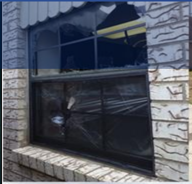
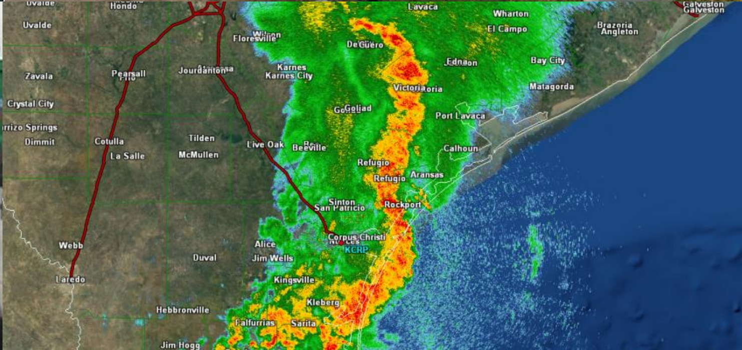
Severe Weather Forecasting Seminar

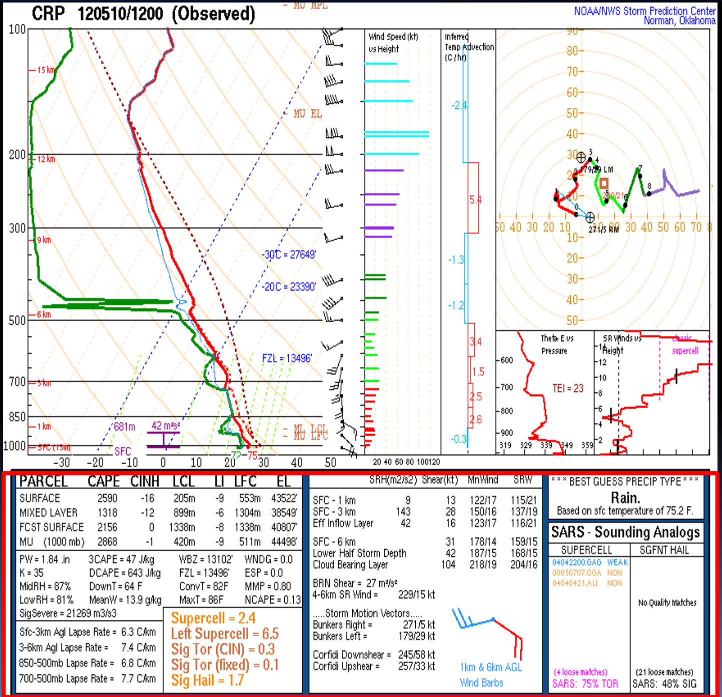
Utility of Severe Weather Parameters and Indices

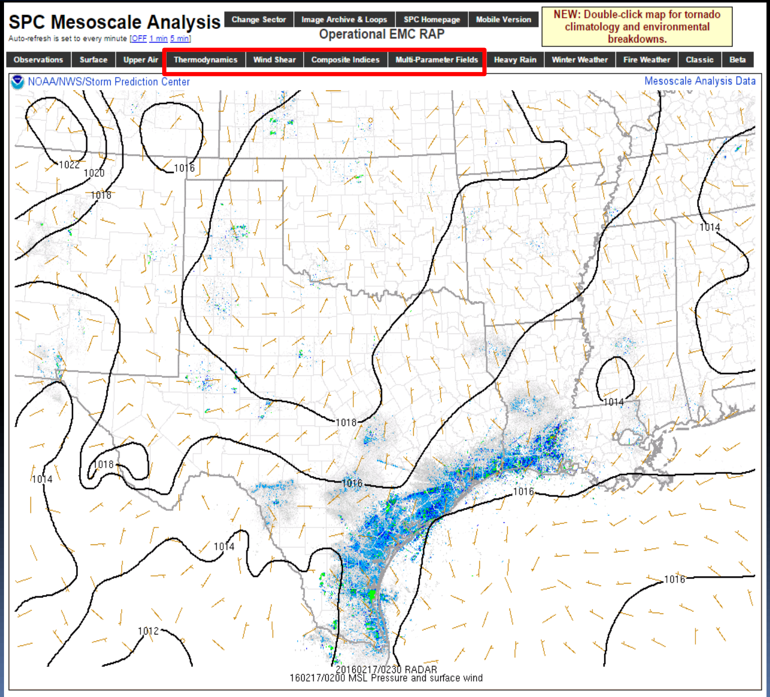




Severe Weather Parameters and Indices

Sounding Data/ SPC Meso Analysis / AWIPS Model Forecast Data (Soundings)





Severe Weather Parameters and Indices

References

- A Baseline Climatology of Sounding-Derived Supercell and Tornado Forecast Parameters by E. Rasmussen and D. Blanchard *(Wea. and Forecasting 1998*)
- Refined Supercell and Tornado Forecast Parameters by E. Rasmussen *(Wea. and Forecasting, 2003)*
- Evaluation and Interpretation of the Supercell Composite and Significant Tornado Parameters at the Storm Prediction Center by R. Thompson, R. Edwards, and J. Hart
- An Update to the Supercell Composite and Significant Tornado Parameters by R. Thompson, R. Edwards, and C. Mead
- Baseline Climatology of Sounding Derived Parameters Associated with Deep Moist Convection by J. Craven and H. Brooks (*National Weather Digest, 2004*)
- A Climatology and Comparison of Parameters for Significant Tornado Events in the United States by J. Grams, R. Thompson, D. Snively, J. Prentice, G. Hodges, and L. Reames (*Wea. and Forecasting, 2012*)

Severe Weather Parameters and Indices

Important Facts of Study

A Baseline Climatology of Sounding-Derived Supercell and Tornado Forecast Parameters by E. Rasmussen and D. Blanchard (*Wea. and Forecasting 1998*)

- Derived from almost 6800 soundings with nonzero CAPE at 00Z during 1992
- Used proximity (within 400 km of event) and inflow (150 degree sector centered on boundary layer mean wind) criteria
- Associate with every lightning flash, hail report greater than 2 inches, or tornado with F2 damage or greater within -3 to + 6 hours of 00Z
- Classified ordinary for non-supercell storms (ORD) with 10 or more CGs, non-tornadic supercells (SUP) for hail > 2” and no tornadoes >F1, or tornadic supercells (TOR) for tornadoes F2 or greater
- Only 51 soundings classified TOR, 119 for SUP, and 2767 for ORD

Severe Weather Parameters and Indices

Important Facts of Study

Baseline Climatology of Sounding Derived Parameters Associated with Deep Moist Convection by J. Craven and H. Brooks (*National Weather Digest, 2004*)

- Derived from over 60,000 soundings at 00Z from 1997-1999
- Used proximity (within 185 km of event) criteria and associated with events within -3 to + 3 hours of 00Z
- Classified general thunder for storms with 2 or more CGs, severe for hail (3/4" to less than 2")/50-64 knot wind gust/wind damage/F0-F1 tornadoes, significant hail/wind for hail 2" or greater and/or wind gusts equal or greater than 65 knots, or significant tornadoes (F2 or greater)
- ~11,300 for thunder, over 2600 for severe, 512 for sig hail/wind, and 87 for sig tor (~28,000 for no thunder/no CAPE and ~17,500 for no thunder/CAPE)

Severe Weather Parameters and Indices

Important Facts of Study

A Climatology and Comparison of Parameters for Significant Tornado Events in the United States by J. Grams and R. Thompson,et. al. (*Wea. and Forecasting 2012*)

- Sample of 448 significant tornado events was collected, representing a population of 1072 individual tornadoes from 2000 to 2008
- Classified by convective mode – Discrete cell, QLCS, or Cluster
- Determined seasonal and regional variability
- Sample of 355 significant hail and 556 significant wind events was collected during period from 2003 to 2008 for comparison over three different regions' seasons (Southern Plains spring, Southeast spring, and Northern Plains summer)
- Also looked at data from mandatory pressure levels (850 and 500 mbs wind speed and direction)

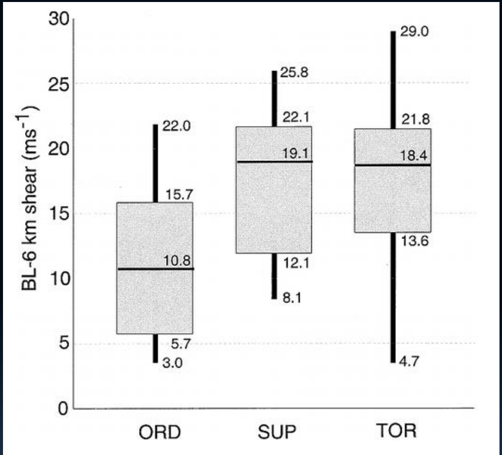
Severe Weather Parameters and Indices

Different Types

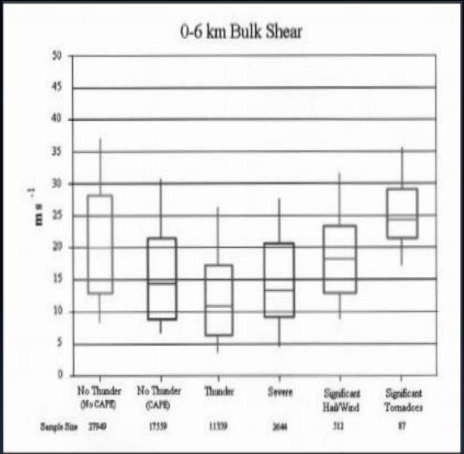
- Shear Related Parameters
  - BL-6 km Shear, BRN Shear, Effective Bulk Shear, 0-1 km Shear
  - 0-1 km/0-3 km Storm Relative Helicity, Effective SRH
- Stability Parameters
  - CAPE (Surface-based, Most Unstable, Mixed Layer)
  - CAPE below 3 km AGL, Downdraft CAPE (DCAPE)
- Shear-CAPE Combinations
  - Bulk Richardson Number, Vorticity Generation Parameter
  - Energy Helicity Index (EHI), Modified EHI (0-1 km), Craven/Brooks Significant Severe
- Low-Level Thermodynamics
  - LCL , Convective Inhibition (Surface-based, Mixed Layer), 0-3 km Theta-E Differential
- Composite Parameters
  - Supercell Composite Parameter (SCP), Significant Tornado Parameter (STP)
  - Significant Hail Parameter (SHIP), Severe Hazards in Environments with Reduced Buoyancy (SHERB)

