An Analysis of the Tornadic Tendencies of SW and NW Flow Severe Weather Events in the Southern Plains: 1992 - 2001

A Research Project for the Fall 2004 SPC Internship

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1. Introduction

The Southern Plains region of the United States is well known for its high frequency of severe weather events which occur under synoptic conditions that vary throughout the year. Most commonly, severe weather events in this region have been observed to occur under a pattern of southwesterly flow (hereafter SW flow) at 500 mb. Such events are associated with a 500 mb pattern that consists of a trough west of the observed storm region and a ridge to the east. It has also been found that a considerable number of severe weather events in the Southern Plains take place when the flow is northwesterly (hereafter NW flow) at 500 mb (Johns 1982, 1984). NW flow severe weather events in the Southern Plains are typically associated with an amplified ridge pattern throughout the western U.S. and a strong trough in the eastern U.S.

From a previous unpublished research project, Fahrig and Hocker (hereafter FH) found that SW and NW flow at 500 mb accompanied the majority of the 417 severe weather events that occurred in the Southern Plains from 1992-2001. SW flow was associated with 62.6% of the events and NW flow was associated with 21.3% of the events. Other flow types such as westerly flow and hybrid flow (quickly changing and thus unidentifiable) happened much less frequently and accounted for only 6.2% and 9.8% of the severe weather events, respectively. Furthermore, it became quite apparent in the study that SW and NW flow severe weather events were associated with a similar number of wind and hail reports. However, there was a rather distinct difference in the number of tornado reports observed with these flow types. In order to gain a greater understanding for the significant disparity in tornado occurrence under NW and SW flow in the Southern Plains, an augmented observational study has been performed on the severe weather event dataset from FH.

2. Methodology

Two main phases of research were conducted to compare the differences in tornado occurrence under SW and NW flow. The first phase involved using storm report data to verify the frequency of tornadoes for each flow type. The second phase of the research was focused on comparing the environmental conditions for SW and NW flow events as well as significant tornado cases under SW and NW flow using observed environmental soundings.

a. Verifying tornado frequency for each flow type (phase 1)

The FH event list was used to compile detailed tornado statistics needed for this study. The dataset consists of 417 severe weather events that occurred between 1992 and 2001 in the Southern Plains region (which was defined in FH). Using the event listing and the storm report plotting program SeverePlot2[1], tornado reports were tallied by year, month, and F-scale rating. Only reports that resided within the defined Southern Plains region were counted and all information was entered into a spreadsheet. Additionally, events that contained at least 1 F2 or greater tornado were labeled significant tornado cases (hereafter sig tor cases) and these were identified for each flow type over the 10 year period.

[1] http://www.spc.noaa.gov/software/svrplot2/

b. Picking representative soundings for NW and SW flow severe weather events

To compare the environments associated with NW and SW flow severe weather events, one representative sounding was selected for each event. Before this was done, however, the number of SW flow events had to be reduced since there were many more SW flow events (261) than NW flow events (89). In order to do this, a sample of 89 SW flow events was systematically selected from all the SW events taking into account the percentage of sig tor cases that occurred each month. Additionally, the sample events were selected so that at least one week separated each sample. This was done to ensure that the sampling was well spaced with no biases towards certain time periods. Once the samples were made, SeverePlot2 was used to print the storm reports that corresponded to each event.

Next, a representative proximity sounding was selected for each NW and SW flow event. Since only one sounding was desired per event, a method for selecting a single proximity sounding was needed. Ultimately, an inflow sounding method used in Rasmussen and Blanchard 1998 (hereafter RB98) was adopted for use in this study. Using the storm report printouts, the inflow method, and the Storm Prediction Center (SPC) sounding database along with NSHARP (v. 3.95), one representative sounding was selected for each of the 89 NW and 89 SW flow severe weather events. Sounding selection was done in the following series of steps:

1) The storm report centroid (the area averaged midpoint of the storm reports) and storm reports times were marked on the storm report printout

2) Sounding sites within 400 km of the centroid were viewed in NSHARP
3) Only soundings that were launched around or before the storm report times were viewed
4) Of the soundings that met steps two and three, the lowest 2 wind observations were averaged and drawn as a wind vector on the storm report printout (this represents the boundary layer wind). If the storm report centroid fell within roughly ±75° of the wind vector, the sounding was selected (see RB98 for more details)
5) If more than one sounding met all the above requirements, the sounding with the largest Convective Available Potential Energy (CAPE) was selected
6) If no sounding met the above requirements, or contamination existed (thunderstorm, frontal, dryline, etc.), the case was thrown out and replaced

Overall, only 1 NW flow event had no usable sounding. After the sounding selection process was completed, there were a total of 88 NW and 88 SW flow events. All but six of the soundings were from 0000 UTC with the 6 non-0000 UTC soundings taken at either 0100 UTC, 0600 UTC, 1200 UTC, or 1800 UTC. Each representative sounding was printed (with both the 100 mb mixed and the MU lifted parcel) and key meteorological parameters were taken from the printouts and entered into a spreadsheet.

