7A.1 USING RUC-2 ANALYSIS PARAMETERS TO IDENTIFY SEVERE CONVECTIVE WIND ENVIRONMENTS

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1. INTRODUCTION

Convectively generated surface winds are a common occurrence in the United States. Most thunderstorms generate outflow winds when precipitation-cooled air becomes negatively buoyant, descends to the surface and diverges. Typically these outflow winds are cooler and more humid than the ambient environment, and do not cause structural damage. In intense or organized systems however, winds can exceed 70 m s^{-1} (Fujita and Wakimoto 1981) easily damaging structures and putting lives at risk. These types of convective storms are of particular interest to the operational forecaster, and a key challenge to researchers is delineating convective environments that will produce severe winds from those that will not. This project identified the environments where widespread damaging winds occurred, and compared them to environments where strong convection occurred, but severe surface winds were isolated or non-existent.

2. BACKGROUND

Atmospheric parameters have long been analyzed to forecast and understand severe convective weather. Proximity soundings have been used near where tornadoes have occurred (e.g., Rasmussen and Blanchard 1998) and Rapid Update Cycle (RUC) model analysis soundings have also been used due to the sparse network of observed soundings (Thompson et al. 2003; Markowski et al. 2003). Most of these studies were done to determine the likelihood of tornadic occurrence; however, Evans and Doswell (2001) used observed proximity soundings to investigate derecho environments.

To use RUC model analyses, one must be confident that the data have an acceptable degree of accuracy. Thompson et al. (2003) compared numerous observed soundings to RUC model analyses and found them to be reasonable, with some inaccuracies for the environment close to the surface. They suggested that if RUC proximity soundings were to be used, a large dataset be utilized to minimize error.

The literature focuses on two aspects of the severe thunderstorm wind problem; the first is related to downbursts, and the second is related to the convective systems that produce numerous, quasi-continuous severe surface winds, such as bow echoes (Weisman 1993; Lee et al. 1992) and derechos (Johns and Hirt 1987; Evans and Doswell 2001). Both are interrelated aspects of the widespread damaging wind problem but are typically addressed separately. These papers and others have identified dry air entrainment into clouds, steep lapse rates, and heavy precipitation as reasons for strong downdrafts. Additionally, strong atmospheric wind fields and wind shear, along with high instability have been identified as reasons organized damaging wind-producing systems develop.

3. METHODOLOGY

3.1 *Sounding Parameters*

With the various causes of damaging surface winds in mind, 45 sounding parameters were calculated from 20 km RUC model analyses. These parameters included wind velocities, wind shear, instability, WINDEX (McCann 1994) DCAPE (Gilmore and Wicker 1998) and others related to damaging winds. The latitudes, longitudes, and occurrence times of tornadoes, damaging convective winds, and large hail as reported in the National Weather Service/Storm Prediction Center's preliminary database (http://www.spc.noaa.gov/climo/) were compared to the sounding parameters from up to 3 hours before the report occurred. For example, all severe reports from 1200-1459 UTC were compared to the 1200 UTC RUC analysis. Tornado and large hail occurrences were compared to damaging wind occurrences to determine if the atmosphere was favorable for all types of severe weather, or just favorable for damaging winds.

Next, lightning occurrences were compared to the sounding parameters in the same manner. If at least 5 lightning occurrences were observed within a 20 km grid box in the 3-h period, that grid box was considered convectively active (regardless of whether severe weather occurred there). Finally, all RUC analysis points where the 300 hPa most unstable convective available potential energy (MUCAPE) was greater than 100 J kg^{-1} (i.e. at least minimally unstable but not necessarily having convection) were compared to RUC analysis parameters for

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reference ("null" points). There were over 500 RUC analyses from all months in 2003 (except January) compared to 958 reports of tornadoes, 6355 reports of hail, 7055 reports of damaging winds, and 377081 lightning points, with one datum for each report. In total, 11983189 model points met the "null" condition.

All of the parameters associated with severe reports, lightning, or MUCAPE greater than 100 were sorted from greatest to least, and the 1st, 5th, 10th, 25th, 50th, 75th, 90th, 95th, and 99th percentile categories were output for comparison in tabular and box and whisker format. Severe modes were compared with one another, and severe modes were compared with lightning points to contrast the different environments present with each kind of severe weather (or lack of it). To do an objective comparison between categories, a statistical method (COMP) to compare severe modes to lightning points was developed. It started with the average interquartile range:

$$AVGIQR=(IRQ1+IQR2)/2,$$

where IQR1 is the interquartile range for the severe mode, and IQR2 is the interquartile range for the lightning point. The interquartile range is defined as the 75th percentile subtracted from the 25th percentile. Next, the median of the lightning point (M2) is subtracted from the median of the severe mode (M1) and divided by AVGIQR:

$$COMP=(M1-M2)/AVGIQR.$$

Dividing the difference in the medians by the average interquartile range normalizes the comparison by the range of the sample distributions, which is similar to how standard statistical significance is calculated. Statistical significance tests were performed on the distributions but due to the large sample size even distributions with differences that seemed small or insignificant were significantly different at the 99% confidence level and above. Therefore the COMP statistic was chosen to delineate how significantly different severe mode distributions were from lightning distributions.

