# Climatology of the Supercell Composite Parameter (1979 – 2004)

Bryan Smith*
National Weather Center Research Experiences for Undergraduates
Ball State University, Muncie, Indiana

Greg W. Carbin, Richard L. Thompson, and John A. Hart
NOAA/NWS Storm Prediction Center, Norman, Oklahoma

August 5, 2005

* *Corresponding author address:* Bryan T. Smith, Ball State University, 4708 N. Weir Dr., Muncie, IN 47304; E-mail: btsmith@bsu.edu

ABSTRACT

The Storm Prediction Center uses “ingredients-based” indices as one part of severe storm prediction and one of the indices is named the Supercell Composite Parameter. The Supercell Composite Parameter (SCP) is a multi-component index that includes CAPE, storm relative helicity, and deep layer vertical wind shear. Each SCP component is normalized to "threshold" values determined to be favorable for supercell storms, and the product of these three normalized components forms the SCP. With the availability of 32km resolution North American Regional Reanalysis data, a 26-year climatology of the SCP at 00 UTC was developed in order to view daily, monthly, and seasonal variations in the SCP across the continental U.S. The SCP was investigated quantitatively by the number of days that the values were greater than or equal to one at a gridpoint during each month of the year. The central plains were found to have the highest number of days with environments supportive of supercells.

## 1. Introduction

Severe weather climatologies have described probability of tornadoes, wind, and hail. Only a few climatologies (e.g., Brooks et al. 2003, Brooks et al. 2005, in press) have examined severe weather parameters derived from reanalysis datasets. This study's objective was to create a 26 year climatology of environments supportive of supercells based on the Supercell Composite Parameter (SCP) (Thompson, et al. 2003; hereafter T03) for the continental U.S. (CONUS). By looking at a parameter climatology from this perspective, the focus is solely on the atmospheric variables that characterize environments supportive of supercells. This approach may be less susceptible to errors commonly found in the severe weather report database.

The SCP combines a measure of CAPE, storm relative helicity, and deep layer vertical wind shear into one value. It is capable of identifying atmospheric environments where supercells may (may not) exist based on more supportive (unsupportive) atmospheric environments (T03). A modified version of the SCP was used for this study due to post processing data limitations. The North American Regional Reanalysis (NARR) modified version of SCP used in this study will be discussed in Section 2a. Limitations of the NARR and SCP data can lead to misrepresentation of some potential supercell environments and this will be discussed further in Section 2 and 4. In section 3, the climatology of SCP will be described. The discussion and conclusions follow in section 5.

## 2a. Data Acquisition Methodology

The data used to construct the SCP for this study was a subset of the NARR. The native NARR grib data has a horizontal resolution of 32km, a vertical resolution of 45 layers, and covers all of North America.  The NARR uses the 2003 operational Eta model as part of the assimilation cycle (Manikin 2005).  Daily files valid at 00Z for all days from 1979 through 2004 were downloaded for a smaller domain covering primarily the CONUS.  The following parameters were acquired:

- 0:180 mb Most Unstable CAPE (MUCAPE with no virtual temperature correction)
- 0-3 km Storm Relative Helicity (SRH) (using Bunkers storm motion; Bunkers 2000)
- 10 m AGL U,V winds
- 500mb U,V winds

The NARR grib files were post-processed into GEMPAK grids using the GEMPAK nagrib application (see GEMPAK documentation).  The daily grids were further post-processed to compute the magnitude of the vector difference between the 10 m and 500 mb winds will hereby be referred to as the "bulk shear" for purposes of this climatology. After the bulk shear grid was computed, the GEMPAK gddiag application was used to compute SCP for 00z on every day for all years. Finally, the daily 00Z SCP grids were put into yearly GEMPAK grid files.  For the purposes of this study, the authors configured SCP as such:

SCP = (MUCAPE / 1000 J $kg^{-1}$) * (0-3 km SRH / 100 $m^2$ $s^{-2}$) * (10 m - 500 mb bulk shear / 20 m $s^{-1}$)

In order to normalize the SCP output values to a 1 value, the approximate threshold values of 1000 J/kg for MUCAPE, 100 $m^2$ $s^{-2}$ for SRH, and 20 m $s^{-1}$ for bulk shear were selected based on previous research (T03). An SCP value of 1 was previously determined by T03 to mark the transition from nonsupercell to supercell environments. The bulk shear used in the configuration of SCP for this study differs from the BRN shear in the surface to midlevel layer used by T03. Due to time and processing constraints, the bulk shear was calculated from standard level data at 10 m and 500 mb. While 500 mb is typically near 6 km AGL for regions near sea level, a substantial difference sometimes exists between the two heights AGL. The 500 mb wind velocities are at times weaker than the 6 km AGL winds for higher terrain (Fig. 1). Therefore, the SCP calculation tends to result in lower SCP values over the domain when compared to SCP calculated using bulk shear in the 0-6 km layer, especially over high terrain where the ground is substantially closer to 500 mb.

The MUCAPE from the NARR does not use the virtual temperature in its calculation (Manikin 2005). Calculating CAPE using the virtual temperature correction is known to result in higher and more realistic values of CAPE (Doswell and Rasmussen 1994). The virtual temperature correction was utilized for the MUCAPE component used by T03. Thus, the MUCAPE component and resultant SCP values used in this study are likely an underestimate of SCP when compared to T03. This underestimate will obviously be most pronounced in low CAPE environments with CAPE underestimates of 15-20% possible (Doswell and Rasmussen 1994). Given the shear and instability constraints applied to the SCP in this study, and elaborated on above, it is likely that the resulting SCP climatology will be conservative in depicting regimes that are favorable for supercell storms.

**2b. SCP Grid Calculations**

Once the daily SCP at 00 UTC was available for the period of record, the long-term SCP daily climatology was determined by calculating the individual grid's values inside the CONUS domain for each day over the entire domain and dividing by the number of years (26) to determine the individual grid average value. A 9-point smoother was applied over the grids. Daily, monthly, and seasonal SCP averages were calculated by summing the individual grid's average value over the 26 year period and then dividing by the selected periodicity. The SCP 26 year daily long term average at 00 UTC will be discussed in section 3. The long term monthly and seasonal frequency for SCP equal or exceeding a value of 1 was determined and this output will also be discussed in section 3.