3. Results

From the FH dataset of 417 severe weather events in the Southern Plains, notable differences were found in the number of tornado reports occurring in SW and NW flow severe weather events. The total number of tornado reports occurring in SW and NW flow severe weather events is shown below with an average number of reports per event shown in parentheses:

- SW Flow: 1767 tornado reports (6.8 reports per event)
- NW Flow: 269 tornado reports (3.0 reports per event)

SW flow events were found to be accompanied by more than twice as many tornado reports per event as NW flow. Fig. 1 shows the average number of tornado reports for both SW and NW flow events by month. With the exception of March, SW flow events always have a higher average number of tornado reports than NW flow events. A greater difference occurs when the percentage of sig tor cases (events with at least 1 F2 or greater tornado) is examined for each flow type. It was found that 30.3% of all the SW flow events were sig tor cases while only 5.6% of all the NW flow events were sig tor cases. Thus, there is a tendency for SW flow cases to not only produce more tornadoes, but more significant tornadoes than NW flow cases. Fig. 2 illustrates the sharp contrast between sig tor cases under each flow type by focusing on the number of cases per month. It is interesting to note that whereas SW flow sig tor cases tended to occur in May, the NW flow sig tor cases were much more sporadic with no monthly trends found. The F2 criterion for sig tor cases was chosen upon to make a distinction (albeit inexact) between tornadoes produced by supercells and tornadoes produced from other storm types. Therefore, it appears that NW flow produces far fewer significant tornadoes from supercells than SW flow in the Southern Plains.

In order to better understand why tornadoes occur more commonly under SW flow at 500 mb, a series of box and whisker plots were developed for several key tornado parameters using the representative atmospheric soundings from the SW and NW flow severe weather events. The tornado parameters that are investigated include: convective available potential energy (CAPE), lifted condensation level (LCL) heights, surface – 1 km shear, surface – 6 km shear, and storm relative environmental helicity (SREH). Although Doswell and Rasmussen (1994) suggest use of a most unstable (MU) parcel in determining CAPE in proximity sounding studies, this study utilized an NSHARP derived 100 mb mixed parcel to be more consistent with the inflow method employed in RB98.

a. CAPE

Using the CAPE data from all of the soundings, four box and whisker plots were developed for this parameter: all NW flow events, all SW flow events, NW flow sig tor cases, and SW flow sig tor cases (Note: There were only 5 NW flow sig tor cases, so this group has far fewer samples than all the other groups). The box and whisker plots were developed using standard conventions with the lower and upper portions of the box representing the 25th and 75th percentiles, respectively, and the thin vertical lines (whiskers) extending to the 10th and 90th percentiles. A heavy horizontal line demarks the median value of the data. The four CAPE box and whisker plots are shown in Fig. 3.

Comparing the plots it appears that the 'all' category SW and NW flow events were quite similar, although the SW flow events tended to be more unstable towards the upper range of the data. It does appear that both the NW and SW flow sig tor cases were a little more unstable than their 'all' event counterparts. Furthermore, NW flow sig tor cases tended to be a little more unstable than the SW flow sig tor cases when considering the median values of the data.

b. LCL Heights

A similar box and whisker plot analysis was done for LCL heights using the data from all of the representative soundings. Comparing all the NW flow and SW flow events, it appears that the LCL heights are generally lower in SW flow situations (Fig. 4). The higher LCL heights associated with NW flow events may be one reason why tornadoes are less frequent in NW flow situations (RB98). Looking at sig tor cases, it can be seen that both NW and SW flow sig tor cases have lower LCL heights than all NW flow and SW flow events, respectively. Additionally, SW flow sig tor cases were observed to have considerably lower LCL heights than NW flow sig tor cases. All of these findings support the tendency for tornadoes to occur more frequently under SW flow than under NW flow.

