P5.3 NON-CONVECTIVE WINDSTORMS IN THE MIDWEST UNITED STATES: SURFACE AND SATELLITE CLIMATOLOGIES

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1. INTRODUCTION

Windstorms cause hundreds of deaths and billions of dollars in damage in the United States annually. The media and the public normally associate windstorms with tornadoes or hurricanes. But non-convective high wind events *not* associated with thunderstorms, tornadoes or tropical cyclones can cause a sizable amount of fatalities, injuries and property/crop damage.

Event in 2000-02	Deaths	Injuries	Damage (M)
Tornado	136	2593	$1870.1
Tropical Cyclone	77	354	$6581.1
Thunderstorm Wind	59	924	$1027.3
High Wind	***68***	***389***	***$ 232.6***
ALL Weather	1482	8603	$26,464.3

Table 1. Cumulative 2000-2002 weather hazard statistics for the United States, from the annual *Summary of Natural Hazard Statistics*, National Weather Service (2002 data is preliminary)

High winds not associated with tornadoes, hurricanes or thunderstorms have caused about 5% of all weather-related deaths, 5% of all weather-related injuries, and 1% of all weather-related property/crop damage that have occurred in the United States since January 1, 2000. From 1996 through 2002, the exact percentages are: deaths: 4.6%; injuries: 2.8%; and property/crop damage, 0.9%.

These statistics reveal that the human costs due to non-convective winds can rival or exceed those due to hurricanes and thunderstorm winds, even though the property damage from non-convective winds is far less extensive. This raises the possibility that non-convective windstorms may be less well forecast than other wind events. Also, official advisories for non-convective winds may not be heeded as strictly by the public as, for example, hurricane warnings because of a lack of awareness of the danger from these windstorms.

A type of non-convective windstorm with relevance to the Midwest United States is a high wind event associated with an extratropical cyclone. For example, on November 10, 1998, non-convective high winds associated with a record-breaking 963-mb cyclone caused ten deaths and over $40 million in damage in the states of Illinois, Iowa, Kentucky, Michigan, Minnesota, and Wisconsin (Iacopelli and Knox 2001).

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On this day in 1998, wind gusts up to 42 ms^{-1} (93 mph) blew cars and trucks off the road and into pedestrians, snapped flagpoles, and tore down water towers and interstate signs. This storm occurred on the 23rd anniversary of a similar Great Lakes cyclone that contributed to the deadly sinking of the ore freighter *Edmund Fitzgerald*. The *Fitzgerald* sank shortly after wind gusts on Lake Superior that were estimated by a nearby boat captain to have exceeded 45 ms^{-1} (100 mph) (Ackerman and Knox 2003, p. 292). These "Witch of November" storms are both extreme and extremely hazardous, deadly even when forecasters anticipate their development more than a day in advance—as was true in 1998, and even to a surprising extent in 1975.

It should be noted that cyclone windstorms are not limited to the Midwest. Similar events occur in the Northeast and West, and less frequently in the Southeast. The Midwest was chosen as a focus for study because of the prominence of cyclone wind events in the Midwest, and the wealth of data coverage in the region.

2. LITERATURE REVIEW

Despite the impact of non-convective wind events on the Midwest, only a few climatological studies have examined Great Lakes cyclones. Even fewer studies have focused on these cyclones' potential for producing extreme and hazardous winds at the surface.

The only comprehensive study using strong winds as a primary criterion appears to have been Lewis (1987). Lewis examined 100 storms with sustained (one-minute mean) winds greater than 25 ms^{-1} (55 mph) that traversed the Great Lakes between 1957 and 1985. Angel (1996) reanalyzed Lewis's results and found that 92% of the 100 storms were cyclones; 83% of the cyclones occurred in November through March. Lewis (p. 3-3), using ship observations of surface wind, determined that 0.08% of all observations were greater than 25 ms^{-1} (55 mph). However, these observations were limited during the late winter months due to the freezing of the Great Lakes in many years. About 0.25% of observations made on the Lakes during November, December and January exceeded 25 ms^{-1} (55 mph), when cyclones track near the Great Lakes.