As with any climatological study, there are drawbacks and limitations on both temporal and spatial scales. The SCP only determines whether an atmospheric environment is supportive or not supportive of supercells based alone on three individual variables that comprise the SCP. Therefore, much caution should be used interpreting SCP climatology.

Weaknesses were found in both the NARR/EDAS assimilation and SCP. Diurnal effects are the most obvious hindrance on the SCP climatology. With only a one time sample of the environment at 00 UTC, there are inevitably environments that will be missed due to the data constraints. Effects from interseasonal variability in the diurnal cycle appear to have a large influence on the number of SCP Days during the cool season. It is speculated that areas north of the Gulf States most likely will have a relatively substantial under-representation in the number of SCP Days during the cool season because the time of maximum heating usually occurs earlier in the afternoon compared to the spring and summer. Earlier peak heating times will result in a longer time period between maximum heating and 00 UTC. As a result, the SCP coverage and frequency during the cool season may be under-represented with a 00 UTC analysis than other seasons of the year. Figure 2 shows a sizable proportion of the supercells investigated in proximity soundings occur throughout the 24 hour period.

A potentially large erroneous portion of the climatology results from using 0-3 km SRH. The NARR data reduces the relatively larger values in the 0-3 km portion of the hodograph because relatively larger values get smoothed with small values resulting in an underestimate of the 0-3 km SRH. The sources of error are the assimilation cycle and truncation due to limited vertical resolution. Also, due to model assimilation scheme, the 2003 version of the Eta model did not use virtual temperature in the integration to calculate CAPE (Manikin, personal communication). This will result in CAPE values being underrepresented according to Doswell and Rasmussen (1994). Underestimates of CAPE may also result in substantial underestimates of SCP values. This can be particularly critical in trying to identify areas where low buoyancy environments already exist and are marginally supportive of supercells. The NARR data under-represents the SCP CAPE component thereby resulting in a relatively low SCP value. Also, since the NARR/EDAS has 32 km horizontal resolution, events influenced by mesoscale and storm scale events (e.g. outflow boundaries) will not be identified well.

The SCP meets supercell criteria over a relatively large horizontal area especially over the spring and summer. Because this area is large, the false alarm area (FAA) is large when compared to storm reports. Additionally, the large FAA is due to the elevated mixed layer and weak warm season forcing.  The SCP is conditional on convection. Since CAPE is partly independent of convection, the FAA is relatively large.

## 3.  SCP Climatology

The main objective of our study was to develop an SCP climatology using 26 years worth of daily data valid at 00 UTC. The long-term SCP daily climatology, the calculation of which was described in section 2b, shows a mean SCP value of 1 first appears along the lower Texas gulf coast region in late March.  During April, the 00 UTC average SCP of 1 or more expands northward.  By early May, a 2 value appears in south Texas with a value of 2 with values of 1 appearing sporadically in the lower to middle Mississippi Valley region.  A 2 value appears in Oklahoma and Kansas after the first week in May with the one contour expanding northward in the central plains.  The mean SCP showed an average maximum value of 3 over relatively small regions of northern Oklahoma and southern Kansas on a few days in the late spring and early summer seasons (Fig. 3).  Parts of the middle Mississippi Valley see sporadic days with mean SCP values of 1.  By early June, parts of the upper Midwest have mean SCP values exceeding 1 and sometimes a 2 value.  However, the spatial coverage remains centered over the Plains states during the spring and early summer months.

The spatial extent covered by a 1 contour increases by early July with the 1 value concentrated in the central plains.  During July, the mean SCP coverage area sporadically extends into the Great Lakes and Ohio Valley region, but the consistent mean SCP values remain in the north central Plains.  The mean SCP 1 value begins to decrease in spatial coverage across the upper Midwest and north central Plains. By early September, there are no mean SCP values above 1.

When viewing the individual days included in the long-term SCP average it was noted that SCP tends to show large variability from day to day, even in areas and during times of the year when the values are expected to be high and somewhat constant (i.e. the Plains in May). Thus, another measure of the long-term behavior of SCP that can perhaps provide more insight into the prevalence of supercell environments is the frequency of days when the SCP at 00 UTC equals or exceeds a value of 1.

A "SCP Day" is defined as a day when the 00 UTC SCP value at a grid point was greater than or equal to 1. The number of SCP Days per month for each month over the 26 year period where averaged and then the averaged months were summed to compute the number of SCP Days per season. These seasonal frequency plots further illustrate the long term characteristics of environments favorable for supercell storms and will now be described further.

The maximum number of SCP Days during the winter season (December-February) was about 8 located in south Texas. The western Gulf States and lower Mississippi Valley region expect to see at least one SCP Day at least once during the average winter season. Parts of the Plains extending eastward to the Ohio Valley and parts of the Southeast appear to experience an SPC Day only a few times a decade (Fig. 4a). Galway and Pearson (1981) showed that tornado outbreaks, although rare during the winter, were most common in the Gulf States and Mississippi Valley region, well removed from the greater SCP Day values over south Texas. The supportive environments for supercells can include an area as far north as the Mid-Mississippi

Valley region during the winter season. However, our frequency climatology reveals that these conditions occur infrequently.

During the spring season (March-May), an increase in SCP Days spreads northward through the Plains (Fig. 4b). The SCP Day maximum remained in south Texas with the number of SCP Days increasing to at least 37, which was the highest value displayed for the four seasons. A high number of SCP Days occurs across the south central plains with a SCP axis directed northward from Texas to Kansas, while a secondary axis of high SCP Days begins in eastern Texas and extends eastward to the lower Mississippi Valley region. Areas further east in the Mississippi Valley and along the Atlantic coast show a similar progression northward but have fewer SCP Days on average.

