A Study of Proximity Sounding Derived Parameters Associated with Significant Severe Weather

By

Corey K. Potvin

Oklahoma Weather Center REU Program, Norman, OK

Storm Prediction Center, Norman, OK

Lyndon State College, Lyndonville, VT

Steven J. Weiss

Storm Prediction Center

Sarah J. Taylor

Storm Prediction Center

Last Modified : 1 August, 2003

Corresponding author: Corey K. Potvin, Mailbox 8186, Lyndon State College, Lyndonville, VT, 05851, <corey.potvin@lyndonstate.edu>

Contents

Acknowledgements

First and foremost, I would like to thank the Oklahoma Weather Center Research Experiences for Undergraduates Program for providing me the wonderful opportunity to conduct the research herein. I am very grateful to my mentors, Steven Weiss and Sarah Taylor, for their guidance in this project. Many thanks also to Harold Brooks, John Hart, who created the script that made this work possible, and to Richard Thompson and my mentors, who took great care in helping to refine this paper. This work was funded by the National Science Foundation grant NSF 0097651.

Abstract

This study focuses on the sensitivity of significant severe weather climatology to proximity criteria. Six independent definitions of proximity are used. These criteria are then used to develop a climatology of several sounding derived parameters for significant wind, hail, and tornado cases. Geographical and significant severe type comparisons are made.

One of the major findings is that little variance occurs in distributions of the parameters studied over the range of proximity criteria considered, namely, from 40 km and 30 min to 185 km and 3 h. Therefore, criteria on the upper end of this range can be confidently applied to significant severe storm climatologies in order to maximize sample size.

Substantial differences between the climatological significant severe thunderstorm environment in the High Plains and that of other regions of the country are noted. However, significant tornado cases in all the regions studied are found to be associated with higher values of wind shear between the surface and 1 km, and lower mean layer LCL heights. The climatology compiled in this study describes mean significant severe weather environments for eight regions of the United States.

I. Introduction

Proximity sounding studies are frequently used to analyze severe and tornadic thunderstorm environments. Previous studies have employed a wide range of proximity criteria in sampling these environments. An important consideration in such work is which spatial and temporal criteria can be used to represent the storm environment while allowing for a sufficiently large sample size. Admittedly, what exactly constitutes the environment of a storm is a very subjective matter. The primary purpose of this study is not to assess which proximity definitions provide an accurate description of the storm environment, but to test the variability in this description over a range of criteria. Once a "representative" set of proximity criteria is developed, sounding parameters can then be compared in a variety of ways, such as seasonally, geographically, and by severe weather type. Such analyses provide valuable insight into the environments that produce various forms of severe weather, which in turn increases forecasters' ability to differentiate between general thunder, severe, significant severe, and tornadic scenarios. One major limitation of this approach is that larger datasets are often generated based solely on storm reports. These reports are frequently subject to human error, and give little idea of the actual structure of the storms in question.

A wide range of proximity definitions has been used in previous studies of this nature. Rasmussen and Blanchard (1998) used observed soundings within 400 km of an event and a time interval of 2100-0600 UTC to analyze inferred supercell, non-supercell and significant tornado environments. Brooks and Craven (2002) used criteria of 185 km and 3 h to examine climatological no thunder, general thunder, severe, and significant severe environments. Johns et al. (1990, 1993) defined proximity as occurring within 121 km and 3 h of a sounding in their study of strong/violent tornadoes. Thompson et al. (2003) used RUC-2 model soundings within 40 km and 30 min of supercell events.

This work begins by comparing sounding derived parameter statistics for significant severe weather events using several proximity criteria (Section III). This is done to assess how sensitive the results of climatology studies such as this are to the proximity criteria employed. Section IV makes geographic comparisons of the selected parameters, and investigates the significant severe storm environment found in the High Plains. In Section V, parameter distributions are compared between three categories of significant severe weather for different regions of the United States. All these results are summarized in Section VI.

II. Data and Methodology

This study analyzed approximately 4000 significant severe weather 0000 UTC proximity soundings collected by Brooks and Craven (2002) from the lower 48 states for the period 1957-1996. Proximity was defined as the event being within 185 km of the sounding release location between 2100 UTC and 0300 UTC. Three categories of significant severe weather cases were used: 1) significant hail (SigHail), 2) significant wind (SigWind), and 3) significant tornadoes (SigTorn). Significant hail is defined as being 2 inches or greater in diameter; significant wind includes gusts of 65 kts or greater; significant tornadoes are rated F2 or higher. These three categories were divided into mutually inclusive subcategories by proximity of the event to the sounding location using six criteria: 1) 185 km and 3 h; 2) 121 km and 2 h; 3) 80 km and 1 h; 4) 40 km and 2 h; 5) 40 km and 1 h; and 6) 40 km and 30 min. Samples sizes for all proximity criteria used in this study are listed in Table 1. Figure 1 visually depicts an example of the spatial components of these criteria. All these criteria range between those used in Thompson et al. (2003) and Brooks and Craven (2002). Thirteen parameters were examined for each significant severe category over the six proximity criteria (Table 2). A new proximity definition, 185 km and 3 h exclusive (121-185 km and 3 h), derived by subtracting the 121 km and 2 h criteria soundings from the 185 km and 3 h dataset, was used to calculate percentile ranks for 100 mb mean layer CAPE (ML CAPE), 100 mb mean mixed layer lifted index at 500 mb (ML LI), mean layer lifted condensation level height (ML LCLH), magnitude of vector difference between sfc and 1 km wind (Sfc-1km shear), and magnitude of vector difference between sfc and 6 km wind (Sfc-6km shear). The results were compared to those for the 185km and 3h (inclusive) and 40 km and 1 h criteria to determine the extent that differences in parameter distributions using different proximity criteria are smoothed out by the repetition of soundings in successive proximity categories. Next, the 185 km and 3 h dataset was stratified geographically into four distinct longitudinal regions: 1) East, 2) Central, 3) Great Plains, and 4) High Plains (Figure 2). These regions were then bisected latitudinally to yield eight subregions. Parameter spaces were compared first over the four larger regions, and then again over the eight subregions.   Finally, sounding parameters were compared between SigTorn, SigHail and SigWind for each of the four initial geographical regions.

No subjective quality control was applied due to the large sample sizes used in the dataset. Only soundings with MUCAPE less than 150 Jkg^{-1} were removed in Brooks and Craven (2002).

Percentile ranks (10^{th}, 25^{th}, 50^{th}, 75^{th}, 90^{th}) were calculated for each sounding parameter. Box and whisker plots were used to compare each parameter over the various categories. An offset of at least one quartile between categories is considered in this study to be statistically significant, as in Brooks and Craven (2002). If no overlap occurs between the interquartile range (IQR), or middle 50 percentile, then the two categories are considered very significantly different from each other. These are subjective estimates of statistical significance; no quantitative statistical testing was performed in this study.

III. Proximity Criteria Comparisons

Little difference was noted between any of the mutually inclusive proximity criteria for any of the selected parameters for SigTorn and SigHail.   Figure 3 represents a typical parameter distribution over the six criteria.   The SigWind category was the most sensitive to proximity definition, with significant differences noted between 40 km and 30 min and 185 km and 3 h criteria for ML LCLH (Figure 4) and 2km-4km Mean RH. The overall small variability between proximity definitions for significant severe weather events suggests that future studies using proximity criteria to analyze significant severe thunderstorm environments should employ the most liberal criteria possible (within the range of those examined in this study) in order to maximize sample size. In accordance with this, all results to follow were derived using proximity criteria of 185 km and 3 h.

Variability in distributions of several parameters (ML CAPE, ML LI, ML LCLH, Sfc-1km shear and Sfc-6km shear) using 185 km and 3 h exclusive vs. 40 km 1 h criteria was examined. Parameter distributions for both categories were very similar (Figure 5). This suggests that sampling environments a certain distance away from significant severe storms (within the range of criteria used in this study) can be done using mutually inclusive criteria without a significant change in results.

IV. Geographical Comparisons

Our dataset was stratified longitudinally into four distinct geographical regions: 1) High Plains, 2) Great Plains, 3) Central, and 4) East. Each sounding parameter was compared over each of the four geographical regions for each significant severe category. These four regions were further subdivided latitudinally for SigTorn, but yielded far less substantial results, except to suggest that significant severe weather climatology varies more longitudinally than latitudinally. Figure 6 depicts this pattern using SigTorn ML LI as an example.

ML LI was found to be fairly uniform over the East and Central regions for SigHail and SigWind, with noticeably more negative values over the Great Plains. ML LI values became more negative westward for the SigTorn cases, with a significant offset between the East and Great/High Plains (Figure 7). ML CAPE values were highest in the

Great Plains and lowest in the High Plains for all three significant severe categories. ML LCL heights generally increased westward, with distributions in the High Plains significantly higher than in the rest of the country for all three significant severe weather categories. In the case of SigWind and SigTorn, very significant offsets occurred between LCL distributions in the High Plains and East/Central regions (Figure 8). Sfc-1km shear decreased from the Central region westward, with a significant decrease from the East/Central regions to the High Plains noted for all three significant severe categories. Sfc-6km shear was fairly uniform over all four regions. These two parameter distributions are shown for SigTorn in Figure 9. Variation of ML CAPE, ML LI, ML LCLH and Sfc-1km shear with geography was found to be largely independent of the associated type of significant severe weather. Figures 10 demonstrates this relationship using ML LCLH as an example.

The climatologically low values of Sfc-1km shear and high ML LCL heights associated with SigTorn events in the High Plains may infer that different processes typically contribute to tornadogenesis here as compared to the other three regions. Or, this could simply reflect a failure of the 185 km and 3 h criteria to depict storm environments in the High Plains due to more mesoscale driven events. To investigate this latter hypothesis, variability in SigTorn ML CAPE, ML LCL, ML LI, Sfc-1km shear and Sfc-6km shear between the 40 km and 1 h and 185 km and 3 h exclusive criteria was compared between the High Plains and Central regions. In both regions, variability on this scale was found to be small (Figure 11). Further investigation demonstrated that low (25^{th} percentile or lower) Sfc-1km shear is associated with higher ML LCL heights and moderate to high (25^{th} percentile or higher) Sfc-1km shear is associated with lower ML

LCL heights in all regions for all significant severe types. Figure 12 uses Great Plains SigTorn cases as an example. These results suggest that low Sfc-1km shear environments tend to have higher ML LCL heights when significant severe weather occurs. Steeper low level lapse rates associated with higher ML LCL heights likely contribute to strong downdrafts and therefore SigWind cases through enhanced evaporational cooling. Any connection between high ML LCL heights and SigHail cases is not immediately clear. That higher ML LCL heights occur in low Sfc-1km shear SigTorn cases is unexpected in light of the fact that tornadoes are normally associated with higher values of Sfc-1km shear and lower ML LCL heights.

Low Sfc-1km shear, high ML LCLH SigTorn cases for each region were investigated to determine how often these conditions resulted in outbreaks, arbitrarily defined as the occurrence of ten or more tornadoes in a relatively small region. This environment was found to produce outbreaks far less frequently than more typical environments. For example, a random sampling of 40 SigTorn Central region soundings yielded 20 outbreak cases, or 50 %. A random sampling of low Sfc-1km shear, high ML LCLH SigTorn Central soundings yielded only 2 outbreak cases, or 8 %. Furthermore, major tornado outbreaks have been found to be significantly less frequent in the High Plains than in other regions of the United States (Thompson, personal communication). These two findings suggest that low values of Sfc-1km shear and high ML LCL heights are more strongly associated with isolated significant severe events than with outbreak events.