Angel and Isard (1998) compiled a 90-year climatology of Great Lakes cyclones. Among their many intriguing conclusions, the authors found that eleven strong (992 mb or less) cyclones occur in the Great

Lakes each year, and that the number of strong November-December Great Lakes cyclones doubled during the 20th century while the overall number of cyclones per year decreased. Angel and Isard (1998, p. 63) note that some very strong cyclones do not create much damage. They cite the direction of cyclone movement in relation to the position, shape and orientation of the lakes as a possible explanation.

There is apparently even less extant research on non-convective wind events. In the words of Klink (2001, p. 3316), “we know comparatively little about how wind varies over space and through time.”

However, at least one climatological study has examined non-convective wind events directly using surface wind data. Niziol and Paone (1991) created a climatology of non-convective wind events for western New York state, which naturally focused on the role of extratropical cyclones. The authors’ threshold for an event was a day during which a non-convective wind gust of 26 ms^{-1} (50 knots or greater, i.e. 58 mph) occurred at Buffalo, NY. Fifty-two events over twenty years were examined, and a strong low moving to the north and west of the Buffalo area was identified as a necessary element for a high wind event in the region.

A late-fall through early-spring seasonality in non-convective wind events was also identified by Niziol and Paone. Significantly, the prevailing wind direction for these events was “overwhelming”ly southwest to west, with very few events from a northwest through southeast direction. Niziol and Paone attribute this directional bias to the SW-NE orientation of Lake Erie (p. 2). The authors also cite the work of Hubert et al. (1987), graphically depicting Hubert et al.’s finding that about 25% of all significant fall and winter Great Lakes storm events (defined as at least one death or $500,000 in property/crop damage) are wind-related, the second largest percentage behind snow.

Given the paucity of research on non-convective wind events in the Great Lakes, the thrust of the research presented below is to create a climatology of Great Lakes cyclones that produce high non-convective winds. This approach melds surface wind data with derived products from the GOES satellite, particularly water vapor and ozone. The ultimate purpose is to diagnose the dynamics of these wind events and create the knowledge base necessary to improve awareness of these wind events and to facilitate better forecasts of their occurrence.

