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NON-CONVECTIVE HIGH WIND EVENTS: A CLIMATOLOGY FOR THE GREAT LAKES REGION

John A. Knox *
University of Georgia, Athens, Georgia

Matthew C. Lacke
Air and Radiation Protection Division, Jefferson County Department of Health, Birmingham, Alabama

John D. Frye
Kutztown University, Kutztown, Pennsylvania

Alan E. Stewart
University of Georgia, Athens, Georgia

Joshua D. Durkee
Western Kentucky University, Bowling Green, Kentucky

Christopher M. Fuhrmann
University of North Carolina, Chapel Hill, North Carolina

Sarah D. Dillingham
Texas Tech University, Lubbock, Texas

1. INTRODUCTION

The folklore of the Great Lakes region is steeped in stories of shipwrecks in howling windstorms. From the Great Lakes Storm of 1913 to the Armistice Day storm of 1940, tales of tragedy on the water have been intertwined with extreme weather. In more modern times, the shocking sinking of the ore freighter *Edmund Fitzgerald* on Lake Superior in 1975 (Hultquist et al. 2006) reinforced this connection with a new generation of Great Lakes residents.

The common climatological threads in all of these stories are that the events occurred during the "cold season" of November through April, and that the weather phenomenon associated with the shipwrecks was the mid-latitude cyclone, not a thunderstorm or tornado. To distinguish these events from the more familiar warm-season thunderstorm-related windstorms, they are called non-convective wind events or NCWEs.

The definition of NCWE used in this paper is any non-thunderstorm wind that meets the National Weather Service criteria (NWS 2006) for a high wind watch and warning (i.e., sustained winds of 18 m s^{-1} or 40 mph for at least one hour; or a gust of 26 m s^{-1} or 58 mph for any duration). The sustained-wind threshold is referred to as "criterion A" and the wind-gust threshold as "criterion B."

* *Corresponding author address:* John A. Knox, Univ. of Georgia Department of Geography, Athens, GA 30602; e-mail: johnknox@uga.edu

Because these wind speed thresholds exceed the minimum wind speed of tropical storms (17 m s^{-1}), as well as match severe weather criteria (i.e., wind gust greater than or equal to 26 m s^{-1}), NCWEs can produce considerable socioeconomic impacts including downed trees and power lines, property and crop damage, travel delays, injuries, and casualties. Over the period of 2000-04, high winds (a NWS category that includes NCWEs) were responsible for approximately the same number of deaths as those that resulted from tropical cyclones. In addition, high winds caused more property- and crop-related damages than did winds produced by either convective storms or tornadoes from 2000-04 (NWS 2005).

Returning to the Great Lakes, NCWEs play a particularly important role in this region, causing 21% of weather-related deaths and property damage events exceeding $0.5 million from 1960-85 during the fall season, and causing 28% of such events in the winter season (Niziol and Paone 2000).

Several studies have addressed the synoptic and dynamic aspects of NCWEs in specific case studies (e.g., Pauley et al. 1996; Iacopelli and Knox 2001; Browning 2004; Crupi 2004; Knox and Schmidt 2005; Hultquist et al. 2006). However, very little is known about the climatology of damaging non-convective winds. One exception is the study by Niziol and Paone (2000), who created a climatology of NCWEs based on criterion B for Buffalo, NY from 1977-97. Otherwise, the literature on wind in the Great Lakes region is surprisingly sparse and is limited mostly to wind energy-related analyses.

This study seeks to advance our understanding of NCWEs by examining cold-season events across the Great Lakes region from 1951-95. A 44-year sample of NCWEs produces robust estimates of meteorological variables that are relevant to these events, such as pressure, sustained winds, and wind directions of sustained winds and wind gusts, some of which are discussed below. The reader is directed to Lacke et al. (2007) for a more complete description of many aspects of this work.

2. DATA AND METHODOLOGY

Hourly wind and sea-level pressure data were extracted from Climate Data Online (CDO) provided by the National Climatic Data Center (NCDC 2006). The data consist of quality-controlled, decoded METAR reports for 38 NWS first-order weather stations throughout the Midwest and Great Lakes regions (Figure 1) for the cold seasons of 1951-95. These stations were chosen because they closely delineated the area studied by Angel and Isard (1998) with respect to the frequency of Great Lakes cyclones.