One possibility as to why low shear, high ML LCLH scenarios can be supportive of significant tornadoes is that very steep low level lapse rates associated with high ML

LCLH environments tend to enhance vertical stretching of vorticity in some tornado events. This may be a more dominant process in tornadogenesis in the low Sfc-1km shear, high ML LCLH cases while the more common, high Sfc-1km shear, low ML LCLH environment is more strongly associated with buoyancy processes.

V. Significant Severe Type Comparison

ML CAPE, ML LI, ML LCLH, Sfc-1km shear and Sfc-6km shear distributions for each of the four predefined geographic regions were compared over the three significant severe categories. This was done in order to identify ways to differentiate between environments for each of the three types of significant severe weather in each region.

a) ML CAPE

ML CAPE values increased between SigWind and SigHail and SigHail and SigTorn in the High Plains, and was roughly uniform over all thee categories in the Great Plains. In the Central and East regions, ML CAPE was lowest for SigTorn cases (Figure 13).

b) ML LI

Patterns in the ML LI values corresponded well with those of the ML CAPE for each region. The only exception was in the East, where SigTorn ML LI values were significantly more negative than those for SigHail.

c) ML LCL heights

In all four regions, ML LCL heights were lower for SigTorn than for the other two categories (Figure 14). In the East, SigTorn ML LCL heights were significantly lower than those for both of the other types, while in the Great and High Plains, ML LCL heights were significantly lower than those for SigWind only. In the western two regions, the SigHail parameter space was located roughly equidistant between the SigWind and SigTorn spaces. In the eastern two regions, ML LCL heights for SigWind and SigHail were very similar.

d) Sfc-1km Shear

Sfc-1km shear values were higher in SigTorn than in the other two types for all four regions (Figure 15). In all regions but the High Plains, SigTorn was significantly offset from both SigHail and SigWind. In the East and High Plains, SigHail sfc-1km shear values fell roughly midway between those of SigWind and SigTorn, while in the Central and Great Plains regions, SigWind values closely resembled SigHail values. Nationally, sfc-1km shear was offset by only one quartile from SigHail and SigWind , which is different from the very significant difference between SigTorn and Sig Hail/Wind observed in Craven et al. (2002). Moreover, the national median and 25th ranks for sfc-1km shear in this study for SigTorn were 18.5 and 12.5 kts, respectively, whereas in Craven at al. (2002) they were closer to 23.5 and 19.5 kts. Therefore, the results of this study imply a lower threshold for sfc-1km shear for significant tornadoes than Craven at al. (2002), which only used soundings between 1997 and 1999. Sfc-6km shear and ML LCL height were also found to vary less between SigTorn and Sig Wind/Hail in this study than in Craven et al. (2002).

e) Sfc-6km Shear

In all four regions, sfc-6km shear was lowest for SigWind (Figure 16). In the High Plains, SigTorn and SigHail deep layer shear values were similar. In the other regions, SigTorn values were significantly higher than SigWind values, with SigHail shear values in between.

f) Summary/Conclusions

There seem to be several key factors that differentiate between types of significant severe weather. These patterns apply regardless of geography and therefore most strongly indicate the fundamental differences in SigHail vs. SigTorn vs. SigWind environments. SigTorn cases are much more strongly associated with low ML LCL heights and large values of sfc-1km shear than are SigHail and SigWind events. SigWind events seem to require less sfc-6km shear than do the other severe types. This infers that supercells may be more prevalent in SigTorn and SigHail cases. Differentiating between SigHail and SigWind events would be difficult using the parameters selected for this study. The only significant difference in environment occurs between SigTorn and the other two categories.

VI. Summary and Future Research

It appears that the choice of proximity definition is not critical in proximity studies of significant severe storm climatology, at least within the 185 km and 3 h range employed in this particular study. Mesoscale variability in the environment surrounding significant severe storms is not substantial.

Geographical comparisons of SigHail, SigTorn and SigWind environments highlighted major differences between typical significantly severe storm environments in various regions of the country. Variation of instability, wind shear, lapse rates, and moisture with geography was shown to be largely independent of the associated type of significant severe weather. The low-shear, high-ML LCLH environment found in the High Plains was shown to exist in other regions of the country for a significant number of non-outbreak SigTorn cases. It was suggested that this scenario favors isolated significant severe events while the more common high-shear/low-ML LCLH scenario better favors outbreak events.

Comparisons between SigHail, SigTorn and SigWind for each of four major geographical regions indicated important universal differences between SigTorn and SigHail/SigWind environments. However, the number of significant differences within the selected parameters between SigHail and SigWind was small enough to suggest that future efforts to discriminate between significant severe weather types should adopt a different approach, such as convection mode.

Future research will make comparisons between no thunder, general thunder and severe in addition to significant severe weather environments. The results of this work should therefore be of much broader predictive value, and will serve as a very complete climatology of convection in the United States from the High Plains to the East Coast. Sensitivity to proximity criteria will be evaluated for these thee additional categories. Broader proximity criteria may be examined in addition to those used in this study in order to determine a theshold beyond which proximity definition is critical to the results.

References

Craven, J.P.[*], H.E. Brooks and J.A. Hart, 2002: Baseline Climatology of Sounding Derived Parameters Associated with Deep, Moist Convection. *Preprints*, 21st Conf. Severe Local Storms, San Antonio.

Johns, R.H., J.M. Davies, and P.W. Leftwich, 1993: Some wind and instability parameters associated with strong and violent tornadoes. 2. Variations in the combinations of wind and instability parameters. *The Tornado: Its Structure, Dynamics, Prediction, and Hazards, Geophys. Monogr.,* No.79, Amer. Geophys. Union, 583-590.

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

Thompson, R.L., R. Edwards, and J.A. Hart, 2002: Close proximity soundings within supercell environments obtained from the rapid update cycle. *Wea. Forecasting,* ******

Table 1. Samples sizes for each proximity category for SigTorn, SigWind and SigHail.

	SigTorn	SigHail	SigWind
185 km, 3 h inclusive	1265	1787	1315
185km, 3 h exclusive	683	960	573
121 km, 2 h	539	790	1071
80 km, 1 h	182	240	121
40 km, 2 h	108	159	106
40 km, 1 h	59	97	61
40 km, 30 min	32	61	33

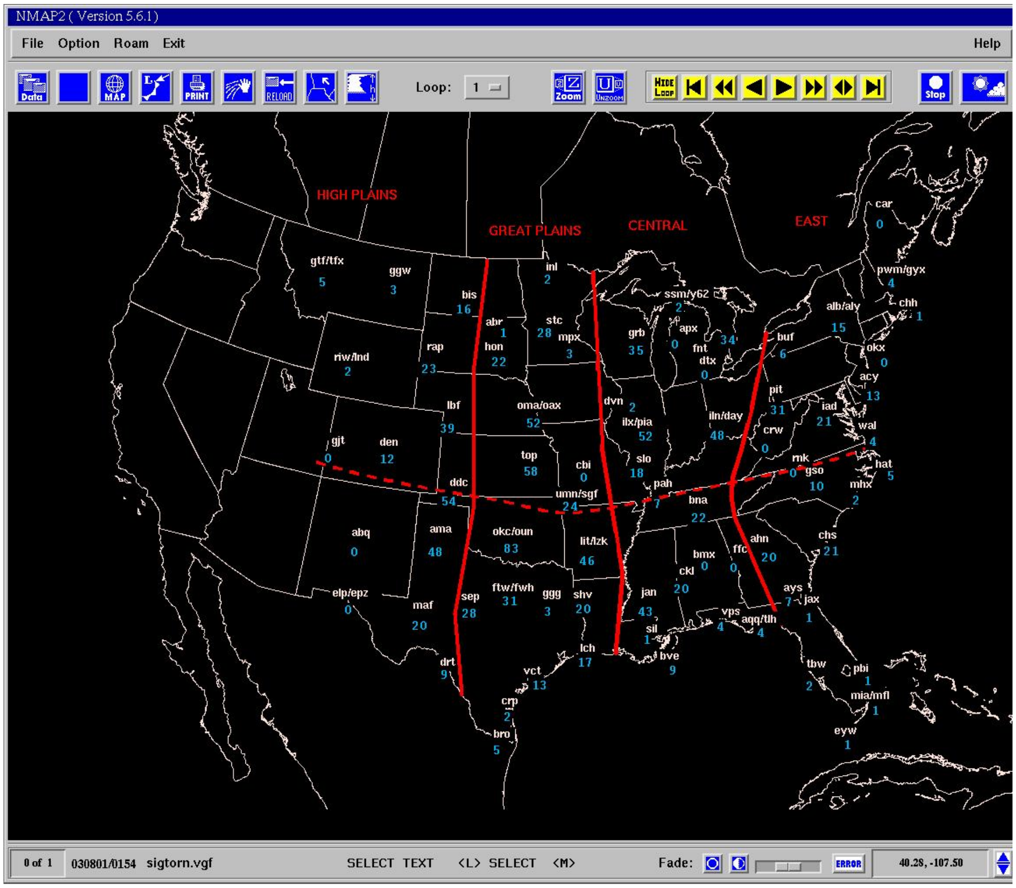
Table 2. Sounding parameters used in proximity criteria comparisons

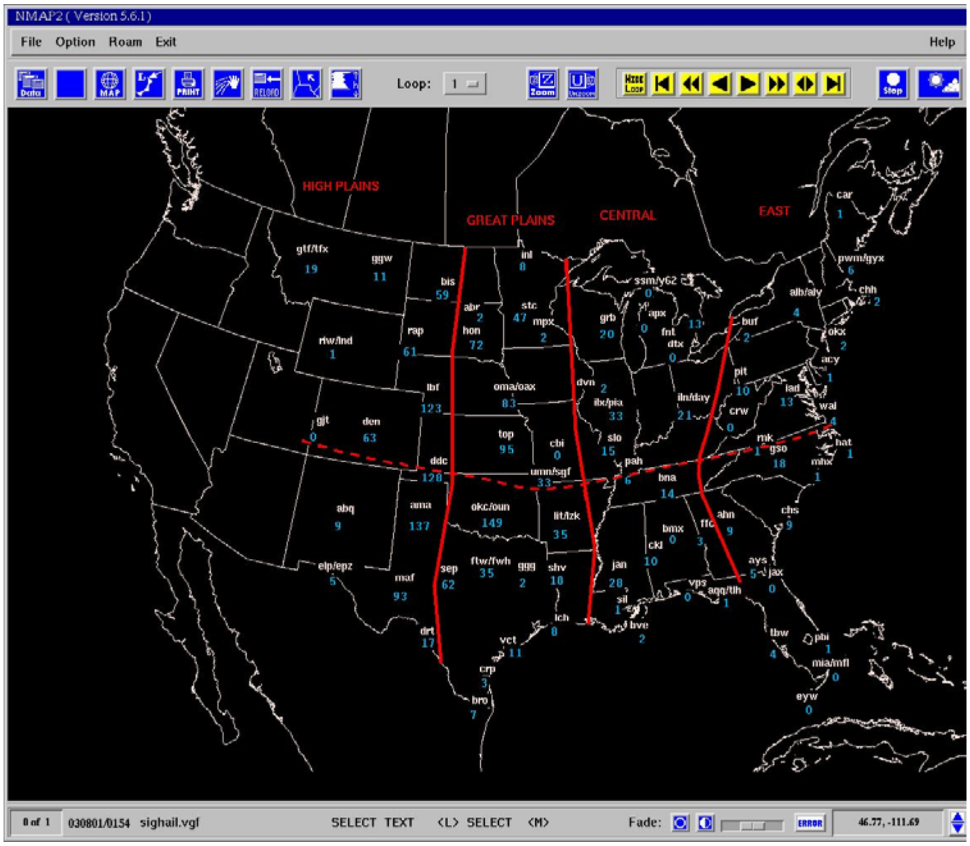
1. ML CIN (100 mb mean mixed layer convective inhibition)
2. ML LCLH (100 mb mean mixed layer LCL)
3. ML CAPE (100 mb mean mixed layer CAPE)
4. ML 3km CAPE (100mb mean mixed layer CAPE in lowest 3 km)
5. ML LI (100 mb mean mixed layer lifted index at 500 mb)
6. Sfc-2km Mean RH
7. 2km-4km Mean RH
8. 4km-6km Mean RH
9. Sfc-2km Lapse Rate
10. 2km-4km Lapse Rate
11. 4km-6km Lapse Rate
12. Sfc-1km Shear (magnitude of vector difference between sfc and 1 km wind)
13. Sfc-6km Shear (magnitude of vector difference between sfc and 6 km wind)

Figure 1. Depiction of 185 km, 121 km, 80 km, 40 km radii used in proximity definitions, using KOUN as an example.