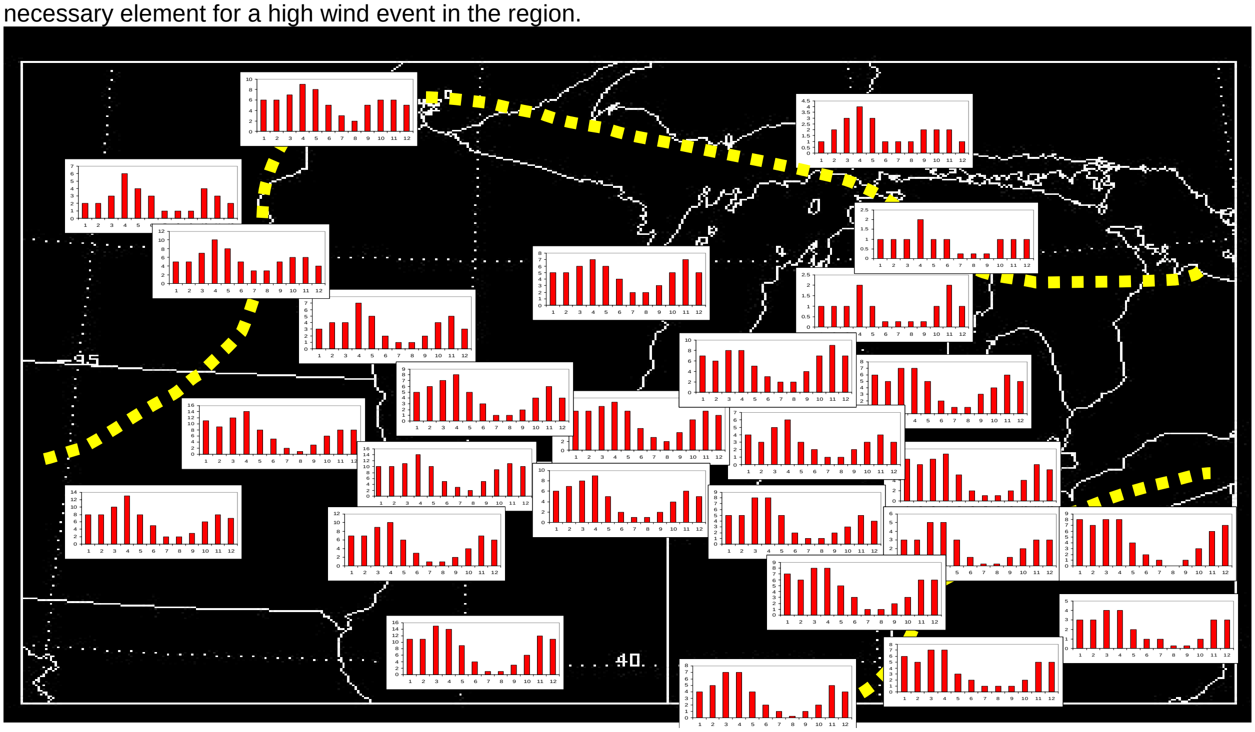

Figure 1. Percent of flying hours during which no precipitation occurred and winds reached or exceeded 9 ms^{-1} (17 kt, or 20 mph) at first-order stations across the upper Midwest. Bar graphs depict the percent (vertical axis) on a month-by-month basis from January to December (left to right on horizontal axis). Not all vertical scales are identical. Graphs are situated at or near the geographical location of the weather station. Contours indicate the month during which the autumn peak in non-convective winds takes place.

3. CLIMATOLOGY OF NON-CONVECTIVE WINDS

As a first step toward developing a climatology of high wind events, data from the International Station Meteorological Climate Summary (ISMCS) CD were used to isolate the seasonal patterns of non-convective winds. One archived statistic proved particularly useful in this regard: the percent of flying hours with winds of at least 9 ms^{-1} (17 kt, or 20 mph) during which precipitation was *not* occurring. Data from first-order stations in the region bounded by 39.5˚-47.5˚N, 82˚-94˚W were analyzed, in order to focus upon the strong cyclones that rake the upper Midwest. The period of record for these 32 first-order stations was typically 1948-1995, providing statistical confidence in the results.

The results, as depicted on a monthly basis in Figure 1 on the previous page, reveal a double peak in non-convective wind occurrences across the Midwest. These occurrences are most common in spring and in fall. The spring peak is in April throughout most of the region. However, the autumn peak varies from northwest to southeast across the upper Midwest, from October in Minnesota to December in Ohio. This spatial trend mimics the seasonal trend of cyclone paths across the Midwest, highlighting the key role of cyclones in producing windy non-convective conditions.

4. CLIMATOLOGY OF NOVEMBER 12Z WINDS

To zero in on strong winds caused by autumn cyclones, a climatological statistic that categorizes winds in several speed classes must be used. Unfortunately, no statistic available in the ISMCS database categorizes non-convective winds in this way. Therefore, in order to eliminate convective wind events as much as possible, sustained winds at 12Z in November were examined.

The choice of November is driven by the broad geographic maximum in non-convective winds in November across the region, as seen in Figure 1. The assumption behind using 12Z data is that strong winds at 6 or 7 am local time are highly unlikely to be caused by thunderstorms in the upper Midwest in November. This assumption is generally buttressed by the statistics on thunderstorms in the ISMCS database: stations from Toledo, OH to Minneapolis, MN reported either 0.0% or 0.1% occurrence of thunderstorms at 12Z.

However, since extremes are being sought that occur very rarely, the inability to ensure exclusion of all convective events is a weakness of this analysis. Patterns based on observations at many first-order stations are relied on, therefore, instead of a single station's results that may be contaminated by convective events.

The 31 first-order upper Midwest stations used in this analysis have records ranging from 32 years to 51 years in length, with an average length of 46.13 years. An average of 1384 November 12Z observations per station were used in the analysis, for a total of nearly 43,000 observations used in this aspect of the study. Occurrences at the 1% frequency level reflect about 14 observations during the period of record at an individual station, 0.1% occurrences reflect about 1 or 2 observations during the period of record, and so forth.

To graphically depict the results with a tight focus on strong winds, a "strong-wind rose" was developed that shows the frequency of wind as a function of direction for three categories: all sustained winds at least 9 ms^{-1} (17 kt, or 20 mph); all sustained winds of at least 14.4 ms^{-1} (28 kt, or 32 mph); and the maximum sustained wind category (binned in 5-kt increments), which could include multiple directions.

