori" manner by this investigation or by the authors. In its simplest form, it provides for distinction between severe and non-severe weather patterns (bimodal); either of which may be further sub-divided to consider the distributional characteristics within the populations. In the case of severe weather patterns it would assist in defining a "family" of patterns that may lead to cool season severe weather. The approach facilitates the application of the technique to any relational database, particularly those that involve synoptic weather types. It therefore allows for portability to any other location as the phenomenon of interest is a function of the synoptic patterns predominant in that location.

Based on the foregoing reviews and considerations, one of the event days was removed from further study as it was clearly a high-wind event 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 and noted hereafter as 14 January 2005 as it was found that the storm reports were associated with the same synoptic scale event (13-14 January 2005) but reported on different calendar dates. The remaining data (ten event days, see Table 3) were then analyzed according to their synoptic patterns and features from an operational point of view. Therefore, the occurrence of cool season severe weather was reduced to ten of 911 days, or 1.1 percent; making the frequencies of each severe weather type to be: wind 80%, tornado 40%, and hail 20%.

c. Null and test datasets

While cool season severe weather events in the study region are rare, as demonstrated above, the patterns found to produce them may be fairly common for the given time of year. Therefore, an examination of null cases was deemed important to the understanding of whether to expect severe weather for those weather patterns associated with local storm reports. This was predicated upon the synoptic patterns found for the severe weather events so that differences from the non-occurrences could be determined to help forecasters in predicting severe weather, and therefore reducing false alarms.

Given the large number of null cases that would exist for such a large database (five cool seasons times an average of 1820 days; or nearly 1000 null cases to investigate), the authors selected the most active cool season of October 2003 through March 2004 as a representative sampling. This season produced severe weather reports of damaging winds, tornadoes, and hail. Of the ten severe weather days identified in this study, four days occurred during the 2003-2004 cool season, or 2% of all days of that season, and produced the majority of the local storm reports (39 of the 82, or 48%) found in the study.

For this most active season there were 179 of 183 days, or 98% of the dates, with no severe weather occurring and only four days, or 2%, with storm reports. Of these 183 days, there were an additional 25 having a pattern matching those identified by the methodology to be associated with storm reports. Therefore a total of 29 days had a severe weather pattern, but only four of these (14%; or approximately one in seven) produced severe weather in the study region.

In an operational sense the application of these findings implies that, should a severe weather synoptic pattern be forecast to occur during the cool season, a forecaster would expect only one in seven of these to result in severe weather. To distinguish that one day from the other six requires an examination of the “non-producers”, or null cases, to determine similarities and differences that a forecaster could use to separate the real threat from a “false alarm”.

In addition to a null case investigation, it was of practical importance to also consider a test season to explore the usefulness of the findings. Therefore, the authors selected the first half of the 2005-2006 cool season for testing of both severe weather event and null cases. This independent data set would retrospectively provide confirmation of the study’s results, reveal any apparent discrepancies in methods or conclusions, and could be used to assess the effectiveness and usability of the results in an operational forecasting environment.

3. Analysis

The ten event days (Table 3) were analyzed based on inspections of the DWM Series and three distinct surface and upper- air synoptic patterns were identified. These were named based on their upper- air patterns: five North American Trough (NAT), two Central Trough (CNT), and three Great Lakes Trough (GLT) (see Table 4). The timing of severe weather reports was found to be confined to the period of 1900 through 0000 UTC for both CNT (1946-2102) and GLT (1915-0045) but varied from 0200 through 1400 UTC for the NAT events with an outlier being reported at 2125. Therefore, while there was a preference for types CNT and GLT to follow the diurnal maxima cycle according to instability, there was an overnight to early morning preference for the first type (NAT) in which a full-latitude and phased trough was present.

For each of these synoptic types and for all types combined, summary statistics of their associated attributes were generated (not shown). These included location and intensity of surface low and high pressure systems and pressure gradients as derived from the DWM Series. As complete box-and-whisker plots were not possible given the small sample size available for each synoptic 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 surface low pressure intensity was weakest for GLT and strongest for NAT, as was the local surface pressure gradient. The CNT produced the least, the NAT and GLT the most, total storm reports among synoptic types. The NAT and GLT produced the most.

Composite maps were also generated for the synoptic weather patterns identified using the images provided by the NOAA/Earth System Research Laboratory (ESRL), Physical Sciences Division, Boulder, Colorado from their Web site at http://www.cdc.noaa.gov/composite, based on datasets from the NCAR/NCEP 40-year Rea-Analysis Project (Kalnay et al. et al. 1996), for all severe weather report dates combined (Fig. 2) for all severe weather report dates combined (Fig. 2) and for each of the synoptic patterns in Figs. 3, 4, and 5 (NAT, CNT, and GLT) based on the event days available. Each set of composites,

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

Event Dates Remaining	Synoptic Types NAT	CNT	GLT
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**

Figs. 2 through 5, included geopotential height at 500 mb (a), omega (b), and sea level pressure (c). These were analyzed with regard to their features, differences from one another; and the type and distribution of severe weather reports in the study region. Although these are by their very nature mean charts, they do represent the summative results of atmospheric forcing related to the severe weather occurrences for the study region.

The overall flow for all events includes a full-latitude trough axis through central North America to the west of the study region, as would be expected, and thus provided dynamic forcing with or without substantial instability. While it is very possible that these patterns are also related to one another because of the evolution of the upper air pattern with time, no distinctions were made as the timing and placement of the mass fields themselves would dictate the occurrence of severe weather. The methodology used here simply provides a “snapshot in time” and therefore cannot distinguish one from another or the actual evolution. The intent was to identify recognizable synoptic patterns occurring in real-time, or forecast to occur, in order to help discern the cool season severe weather threat. These patterns were then further examined to determine how often they occurred as compared to how often they produced severe weather.

a. North American Trough (NAT)

Review of the DWM Series in conjunction with the composites indicated that although all types shared a strong southwest flow aloft as shown by the 500- mb geopotential height analyses, the NAT was characterized by a progressive frontal system associated with a full-latitude trough, strong flow from the Pacific Ocean, and an intense primary surface low pressure center in Canada and the northern Great Lakes (Fig. 3). In each case, this led to the passage of a warm frontal feature leaving the entire study area within a warm- sector environment, and possibly favorable low- level jet dynamics during the