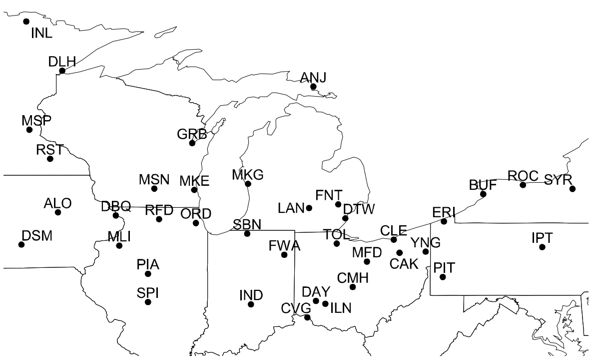


Figure 1. The 38 first-order station network used to create a climatology of NCWEs in the Great Lakes region during the cold season (November-April) for the period 1951-95.

A period of record of 1951-95 was used in this study for two reasons. First, 1995 was chosen as the endpoint of the data range because this year marked the transition from human observers to the widespread deployment of automated surface observing stations across the United States. Secondly, the 44-year period of record permitted the maximum possible number of observing stations (i.e., 38) to be included in the analysis.

One small drawback of the NCDC CDO archive is non-archived and missing data. Only three-hourly reports are archived for most stations during a subset of the years 1965-73. In addition, missing data were noted at four of the stations chosen for the study (Rockford, IL; Lansing, MI; Dubuque, IA; and Waterloo, IA). However, the missing data at these four stations represent no more than about 2.5% of the more than six million hourly wind observations collected at the 38 stations during the cold seasons of 1951-95 and do not appear to affect the conclusions of this study. In addition, no wind gust data prior to 1974 is available in the NCDC CDO for the stations analyzed. Although this reduces the amount of data, it also eliminates the (minor) complicating effects of anemometer height changes at some stations between 1951-73.

Only the months of November through April were used because convective events are rare in the Great Lakes region during the cold season. The study also included only those observations with no indication of convective storms in the “present weather” data field.

Wind data were subdivided according to the two NWS high wind warning criteria. There are some ambiguities in how best to identify occurrences of high winds from the NCDC CDO database. On the advice of National Weather Service personnel a one-hourly occurrence of sustained winds at or above 18 m s^{-1} was defined as satisfying criterion A. While this compromise may overestimate the number of criterion-A NCWE occurrences, it is far preferable to omitting the analysis of sustained winds.

In the case of criterion B, wind gust data rather than peak wind speed data was used. The NCDC CDO database contained little peak gust information. In addition, Niziol and Paone (2000) also used wind gust data rather than peak wind speed data in their analysis. This choice likely underestimates the occurrences of criterion-B NCWEs, but seems to be the best option given data availability and consistency with antecedent research.

Observations of mean sea-level pressure, wind speed, and wind direction were recorded for each NCWE. Wind roses were created for six stations across the Great Lakes region: Buffalo, NY (BUF), Dayton, OH (DAY), Lansing, MI (LAN), Moline, IL (MLI), Rochester, MN (RST), and Springfield, IL (SPI). These stations were chosen because they generally had the highest occurrence of NCWEs in both wind categories.

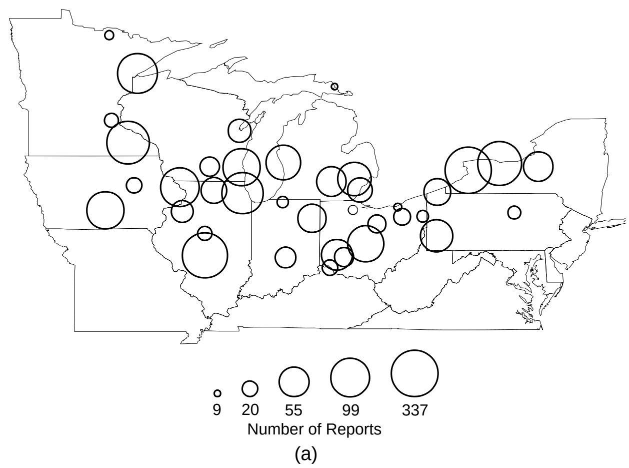
3. RESULTS

Temporal and spatial distribution

During the cold seasons of 1951-95, the 38 first-order Great Lakes region stations recorded 2,336 observations that satisfied the sustained-high-wind criterion A. These observations represent approximately 0.04% of the over six million hourly sustained-wind observations at these stations for this period. A total of 239 observations satisfied the high-wind-gust criterion B. These events were not distributed equally in space or time, but did span all cold-season months and the entire geographic extent of the Great Lakes region.