3.2 *Wind Probability Index (WINDPROB)*

Previous severe weather indices have relied on adding parameters together (total totals, Severe Weather Threat or SWEAT, K index) or multiplying/dividing them, such as the SPC supercell and significant tornado predictors (Thompson et al. 2003), Energy-Helicity Index (EHI), Bulk-Richardson number (BRN). These methods assume that a change in one parameter in the index makes the environment proportionally more or less favorable for the type of weather the index is attempting to predict. However, using the EHI (a supercell and tornado predictor) as an example, the multiplication of two parameters may merely "average" the discriminatory ability of the two parameters. The EHI is formulated by multiplying CAPE and helicity together, then dividing by a constant. For observed tornadoes, 0-3 km AGL Storm Relative Helicity in J kg^{-1} (KM03SRH) discriminated well (COMP value 0.71) between tornado environments and environments with ordinary convection (Table 1). The 0-30 hPa mixed layer CAPE in J kg^{-1} (MIXCAPE) was somewhat discriminatory (COMP value 0.17) but not nearly as much as KM03SRH. When KM03SRH was multiplied by MIXCAPE and divided by the constant to get EHI, the COMP value for EHI was lower (0.49) than it was for KM03SRH, but higher than it was for MIXCAPE. Since some MIXCAPE is probably necessary for tornadoes and surface-based supercells to form, it may be true that there is some minimal threshold value of MIXCAPE above which the chance of tornado occurrence does not increase as much as it does for an increase of similar magnitude in KM03SRH. In other words, the result of multiplying two discriminatory parameters together may not necessarily be better than both parameters were individually.

TABLE 1. Percentile and COMP values for reports of tornadoes (T), large hail (H), damaging winds (W), model grid points with most unstable CAPE greater than 100 Jkg^{-1} (N), and model grid boxes with at least 5 lightning occurrences (L).

		0.01	0.05	0.10	0.25	0.50	0.75	0.90	0.95	0.99	COMP
	T	0.0	0.0	0.0	0.3	1.7	5.1	7.5	9.6	14.1	0.49
0-3 km EHI	H	0.0	0.0	0.0	0.2	1.0	2.5	4.9	6.6	11.5	0.41
	W	0.0	0.0	0.0	0.2	0.9	2.0	3.7	5.4	10.1	0.40
	N	0.0	0.0	0.0	0.0	0.2	0.6	1.4	2.2	4.7	
	L	0.0	0.0	0.0	0.0	0.3	1.0	2.2	3.5	7.1	
		0.01	**0.05**	**0.10**	**0.25**	**0.50**	**0.75**	**0.90**	**0.95**	**0.99**	**COMP**
	T	12	63	97	182	316	440	564	719	876	0.71
0-3 km SRH	H	-24	25	51	110	197	325	500	629	860	0.51
	W	-18	21	43	87	153	274	444	549	805	0.21
	N	-70	-24	-5	25	65	125	212	287	476	
	L	-50	-10	9	45	103	207	362	484	775	
		0.01	**0.05**	**0.10**	**0.25**	**0.50**	**0.75**	**0.90**	**0.95**	**0.99**	**COMP**
	T	0	0	4	277	1150	2394	3451	3981	5470	0.17
MIXCAPE	H	0	0	1	294	1117	2199	3195	3812	5075	0.16
	W	0	0	7	371	1143	2131	3124	3840	5246	0.18
	N	0	0	4	175	783	1706	2575	3150	4418	
	L	0	0	0	152	837	1792	2727	3338	4700	

Therefore, the new algorithm (WINDPROB) treats each parameter separately and does not assume that numerical changes in favorable parameters should always change the algorithm output in the same proportions. The algorithm starts with select parameters that discriminated between damaging wind and ordinary convective environments, and did not show too much correlation to one another. It then combines them such that the output will change only when changes in parameters' values make damaging winds more or less likely.

3.3 *Case Studies*

To evaluate the utility of the sounding parameters and wind probability index, 11 cases were selected where strong convection occurred. In six of these cases, widespread damaging winds were observed. In the other five, only isolated damaging winds were observed. For all 11 cases, the parameters in the wind probability index were evaluated, and the evolution of convection was analyzed with respect to frontal systems, synoptic, thermodynamic, and kinematic patterns. Favored regimes for damaging winds were compared to those where sounding parameters indicated widespread damaging winds were probable, but none were observed. This helped to gain practical forecasting knowledge and insight into the physical processes involved in generating damaging winds.