Shear-Related Parameters

Boundary Layer to 6 km Shear



RB98



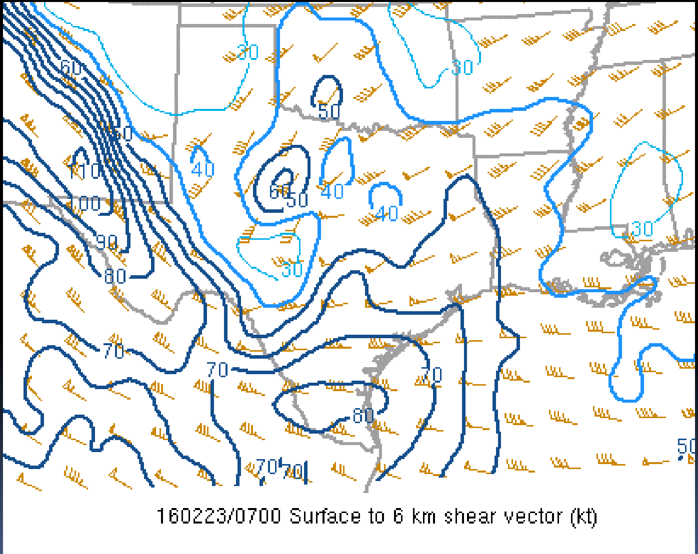
CB04

- Magnitude of shear vector between 0-500m mean wind or surface wind and 6 km AGL wind
- RB98 showed utility distinguishing between ORD and SUP/TOR
- No difference between SUP and TOR
- CB04 did show difference for significant tornadoes
- 30-40 knots supercells
- 45-60 knots significant tornadoes

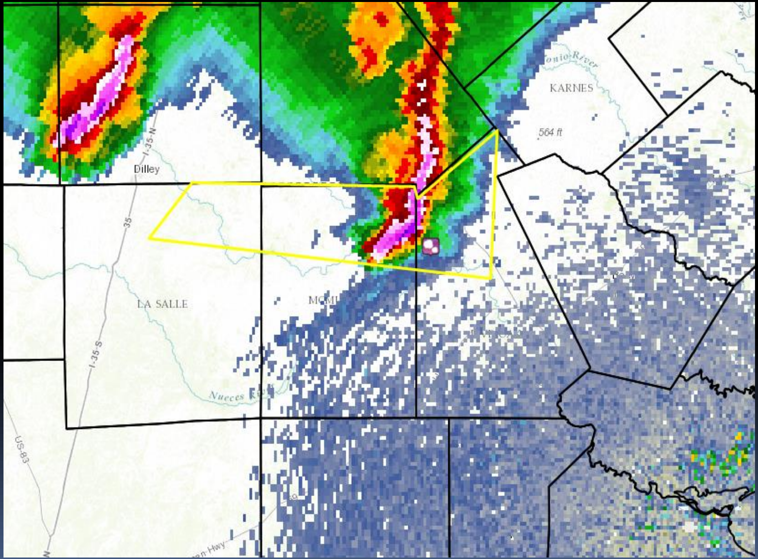
Shear-Related Parameters

Boundary Layer to 6 km Shear

Severe Hail/Winds February 23rd, 2016



70-80 knots 0-6 km Shear



Quarter-Golf Ball Hail & 60-70 mph Winds

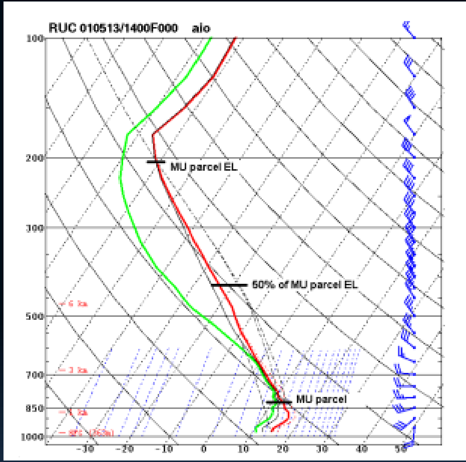
Shear-Related Parameters

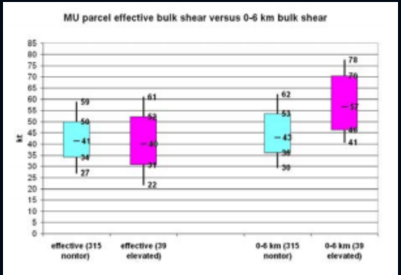
Bulk Richardson Number (BRN) Shear

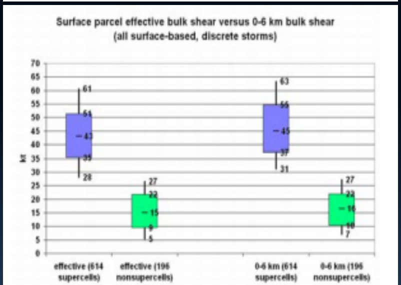
- BRN Shear is similar to the BL-6 km Shear
- Denominator of the Bulk Richardson Number
- Uses the bulk vector difference between the low level (0-500 m AGL) mean wind and a density-weighted mean wind through the mid levels (5500-6000 m AGL)
- Values of 40 m^2/s^2 or greater have been associated with supercells
- Values between 80-100 m^2/s^2 associated with long lived supercells

Shear-Related Parameters

Effective Bulk Shear







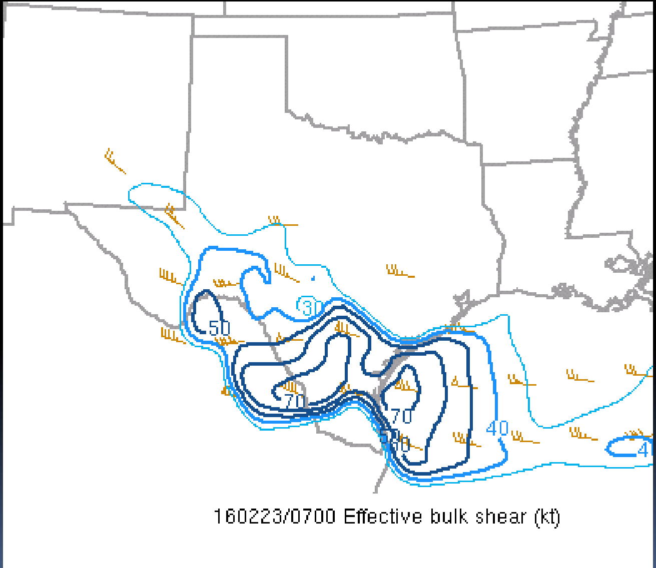
Effective Bulk Shear in Supercell Thunderstorm Environments by R. Thompson, C. Mead, and R. Edwards

- Fixed layer parameter less reliable for environments of very tall storms, very short storms, or elevated storms
- Uses storm layer defined by height of the most unstable lifted parcel in the lowest 300 mb as the inflow base
- More consistent over the range of supercells (0-6 km shear too high for elevated supercells)
- Differentiates between ordinary storms and supercells
- 30-40 knots supercells

