# SPATIOTEMPORAL VARIABILITY OF EXTREME CONVECTIVE WIND EVENTS

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## 1. INTRODUCTION

The months of April and May 2011 produced a number of extreme convective events. A total of six EF5 tornadoes were recorded over the course of the two months, including the Joplin, Missouri tornado on 22 May which caused the highest fatality count (161) for a single tornado since official records have been kept. The greatest single daily tornado outbreak (200) in official history occurred on 27 April which also contributed to the highest monthly tornado total in recorded history (895). In addition, monthly large-scale convective parameters such as CAPE and wind shear were higher than normal (NOAA, 2011a). These events have inevitably brought up the question of climatological factors enhancing the frequency and intensity of extreme convective events, a topic that has not been of detailed study (Emanuel, 2011) due to a significant number of factors. These factors include difficulties in representing small scale phenomena (i.e. tornadoes, downbursts) in models. Additional issues include uncertainties in the rating process (Phan and Simiu, 1998; Edwards et al., 2010) (e.g., F or EF scale for tornadoes) and the lack of actual measured extreme wind speed data (Lombardo, in press). Even if extreme wind data is measured with anemometry, difficulties with standardization of data due to local surrounding terrain can introduce differences of up to 50% of the measured value (Lombardo, in press; McVicar and Roderick, 2010). Yet other issues include the relatively short length of official records and the efficacy of these records due to low population density in prone regions (Doswell et al., 2005). These difficulties are reiterated in the latest Intergovernmental Panel on Climate Change (IPCC) report discussing extreme events (IPCC, 2011) and in a presentation by the NOAA Undersecretary for Commerce (NOAA, 2011b). This lack of detailed understanding about the spatial and temporal distributions of extreme wind events is coupled by the fact that convective windstorms cause the majority of natural disaster damage and deaths in the US (NOAA, 2011c) and current wind load standards routinely use this data as a basis for structural design (Simiu, 2011).

## 2. DATA AND METHODOLOGY

Large scale climatological parameters (32 km x 32 km grid) at 3 hr time periods related to convective weather were collected from the North American Regional Reanalysis (NARR) dataset (Mesinger et al., 2006) from the period 1979-2010. In addition, estimated and measured wind speed gusts from the NOAA-SPC database as well observed extreme wind speeds extracted from selected Integrated Surface Hourly (ISH) stations, including ASOS data, from the 1973-2010 time period were collected.

Data from these observing systems were compiled to put together a comprehensive, spatiotemporal database of extreme measured wind speeds. ISH data was initially quality controlled using an automated program (Lombardo et al., 2009). All other data, including ISH data > 70 knots was manually quality controlled, increasing the confidence of these measured wind speeds.

The location of these measured extreme wind speeds was then matched with the closest grid point of the NARR dataset. The time of the observed gust was coupled with the closest time point of the NARR data. Relevant parameters from the NARR data were then associated with the magnitude of the measured gust. This process was done as a type of qualitative downscaling to determine what information can be learned relating large-scale parameters with observed extreme winds. As future climate scenarios suggest Convective Available Potential Energy (CAPE) and wind shear will increase and decrease respectively (Trapp et al., 2007), important qualitative information may be gained with respect to measured extreme winds.

Estimated wind events from the Storm Prediction Center's Database (NOAA, 2011d) were manually separated or clustered into "events" based on a few main criteria. A minimum of 30 reports were required for each event and no more than 4 hours could elapse between successive reports. Each event must have estimated or measured wind gust > 65 knots and a measured wind gust > 50 knots. Reports grouped as part of the same event were associated with the same general area of convection, which was verified by radar imagery. This clustering was done to analyze spatiotemporal variability in the data and to assess any possible trends/patterns emerging in the data as compared to both the observed and NARR databases.

## 3. MEASURED EXTREME WIND DATABASE

Measured wind speed data > 65 knots (Hales, 1988) were extracted from the ISH database 3505. ISH data was standardized to 10 meter height and 3 second gust. Terrain properties, for the time being, were assumed representative of open, flat country. The NOAA measured wind gust database was left unmodified.

Analyzing the ISH data revealed around 3,000 measured reports > 65 knots (~ 75 mph) over an approximately 40 year period.