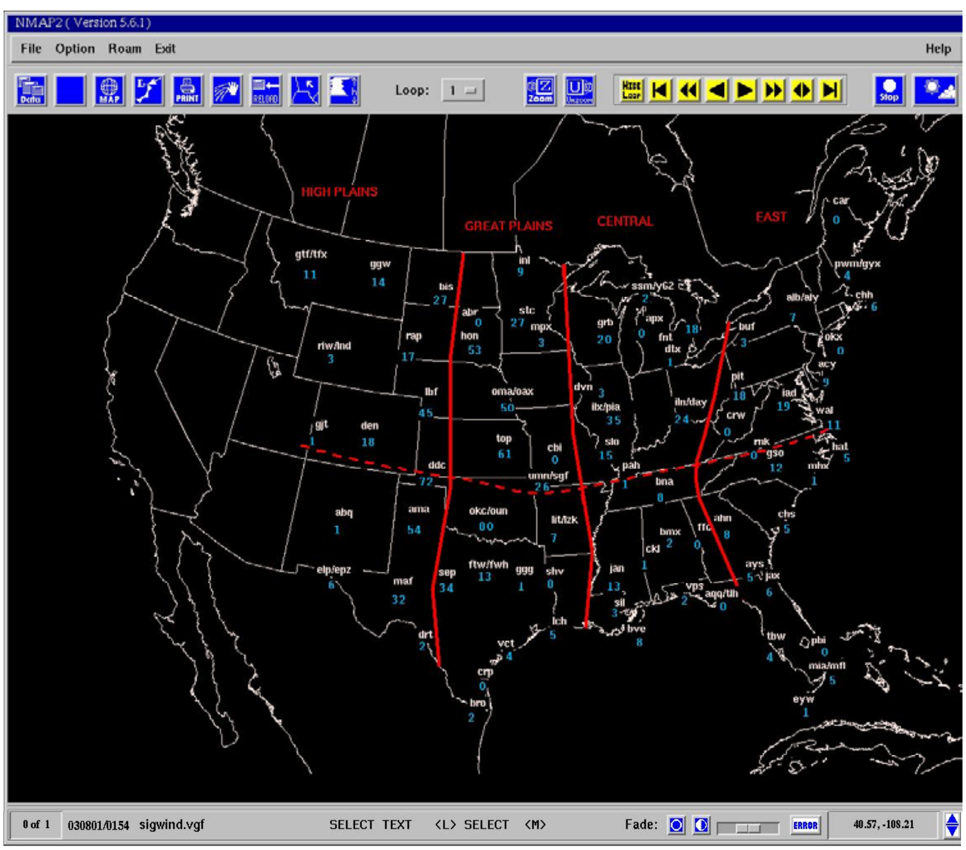
Figure 2. Total sample sizes from each sounding location for a) SigTorn, b) SigHail and c) SigWind.

a)




NMAP2 (Version 5.6.1)
File Option Roam Exit
Help
Loop:
HIGH PLAINS
GREAT PLAINS
CENTRAL
EAST
0 of 1 030801/0154 sighail.vgf
SELECT TEXT <L> SELECT <M>
Fade:
46.77, -111.69

b)


NMAP2 (Version 5.6.1)
File Option Roam Exit
Help
Loop:
HIGH PLAINS
GREAT PLAINS
CENTRAL
EAST
0 of 1 030801/0154 sigwind.vgf
SELECT TEXT <L> SELECT <M>
Fade:
40.57, -108.21

c)

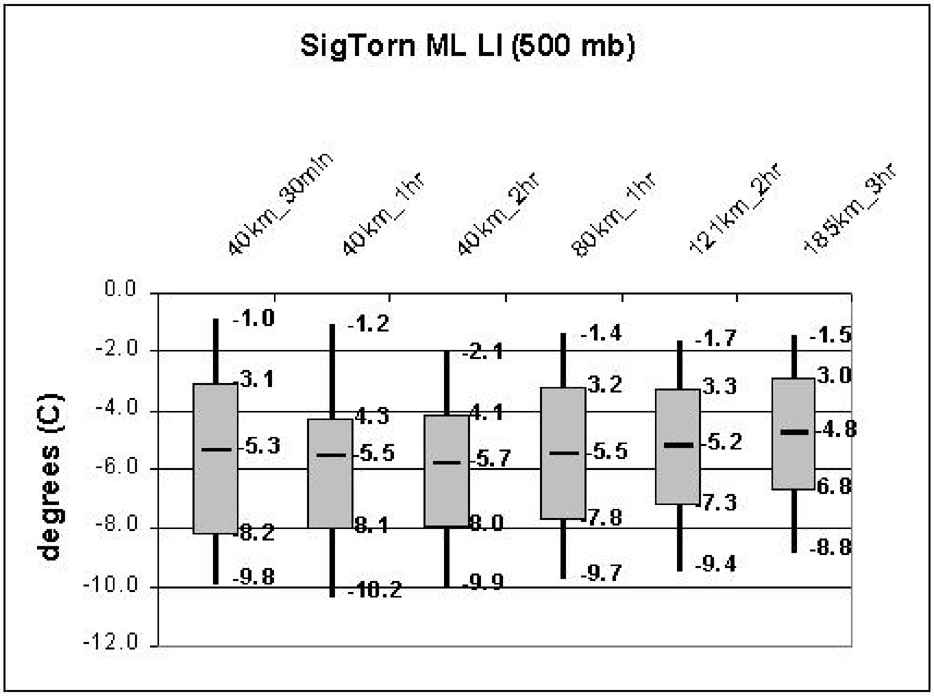


Figure 3. Proximity Comparison for SigTorn ML LI distributions.

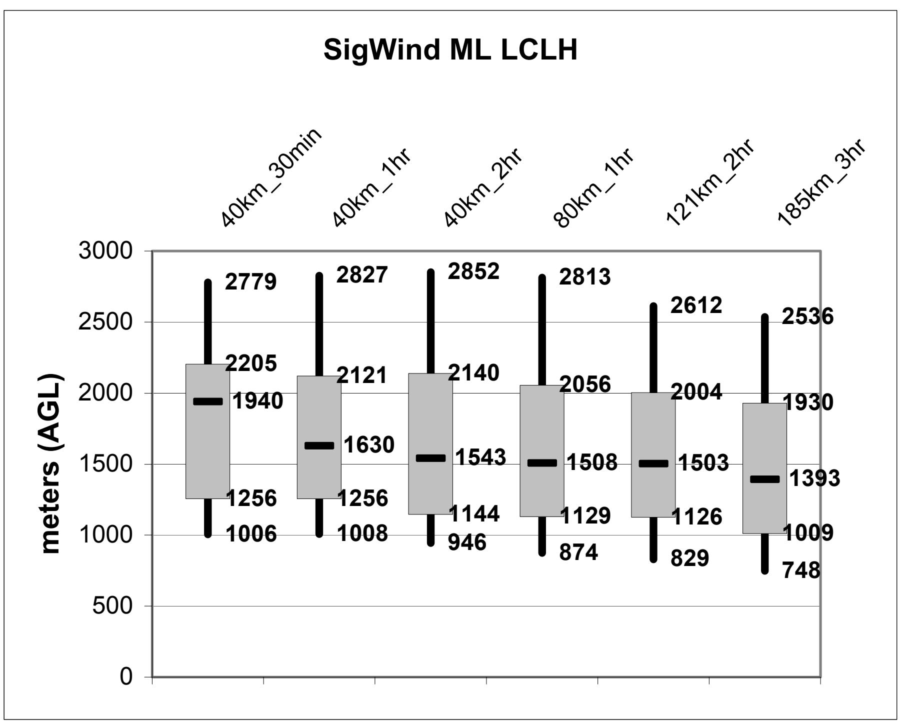


Figure 4. Proximity Comparison for SigWind ML LCLH distributions.

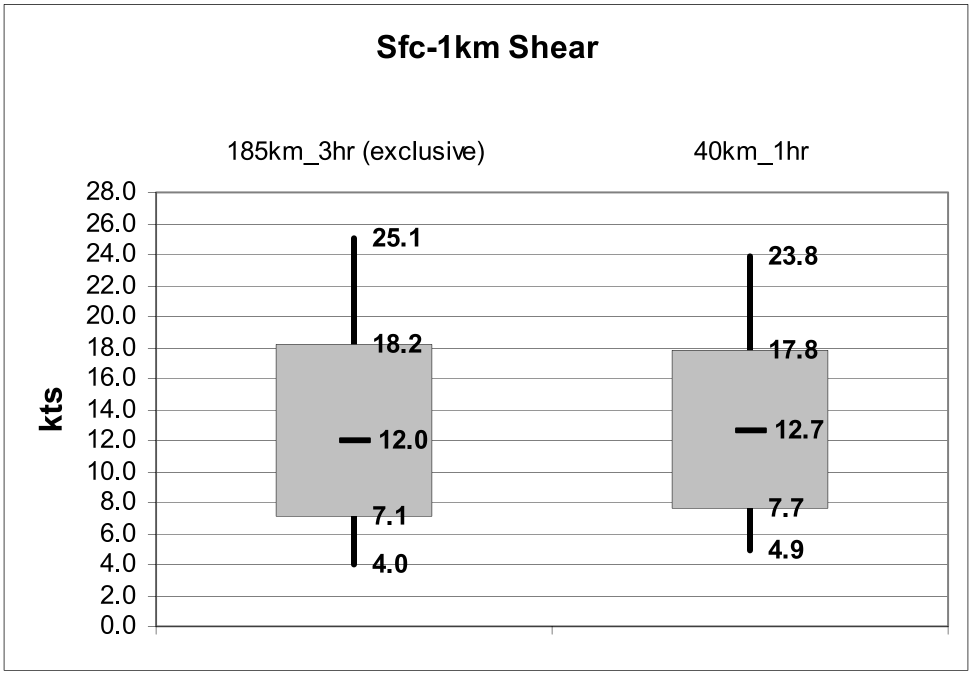


Figure 5. Proximity Comparison of SigHail Sfc-1km Shear for 185 km and 3 h exclusive and inclusive and 40 km and 1h criteria.