The "strong-wind rose" for Waterloo, IA (ALO) is shown in Figure 2. The dark blue line indicates the wind

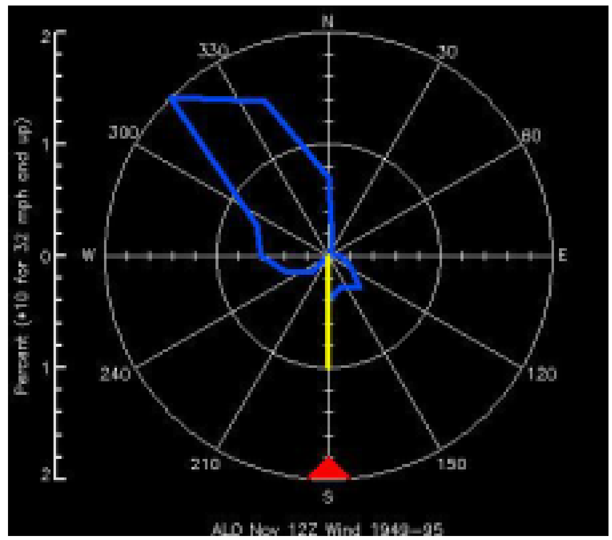

Figure 2. "Strong-wind rose" for Waterloo, Iowa (ALO). The blue line indicates percentage of all sustained wind observations that are at least 17 kt; yellow line, at least 28 kt (percentages multiplied by ten for ease of plotting); red triangle, the direction for the highest category of wind observed at the station. The results here are for 12Z in November for the period of record in the ISMCS database: 1949 through 1995.

rose for all sustained winds at Waterloo at 12Z in November from 1949 through 1995 that were at least 9 ms^{-1} (17 kt, or 20 mph). A clear preference for NW winds (about 2% of all observations) is seen in the figure. The light yellow line in Figure 2 is the wind rose for just the sustained winds of at least 14.4 ms^{-1} (28 kt, or 32 mph). In this subset of the data, there is no hint of a NW bias. Instead, *all* occurrences of very strong winds at Waterloo were from the south direction. (The frequency of south winds at or greater than 28 kt is 0.1%; as the vertical legend in Figure 1 states, the percent is multiplied by ten for this subset.) The red triangle shows that the strongest winds ever witnessed at Waterloo at 12Z in November are also from the south.

The results for Waterloo are mirrored to a large extent by the full results for all 31 stations across the upper Midwest, a subset of which is shown in Figure 3. Throughout the region, a persistent southwest quadrant bias for strong winds is evident, and this bias increases steadily as one looks at higher and higher wind categories. Only a few stations, such as La Crosse, WI

