Extended abstract
AMS 24th Conference on Severe Local Storms
27-31 October 2008, Savannah, Georgia

P12.13 ASSESSING THE IMPACT OF PROXIMITY SOUNDING CRITERIA ON THE CLIMATOLOGICAL SIGNIFICANT TORNADO ENVIRONMENT

Corey K. Potvin *
School of Meteorology, University of Oklahoma, Norman, OK

Kimberly L. Elmore
Cooperative Institute for Mesoscale Meteorological Studies, University of Oklahoma, and NOAA/OAR/National Severe Storms Laboratory, Norman, OK

Steven J. Weiss
NOAA/Storm Prediction Center, Norman, Oklahoma

I. INTRODUCTION

Proximity sounding studies have been used for many decades to examine severe storm environments (e.g. Showalter and Fulks 1943; Fawbush and Miller 1952, 1954; Beebe 1958; Darkow 1969; Maddox 1976; Davies and Johns 1993; Brooks et al. 1994; Rasmussen and Blanchard 1998; Thompson et al. 2007). In this approach, distributions of severe weather parameters are compiled from soundings which occurred in spatial and temporal proximity to events (e.g. tornadoes, ≥ 2" diameter hail). The primary objective is to identify criteria which can help forecasters anticipate when and where particular types of severe weather may occur. For example, the Supercell Composite Parameter (SCP) and Significant Tornado Parameter (STP) are based on a study (Thompson et al. 2003) of model soundings which identified several sounding parameter thresholds which discriminate between supercell and non-supercell environments.

Proximity sounding studies require the selection of a set of proximity criteria which presumably provide a representative sampling of the "storm environment", that is, the region of the atmospheric parameter space supporting the storm during the time(s) when severe weather occurred. Unfortunately, the spatial

* Corresponding Author Address: Corey Potvin, 120 David L. Boren Blvd. Suite 5900, Norman, OK 73072; E-mail: corey.potvin@ou.edu.

and temporal scales of the typical storm environment are not known with any degree of precision. This uncertainty is reflected in the wide range of proximity criteria that have been employed in previous studies (Table 1). The more restrictive of these criteria implicitly acknowledge the large mesoscale variability which is often observed on severe weather (particularly tornado outbreak) days (Doswell 1982; Davies-Jones 1993). It is tempting to presume that conditions nearer a severe weather event are generally more representative of the region of the atmosphere which fostered the development of the parent storm. Although this is undoubtedly true for some range of spatial and temporal scales, thunderstorms often significantly modify the atmosphere immediately around them, creating conditions which are uncharacteristic of the environment which gave rise to the severe weather. Most proximity sounding studies mitigate this effect by removing soundings which are obviously convectively contaminated; however, soundings taken in regions which have been more subtly affected by the nearby storm are unlikely to be identified and removed.

Another important consideration in the selection of proximity criteria is the inherent tradeoff between collecting larger numbers of soundings (more inclusive criteria) and sampling the environment closer to the storm (more restrictive criteria). Due to the rarity of severe weather and the large separation in time and space between soundings, it is sometimes tempting to adopt less restrictive criteria in order to obtain statistically robust sample sizes. Whether such a step is justified depends on the typical scales of the storm environment which, again, have not been well-defined.

The preceding discussion makes clear that the selection of proximity criteria is a non-trivial matter. Nevertheless, until now, little attempt has been made to statistically assess the impact of proximity criteria on the analyzed climatological storm environment. In this paper, we examine and compare the climatologies of significant tornado environments obtained using several sets of proximity criteria. We seek to answer two important questions: (1) do different definitions of proximity result in significantly different climatologies, and (2) if so, can any of these climatologies be confidently identified as being most representative of the storm environment?

II. METHODOLOGY

This study makes use of a database of 1265 significant (F2+) tornado soundings (valid 0000 UTC) collected by Brooks and Craven (2002) from the lower 48 states for the period 1957-1996. In that study, proximity was defined as the event occurring within 185 km of the sounding release location between 2100 UTC and 0300 UTC (within 3 h of the sounding). Soundings with MU CAPE < 150 J kg^{-1} were removed; no further quality control was performed. In the present study, all soundings taken within 40 km of a tornado were subjectively examined for convective contamination. Six contaminated soundings were identified and removed. Seventeen kinematic, thermodynamic and composite sounding parameters were examined (Table 2). In order to prevent extreme outliers (many of which were bad data) from contaminating the statistical analysis, all sounding parameter values occurring outside of the 2.5th to 97.5th percentile range were omitted.

Some proximity sounding studies have employed relatively sophisticated proximity criteria, for example, requiring soundings to be located within the storm inflow sector (e.g. Rasmussen and Blanchard 1998). Due to the very large number of significant tornado soundings being analyzed in this study and, to a lesser degree, the fact that criteria defining the inflow sector are rendered somewhat arbitrary by the lack of supporting storm-scale observations, we restrict our attention to the two fundamental proximity criteria common to all studies: a spatial range and a temporal interval. The various proximity definitions used in this study are based on several previous studies (Table 1) but are different in one very important respect: they are comprised of a mutually exclusive, collectively exhaustive (MECE) set of categories. Thus, every sounding in our original 0-185 km, 0-3 h dataset is assigned to exactly one of 12 proximity categories (Table 3). All of the sample sizes are large enough to allow confident statistical interpretation. Figure 1 illustrates the sizes of the annuli for the four spatial proximity criteria. The mutual exclusiveness of the proximity definitions facilitates the identification of significant differences between different spatiotemporal regions of the climatological storm environment.

Two statistical significance tests are used to identify differences between the parameter distributions obtained using different proximity criteria. A permutation test (Efron and Tibshirani 1993) is used to identify significant differences between the means of the distributions. The Kolmogorov-Smirnov (K-S) test is used to identify differences between the distributions themselves. Statistical comparisons like these are crucial since subjective comparison of distributions (e.g. visual inspection of box and whisker plots) does not account for sample size. It is very important to note, however, that failure to reject the null hypothesis does *not* necessarily mean that either the null hypothesis is true or the difference between the populations is small (a discussion of this and other limitations of null hypothesis significance testing can be found in Nicholls 2001). Two samples may come from very different populations and yet be too small for significance tests to confidently establish that the two populations are indeed different.