During the summer season (June-August), Nebraska and areas of the north central Plains experience the most SCP days per month. A greater number of SCP Days also shifts northward over the Mississippi Valley (Figure 4c). Based on the 26 year climatology, the largest spatial extent of SCP Days occurs during the summer season. The maximum SCP Day axis again starts in central Texas before extending northward to the eastern part of the Dakotas. A secondary axis begins in western Missouri and extends eastward into the Ohio Valley. The areas near the southeast Atlantic coast also experience an annual maximum during the summer season. During the late summer months, the number of SCP Days begins to decrease everywhere, but the maximum number of days remains located over the north central Plains.

The fall season (September-November) shows an abrupt shift southward in the number of SCP Days for all geographic areas with the maximum number of 15 SCP Days located in south Texas (Fig. 4d). The SCP axis extends south to north, from Texas to Kansas then shifts north-northeastward into western Iowa. Despite a lower number of SCP days, the frequency analysis reveals that environmental conditions supportive of supercells can occur about once per decade as far north as Canada east of the Rockies.

## 4. SCP Climatology vs. Severe Report Climatology

Verification of SCP Climatology requires a comparison of SCP Days to severe report climatologies. This was done by comparing the distribution of severe reports and SCP Days over various periods of the year. The CONUS yearly SCP Day maximum was located in south Texas but the severe report maximum was located further north (not shown). This study used the climatologies of Schaefer et al. (2004) and Brooks et al. (2003) for the distribution of severe reports. Using Brooks et al. (2003), the timing of the SCP values appears to be linked with the climatological return of low-level moisture northward. From Schaefer et al. (2004), significant hail reports were found to be linked with the higher values of mean SCP and a greater number of SCP Days.

There were shortcomings found in the NARR SCP besides the previously mentioned shortcomings from the model. One of the more important objectives was to qualitatively verify whether or not the SCP showed a strong relationship to particular atmospheric environments and different geographic regions. This was accomplished by comparing the SCP to severe storm reports. The authors contend that supercells occur in environments where SCP $\geq$ 1, and that SCP shows associated relationships with severe weather events resulting from supercells.

Severe storm reports were gathered from the Storm Prediction Center Rough Log database for 21 – 03 UTC and reports were plotted on SCP contours valid at 00 UTC. Specifically, the SCP values were examined and compared to reports of tornadoes and 2" or greater diameter hail which are usually byproducts of supercells (Rasmussen and Blanchard 1998; T03). Wind reports were not compared to SCP values because many wind reports come from other types of deep moist convection and are generally not unique to supercells. Upon examining tornado reports, much caution was given by not solely inferring tornado occurrence with supercells. It is widely accepted that some tornadoes are produced by nonsupercell storms. Some tornadoes are known to form and exist from nonsupercell storms include "landspout" tornadoes (e.g., Bluestein 1985; Brady and Szoke 1989; Wakimoto and Wilson 1989) and quasi-linear mesoconvective systems described by Trapp and Weisman (2003).

There are supercellular environments that sometimes appear to be inaccurately depicted. It is important to note that right-moving supercellular environments were favored compared to left-moving supercellular environments via the Bunkers storm motion estimate for right-moving supercells. The SCP can be underestimated in low buoyancy/high shear environments more typically associated with the cool season and tropical cyclone/remnants, largely attributable to a poor sampling by soundings and lack of virtual temperature correction. Bulk shear can also be under-represented in higher terrain areas (Fig. 1). By using tornadoes as a proxy for supercells and supercell environments, one can arbitrarily suggest higher tornado frequency variability during the diurnal period may also lead to an under-represented number of supercells for some areas compared to other areas. Contrarily, the SCP overestimates potential in elevated thunderstorm environments with large MUCAPE and strong shear near the ground.

According to Galway and Pearson (1981), tornado outbreaks from December through February are a rare but significant occurrence. Galway and Pearson looked at datasets from 1950 – 1979 and found 23 major outbreaks during that time period. The climatology analysis showed that nearly all of the tornadoes from Galway and Pearson's study were located outside of the highest values in south Texas and instead the tornadoes were located in the South and Mississippi Valley. Though SCP Days are not common in the winter season, when there happens to be a SCP Day, it can be a very serious situation as evidence by the January 21, 1999 tornado outbreak in the lower to middle Mississippi Valley region (Fig. 5). The SCP values for supercells embedded in tropical cyclone squalls appear to correspond well with severe reports for some cases and poorly in other cases. Every tropical cyclone investigated showed SCP values but sometimes the values were not coincident with the tornado reports. Again, low buoyancy and the exclusion of the virtual temperature correction in the NARR MUCAPE calculation appear to contribute to the under-represented SCP values (Doswell and Rasmussen 1994), as well as poorly sampled wind environments.

## 5. Discussion/Conclusions

A Supercell Composite Parameter climatology was developed using the NARR data to identify environments favorable for supercells based on the three normalized components: MUCAPE, 0-3 km SRH, and bulk shear. This study focused on a very small subset of the NARR data in both temporal (00 UTC) and spatial scales (CONUS only). Nonetheless, we are able to show that the SCP appears to be clearly associated with climatological distributions of tornadoes and hail 2" or larger in diameter (Fig. 6). From severe report climatologies, SCP Day maximum axes verify while some of the maximum SCP Day values do not. The maximum of SCP Days over south Texas may be the result of a consistent presence of convective inhibition because of the relatively low number of significant hail and tornado reports, although that is speculative. The Plains states have the greatest concentration and probability of atmospheric environments favorable for supercells based on a 26 year analysis. A similar substantial threat of environments supportive of supercells exists east of the Plains (i.e. The South, Mississippi and Ohio River Valleys), but the threat exists in a less consistent manner. The timing of the SCP during the spring and summer is likely associated with the climatological return of low level moisture. Much caution should also be used in SCP interpretation with magnitude differences. It is important to note that even small SCP values (i.e. Jarrell, TX) should not be ignored. Through this research, it is hoped the SCP climatology results will help the operational and applied meteorology communities when diagnosing environments supportive of supercells.

The methodology explored and utilized in this study can be applied to other severe weather parameters via the NARR data. Future work includes quantifying the SCP climatology values versus severe reports.