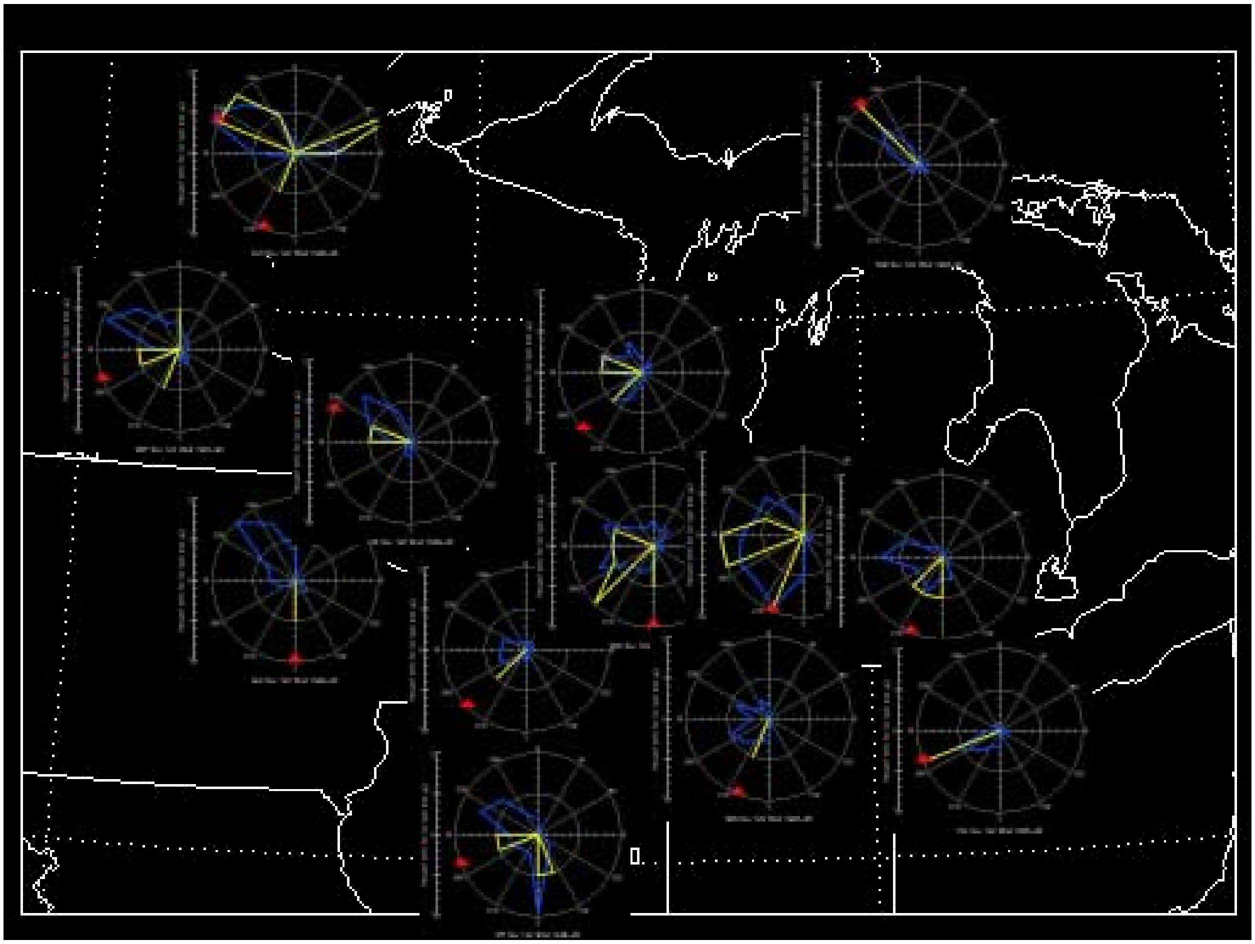

Figure 3. “Strong-wind rose” for selected Midwest stations. The blue line indicates percentage of all sustained wind observations that are at least 17 kt; yellow line, at least 28 kt (percentages multiplied by ten for ease of plotting); red triangle, the direction for the highest category of wind observed at the station. The station climatologies typically span the period from the 1940s through 1995.

and Sault Ste. Marie, MI fail to capture this preference for strongest winds from the south through west direction. In these few cases, either topography or geographic location vis à vis cyclone paths may explain the lack of a southwest quadrant bias.

Because stations as wide-ranging as Toledo, OH and Minneapolis, MN reveal a southwest quadrant bias in the highest sustained winds, no simple geographical explanation can suffice for this occurrence. Instead, in the next section a dynamical cause is proposed for this directional bias in strong Midwest cold-season winds.

5. CYCLONE WINDSTORM DYNAMICS

The common link uniting the strong wind climatologies in Section 4 is not geography, but atmospheric dynamics—the recurrence of strong extratropical cyclones across the Midwest each fall. How could these cyclones cause very strong winds that are preferentially from the south-through-west direction? The large-scale pressure gradient pattern around these lows is roughly symmetrical, and so from geostrophic wind considerations no southwest quadrant bias should be expected for stations where lows routinely pass overhead or to the south. Lewis (1987) shows that the windy cyclones in his 1957-1985 database took SW-NE paths from southern Ohio to a cluster in Wisconsin and Minnesota. Therefore, if the explanation were simply the cyclone’s large-scale pressure pattern and the path that cyclones take, the southwest quadrant bias should be less evident than it is in MN, WI and IA.

A second possibility is that these southwest quadrant winds are associated with features of extratropical cyclones on a smaller scale. One known cause of strong winds in cyclones is the “dry slot” or “stratospheric intrusion” that develops aloft above and to the south and west of strong cyclones (Browning 1997). These intrusions also help form what is known as the “dry conveyor belt” in mid-latitude cyclone theory. These intrusions drag down high-speed air from the tropopause and, under conditions of weak or no stability near the surface, can be mixed down, causing high surface winds (Browning and Reynolds 1994). The orientation of the dry slot with the cyclone normally is such that the upper-level winds are from the south or southwest.

The connection between stratospheric intrusions and extreme local winds is plausible and has been suggested in previous individual case studies (Browning and Reynolds 1994; Iacopelli and Knox 2001). The next step of this research was therefore to develop satellite-based research predicated on the connection between strong southwest quadrant winds and strong cyclones.