Our investigation does not stop with significance testing. Rejection of the null hypothesis merely indicates that two distributions are likely different. It is also necessary to consider whether these differences are large enough to be *practically meaningful*. For example, a difference of 100 J kg^{-1} between the mean ML CAPE calculated using two different proximity criteria may mean little to a forecaster. This is because errors in vertical temperature and dewpoint measurements can result in uncertainty in CAPE of 100 J kg^{-1} or more. On the other hand, a difference of 100 J kg^{-1} may be important to a research scientist developing a discriminant analysis technique to distinguish between, for example, significant tornado and significant hail (2"+) environments. Thus, in determining which proximity criteria to adopt, it is important to consider how the resulting analysis will be used. If a less restrictive proximity definition provides a much larger sample size without changing the results in a way that is meaningful to their application, then it may be advantageous to adopt the broader criteria.

III. SENSITIVITY TO SPATIAL CRITERIA

The set of soundings valid within one hour of a significant tornado report was subdivided into four categories based on the distance to the report: 0-40 km, 40-80 km, 80-121 km, and 121-185 km. The K-S and permutation tests were performed on each pair of distributions. It is seen from Table 4 that there are many cases where the sample distributions or means are statistically significantly different from one another.

Given that the analyzed storm environment is sensitive to the proximity of the sounding to the (significant) tornado, it is now necessary to determine whether any of our proximity categories provide a more representative sampling of the portion of the atmosphere supporting the storm. Since significant tornadoes are more likely to occur in regions of lower ML LCL and higher instability, wind shear, and storm-relative helicity (e.g. Thompson et al. 2003), it is reasonable to expect measures of these properties to become more favorable as proximity to the storm increases. However, very close to the storm, some of these properties may become less favorable due to convective feedbacks to the near-storm environment (e.g. anvil shadow, enhanced low-level inflow, cold outflow, and precipitation). The most representative (and therefore optimum) storm environment may therefore occur at some intermediate distance and/or time from the storm. We will call this hypothetical region the "Goldilocks zone" (or GZ).

Figure 2 shows box-and-whisker plots of the bootstrapped means for selected parameters. The boxes in the plots indicate the interquartile range (IQR) of the bootstrapped means for each distribution. The hatched area in each IQR indicates the 95% confidence interval for the median. The "whiskers" extend to 1.5 times the IQR, and the lines above and below the box-and-whisker diagrams depict outliers. In general, the parameters either become more favorable or remain relatively constant as distance to the tornado decreases from 121-185 km to 40-80 km. Between the 40-80 km and 0-40 km ranges, however, the parameters tend to either become less favorable or remain relatively constant. (There may be regions of the atmospheric parameter space where, once a "sufficiency" threshold of a particular parameter is met, exceeding this threshold does not make significant tornadogenesis more likely. However, this does not change the fact that, *in general*, more "favorable" values of any given parameter will make significant tornadogenesis more likely). This pattern suggests that a GZ indeed exists in the climatological significant-tornadic storm environment and that the 40-80 km spatial proximity criterion does a better job of sampling this atmospheric "sweet spot" than do the other three spatial criteria, at least for the 0-1 h time frame. In some cases, the 40-80 km annulus did not do a substantially better job of representing the climatological storm environment, but in no case did it do a substantially worse job. The finding that significant-tornadic storms can significantly modify their nearby environment is consistent with the supercell simulations of Weisman et al. (1998). Also consistent with that and other numerical sensitivity studies is our finding that the kinematic environment is more strongly modified by convective feedbacks than is the thermodynamic environment [although in Weisman et al. (1998), 0-6 km shear was enhanced very near storms, not reduced].

The plots in Figure 2 also illustrate the danger of misinterpreting the results of null hypothesis significance tests. The tendency toward less favorable parameter values very close to the tornado is evident in the plots of ML CIN and ML 3km CAPE. However, the p-values for the statistical comparisons of the 0-40 km and 40-80 km distributions are larger than 0.20 for both of these cases. Based solely on the significance tests, we would not be justified in saying that these parameters become less favorable very close to the storm. However, this trend is apparent for a variety of the examined parameters, and in fact is statistically quite significant ($p < .05$) for some of them. Thus, the failure to reject the null hypothesis in those cases where a trend is suggested by the plots likely arises (in at least some of these cases) from insufficient sample size, and not necessarily because the two samples were collected from the same or very similar populations.

It has been established that different proximity criteria can produce statistically significantly different parameter distributions, and that the 40-80 km proximity criterion provides a more representative sampling of the climatological significant-tornadic storm environment than do the other three considered criteria. It is also necessary to determine whether any of the differences arising from varying the proximity criteria have important conceptual or operational implications. Table 5 lists the absolute differences between the sample means of each pair of distributions for each sounding parameter. Many of the differences in the sample means have magnitudes which are similar to or smaller than the typical measurement and model analysis and forecast errors associated with these parameters (Elmore et al. 2002). This is true even for those distributions whose means are distinguishable at a 95% significance level. At first glance, then, it would seem that the choice of proximity criteria would be of little concern to an operational forecaster. However, it is important to keep in mind that some of the differences between the means of the actual populations from which these distributions were sampled are very likely larger than the differences in the sample means (others, of course, are likely smaller). The uncertainty in the population mean estimates (the sample means) is visualized in the box-and-whisker plots of the bootstrapped means. Inspection of the plots (some of which are shown in Figure 2) reveals that the difference between the 25th percentile of one distribution and the 75th percentile of another is often significantly larger than the difference between the sample means. Since the actual population means may differ substantially for some parameters as a sample is taken closer to or further from the event, it would be risky for future proximity sounding studies of significant tornadoes to develop proximity criteria without regard for the differences (and the GZ) we have identified herein. Furthermore, even some of the differences between our sample means may be important to an individual developing a discriminant analysis technique to distinguish between significant tornado and significant hail environments.

