A Comprehensive Severe Weather Forecast Checklist and Reference Guide

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1. **INTRODUCTION**

The National Weather Service Modernization and Restructuring Program has brought the operational meteorologist a wealth of weather data. Radar (WSR-88D), high resolution satellite (GOES Imagery), ASOS, and wind profilers have brought weather forecasters an ever increasing amount of raw meteorological data in near real time. Increased amounts of weather data on ever decreasing temporal and spatial scales, combined with the increasing processing capability of workstations, personal computers, and computer servers, bring the operational meteorologist an unprecedented amount of information. AWIPS and other new workstations will take even more advantage of this processing capability in the near future.

Given the scale and depth of meteorological data available, both now and in the future, a operational meteorologist has to assimilate larger data sets than ever before. The wealth of data can sometimes be overwhelming, especially during and just prior to the outbreak of severe weather. Systematic methods to diagnose the atmosphere's potential to produce severe convective weather can be a great help. Many such systematic approaches have been devised in the past, the most notable being by Miller (1972). Many of, if not most of, Miller's rules are still used today. A plethora of other scientifically based "rules of thumb" and pattern recognition models have also been developed. Every forecast office should develop a climatology and rules that work for their particular region.

This paper discusses the structure and parameters of the severe weather checklist/worksheet for the National Weather Service Office at Springfield, Missouri (NWS SGF). This checklist and reference guide is specifically designed to aid in the diagnosis of severe convection and to determine what types of severe weather are most likely (i.e. severe convective winds, large hail, and tornadoes).

A word of caution: "Rules of thumb" are good tools when a forecaster is under the stress of severe weather or impending severe weather. Some of these rules are scientifically based and others have been derived empirically. The basis for any such "rules" must be fully understood by operational meteorologists. In this way, the meteorologist will know when these rules can and cannot be applied. This checklist is a tool to guide a meteorologist through the meteorological reasoning process. This paper assumes the forecaster has a good understanding of severe weather parameters.

2. **CHECKLIST**

The following severe weather checklist was developed for NWSO SGF, but can be used for the much of the midwestern and southern United States. Local adaptations due to elevation, terrain and other local and regional factors must be made to fit a particular location. After a detailed surface and upper air analysis, you should proceed to this checklist (Table 1).

Table 1 - NWSO Springfield Severe Weather Checklist

Severe Weather Parameter	Indicators (Circle Letter)	Favorable Y/N (Add remarks as necessary)
. Low Level Temperature and Moisture	Depth of low level moisture now (or expected) to be greater than 3000 ft? Surface dew point >60°F? Distinct low level surface moisture axis present? Location/Time? Low level moisture convergence expected? Location/Time? Will the 850 mb max temperature ridge be over or west of the 850 mb moisture axis? Will temperature exceed computed convective temperature?	
Low Level Jet	Is a low level jet present or expected to develop? Location/Time? Highest 850 mb jet speed expected over CWA 850mb moisture convergence expected? Location/Time?	
Upper Level Support	Will there be a 300/250 mb jet > 65 kts	

	Ageostrophic circulation expected? Location? Coupled jet expected? Location?	
Lifting Mechanisms	Are any lifting mechanisms such as fronts or outflow boundaries present? List them along with their location. Will any intersecting boundaries be present? Location? Will lifting mechanisms be able to overcome capping inversion (generally if cap strength < 2°F and CIN <50 J/kg. Also note severe storms can develop regardless of CAP strength, **<u>if</u>** sufficient dynamic strength is available.)?	
Vertical Wind Shear	Will winds show significant veering (0-3km shear values > 35kts)? Is there (or will there be) speed shear > 25kts and/or directional shear > 30 degrees between 850 and 500 mb?	
Instability	Is/will the Lifted Index be £ 0? Is/will the K Index be > 30? (Can be as low as 20-25 with elevated convection) Will CAPE > 800 J/kg? Will there be high mid level lapse rates (700-500 mb) 6.5°C/km? Will there be warm advection at 850 mb? Will a significant capping inversion remain in place?	
700 mb Dry Intrusion	Is there or will there be a dry intrusion of air at or near the 700 mb level? (Dew point depression > 6°C)	
Upper Vertical Motion	A. Is large scale forcing indicated by model Q vector and omega fields? Will there be significant PIVA/Differential PVA?	
Satellite Imagery/ Cloud Indicators	Are there lines of cumulus or mid clouds (altocumulus castellanus–ACCAS) on the morning satellite imagery? Does satellite imagery indicate a short wave moving into the area with corresponding significant height falls on upper air analysis?	

	Is there significant mid level drying present on water vapor imagery?	
Surface Pressure Falls	Is there or will there be strong surface pressure falls? If 10A is yes, will there be a corresponding pressure rise moving toward the fall area? (The larger the absolute value of this rise-fall couplet, the larger the potential for severe weather in the pressure fall area)	

If you have **6 or more positive (or yes) parameters**, proceed to the Miller/SPC checklist. In addition, calculate the wind index (WINDEX), and the height wet bulb zero (WBZ). If you **have less than 6 positive parameters**, you will probably not have <u>organized</u> severe weather in your area. One word of caution: Be vigilant for elevated convection above an elevated capping inversion. If your analysis reveals a stable atmosphere in the lower levels but has moisture above a fairly strong inversion, recalculate the indices above the inversion or check for steep mid level lapse rates. See section 8A for more information on elevated convection. One last word of caution: Beware of rapidly changing synoptic environments.