6. CYCLONE WINDSTORM CLIMATOLOGY

A climatology of Midwest cyclone windstorms for the period July 1996-December 2002 was developed using both surface wind data and GOES satellite imagery. This time period was chosen because of 1) the easy accessibility of wind data online for these years, 2) the recent advances in GOES derived products which ultimately may allow advanced examination of total ozone in these cyclones, and 3) the lack of overlap with the climatologies already performed.

Over 4500 twice-daily satellite images and 2262 monthly peak surface wind gust observations at 29 upper Midwest first-order stations were examined. Satellite images were analyzed for evidence of dry slot formation in visible, infrared and particularly water vapor imagery. The monthly peak gust data were analyzed informally for a SW quadrant bias, which was evident.

The criteria for inclusion in the climatology were:

1) Satellite imagery confirmed dry slot development; and/or
2a) 75% of more of the upper Midwest stations reported peak gust for the month on the same date; plus
2b) The peak gust for the month at three or more stations was from the southwest quadrant; and
3) Examination of the *Daily Weather Map* confirmed existence of a cyclonic circulation

Given these criteria, twenty cyclones during July 1996-December 2002 were tentatively chosen for study. Work is in progress on the analysis of these cyclones, using a combination of satellite- and ground-based data.

7. CYCLONE WINDSTORM CASE STUDY

In addition to the climatology, individual cases of cyclone windstorms are being examined in closer detail. One such event occurred on November 12, 2003 across the upper Midwest. According to *Storm Data* (http://www4.ncdc.noaa.gov/cgi-win/wwcgi.dll?wwEvent~Storms), non-convective high winds from this cyclone gusted up to 39 ms^{-1} (76 kts) and caused $26.5 million in property and crop damage and six injuries across Iowa, Illinois, Indiana, Michigan, Minnesota, Ohio, and Wisconsin. A utility company in northwest Lower Michigan called it the worst windstorm since the Fitzgerald storm, and a state park in Michigan reported the most tree damage from one storm since the 1940 Armistice Day cyclone.

Event record details in *Storm Data* reveal some confusion about the origin of the strong winds: the discussion from Iowa cites a "tropospheric fold… below 700 mb in the wake of the storm, enhancing the wind." However, other reports in *Storm Data* attribute the strong winds to: a surface ridge strengthening the gradient winds; strong and intensifying low pressure; and a strong cold front. Clearly there was no consensus among operational meteorologists regarding the ultimate trigger for the high winds.

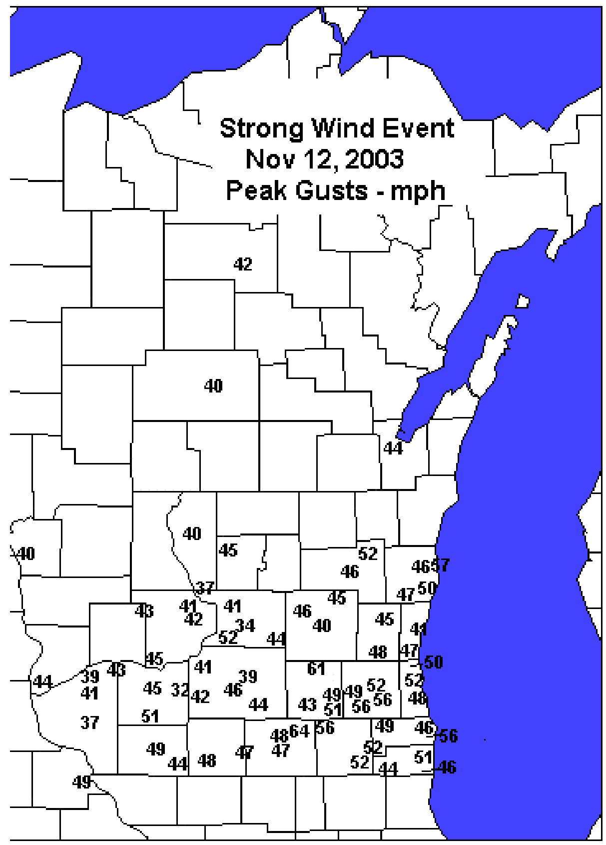

Figure 4. Wind gusts measured across Wisconsin in the November 12, 2003 cyclone windstorm event. Image from National Weather Service Milwaukee/Sullivan Web site http://www.crh.noaa.gov/mkx/document/wind/wind_11-12-03.htm

