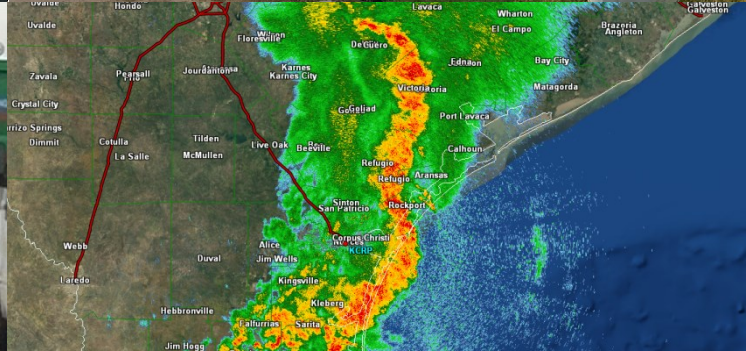# Severe Weather Forecasting Workshop
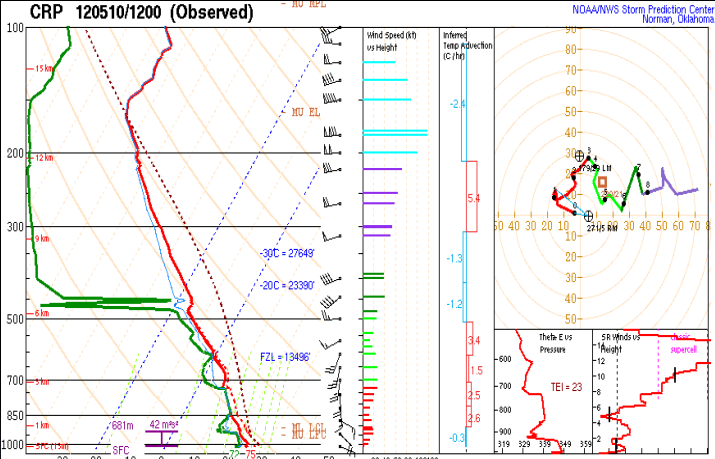
Utility of Severe Weather Parameters and Indices

Severe Weather Parameters and Indices
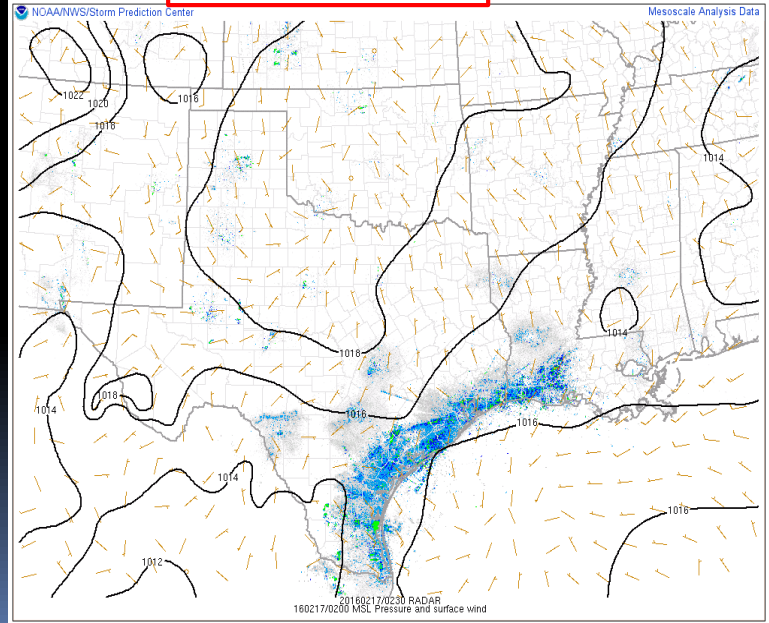
Sounding Data/ SPC Meso Analysis / AWIPS Model Forecast Data (Soundings)

- 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*)

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

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)

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

- Determined seasonal and regional variability and classified by convective mode – Discrete cell, Quasi-linear Convective System (QLCS), or Cluster

- Sample of 355 significant hail (2">) and 556 significant wind events (65 knots >) 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)

- ❑ *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)*
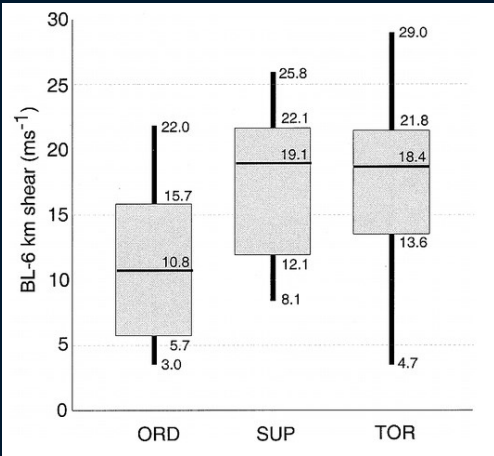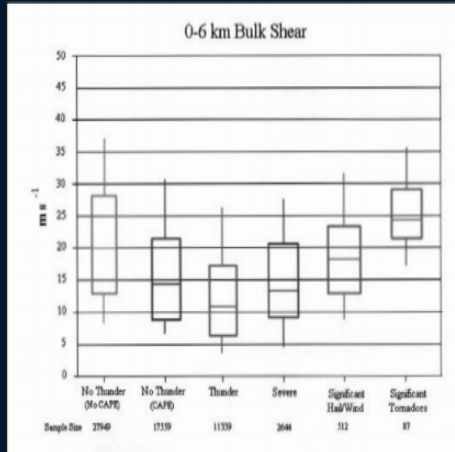
RB98

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

Severe Hail/Winds February 23rd, 2016

160223/0700 Surface to 6 km shear vector (kt)
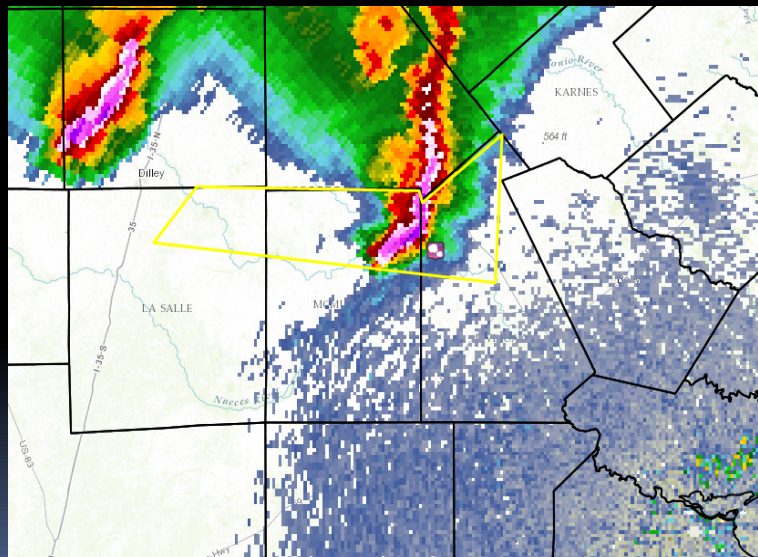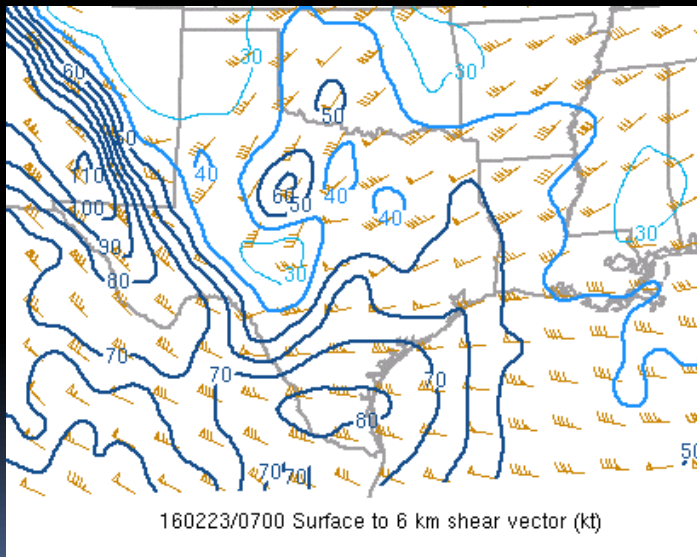
70-80 knots 0-6 km Shear