4. RESULTS

4.1 *Sounding Parameters*

For ground relative wind velocity data in m s^{-1} for 2003, COMP reached a maximum for at 2 km AGL (KM2WIND) for damaging winds (0.45), indicating that KM2WIND best discriminated (among the ground relative wind parameters) between ordinary convection (lightning points) and convection with damaging winds (Fig. 1). Additionally, KM2WIND had the highest COMP

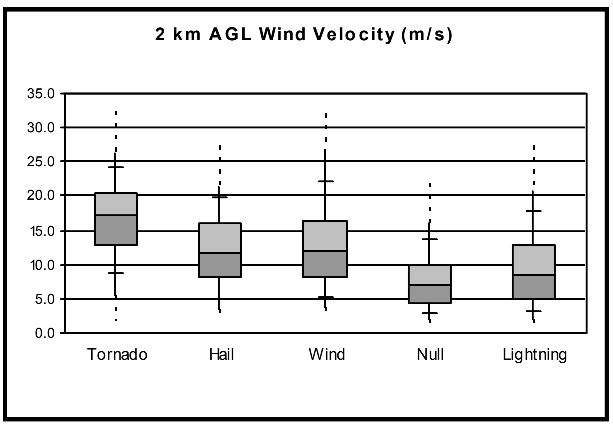

Fig. 1. Box and Whisker plot for wind velocity at 2 km AGL associated with reports of tornadoes, large hail, damaging winds, lightning, and model grid points with most unstable CAPE greater than 100 Jkg^{-1} (null). Markings indicate the 1st, 5th, 10th, 25th, 50th, 75th, 90th, 95th, and 99th percentile values. Boxes enclose the 25th to 75th percentiles.

value for damaging winds among all 45 parameters tested. However, all the COMP values for ground relative winds from 1-6 km AGL were fairly similar (ranging from 0.36 to 0.45), indicating that strong wind fields at those levels were generally favorable for damaging winds. Additionally, COMP values for storm relative helicity and wind shear were similar but slightly less (ranging from 0.24 to 0.30) than the wind velocity COMP values. The similarity can be seen in Fig. 2. The wind velocity, wind shear, and storm relative helicity data suggest that damaging wind occurrence was dependent on strong wind fields in the lowest 5 or 6 km AGL, and may have been most dependent on strong wind fields above the surface but in the lowest 2 km AGL.

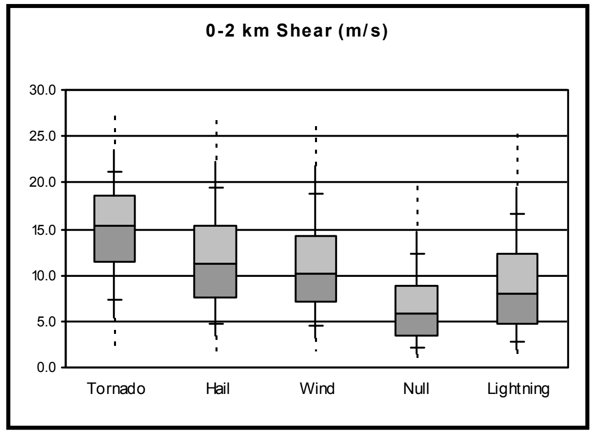

Fig. 2. As in Fig 1, except for 0-2 km shear.

Instability (CAPE, lapse rates) parameters did not discriminate between environments producing damaging winds and environments producing ordinary convection as well as the wind related parameters did. The box and whisker plot for MIXCAPE in J kg^{-1} (Fig. 3) looks less discriminatory, and the COMP value was only 0.18. MUCAPE was somewhat better, with a COMP value of 0.26. For damaging wind points, no lapse rate parameter (in minus K km^{-1}) tested had a COMP value higher than 0.16, but the 1-4 km AGL lapse rate (KM14LAPSE) and surface to melting level lapse rate (MELTLAPSE) were slightly discriminatory below the 50th percentile,

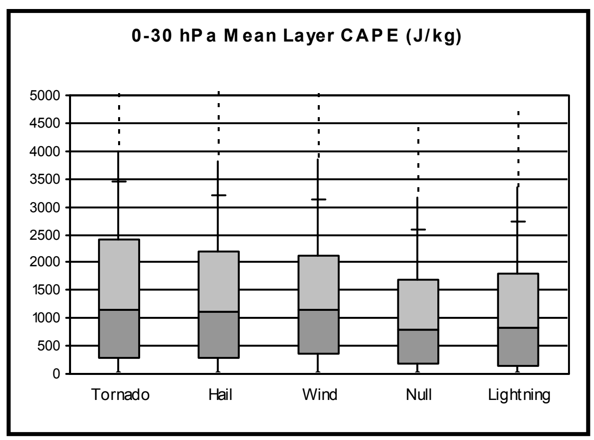

Fig. 3. As in Fig 1, except for 0-30 hPa mixed layer CAPE.