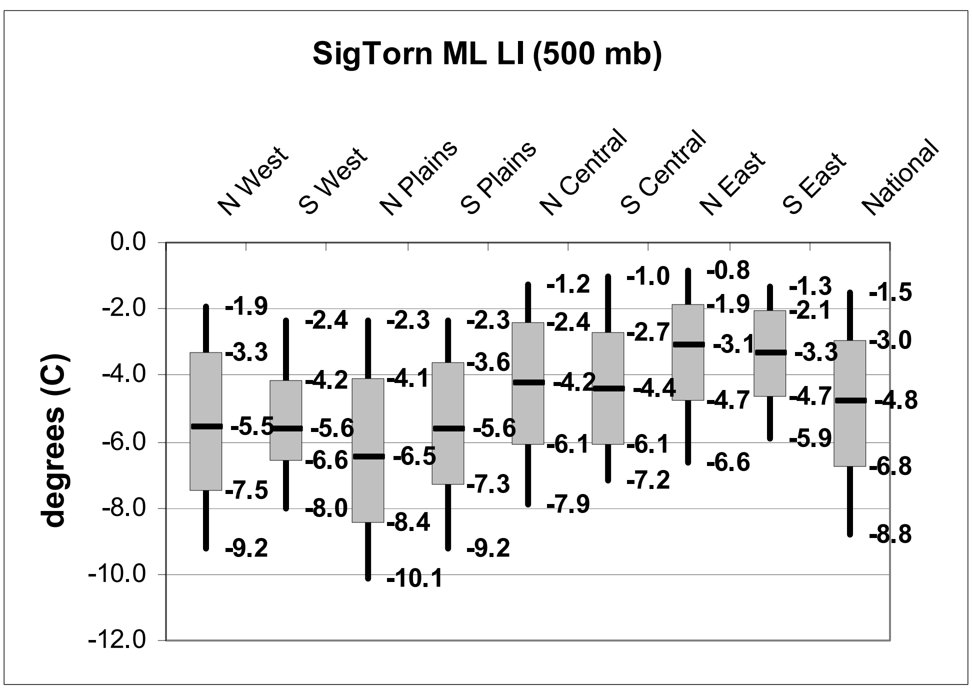


Figure 6. Geographic Comparison of SigTorn ML LI distributions for eight subregions.

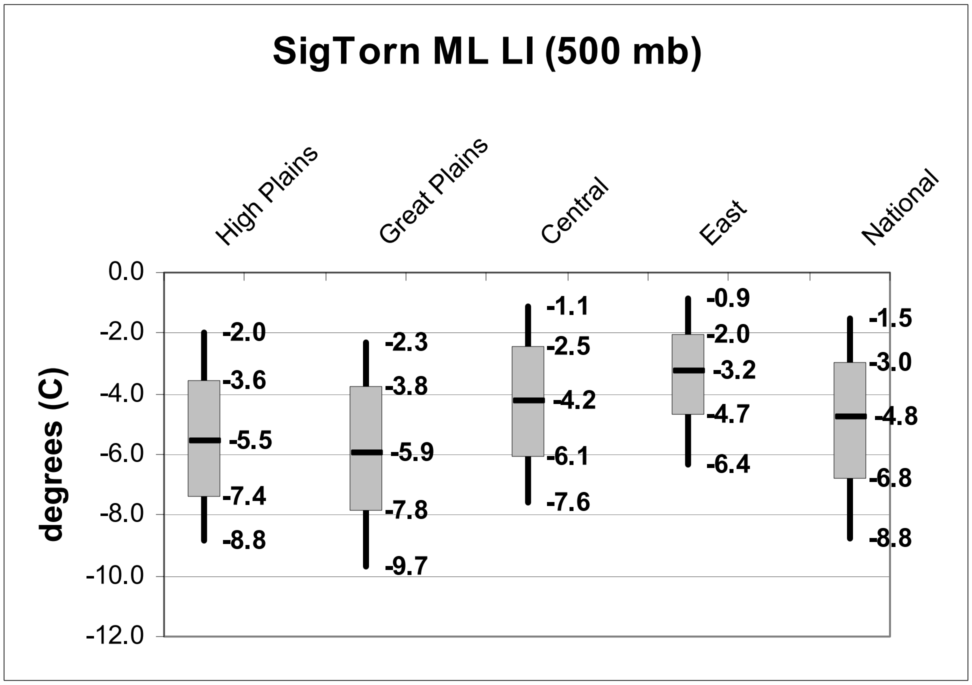


Figure 7. Geographic Comparison of SigTorn ML LI distributions.

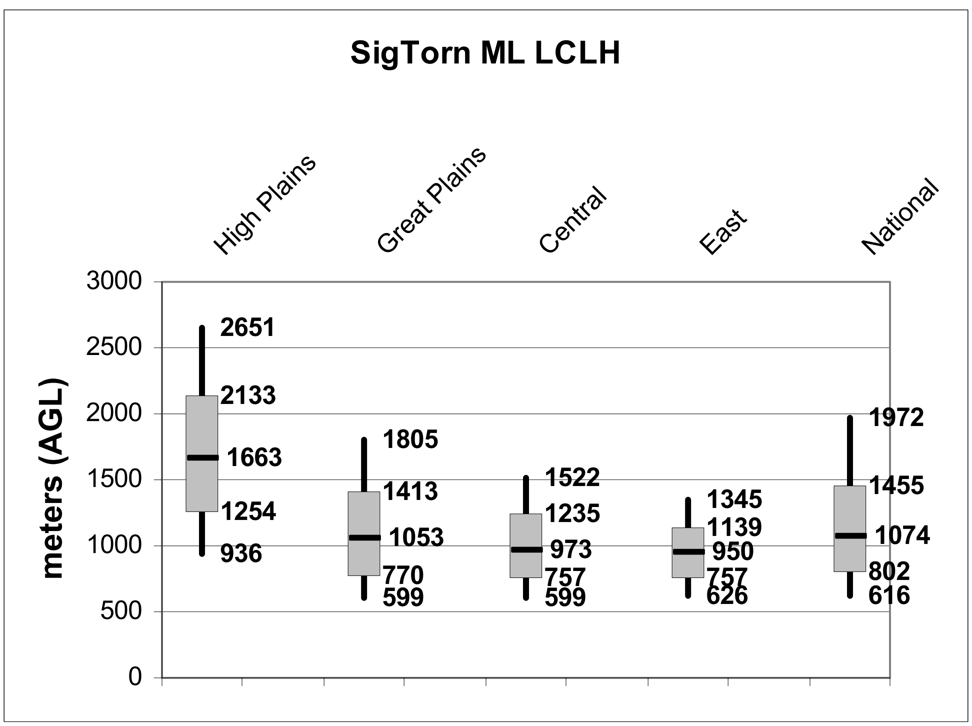
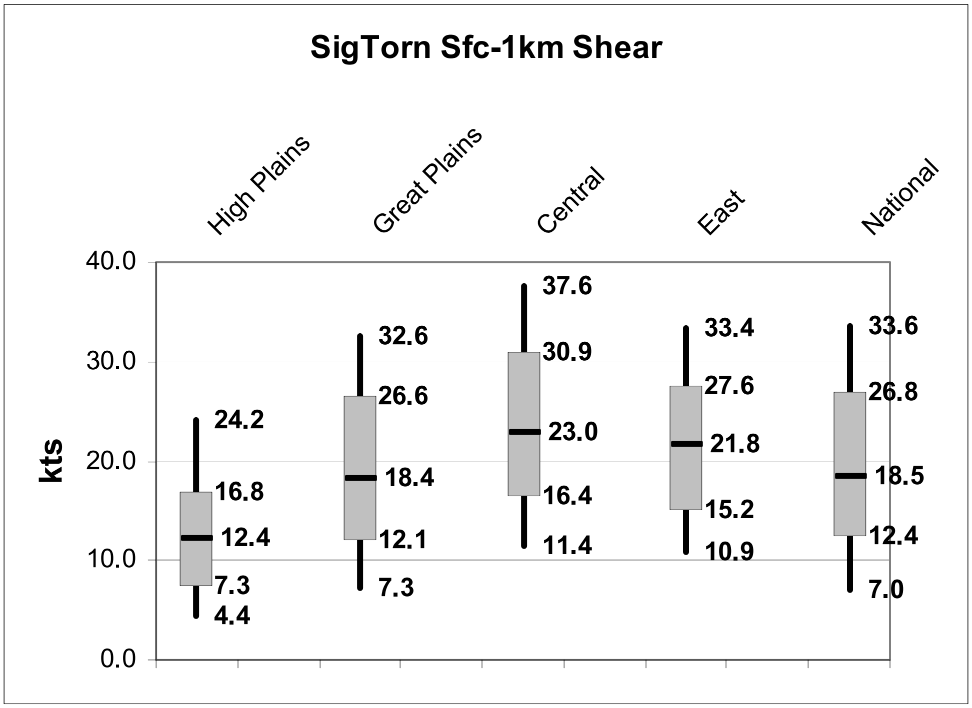


Figure 8. Geographic Comparison of SigTorn ML LCLH distributions.

Figure 9. Geographic Comparison of SigTorn a) Sfc-1km shear and b) Sfc-6km shear distributions.

a)



b)

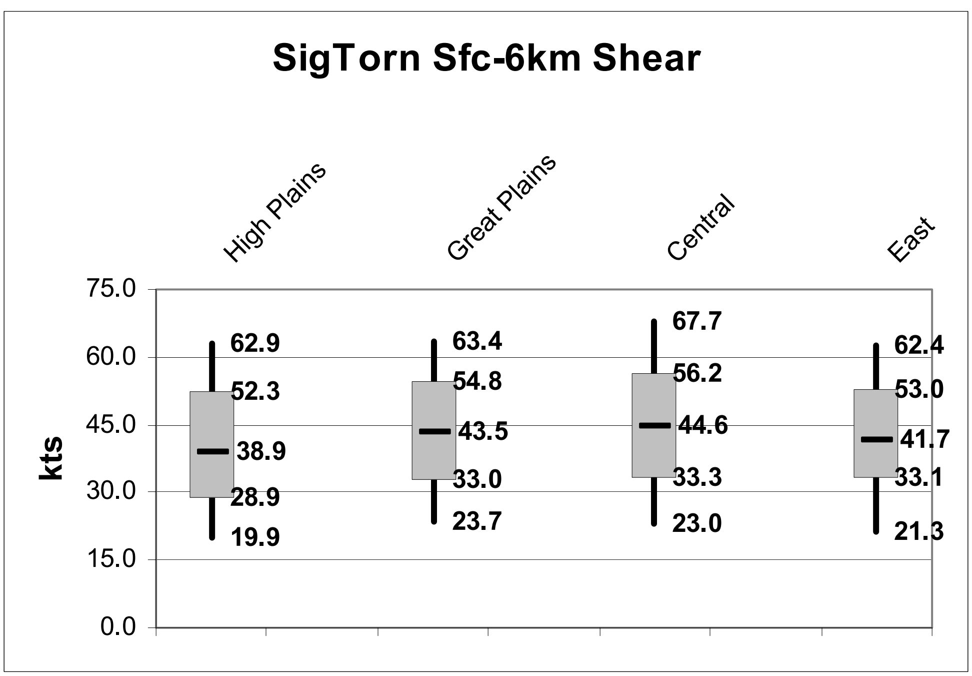
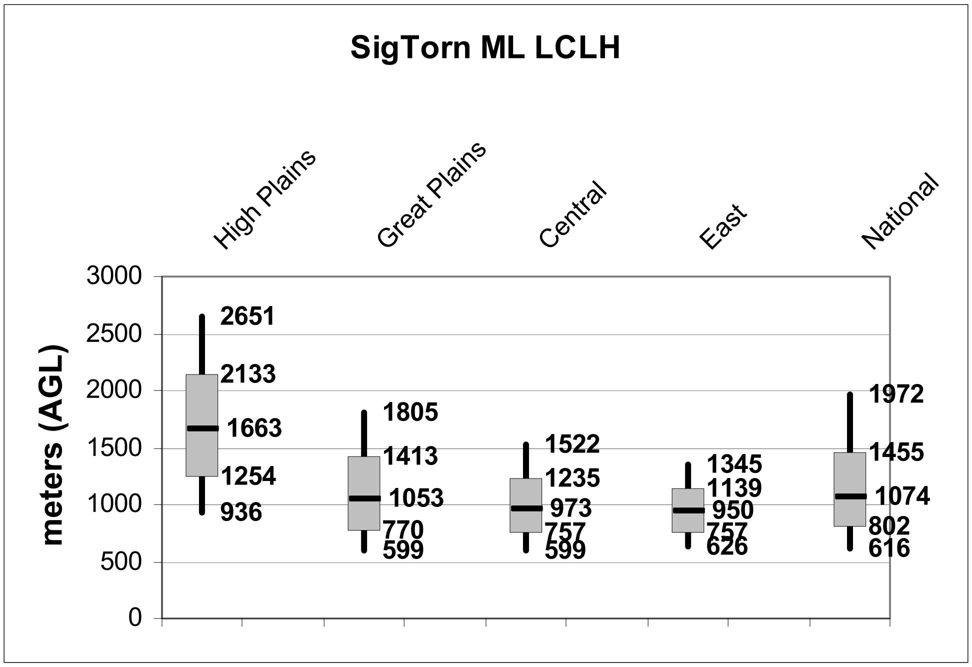
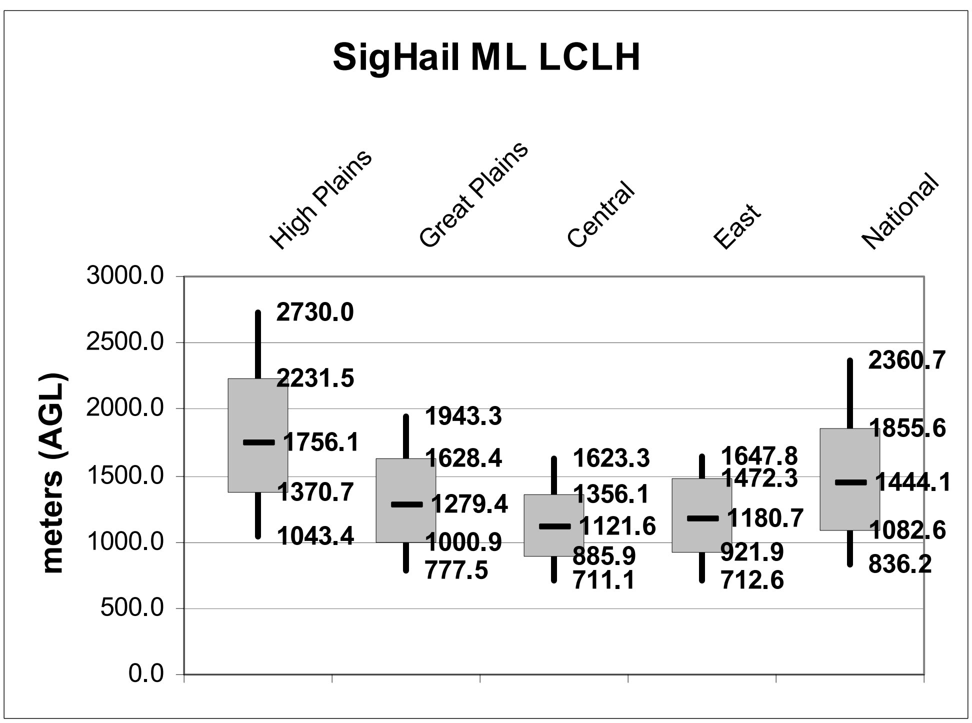