It is important to note that the findings presented here represent the upstream environment that is advecting into the storm report centroid region. Therefore, the LCL height values in Fig. 4 are probably not the same as values that may exist in the mesoscale storm environment. The LCL heights in this study are intended to represent the general synoptic conditions in the storm region.

c. Surface to 1 km shear

The box and whisker plot analysis for the surface to 1 km shear can be seen in Fig. 5, and it establishes rather distinct differences in the magnitudes of shear observed in SW and NW flow severe weather events. First comparing all NW flow and all SW flow events, it is quite apparent that the SW flow events typically have stronger shear between the surface and 1 km. All SW flow events were observed to have a median value of 14 knots while all NW flow events had a median of only 9 knots. Focusing on only sig tor cases for each flow type, both flows display a slight increase in median values over the 'all' event categories. Compared against each other, SW flow sig tor cases exhibit a larger surface to 1 km shear value than NW flow sig tor cases. Thus, it appears that one possible reason for the greater likelihood of tornadoes (and strong tornadoes) under SW flow stems from the stronger low level shear that occurs during many of these events as compared to the weaker low level shear that occurs during a majority of the NW flow severe weather events.

d. Surface to 6 km shear

The trends that were observed in the surface to 1 km shear plots are further supported by the plots developed for the surface to 6 km shear as seen in Fig. 6. Much like in the surface to 1 km plots, all SW flow events were observed to have slightly stronger shear than all the NW flow events. It appears that in general (since there is overlap of data) SW flow events have a greater magnitude of deep layer shear which supports a greater probability of having supercell storms and tornadoes. Furthermore, the NW and SW flow sig tor cases show evidence of increased values of shear over the corresponding 'all' events categories, however, the shear did not vary much between SW and NW flow sig tor cases. It appears that NW flow can support sig tor cases, but this typically occurs when the deep layer shear is well above the median value of all the NW flow events (35 knots).

e. SREH

The last set of box and whisker plots illustrates the differences in the surface – 3 km SREH for the different categories and is provided in Fig. 7. Although surface to 1 km and surface to 6 km shears exhibited some differences in magnitude for SW and NW flow events, SREH does not seem to vary much between SW flow and NW flow events. The first two box plots show that there is little difference between SREH for all SW and all NW flow events, although NW flow is observed to have a slightly larger spread and a higher median value. Moreover, both SW and NW flow sig tor cases are shown to have

SREH values that are roughly 30 m^2s^{-2} higher than the 'all' events (when considering the median values). Comparing the sig tor cases for each flow type together, both are seen to be quite comparable with the main differences existing at the upper ranges of the data (which is a strong function of the limited number of NW flow sig tor cases). Overall, there seemed to be very little disparity in SREH between SW and NW flow events, although sig tor cases did have higher values.

4. Conclusion

It has been found that tornadoes more frequently develop under a synoptic pattern of SW flow at 500 mb than under NW flow in the Southern Plains. This was done by analyzing storm report data for 417 severe weather events that occurred in the Southern Plains between 1992 and 2001. To better understand why this is the case, an analysis of atmospheric soundings was performed on 88 NW and 88 SW flow severe weather events.

Five key tornado parameters were selected and analyzed for each of the flow events and comparisons were made between all SW flow events (88), all NW flow events (88), SW flow sig tor cases (26), and NW flow sig tor cases (5). CAPE comparisons showed that while both flow types were typically associated with very unstable environments, SW flow was typically a bit more unstable. Additionally, sig tor cases tended to be associated with higher CAPE values than all the cases together. Looking at another thermodynamic parameter, it appears that the LCL heights were generally lower during SW flow events than during NW flow events. Furthermore, sig tor cases for each flow type were observed to have noticeably lower LCL heights than the 'all' events categories, but overall SW flow sig tor cases had considerably lower LCL heights than the NW flow sig tor cases.

One reason behind the differences in thermodynamic parameters such as CAPE and LCL heights may stem from the differences in the synoptic patterns associated with SW and NW flow. Under SW flow in the Southern Plains, synoptic forcing features such as ageostrophic curvature divergence and cyclonic vorticity advection increasing with height help to provide rising motion and surface pressure falls. The result is that southerly/southeasterly winds can develop which help to advect Gulf of Mexico moisture into the region. Under NW flow synoptic features such as ageostrophic curvature convergence and anticyclonic vorticity advection increasing with height tend to create sinking motion which makes surface cyclogenesis and moisture advection less favorable. This synoptic difference may be one reason why NW flow events tend to be associated with slightly lower CAPE values and higher LCL heights than SW flow events in the Southern Plains. The combination of these thermodynamic features results in an environment that is generally less favorable for tornadoes.