## Acknowledgements

The authors thank Steve Corfidi, Steve Weiss (SPC), Harold Brooks (NSSL), Charles Doswell III (CIMMS), and Bob Johns for sharing their intellectual insight and helpful discussion in compiling this article.  A special thanks is extended to Daphne Zaras (NSSL) for helping to make this research project possible.  This work was partially funded by NSF Grant 0097651.

**References**

Bluestein, H. B., 1985: The formation of a "landspout" in a "broken-line" squall line in Oklahoma. Preprints, *14th Conf. on Severe Local Storms*, Indianapolis, IN, Amer. Meteor. Soc. 267-270.

Brady, R. H., and E. J. Szoke, 1989: A case study of nonmesocyclone tornado development in northeast Colorado: Similarities to waterspout formation. *Mon. Wea. Rev.*, **117**, 843-856.

Brooks, H. E., A. R. Anderson, K. Riemann, I. Ebbers, and H. Flachs, 2005: Climatological aspects of convective parameters from the NCAR/NCEP reanalysis. *Atmos. Res.*, in press.

Brooks, H. E., C. A. Doswell III, and M. P. Kay, 2003: Climatological estimates of local daily tornado probability for the United States. *Wea. Forecasting*, **18,** 626-640.

Brooks, H. E., J. W. Lee, and J. P. Craven, 2003: The spatial distribution of severe thunderstorm and tornado environments from global reanalysis data. *Atmos. Res.*, **67-68**, 73-94.

Bunkers, M. J., B. A. Klimowski, J. W. Zeitler, R. L. Thompson, and M. L. Weisman, 2000: Predicting supercell motion using a new hodograph technique. *Wea. Forecasting*, **15**, 61-79.

Doswell, C. A. III, and E. N. Rasmussen, 1994: The effect of neglecting the virtual temperature correction on CAPE calculations. *Wea. Forecasting*, **9**, 619-623.

Edwards, R., R.L. Thompson, K.C. Crosbie, J.A. Hart, and C. A. Doswell III, 2004: Proposals for modernizing the definitions of tornado and severe thunderstorm outbreaks. *Preprints*, 22nd Conf. Severe Local Storms, Hyannis MA, Amer. Meteor. Soc. (CD-ROM).

Galway, J. G., and A. D. Pearson, 1981: Winter Tornado Outbreaks. *Mon. Wea. Rev.* **109**, 1072-1080.

GEMPAK: NAWIPS 5.4 User's Guide. U.S. Dept. of Commerce/NOAA.

Hart, J. A., and P. R. Janish., 1999: SeverePlot v2.0. National Weather Service, National Centers for Environmental Prediction, Storm Prediction Center.

Manikin, G., 2005: personal communication.

McCarthy, D., and J. Schaefer, 2004: Tornado trends over the past 30 years. Preprints, *14th Conf. Applied Climatology*, Seattle, WA, Amer. Meteor. Soc., CD-ROM.

Erik N. Rasmussen and David O. Blanchard. 1998: A Baseline Climatology of Sounding-Derived Supercell andTornado Forecast Parameters. *Weather and Forecasting*: Vol. 13, No. 4, pp. 1148–1164.

Schaefer, J. T., J. J. Levit, S. J. Weiss, and D. W. McCarthy, 2004: The frequency of large hail over the contiguous United States. Preprints, *14th Conf. Applied Climatology*, Seattle, WA, Amer. Meteor. Soc., CD-ROM.

Schaefer, J. T., and H. E. Brooks, 2000: Convective storms and their impact. Preprints, *2nd Symposium on Environmental Applications*, Long Beach, CA, Amer. Meteor. Soc., 152-159.

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

Trapp, R. J., M. L. Weisman, 2003: Low-level mesovorticies within squall lines and bow echoes. Part II: Their genesis and implications. *Mon. Wea. Rev.*, **131**, 2804-2823.

Wakimoto, R. M., J. W. Wilson, 1989: Non-supercell tornadoes. *Mon. Wea. Rev.*, **117**, 1113-1140.