Table 2 - Severe Weather Checklist (After SPC (1998) and Miller (1972))

PARAMETER	**WEAK**	**MODERATE**	**STRONG**
Surface Pressure	>1010 mb	1010 to 1005 mb	<1005 mb
	<55° F	55-64° F	65°
12hr Surface Pres Change	0 to -3	- 4 to -7	-8
850 mb Temp Axis	East of Moist Axis	Over Moist Axis	West of Moist Axis
850 mb Jet	<25 kts	25-35 kts	>35 kts
850 mb Dew Point	8° C	8 - 12° C	>12° C
700 mb Dry Intrusion	N/A or Weak 700 mb winds	Winds from dry to moist intrude at <40° and are 15 kts	Winds intrude at an 40° and are 25 kts

) mb Temp No ChangeLine	Winds cross line 20°	Winds cross line >20° and40°	Winds cross line >40°
500 mb Height Change	< 30 m	30 and 59 m	60 m
500 mb Wind Speed	35 kts	36-49 kts	50 kts
500 mb Vorticity Advection	Neutral or NVA	PVA-Contours Cross Vorticity Pattern 30°	PVA-Contours Cross Vorticity Pattern >30°
850-500 mb Wind Shear **Speed Shear** **Directional Shear**	15-25 kts 20-30°	26-35 kts 30-60°	>35 kts >60°
300-200 mb Jet	65 kts	66-85 kts	>85 kts
	70-80% or 40-50%	50-70%	50-70%
TT	<50	50-55	>55
LI	>-2	-3 to -5	-6
CAPE	800-1500 J/kg	1500-2500 J/kg	>2500 J/kg
SWEAT	< 300	300-500	> 500
WBZ	>11000 ft <5000 ft	9000-11000 ft 5000-7000 ft	7000-9000 ft
Helicity (0-3km)	150-300 m^2/s^2	300-450 m^2/s^2	> 450 m^2/s^2
SSI	-1 to +2	-1 to -3	<-3

The rest of this paper contains various weather checklists, rules of thumb, and other severe weather information. Forecasting large hail, strong winds, tornadoes, derechos, and pattern recognition are examined.

This paper will not address radar techniques while working severe weather. The best compendium that we've come across on 88D severe weather reference materials is by Falk (1997).

3. SURFACE, UPPER AIR, AND COMPOSITE CHARTS

Surface

Hourly surface mesoscale analysis is critical in severe forecasting. Detailed analysis can uncover features such as boundaries, mesolows, bubble highs, strong pressure falls, and moisture pooling. Here is a list of the **optimum** surface features to key in on for severe weather:

- Dew Points 65°F
- Theta E ridge and positive Theta-E advection
- Low-level moisture flux convergence
- Thermal ridge over or west of the moisture axis
- Areas experiencing strong temperature and dew point rises
- Rapidly developing cumulus congestus within areas
- Areas reaching convective temperature
- Focusing mechanisms (fronts, troughs, gust fronts, dry lines, outflow boundaries, etc.)
- Surface pressure 1005 mb
- Areas with concentrated pressure falls of 5 mb over 12 hours. Pressure falls can **sometimes** give clue to where mesolows form. Mesolows may develop from intersections of discontinuity lines. Winds back by 10 to 30 degrees near the northeast quadrant due to enhanced convergence. Some prime locations for mesolows development include a squall line intersecting a front or dry line and a low level jet intersecting a warm front.

A. Upper Air Conditions

The rawinsonde sounding is the principle tool for diagnosing the stability of the troposphere quantitatively (Kula, 1996). Despite, only two upper air soundings a day, a forecast should start with a 4-dimensional mental picture of the atmosphere (Doswell, 1982). Upper air and surface maps can and should be enhanced to emphasize features of importance to convective storm forecasting (Maddox, 1979b). Listed below are the**optimum** upper air features for severe weather.

1. 925 mb

- Areas under and just west of the low level jet (winds 25 kts)
- Thermal ridge west of moisture axis
- Significant warm air advection
- Strong moisture flux convergence
- Focusing mechanisms (fronts, troughs, and dry lines)

2. **850 mb**

- Areas under and just west of the low level jet (winds 35 kts) or on the nose of the jet
- Thermal ridge west of moisture axis
- Dew Point 8°C
- Significant warm air advection

- The greater the angle of the winds from dry to moist air, the greater the instability.
- Strong moisture flux convergence
- Focusing mechanisms (fronts and troughs)
- Moisture transport axis

3**. 700 mb**

- Wind veering 30 degrees between surface and 700 mb
- Dry air intrudes at a 40 degree angle and speeds of at least 25 knots. Look at Skew-T's, model soundings, and gridded data for significant entrainment.
- Dew point depression > 6°C. Significant dry air in mid levels may signal possibility of strong downdrafts.
- Winds cross 12 hr temperature no change line at > 40 degrees
- Focusing mechanisms (fronts and troughs)
- Significant upward vertical velocity (UVV)

4. **500 mb**

Wind speeds of 50 knots

- Short Waves, especially negatively tilted rapidly moving short waves
- PIVA with contours crossing vorticity pattern > 30 degrees
- Significant cold pool aloft **(-16°C** Dec-Feb; **-14°C** Mar-Apr and Oct-Nov; **-12 °C** May-Jun; **-10°C** Jul-Sep)
- Horizontal shear over 90 miles is 30 kts

5. **300 and 200 mb**

- Wind speeds 85 kts
- Diffluent areas
- Left exit region and right entrance region of straight jet streaks; left exit region of cyclonically curved jet streak; right entrance region in anticyclonic jet streak
- Most severe weather occurs south of the polar jet, and north of the subtropical jet (coupled jet) or in the left exit region of a jet
- Severe weather outbreaks often occur in the diffluent zone between the polar and subtropical jet streams
- Long wave troughs and strong synoptic scale lift
- Significant height falls and or a deepening of an upper level low

C. **Composite Chart**

Many offices use a composite chart methodology which Miller (1972) advocated. The composite chart provides a structured way of combining the crucial features on one map. Including all the surface and upper air features on a central map in different colors will allow the operational forecaster to better access the potential for severe convection. However, the relevant parameters on any given day may or may not be useful. The weather situation should, in part, dictate the parameter choices (Doswell, 1982).

In tornado forecasting, SPC uses composite charts (Doswell, et al., 1993) that emphasize:

- Synoptic and mesoscale upward motion
- Sufficient moisture and lapse rate for a parcel to be positively buoyant
- Vertical wind structure

4. **MESOSCALE ANALYSIS , HODOGRAPHS, PROFILERS, AND SATELLITE**

A. **Mesoscale Analysis**

There are a number of useful tools to diagnose the mesoscale meteorological environment. Evolving mesoscale analysis tools on AWIPS workstations (MSAS and LAPS) allow forecasters to utilize hourly surface data to identify mesoscale lifting mechanisms needed to force boundary layer air beyond the LFC. Hourly parameters include lifted indices, pressure change, and moisture flux convergence, just to name a few. The ADAP decision tree section on pages 28 to 33 in the Bothwell (1988) paper can be very useful in severe weather forecasting and can be adapted to the new mesoscale analysis programs. Figure 1 is just one portion of this decision tree. In addition to Bothwell's paper, three other operational papers on mesoscale analysis are from Byrd (1994), Vallee (1991), and Waldstreicher (1988).