Thus, in deriving a climatology of significant-tornadic storm environments, it may be preferable to restrict one's sounding set to those valid within the GZ identified herein (40 – 80 km). Of course, this is assuming a temporal criterion of 0-1 h; the impacts of sampling further in time from the storm are examined in the next section.

IV. SENSITIVITY TO TEMPORAL CRITERIA

The original set of soundings was next stratified by spatial proximity (0-40 km, 40-80 km, 80-121 km, and 121-185 km) and then by temporal proximity (0-1 h, 1-2 h and 2-3 h). This allowed us to determine the sensitivity of the analyzed climatology to the temporal proximity criterion for different intervals of distance from the tornado. Results of the permutation and K-S tests for the 0-40 km and 40-80 km criteria as well as the magnitudes of the differences between the sample means are shown in Tables 6 and 7.

It is found that the sensitivity of the parameter distributions (only the 0-40 km and 40-80 km distributions are shown here) to the temporal interval generally decreases as the range from the tornado increases. This is likely because most of the variability due to convective feedback is confined very close to the storm. In all four datasets, the 2-3 h temporal criterion produced the least favorable environment when compared to the 40-80 km, 0-1 h distributions. For the 80-121 km dataset (not shown), the 0-1 h distributions generally appeared to better represent the storm environment, whereas for the 0-40 km dataset, the 1-2 h distributions appeared most representative. The latter result is most dramatically evidenced in the differences between the SCP and STP parameter distributions (Figure 3), which combine differences between the kinematic and thermodynamic environments. Thus, as spatial proximity to the event decreases, it is necessary to look further in time from the event in order to minimize the influence of the storm. The 0-1 h and 1-2 h distributions were relatively similar for the 40-80 km dataset, indicating that the proximity definition identified in the previous section as best representing the GZ (40-80 km, 0-1 h) can be expanded to include all soundings taken within 40-80 km and 0-2 h of a significant tornado. Further tests are needed to determine if this definition could be still further expanded to include soundings taken within 0-40 km and 1-2 h of significant tornadoes.

V. SUMMARY AND FUTURE WORK

Previous proximity sounding studies have employed a wide range of proximity criteria. Until now, little has been done to assess the sensitivity of the analyzed climatology to the definition of proximity. Using a large database of significant tornado soundings, it is found that varying the definition of proximity can produce statistically-significant differences in distributions of thermodynamic, kinematic and composite sounding parameters. The importance of these differences depends on how the climatology is intended to be applied. The uncertainty in the actual (population) means presents the possibility that the sensitivity of some parameter distributions to proximity definition may be operationally significant. Thus, it is recommended that future proximity sounding studies perform sensitivity analyses similar to those presented herein in order to avoid potentially inappropriate proximity criteria.

This analysis revealed the existence of what we have termed a "Goldilocks zone" – a spatiotemporal distance from a thunderstorm-related event (in this case, significant tornadoes) which, climatologically, is close enough to the parent storm to be representative of its background environment, yet distant enough to minimize the effects of convective feedbacks. The more closely a proximity definition matches the location (in space and time) of the GZ (assuming one exists for a particular type of climatological storm environment), the more accurately the climatological storm environment can be analyzed.

The same procedure used to assess the dependence of significant-tornadic storm climatology on the choice of proximity criteria will next be applied to storms producing significant ($\geq$2" diameter) hail. The impact of proximity definition on the analyzed differences between significant tornado and significant hail environments will then be examined. A potentially valuable byproduct of these efforts will be a highly reliable (by virtue of the relatively large sample sizes available and the care taken in selecting the proximity criteria) climatology of two very important kinds of severe weather.

ACKNOWLEDGEMENTS

The authors thank Jeff Craven for providing the sounding dataset used for this study.

REFERENCES

Beebe, R. G., 1958: Tornado proximity soundings. *Bull. Amer. Meteor. Soc.,* **39,** 195–201.

Brooks, H. E., C.A. Doswell, and J. Cooper, 1994: On the Environments of Tornadic and Nontornadic Mesocyclones. *Wea. Forecasting*, **9**, 606–618.

_____, and J. P. Craven, 2002: Database of proximity soundings for significant severe thunderstorms, 1957–1993. Preprints, *21st Conf. on Severe Local Storms,* San Antonio, TX, Amer. Meteor. Soc., 639–642.

Darkow, G. L., 1969: An analysis of over sixty tornado proximity soundings. Preprints, *Sixth Conf. on Severe Local Storms,* Chicago, IL, Amer. Meteor. Soc., 218–221.

Davies, J. M., and R. H. Johns, 1993: Some wind and instability parameters associated with strong and violent tornadoes. 1.Wind shear and helicity. *The Tornado: Its Structure, Dynamics, Prediction, and Hazards, Geophys. Monogr.,* No. 79, Amer. Geophys. Union, 573–582.

Davies-Jones, R., 1993: Helicity trends in tornado outbreaks. Preprints, *17th Conf. on Severe Local Storms*, Saint Louis, MO, Amer. Meteor. Soc., 56-60.

Doswell, C.A., III, 1982: The Operational Meterology of Convective Weather. Vol. 1, Operational mesoanalysis. NOAA Tech. Memo. NWS NSSFC-5, 158 pp. [NTIS PB83-162321.]

Efron, B., and R. J. Tibshirani, 1993: An Introduction to the Bootstrap. Chapman and Hall, 436 pp.

Elmore, K. L., D. J. Stensrud and K. C. Crawford, 2002: Explicit cloud-scale models for operational forecasts: A note of caution. *Wea. and Forecasting,* **17,** 873 – 884.

Fawbush, E. J., and R. C. Miller, 1952: A mean sounding representative of the tornadic airmass environment. *Bull. Amer. Meteor. Soc.,* **33,** 303–307.

_____ and _____, 1954: The types of air masses in which North American tornadoes form. *Bull. Amer. Meteor. Soc.,* **35,** 154–165.

Kerr, B.W., and G.L. Darkow, 1996: Storm-Relative Winds and Helicity in the Tornadic Thunderstorm Environment. *Wea. Forecasting*, **11**, 489–505.

Maddox, R. A., 1976: An evaluation of tornado proximity wind and stability data. *Mon. Wea. Rev.,* **104,** 133–142.