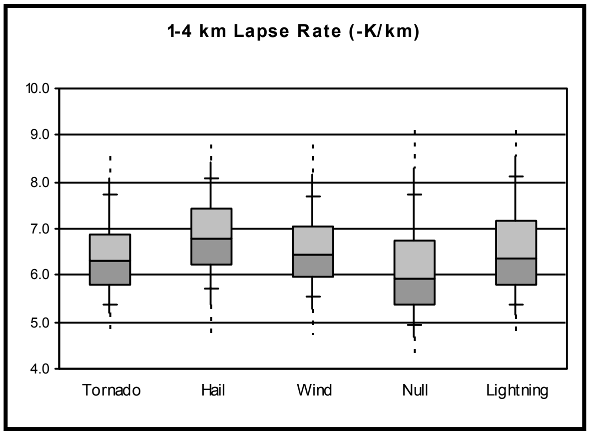

Fig. 4. As in Fig 1, except for 1-4 km lapse rate.

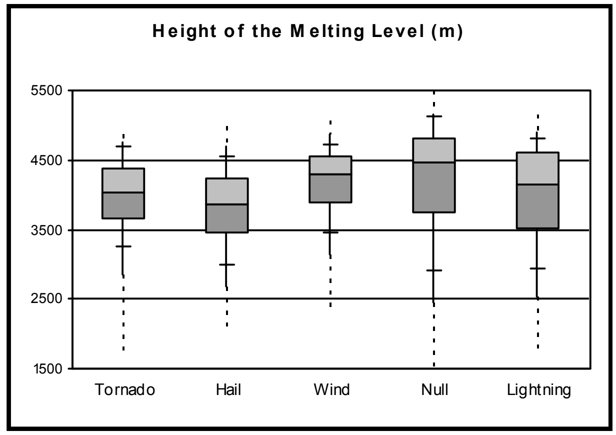

Fig. 5. As in Fig 1, except for height of the melting level.

especially when compared to nulls (Fig. 4). These data suggest that increases in wind velocity are more important to generating damaging winds than increases in instability, but that there is a low threshold of instability below which the likelihood of damaging winds decreases.

WINDEX and DCAPE, two parameters used to estimate convectively generated winds, were similar to MIXCAPE/MUCAPE in that they tended to distinguish damaging winds from ordinary convection fairly well, but not as well as the wind and wind shear parameters. Since WINDEX (COMP 0.19) and DCAPE (COMP 0.30) distinguished between severe weather and lightning the same as MIXCAPE/MUCAPE, it was difficult to discern if these parameters were discriminatory, or if the similarities to CAPE in their formulation was the reason for the discrimination.

Several mid-level and low-level relative humidity parameters were tested, and all of them had COMP values below zero, indicating that the low and mid levels of damaging wind environments tend to be moister than ordinary convective environments. The maximum mixing ratio (MAXRV) and the height of the melting level (MELT) were also both tested. These two variables had a correlation coefficient above 0.7, due to the fact that the atmosphere is generally stable if MELT is high and MAXRV is low, and the atmosphere is unrealistically unstable if MELT is low and MAXRV is high. The distribution of damaging wind points was similar to lightning points above the 50th percentile, but damaging wind points below the 50th percentile had much higher values than lightning points (Fig. 5). This suggests that there is some low threshold of MAXRV and MELT below which damaging winds become less likely. Other parameters, such as the lifted condensation level, convective inhibition, and the level of free convection were tested, and found to generally not be discriminatory.

4.2 *Wind Probability Index (WINDPROB)*

The parameter with the highest correlation to damaging wind occurrence was KM2WIND, (Fig. 1) and therefore it was chosen to be one of the base components of the algorithm. In addition to KM2WIND, MIXCAPE was chosen to be a base component of the algorithm. Clearly, MIXCAPE is associated with surface-based convection. Since damaging winds occur at the surface, convection based near the surface may be more likely to produce damaging winds than elevated convection. The other parameters selected were KM6WIND, MELT, and KM14LAPSE. When these parameters' values were low (Figs, 4,5,6), damaging wind reports were infrequent. Therefore, if any of these three parameters' values are in a range where damaging winds were infrequent, the