Quarter-Golf Ball Hail & 60-70 mph Winds
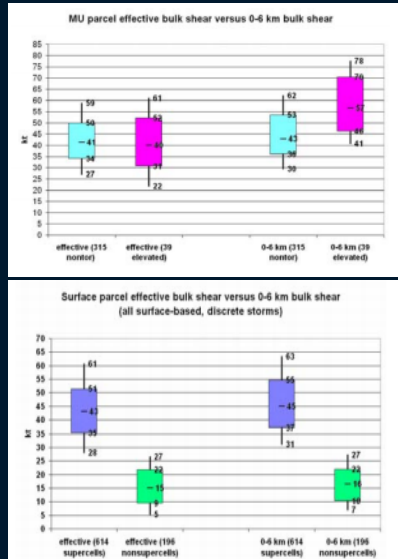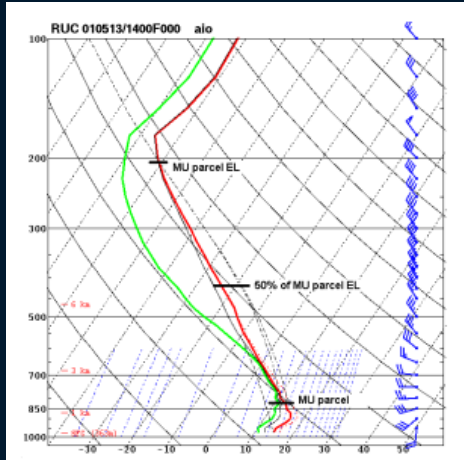
- BRN Shear is similar to the BL-6 km Shear

- 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 $m2/s2$ or greater have been associated with supercells

- Values between 80-100 $m2/s2$ associated with long lived supercells

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, 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
- 35-40 knots supercells

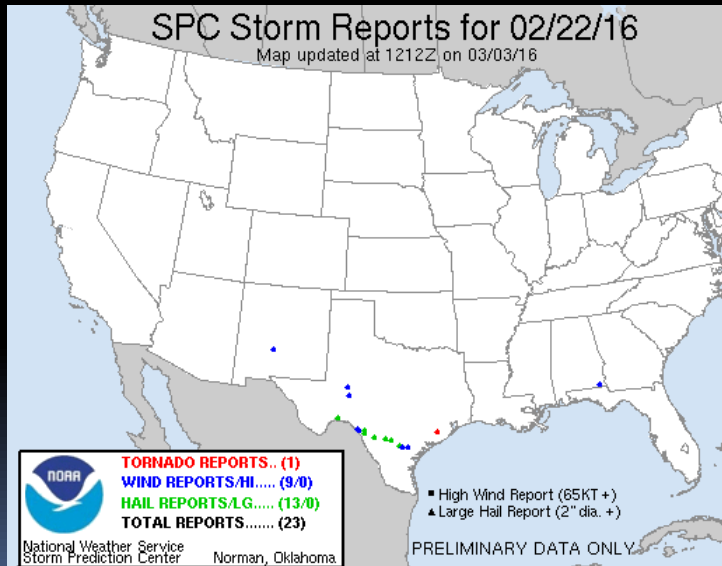# Shear-Related Parameters

Effective Bulk Shear

Severe Hail/Winds February 23rd, 2016

160223/0700 Effective bulk shear (kt)

60-70 knots Effective Bulk Shear

SPC Storm Reports for 02/22/16
Map updated at 1212Z on 03/03/16

TORNADO REPORTS.. (1)
WIND REPORTS/HI..... (9/0)
HAIL REPORTS/LG..... (13/0)
TOTAL REPORTS....... (23)

National Weather Service
Storm Prediction Center   Norman, Oklahoma

■ High Wind Report (65KT +)
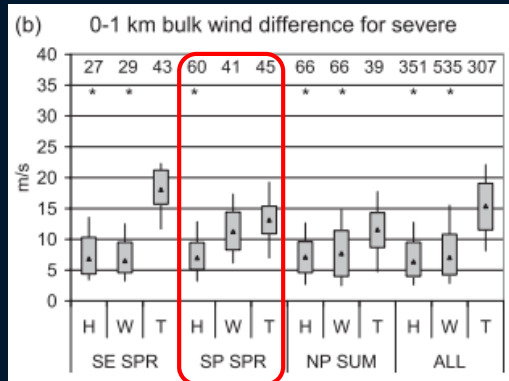▲ Large Hail Report (2" dia. +)

PRELIMINARY DATA ONLY

Storm Reports February 22-23, 2016
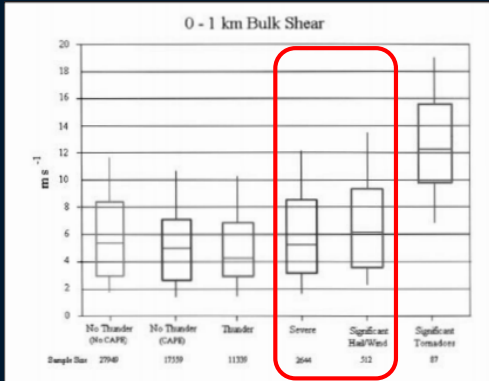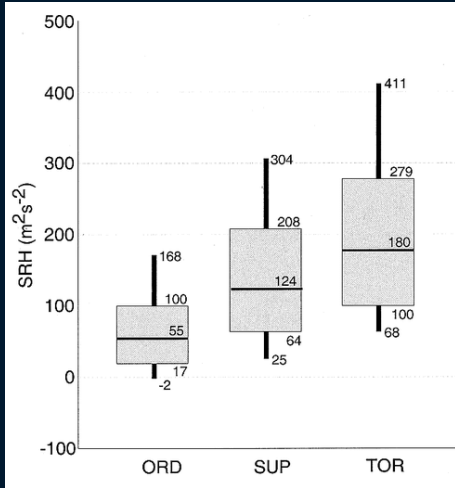
CB04   GT12