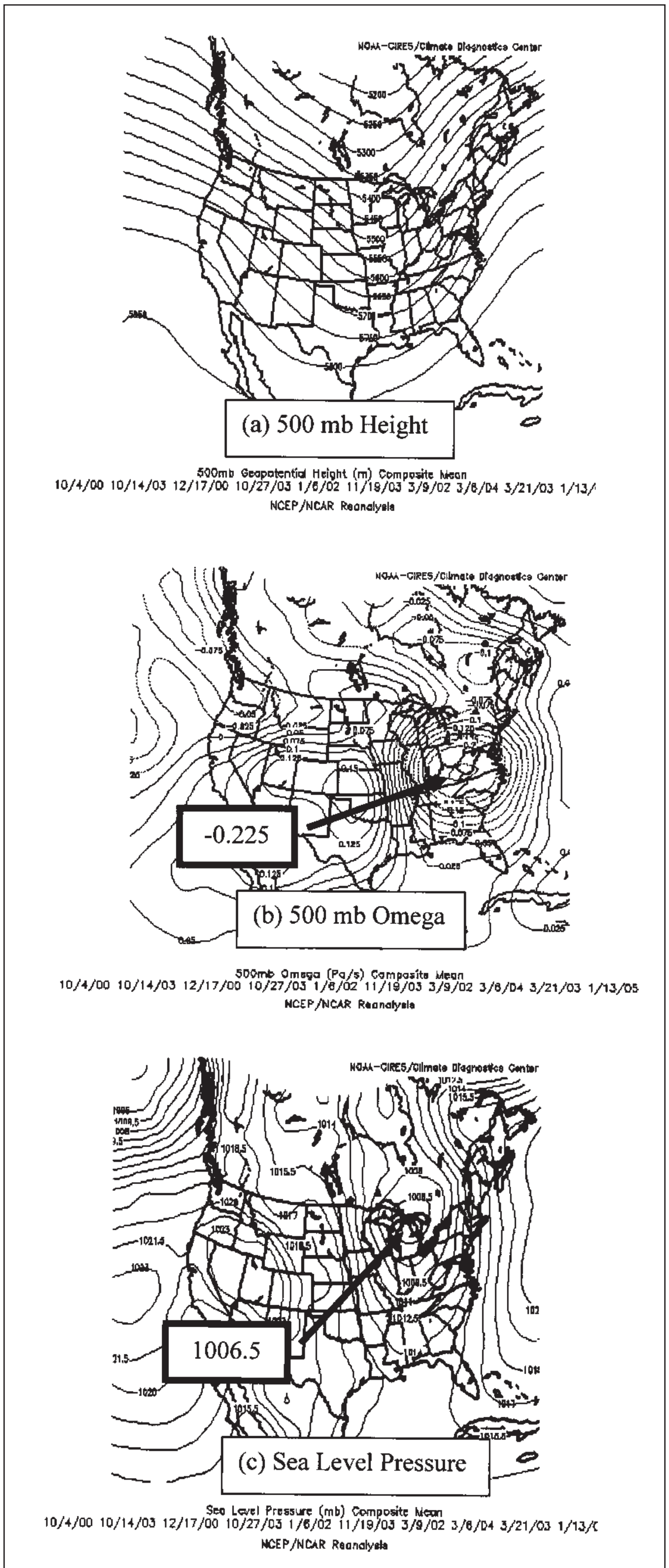

Fig. 2. Combined synoptic patterns for all events identified from Daily Weather Map Series through surface and upper-air patterns and features as analyzed through the NOAA/ESRL Physical Sciences Division compositing Web site. Analyzed charts are provided of (a) Geopotential Height (m) at 500 mb, (b) Omega (Pa/s), and (c) Sea Level Pressure (mb). Minimum value of inner isopleth of interest is highlighted in (b) and (c).

overnight period, prior to cold frontal and trough passage and, therefore, the development of severe weather. The accompanying omega field chart was very distinct with the advancing shortwave developing a negative tilt and showing a lobe extending eastward.

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, particularly given the extent and strength of upper-level forcing. 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 observed to produce severe weather in all cool season months studied 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, as compared to CNT and GLT, the overall composite maps share greatest similarity with this pattern. The only type as prolific in generating the same number of severe weather reports was GLT which occurred over only three event days in the data sample.

b. Central Trough (CNT)

The second synoptic pattern (CNT) differed in that it included a distinct cold- core system aloft located in the Gulf States (Fig. 4). The system moved in closer proximity to the study area than the NAT type. The primary surface system was located over the Great Lakes region prior to its 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, and had a more distinct upper- air and surface ridging from the Atlantic Ocean. The frontal system was less intense at the surface as compared to the NAT events and the stronger ridging may have supported the stabilization of the boundary layer.

The associated omega field chart indicated a less focused and more spread-out region of lift, as might be expected based on the upper- air pattern given the dual features at the 500- mb level, 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 reports and one waterspout moving onshore and reported as a tornado. These 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 which was apparently focused along and in association with the Chesapeake Bay region. This limited both the number and distribution of severe weather reports across the study region as compared to the NAT events.

c. Great Lakes Trough (GLT)

The third synoptic type (GLT) is very different from the prior two, as it is characterized by the presence of quasi-stationary boundaries at the surface under a strong southwest flow aloft, with some contours originating in Mexico suggesting the introduction of an elevated mixed layer with time (Fig. 5). 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 contained less significant dynamic forcing as compared to the NAT and CNT types. The isobaric field also suggesteds an east-west oriented boundary, or northeast-southwest, existing under a strong parallel flow aloft (and streamwise vorticity) that could assist in the generation of severe weather because of localized boundary layer instabilities. The GLT events occurred on three separate days, during October 2000 and 2003 and March 2003, and produced all of the observed hail reports in this study as well as three tornadoes and 21 wind reports in both Octobers.

d. Spatial distribution

In order to further consider any spatial patterns of these severe weather occurrences, the storm reports were also plotted by synoptic type (Fig. 6) to determine features specific to the severe weather occurrences, and by time of year (not shown) to identify any trends. The NAT events (Fig. 6a), in which the primary system moves from the Great Lakes region into Canada and which have the strongest pressures and pressure gradients indicated the majority of wind reports occurred inland away from the immediate coast. This type, dominated by wind reports, suggests a greater synoptic scale role of dynamic forcing in the production of severe weather and the possibility of upslope contributions to increase events versus the coastal plain.

In CNT events (Fig. 6b) storm reports were 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 and surface convergence. Most of the reports also occurred at the coastal margin suggesting interactions on a mesoscale related to surface friction and other influences.