Figure 10. Geographic Comparison of ML LCLH for a) SigTorn, b) SigHail and c) SigTorn

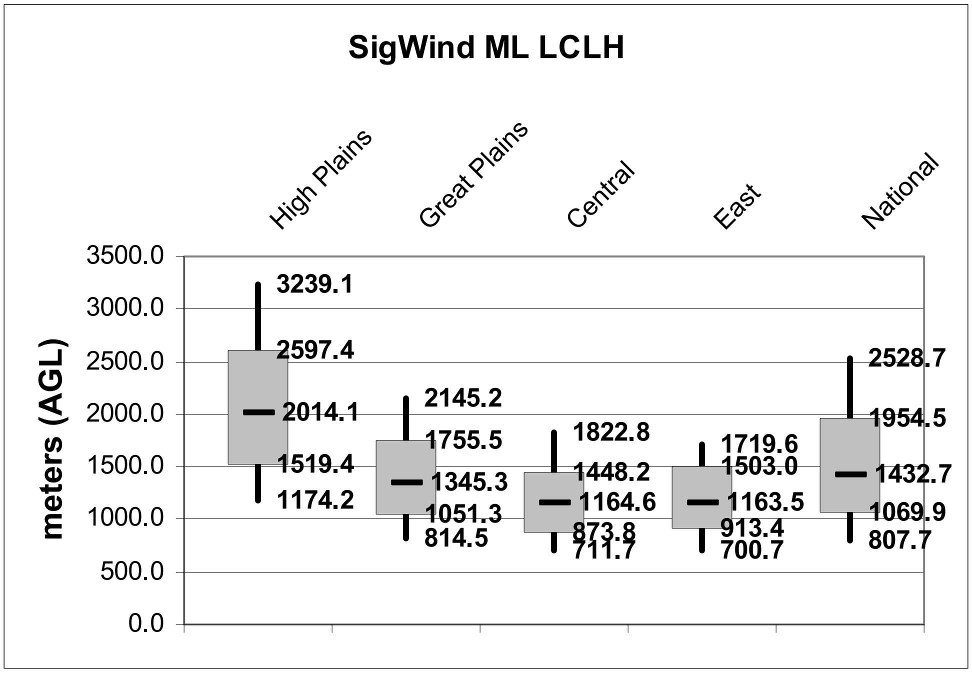
a)



b)



c)



SigWind ML LCLH
High Plains
Great Plains
Central
East
National
3500.0
3000.0
2500.0
2000.0
1500.0
1000.0
500.0
0.0
meters (AGL)
3239.1
2597.4
2014.1
1519.4
1174.2
2145.2
1755.5
1345.3
1051.3
814.5
1822.8
1448.2
1164.6
873.8
711.7
1719.6
1503.0
1163.5
913.4
700.7
2528.7
1954.5
1432.7
1069.9
807.7

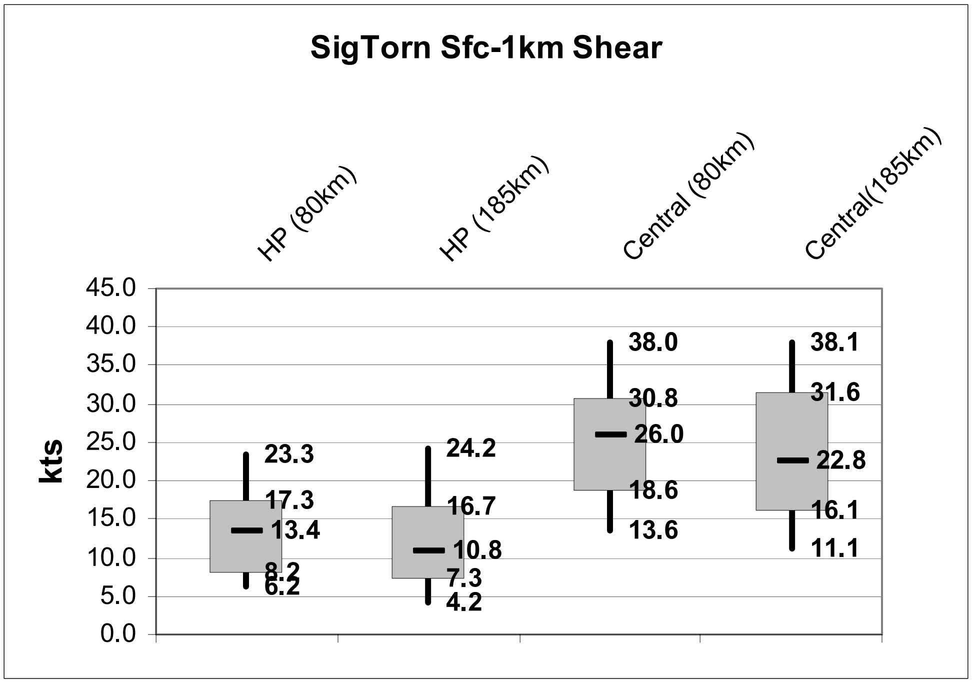


Figure 11. Proximity Comparison for SigTorn Sfc-1km shear for High Plains vs. Central regions, 80 km and 1 h vs. 185 km and 3 h exclusive.

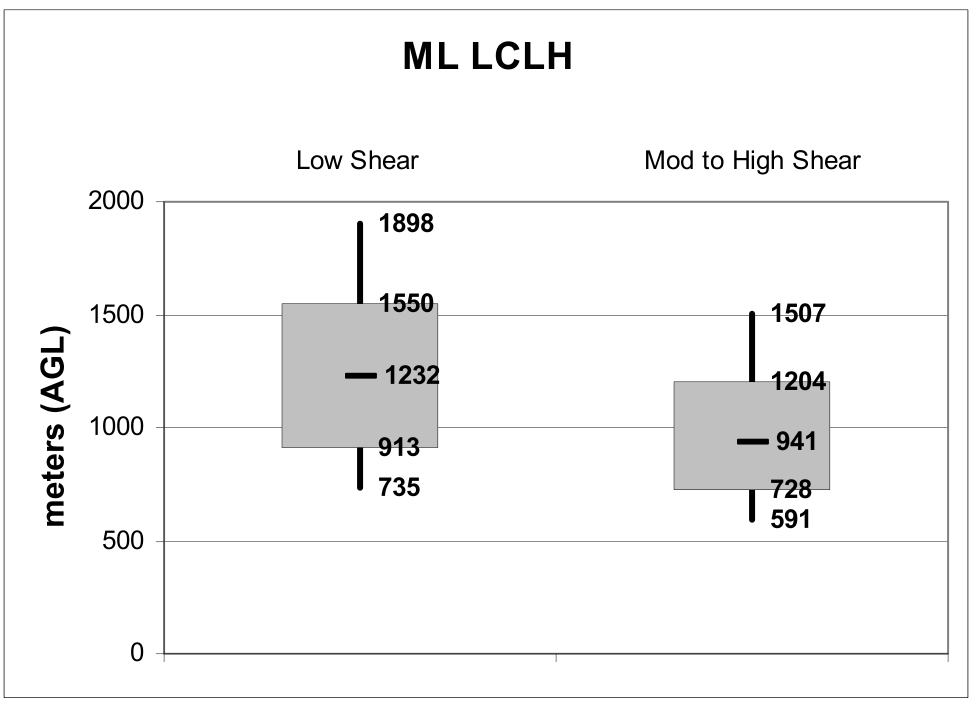
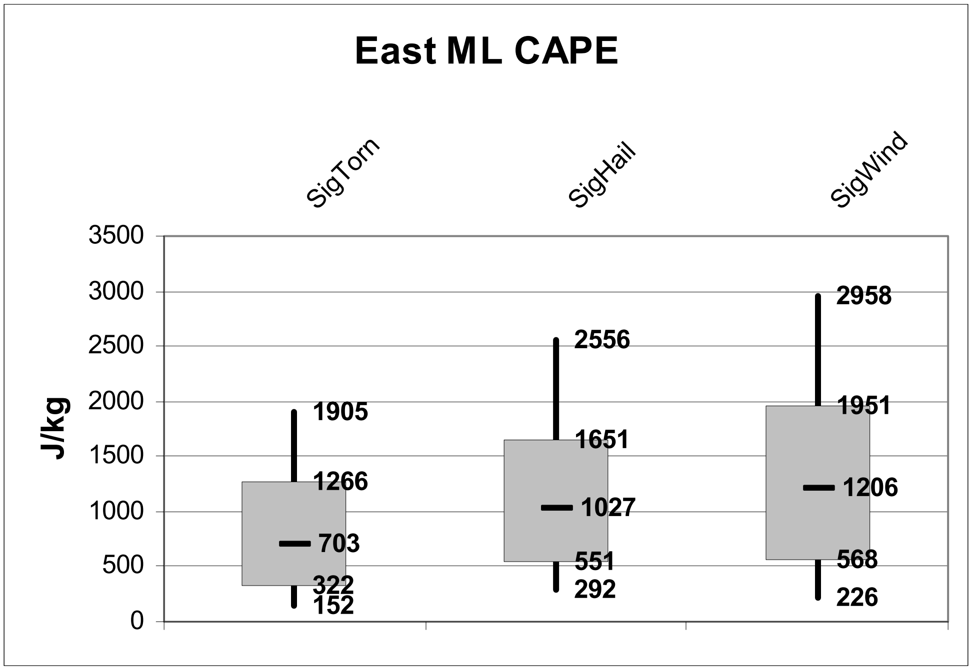