- 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
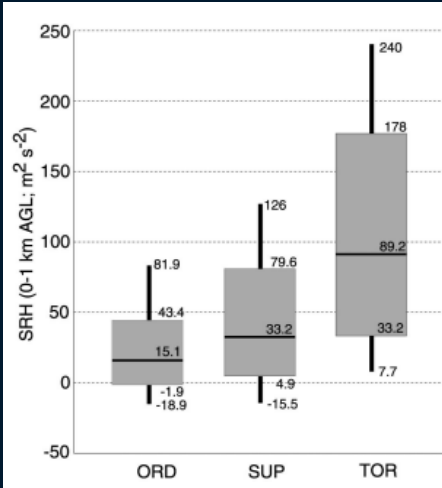- 20 knots the lower bound threshold for tornadic supercells

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

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)
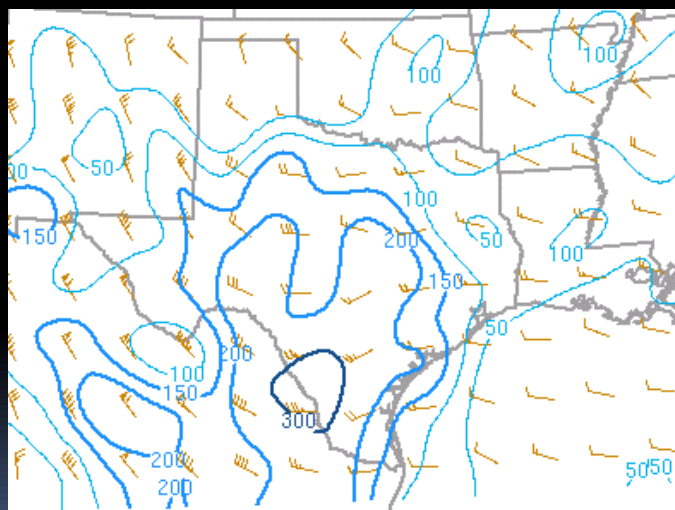
Shear-Related Parameters

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

Severe Hail/Winds February 23rd, 2016
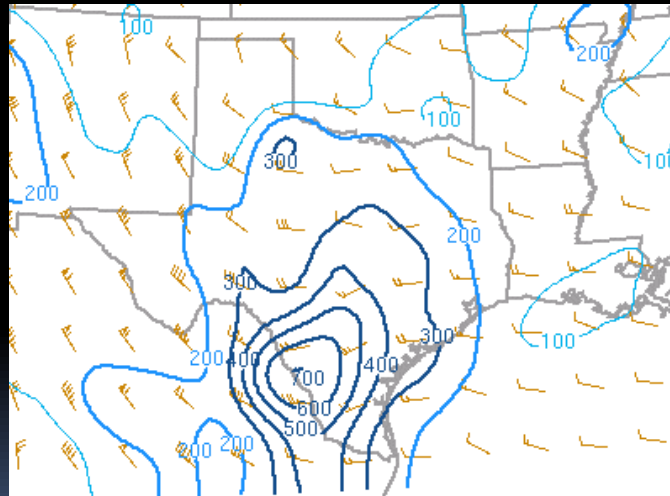
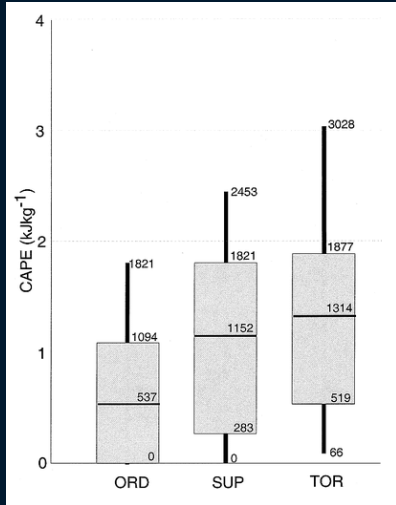160223/0700 0-3 km SRH (m2/s2) and storm motion (kt)

160223/0700 0-1 km SRH (m2/s2) and storm motion (kt)

500-700 m2/s2 0-3 km SRH

200-300 m2/s2 0-1 km SRH
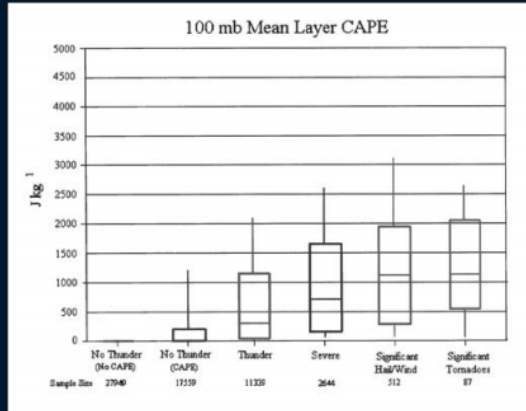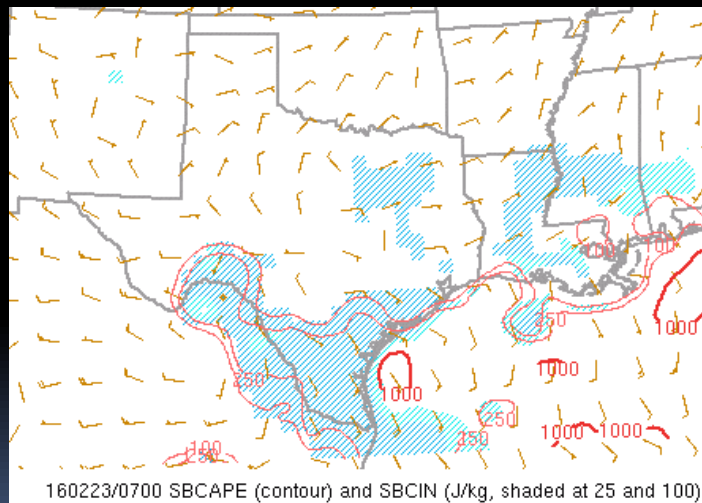
RB98

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
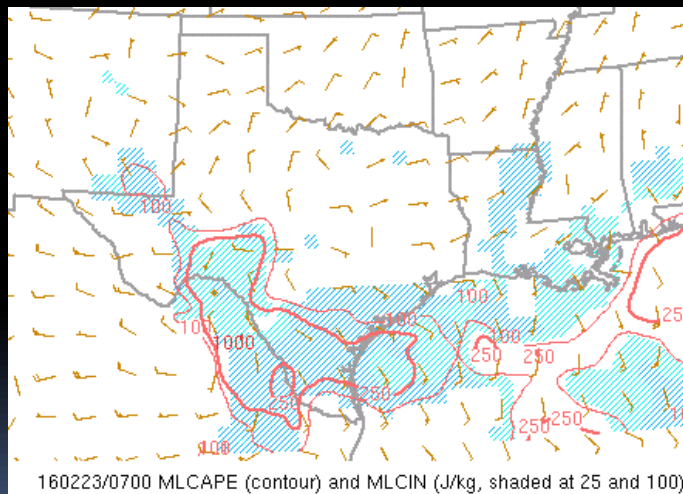
Instability Parameters

CAPE (Surface Based and Mixed Layer)