For GLT events (Fig. 6c), in which pressure values and gradients were the weakest, all storm reports were located in the northern half of the study region suggesting the possibility of frictional and elevation effects within the local storm environment. These cases were characterized by an unstable boundary layer with local focusing related to mesoscale features. This was the only synoptic type which produced all of the possible severe weather types (i.e., tor-

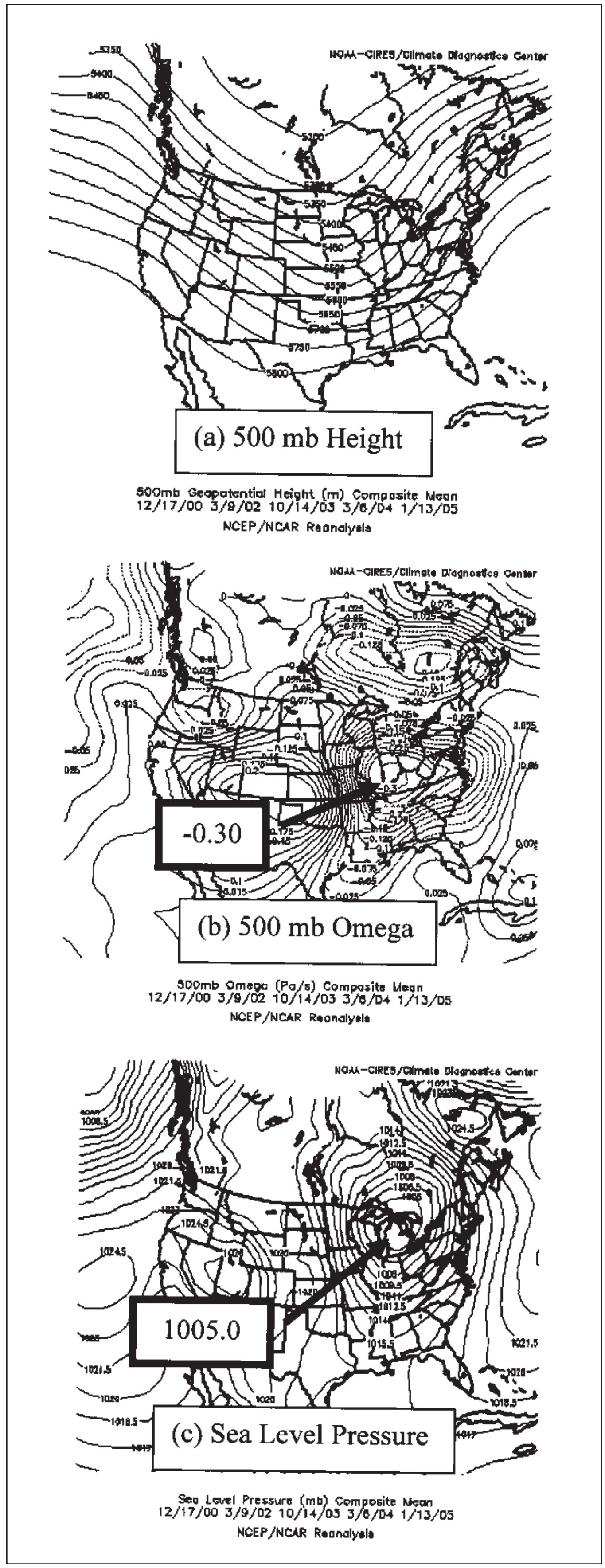

Fig. 3. Same as Fig. 2 except for all NAT cases.

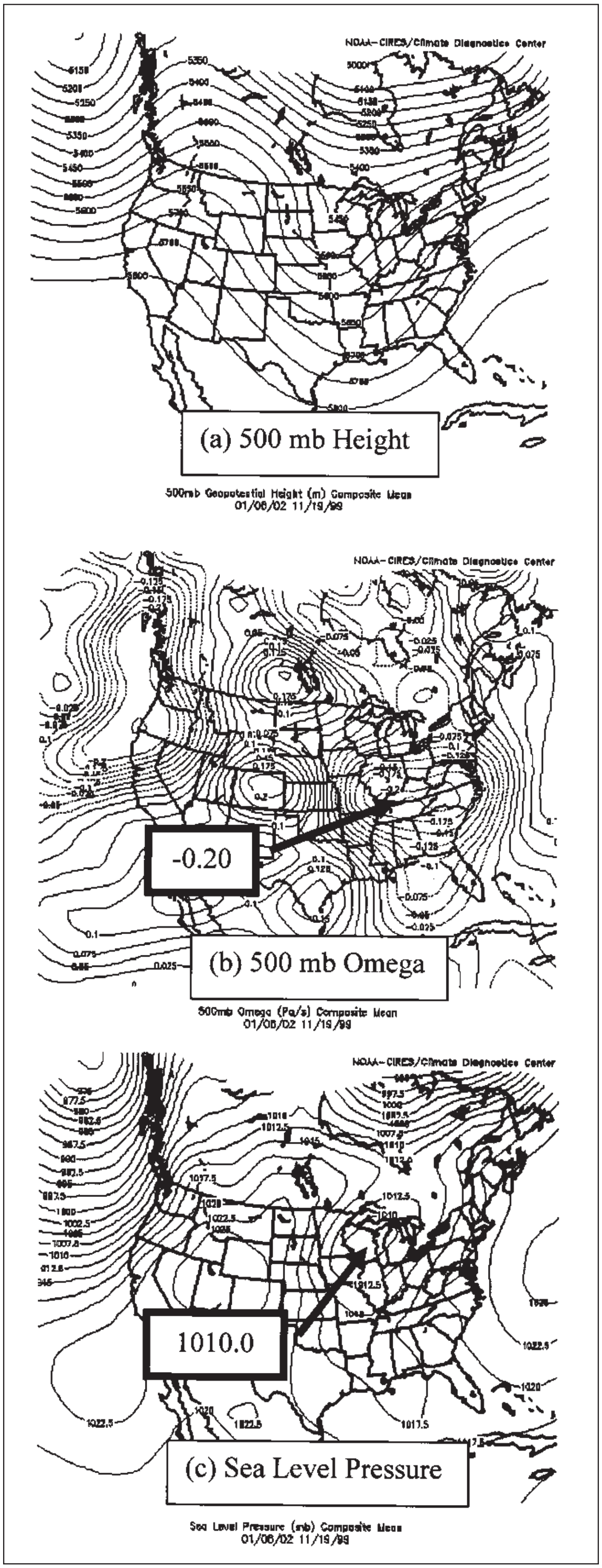

Fig. 4. Same as Fig. 2 except for all CNT cases.