Approximately one-half of all events satisfying criterion A occurred in the months of March and April. March (27%) had the highest frequency of this type of NCWE. Slightly different results were observed for events with criterion B in that most events occurred in the months of January (35%) and April (32%).

Data from each of the 38 first-order stations were analyzed to determine the climatology of criterion A. Figures 2a and 2b are graduated circles maps of the number of these events observed at each station. In events that met criterion A or criterion B, they most commonly occurred at stations along Lake Erie, Lake Ontario, and the western part of the Midwest.



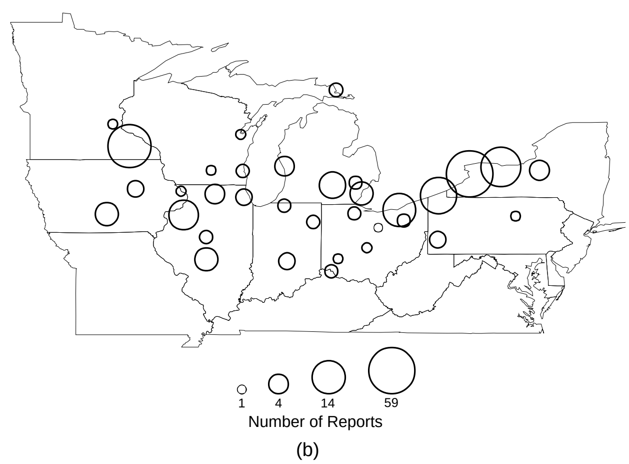


Figure 2. Graduated circles maps indicating the discrete number of reports of NCWEs associated with a) criterion A and b) criterion B.

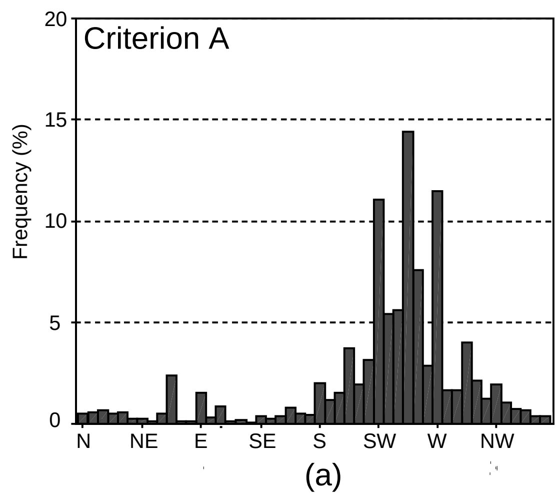
Sea-level pressure

Sea-level pressures observed during NCWEs were examined to determine the typical values and ranges of pressure for the two categories of NCWEs. As expected, these events were generally associated with low pressure, i.e. cold-season mid-latitude cyclones. High wind speeds were generally associated with low sea-level pressures, and the highest gusts were generally associated with the lowest sea-level pressures.

For events satisfying criterion A, there were 2,018 observations that also reported sea-level pressure. From this sample, a median sea-level pressure of 1000.8 hPa was calculated. The lowest pressure with sustained non-convective high winds was 959.6 hPa and the highest pressure was 1035 hPa. For NCWEs satisfying criterion B, 185 of those observations that also reported sea-level pressure had a median pressure of 993.5 hPa. The lowest sea-level pressure recorded was 967.1 hPa and the highest was 1016.7 hPa.

Temporal and spatial distribution

A persistent directional preference for NCWEs was discovered across the entire Great Lakes region. The vast majority of NCWEs in the dataset occurred with winds from the southwest quadrant (180˚-270˚).