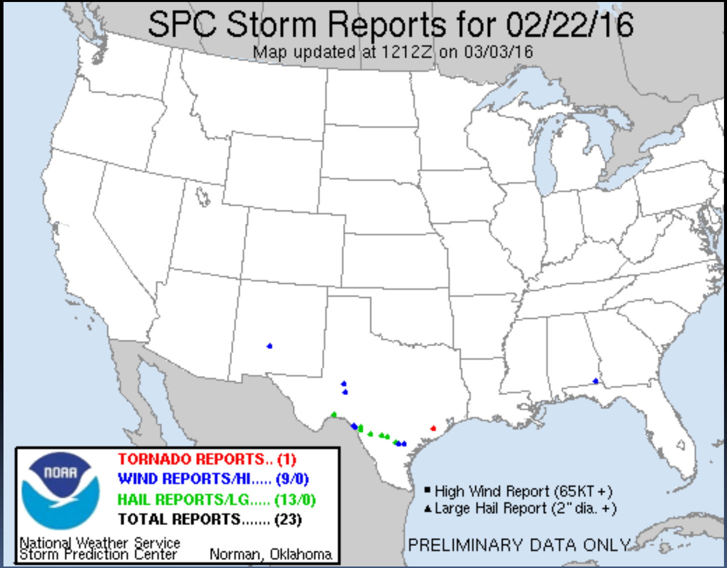
Shear-Related Parameters

Effective Bulk Shear

Severe Hail/Winds February 23rd, 2016



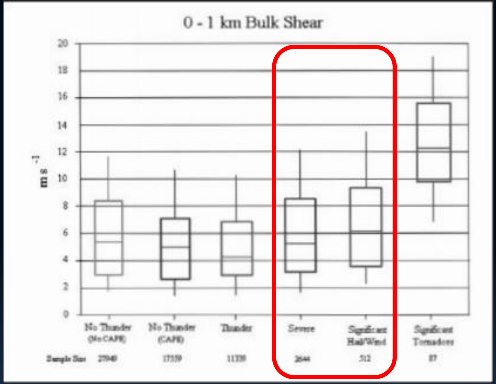
60-70 knots Effective Bulk Shear

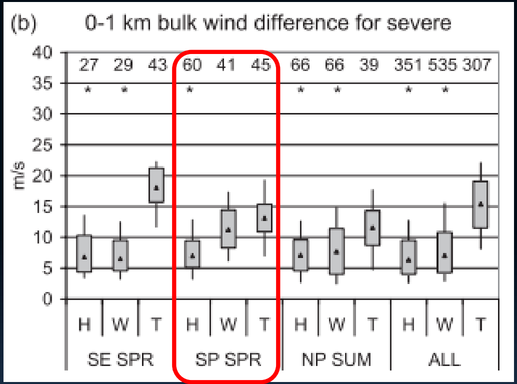


Storm Reports February 22-23, 2016

Shear-Related Parameters

0-1 km Bulk Shear





CB04

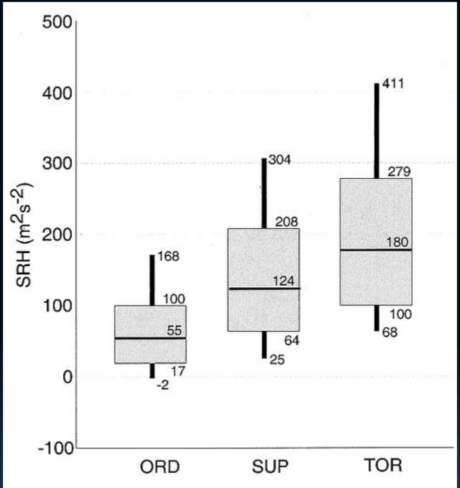
GT12

- Better results were shown with low level (0-1 km) shear
- Not much difference between marginal severe and significant severe
- Marked increase seen for significant tornadoes
- Indicative of the importance of the near-ground layer for tornado formation
- 20 knots the lower bound threshold for tornadic supercells

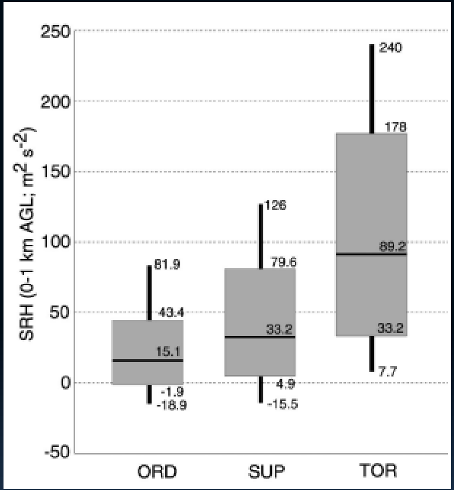
Shear-Related Parameters

0-3 km/0-1 km Storm Relative Helicity

$$\mathrm{SRH} = -\int_0^h \mathbf{k} \cdot (\mathbf{V} - \mathbf{c}) \times \frac{\partial \mathbf{V}}{\partial z}\, dz$$



RB98



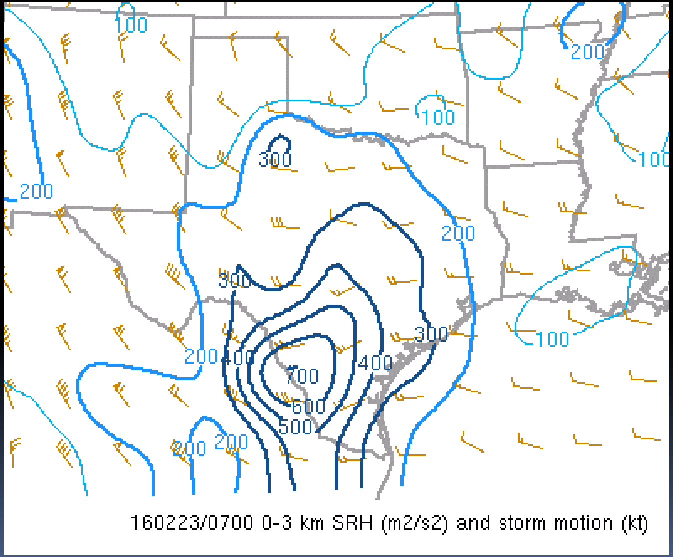
R03

- RB98 showed utility distinguishing between tornadic supercells and non-tornadic supercells
- Initial version used 0-3 km layer as inflow layer
- Changing to near surface layer (0-1 km) showed distinction between tornadic supercells and non-tornadic supercells
- 100 m2/s2 threshold for supercells (0-3 km SRH)
- 80 m2/s2 threshold for significant tornadoes (0-1 km SRH)

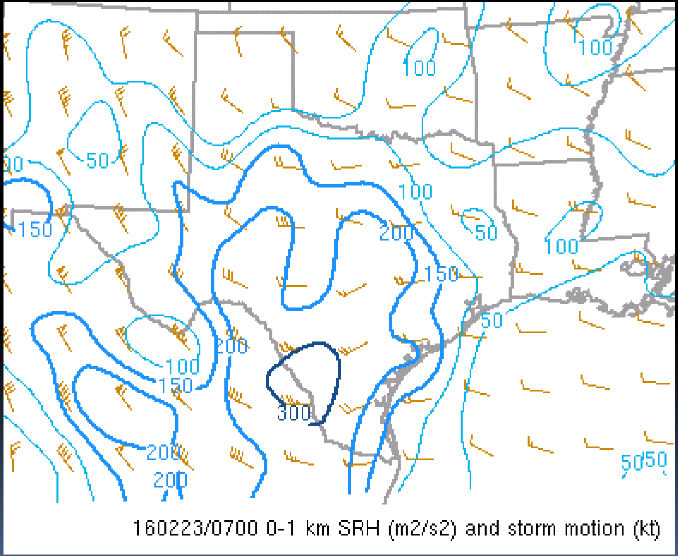
Shear-Related Parameters

0-3 km/0-1 km Storm Relative Helicity

Severe Hail/Winds February 23rd, 2016



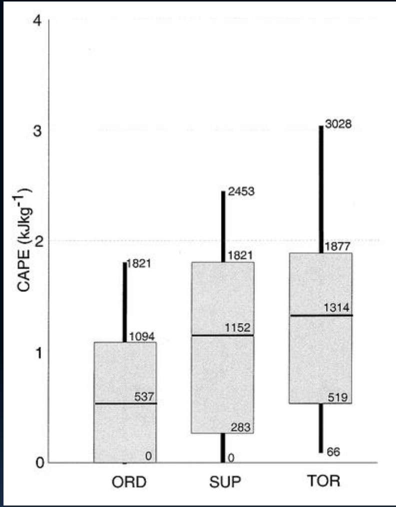
500-700 m2/s2 0-3 km SRH



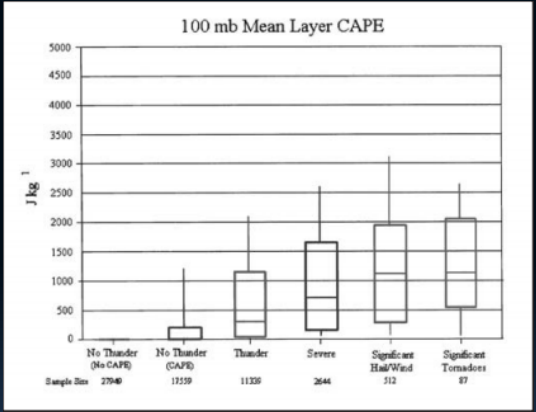
200-300 m2/s2 0-1 km SRH

Instability Parameters

Convective Available Potential Energy (CAPE)