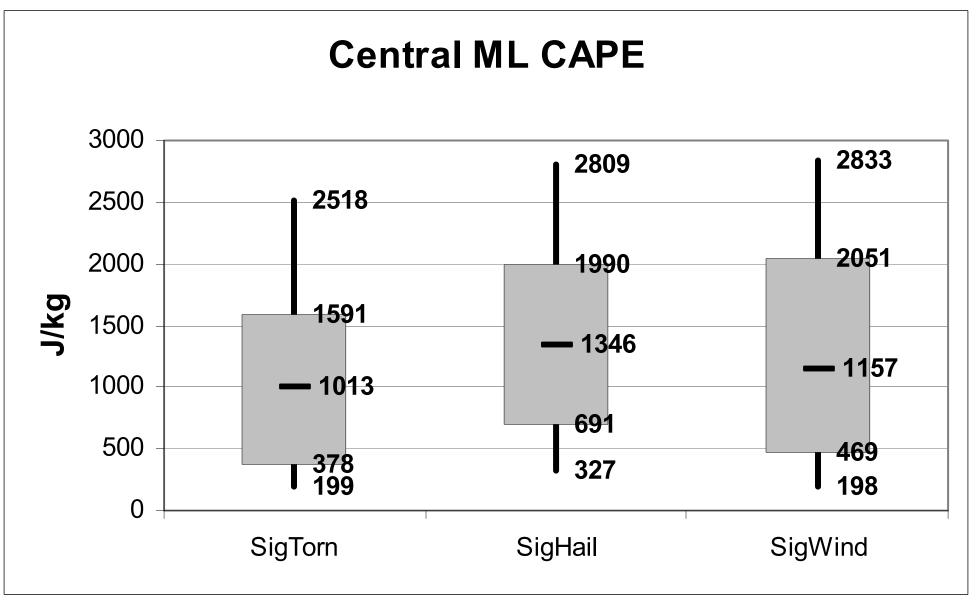
Figure 12. SigTorn ML LCLH distributions in Great Plains, Central and East regions for low vs. high Sfc-1km shear.

Figure 13. Significant Severe Type Comparison for ML CAPE for a) East, b) Central, c) Great Plains and d) High Plains regions.

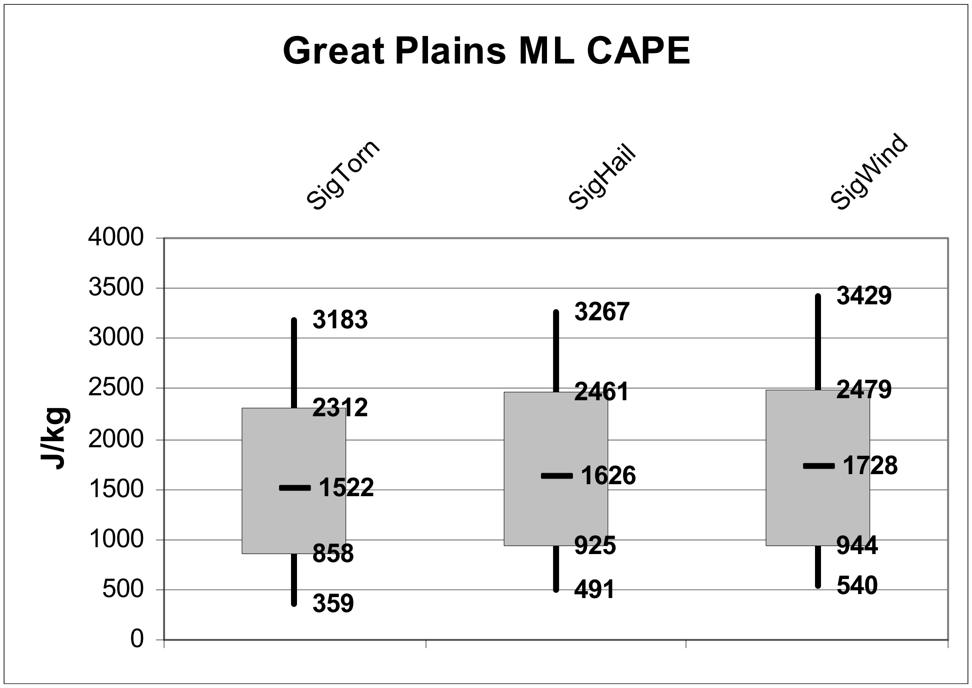
a)



b)



c)


Great Plains ML CAPE
SigTorn
SigHail
SigWind
J/kg
4000
3500
3000
2500
2000
1500
1000
500
0
3183
2312
1522
858
359
3267
2461
1626
925
491
3429
2479
1728
944
540

d)

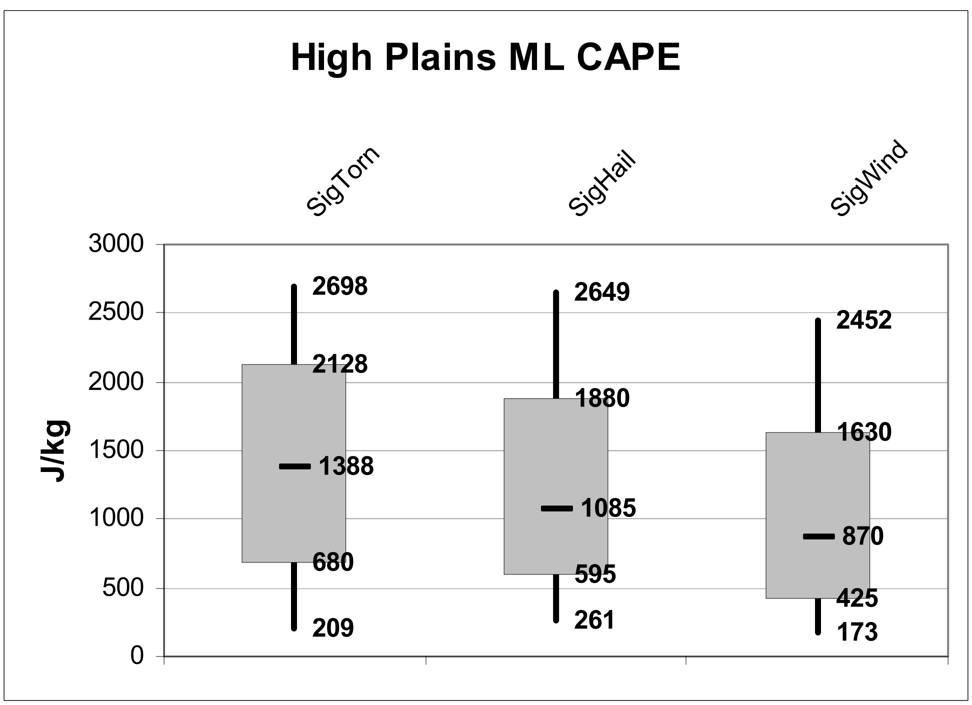
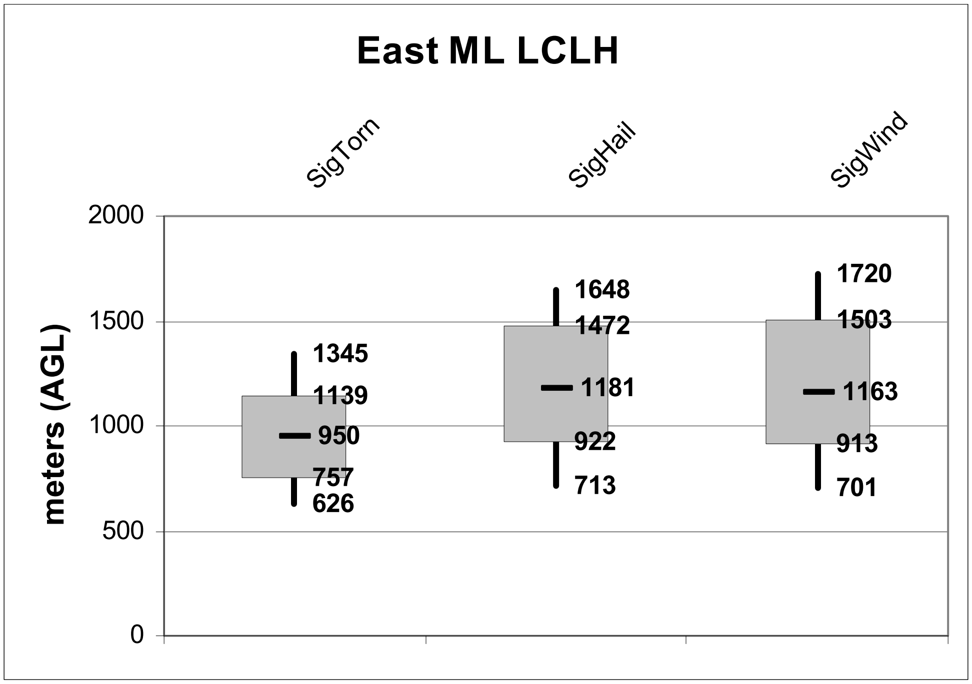
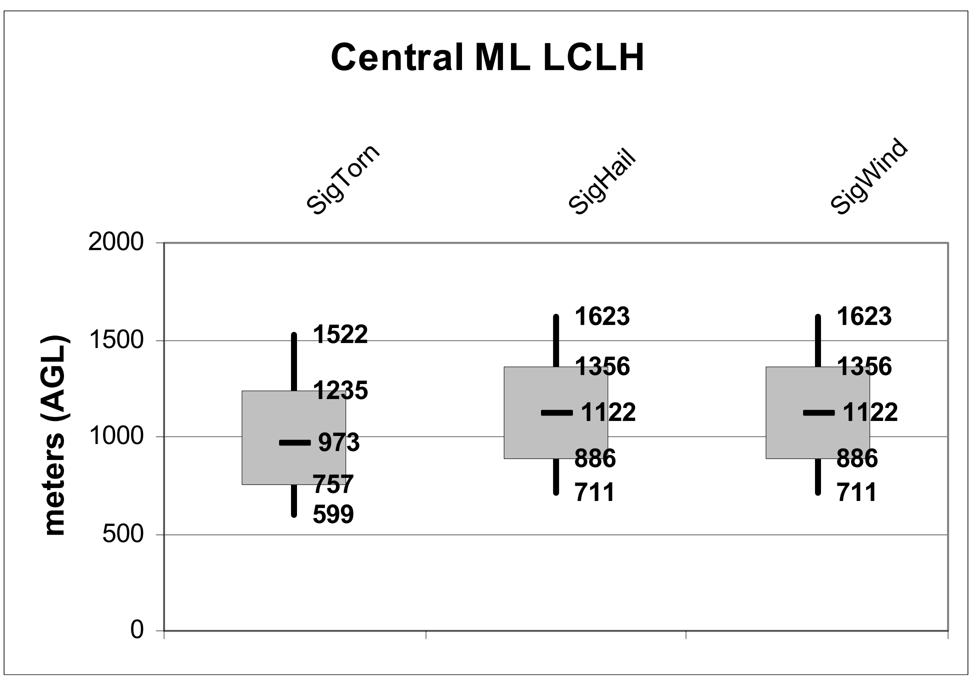

High Plains ML CAPE
SigTorn
SigHail
SigWind
J/kg
3000
2500
2000
1500
1000
500
0
2698
2128
1388
680
209
2649
1880
1085
595
261
2452
1630
870
425
173

Figure 14. Significant Severe Type Comparison for ML LCLH for a) East, b) Central, c) Great Plains and d) High Plains regions.