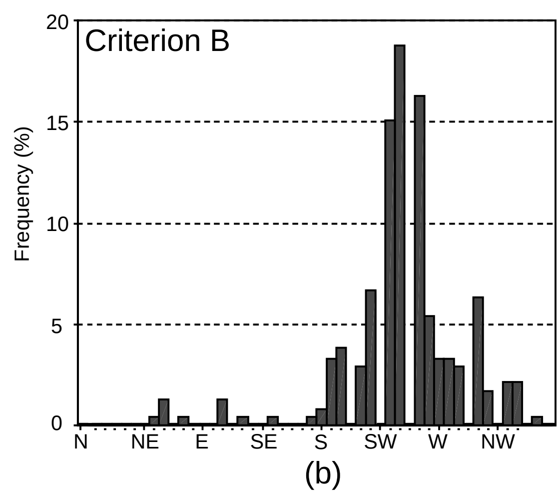


Figure 3. The frequency of wind observations in percent by cardinal direction for observations satisfying a) criterion A and b) criterion B.

For NCWEs satisfying criterion A, 70% of the events occurred with southwest quadrant winds (Figure 3a). Within the southwest quadrant, the west-southwest direction was the most common, accounting for nearly

14% of the events. NCWEs with winds from the other quadrants, while present, were noticeably less frequent. Figure 3b shows that about 76% of all events satisfying criterion B occurred in the southwest quadrant. The most common wind direction was from the west-southwest and occurred approximately 35% of the time during these events. In summary, both types of NCWEs were associated primarily with southwest quadrant winds, and a plurality of events emanated from just one compass heading: west-southwest.

To explore the wind direction results in more detail, wind roses were created for BUF (at left in Figure 4), LAN, MLI, DAY, SPI (at right in Figure 4), and RST depicting: a) the wind directions for all wind reports for the entire 44-year cold-season period of record (POR), b) wind directions observed for events satisfying criterion A, and c) wind directions observed for events satisfying criterion B.

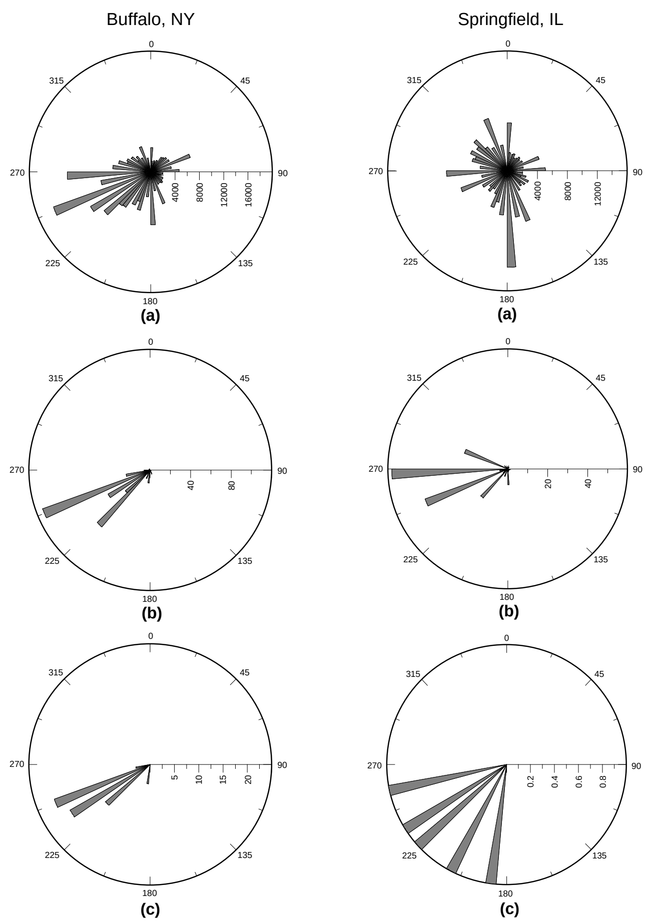


Figure 4. Wind roses for Buffalo, NY (left) and Springfield, IL (right) that indicates the frequency of wind observations along the inner line and the wind direction in degrees on the outside of the circle for a) the POR, b) those satisfying criterion A, and b) those satisfying criterion B.

Five out of the six stations (all but RST, on the northwest fringe of the domain) exhibited preferred NCWE wind directions from the southwest quadrant, in agreement with the regional climatology. In some locations (e.g., BUF) this directional preference of NCWEs was the same as for all winds; in others (e.g., SPI) NCWEs came from a wind direction that is comparatively rare for the entire POR.