Severe Hail/Winds February 23rd, 2016

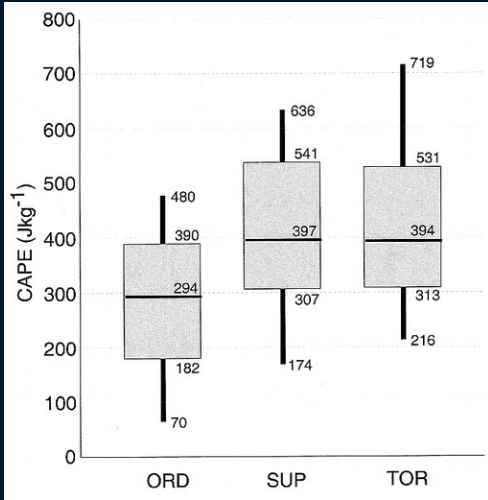160223/0700 SBCAPE (contour) and SBCIN (J/kg, shaded at 25 and 100)

160223/0700 MLCAPE (contour) and MLCIN (J/kg, shaded at 25 and 100)

250-500 J/kg SBCAPE

250-500 J/kg MLCAPE
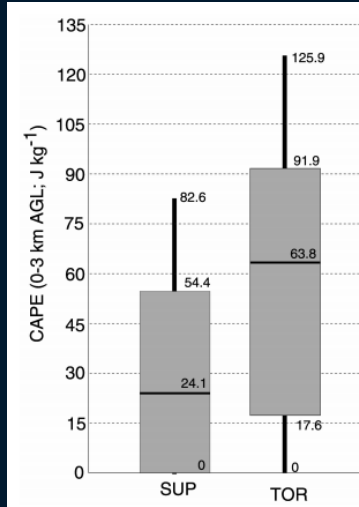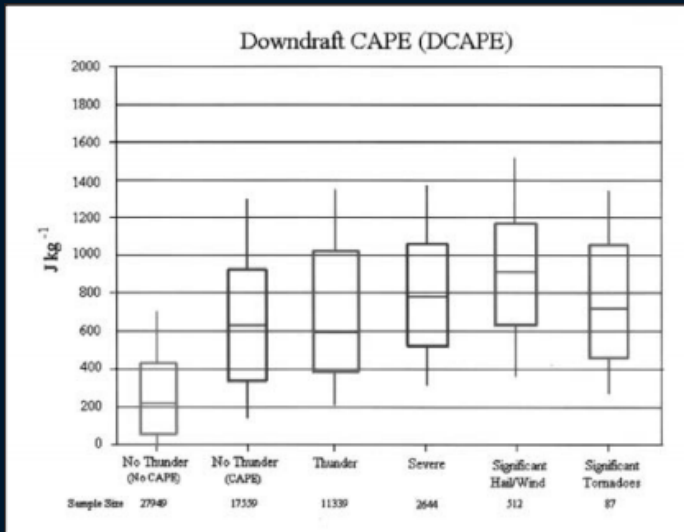
RB98

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

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 result in stronger downdrafts and supercell becoming outflow dominant

- Analytical process started at an estimated downdraft initiation level, usually around 700 mbs. Choosing a higher (lower) level likely creates larger (smaller) DCAPE.

- Downdraft unsaturated as evaporation not efficient to compensate for adiabatic compressional warming. Downdraft warms more quickly with realized DCAPE weaker.

- DCAPE does not account for negative buoyancy due to precipitation loading. A reflectivity core of 60 dBz or greater could lead to a stronger downdraft than DCAPE would suggest.

- DCAPE does not account for non-hydrostatic downward directed pressure deficits that result from strong mesocyclogenesis. DCAPE will not be an accurate estimate for downdrafts in supercells.
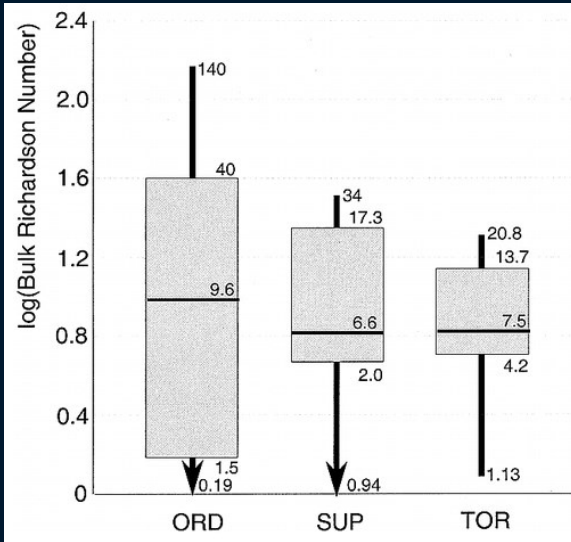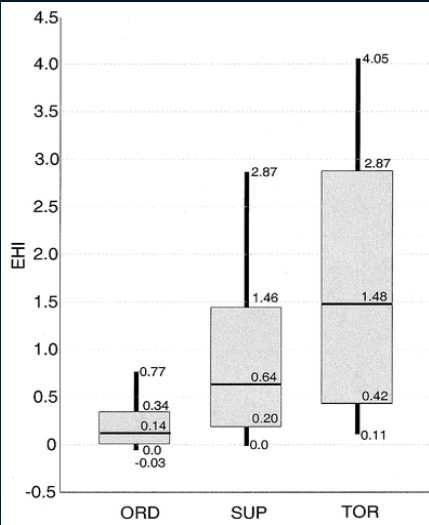
RB98

- 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)

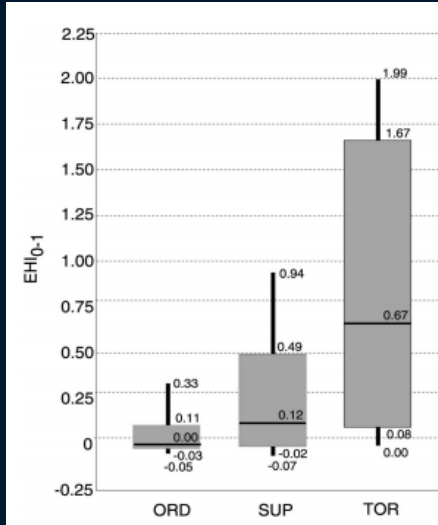- Poor discriminator between supercells and non-supercells

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

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)

$$\mathrm{VGP} = \left[S(\mathrm{CAPE})^{1/2} \right]$$
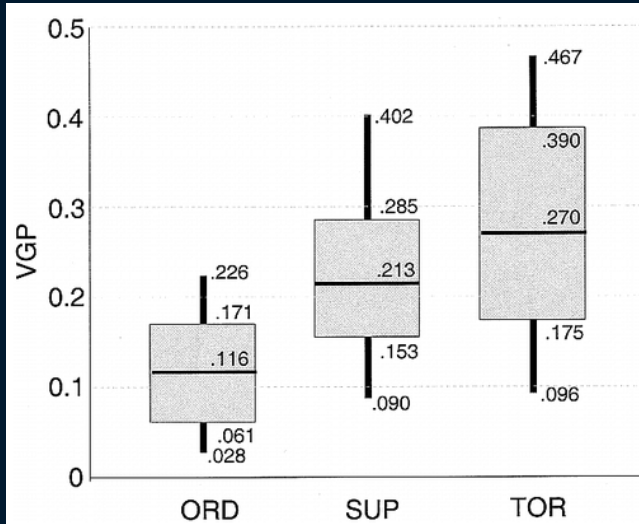
RB98