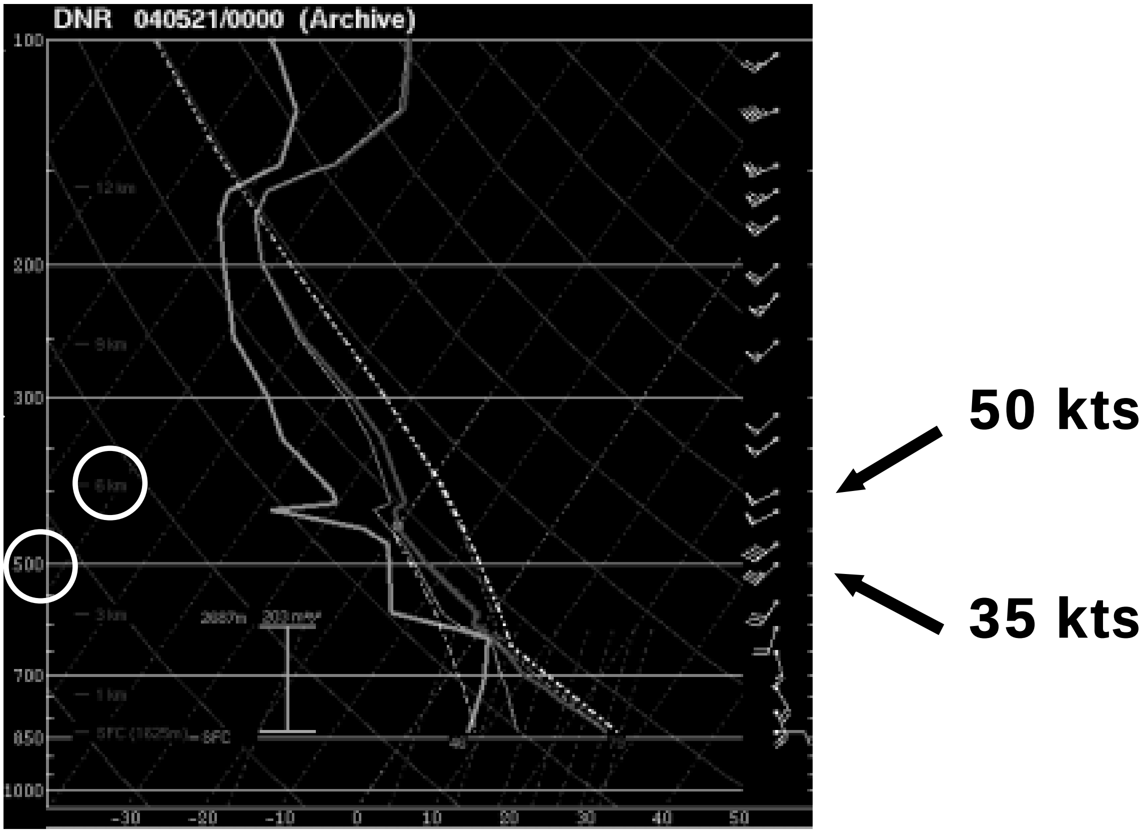


Figure 1. Skew-t log P plot of 21 April 2004 sounding valid at 00 UTC. At higher elevations, such as Denver, the difference in wind speed between 10 m and 500 mb is sometimes smaller than that between 0 and 6 km.

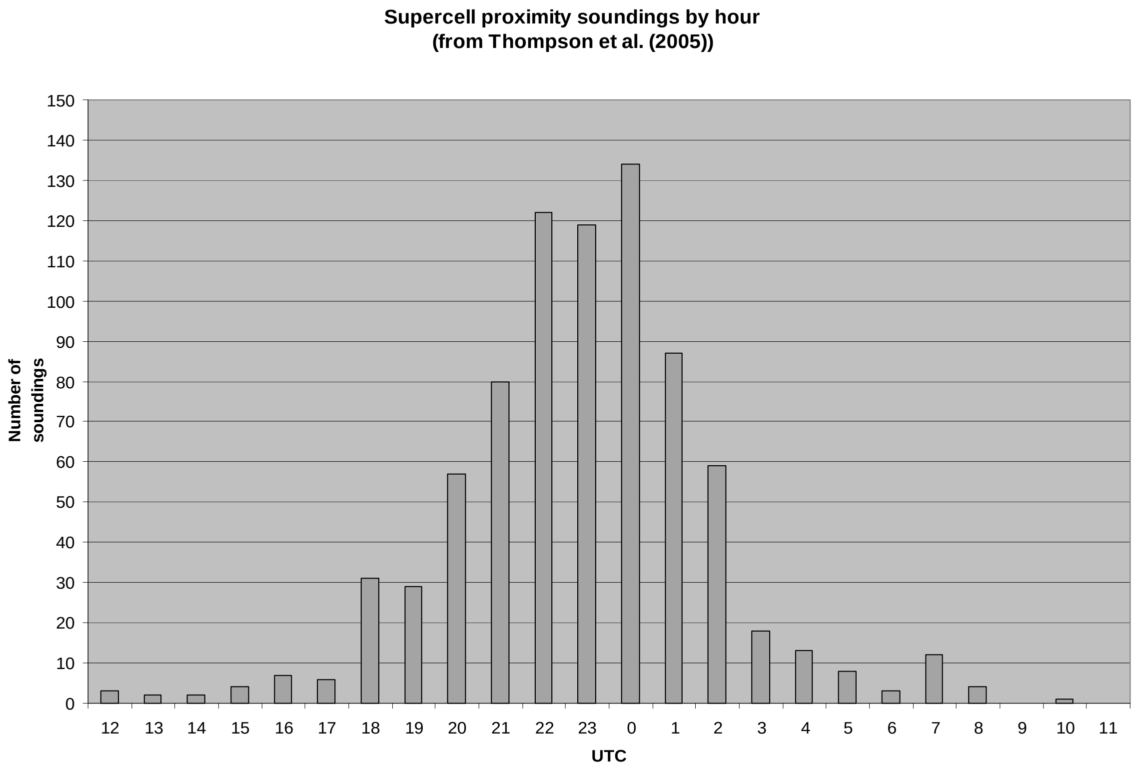


Figure 2. Plot of supercell proximity soundings by hour (UTC) from Thompson et al. (2005).

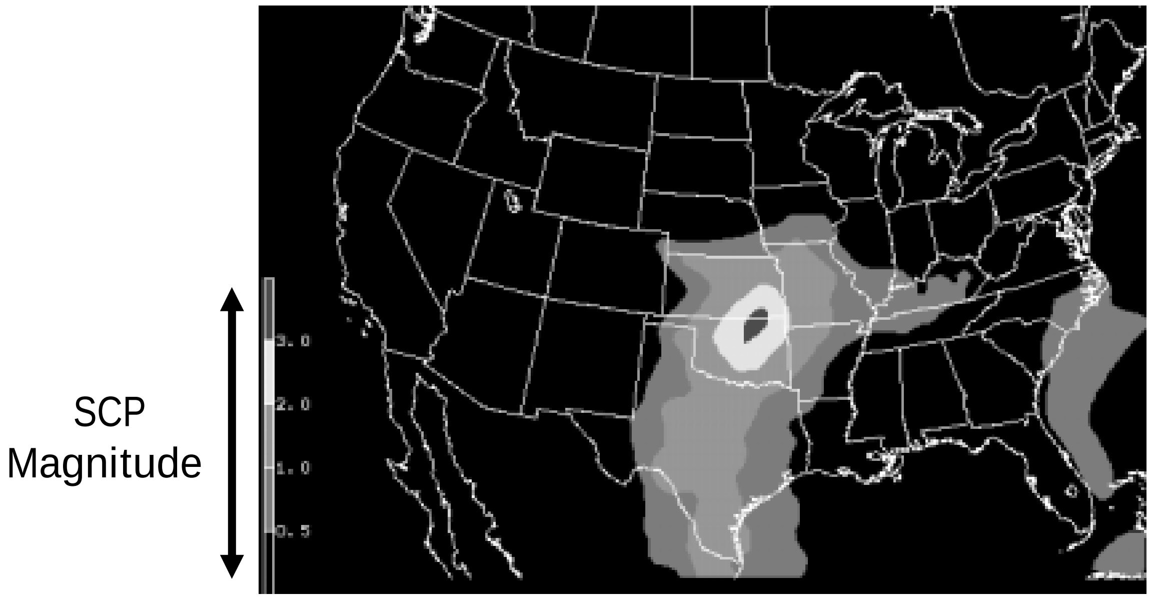


Figure 3.  00 UTC May 25 mean SCP values are plotted according to the y-axis values.