Shear comparisons also help to show distinct differences that existed in SW and NW flow environments. Both surface to 1 km and surface to 6 km shear plots showed that SW flow events typically had stronger shear when considering all the events together. This means that SW flow events are generally more likely to have supercells (via the higher surface – 6 km shear) and tornadoes (via the higher surface – 1 km shear). In addition, the shear associated with SW and NW flow sig tor cases tended to illustrate two interesting trends: 1) sig tor cases had considerably higher values of shear compared to the corresponding ‘all’ categories, and 2) SW and NW flow sig tor cases displayed fairly similar deep layer shear but rather different low level shear. Therefore, more significant tornadoes occurred most often for both flow types when the shear was unusually high. More interestingly, it appears that the weaker low level shear associated with NW flow may be one explanation for the lower frequency of tornadoes (and significant tornadoes) for this flow type.

Differences in NW and SW flow severe weather event shear values can probably be explained by the annual peak in activity of each flow type. Since SW flow severe weather events peak during May, the events are more likely to be associated with stronger synoptic waves and thus more environmental shear than NW flow severe weather events which peak during the less synoptically active month of June. The occurrence of less environmental shear in both the surface to 1 km layer and the surface to 6 km layer in association with NW flow makes the environment less suitable for tornadic activity.

Lastly, SREH comparisons yielded little insight into the tornadic differences of SW and NW flow severe weather events. Both flow types were observed to have nearly identical SREH values when considering all the events together. In analyzing sig tor cases, however, SREH values displayed a noted increase from the 'all' events categories. Unfortunately, no major differences existed between the SREH values when comparing the SW and NW flow sig tor cases categories.

Considering all the major tornadic parameters together, it appears that SW flow events are generally more tornadic than NW flow events in the Southern Plains due to slightly higher instability, lower LCL heights, and slightly more environmental shear. Other small scale features probably play key roles in the generation of tornadoes under each flow type, but considering only the overall synoptic environment, SW flow in the Southern Plains is associated with conditions that are the most conducive to the formation of tornadoes.

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FIGURES

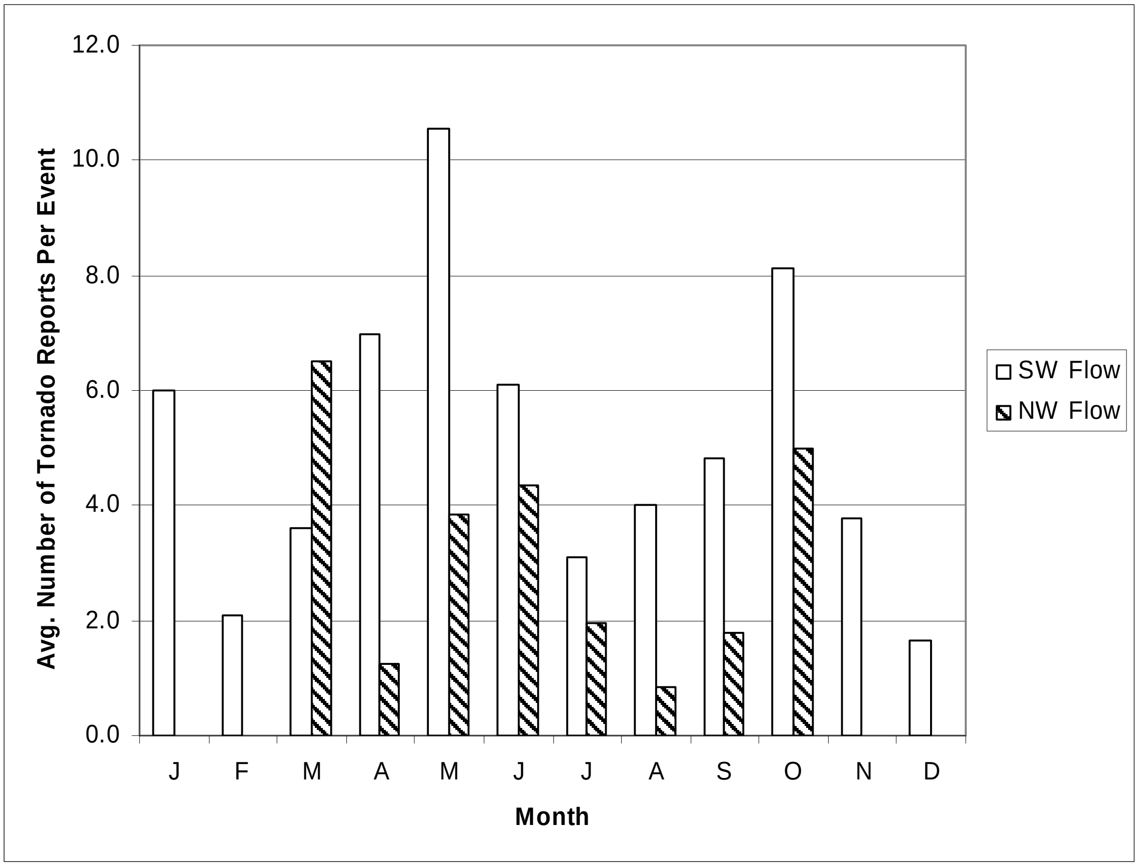

Figure 1: Average number of tornado reports occurring with SW and NW flow severe weather events for the 1992-2001 period in the Southern Plains.