To further analyze this information the convective wind speeds were separated from the dataset using reporting codes available in ISH data by means of an extraction program outlined in Lombardo et al. (2009). Tropical events were also removed from the analysis using information from the HURDAT database. Using this extraction program, approximately 1,500 reports were attributed to convective activity. The smaller number relative to all recorded winds is likely due to the smaller number of stations reporting the occurrence of convection (i.e., observer at station) as well non-convective wind events and tropical events (in the case of all recorded winds) lasting a longer time period and generating additional reports. To circumvent this problem, the measured convective wind gusts were separated by specific time periods to reduce mutual correlation between the values to arrive at the number of "independent" convective events. Approximately 1,000 independent recorded convective events >65 kt were noted by reducing correlation between extreme values. The total number of these events, by year, is illustrated in Figure 1, along with the number of stations available to measure.

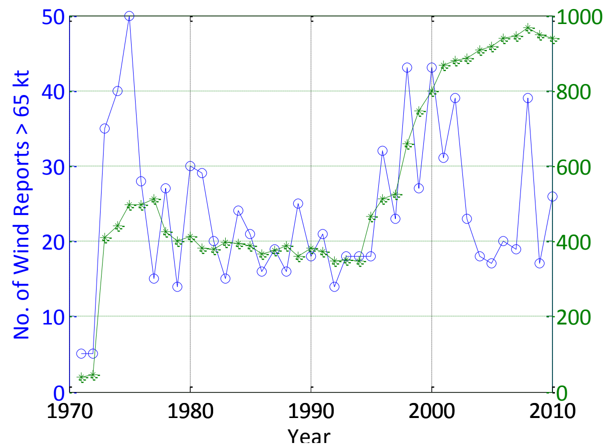


**Figure 1.** Number of Extreme Winds and Recording Stations (Green) 1971-2010.

Figure 1 illustrates the annual variability over time in the extreme wind count. Stations were few in 1971-72 and the low count of extreme winds can easily be attributed to the small number of stations. The number of stations increased and remained relatively constant from 1973-1996 (in the early 1990's most stations became automated, or ASOS stations) and then increased until about 2000, only to level off again until the present day. Increases in the number of extreme winds in any given year typically increased with a station count increase. No particular trends are readily identifiable by visually inspecting Figure 1. A noticeable decrease in the number of measured in extreme winds is noticed in the early 2000's continuing until 2010, with a notable exception in the active year of 2008, even while the number of stations remained relatively constant. As stated previous, an attempt was made to standardize the data.

However, numerous issues such as certain reporting procedures and variable terrain roughness, which was not accounted for in this study could contribute to a wind speed being above or below a selected wind speed threshold (Lombardo, in press) and could significantly affect the extreme wind count. More study is warranted, and will be pursued on this topic.

For the nearly 1,000 measured convective events, a spatial probability density function using a bivariate Gaussian kernel density estimation (Silverman, 1986) is shown in Figure 2. Figure 2 shows a “bullseye” of sorts (highest density) in the Central Plains with a relatively high frequency of extreme winds extending east of the Rockies throughout the Plains and east through the Corn Belt region, an area of the country noted for its large-scale convective wind events (Johns and Hirt, 1988). When examining the measured convective winds by decade (Figure 3), a slight shift to the southwest is observed in the “bullseye.” Smith et al. (2010) shows very similar results for a measured database > 50 kt from 2003-2009, including higher resolution station networks.