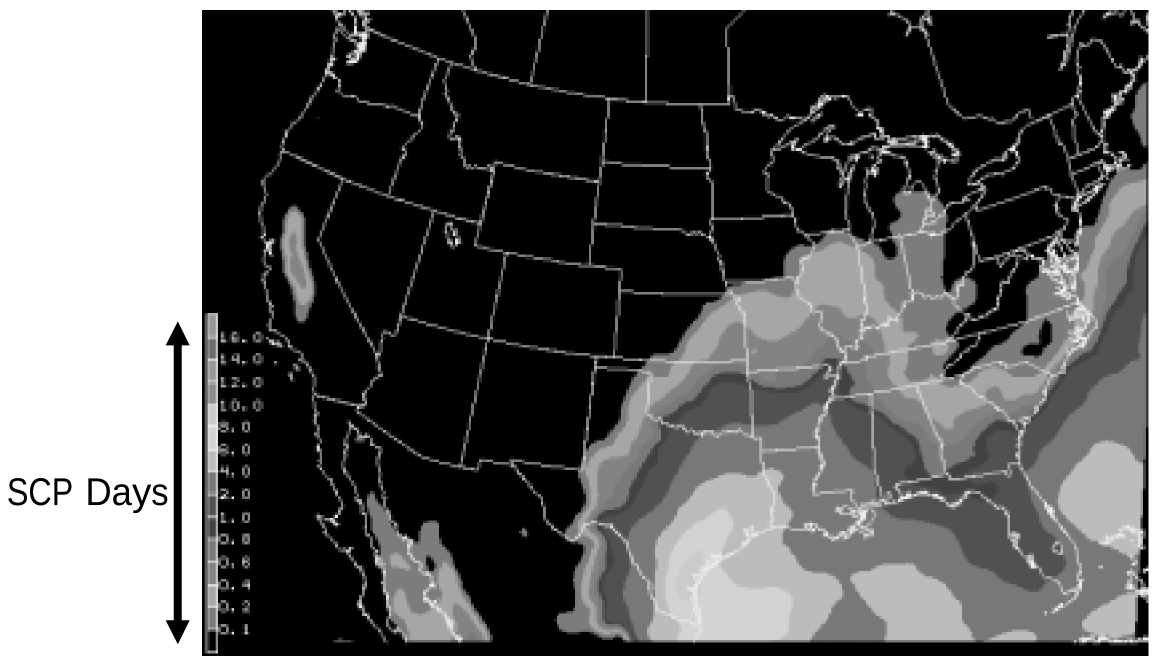


Figure 4a.  Number of SCP Days (Winter Season) are plotted according to the y-axis values.

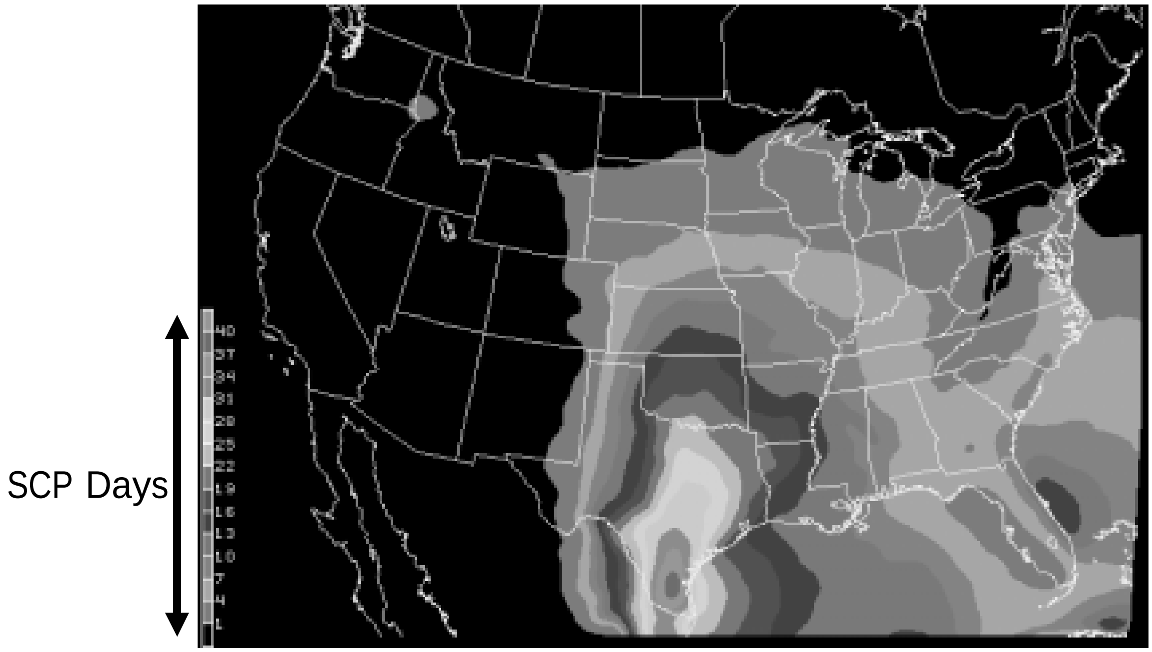


Figure 4b. Number of SCP Days (Spring Season). Please note the different SCP Day contour intervals.