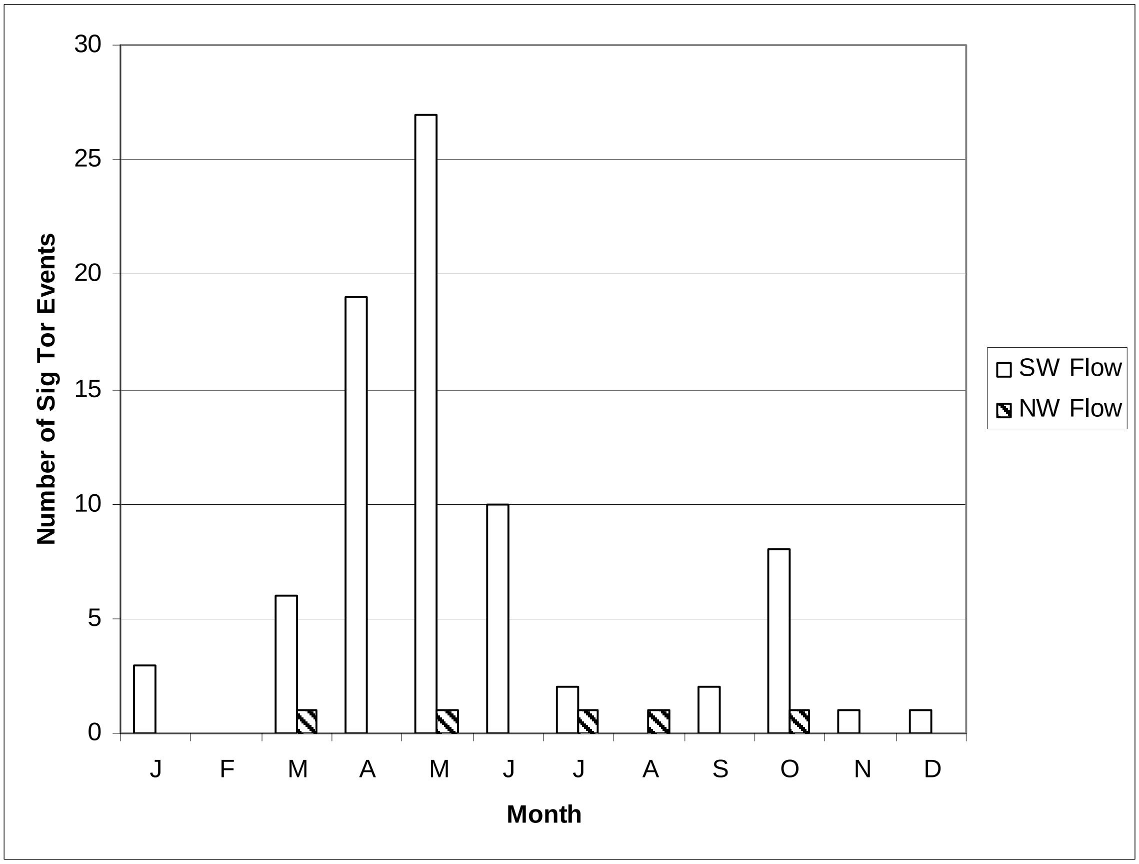

Figure 2: Number of sig tor cases (at least 1 F2 or greater) for SW and NW flow severe weather events for the 1992-2001 time period in the Southern Plains.