McCaul, E.W., 1991: Buoyancy and Shear Characteristics of Hurricane-Tornado Environments. *Mon. Wea. Rev.*, **119**, 1954–1978.

Nicholls, N., 2001: Commentary and analysis: The Insignificance of Significance Testing. *Bull. Amer. Meteor. Soc.*, **82**, 981–986.

Novlan, D.J., and W.M. Gray, 1974: Hurricane-Spawned Tornadoes. *Mon. Wea. Rev.*, **102**, 476–488.

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

Showalter, A. K., and J. R. Fulks, 1943: Preliminary report on tornadoes. U.S. Weather Bureau, 162 pp.

Thompson, R.L., R. Edwards, J.A. Hart, K.L. Elmore, and P. Markowski, 2003: Close Proximity Soundings within Supercell Environments Obtained from the Rapid Update Cycle. *Wea. Forecasting*, **18**, 1243–1261.

_____, C.M. Mead, and R. Edwards, 2007: Effective Storm-Relative Helicity and Bulk Shear in Supercell Thunderstorm Environments. *Wea. Forecasting*, **22**, 102–115.

Weisman, M. L., Wicker, L.J., and M. Gilmore, 1998: The impact of convective storms on their local environment: What is an appropriate ambient sounding? *Preprints, 19th Conf on Severe Local Storms,* Mineapolis, MN., American Meteorological Society. 238-241.

Study	Spatial criterion	Temporal criterion (sounding time – event time)
Thompson et al. (2003)	40 km	+/- 30 min
McCaul (1991)	40 km	+/- 2 h
Kerr & Darkow (1996)	80 km	-1 h 45 min to +15 min
Maddox (1976)	92.5 km	-2 h to +1 h
Davies and Johns (1993)	121 km	+/- 3 h
Brooks et al. (1994)	160 km	+/- 1 h
Novlan and Gray (1974)	185 km	+/- 3 h
Rasmussen and Blanchard (1998)	400 km	-6 h to +3 h

Table 1. Proximity criteria used in selected previous studies.

Parameter	Description
ML CAPE	Mixed Layer (lowest 100 mb) CAPE (J kg^{-1})
3 km ML CAPE	0-3 km AGL Mixed Layer CAPE (J kg^{-1})
ML LI	Mixed Layer Lifted Index (°C)
ML CIN	Convective Inhibition (J kg^{-1})
ML LCL	Lifted Condensation Level (m)
0-6 SHR	0-6 km AGL bulk wind shear (s^{-1})
0-1 SHR	0-1 km AGL bulk wind shear (s^{-1})
0-3 SRH	0-3 km AGL Storm Relative Helicity (m^2 s^{-2})
0-1 SRH	0-1 km AGL Storm Relative Helicity (m^2 s^{-2})
0-2 LR	0-2 km AGL Lapse Rate (°C km^{-1})
2-4 LR	2-4 km AGL Lapse Rate (°C km^{-1})
4-6 LR	4-6 km AGL Lapse Rate (°C km^{-1})
0-2 RH	0-2 km AGL mean Relative Humidity (%)
2-4 RH	2-4 km AGL mean Relative Humidity (%)
4-6 RH	4-6 km AGL mean Relative Humidity (%)
SCP	Supercell Composite Parameter
ML SigTorn	Mixed Layer Significant Tornado Parameter

Table 2. Sounding parameters examined in this study.

Proximity category	**Sample size**
0-40 km, 0-1 h	35
40-80 km, 0-1 h	92
80-121 km, 0-1 h	133
121-185 km, 0-1 h	286
0-40 km, 1-2 h	29
40-80 km, 1-2 h	63
80-121 km, 1-2 h	83
121-185 km, 1-2 h	218
0-40 km, 2-3 h	27
40-80 km, 2-3 h	45
80-121 km, 2-3 h	70
121-185 km, 2-3 h	178

Table 3. Sample sizes for the 12 proximity categories.

Parameter	**0-40/ 40-80**		**0-40/ 80-121**		**0-40/ 121-185**		**40-80/ 80-121**		**40-80/ 121-185**		**80-121/ 121-185**	
ML CAPE (J kg^{-1})									.10	.11		
3 km CAPE (J kg^{-1})							.14		**.01**	**.03**		.10
ML LI (°C)				.14	.07	**.05**			.08	.15		
ML CIN (J kg^{-1})									.10			.19
ML LCL (m)		**.02**					.14	**.01**		.12	.16	.17
0-6 SHR (s^{-1})	.12	.18	.18	.10					.16	**.04**		
0-1 SHR (s^{-1})		.08		.20	.18	.18						
0-3 SRH (m^{-2} s^{-2})	.18	.16	.13	.12	.16							
0-1 SRH (m^{-2} s^{-2})	.18		.09	.15	.06	.20						
0-2 LR (°C km^{-1})											.08	.12
2-4 LR (°C km^{-1})												
4-6 LR (°C km^{-1})									.14	.12		
0-2 RH (%)							.18	.11	.16	.15		
2-4 RH (%)							.16	**.03**	**.05**	**.01**		
4-6 RH (%)									.20			
SCP	**.03**	.18	**.03**	.10	.07							.11
ML SigTorn												

Table 4. P-values for 0-1 h proximity categories. The left (right) column under each heading contains p-values for the permutation tests (K-S tests). Only values of .20 or less are shown; values of .05 or less are in bold font.