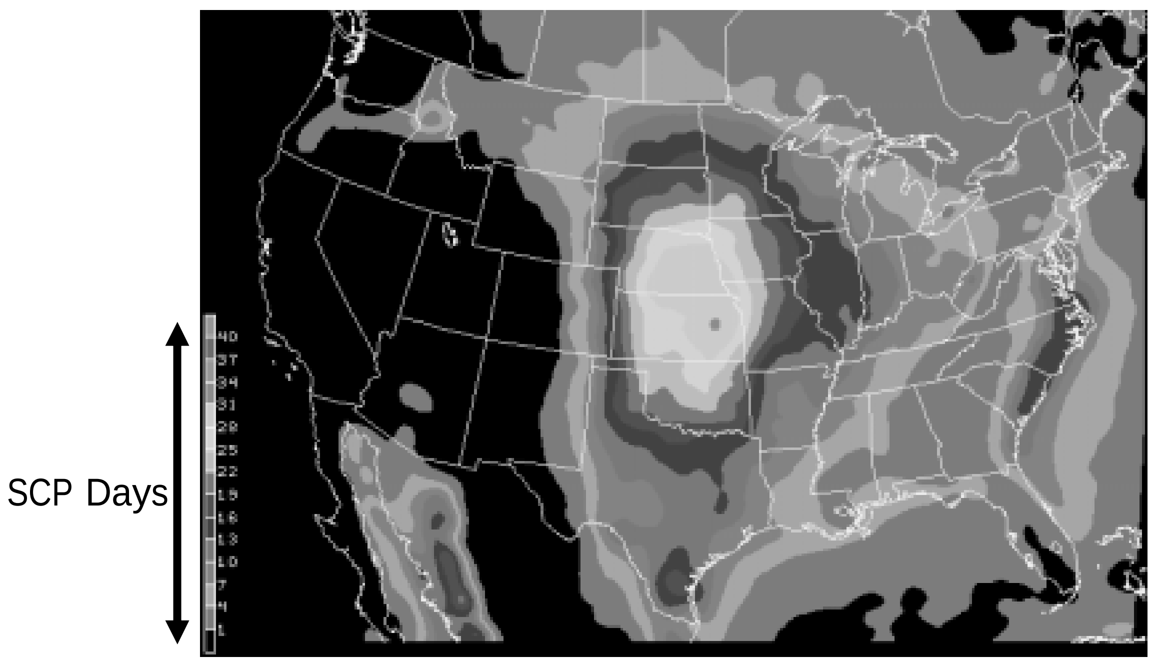


Figure 4c. Number of SCP Days (Summer Season).

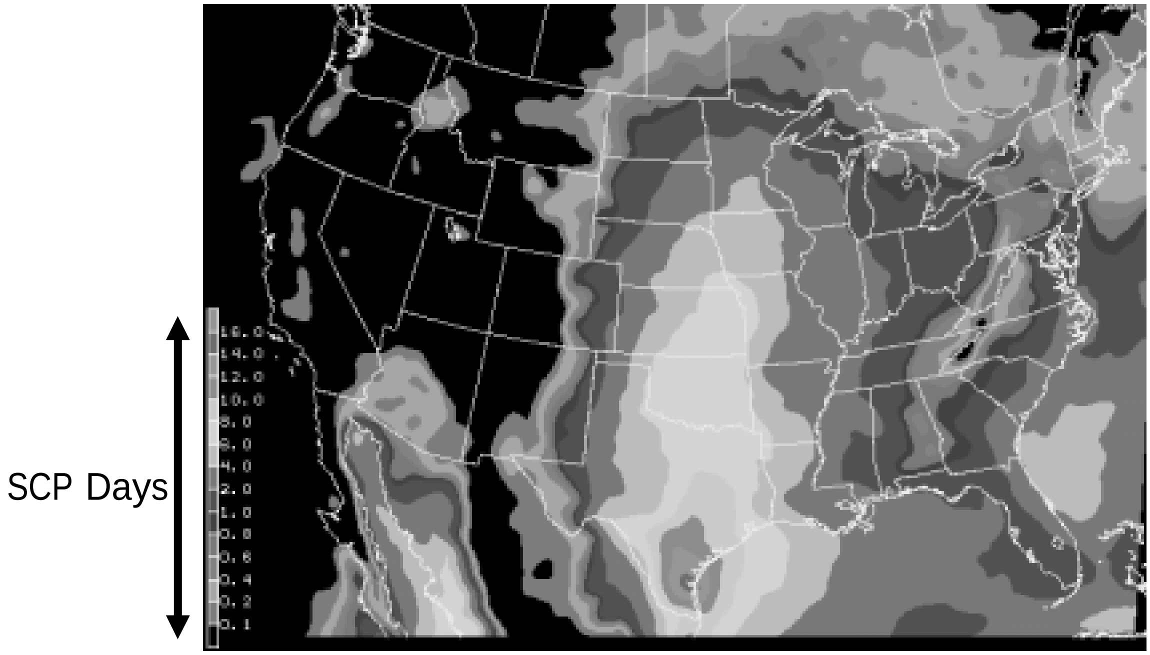


Figure 4d. Number of SCP days (Fall Season). Please note the different SCP Day contour intervals.

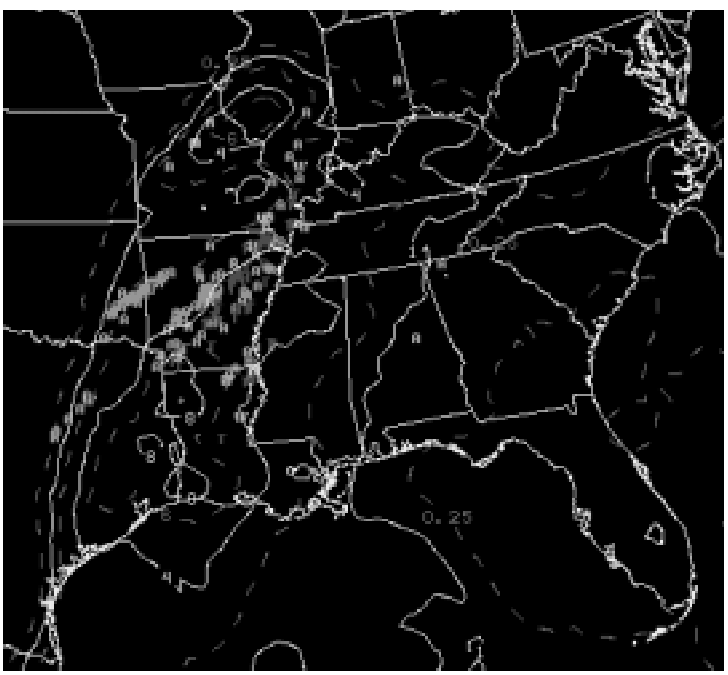


Figure 5. SCP contours in dashed gray and yellow contours. Tornadoes (red T's), hail (green A's), and wind reports (blue W's) signify the storm reports from 21 UTC- 03 UTC on January 22, 1999.