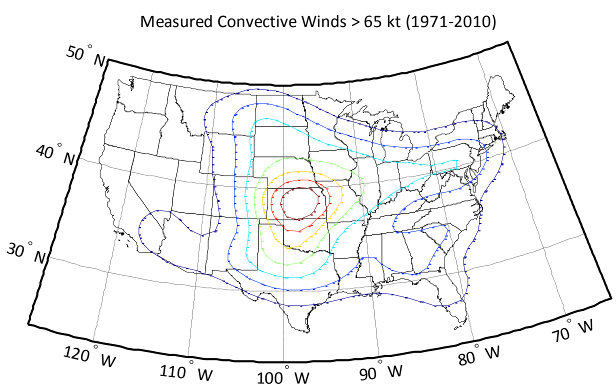


**Figure 2.** Spatial Density of Measured Extreme Winds (> 65 kt) from ISH 3505 (1971-2010)

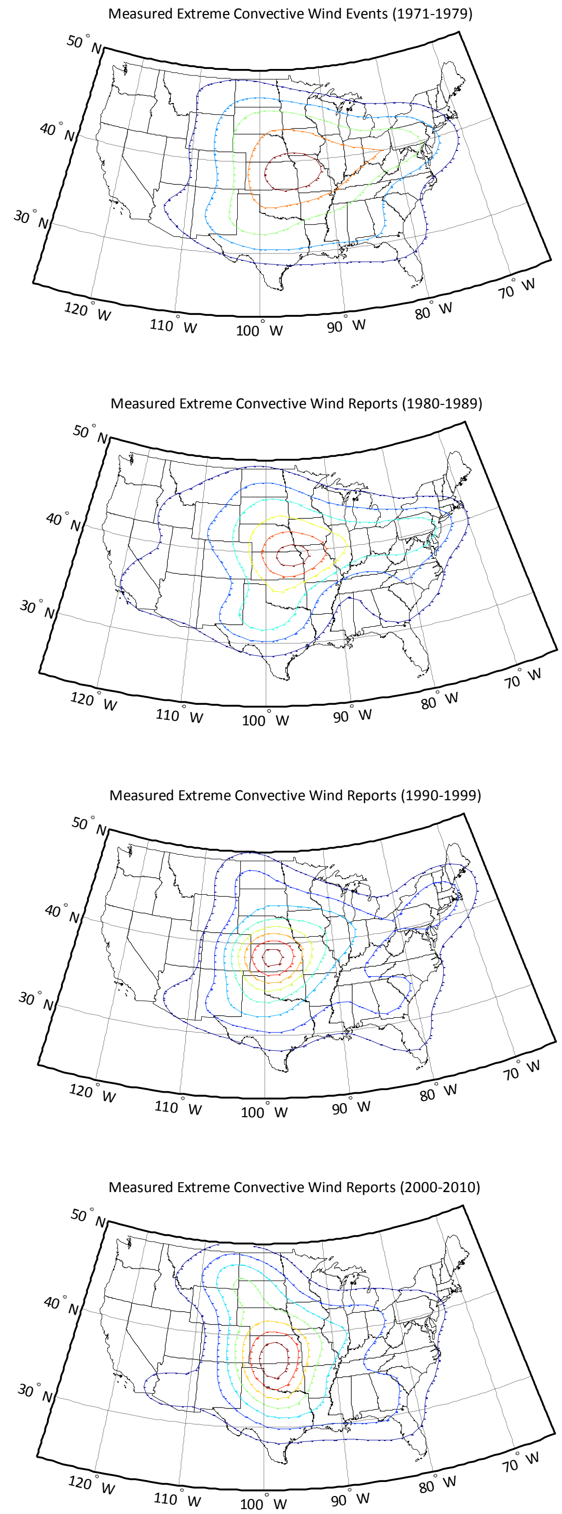


**Figure 3.** Spatial Density of Measured Extreme Winds (> 65 kt) from ISH 3505 by decade.

The ISH database revealed that although the measured extreme winds occurred in every month and at all times of day, the vast majority of extreme winds have occurred in the spring and summer months (Apr.-Aug.) and in the late afternoon to evening hours (20Z-06Z). In addition, nearly all wind directions as measured in the ISH database have a significant westerly component. Over 50% of measured extreme wind gusts had wind directions between 240 and 330 degrees while 80% were between 180 and 360 degrees. This directional distribution would suggest a likely some transfer of mid to upper level momentum down to the surface (Geerts, 2001). It would be interesting to eventually compare wind directions at different levels using the NARR data against measured surface wind directions. This information is illustrated in Figure 4.