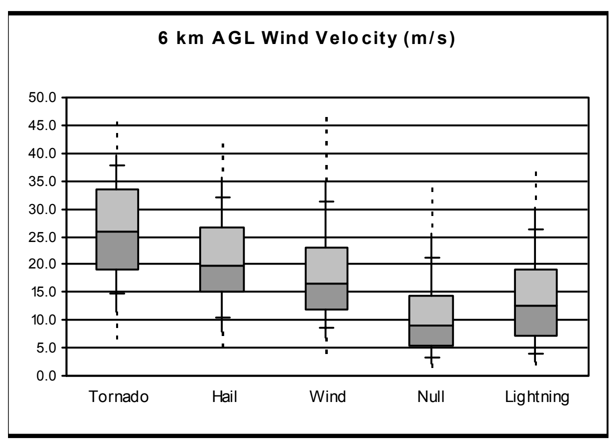

Fig. 6. As in Fig 1, except for wind at 6 km AGL.

algorithm output is decreased. Since dry microbursts occur in environments with low MAXRV but high MELT values (Wakimoto 1985), MELT was chosen for the algorithm over MAXRV.

WINDPROB=3.5*KM2WIND +0.01*MIXCAPE
(max KM2WIND 20, max MIXCAPE 3000)

IF KM6WIND < 10.0 THEN
WINDPROB=WINDPROB-15.0*(10-KM6WIND)

IF KM14LAPSE < 5.8 THEN
WINDPROB=WINDPROB-100.0*(5.8-KM14LAPSE)

IF MELT < 3700.0 THEN
WINDPROB=WINDPROB-0.067*(3700-MELT)

IF WINDPROB < 0 OR MIXCAPE=0 THEN
WINDPROB=0

WINDPROB=WINDPROB*1.2 (Max of 99)

Fig. 7. Chart showing formulation of WINDPROB, variables defined in text.

The parameter contributions in the algorithm are scaled and combined so that the end result corresponds to approximately the observed percentile distribution where damaging winds occurred. For example, if the algorithm returns a 75, that means that 75% of damaging wind reports occurred with a value lower than 75. The first step in the creation of this algorithm was to examine how KM2WIND and MIXCAPE changed as the percentile values changed. Using statistical software, the parameters were plotted as the x-value, and the percentiles were plotted as the y-value. The slope of the best linear fit to the plot was then multiplied by the parameter to achieve a 0-100 percentile-like distribution. For KM2WIND, this slope was approximately 4.9 (not shown) while for MIXCAPE it was approximately 0.03 (not shown). Upper bounds were set for KM2WIND (20) and MIXCAPE (3000) to ensure any outliers did not impact algorithm output. The next step was to combine these two parameters into one preliminary algorithm by adding them together. Since adding them together would no longer result in a 0-100 distribution, both were multiplied by factors whose total was 1. Since the COMP value of KM2WIND was higher than the COMP value of MIXCAPE, it is desirable to weight it more heavily. Therefore the slope of KM2WIND (4.9) was multiplied by 0.7 and the slope of MIXCAPE (0.03) was multiplied by 0.3, and both were rounded to 3.5 and 0.01 respectively.

Next, reductions were calculated for KM6WIND, MELT, and KM14LAPSE. Since "low" values of these parameters occurred infrequently with damaging winds, a threshold value was selected for each halfway between the 10th and 25th percentile of the observed distribution (and then rounded), below which values were considered "low." Then, a scalar constant was multiplied by the difference between the threshold value and the actual value (as seen in Fig. 7) of the parameter that was "low." This constant, when multiplied by the difference between the "low" threshold value and the 1st percentile value, leads to a reduction of approximately 100.

For example, the KM6WIND threshold was determined to be 10.0. Since the 1st percentile value of KM6WIND was 2.8 for damaging winds, a multiplication of 15.0 times the quantity (10.0-2.8) returns approximately 100. A KM6WIND value of 6.0 (around the 5th percentile) would return a 15.0 multiplied by (10.0-6.0) reduction, or a reduction of 60. Each constant and threshold is reported in Fig. 7, along with the entire formulation of the algorithm. Since there were numerous reductions associated with the unfavorable parameters, the algorithm no longer had a 0-100 distribution. Therefore, the final product was multiplied by 1.2 and an upper bound was set at 99 (since values of 100 imply certainty, which is of course not possible). The COMP value for the algorithm final result (1.03) is more than double what the best individual parameters' COMP values were, indicating that this combination of parameters is more discriminatory than any individual parameter for damaging winds (Fig. 8).