- 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
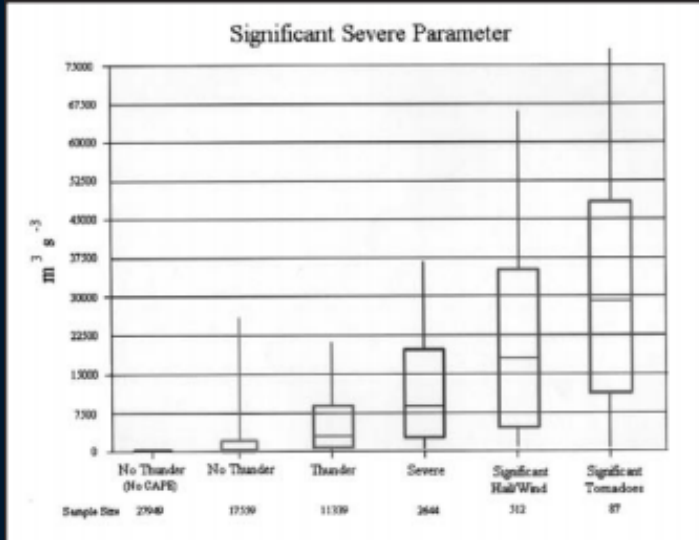
CB12

- 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 (Note the wide range in Significant Tornado category)

- Lower threshold for
  - Severe – 10,000 m3/s3
  - Significant Hail/Wind – 20,000 m3/s3
  - Significant Tornadoes – 30,000 m3/s3
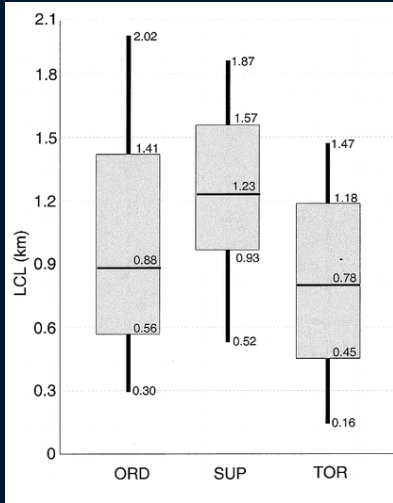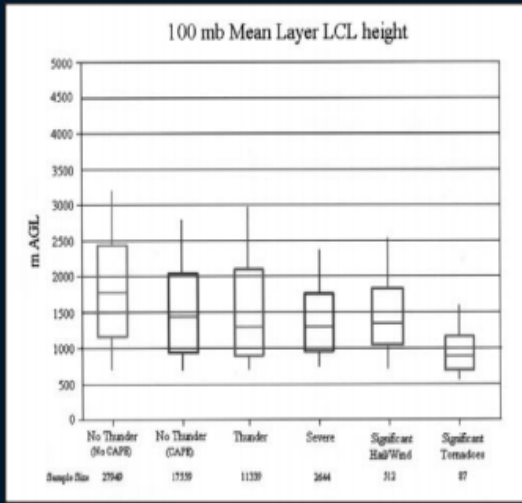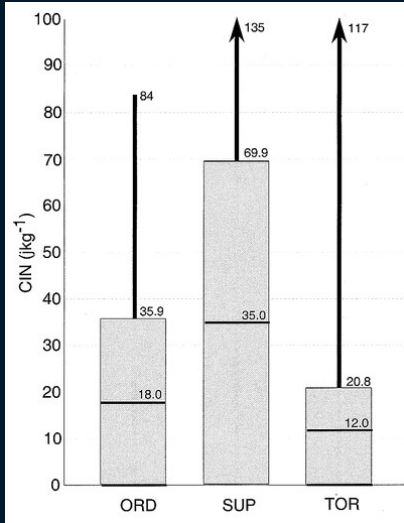
RB98

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

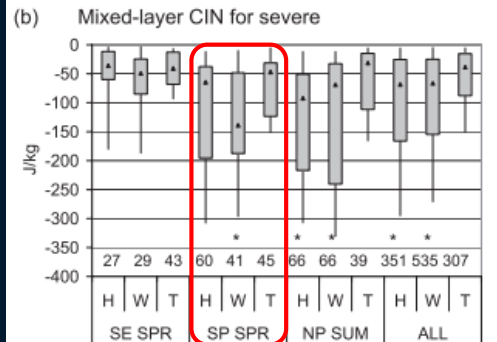- LCL around 1000 meters upper threshold

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
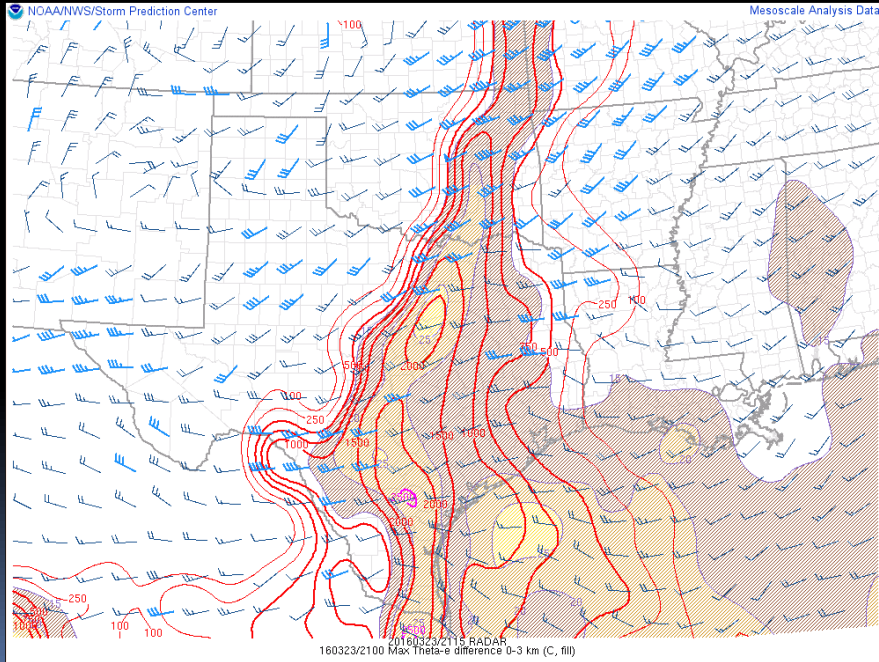
- SPC highlights area potentially favorable for QLCS mesovortex generation