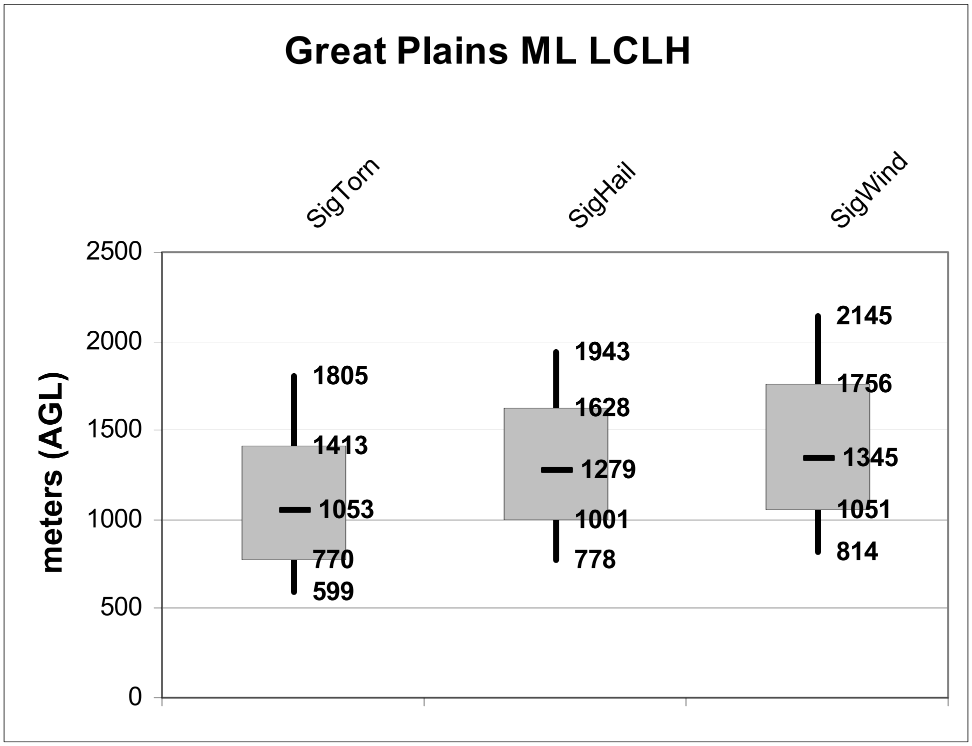
a)



b)

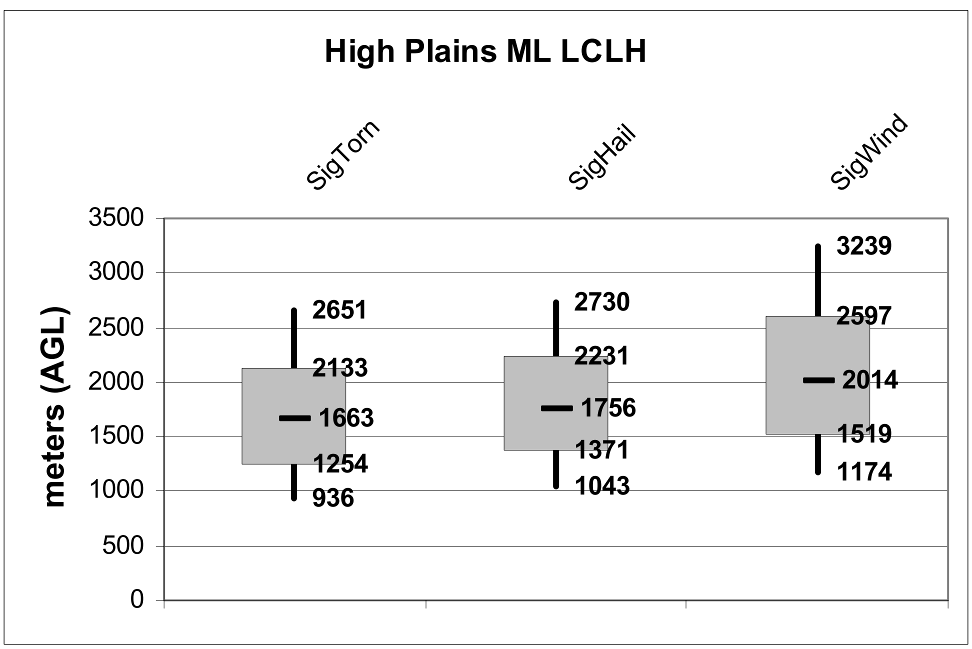


c)



Great Plains ML LCLH
SigTorn
SigHail
SigWind
meters (AGL)
2500
2000
1500
1000
500
0
1805
1413
1053
770
599
1943
1628
1279
1001
778
2145
1756
1345
1051
814

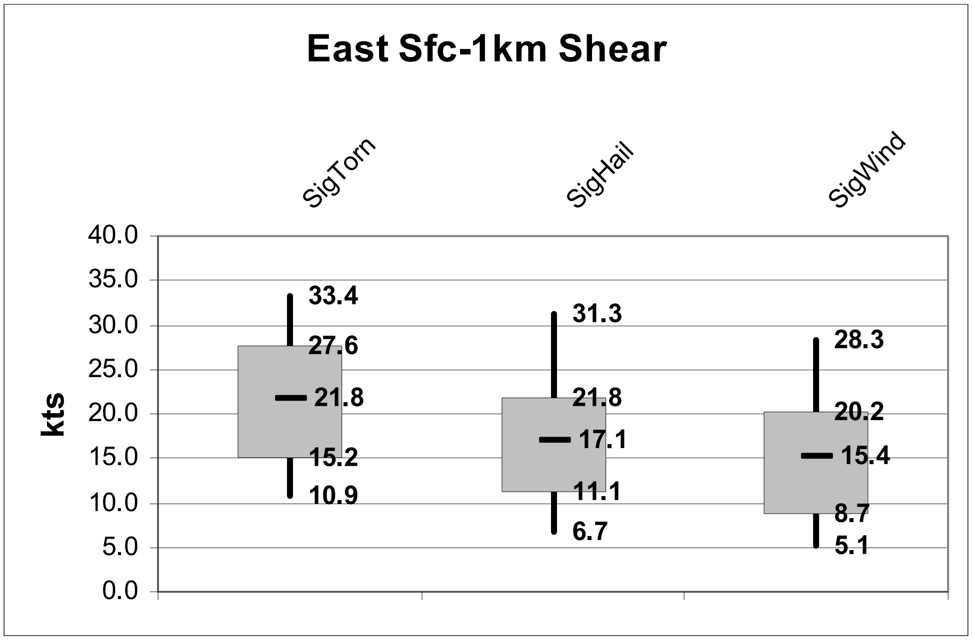
d)



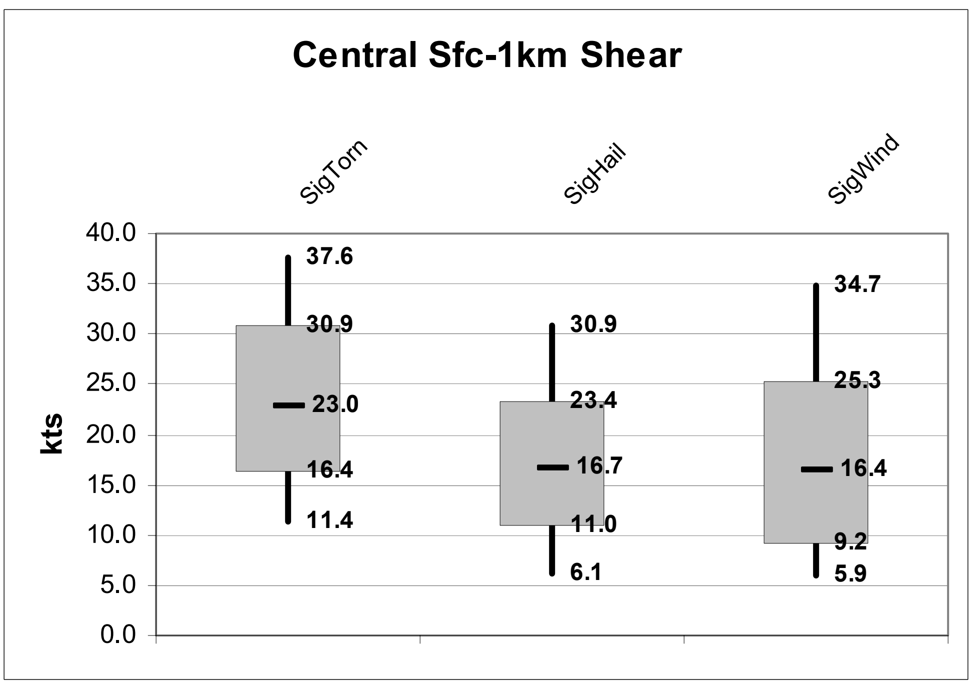
High Plains ML LCLH
SigTorn
SigHail
SigWind
meters (AGL)
3500
3000
2500
2000
1500
1000
500
0
2651
2133
1663
1254
936
2730
2231
1756
1371
1043
3239
2597
2014
1519
1174

Figure 15. Significant Severe Type Comparison for Sfc-1km shear for a) East, b) Central, c) Great Plains and d) High Plains regions.

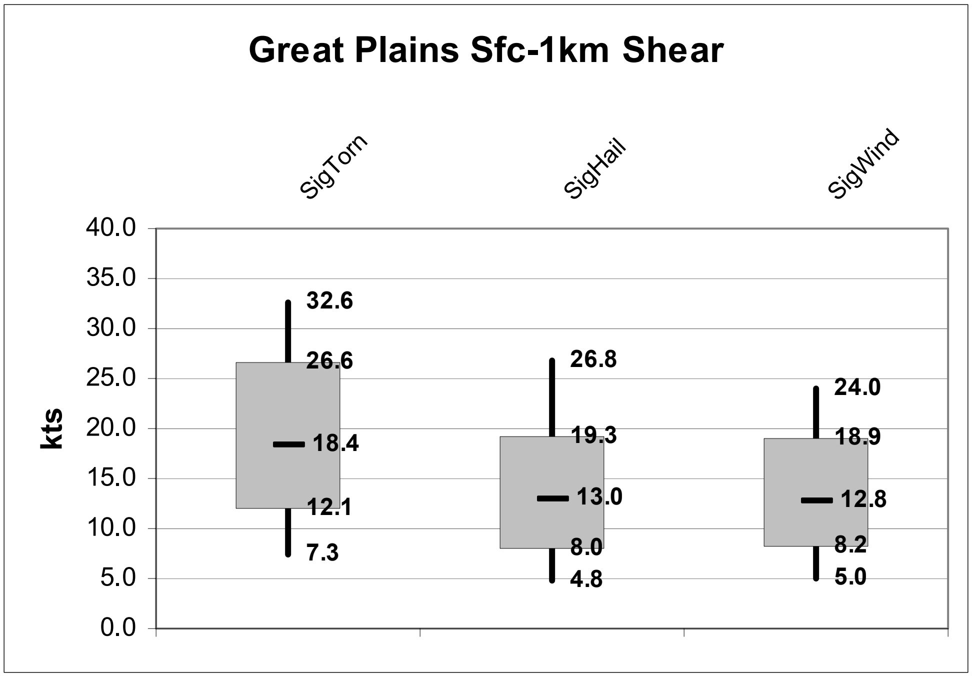
a)



b)



c)