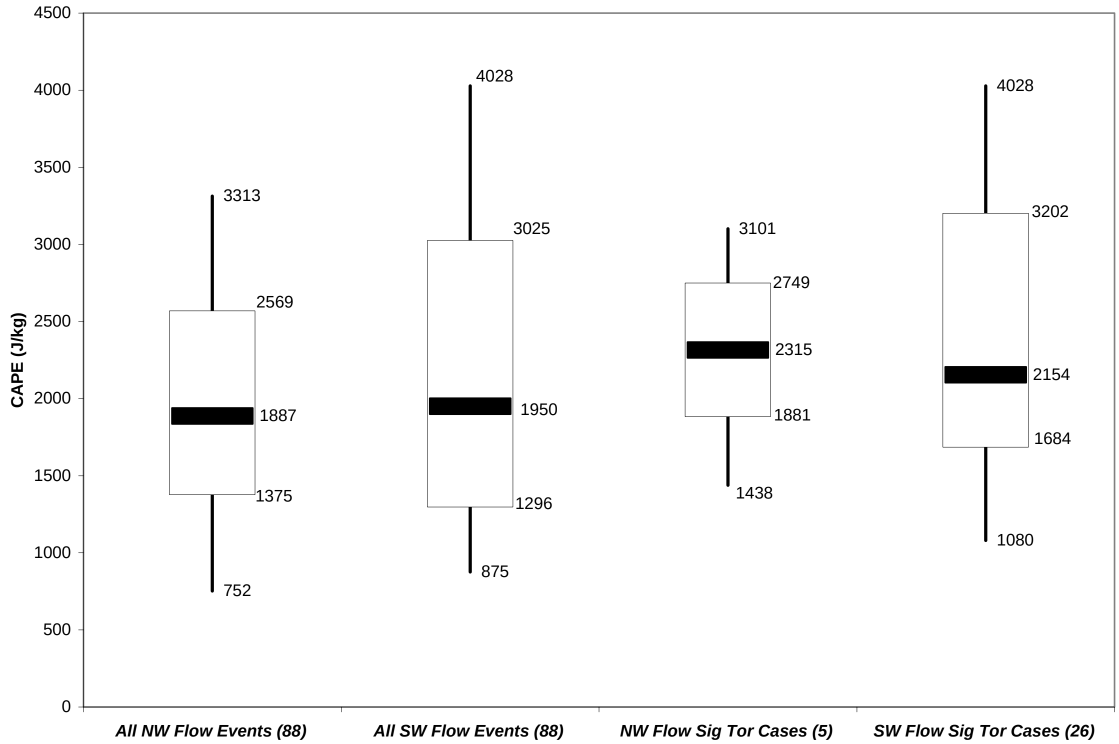

Figure 3: CAPE (100 mb mixed parcel) box and whisker plots for all NW flow events, all SW flow events, NW flow sig tor cases, and SW flow sig tor cases (from left to right). The lower and upper portions of each box denotes the 25^{th} and 75^{th} percentiles, respectively, and the vertical lines extending downward and upward from the box mark the 10^{th} and 90^{th} percentiles. The heavy horizontal line indicates the median value. The number in parentheses denotes the sample size for the box and whisker plot.