Break?

One of the most challenging parts of severe weather forecasting is determining when, and if, the cap will break. Most forecasters have experienced a busted forecast where they had a very unstable environment, with a cap in the low levels, and a convective temperature that was never reached. Conversely, situations such as the Plainfield, IL 1990 tornado, can occur when you have a strong cap with prodigious CAPEs and helicities. Temperatures 12°C at 700 mb and/or CIN < -50 j/kg **normally** inhibits thunderstorms, **however**, severe storms can develop regardless of CAP strength, if low level forcing exists. Typically, the cap will be eroded by surface heating and/or large scale lifting.

Emlaw (1991) has the one of the best operational paper we've come across on this subject to date. He offers two techniques designed to be used 4 to 8 hours in advance of late afternoon convection to determine the probability of strong convection in a capped environment. Forecasters should also utilize data from special and modified soundings, pireps, mesonet hourly data (where available), LAPS and MSAS based skew-t's , and GOES soundings.

nalysis

Hales (1996) states, that many severe weather outbreaks are preceded by 1-2 hours of strong pressure falls such as the Tulsa tornado of 1993. The potential is further enhanced if there is a corresponding pressure rise moving towards the fall area. Additional information on isallobaric analysis can be found in Togstad (1994).

B. **Hodographs**

Hodographs indicate vertical wind shear from an upper air sounding wind profile or model derived wind profile. Environmental storm motion and shear vectors (both general and storm relative) can be determined by hodographs and these parameters are a useful tool in determining storm organization.

A hodograph's length and shape over a given depth are the best means for determining a potential storm environment's vertical wind shear and provides implications for anticipating convective storm structure and evolution. Hodographs are an extremely helpful forecasting tool, especially in recognizing the potential for supercell thunderstorms. Severe weather hodographs can be broken down into four main groups (Sturtevant, 1995):

Implies storm splitting into left and right movers and some supercells

Implies short lived multicells

Implies squall lines

Implies supercells (can be open or closed)

Additional information can also be found in Bunkers et al., (1998) and Johns and Hart (1993).

C. **Profilers**

There are a number of operational uses for profiler data. Wind profilers can be extremely beneficial to identify features for general and severe thunderstorms**.** An excellent operational paper on profilers is by Rich (1992). Some of the operational convective uses for profiler data include:

- Increasing or decreasing vertical wind shear
- Identify the presence and location of upper level diffluence
- Location of jet streaks, descending jets, and mid level rear-inflow jets
- Onset, cessation and location of low level jets
- Areas of possible differential temperature advection leading to the destablization of the air mass
- Locate troughs, ridges, and fronts

- Identify areas of upward vertical motion that will enhance convection. In addition, observed profiler winds along with isentropic surface analysis can indicate areas of isentropic lift

The sounding's density layers and areas of low and mid level wind shear can also be modified. Modified data can be used to create a modified hodograph and recalculated helicity.

D. **Satellite**

Satellite data contains an cornucopia of invaluable severe weather information. New satellite tools such as NSAT, AWIPS, and internet sites with special satellite features, have improved severe weather forecasting. Goetsch (1987) is the best paper we have come across addressing the satellite aspects of thunderstorms. His paper addresses such features as low level boundaries, intersections, arc clouds, low level moisture axis and wind flow, upper level short waves, and cirrus streaks.

Reports of altocumulus castellanus (ACCAS) offer the first clue to an unstable atmosphere. Water vapor imagery can be very beneficial at locating such features as mid level drying (dark areas), upper level jet maxes, and tropical moisture connections. For additional satellite information, refer to the NESDIS web site (http://www.nesdis.noaa.gov/)**.**

5. **FORECASTING LARGE HAIL**

The four primary forecasting keys for hail (Hales, 1996) are:

- Strength of Updraft (CAPE)
- Height of freezing level (WBZ)
- Environmental wind structure
- Remembering that supercells **(**especially HP supercells) **can** produce prodigious hail

Some operational considerations include the size and distribution of CAPE, using a reasonable lifted parcel, and the environmental lapse rates. Another important factor is the melting of the hailstone as it falls to the surface from the freezing level (Sturtevant, 1995). Forecasters should look for a cold pool at 500 mb (usually associated with a closed low), as it moves into an area of moderate low level moisture.

Figure 2 has Miller's two methods of predicting hail size. These charts are over 25 years old but still work quite well. Additional information can be found in Polston (1996), D. Smith (1996) and Shanklin (1989).

FORECASTING HAIL SIZE

1. Determine Convective Condensation Level (CCL is found using the mean mixing ratio, in moist layer of lowest 150mb, to its intersection with the temperature). Where the CCL crosses the temperature is point A (Fig 1).
2. Point B is where the temperature is -5°C.
3. From point A go moist adiabatically to the pressure at B, this is point B'.
4. The difference in temperature (°C) between B and B' is used with the horizontal axis in figure 2.
5. Go from B dry adiabatically to the CCL, this is point C. The temperature difference between B and C is used with the vertical axis in Figure 2.
6. Forecast hail size, using Figure 2 *unless the wet-bulb-zero height is above 10,500 feet*, then also use Figure 3. (See 3WU Aerospace Science Extract, Mar 78, for determination of the wet bulb).

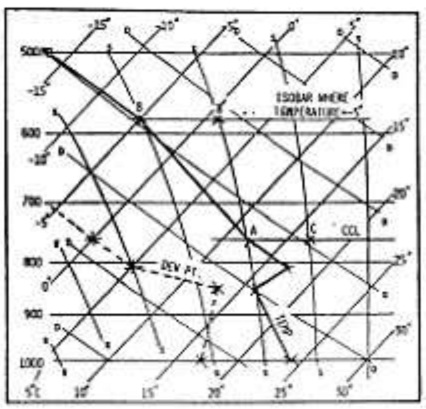

Figure 1

Example:

BB' = -5 to +1 = 6°C
BC = -5 to +17 = 22°C

From Figure 2 a hail size approximately 1" is determined. Assuming the Wet Bulb Zero is below 10,500 feet, the forecast hail size would be 1".