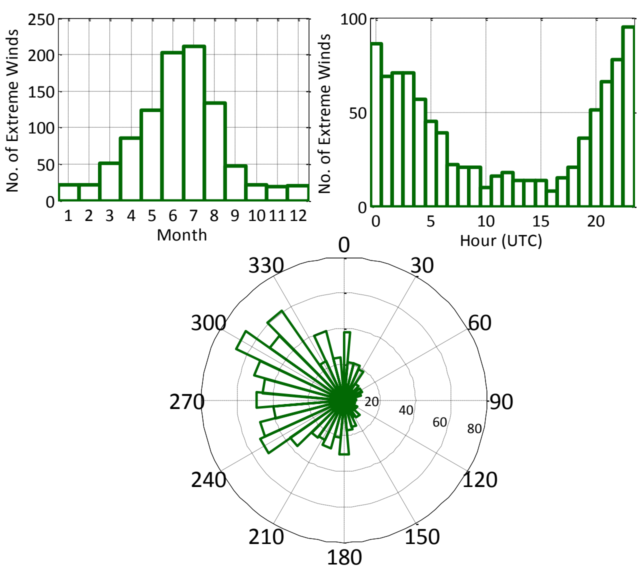


**Figure 4.** A breakdown of extreme wind reports by time of year and day as well as by wind direction.

## 4. DOWNSCALING USING NARR DATA

Analysis was performed on two sets of data. One includes all measured extreme wind values >50 kt from the NOAA-SPC database (NOAA, 2011d) in June 2010. The second includes all measured values from the entirety of 2010 that were 65 knots or greater. Both sets of extreme wind values were then coupled with some relevant convective parameters from the NARR data. These parameters include CAPE, Convective Inhibition (CIN), helicity (HLCY), precipitable water (PW), Lifted Index (LI), Specific Humidity (q), surface temperature (T) and dewpoint (Td) and *u* and *v* flow components from all NARR levels. In addition, derived quantities relevant to convective weather such as wind shear, relative humidity were also calculated.

NARR data from east of the Rockies were downloaded and relevant parameters were extracted. The NOAA database was manually scrubbed of all winds deemed to be non-convective. As stated in Section 2, the NARR grid point in closest spatiotemporal proximity to the measured extreme wind gust was used for comparison.

As shown in Figure 5, a graphical comparison of some of the NARR parameters and observed wind speed data for June 2010 yields some interesting results. Generally, for all parameters shown in Figure 5, there is no distinctive value or range of values that suggests extreme wind speeds will only occur within those constraints. In addition, the extremes of any one parameter do not seem to tend to more extreme wind speeds. However there are a few items that should be noted. One is that extreme winds < 80 kt are evenly distributed throughout the range of dewpoint depressions (T-Td), the most extreme winds (>80 kt) occur at relatively low T-Td (<10 deg C). For the LI parameter, the distribution is skewed from uniform with approximately 25 percent of LI values in the range (-5, -7), including all winds > 80 kt. As expected CIN values closer to zero yielded the majority of extreme wind environments with nearly zero events at CIN values < -200. Values of CAPE and HLCY were spread fairly evenly throughout the extreme wind speeds.

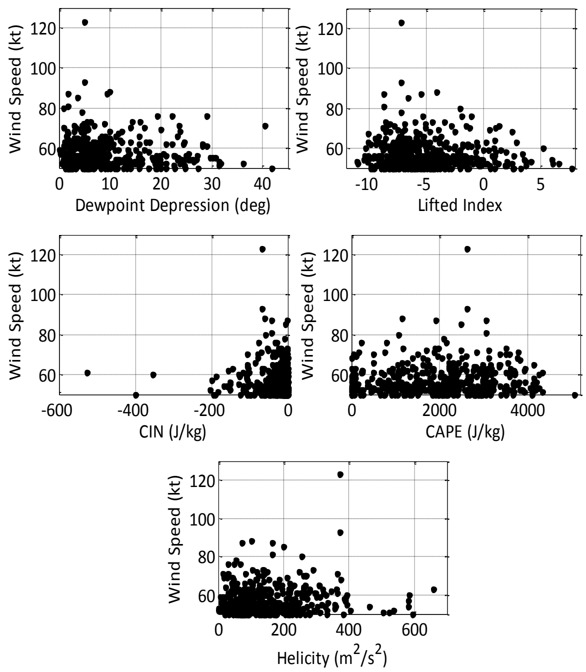


**Figure 5.** Observed extreme wind speed vs. selected NARR parameters

For measured winds > 65 kt for all of 2010 (163 total), an examination of CAPE versus surface-500mb shear distributions indicated a seasonal dependency in Figure 6. Extreme wind reports for October-March tended to have higher shear and much lower CAPE values than those reports from the spring and summer. This is attributed to