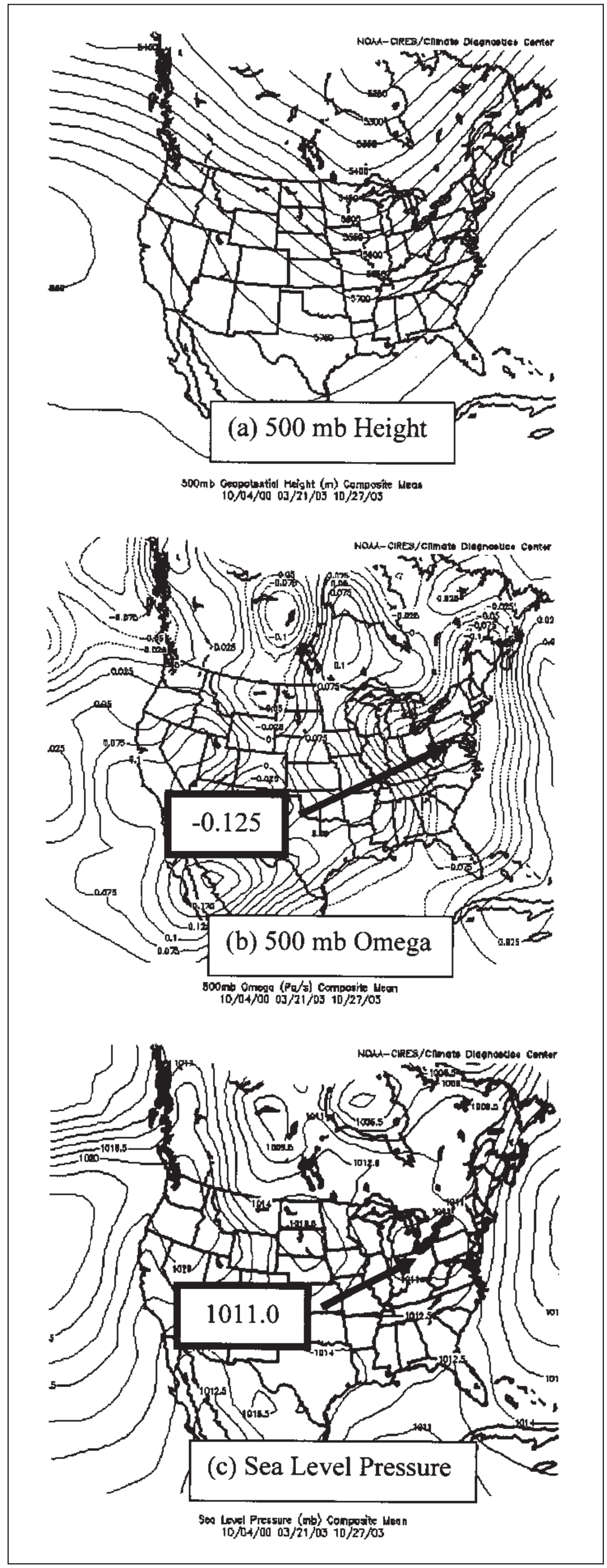

Fig. 5. Same as Fig. 2 except for all GLT cases.

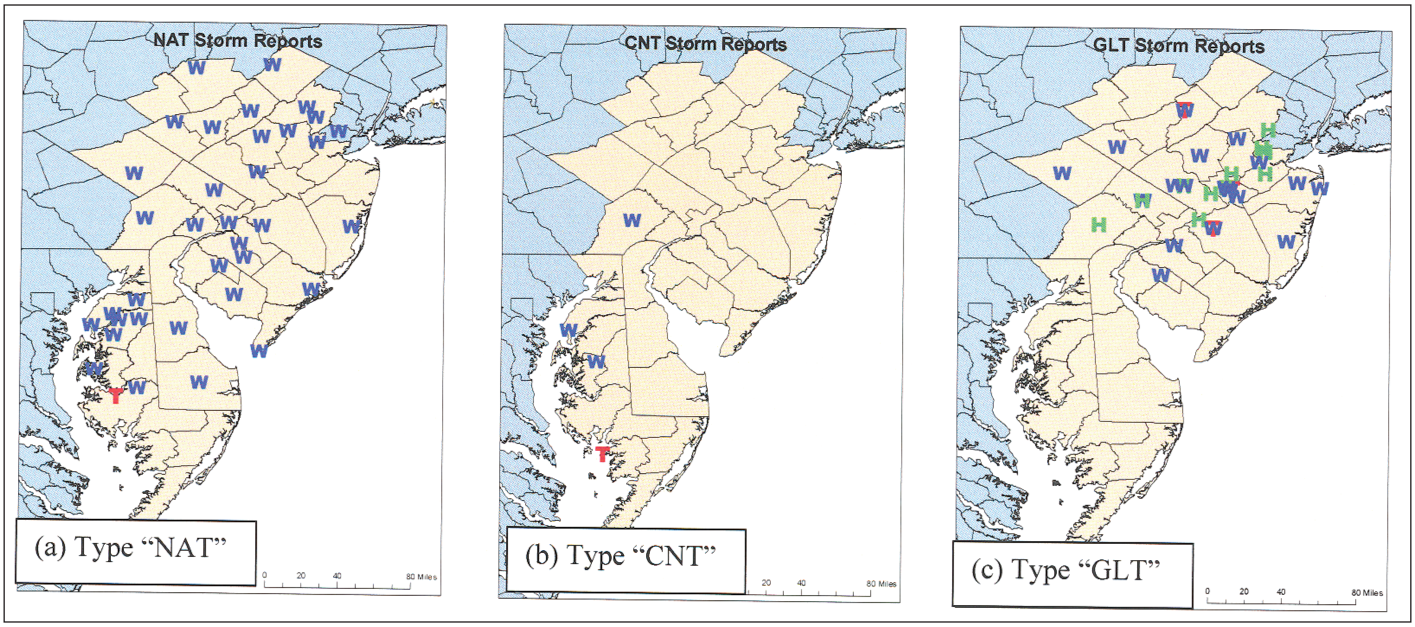

Fig. 6. Distribution and type of storm reports within the study area according to synoptic types (a) "NAT", (b) "CNT", and (c) "GLT".

nado, hail, and damaging wind) and was as prolific in generating severe reports as the NAT type (see Table 4).

e. Null investigation

Based on examination of the 2003-2004 cool season (using the DWM Series available online), 25 additional days (or 14% of 183 days) were found that shared the synoptic type patterns identified for the cool season severe weather events. The pressure gradient event of 13 November 2003 was eliminated as per the *Synoptic setting* discussion. Therefore a total of 154 days (85%) did not share the synoptic type patterns and suggests that the patterns producing severe weather, although not as rare as the events themselves, are much less frequent in occurrence than other synoptic patterns experienced during the cool season. Of the 29 days, 13 were NAT (45% as compared with 50% of all severe event days), eight CNT (28% versus 20%), and eight GLT (28% versus 30%); and therefore each occurred with nearly comparable frequency as the severe weather events database already developed.

Those 25 days that shared synoptic patterns associated with cool season severe weather, but not producing severe weather in the study region, were retained (Table 5) to determine whether they produced any severe weather "nearby" (i.e., occurring within the northeastern quarter of the contiguous United States from Ohio, West Virginia, and Virginia northward), at some "distance" (i.e. east of the Mississippi River, but not including the northeastern United States), or not at all (i.e. no storm reports). This was completed through review of the SPC online storm reports for all 25 of the 2003-2004 cool season dates identified.