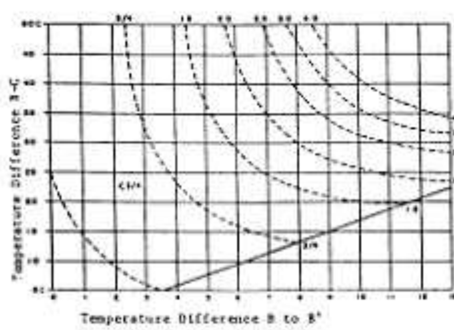

Figure 2. Hail Size

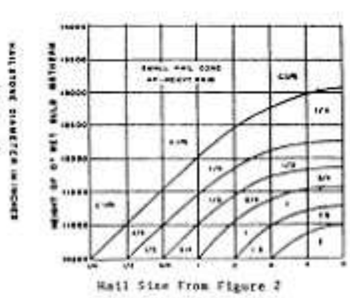

Figure 3.

6. **FORECASTING DAMAGING WINDS**

The <u>four</u> primary forecasting keys for damaging winds with environments with **<u>weak shear</u>** (Hales, 1996) are:

- Amount of dry mid-level air
- Strength of the updraft
- Amount of low-level moisture
- Downdraft instability.

Operational forecasters should look for Inverted-V soundings, steep low level Theta-E lapse rates, and the strength of the CAPE. Sometimes high CAPE and weak shear environments can lead to derecho development. When the environmental shear is weak, the thermodynamic profile is a primary signal for identifying when strong convectively induced winds are likely to occur. (Johns and Doswell, 1992).

The four primary forecasting keys for damaging winds of air-masses with **moderate to strong shear** (Hales, 1996) are:

- Amount of low and mid level helicity
- Degree of instability
- Amount of dry mid level air
- Rapid storm motion (> 40 knots)

Precipitation loading and negative buoyancy due to evaporative cooling are recognized factors in initiating and sustaining downdrafts (Johns and Doswell, 1992). Once a downdraft is established, continued entrainment of unsaturated air in the mid levels aids in evaporation and consequently stronger downdrafts. Storms in moderate to strong shear can turn into supercells, bow echos, and derechos (Hales, 1996).

A. Bow Echoes and Derechos

1. Warm Season

- Often form and travel along a quasi-stationary low level thermal boundary orientated parallel to the mean tropospheric flow (Johns, 1993).

- Almost always initiated in an area of low level warm air advection. Can also form with weak upper troughs with lifted indices < -8 and CAPE ^{3} 4500 J/kg.
- Many times moisture values in the convergence zone are higher than in surrounding areas.
- Numerical simulation experiments by Weisman (1990) suggests that a favorable environmental condition for bow echo development is one where there is <u>moderate to strong shear between the surface and 2.5 km AGL (0-8200 ft)</u>. The wind field is unidirectional above.
- Bow echoes can occur in areas where the mid level wind speeds are relatively weak (25-35 kts) (Johns, 1993).

2. <u>Cool Season</u>

- Usually a squall line develops ahead of a cold front and bow echo activity is embedded within this line
- 500 mb wind speeds up to 75 to 85 kts
- Dry, potentially cold layer in the downdraft entrainment region (3-7 km or 9800- 23,000ft)
- Bow echoes often display hodographs that are relatively straight with storm motions a little to the right of the hodographs and very fast, even faster than the 0-6km AGL (0-19,700 ft) mean wind (Johns and Hart, 1993).
- Can occur in marginally unstable air-masses

There is a large number of excellent operational papers on bow echoes. Forecasters seeking additional information on these phenomena should refer to Przybylinski (1995), Johns (1993), Weisman (1993), and Johns and Hirt (1987).

3. <u>Johns and Hirt Derecho Checklist</u>

Derechos are essentially long-lived bow echoes. Johns and Hirt (1987) developed a checklist for warm season derechoes. They defined a derecho “to include any family of downburst clusters provided by an extratropical mesoscale convective systems (MCS)”. The checklist was designed for the operational forecaster to assess the potential for warm season derechoes, which occur with stagnant weather patterns and weak synoptic scale features (Johns, 1993). The checklist is used after convection has developed in the area of interest (Anderson, 1994)**,** and forecasters should look over a large area and not just a single point**.**

Table 3, Part A -Johns/Hirt Derecho Checklist

Parameter	**Yes**	**No**
500mb flow direction ³240°		
Quasi-stationary boundary nearly parallel to 500 mb flow?		
850 mb warm advection within 200 nm		
700 mb warm advection within 200 nm		
ELWS ³25 knots *		
If <u>all</u> of the following <u>five</u> conditions are present in the area of interest, proceed to Part B. Otherwise, derecho development is not likely		

* Johns and Hirt define ELWS as the Estimated Lower Mid Tropospheric (LMT) Wind Speed. The LMT is the layer approximately 8200 to18,000ft. A simple way to calculate this is to average the 700 and 500 mb winds.

Table 3, Part B -Johns/Hirt Derecho Checklist		
Parameter	**Yes**	**No**
500 mb 12 hour height falls 60m?		
SPC lifted index (using the mean temperature and mixing ratio of the lowest 100 mb) -6 or lower?		

ELRH (relative humidity in the LMT) < 80 percent? **		
If all of the following conditions are present in the area of interest, proceed to Part D. Otherwise, proceed to Part C.		

** ELRH is the Estimated Lower Mid Tropospheric (LMT) Relative Humidity

Table 3, Part C - Johns/Hirt Derecho Checklist		
Parameter	**Yes**	**No**
SPC lifted index -8 or lower?		
ELRH < 70% in initiation area (<80% downstream?) **		
If <u>both</u> of the following conditions are present in the area of interest proceed to Part D. Otherwise, derecho development is not likely.		

Table 3, Part D - Johns/Hirt Derecho Checklist		
Parameter	**Yes**	**No**

Do the parameter values satisfying the criteria for the SPC lifted index and ELWS extend downwind along the quasi-stationary boundary for a distance of at least 250 nm from the convective system?		
If yes, be alert for derecho development for areas downstream for at least 250 nm. Otherwise, the potential for wind damage will probably be too localized to meet the areal criterion for a derecho.		