GOES water vapor and ozone imagery is being used to correlate wind gusts with the presence of dry surface air and high values of total column ozone, indicative of a stratospheric intrusion. Figure 6 is an AWIPS screen capture illustrating the penetration of dry air on the southwest side of the cyclone, and Figure 7 is a preliminary high-resolution 1x1 field-of-view GOES total ozone product showing the high (green) levels of ozone coincident with this dry slot. Additional work is in progress to relate features in satellite imagery with the location and timing of surface wind gusts, as in Iacopelli and Knox (2001) for the November 1998 cyclone.

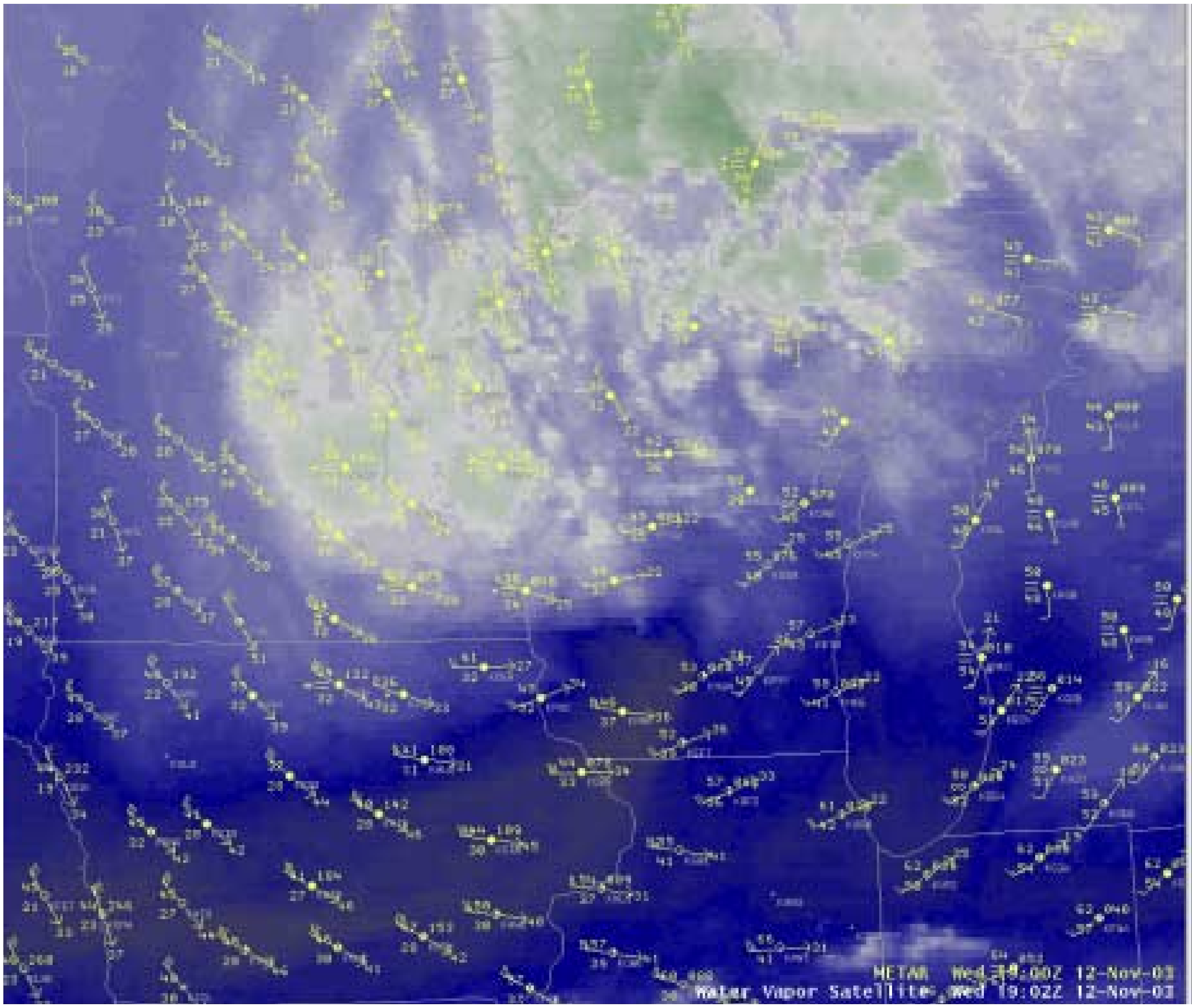

Figure 5. AWIPS screen capture at 19Z on 12 November 2003 across the upper Midwest. 1902 UTC GOES water vapor is shaded (darkest colors denote dry slot over Iowa and southwest Wisconsin). Wind gusts in knots are indicated with arrows and numbers.