Based on these criteria, 22 of 25 null case dates (88%) either did not produce severe weather (17 days) or produced severe weather at some "distance" (five days) from the study area. This implies that when a severe weather pattern is observed in the cool season (NAT, CNT, GLT), only about one of ten would be expected to cause severe weather in the study region. Only three days produced severe weather "nearby" and were investigated to determine how close to the region the reports were and whether they should be considered as "near misses" or potentially "false" events (e.g., a pressure gradient situation).

The "nearby" event dates included 20 October, 5 November, and 6 December of 2003 and produced one report of hail; one tornado and eight wind reports; and three wind reports respectively. Synoptic examination revealed the first case to be an isolated incident (in upstate NY) under surface high pressure with a fast zonal flow aloft. The second event showed strong ridging and a quasi-stationary boundary responsible for severe weather across Maryland. The third event was characterized by a major trough over the region with a

Table 5. Frequency of synoptic weather types associated with cool season severe weather occurring during the 2003-2004 season and classified as producing: no severe weather, severe weather at some "distance" from the study area, "nearby" the study area, or severe weather events in the study area.

Synoptic Weather Type Identified	Number of Storm Reports				
	No Severe Weather	Severe Weather "Distance"	Severe Weather "Nearby"	Severe Weather Event	Totals
NAT	7	2	2	2	13
CNT	4	2	1	1	8
GLT	6	1	0	1	8
Totals	**17**	**5**	**3**	**4**	**29**

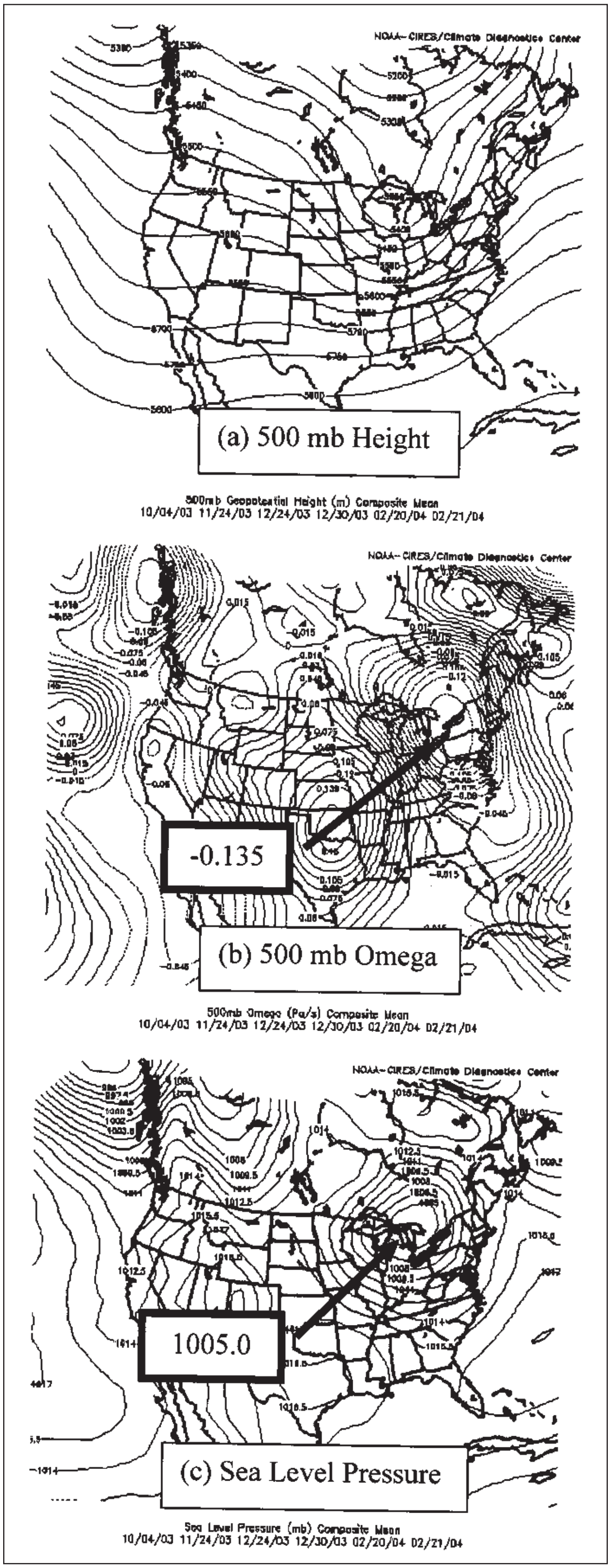

Fig. 7. Null case synoptic composite fields (as in Fig. 2) for NAT synoptic type.

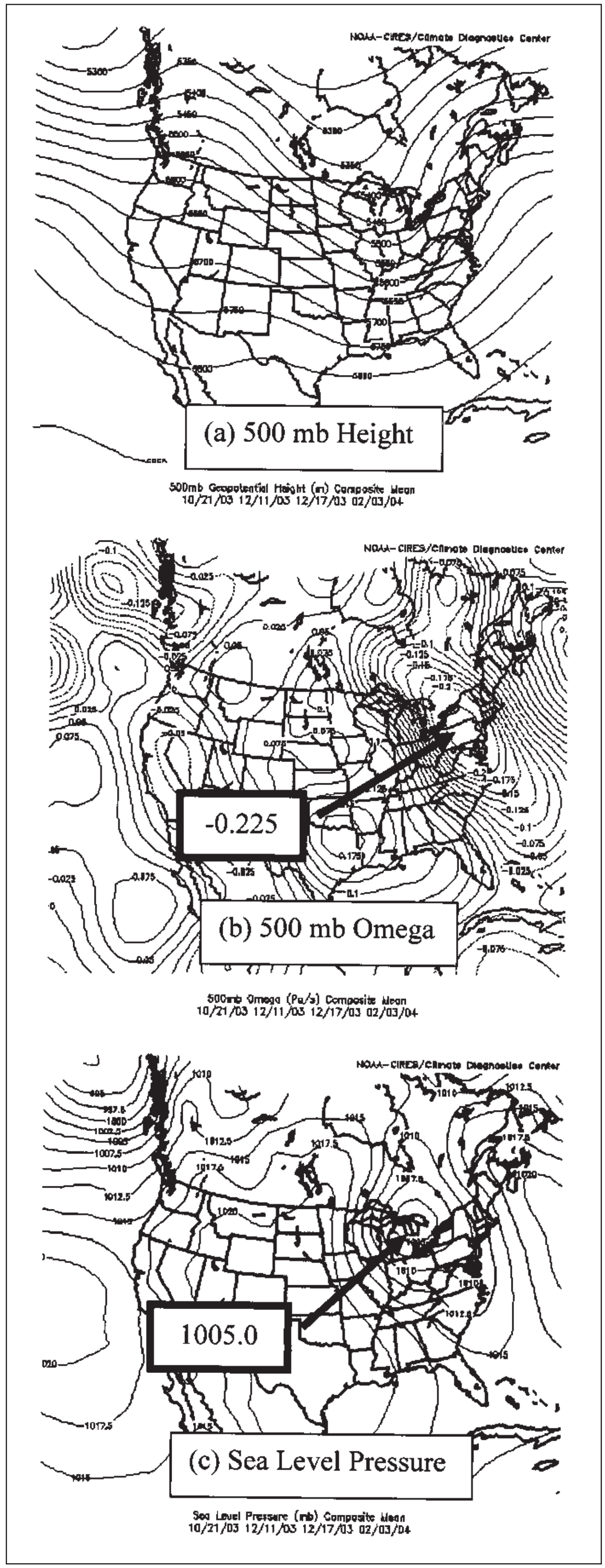

Fig. 8. Same as Fig. 7 but for CNT synoptic type.