In addition to a surface boundary parallel to the mid level flow and strong instability, Hales (1996) points to two other considerations for possible derecho development. He also looks for:

- High surface Theta-E airmass
- West to northwest flow aloft

B. **Dynamic Squall Lines (Imy (1998) and Sturtevant (1995))**

Squall lines may form on some surface or low level discontinuity line and may or may not be parallel to a front. Squall lines produce a variety of severe weather with strong damaging winds the main threat.

1. Key Parameters

- Strong directional shear from the surface to 700 mb with little or no shear aloft
- 500 mb winds > 50 kts
- Well defined westerly jet stream
- Great range of instability, from marginally unstable to extreme
- Active southeast low level jet transporting deep low level moisture into the threat area
- Warm moist air is usually overrunning cooler air
- Evaporative cooling in the upper levels
- Cold air advection at 500 mb and layer of dry potentially cold air 3-7km AGL (9800-23,000ft)

- Essential ingredient that sustains a long lived line of time dependent cells is the amount of low-level wind shear which encounters the circulation induced by the cold thunderstorm outflow (Rotunno et al., 1988).

2. <u>850/500 mb Thickness Chart</u>

- Squall lines often develop about 100 miles upstream of the 850/500 thickness ridge
- Squall lines often develop in the area of the maximum horizontal anticyclonic shear zone of the thickness ridge

3. <u>Initial Outbreak Area</u>

- Along and just ahead of a cold front or along an advancing dry line
- Along a low level trough, within or just above the moist layer
- Bounded by 700 mb cold front and east from there to a point where air is too stable to produce severe weather
- Where the dry air at 700 mb meets the overrunning warm moist air

4. <u>Steering and Timing</u>

- Steering of squall lines is generally the 500 mb wind direction at 40 % of the wind speed
- Maximum threat time is from peak of afternoon heating to shortly after sunset

C. **Four Types of Squall Lines (Bluestein and Jain, 1985)**

1. <u>Broken Line</u>

- Forms along cold front
- Relatively weak wind shear
- Large CAPE and large BRN
- Low relative helicity

2. <u>Back Building</u>

- Can occur with or along a number of different types of surface boundaries
- Environments with large CAPE, small BRN
- Usually unidirectional flow through a deep layer wth minimal shear

3. Broken Areal

- Formation appears to result from the interaction of outflow boundaries
- Low CAPE

4. Embedded Areal

- Convective line appears within a larger area of weaker stratiform precipitation

D. AFGWC Method For Determining Maximum Convective Wind Gusts

If severe thunderstorms are forecast, use Figure 3 to calculate maximum wind gusts. This method is over 25 years old, but still has merit today.

A. McDonald Method For Gust Potential Forecast Procedure (1976)

Another useful method to determine maximum wind gusts is from McDonald (1976). Figure 4 contains this technique, which has been successfully used in the western U.S. for many years.

A. Maximum Vertical Velocity Using CAPE

A maximum vertical velocity (w max) at the equilibrium level for a parcel can be computed using the CAPE. The following equation (from Doswell, et al., 1991) gives the maximum vertical speeds of about 95 to 135 knots for CAPEs in the range from 1500 to 2500 J/kg. Owing to water loading and mixing effects, the vertical velocity in real storms is usually about half this value.

G. **Downbursts and Microbursts**

This of the section paper will address dry and wet microburst forecasting, and will not focus on radar techniques associated with either. If you desire additional information, two excellent operational papers regarding microburst techniques on radar are by Vasiloff (1997) and Ellis and Oakland (1989).

1. Forecasting Dry Microbursts

Wakimoto (1984) wrote an excellent paper on forecasting dry microbursts. The study used 155 dry microburst days out of 186 total. The highest number of microbursts occurred in mid July, although late May had several active days. Forecasters should look at the following features:

a. Shallow radiation inversion on 12Z sounding at the surface, approximately 40–50 mb deep

b. Dry adiabatic layer must extend to approximately 500 mb

c. Mean subcloud mixing ratio is approximately 3-5 g/kg, with moisture present around 500 mb

d. Convective temperature must be reached during the day.

2. Forecasting Wet Microbursts

Atkins and Wakimoto (1990, 1991) wrote two excellent papers on wet microburst activity in the southeastern United States. All of the events studied were accompanied by heavy precipitation and a temperature drop. There was a peak of microburst activity at 20Z, and a secondary peak at 12Z. Forecasters should look for the following:

a. Sounding close to the moist adiabatic lapse rate and has warm cloud bases

b. Thermal environment is statically stable

c. Shallow radiation inversion on 12Z sounding at the surface, approximately 50 mb deep

d. Low level moisture extends from the surface to about 500 mb and is capped by dry mid level layer above 500 mb

e. Equivalent potential temperature profiles are potentially quite unstable with a minimum at about 650 mb

f. Larger (negative) lifted indices, CAPE, and BRN for both the morning and the afternoon

g. Afternoon Theta- E from surface to mid levels (650-500mb) 20K. For days with thunderstorms, with no microburst (null days), theta E was observed to be < 13K. Figure 5 depicts typical theta E profiles for downburst and non- downburst days.

3. <u>An Approach to Forecasting Downbursts (Ladd, 1991)</u>

Ladd (1991) broke down forecasting downbursts into two phases:

1. Assessing the potential for downburst development
2. Determining the most likely location for downburst occurrence

You can further break down the first phase into two sub-phases: a thermodynamic assessment of the atmosphere and a kinematic assessment of evolving features. Forecasters should:

a. Narrow the region of suspicion based on upper level flow regimes and expected advection of properties. Therefore, an analysis of upper level charts is a must.

b. Look for subtle features by carrying out height analysis at a 10-20 meter interval and temperature and dew point analysis at 2-3°C intervals.

c. At 850 mb and 700 mb, look for convergence zones, temperature ridges and moisture axes

d. Look for advection of dry mid-level air over low-level moist air

e. Determine the CCL and note the degree of positive energy available on modified soundings. Eblen (1990) looks for the CCL 5000 feet.

f. Look at subcloud lapse rates. High subcloud lapse rates (700-500 mb) have been positively correlated with downburst potential over the High Plains (4°F/1000ft or 8°C/km). Across north and east Texas, the subcloud layers are more aptly reflected by the 850-700 mb layer.

g. Analyze and track surface boundaries, development of temperature ridges, and increased moisture pooling (or convergence) into an area.

h. Look for "second generation" convection. In other words, outflow from a parent storm complex eventually triggered the downburst-producing thunderstorm. An hourly 1-2 mb analysis is necessary, as well as closely monitoring of radar and satellite to detect and track these outflows.

i. Use LAPS, MSAS, MESONET and ACARS (aircraft) data to track instability, temperature and moisture convergence into an area.