RB98



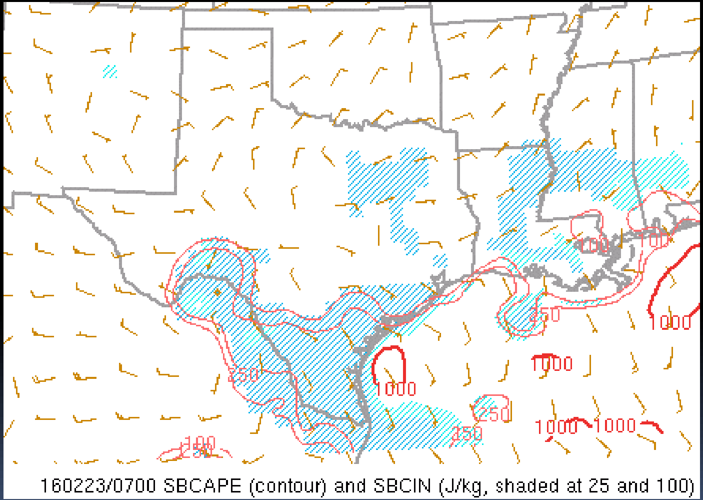
CB04

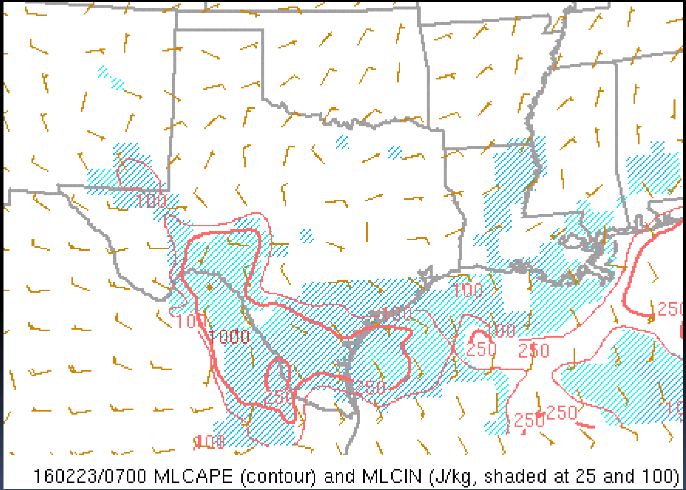
- Integrated "positive area" in J/kg (from the LFC to EL) for the lifted parcel
  - Surface-based (SBCAPE)
  - Mixed-layer (MLCAPE)
    - Lowest 1 km
    - Lowest 100 mb
  - Most Unstable (MUCAPE) within lowest 300 mbs
- Papers used mixed-layer CAPE
- Overlap between the categories but 1100 J/kg threshold between general thunderstorms and severe
- 1800 J/kg considered extreme for non-tornadic supercells and tornadic supercells

Instability Parameters

CAPE (Surface Based and Mixed Layer)

Severe Hail/Winds February 23rd, 2016



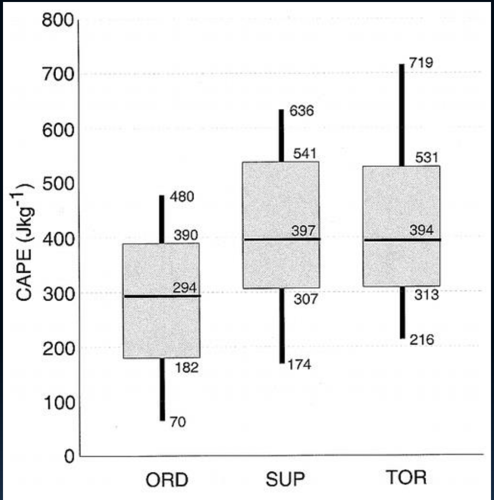


250-500 J/kg SBCAPE

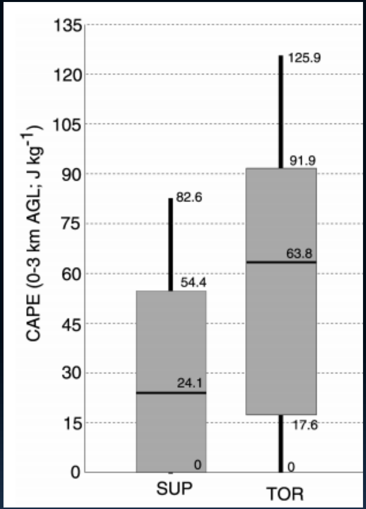
250-500 J/kg MLCAPE

Instability Parameters

CAPE (Lowest 3 km Above LFC/Below 3 km AGL)



RB98



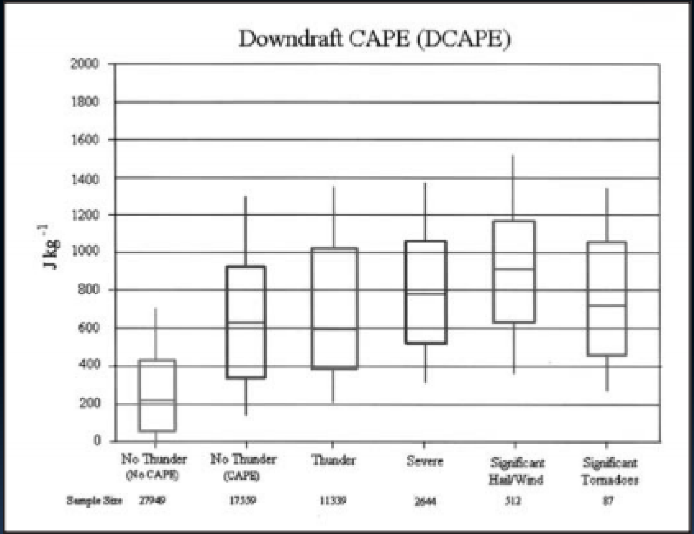
R03

- Looked at distribution of CAPE in the low levels -- low level stretching beneficial for mesocyclone intensification
- RB98 used layer 3 km above the LFC
- No utility indicated with little difference shown between non-tornadic and tornadic supercells

- Larger CAPE occurs closer to the surface, Rasmussen (2003) used the 0-3 km layer for CAPE calculation
- Better ability to discriminate between non-tornadic and tornadic supercells

Instability Parameters

Downdraft CAPE (DCAPE)

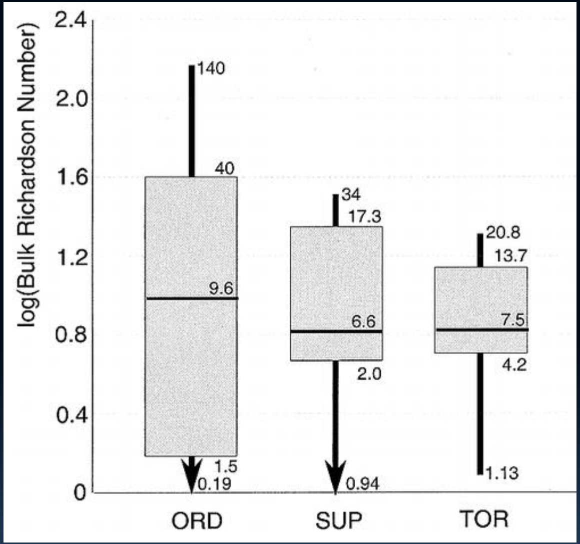


CB04

- DCAPE values greater than 1000 J/kg have been associated with increasing potential for strong downdrafts and damaging outflow winds.
- RB98 found no distinction between the categories
- Craven/Brooks showed values lower for tornadic supercells compared to non-tornadic supercells
- Higher DCAPE values permit stronger RFDs and result in outflow dominant supercell

Shear-CAPE Combination Parameters

Bulk Richardson Number



RB98

- Ratio of buoyancy (MLCAPE) to vertical shear (BL-6 km shear)
- Estimate balance between vertical shear and buoyancy

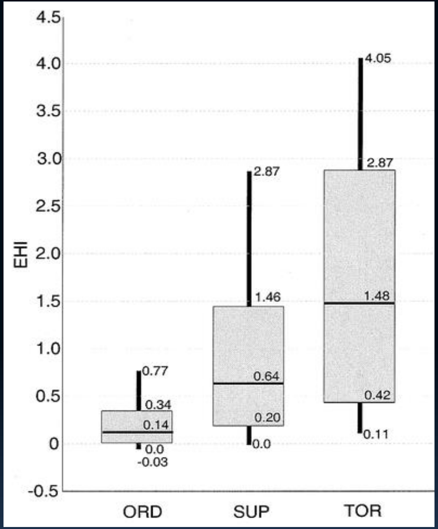
- Environments with BRN < 50 favored supercells
- BRN > 50 favored multicells

- RB98 confirmed lower values for supercell soundings (75% lower than 17)
- Poor discriminator between supercells and non-supercells

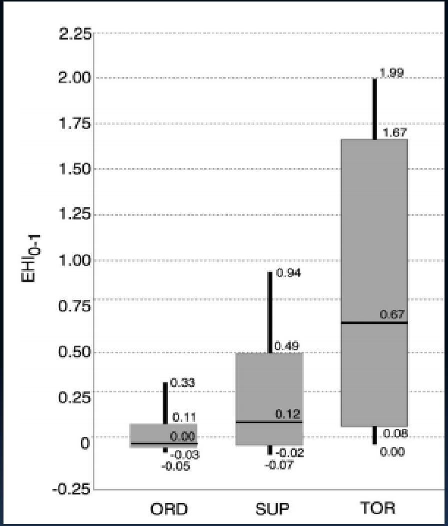
Shear-CAPE Combination Parameters

Energy Helicity Index/Modified EHI (0-1 km)

$$EHI = \frac{(CAPE)\,(SRH)}{1.6 \times 10^5}$$



RB98



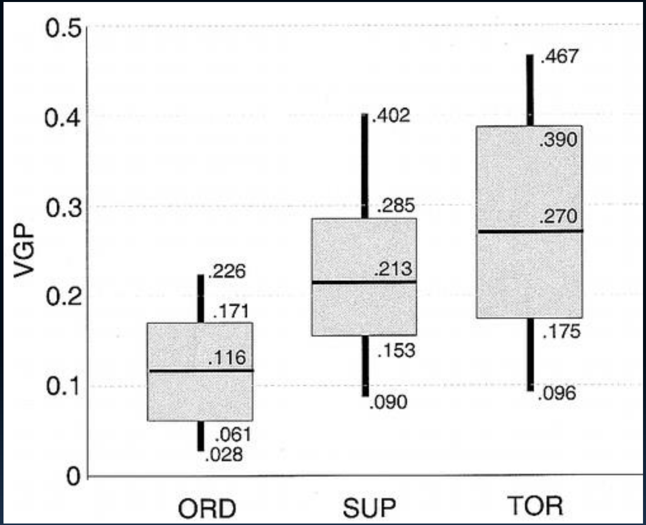
R03

- Based upon idea that storm rotation should be maximized when CAPE and 0-3 km SRH values are large
- Good discriminator between the categories
- Significant tornadoes occurred with higher EHI (EHI >1.5 being a threshold from non-tornadic to tornadic supercells)
- Modified using 0-1 km SRH even better (Modified EHI > 0.5 for discriminator between SUP and TOR)