Parameter	**0-40/ 40-80**	**0-40/ 80-121**	**0-40/ 121-185**	**40-80/ 80-121**	**40-80/ 121-185**	**80-121/ 121-185**
ML CAPE (J kg^{-1})	8	90	190	97	**198**	101
3 km CAPE (J kg^{-1})	9	0	6	**9**	**16**	6
ML LI (°C)	.3	.5	**.9**	.2	**.6**	.4
ML CIN (J kg^{-1})	17	11	3	6	**14**	8
ML LCL (m)	69	106	18	**176**	52	**124**
0-6 SHR (s^{-1})	**4**	**3**	2	1	**3**	2
0-1 SHR (s^{-1})	2	2	**2**	0	0	0
0-3 SRH (m^{-2} s^{-2})	**32**	**34**	**28**	2	4	6
0-1 SRH (m^{-2} s^{-2})	**23**	**29**	**30**	6	7	1
0-2 LR (°C km^{-1})	.1	.1	.2	.2	.1	**.3**
2-4 LR (°C km^{-1})	.1	.1	.1	.1	0	.1
4-6 LR (°C km^{-1})	.3	.1	.1	.1	**.2**	0
0-2 RH (%)	2	1	0	**3**	**3**	0
2-4 RH (%)	2	2	3	**4**	**5**	1
4-6 RH (%)	1	2	2	4	**3**	1
SCP	**1.2**	**1.2**	**.8**	.1	.4	.3

ML SigTorn	.3	.1	.1	.1	.1	0

Table 5. Absolute differences between the means of the sample distributions. Bolded values indicate pairs of distributions whose permutation test p-values are 0.20 or less.

	P-values							**Absolute differences between means**		
Parameter	**0-1/ 1-2**		**0-1/ 2-3**		**1-2/ 2-3**			**0-1/ 1-2**	**0-1/ 2-3**	**1-2/ 2-3**
ML CAPE (J kg^{-1})			.10	.16	**.03**	.13		241	**363**	**605**
3 km CAPE (J kg^{-1})	.17	.08			.09			**20**	4	**24**
ML LI (°C)			.14	.08	.18	.09		.2	**1.1**	**1**
ML CIN (J kg^{-1})								6	19	25
ML LCL (m)	**.05**			.10				**206**	151	55
0-6 SHR (s^{-1})		.19						1	2	1
0-1 SHR (s^{-1})	.09	**.04**						**4**	1	3
0-3 SRH (m^{-2} s^{-2})								13	15	2
0-1 SRH (m^{-2} s^{-2})								6	6	0
0-2 LR (°C km^{-1})				**.04**				.4	.5	.1
2-4 LR (°C km^{-1})	.06		.09					**.5**	**.5**	.1
4-6 LR (°C km^{-1})			**.02**	**.03**	.12	.08		.2	**.7**	**.5**
0-2 RH (%)	**.04**	**.05**	.13	.20				**7**	**6**	1
2-4 RH (%)								2	3	1
4-6 RH (%)		.09						4	1	6
SCP	**.01**	**.05**			**.02**	.07		**2.3**	.2	**2.0**
ML SigTorn	**.04**	.14			**.05**	.17		**1.0**	.0	**1.0**

Table 6. P-values and absolute differences between sample means for 0-40 km proximity categories.

	P-values							**Absolute differences between means**		
Parameter	**0-1/ 1-2**		**0-1/ 2-3**		**1-2/ 2-3**			**0-1/ 1-2**	**0-1/ 2-3**	**1-2/ 2-3**
ML CAPE (J kg^{-1})			**.02**	**.02**	**.01**	**.00**		184	**436**	**620**
3 km CAPE (J kg^{-1})			.13	.12		.10		5	**15**	10
ML LI (°C)			**.05**	**.00**	**.03**	**.01**		.3	**1.0**	**1.3**
ML CIN (J kg^{-1})			**.03**	**.04**	.09	.06		5	**29**	**24**
ML LCL (m)								80	51	29
0-6 SHR (s^{-1})	.13							**4**	2	2
0-1 SHR (s^{-1})		.18	.16	**.04**	**.04**	.07		2	**2**	**4**
0-3 SRH (m^{-2} s^{-2})						**.04**		15	9	24
0-1 SRH (m^{-2} s^{-2})			.18		.15			6	**22**	**28**
0-2 LR (°C km^{-1})			.08	**.05**	**.05**	.15		.1	**.5**	**.6**
2-4 LR (°C km^{-1})		.13		**.02**	.09	**.02**		.1	.2	**.3**
4-6 LR (°C km^{-1})								.1	.0	.1
0-2 RH (%)								1	1	0
2-4 RH (%)								4	1	5
4-6 RH (%)								2	1	3

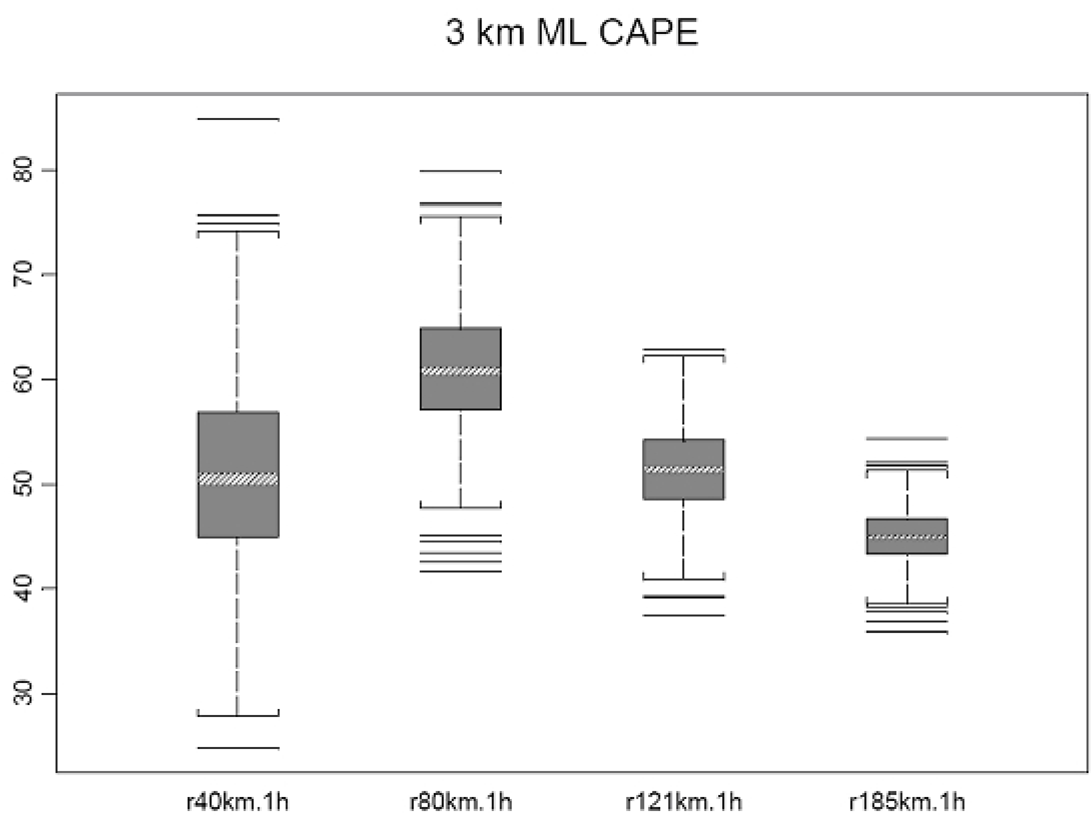
SCP			**.14**	.18				.3	**.8**	.5
ML SigTorn								0	.2	.2