Great Plains Sfc-1km Shear
SigTorn
SigHail
SigWind
kts
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
32.6
26.6
18.4
12.1
7.3
26.8
19.3
13.0
8.0
4.8
24.0
18.9
12.8
8.2
5.0

d)

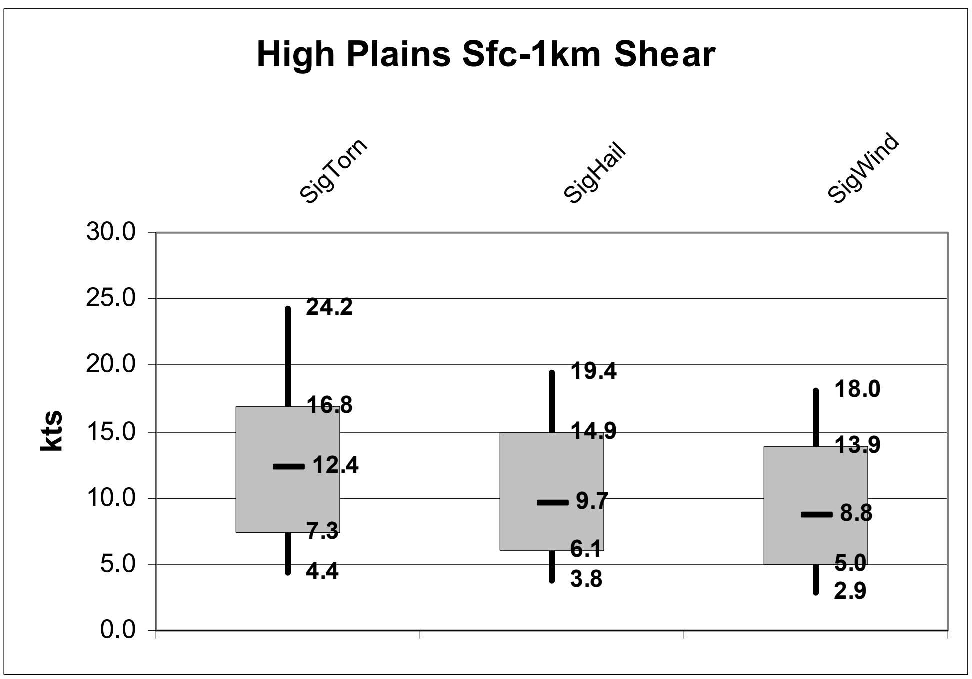
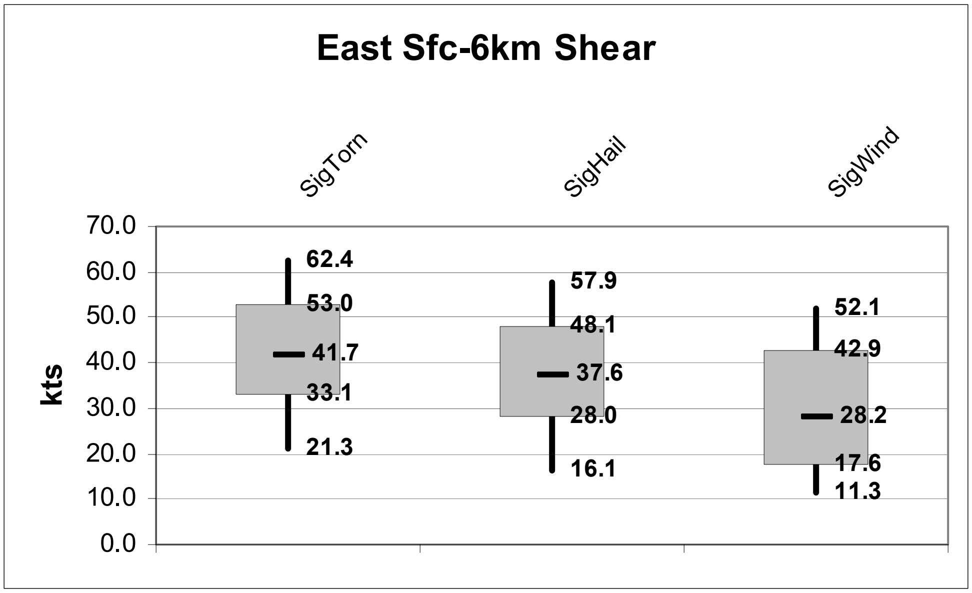
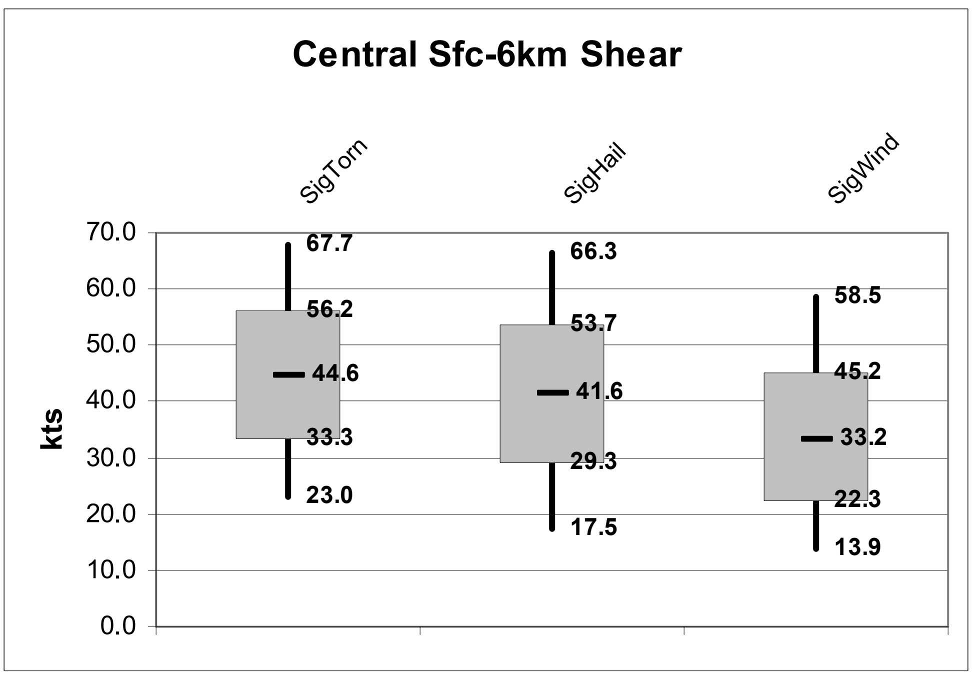

High Plains Sfc-1km Shear
SigTorn
SigHail
SigWind
kts
30.0
25.0
20.0
15.0
10.0
5.0
0.0
24.2
16.8
12.4
7.3
4.4
19.4
14.9
9.7
6.1
3.8
18.0
13.9
8.8
5.0
2.9

Figure 16. Significant Severe Type Comparison for Sfc-6km shear for a) East, b) Central, c) Great Plains and d) High Plains regions.

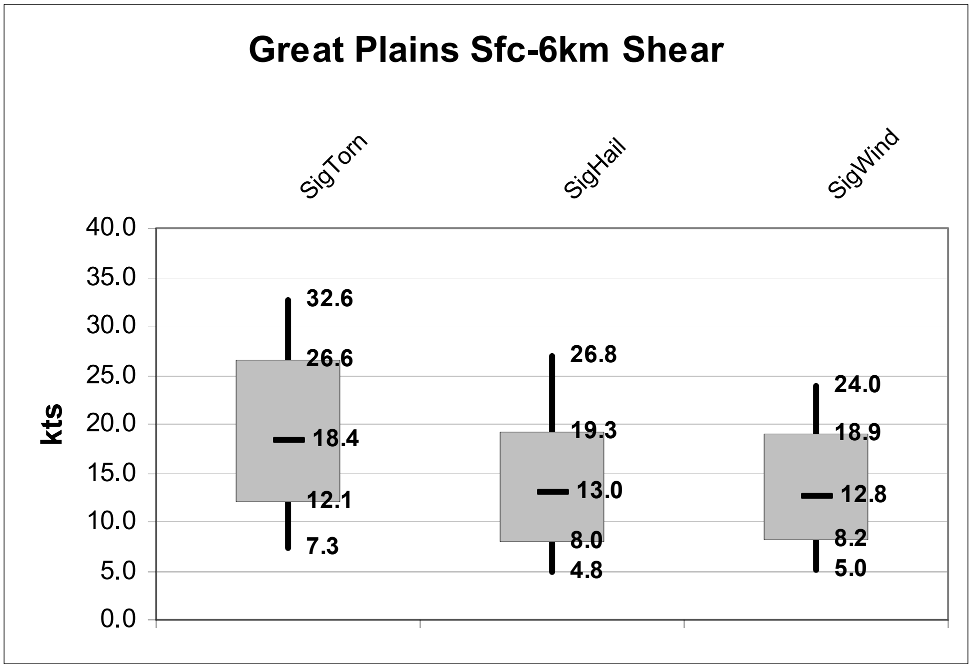
a)



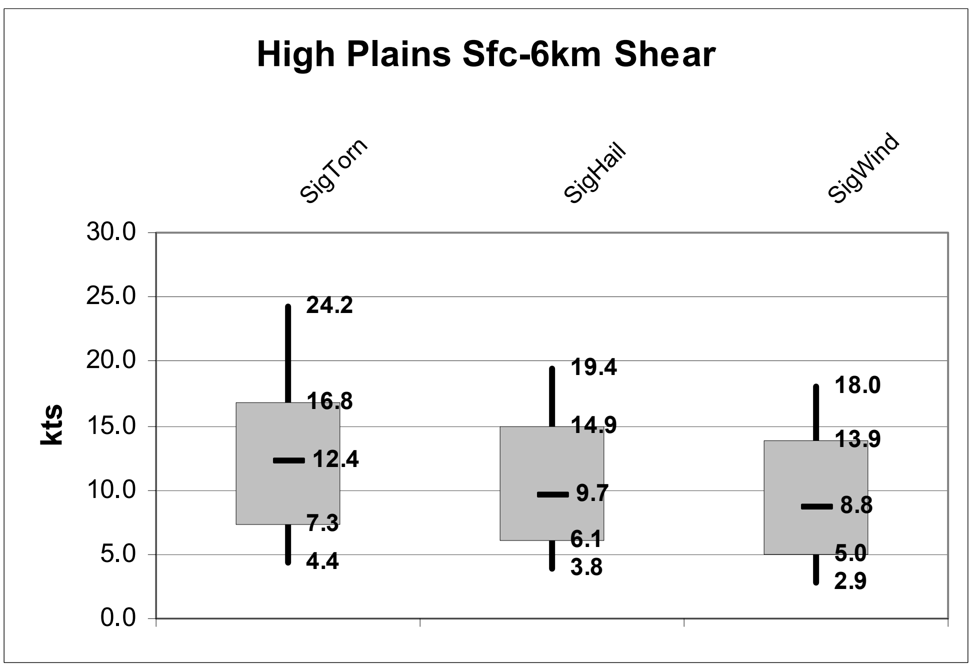
b)



c)


Great Plains Sfc-6km Shear
SigTorn
SigHail
SigWind
kts
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
32.6
26.6
18.4
12.1
7.3
26.8
19.3
13.0
8.0
4.8
24.0
18.9
12.8
8.2
5.0

d)


High Plains Sfc-6km Shear
SigTorn
SigHail
SigWind
kts
30.0
25.0
20.0
15.0
10.0
5.0
0.0
24.2
16.8
12.4
7.3
4.4
19.4
14.9
9.7
6.1
3.8
18.0
13.9
8.8
5.0
2.9