Shear-CAPE Combination Parameters

Vorticity Generation Parameter (VGP)

$$VGP = [S(CAPE)^{1/2}]$$



RB98

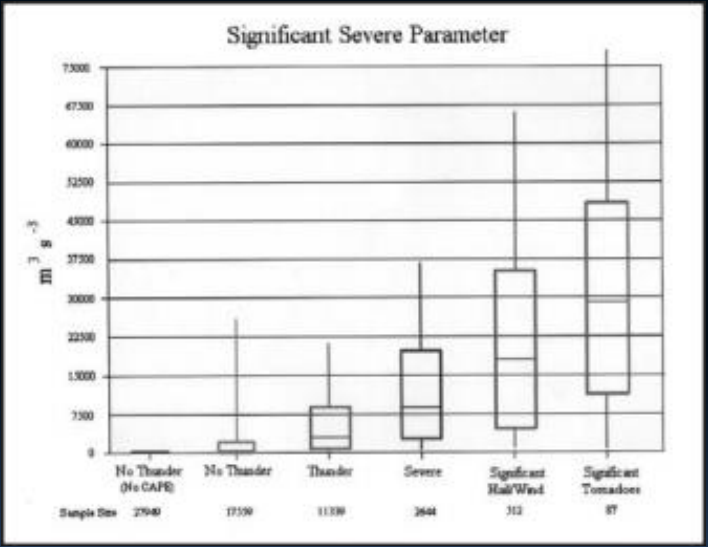
- Estimate the rate of tilting of horizontal vorticity
- S – mean shear over a layer (hodograph length/depth) [0-3 km]

- S proportional to horizontal vorticity vector
- Square root of CAPE is proportional to vertical velocity

- Mean values of the different categories significantly different
- Higher possibility of tornadic storms with VGP > 0.25 m/s2

Shear-CAPE Combination Parameters

Craven/Brooks Significant Severe Parameter

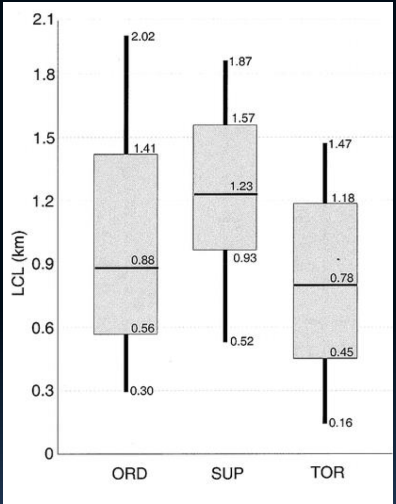


CB12

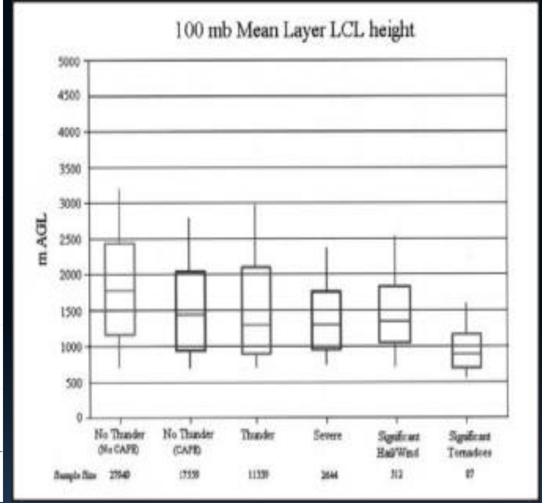
- Better results considering both instability and shear for discrimination between thunder and severe events
- Product of MLCAPE (lowest 100 mb) and 0-6 km shear
- More discrimination shown between the three severe categories
- Lower threshold for
  - Severe – 10,000 m3/s3
  - Significant Hail/Wind – 20,000 m3/s3
  - Significant Tornadoes – 30,000 m3/s3

Low Level Thermodynamics

Lifting Condensation Level (LCL)



RB98

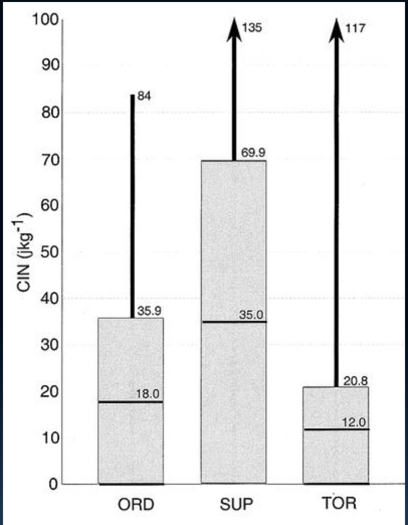


CB04

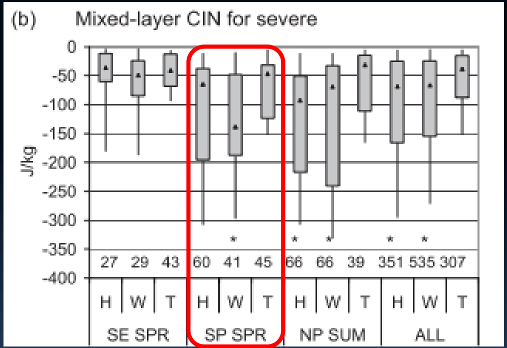
- Level at which a lifted parcel becomes saturated and corresponds to cloud base height for forced ascent
- Higher LCLs –> Lower BL humidity –> More evaporative cooling → Stronger outflow
- LCLs around 500 meters lower with tornadic supercells than non-tornadic supercells
- LCL around 1000 meters upper threshold

Low Level Thermodynamics

Convective Inhibition (CINH)/ Mixed Layer CIN (MLCIN)



RB98

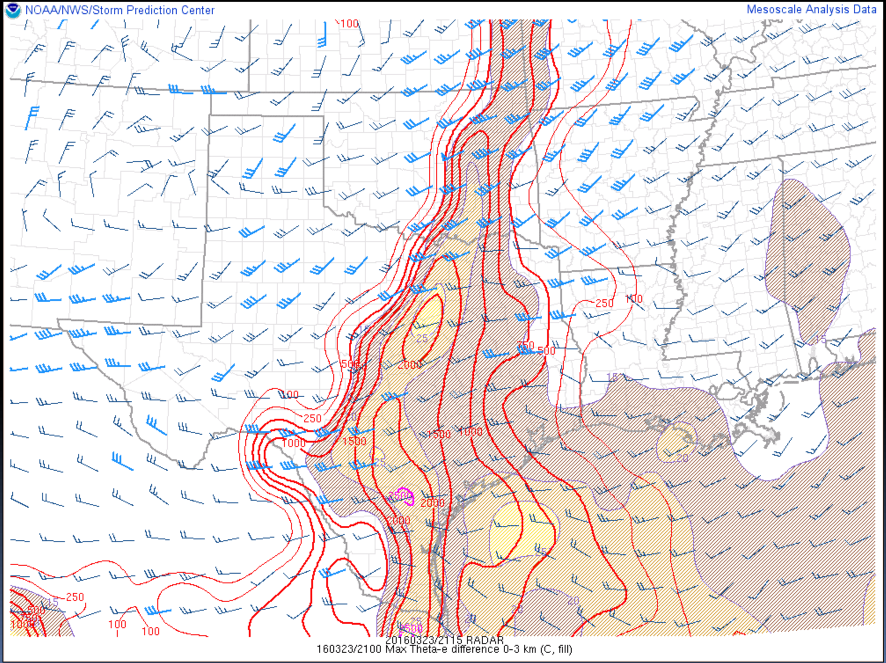


GT12

- The negative area that represents the amount of energy needed for a parcel to reach its LFC
- RB98 used surface based CIN while GT12 used CIN calculated from mixed layer for lowest 100 mbs
- Weaker inhibition involved with significant tornado cases
- Larger CIN associated with elevated storms/strongly forced storms

Low Level Thermodynamics

0-3 km Theta-E Differential with 0-3 km Bulk Shear



- SPC highlights area potentially favorable for QLCS mesovortex generation
- Need areas of substantial buoyancy along with line-normal bulk shear 30 knots or greater
- 0-3 km Theta-E differential is shaded for potential strength of the cold pool
- 0-3 km Theta-E differential values
  - 18-25 favorable
  - >25 very favorable

Composite Parameters

Supercell Composite Parameter (SCP)

$$SCP = (MUCAPE / 1000\ J\ kg^{-1}) * (0\text{-}3\ km\ SRH / 150\ m^2\ s^{-2}) * (BRN\ denominator / 40\ m^2\ s^{-2})$$