Table 7. P-values and absolute differences between sample means for 40-80 km proximity categories.

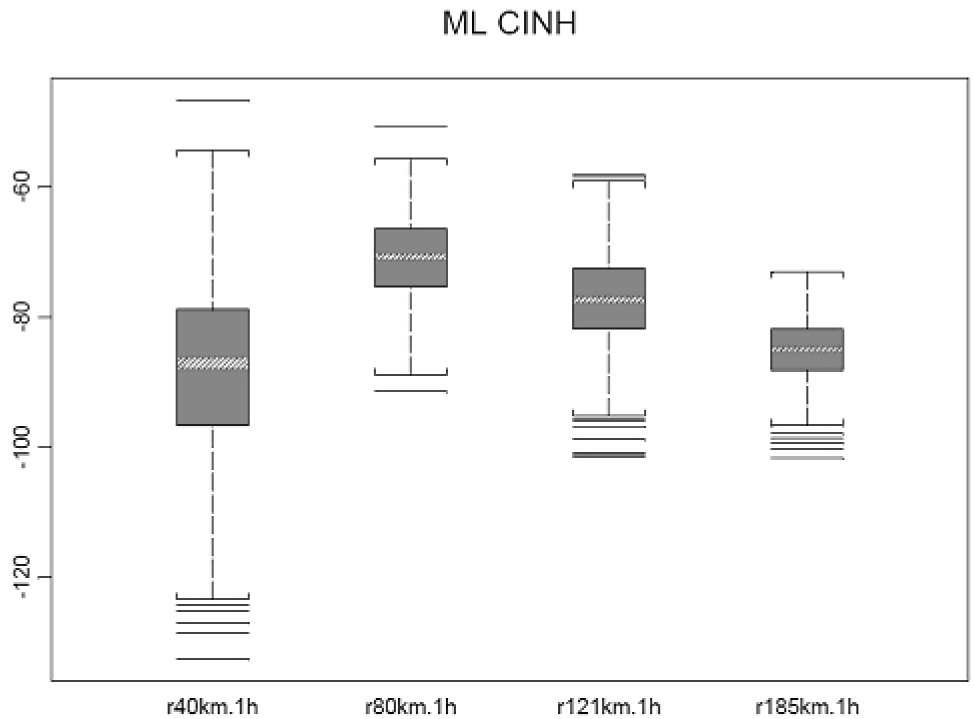
Figure 1. Depiction of 185 km, 121 km, 80 km, 40 km radii used in proximity definitions, using sounding site KOUN (Norman, OK) as an example.

Figure 2. Distributions of bootstrapped means using 0-1 h proximity criterion: (a) 3 km ML CAPE, (b) ML CIN, (c) 0-1 SHR, (d) 0-6 SHR, (e) 0-1 SRH, (f) 0-3 SRH, (g) SCP.

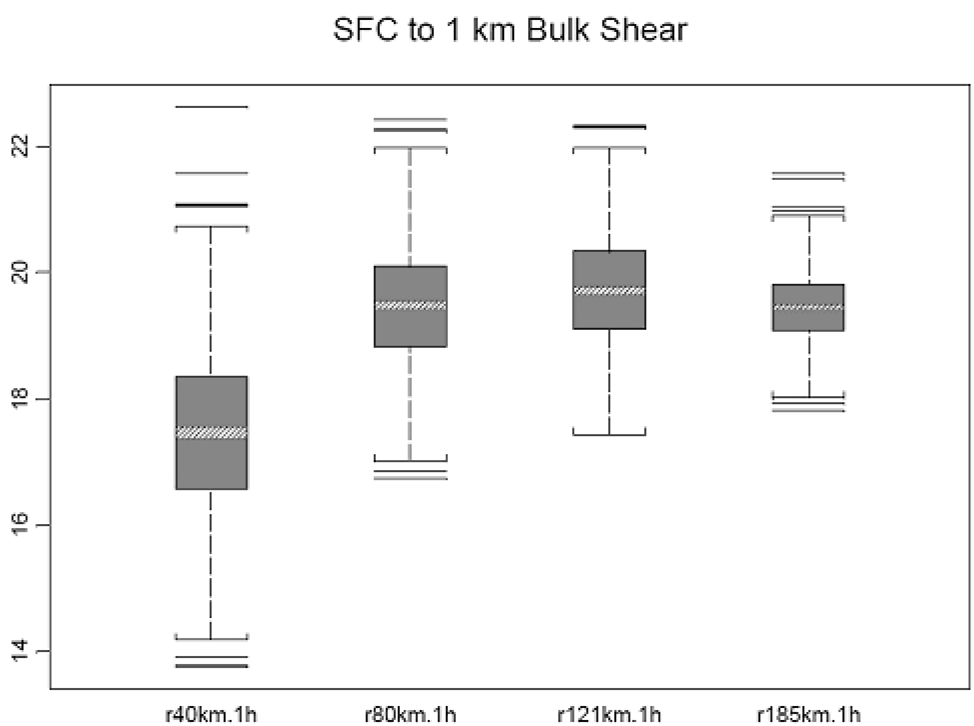
a)