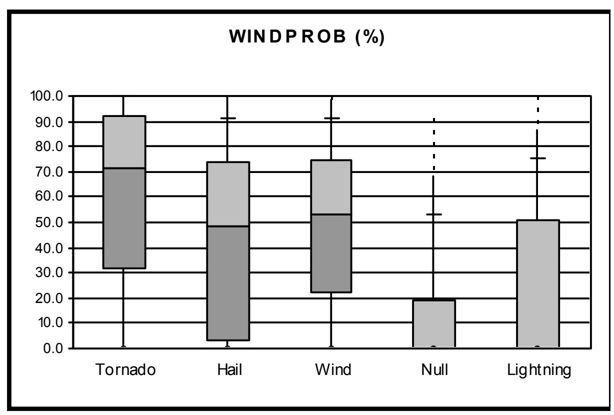

Fig. 8. As in Fig 1, except for WINDPROB.

4.3 *Case Studies*

In most of the case studies, sounding parameters associated with damaging winds, and the WINDPROB algorithm output indicated damaging winds were possible. In cases where widespread damaging winds were observed, KM2WIND was at least somewhat perpendicular to the convective line that existed. However, when KM2WIND was parallel to the convective line, it led to cells that trained or moved slowly, and they generally did not produce damaging winds. Additionally, when

KM2WIND was perpendicular to the convective line, but blowing from warm to cold (i.e. warm air advection), convection tended to be elevated and not produce damaging winds. These are the two expected failure modes when WINDPROB is indicating a potential for damaging winds: when isentropic lift elevates convection, and when KM2WIND is parallel to the convective line.

When categorizing the cases by forcing mechanism, convection in the damaging wind events was either forced by a strong linear forcing, in the presence of at least marginal instability, or by a cold pool gust front in the presence of adequate shear and moderate to high instability. Although it is not possible here to present all of the case studies, the following are conceptual models of what can be expected given each type of forcing, and the failure modes associated with each type.

4.3.1 *Linear Forcing*

Convection is forced and re-generated by a strong linear mechanism (Evans and Doswell 2001, Stoelinga et al. 2003), usually a strong cold front or trough, with near surface instability to form surface based convection, and strong KM2WIND oriented at least somewhat perpendicular to the convection/front (Fig. 9). Damaging winds are favored because any momentum from 2 km AGL descending to the surface will be oriented in the same direction as outflow from the convective line, leading to an additive effect. Buoyancy-generated outflow need not be strong enough to regenerate convection, since the strong linear forcing mechanism will suffice as long as there is some conditional instability near the surface to maintain a surface based storm.

If convection is elevated, damaging winds are less likely because low-level stability will prohibit momentum aloft from reaching the surface. If KM2WIND is oriented parallel to the convection, momentum from 2 km AGL and outflow will not be oriented in the same direction, so there will be no additive effect (Fig. 9). However, if KM2WIND is above severe limits (i.e. 25 m s^{-1}), no additive effects may be necessary to produce damaging winds, provided that momentum can descend to the surface.

4.3.2 *Cold Pool Forcing*

Convection can be initiated by any mechanism, such as isentropic lift over a thermal boundary (Fig. 10) in the presence of moderate or high near surface based instability. If instability is high enough to generate a strong cold pool (Weisman 1993), and low-level shear can sustain deep convective updrafts (Rotunno et al.1988) then strong convection will continue and damaging winds may

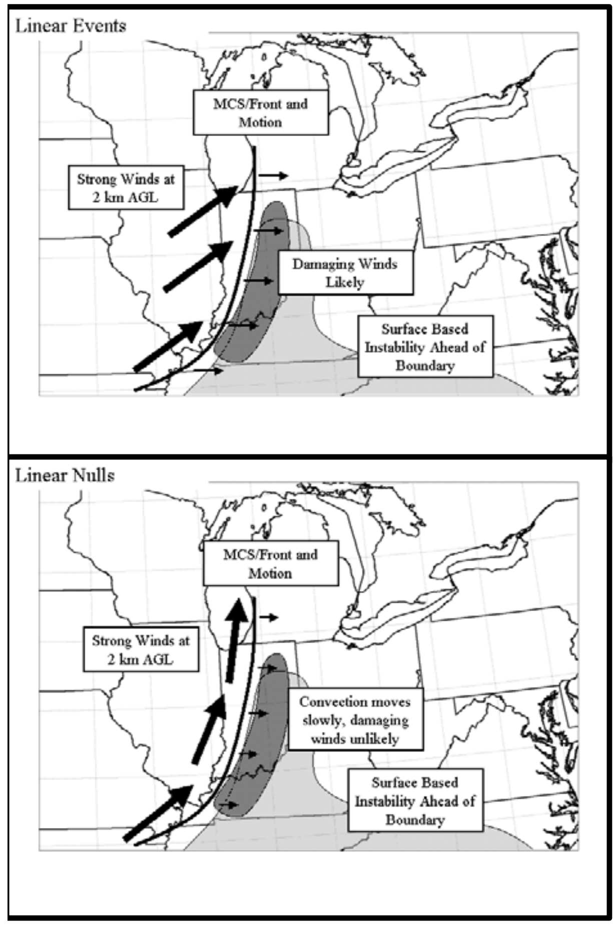

Fig. 9. Conceptual models showing patterns that are favorable and unfavorable for damaging winds with systems forced by a strong linear mechanism.