Thompson, Edwards, Hart - SPC

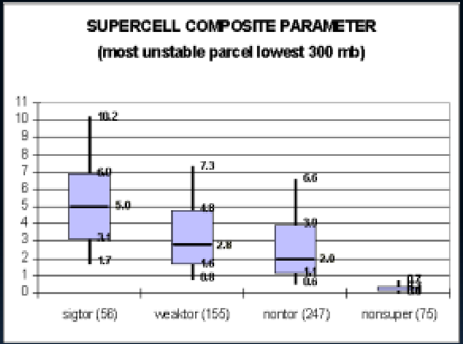
$$SCP = (MUCAPE / 1000\ J\ kg^{-1}) * (effective\ shear / 20\ m\ s^{-1}) * (effective\ SRH / 50\ m^2\ s^{-2})$$

Thompson, Edwards, Mead - SPC

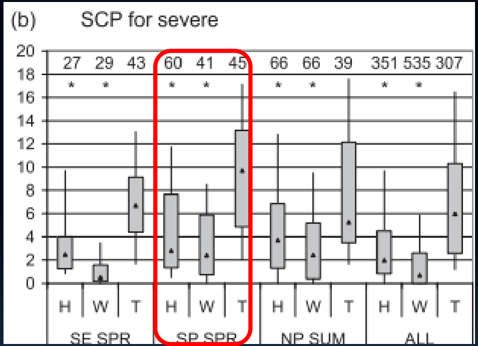
- Information about instability, shear, and helicity combined
- MUCAPE/0-3 km SRH/BRN Shear
- Each component was normalized to supercell threshold values based on previous studies
- Normalized values give SCP value of 1
- SCP modified to account for the effective storm layer

Composite Parameters

Supercell Composite Parameter (SCP)



Thompson, Edwards, Hart - SPC



Grams, Thompson, et. al. - 2012

- SCP values commonly above 2 for supercells while much lower for ordinary storms
- Studies showed SCP significantly higher for tornadic supercells compared to non-tornadic supercells or weak tornadoes
- Threshold to distinguish the significant tornadoes from non-tornadic supercells around 5

Composite Parameters

Significant Tornado Parameter (STP)

STP = (MLCAPE / 1000 J kg^{-1}) * (0-6 km vector shear / 20 m s^{-1}) * (0-1 km SRH / 100 m^2 s^{-2}) * ((2000 - MLLCL) /1500 m) * ((150 - MLCIN) / 125 J kg^{-1})

Thompson, Edwards, Hart - SPC

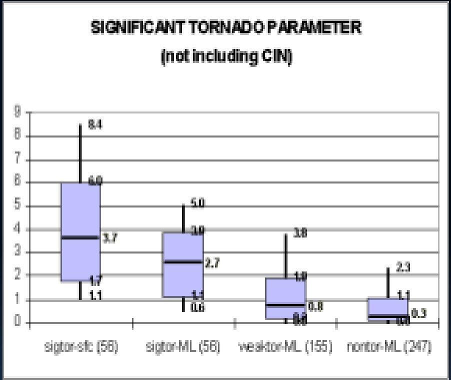
Sig Tor (CIN) = (MLCAPE / 1500 J/kg) * (ESRH / 150 m2/s2) * (EBWD / 12 m/s) * ((2000 - MLLCL) / 1000m) * ((MLCIN + 200) / 150 J/kg)

Thompson, Edwards, Mead - SPC

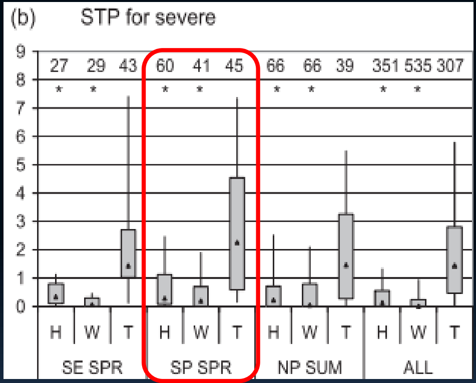
- Information about instability, shear, helicity, LCL, and inhibition combined
- MLCAPE/0-6 km Shear/0-1 SRH/MLLCL/MLCIN
- Each component was normalized to significant tornado threshold values
- Normalized values give STP value of 1
- STP modified to account for the effective storm layer

Composite Parameters

Significant Tornado Parameter (STP)



Thompson, Edwards, Hart - SPC



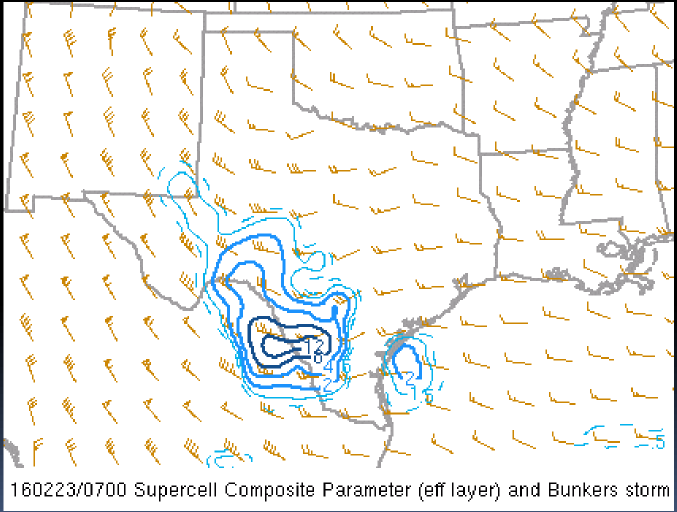
Grams, Thompson, et. al. - 2012

- STP values commonly above 2 for tornadic supercells
- Studies showed STP significantly higher for tornadic supercells compared to non-tornadic supercells or weak tornadoes
- Threshold to distinguish the significant tornadoes from non-tornadic supercells around 1