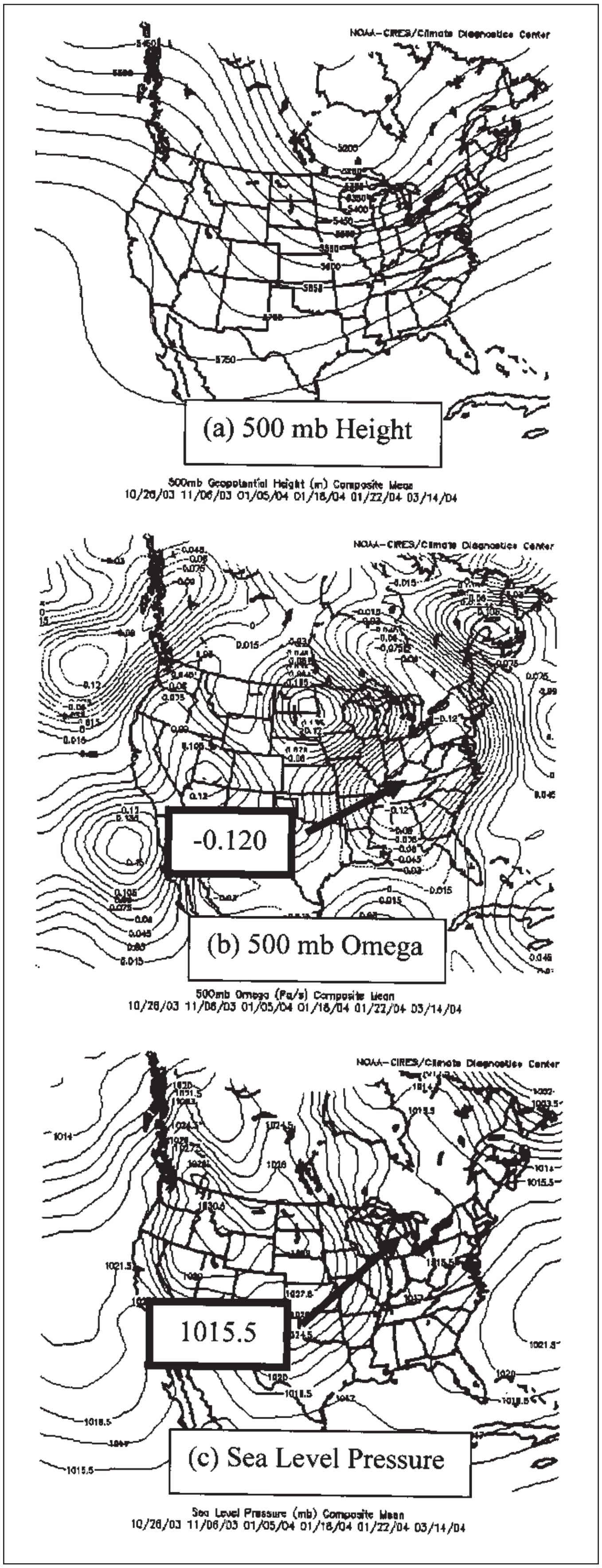

Fig. 9. Same as Fig. 7 but for GLT synoptic type.

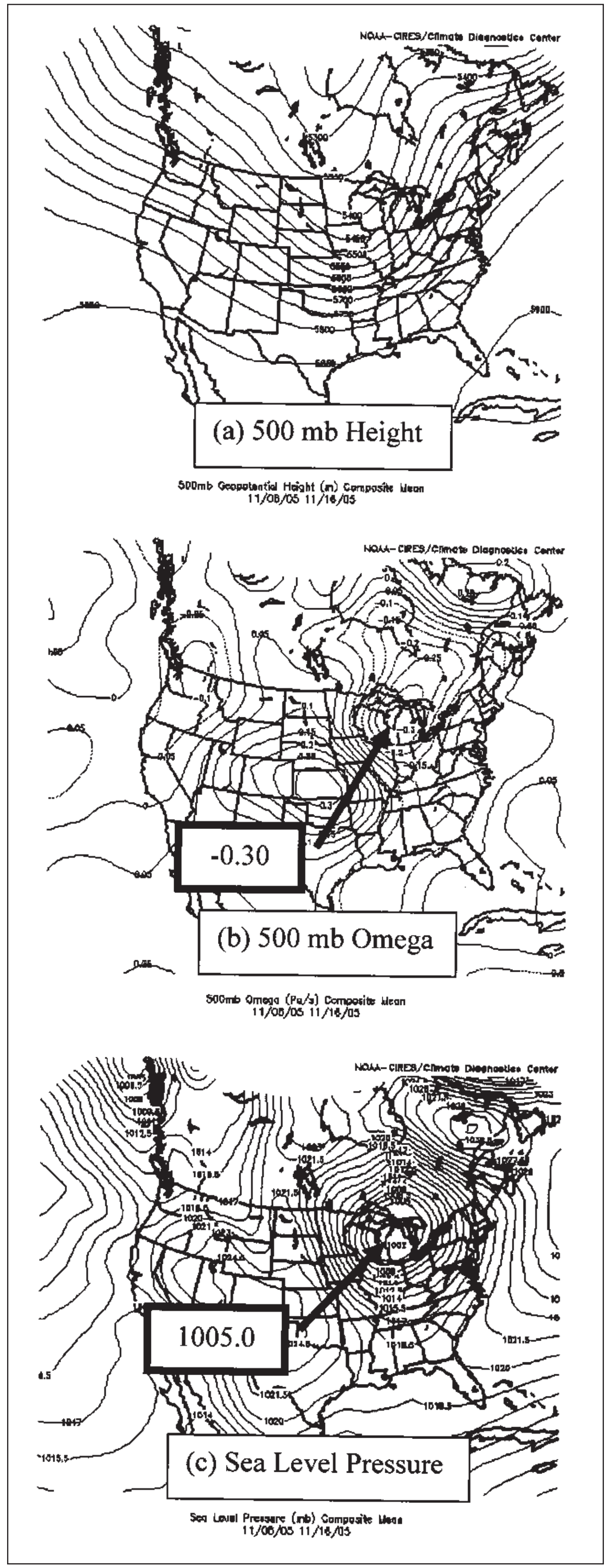

Fig. 10. Test season composites (as in Fig. 2) for NAT.