- 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

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

Thompson, Edwards, Hart - SPC

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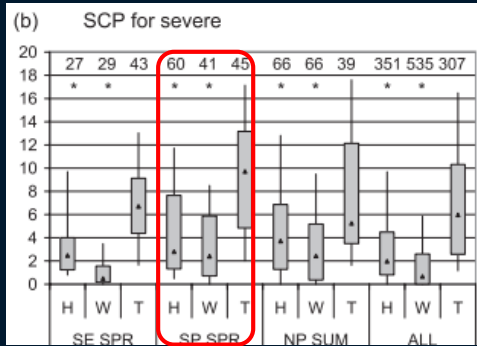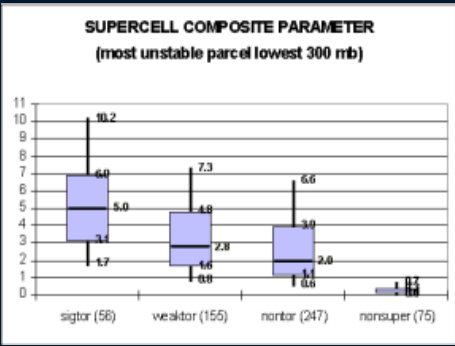$$(\text{effective SRH} / 50 \text{ m}^2\text{s}^{-2})$$

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 using the EBWD for shear

SUPERCELL COMPOSITE PARAMETER (most unstable parcel lowest 300 mb)

SCP for severe

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

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

Thompson, Edwards, Hart - SPC

$$\text{Sig Tor (CIN)} = (MLCAPE / 1500 \text{ J/kg}) * (ESRH / 150 \text{ m2/s2}) * (EBWD / 12 \text{ m/s}) * ((2000 - MLLCL) / 1000\text{m}) * ((MLCIN + 200) / 150 \text{ J/kg})$$
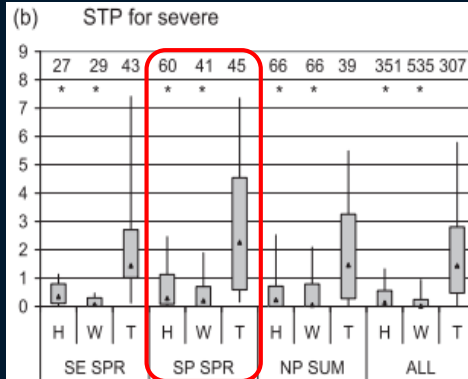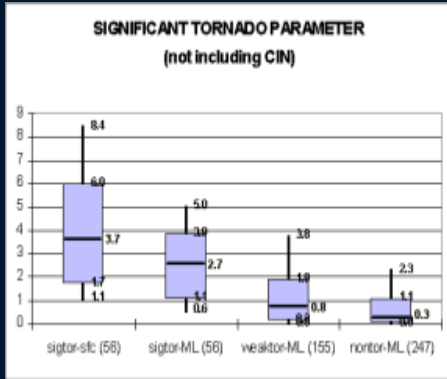
Thompson, Edwards, Mead - SPC

- 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

SIGNIFICANT TORNADO PARAMETER (not including CIN)

Thompson, Edwards, Hart - SPC

STP for severe

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

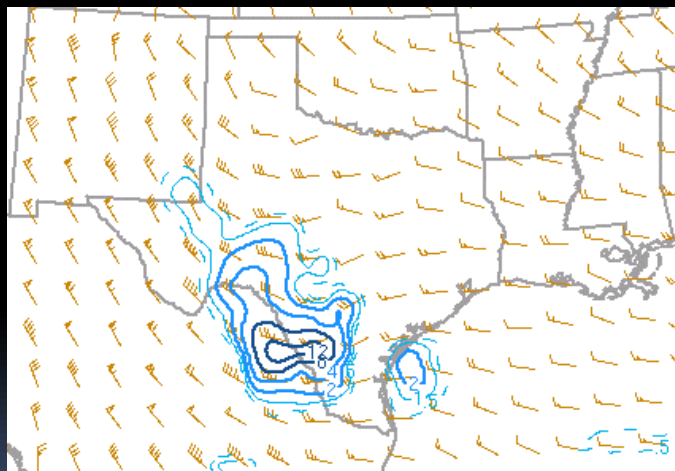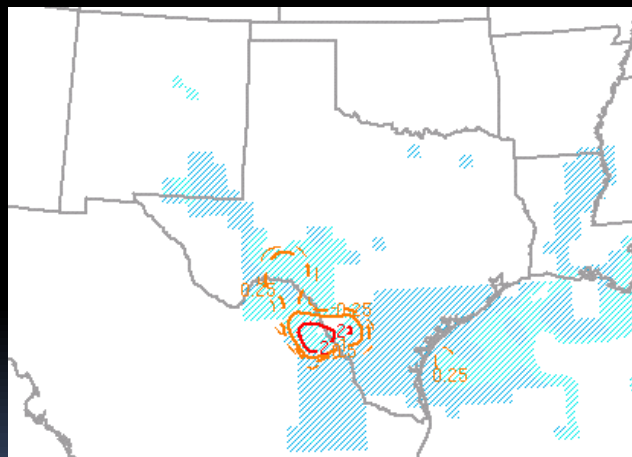- Threshold to distinguish the significant tornadoes from non-tornadic supercells around 1