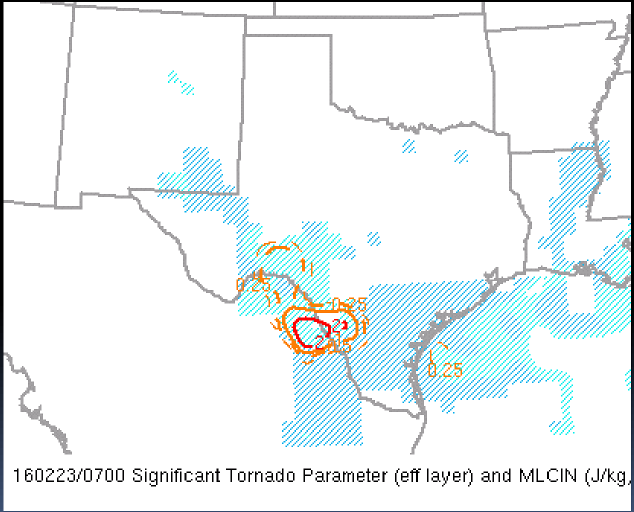
Composite Parameters

SCP / STP

Severe Hail/Winds February 23rd, 2016



SCP from 2 to 8

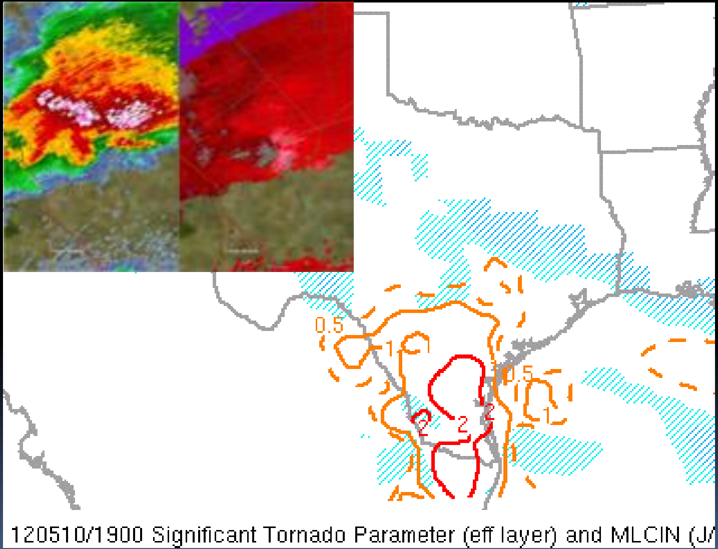


STP below 0.5

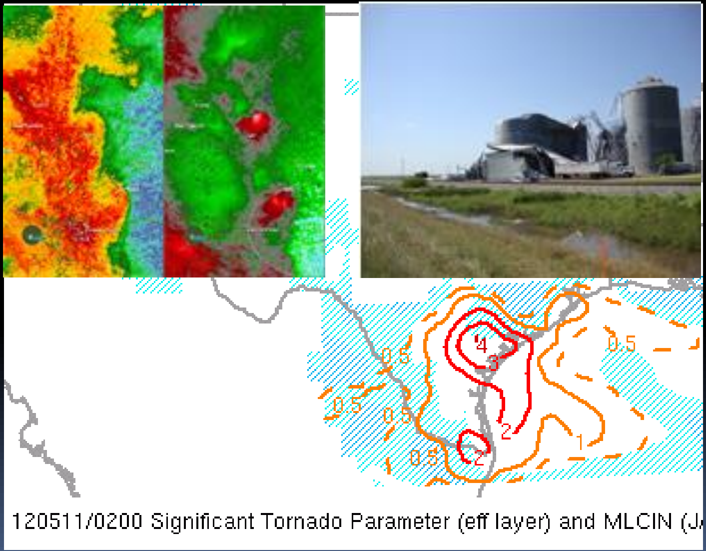
Composite Parameters

Significant Tornado Parameter

Tornado Outbreak May 10th, 2012



STP above 2 at 19 UTC 5/10/12

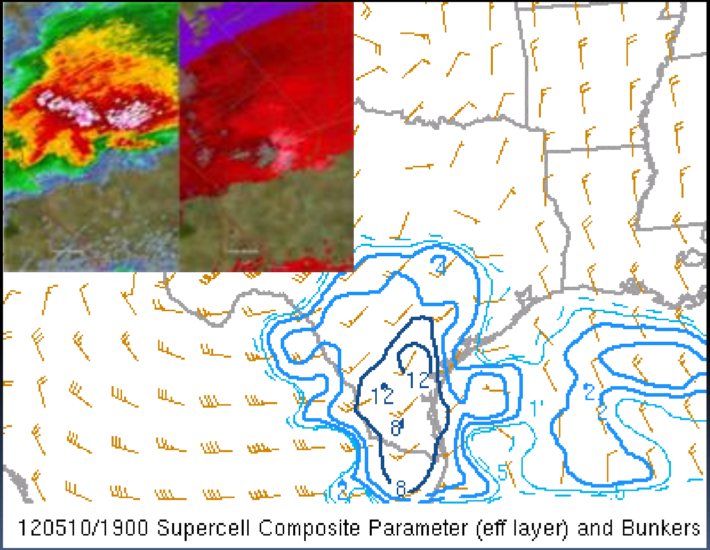


STP above 3 at 02 UTC 5/11/12

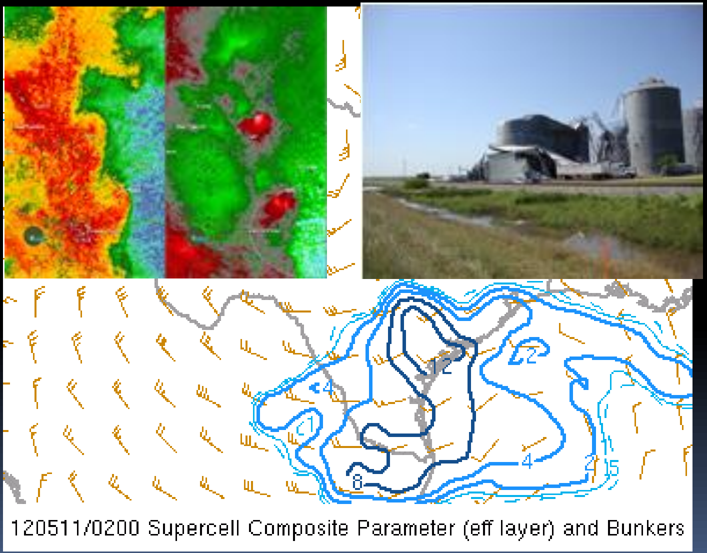
Composite Parameters

Supercell Composite Parameter

Tornado Outbreak May 10th, 2012



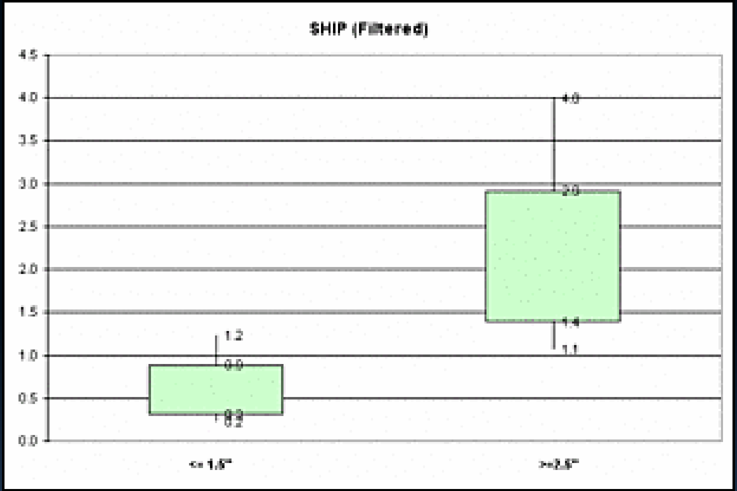
SCP 8-12 at 19 UTC 5/10/12



SCP 8-12 at 02 UTC 5/11/12

Composite Parameters

Significant Hail Parameter (SHIP)



- SHIP based on 5 parameters
  - MUCAPE
  - Mixing Ratio of MU parcel
  - 700-500 mb Lapse Rate
  - 500 mb Temperature
  - 0-6 km Shear
- Delineate between large hail (2” or greater) and hail below 2” diameter
- Threshold to distinguish for significant hail was slightly greater than 1
- Values typically 1.5-2 when significant hail reported

Composite Parameters

Severe Hazards in Environments w/ Reduced Buoyancy (SHERB)

Severe Hazards In Environments with Reduced Buoyancy (SHERB)

$$SHERBS3 = \frac{(0\text{–}3\ km\ shear\ magnitude)}{26\ ms^{-1}}\ X\ \frac{(0\text{–}3\ km\ lapse\ rate)}{5.2\ K\ km^{-1}}\ X\ \frac{(700\text{–}500\ mb\ lapse\ rate)}{5.6\ K\ km^{-1}}$$

(0-3 km Shear Version)

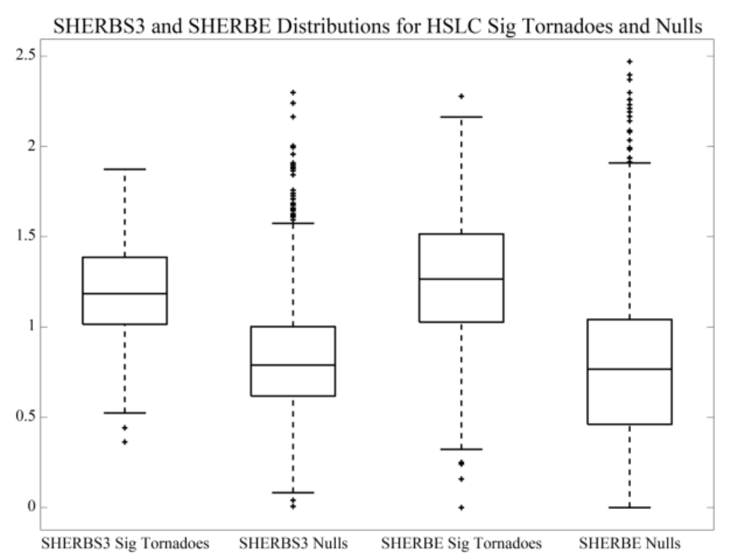
$$SHERBE = \frac{(Effective\ shear\ magnitude)}{27\ ms^{-1}}\ X\ \frac{(0\text{–}3\ km\ lapse\ rate)}{5.2\ K\ km^{-1}}\ X\ \frac{(700\text{–}500\ mb\ lapse\ rate)}{5.6\ K\ km^{-1}}$$

(Effective Shear Version)

- Developed with the idea of improving the forecast of tornadoes in high shear/low CAPE environments
- Examine potential to discriminate between tornadic and non-tornadic meso-vortices with QLCS
- High shear in the 0-6 km layer defined as greater than or equal to 35 knots
- Low CAPE (sfc-based) less than or equal to 500 J/kg

Composite Parameters

Severe Hazards in Environments w/ Reduced Buoyancy (SHERB)

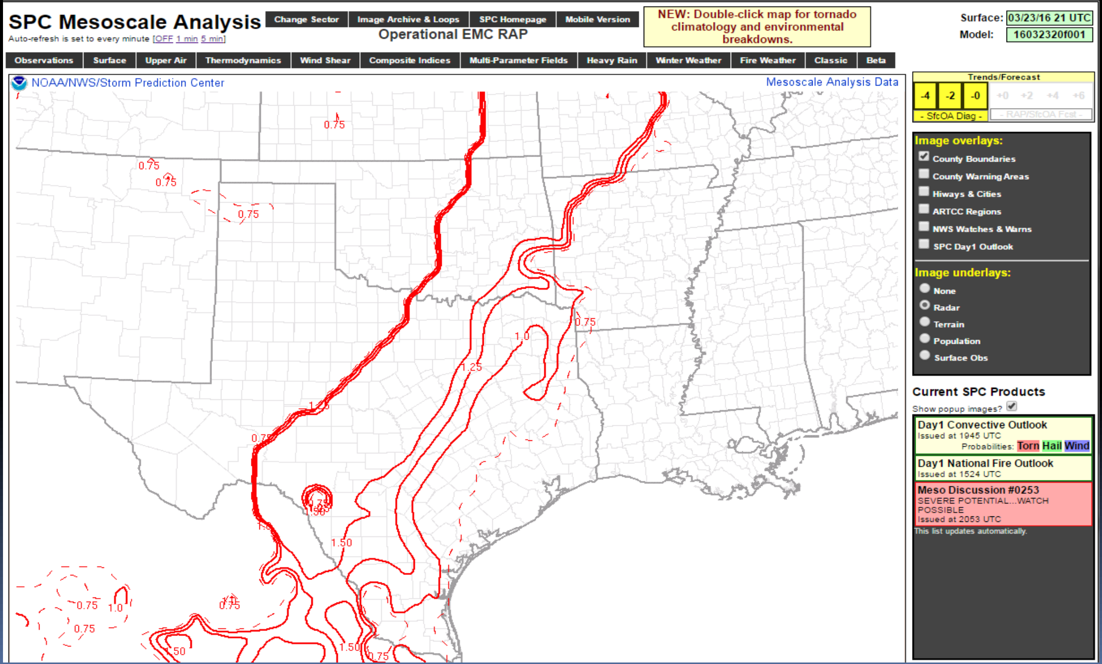


Improving the Forecasting of High Shear, Low CAPE Severe Weather Environments by K. Sherburn and J. Davis (WDTB Webinar)