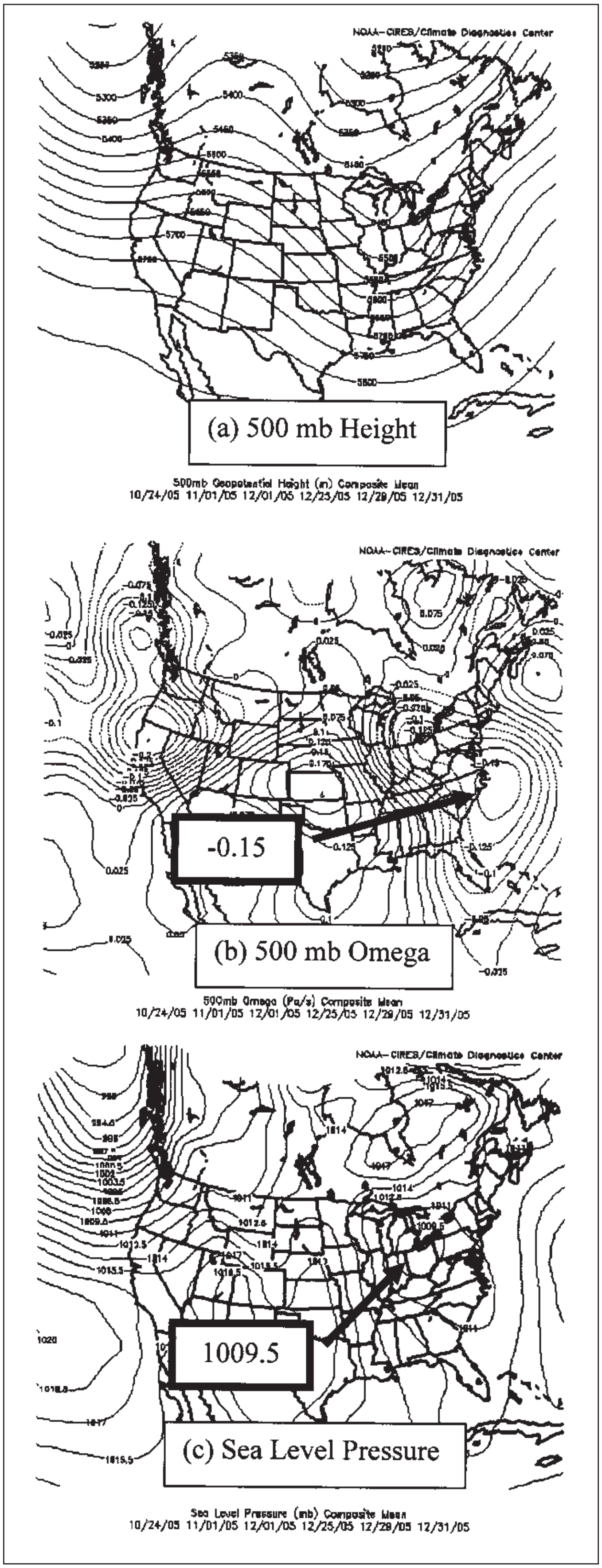

Fig. 11. Test season null composites (as in Fig. 2) for NAT.

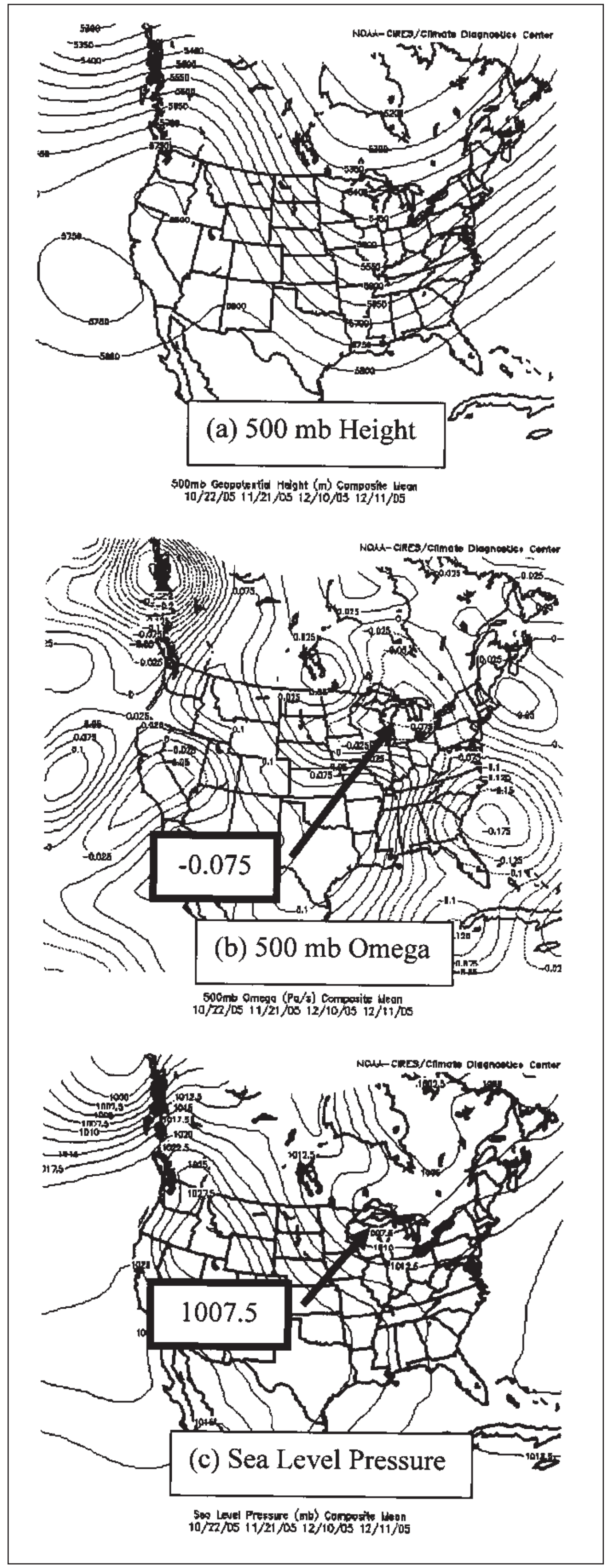

Fig. 12. Same as Fig. 11 but for CNT.