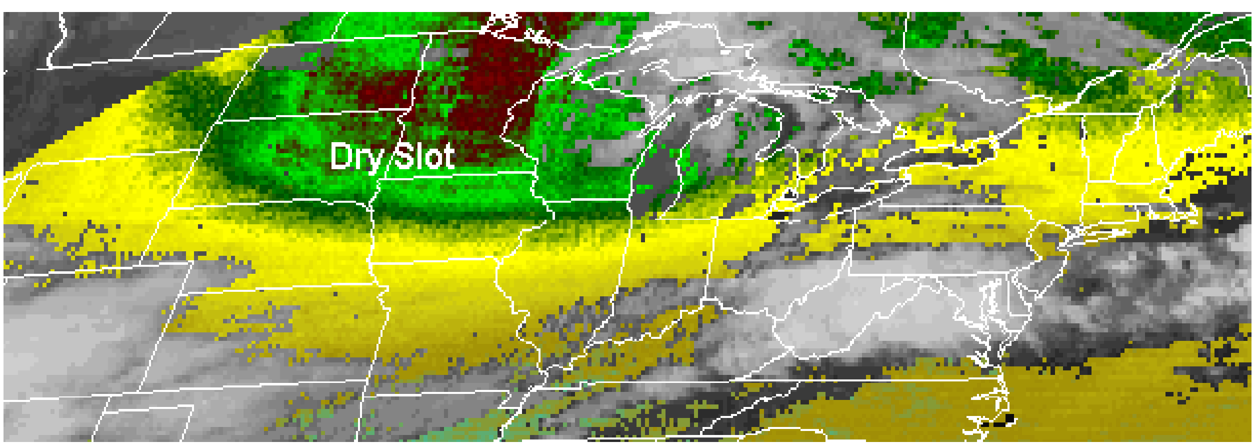

Figure 6. Preliminary GOES 1x1 field-of-view total ozone product for 2246 UTC on 12 November 2003. Total ozone values range from approximately (in Dobson units) 275-340 (shades of yellow); 340-400 (shades of green); to 400 (dark red over Minnesota).

8. CONCLUSIONS AND DISCUSSION

Windstorms cause considerable death and destruction in the United States each year. Windstorms not related to tornadoes, hurricanes and thunderstorms account for a surprising number of deaths and injuries each year. The Midwest is prone to one type of non-convective windstorm that is caused by strong extratropical cyclones.

In this study, surface wind data from the upper Midwest and GOES satellite imagery have been juxtaposed to begin creation of a novel climatology of non-convective wind events in the Midwest. Surface wind data from the 1940s through 1995 have been used to create two regional climatologies, one of non-convective winds and another of November 12Z winds. The results of the first climatology reveal a fall-season trend in the month of most frequent non-convective winds from northwest to southeast. The second climatology reveals a pronounced southwest quadrant preference for the strongest winds in the Midwest on November mornings, a preference that becomes very dominant for the highest winds. This is a central result of this research to date.

Because of the geographic spread and dominance of the southwest quadrant bias, the hypothesis of Niziol and Paone (2000) that the orientation of the Great Lakes plays a dominant role in the southwest bias is *rejected*. Instead, a dynamical cause that would explain this bias from Duluth to Toledo and points in-between is sought.

The possibility that stratospheric intrusions cause preferentially high south-to-west winds across the upper Midwest is being explored. A climatology is being developed based on 20 cyclones during 1996-2002 that either exhibited dry slot development in satellite imagery or were dominant windstorms across the region, as identified through monthly peak wind gust data. A recent Midwest cyclone windstorm is currently being investigated for hallmarks of stratospheric intrusion-related wind gusts using GOES water vapor and total ozone products.

9. ACKNOWLEDGMENTS

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