be widespread. When KM2WIND is strong, the 0-2 km bility. If instability is high enough to generate a strong cold pool (Weisman 1993), and low-level shear can sustain deep convective updrafts (Rotunno et al.1988) then strong convection will continue and damaging winds may be widespread. When KM2WIND is strong, the 0-2 km (low-level) shear vector and the 2 km wind vector will usually be similar (depending on the strength of the surface winds) meaning that new convective development is likely where KM2WIND could contribute to damaging winds (if brought to the surface) by an additive effect with thunderstorm outflow. When KM2WIND and system movement are the same direction, rear inflow jets may also be strengthened (Weisman 1993), leading to a higher likelihood of damaging winds.

Again, if convection is elevated, damaging winds are less likely because low-level stability will prohibit momentum from reaching the surface (Fig. 10). And, as in the linear model, if KM2WIND is parallel to the convective line, damaging winds are less likely, for the same reasons outlined above. Additionally, if the flow at 2 km

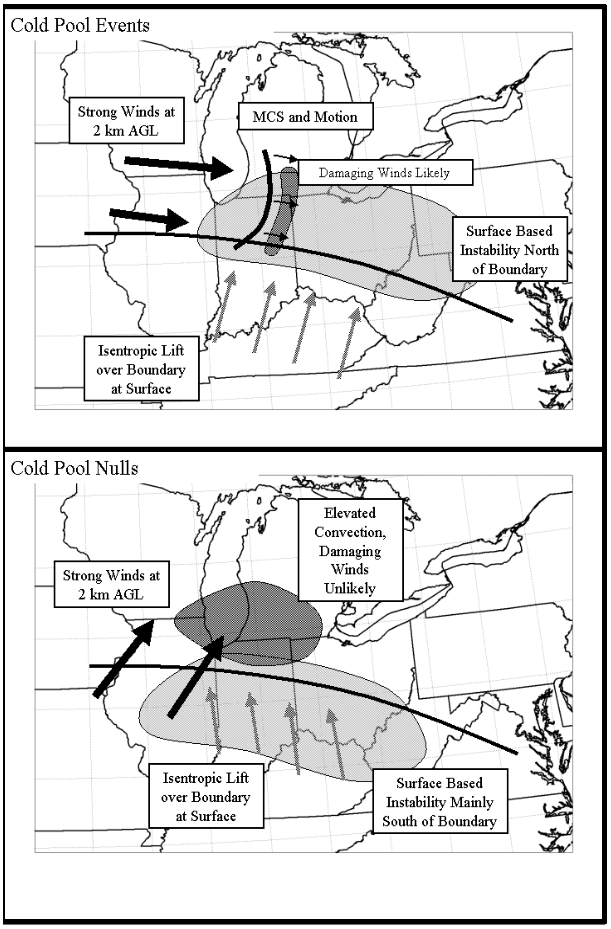

Fig. 10. Conceptual models showing patterns that are favorable and unfavorable for damaging winds with systems forced by a cold pool gust front.

AGL is strong but perpendicular to any frontal boundaries present (and blowing from warm to cold), isentropic lift will tend to elevate convection and the cold pool will be less relevant as ambient low-level stability increases.

5. DISCUSSION

The data examined in this study suggest that atmospheric wind parameters in the low levels (but not at the surface) are the most important when diagnosing damaging wind potential. Strong wind fields throughout the troposphere allow convection to organize into long-lived, intense systems, by removing precipitation from the updraft region. Strong wind fields in the lowest few kilometers are favorable specifically for damaging winds in several ways. The first is that convectively driven downdrafts can transfer high momentum air to the surface. The second is that fast environmental wind fields lead to fast storm motion and fast outflow propagation (and hence strong ground relative winds) in an MCS (Evans and Doswell 2001). The third is that fast environmental wind aloft entails high values of shear, which are favorable for MCS's to be long lived (Rotunno et al. 1988), so that any MCS producing damaging winds would tend to continue for long periods. The fourth is that fast environmental winds leading to organized convective systems can generate their own strong wind perturbations over time (Weisman 1993).

CAPE and lapse rate related parameters were somewhat discriminatory, while low and mid-level relative humidity parameters were not discriminatory for damaging wind versus ordinary convection environments. To generate damaging winds, perhaps small amounts of instability in the presence of strong wind fields can generate the vertical motions necessary to bring strong environmental or storm generated winds to the surface. Numerous hypotheses explain why steep lapse rates are favorable for damaging winds (Wakimoto 1985, Srivastava 1985) mainly due to the fact that buoyant downdrafts are suppressed when lapse rates are stable. The data do hint that stable lapse rates are unfavorable for damaging winds, but not that increasingly unstable lapse rates are necessarily more favorable for damaging winds.