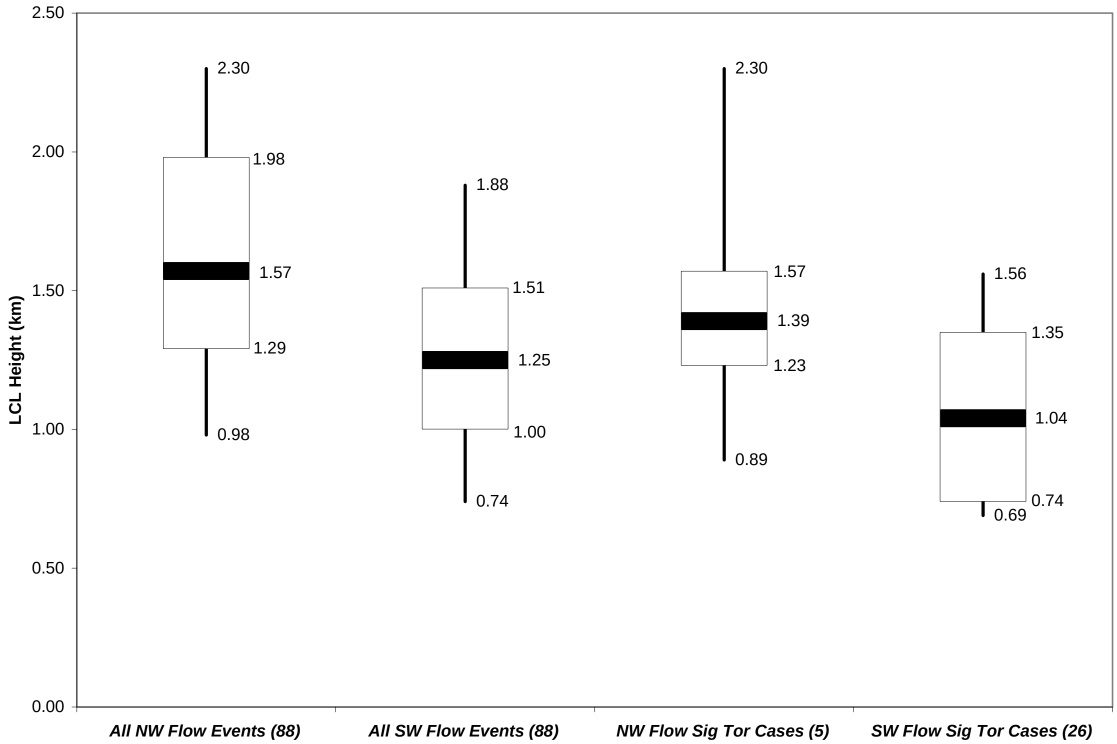

Figure 4: As in Fig. 3 except for LCL height.

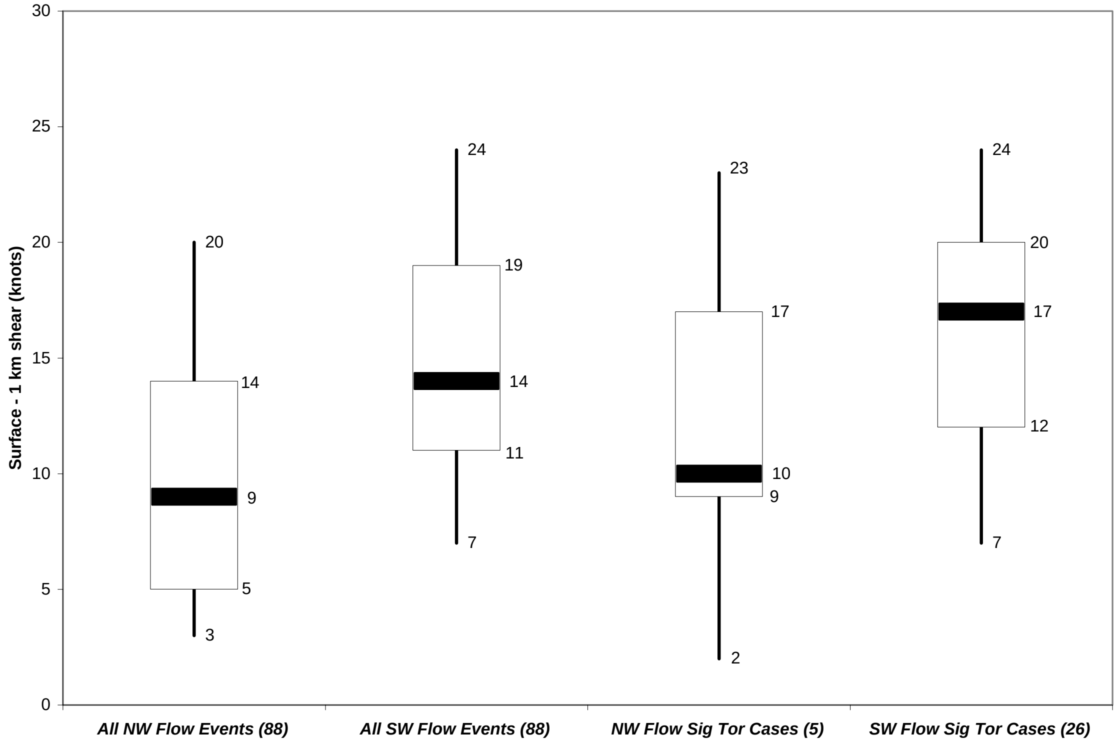

Figure 5: As in Fig. 3 except for surface to 1 km shear.