"Nor'easter" in progress along the coast and storm reports in southern New England appeared related to both the induced pressure gradient force and the ocean fetch available.

f. Null composites

In an attempt to better understand the null cases with regard to those dates on which either no severe weather occurred or on which storm reports were made (whether "nearby" or at a "distance"), composites charts were prepared and analyzed to identify features and differences that would assist a forecaster in assessing the threat of severe weather as compared to the two event dates observed in the study region. This was intended to help the diagnosis of the pattern's "capacity" to produce cool season severe weather given its observed rarity.

The composites were generated according to synoptic type and revealed that for the NAT pattern (Fig. 7) producing no severe weather (seven of 13 dates) the 500-mb trough was further east and deeper, as was the surface low center, while a southern stream system was present over southern California. The omega center was elongated from north-south to the west of the study region and centered over the eastern Great Lakes region. In NAT cases where severe weather was reported "nearby" (two of 13 dates) the omega center was along the Carolina coast with a coastal plain low pressure system. For the occurrence of severe weather at some "distance" (two of 13 dates) the omega center was displaced northwestward and the surface low was over the central Appalachians.

Composites for the CNT pattern (Fig. 8) indicated that no severe weather (four of eight dates) occurred when the upper-air trough was already in the Ohio Valley and deeper in the study region. The omega center was elongated northwest-southeast from the Hudson Bay region of Canada to off the North Carolina coast. At the surface, an occluded system, with triple point in Maryland, suggested ingest of Atlantic air during secondary development that precluded severe weather development. For those CNT producing "nearby" (one of eight dates) a strong zonal flow with the omega center in Ohio and a surface cyclonic flow produced storm reports in western New York and Pennsylvania and one in the Upton, New York (OKX) WFO forecast CWA. In the case of "distance" (two of eight dates), sharper ridging was present over the study region (with surface cold air damming) and two distinct omega centers were observed well away from the area.

Analysis of the composites for the GLT pattern (Fig. 9) producing no severe weather (six of eight dates) revealed that the upper-air trough was further west, had greater positive tilt, and the omega center was centered over the central Appalachians. In the one case of "distance" (there were no "nearby" events) the upper trough was deeper and further southwest with a stronger omega center over the southern Appalachians. Additionally, an elongated low pressure area with several closed isobars helped produced a strong pressure gradient flow as compared to the weakness of flow in those GLT events producing storm reports.

g. Test season cases

Data was collected for the first-half of the 2005-2006 cool season for testing of the findings and methods of this study. This included verification and demonstration of the ability of the synoptic types to identify severe weather events; an assessment of those dates with the severe weather synoptic signature but producing no storm reports (null cases, including "nearby" or "distance"), and the determination of any "missed" cases or failures of the approach. For the months of October through December 2005 two severe weather days were observed in the study region and produced five wind reports and no hail or tornado reports (not shown). The synoptic type responsible on both days was the NAT pattern, and all reports were of wind.

The 92- day period (October through December 2005) was examined with regard to the frequency of the severe weather synoptic types to ascertain the occurrence of the severe weather patterns and to assess among these which produced severe weather. The patterns occurred with a frequency of 11 (NAT), six (CNT), and zero (GLT) days with only 18% of the NAT resulting in storm reports. This was comparable to the null case analyses. Thus the test data showed similar frequencies of the occurrence of the severe weather patterns of 18% (17 of 92 days) with severe weather production of 12% (two of 17 days); or only 2% of time during the season (two of 92 days). Although sample size was rather limited, composites were generated for the NAT test season cases, the only type producing severe weather, and were mostly comparable with those features identified in the original data set (Fig. 10).

Examination of the 15 dates not producing severe weather in the study region revealed that six of the NAT and four of the CNT dates produced no severe weather (ten of 17), three NAT resulted in activity "nearby", and two CNT showed "distance" severe weather occurrence. Composites of these (Fig. 11, NAT; Fig. 12, CNT) again illustrated a variety of differences from those cases in which severe weather took place in the study region. Given the small sample sizes, one could conclude that these differences exist within the natural spread about the composite means, yet the data showed similar frequencies of severe weather patterns of 18% in the test season compared to 16% in the 2003-2004 season. Additionally, severe weather production of 12%; or 2% of time during the halfhalf season as compared to 14%; or 2% of the time during the entire 2003-2004 season. Each of these analyses verified and demonstrated the ability and robustness of the approach and suggests potentially significant use in an operational environment as well as in the development of forecast tools and/or a conceptual model of cool season convective severe weather.

4. Conclusions

An examination of the synoptic climatology of convective severe weather events during the cool half of the year was considered for the PHI WFO CWA and vicinity. Through an examination of five years of online storm reports from the SPC, a small sample of severe weather reports was identified and studied. During the study period, their occurrence was rare (approximately one percent of the time), but found to occur in all cool season months (except February) with maxima in October and March. The events were dominated by wind damage reports (80%) and occurred on average twice each cool season, and more often in active cool seasons. Hail was relatively rare (only two days) versus tornadoes (four days, predominantly in October) and there was little evidence of spatial preference of the storm reports.

Severe weather events did not appear to exhibit any significant patterns until they were examined with regard to the synoptic weather type associated with their occurrence. Through a self-sorting synoptic climatology approach, three synoptic patterns were identified that produce severe weather during the cool season in the study region. Two of the types (NAT, CNT) illustrated the significance of dynamic forcing and the role of the large-scale synoptic setting. These dictated the amount and distribution of severe weather reports across the study region. The third synoptic type (GLT), however, was also a prolific producer of severe weather of all kinds but differed in its dependence on boundary layer instability and forcing (particularly aloft) and thus is fundamentally different from the other two synoptic types.

In fact three of the five tornadoes occurred with type GLT as well as all of the hail cases, which imply that the more traditional severe weather environment associated with quasi-stationary boundaries helped 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 provided 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 convective severe weather episode. In addition, while CNT and GLT showed a time preference for occurrence (i.e. afternoon and evening), the NAT produced severe weather during any of the daytime hours.

An investigation of null cases was also made (based on the very active 2003-2004 season) in order to determine the frequency of the severe weather patterns identified so as to distinguish non-events from those producing severe weather. While the NAT, CNT, and GLT patterns were observed to occur 15% of the time during the cool season, only 14% of these occurrences were associated with severe weather in the study region. Examination of composite charts showed real differences in features between those producing events and those not (or potentially "nearby" or at some "distance" to the study region). Finally, application of the patterns and the null case concept to a portion of a test season (2005-2006) provided evidence of the ability and capacity of the methods applied in helping operational forecasters differentiate severe weather threats in a real-time setting.

Given these findings, it would be of value to determine a list of synoptic precursors for each event type and further specify the features of interest. 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 WFO CWA and vicinity. Further efforts might also focus on expanding the study period to generate a larger sample size to better understand the cool season severe weather population parameters. Consideration of the placement and/or expansion of spotter networks where gaps appear may also be of interest in terms of their impacts on the 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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