4. <u>WINDEX Equation To Forecast Microburst Wind Gust Strength (McCann, 1994)</u>

WINDEX is specifically designed to help forecast microburst potential and is based on studies of observed and modeled microbursts. It can be computed from environmental conditions either based on upper air soundings or numerical model predictions. Data indicates a good correlation between WINDEX and maximum microburst wind gusts in knots.

WINDEX is better at assessing microburst potential versus the traditional stability indices (such as the Lifted Index) which only measure updraft potential. WINDEX not only considers environmental lapse rates, but also considers low level moisture availability for wet microbursts.

The WINDEX equation is as follows:

= The height of the melting level in km above the ground.

= /12 (is the mean mixing ratio in the lowest 1km AGL), and can not be greater than 1

= Lapse rate in degrees celsius per km from the surface to the melting level

= Mixing ratio at the melting level

The radicand in the WINDEX equation is multiplied by 5 to estimate the maximum potential wind gust at the surface in knots. When the lapse rate is low, that is, the lapse rate squared is less than 30, the radicand may beome less than zero. When this happens, WI is set to zero.

Studies indicate that outflow boundaries play an important role in the development of microburst producing thunderstorms. Commonly, strong microbursts develop where outflow boundaries move into the WINDEX maximum (in an analyzed WINDEX field). Large areas of high WINDEX often exist on an analysis in which, because of no significant outflow boundaries, no damaging microbursts develop. However, weaker microbursts can still develop without the presence of significant outflow boundaries.

7. SUPERCELLS AND TORNADOES

A. **Supercells**

The common factor in all supercells is the deep, persistent mesocyclone, regardless of the storms precipitation characteristics. Supercells occur in environments with an extremely wide range of CAPE. Johns and Doswell (1992) came up with the following conclusions on supercells:

- There are <u>three</u> important wind related factors for supercells; 1) nature of the wind profile in the storm inflow layer, 2) strength of the storm-relative inflow, and 3) strength of the wind in the middle levels (deep layer shear).
- <u>Two</u> parameters are related to rotational potential; 1) positive mean shear and 2) Storm Relative Helicity (SRH). Positive shear estimates the mean shear of a given layer of a hodograph. SRH takes storm motion into account.

- Strength of the storm inflow is a critical factor in the development of a strongly rotating updraft.
- During the <u>cooler months</u>, wind environments that favor mesocyclone development are common and widespread, however, instability is usually infrequent and relatively low.
- In the <u>warmer months</u>, moderate to high values of instability occur while sufficient wind environments are infrequent.
- **Between CAPE and vertical wind shear, <u>vertical wind</u> shear is the most crucial for supercell development** (Moller et al., 1994).

1. <u>Characteristics of a Supercell Hodograph (Brown, 1990)</u>

- Marked directional shear in the lowest 3 km (9800 ft)
- Marked speed shear from 3 to 12 km (9800- 39,000ft)
- 2 to 3 km deep layer shear at mid altitudes where the wind shear is a minimum (less than 1 m/s per km on average)

2. <u>LP Supercells (Bluestein and Parks, 1983)</u>

- Found in the surface dry line environment over the western Great Plains
- Characterized by low moisture values in low levels (Inverted V sounding)
- Relatively high LFCs
- Lifted Index is not representative due to a lack of low level moisture

Large hail is the main threat, but narrow rope like tornadoes can occur

3. <u>HP Supercells (Moller, et al., 1990)</u>

- Found in central, southern, and eastern United States
- Significant instabilities, but with helicity which is only marginal for classic supercells
- High moisture content lowers LFC, thus less lift is needed to sustain convection
- Significant low level warm air advection across a pre-existing thermal boundary
- Produce tornadoes, heavy rain and flash flooding, large hail, and damaging winds

4. <u>Low Topped Supercells</u>

- Typically during cool seasons, and resemble Miller (1972) Type D patterns.
- Cold core upper low (mid level temperatures â€‘20°C) positioned above and slightly upwind of a surface low

· Low equilibrium level and low tropopause (less than 30,000ft).

· Often drying in the mid levels, allows diurnal surface heating to play a large role in a development of severe thunderstorms near the leading edge of the upper level cold air pool.

· Low values of CAPE, generally £1000 J/kg, however, airmass is likely more unstable when you consider vertical distribution of CAPE.

· Steep 850 mb to 600 mb lapse rates (Davies 1993)

· Moderate to strong wind fields while exhibiting significant low level vertical wind shear (Foster et al., 1995)

· Davies (1993) found magnitudes of EHI (>3.0), 0â€‘2 km AGL storm relative inflow (>20 kts), and 3â€‘6 km AGL winds (>30 kts) significant and suggestive of tornadic supercells.

· Tornadoes typically occur within the warm sector southeast of the upper cold low, in relative close proximity of the cold air aloft, yet also close to the mid level jet.

Additional information can be found in Boyne (1995) and Murphy and Woods (1992).

5. Mid Level Storm Relative Wind Speed With Supercells (Thompson, 1998)

· Observed or forecast mid level (500mb) storm relative (SR) wind speeds can also help discriminate between tornadic and non-tornadic supercells.

· 500mb SR winds of 7 to 10 m/s seem to be where supercells transition from non-tornadic to tornadic in many cases.

· 500mb SR wind speed forecasts using PCGRIDDS analyses of Eta Model output shows that a threshold of 8 m/s can be effective at determining where supercell tornadic storms may occur.

· Forecasters should be especially aware of supercell tornado potential when 500 mb SR wind speed is forecast, and storm inflow can be enhanced by mesoscale processes (boundaries, mesolows).

6. Other Supercell Notes

· Typical 0-3 km SRH threshold of 150 m/s for mesocyclone formation (Davies Jones et al.,1990)

· SRH can be significantly influenced by smoothing of data, vertical resolution, and small (1-2 m/s or less hodograph changes (Markowski et al., 1998)

· Weisman (1996) considers the 0-6 km shear vector a better indicator of supercell potential than SRH, with a typical threshold of 20 m/s.