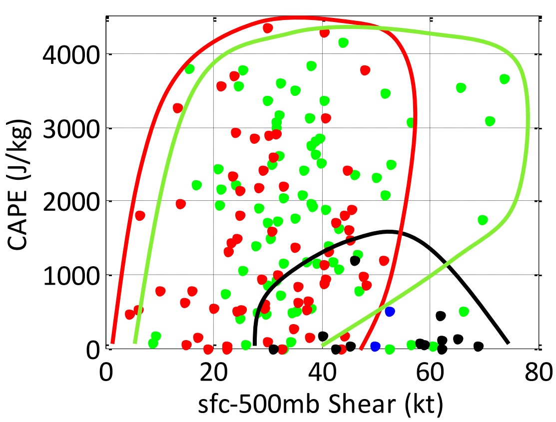


**Figure 6.** CAPE vs wind shear distributions separated by season for 2010. Black/Blue dots represent Oct – Mar events, red dots are for Jul-Sep events, and green dots are for Apr-Jun.

climatology favoring a stronger jet during the late fall and winter months as well as generally lower moisture content in the atmosphere (Brooks et al., 2007). Figure 6 also shows that extreme winds occur at a large range of wind shear values and reiterates the wide range of CAPE values present in extreme wind occurrences (Figure 5). Figure 6 also illustrates the variability of these parameter values within a seasonal construct.

As ambient low and mid-level moisture content likely plays a significant role in the generation of negative buoyancy for convective downdrafts (Wakimoto, 2001; Johns and Hirt, 1987), dewpoint depressions for the 163 events in 2010 at pressure values relative to the surface pressure were investigated as potential precursors to extreme surface winds. This is demonstrated in Figure 7. Figure 7 shows for select data in the months of April-June 2010, as has been visualized in other parameters, the wide range of values associated with measured extreme winds. However, a particular pattern does emerge from a number of cases. Higher moisture content is noted in the lower levels, a condition that may strengthen downdrafts (Proctor, 1989). In addition, a drying is noted in some cases above the levels of higher relative moisture content as well as below the maximum value while approaching the surface, likely indicating a well-mixed boundary layer.

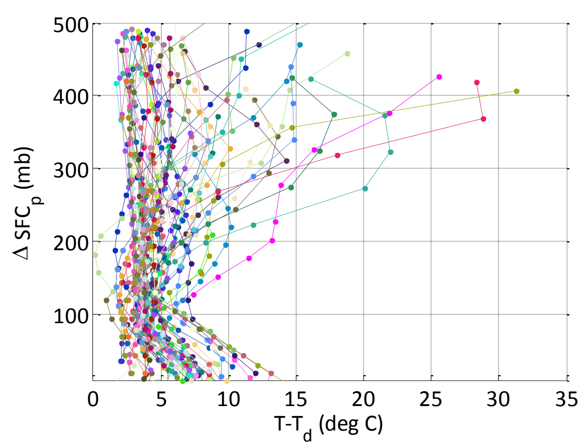


**Figure 7.** Vertical profiles of dewpoint depression relative to surface pressure for select extreme measured wind events.

To begin to assess the regionality of extreme wind events, the average mean sea-level pressure and mean flow vectors from 18 extreme measured wind reports from a 2 deg x 2 deg grid square (Figure 8) in a preferred region for extreme winds were analyzed. Data within the grid square revealed strong veering aloft, a strong horizontal shear zone near the vicinity of the box with decreasing pressure to the southwest.

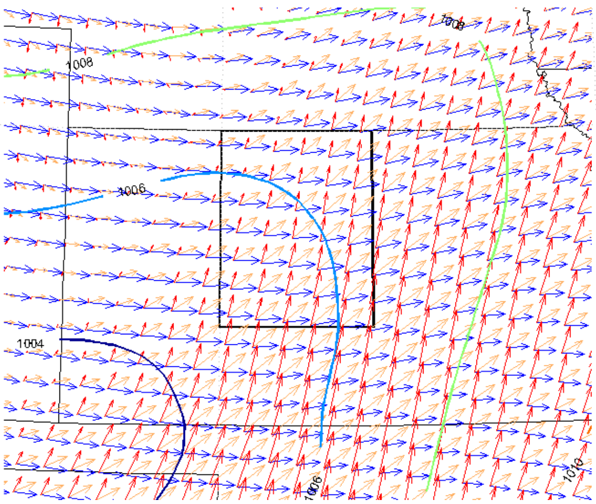

**Figure 8.** Mean flow vectors and mean seal level surface pressure from NARR for 18 extreme wind events within box. Blue: 500mb, Gold: 700mb, Red: 850mb