Severe Hail/Winds February 23rd, 2016

160223/0700 Supercell Composite Parameter (eff layer) and Bunkers storm

160223/0700 Significant Tornado Parameter (eff layer) and MLCIN (J/kg,

SCP from 2 to 8
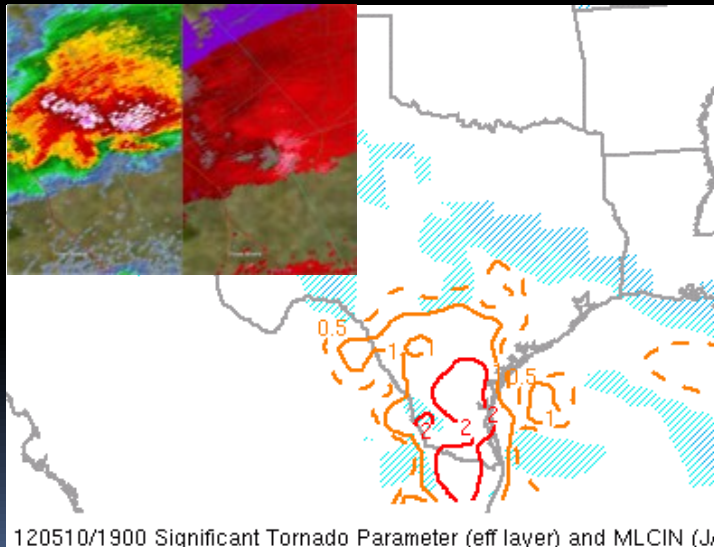
STP below 0.5

Composite Parameters

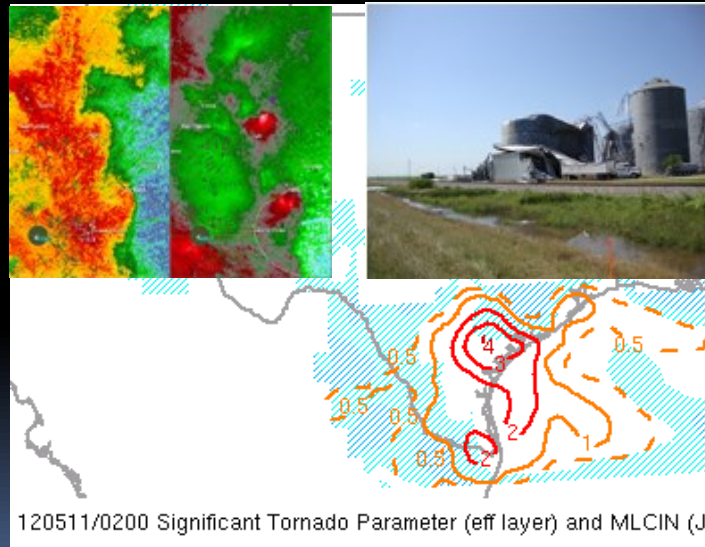## Significant Tornado Parameter

Tornado Outbreak May 10th, 2012

120510/1900 Significant Tornado Parameter (eff layer) and MLCIN (J/

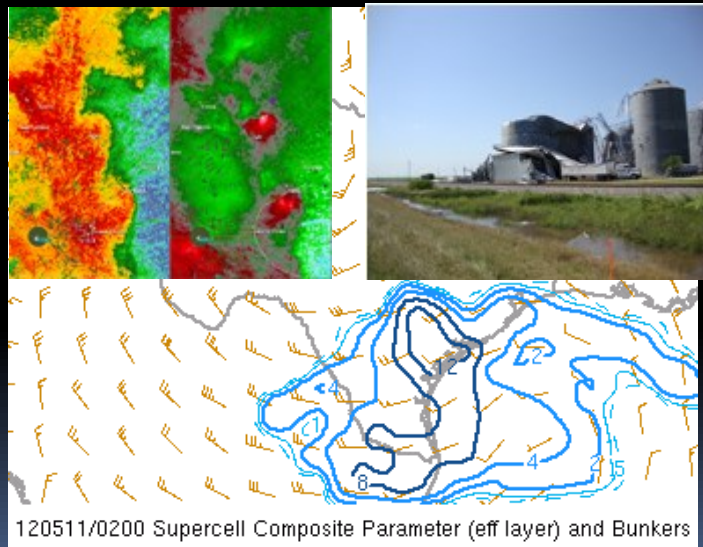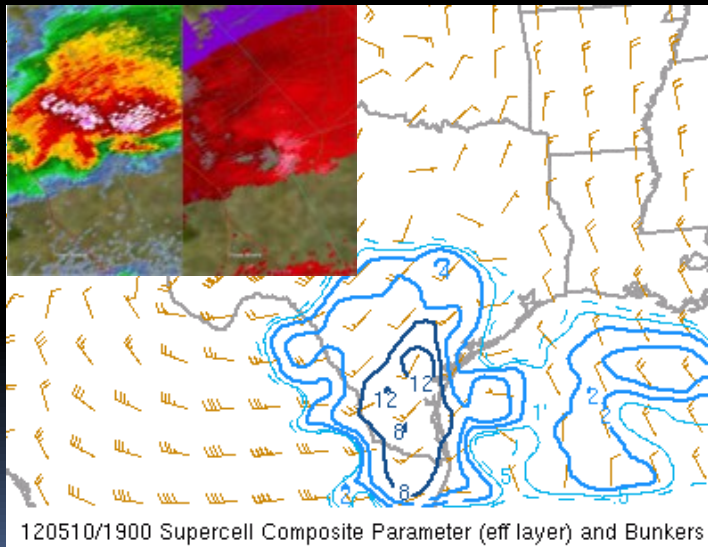120511/0200 Significant Tornado Parameter (eff layer) and MLCIN (J/

STP above 2 at 19 UTC 5/10/12

STP above 3 at 02 UTC 5/11/12

Tornado Outbreak May 10th, 2012

120510/1900 Supercell Composite Parameter (eff layer) and Bunkers

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

120511/0200 Supercell Composite Parameter (eff layer) and Bunkers
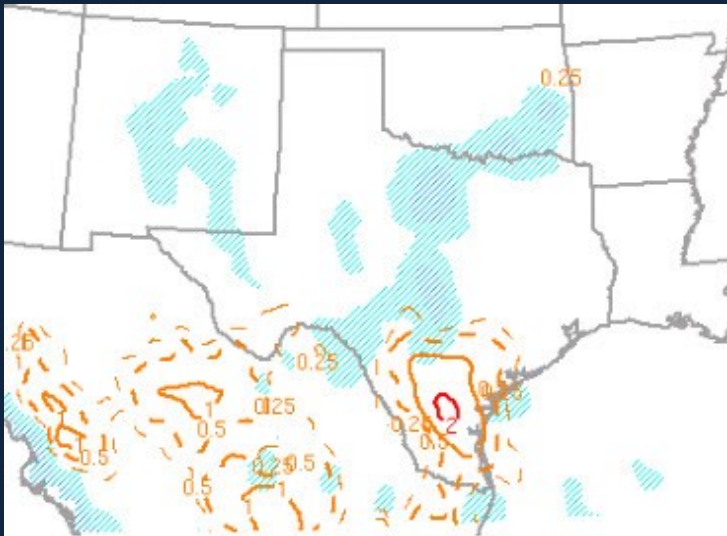
SCP 8-12 at 02 UTC 5/11/12
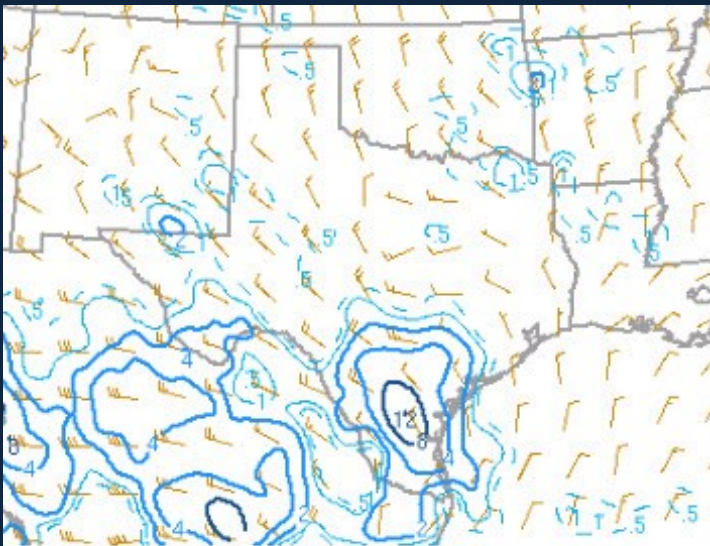
160531/2200 Supercell Composite Parameter (eff layer) and Bunkers

- ❑ Mixed Layer CAPE ranged from 2500 to 3000 J/kg

- ❑ Effective Bulk Shear was 35 to 40 knots

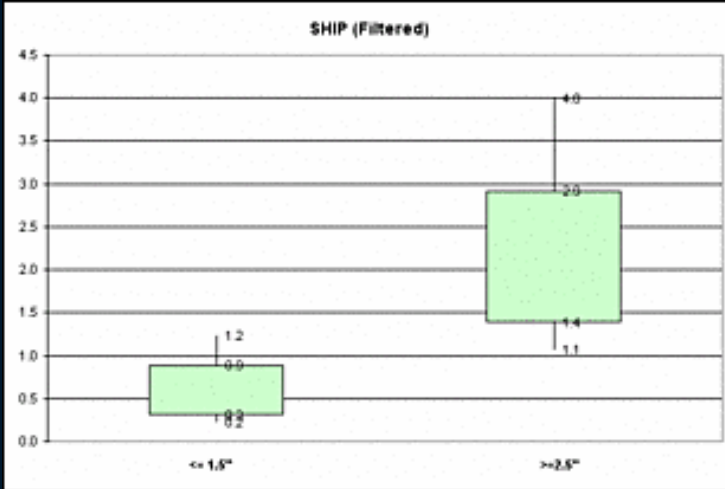- ❑ SCP increased to 8 to 12 from Kleberg County into the Brush Country