Relative humidity in the low and mid levels was not found to discriminate between damaging wind and ordinary convection environments. As with steep lapse rates, numerous hypotheses (e.g., Knupp 1987) link dry air entrainment in the mid levels to downdraft initiation and damaging winds, but the present data suggest that precipitation loading (Srivastata 1985) or dynamic forcing (Orf and Anderson 1999) may be more important to generating downdrafts associated with damaging winds. The maximum mixing ratio and the height of the melting level were found to discriminate between damaging wind and ordinary convection environments, as damaging winds rarely occurred when their values were too low. It could be that high mixing ratio values lead to heavy precipitation, more loading, and stronger negative buoyancy, or it could be that high melting levels values allow time for the generation of negative buoyancy through hail melting. Due to the high correlation of these variables (0.7 correlation coefficient), the physical reasons may be entirely due to one process or the other.

A wind probability index was developed using the parameters that were found to be discriminatory. KM2WIND had the highest COMP value, and along with MIXCAPE was chosen to be the base of the algorithm. If KM6WIND, MELT, or KM14LAPSE values were too low, the algorithm was reduced. In this way, the algorithm output was only lowered when these three parameters had values that were unfavorable for damaging winds. The final result had a COMP value more than double the most discriminatory individual sounding parameter

(KM2WIND).

Several case studies were completed to evaluate the discriminatory parameters and the wind probability index. These case studies revealed that in areas where strong convection was anticipated, the wind probability index was typically high, indicating damaging winds were more probable with convection that occurred there. However, there were times when damaging winds did not occur, typically when the orientation of KM2WIND was parallel to the convective line, or when convection was elevated due to isentropic lift over a thermal boundary. These failure modes are important for forecasters to keep in mind when using the parameters found to be favorable for damaging winds in this study.

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7. REFERENCES

Evans, J. S., and C. A. Doswell, 2001: Examination of derecho environments using proximity soundings. *Wea. Forecasting*, **16**, 329-342.

Fujita, T. T., and R. M. Wakimoto, 1981: Five scales of airflow associated with a series of downbursts on 16 July 1980. *Mon. Wea. Rev.*, **109**, 1438-1456.

Gilmore, M. S., and L. J. Wicker, 1998: The influence of midtropospheric dryness on supercell morphology and evolution. *Mon. Wea. Rev.*, **126**, 943-958.

Johns, R. H., and W. D. Hirt, 1987: Derechos: widespread convectively induced windstorms. *Wea. Forecasting*, **2**, 32-49.

Knupp, K. R., 1987: Downdrafts within high plains cumulonimbi. Part I: general kinematic structure. *J. Atmos. Sci.*, **44**, 987-1008.

Lee, W. C., R. E. Carbone, R. M. Wakimoto, 1992: The evolution and structure of a "bow-echo-microburst" event. Part I: the microburst. *Mon. Wea. Rev.*, **120**, 2188-2210.

Markowski, P. N., C. Hannon, J. Frame, E. Lancaster, A. Pietrycha, R. Edwards, and R. Thompson, 2003: Characteristics of vertical wind profiles n*ear supercells obtained from the Rapid Update Cycle. Wea. Forecasting*, **18**, 1262-1272.

McCann, D. W., 1994: WINDEX-A new index for forecasting microburst potential. *Wea. Forecasting*, **4**, 532-541.

Orf, L. G., J. R. Anderson, 1999: A numerical study of traveling microbursts. *Mon. Wea. Rev.* **127**, 1244-1258.

Rasmussen, E. N., and D. O. Blanchard, 1998: A baseline climatology of sounding-derived supercell and tornado forecast parameters. *Wea. Forecasting*., **13**, 1148-1164.

Rotunno, R., J. B. Klemp, and M. L. Weisman, 1988: A theory for strong, long-lived squall lines. *J. Atmos. Sci.*, **45**, 463-485.

Srivastava, R. C., 1985: A simple model of evaporatively driven downdraft: Application to microburst downdraft. *J. Atmos. Sci.*, **42**, 1004-1023.

Thompson, R. L., R. Edwards, J. A. Hart, K. L. Elmore, and P. M. Markowski, 2003: Close proximity soundings within supercell environments obtained from the Rapid Update Cycle. *Wea. Forecasting*, **18**, 1243-1261.

Wakimoto, R. M., 1985: Forecasting dry microburst activity over the high plains. *Mon. Wea. Rev.*, **113**, 1131-1143.

Weisman, M. L., 1993: The genesis of severe, long-lived bow echoes. *J. Atmos. Sci.*, **50**, 645-670.