**5. "EVENT" CLUSTERING**

An initial sampling of NOAA storm report locations from 2010 was taken and an "event density" was calculated for each discrete convective wind event. An example of the event density for storm reports from 26 Oct 2010 is shown in Figure 10. The event density is similar to that shown in Figure 2

This event density can then be used to compare the spatiotemporal properties of large-scale parameters such as the NARR with those of reported extreme winds. The data can also be used to compare NOAA storm reports with themselves by season, location, etc…The differences and problems in spatial tendencies between reported and measured extreme winds are discussed in Smith et al. (2010).

For all of 2010, a maximum density was calculated for each "event" as explained in Section 2. For example, in Figure 10 the maximum density would be in SE Indiana. This is shown in Figure 6. Yellow dots are for the months of April-June, Green for Jul. – Sep. and Blue for Oct. – Dec. Figure 9 also lines up quite well with known derecho climatology (Johns and Hirt, 1987), suggesting a methodology for determining larger scale convective wind events from storm reports.

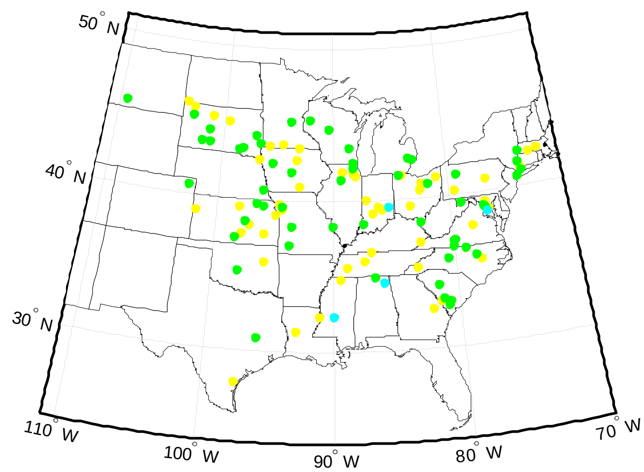


**Figure 9.** Event density for all 2010 estimated extreme wind reports.

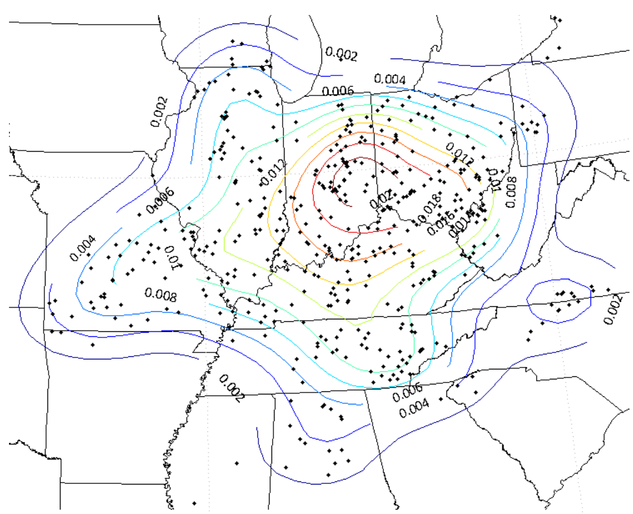

**Figure 10.** "Event Density" for 26 Oct 2010

## 6. PRELIMINARY RESULTS/FUTURE WORK

Approximately 1,000 convective measured gusts > 65 knots were found in the ISH database. Normalizing extreme wind reports by number of stations yielded no discernible trend. Further quality control and separation of spatiotemporal properties of extreme winds such as by season, location and year will be performed.

Qualitative downscaling of NARR parameters revealed that extreme winds are likely to occur at a range of values. For some future climate scenarios, such as an increase in CAPE, this may suggest the increase of extreme wind speeds may not be proportional. Preliminary analysis suggests a particular vertical moisture profile was noticed with a number of events. Detailed validation of NARR parameters with observed data in close proximity to the extreme wind report and separation by storm type will be performed in the near future. Difficulties in quantitatively interpreting parameter relationships with observed peak wind speed magnitude will continue to be difficult due to issues with measuring extreme wind speed data outlined in the paper.