- SHERBS3 and SHERBE are optimized for HSLC events at a value of 1
- SHERBS3 is the better parameter for HSLC events especially when LCL is low
- About 50% HSLC significant severe reports and 75 % of significant tornadoes with SHERBS3/E greater than 1
- 25% of nulls occurred with SHERBS3/E greater than 1

Composite Parameters

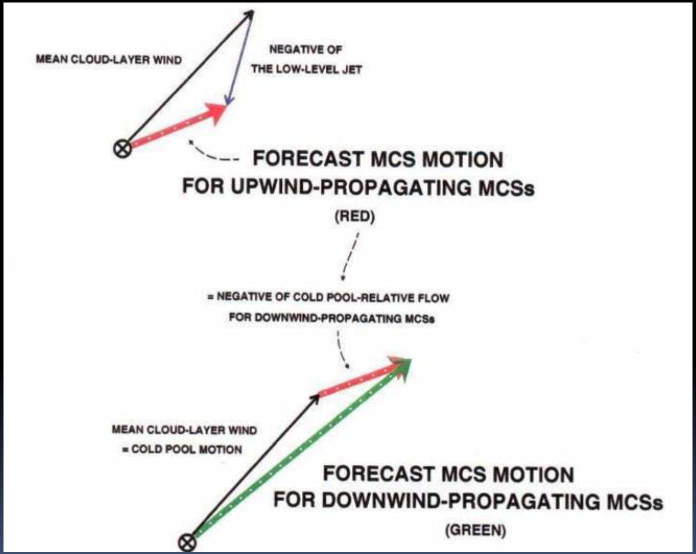
Severe Hazards in Environments w/ Reduced Buoyancy (SHERB)



- SHERBE is under the Beta tab on SPC Meso-Analysis Page
- SHERBS3 is also available in the AWIPS2 Volume Browser under Misc Field

Forecasting MCS Motion

Corfidi Vectors



Upwind Propagating MCSs

- Mean cloud layer + negative of low level jet = upwind propagation vector
- Favored along quasi-stationary (mean flow parallel) portions of gust front
- Environment with moist conditions through the low to mid levels

Downwind Propagating MCSs

- Mean cloud layer + upwind propagation vector = downwind propagation vector
- Favored on progressive (mean flow perpendicular) portions of gust front
- Environment comparatively drier at mid levels or sub-cloud layer

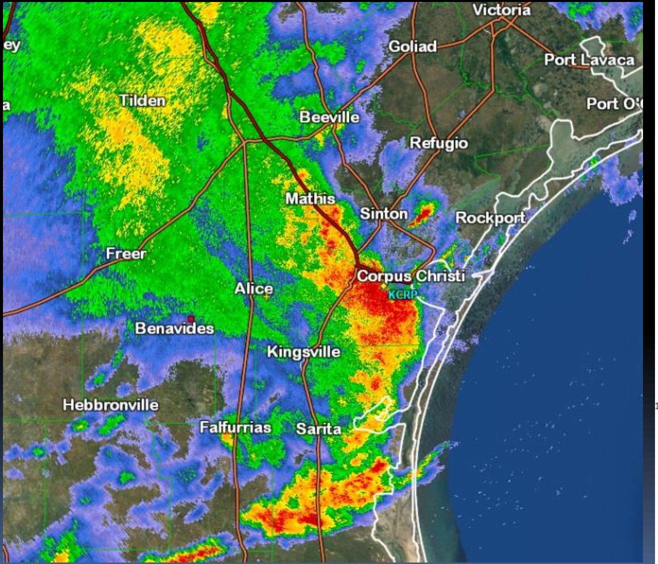
“Cold Pools and MCS Propagation : Forecasting the Motion of Downwind-Developing MCSs” by S. Corfidi (Dec. 2003, W & F)

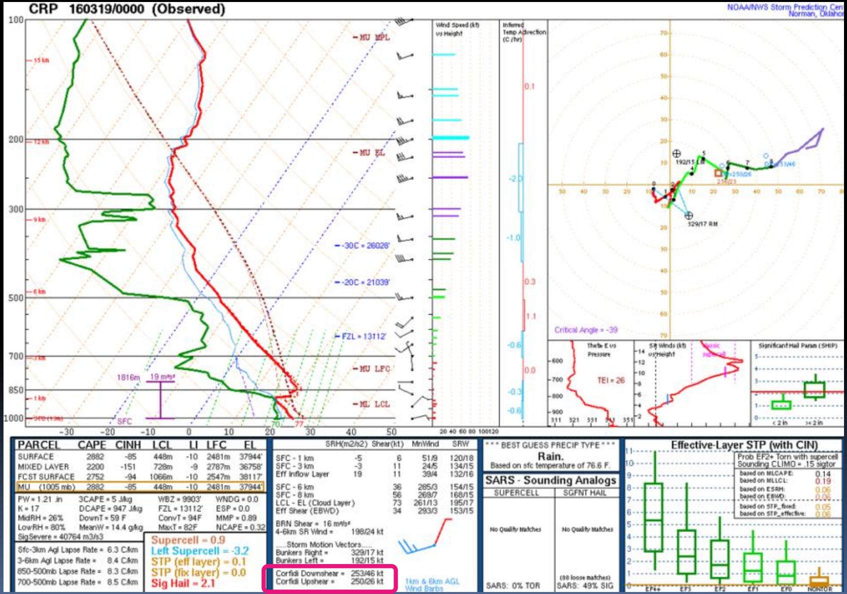
Forecasting MCS Motion

Corfidi Vectors

Severe Winds March 18th, 2016

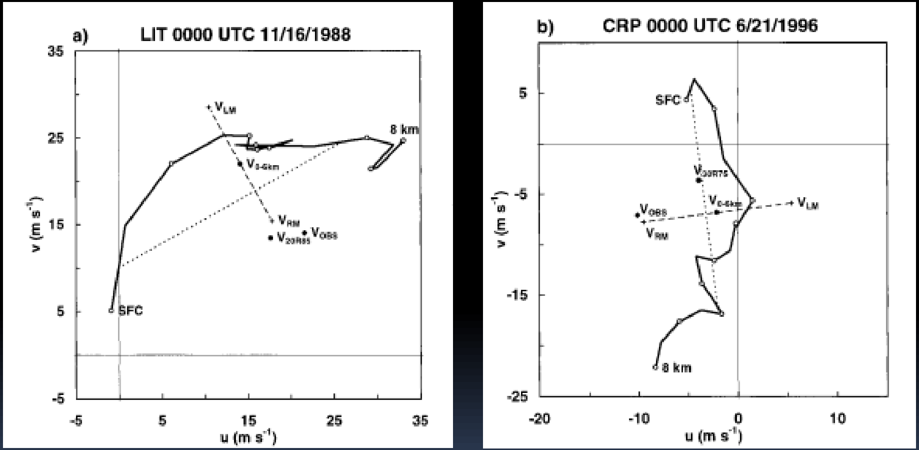
Downwind Propagating MCS





Forecasting Supercell Motion

Bunkers Storm Motion



"Predicting Supercell Motion Using a New Hodograph Technique" by M. Bunkers, et al. (Feb. 2000, Weather & Forecasting)

- Similar results to 30 degrees right and 75% of mean wind speed for southwest flow aloft
- Better results in less common flow regimes

1) Plot 0-6 km mean wind
2) Plot shear vector from 0-500 m AGL mean wind to 5500-6000 m AGL mean wind
3) Draw line perpendicular to the shear vector and passes through the mean wind
4) Right-moving supercell 7.5 m/s to the right the mean wind along the orthogonal line
5) Vice versa for left moving supercell

Parameter Thresholds

Most Valuable Parameters to Distinguish Environments

Ordinary vs. Supercell

- BL-6 km Shear – 30-40 knots
- Effective Bulk Shear – 30-40 knots
- Storm Relative Helicity (0-3 km) – 100 m2/s2
- CAPE – 1100 J/kg
- Supercell Composite Parameter - 2

Null

- CAPE lowest 3 km above LFC
- Downdraft CAPE
- BRN

Non-tornadic Supercell vs. Tornadic

- BL-6 km Shear – 45-60 knots
- 0-1 km Shear – 20 knots
- Storm Relative Helicity (0-1 km) – 80 m2/s2
- CAPE below 3 km AGL – 55 J/kg
- Energy-Helicity Index (0-3 km) – 1.5
- Energy-Helicity Index (0-1km) – 0.5
- Vorticity Generation Parameter - >0.25 m/s2
- Lifting Condensation Level – 1000 m
- Supercell Composite Parameter – 5
- Significant Tornado Parameter -- 1