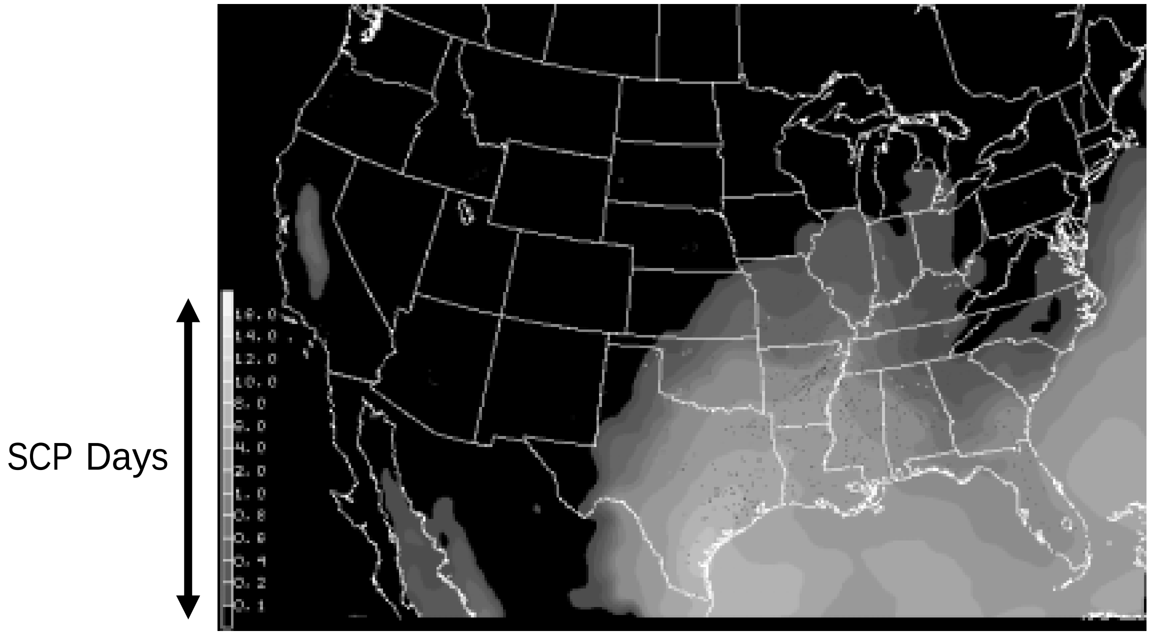


Figure 6a. The number of Winter Season SCP Days are plotted in gray-scale contours according to the y-axis values. The 21 UTC - 03 UTC significant hail (green dot) and tornado (red dot) reports are plotted.

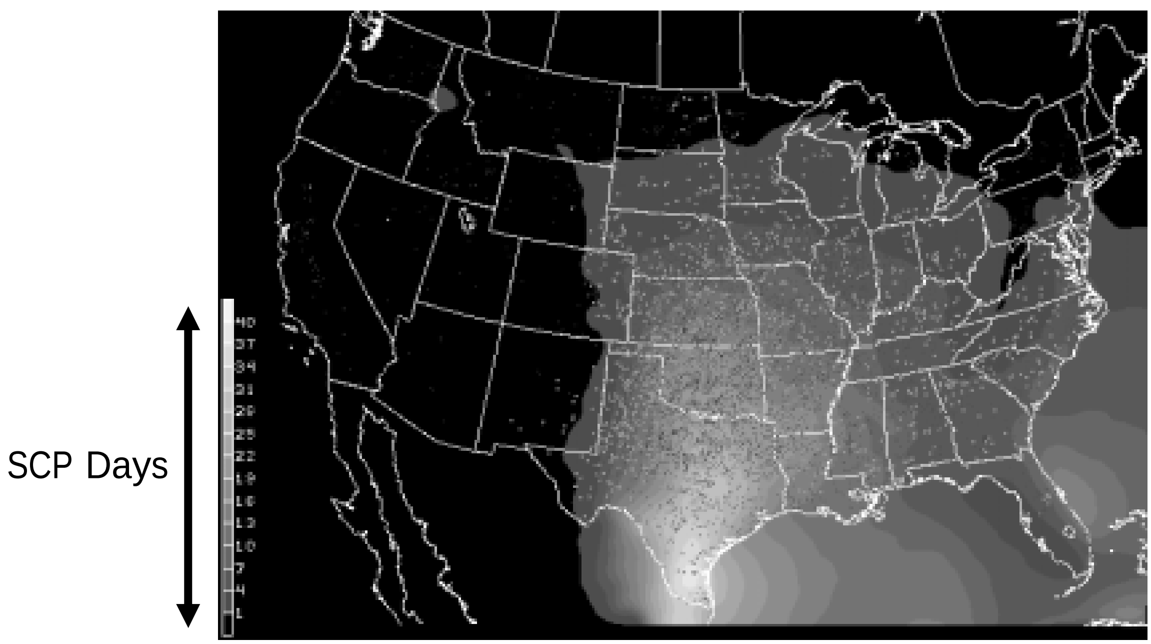


Figure 6b. Spring Season SCP Days with 21 UTC - 03 UTC significant hail (green dot) and tornado (red dot) reports.