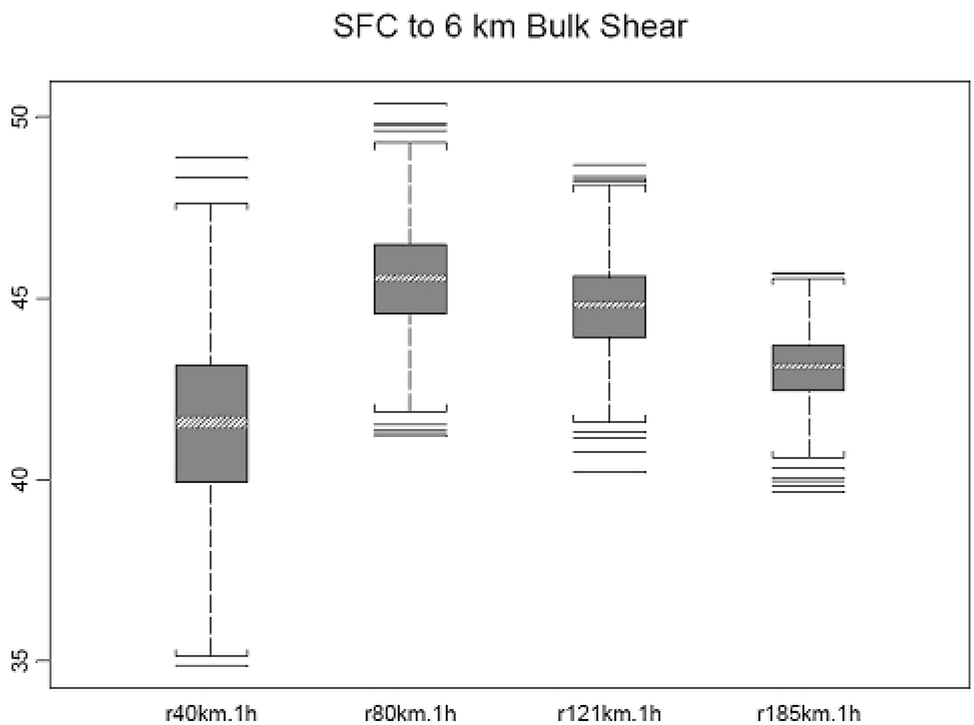
b)


ML CINH
-60
-80
-100
-120
r40km.1h
r80km.1h
r121km.1h
r185km.1h

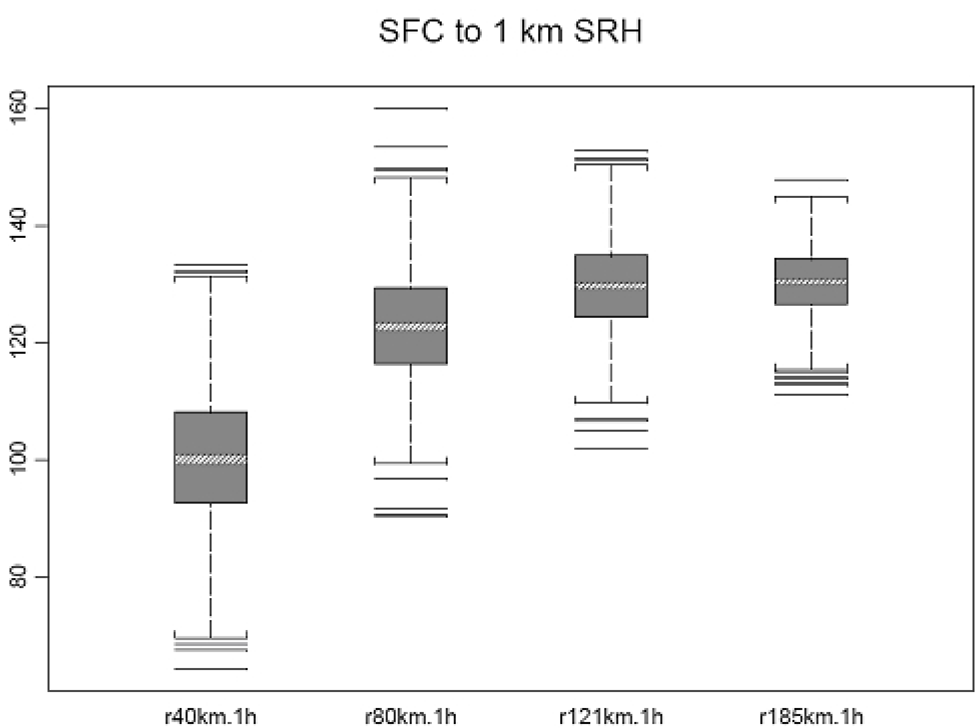
c)


SFC to 1 km Bulk Shear
22
20
18
16
14
r40km.1h
r80km.1h
r121km.1h
r185km.1h

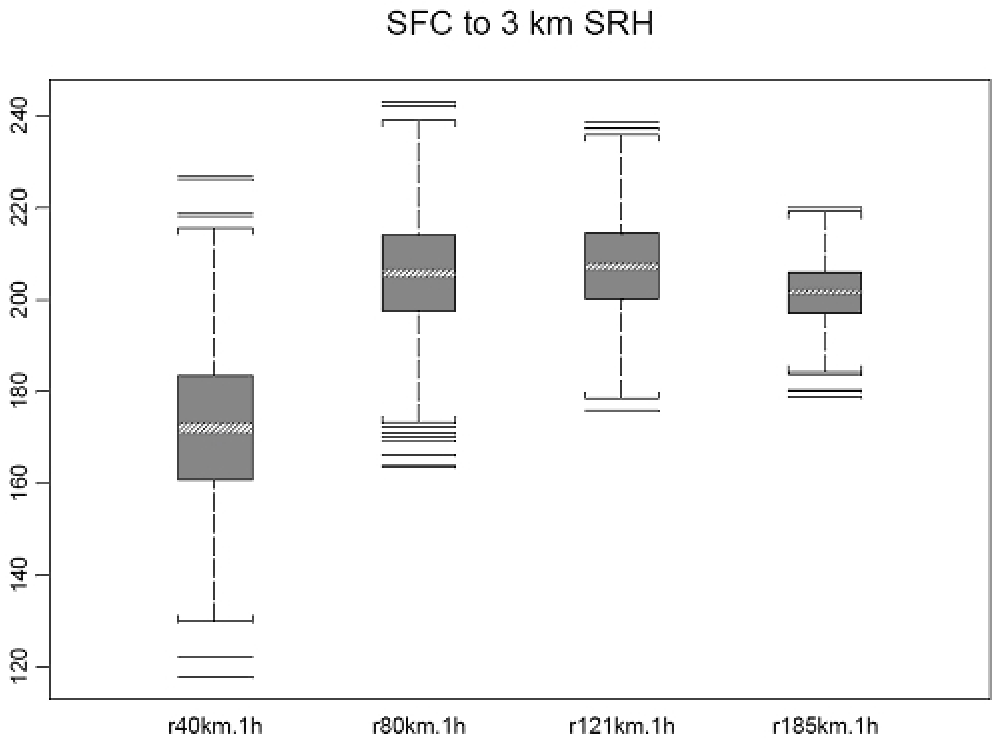
d)