- Due to variations in structure, supercells occurring in the same thermodynamic environments may differ in size, amount and distribution of hail (Sturtevant, 1995).
- Additional information can be found in Przybylinski (1996).

B. **Tornadoes**

The tornado arguably may be the most difficult weather feature to anticipate. Hales (1996), a forecaster at SPC for more than 25 years, has stated that the three primary forecasting keys for tornadoes are:

- Strength of low and mid level wind shear
- Degree of instability
- Some dry air in the mid levels

Tornadoes form in many different types of air masses, some of which are understood and some which are not. Miller classified upper air soundings associated with tornadoes into four types (Great Plains, Gulf Coast, Pacific Coast, and High Plains). This section will only include the Great Plains variety as it is the most common and severe. For additional information on tornado types, see Miller (1972). This paper will not address non-supercell tornadoes, but additional information can be found in R. Smith (1996).

1. <u>Type I - Great Plains Type</u>

- Optimum airmass structure for severe weather and tornadoes
- Continental tropical air overruns maritime tropical air at 8000 - 10000 ft
- Subsidence inversion, conditionally unstable above and below it, and stable through it
- Wind increase in speed and veer with height
- Winds increase in altitude in the dry air above the inversion, having a component of 30 kts perpendicular to the flow in the warm moist air
- Dew point >55° F, Lifted Indices -6 and Total Totals of >54
- Severe weather occurs most often in late afternoon due to strong surface heating

2. <u>Shear Versus Instability</u>

A. Energy Helicity Index (EHI) (Hart and Korotky,1991)

The EHI is an index that incorporates vertical shear and instability for the purpose of forecasting supercell thunderstorms. It is related directly to SRH ( ) in the lowest 2 km and CAPE (J/kg) by the following equation:

Higher values indicate unstable conditions and/or strong vertical shear. Since both parameters are important for severe weather development, higher values generally indicate a greater potential for severe weather.

- Davies (1993) determined that EHI values of 2.0 to 2.5 were indicative of environments in which mesocyclone-induced tornadoes were possible.
- Strong tornadoes are associated with EHI 3.0 to 3.9
- Violent tornadoes are associated with EHI 4

B. Johns et al., (1993) Study

Figure 6 shows the plot of the 0-2 km AGL SRH verus CAPE for 242 strong and violent tornado cases . For a given range of CAPE, there appears to a range of helicity that is most favorable for strong or violent tornado formation, with the values decreasing as CAPE increases.

3. <u>Bulk Richardson Number (BRN)</u>

The BRN measures the relative importance to CAPE and vertical wind shear and correlates well to observed storm types.

U= vertical wind shear and is calculated by taking the difference between the density weighted mean wind over the lowest 6 km of the profile and a representative surface layer wind (500 m mean wind).

- Weisman and Klemp (1986) state that the dimensionless BRN is a better indicator of storm type than of storm severity and works best with CAPE values from 1500 to 3500 J/kg.
- Davies and Johns (1993) state that the BRN correlates well with observed storm type. However, it is a poor predictor of storm rotation in low levels because it does not account for low level curvature shear.

BRN Values	Expected Convection
< 10	Strong vertical wind shear/weak CAPE. Shear may be too strong given the weak buoyancy to develop sustained convective updrafts. With sufficient forcing, thunderstorms may still develop and rotating supercells could develop in the high shear environment.
11-49	Severe weather potential, some supercells
>50	Multicells likely

4. Shear Magnitudes of Hodographs in Tornado Forecasting (Davies and Johns, 1993) and (Davies 1989)

· Magnitude of the vertical wind shear in the 0-2 km layer (0-6600ft)

may have the most direct impact on enhancing updraft rotation in

tornadic supercells.

· Mean shear S = hodograph length (m/s)/depth of layer (m)

Davies and Johns came up the following shear and helicity values for strong and violent tornadoes:

Table 4 - Shear Magnitudes for Strong and Violent Tornadoes ( )		
Layer	**Average Positive Shear For Strong Tornadoes (F2/F3)**	**Average Positive Shear For Violent Tornadoes (F4/F5)**
0-2 km	13.4	14.7

0-3 km	10.5	11.7
0-4 km	9.0	10.0

Research suggests that the **vertical wind shear structure is the most crucial element in supercells**(Doswell, et al., 1993). Additionally, the combination of vertical wind structure and storm motion produce enough storm relative helicity to allow the mesocyclone to reach the surface.

Table 5 - Helicity Magnitudes for Strong and Violent Tornadoes

Layer	**Helicity Observed/Assumed For Strong Tornadoes (F2/F3)**	**Helicity Observed/Assumed For Violent Tornadoes (F4/F5)**
0-2 km	359/317	460/415
0-3 km	369/339	519/452
0-4 km	378/357	539/478

Observed Helicity - No storm motion used

Assumed Helicity - Has storm motion 20 degrees to the right at 85% of the mean 0-6 km wind
Note that helicity is subject to rapid temporal and spatial changes.

5. Violent Tornado Outbreaks and Pattern Recognition

Johns and Sammler (1989) defined violent tornado outbreaks as 1) 10 tornado events with one F4 tornado having a path of 30 miles or more, and 2) six or more tornado events with one or more F4 tornadoes having a combined length of 60 miles or more. The following forecasting conclusions came from their study of 77 outbreaks:

- Temperatures at 850 mb rise, and the 850 mb dew points rise, frequently by 5°C over 12 hours
- In <u>all</u> 77 cases, the low level moisture extends above 850 mb level
- Most outbreaks are associated with a double jet structure with the center-point usually between the jets
- When only one jet is evident at 500 mb, the outbreak center-point is usually beneath the axis of the jet
- Often associated with a rapidly moving 500 mb shortwave trough
- Average winds from 850 mb to 500 mb are 10 to 20 kts stronger in weak instability cases (0 to -3 Showalter Stability Index (SSI)) than in strong instability cases (-7 to -10 SSI).
- The 850 mb to 500 mb directional shear values are smallest with weak instability cases and largest with strong instability cases.
- <u>Directional shear appears to be a major contributor to the shear magnitude associated with violent tornado outbreaks in the plains states during the warm season</u>.
- <u>Speed shear appears to be a primary contributor to shear magnitude in the area east of the plains in the cool season.</u>

SPC uses classic pattern recognition as severe weather forecasting tool (Imy, 1998). Additional information can be found in by contacting SPC or reading Kriehn (1993) and Kleyla (1991).