160531/2200 Significant Tornado Parameter (eff layer) and MLCIN (J/kg

- ❑ Deep moisture was over the region

- ❑ 00Z CRP sounding LCL was below 600 m for most unstable parcel

- ❑ Convective Inhibition was minimal

- ❑ STP Increased to above 2 west of Kingsville at 22Z

SHIP (Filtered)

- 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

Severe Hazards In Environments with Reduced Buoyancy (SHERB)

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

(0-3 km Shear Version)

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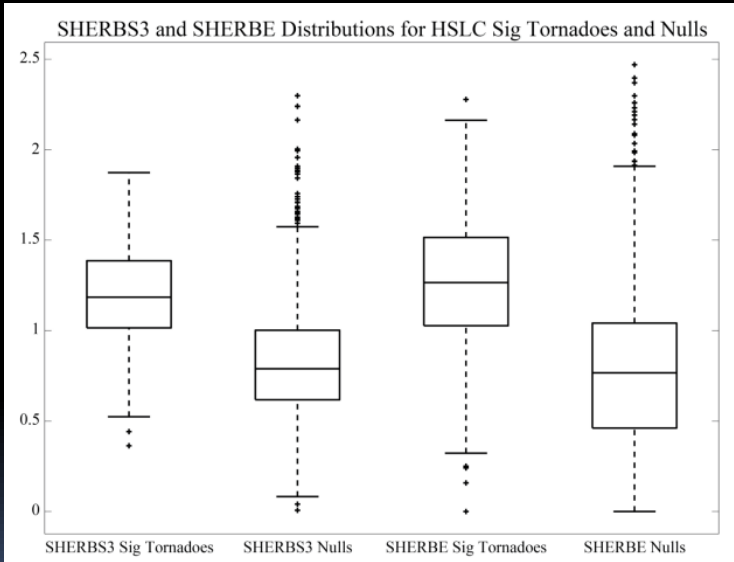
(Effective Shear Version)

- 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

SHERBS3 and SHERBE Distributions for HSLC Sig Tornadoes and Nulls

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

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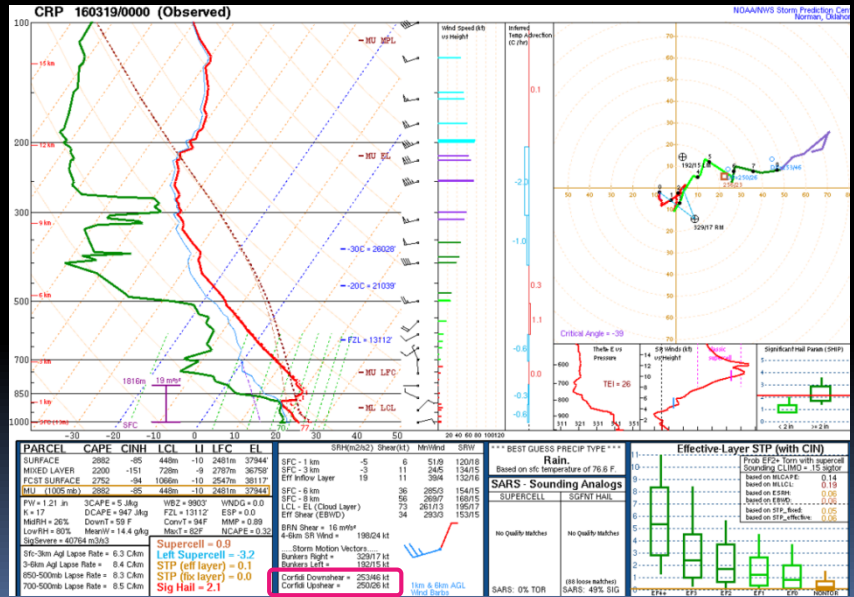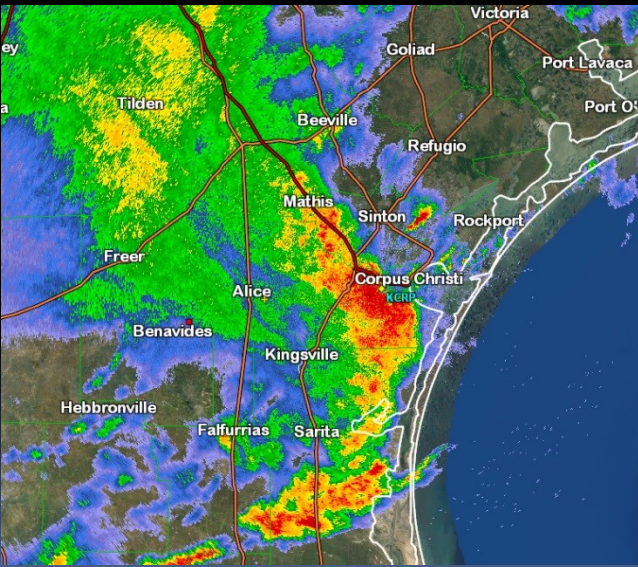
"Cold Pools and MCS Propagation : Forecasting the Motion of Downwind-Developing MCSs" by S. Corfidi (Dec. 2003, W & F)

Forecasting MCS Motion
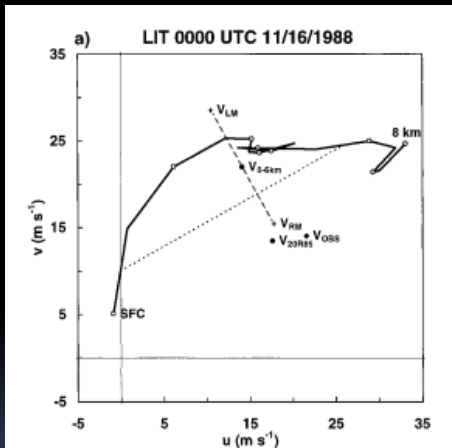
Corfidi Vectors

Severe Winds March 18th, 2016

Downwind Propagating MCS

a) LIT 0000 UTC 11/16/1988

b) CRP 0000 UTC 6/21/1996
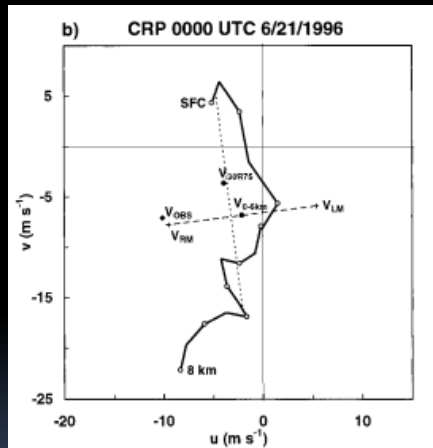
"Predicting Supercell Motion Using a New Hodograph Technique" by M. Bunkers, et al. (Feb. 2000, Weather & Forecasting)

- 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 – 35-40 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