4. CONCLUSIONS AND DISCUSSION

This new climatology of non-convective wind events has revealed that southwest (180˚-270˚) wind directions occurred in 70% and 76% of Great Lakes region NCWEs associated with National Weather Service high-wind criterion A and B, respectively. These results are robust not only over time and space, but also with respect to changes in wind observation measurements. These results are also consistent with the results of Niziol and Paone (2000) for Buffalo and significantly extend their results in both space and time.

What causes this persistent, widespread preference for certain wind directions for NCWEs? Niziol and Paone stated that geographical features (i.e., Lake Erie) might have been a dominating influence on the direction of NCWEs in Buffalo. The present study suggests a more general meteorological cause, because the pattern seen in Buffalo is also widespread and persistent across nearly the entire Great Lakes region.

The analysis of sea-level pressure in this climatology suggests that most cold-season NCWEs may be associated with mid-latitude cyclones. While individual case studies have linked non-convective high winds with mid-latitude cyclones, this is the first study to imply a region-wide climatological connection. Therefore, the southwest quadrant wind preference during NCWEs is hypothesized to be associated with mid-latitude cyclone dynamics. Ongoing research is being conducted to determine the dynamical causes of cold-season NCWEs associated with mid-latitude cyclones. One hypothesis is that high-speed jet-stream air associated with “stratospheric intrusions” may be transported to the ground during NCWEs.

A majority of the NCWEs in this study occurred in January, March and April. High wind events occurred much less frequently in the months of November, December, and February. This result runs counter to anecdotal evidence and weather folklore that suggest “witch of November” storms are the most common source of cold-season NCWEs on the Great Lakes. The explanation for this discrepancy may relate more to sociological factors than to climatology.

In summary, this work reveals for the first time a climatological pattern of southwest-quadrant non-convective high winds during the cold season across virtually the entire Great Lakes region, a pattern previously identified at only one station.

5. ACKNOWLEDGMENTS

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6. REFERENCES

Angel, J.R., and S. A. Isard. 1998. The frequency and intensity of Great Lake Cyclones. *J. Climate* 11:61-71.

Browning, K.A. 2004. The sting at the end of the tail: Damaging winds associated with extratropical cyclones. *Quart. J. Roy. Met. Soc.* 130:375-399.

Crupi, K.M. 2004. An anomalous non-convective high wind episode over upper Michigan. *Natl. Wea. Dig.* 28:3-12.

Hultquist, T.R., M.R. Dutter, and D. J. Schwab. 2006. Reexamination of the 9-10 November 1975 "*Edmund Fitzgerald*" storm using today's technology. *Bull. Amer. Meteor. Soc.* 87:607-622.

Iacopelli, A.J., and J. A. Knox. 2001. Mesoscale dynamics of the record-breaking 10 November 1998 mid-latitude cyclone: A satellite-based case study. *Natl. Wea. Dig*. 25 (1,2):33-42.

Knox, J.A., and C. C. Schmidt. 2005. Using GOES total column ozone to diagnose stratospheric intrusions and nowcast non-convective cyclone windstorms: Methodology and initial results. *Extended Abstracts, 13th Symposium on Meteorological Observation and Instrumentation,* Savannah, GA, Amer. Meteor. Soc.

Lacke, M.C., J.A. Knox, J.D. Frye, A.E. Stewart, J.D. Durkee, C.M. Fuhrmann, and S.M. Dillingham. 2007. A climatology of non-convective wind events in the Great Lakes region. *J. Climate* 20:6012-6022.

National Climatic Data Center (NCDC). 2006. Climate data online. [Available online at http://cdo.ncdc.noaa.gov/CDO/cdo].

National Weather Service (NWS). 2005. Summary of natural hazard statistics for 2004 in the United States. [Available online at http://www.weather.gov/os/hazstats.shtml].

National Weather Service (NWS). 2006. National Weather Service glossary. [Available online at http://www.weather.gov/glossary].

Niziol, T.A., and T.J. Paone, 2000. A climatology of non-convective high wind events in western New York state. NOAA Tech. Memor., NWS ER-91, 36 pp.

Pauley, P.M., N.L. Baker, and E.H. Barker. 1996. An observational study of the "Interstate 5" dust storm case. *Bull. Amer. Meteor. Soc.* 77:693-720.