Clustering by event showed that extreme wind events are likely most places east of the Rockies and north of 30 deg latitude. Further work will include appending a Canadian database to give a better idea of spatial distributions.

Further interpretation of all large-scale parameters and how they may be vital to near-surface extreme wind production will be studiedincluding accounting for the cumulative numbers of large-scale severe weather environments that occurred and the mean and variability of large-scale parameters based on their spatiotemporal properties regardless of whether an extreme near-surface wind speed was observed.

Addition of 2011 data, one of the more extreme convective years on record, will also be included.

## 7. REFERENCES


Brooks, H.E. et al. (2007). “Climatological aspects of convective parameters from the NCAR/NCEP reanalysis”, *Atmos. Research*, 83, 294-305

Doswell, C. et al. (2005). “Climatological Estimates of Daily Local Nontornadic Severe Thunderstorm Probability for the United States”, *Wea. Forecasting*, 20, 577-595

Edwards, R., et al. (2010). “The Enhanced Fujita Scale: Past, Present and Future”, *25th Conf. Severe Local Storms*, Denver, CO

Emanuel, K. (2011). http://dotearth .blogs.nytimes.com/2011/06/01/closeup-aprils-tornado-outbreaks/

Geerts, B. (2001). “Estimating Downburst-Related Maximum Surface Wind Speeds by means of Proximity Soundings in New South Wales, Australia”, *Wea. Forecasting*, 16, 261-269

Hales, J.E. (1988). “Improving the Watch /Warning Program Through Use of Significant Event Data”, Preprints, *15th Conf. on Severe Local Storms*, Baltimore, MD

IPCC (2011). *Managing the Risks of Extreme Events and Disasters to Advance Climate Change Adaptation (SREX)*. Online at: http://ipcc-wg2.gov/SREX/images /uploads/SREX-SPM_Approved-HiRes_opt.pdf

Johns, R.H. and Hirt, W.D. (1987). "Derechos: Widespread Convectively Induced Windstorms", *Wea. Forecasting*, 2, 32-49.

Lombardo, F.T. (in review). “Improved Extreme Wind Estimation for Wind Engineering Applications”, Submitted to *J. Wind Eng. Ind. Aerodyn.*

Lombardo, F.T. et al. (2009). “Automated Extraction and Classification of Thunderstorm and Non-Thunderstorm Wind Reports for Extreme Value Analysis” *J. Wind Eng. Ind. Aerodyn.*, 97, 120-131

McVicar, T.R. and Roderick, M.L. (2010). “Winds of Change”, *Nature Geoscience*, 3, 747-748

Mesinger F. et al. (2006). “North American Regional Reanalysis”. *Bull. Amer. Meteor. Soc.*, 87, 343-360

NOAA (2011a). http://www.esrl.noaa.gov /psd/csi/events/2011/tornadoes/climatechange.html

NOAA (2011b). http://www.noaanews.noaa.gov /stories2011/20111207_speech_agu.html

NOAA (2011c). http://www.nws.noaa.gov/om/ hazstats.shtml

NOAA (2011d). http://www.spc.noaa.gov/wcm/

Phan, L.T. and Simiu, E. (1998). “Fujita Tornado Intensity Scale”. NIST TN 1426, 23 pp.

Proctor, F.H. (1989). “Numerical Simulations of an Isolated Microburst. Part II: Sensitivity Experiments”, *J. Atmos. Sci.*, 46, 2143-2165

Silverman, B.W. (1986). *Density Estimation for Statistics and Data Analysis*, Chapman and Hall – New York, NY

Simiu E. (2011). *Design of Buildings for Wind*. Wiley-Hoboken

Smith, B. T., Winters, A.C., Mead, C.M., Dean, A.R., Castellanos, T.E. (2010). “Measured severe wind gust climatology of thunderstorms for the contiguous United States, 2003-2009”. Preprints, *25th Conf. Severe Local Storms*, Denver CO

Trapp, R.J. et al. (2007). “Changes in severe thunderstorm environment frequency during the 21st century caused by anthropogenically enhanced global radiative forcing”. *Proc. Natl. Acad. Sci. US*., 104, 19,719–723.

Wakiomoto, R. (2001). “Convectively Driven High Wind Events”, *Severe Convective Storms*, Met. Monographs, C. Doswell, ed.