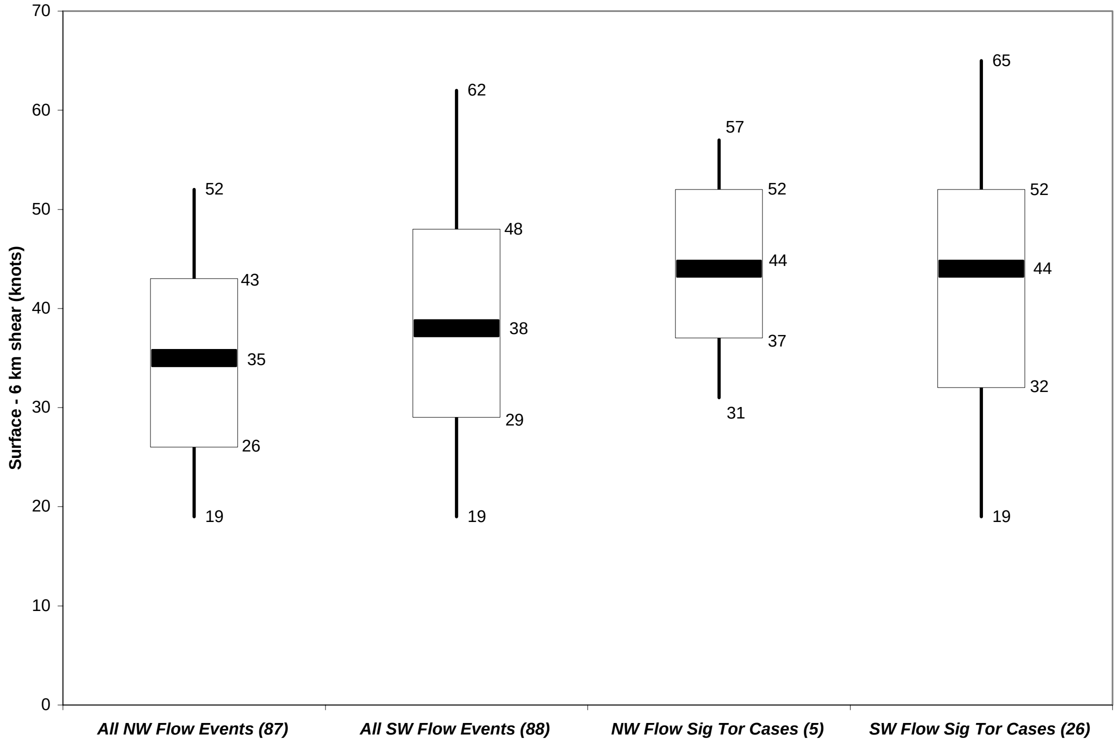

Figure 6: As in Fig. 3 except for surface to 6 km shear.

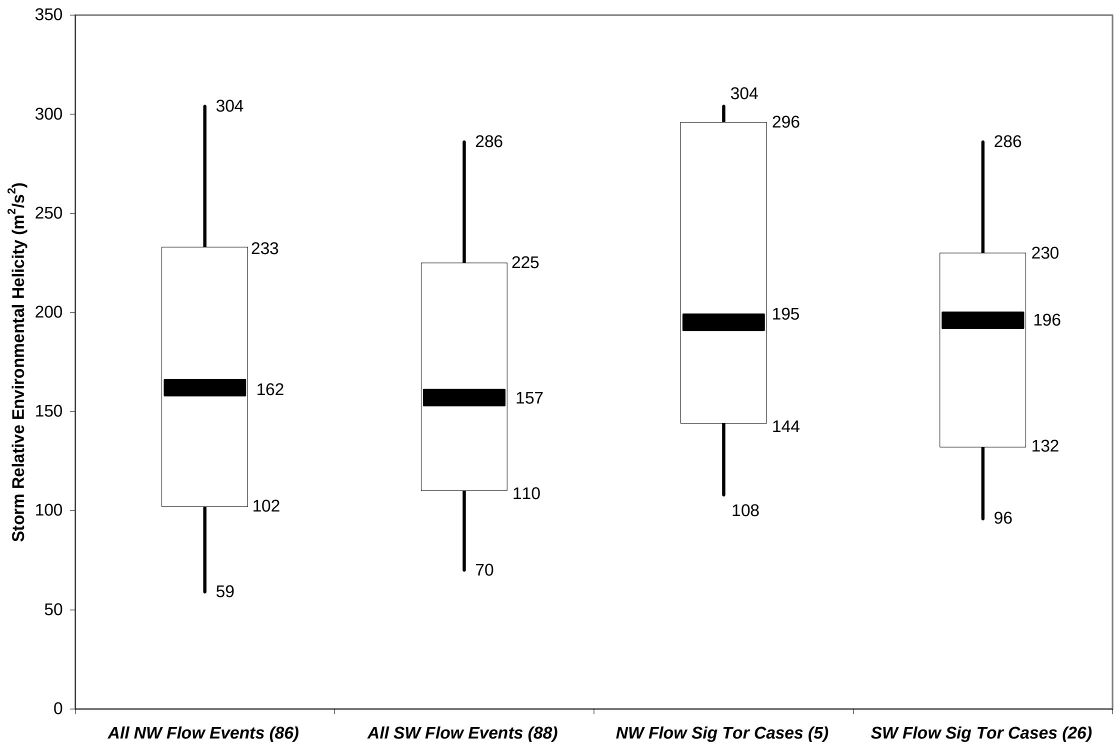

Figure 7: As in Fig. 3 except for storm relative environmental helicity.