SFC to 6 km Bulk Shear
50
45
40
35
r40km.1h
r80km.1h
r121km.1h
r185km.1h

e)


SFC to 1 km SRH
160
140
120
100
80
r40km.1h
r80km.1h
r121km.1h
r185km.1h

f)


SFC to 3 km SRH
240
220
200
180
160
140
120
r40km.1h
r80km.1h
r121km.1h
r185km.1h

g)

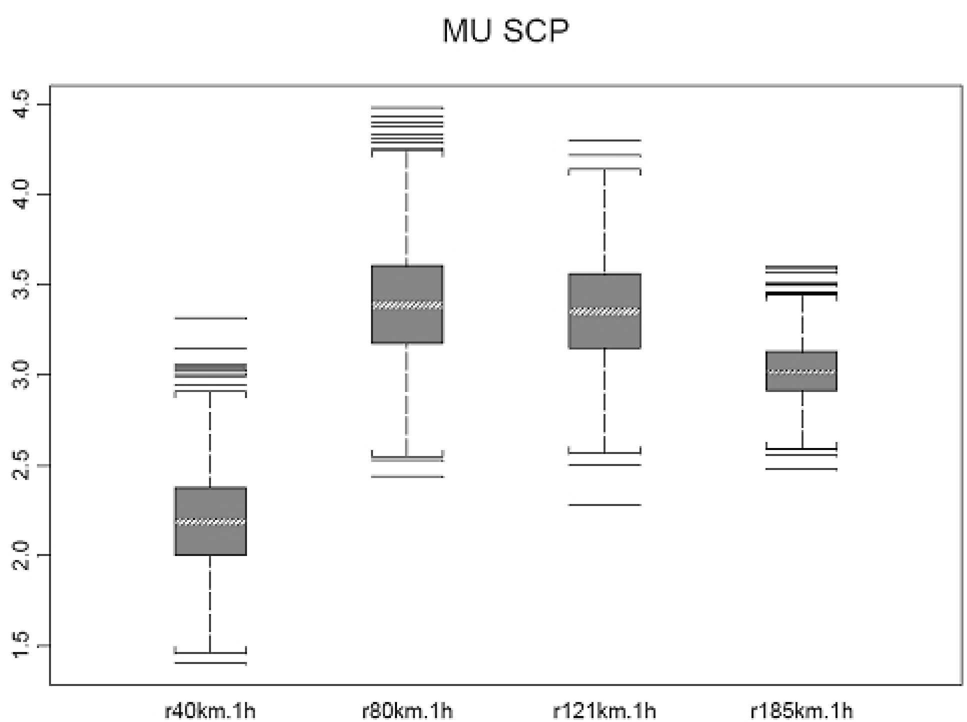
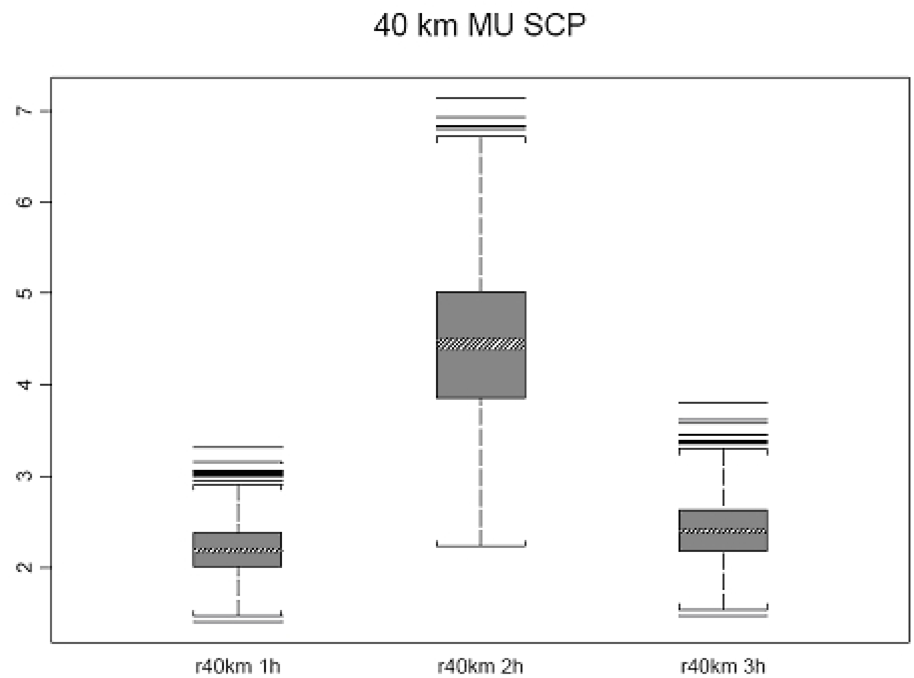

MU SCP
4.5
4.0
3.5
3.0
2.5
2.0
1.5
r40km.1h
r80km.1h
r121km.1h
r185km.1h

Figure 3. Distributions of bootstrapped means for (a) SCP and (b) ML STP using 40-80 km and 0-1 h, 1-2 h and 2-3 h proximity criteria.

a)



b)