6. <u>Boundaries</u>

- Miller (1967) was one of the earliest papers documenting the importance of identifying supercell and boundary interactions.
- Maddox et al., (1980) came up with the following conclusions:
- Boundaries are a source of enhanced CAPE, convergence, and positive relative vorticity.

- Therefore, they are conducive to the development of tornadic storms, <u>even in cases when where the environment was only marginally favorable for severe convection</u>.
- Markowski et al., (1998) found that nearly 70% of all significant tornadoes during VORTEX 95 occurred along or behind boundaries.

7. <u>Tropical Cyclone Tornadoes</u>

Tropical Cyclones, especially hurricanes, that make landfall in the United States frequently produce tornadoes, especially in the right front quadrant. McCaul Jr. has written numerous papers on landfalling tornadic tropical Cyclones, most notably 1991. Infrequently, tropical cyclones produce more tornadoes during the post landfall stage than during landfall (Weiss and Otstby,1993)

8. ADDITIONAL SEVERE WEATHER TOPICS

A. Elevated Convection

Occasionally thunderstorms develop that have no obvious moisture or convergence source in the boundary layer over which they occur. These storms often form above the boundary layer along a frontal surface.

1. <u>Colman (1990)</u>

Colman (1990a), compiled four years of data and determined that most elevated thunderstorms occur between the front range of the Rockies and the Appalachians. They seem to peak in April and once again in September. Listed below are Colman’s observations in his follow-up paper (1990b):

- Hydrostatic environment is stable and standard indices are little, if any, help
- Strong frontal inversion

- Stronger than normal shear
- Mid tropospheric warm air advection
- CSI may be a significant factor
- Low level jet often acts as a convergence mechanism to help initiate thunderstorms above the boundary layer
- Storms form in left exit region of the 850 mb wind maximum in cyclonically curved flow
- Storms form in the right exit region 500 wind maximum in anticyclonically curved flow
- Elevated thunderstorms form in a convectively stable environments and are most commonly a result of frontogenetical forcing in the presence of weak symmetric stability.

2. <u>Grant (1995)</u>

The author investigated the atmospheric conditions during severe thunderstorm events that occurred north of an east-west oriented frontal boundary and came up with the following findings:

- Vast majority of reports were large hail (92%)
- The average distance north of the warm or stationary front was 143 miles
- Environment characterized by strong speed and directional shear in the lower and middle atmosphere. Average surface wind was from the east with an 850 mb wind from the south or southwest
- Surface parcels were stable, but lifting 850 mb parcels produced an average CAPE of 700 J/Kg m, a Lifted Index of -3.1 and Total Totals of 52
- 850 mb warm air advection and positive theta-e advection were good forecast parameters
- 500 mb jet was north of the severe weather area
- Northeast quadrant of the 850 mb jet is a favorable location for severe development

  Average cap for surface parcels was 2.7 C
- Cross sections of theta-e showed the highest values and a decrease with height directly above the frontal inversion, suggesting convective instability

Forecasters should look at individual soundings and recalculate the stability indices above the frontal inversion. High mid level lapse rates (700-500 mb) 6.5°C/km can support convection. Looking at non-traditional methods, such as analysis of gridded data or isentropic cross sections may be the key to improving the ability of forecasters to better anticipate elevated thunderstorm development (McNulty, 1993). Another excellent reference on elevated convection is Jungbluth and Kula (1997).

B. **Dry Line**

The dry line of west Texas, also called Marfa Front or Dew Point Front, can be an important severe weather feature to points much further east. A wide variety of severe weather can occur along and ahead of the dry line. Look for the following features:

- Warm dry intrusion from the surface to 700 mb
- Look for evaporative cooling
- Significant moisture advection through 850 mb
- Well defined upper level jet stream
- If thunderstorms break through the cap, they will likely form in the maximum dew point gradient from dry to moist air.
- Forming along and 200 miles to the right of the upper level jet and from the maximum low level convergence downstream, to a point where the air is too dry to produce severe weather.
- Look for bulges in dry line. <u>Convergence near the bulge can initiate severe weather</u>.
- Storms form from late afternoon to mid evening, and normally last two to six hours. The activity may last longer if a dry line is driven by a 30 knot or greater jet from the surface through 700 mb (average layer wind speed).

- Favorable area for severe thunderstorm development is the triple point of the surface low, warm front, and dry line.

A. **Northwest Flow Severe Weather**

Northwest Flow (NWF) in the mid-troposphere has been noted by Miller to be responsible for the most destructive severe weather outbreaks of the summer (Johns, 1982). The models typically forecast limited precipitation with a large upper level ridge to the west of the forecast area. However, short waves, especially at 500 mb come off the front side of the ridge and produce large clusters of thunderstorms. Look for the following features:

- 500 mb long wave trough east (downstream) and long wave ridge west (upstream)
- 500 mb flow over the geographical midpoint is 280 degrees or greater
- Look for troughs approaching the apex of the upper level ridge from 600- 400 mb
- Optimum time is late afternoon to early morning hours

- 77% of all NWF outbreaks include at least one tornado (Johns, 1982). Outbreaks usually last 8 to 10 hours
- NWF outbreaks are likely to repeat on several successive days (Miller, 1972)

A. **MCS/MCC**

A Mesoscale Convective System (MCS) and the Mesoscale Convective Complex (MCC) produce a large spectrum of hazardous weather. This includes damaging winds, large hail, and tornadoes, but the most pronounced feature is torrential rainfall. Since heavy rain and flash flooding is the biggest culprit of these enormous features, an in depth discussion will not be included.

However, all operational forecasters should read or review Daly's (March, 1998) two papers on MCS Propagation that were used in NWS audio teletraining sessions. Additional reading should include Rochette, et al., (1996), Doswell, et al., (1995), and Maddox (1980, 1979b).

9. Topography **and Climatology**

A forecaster should have a through knowledge of local topography and it's influence(s) on severe weather. This section will briefly touch on some aspects of topography. It is not meant as a thorough treatment of the subject.

A. **Topography**

1. Mountains

Mountain thunderstorms can form due to a variety of mechanisms such as orographic lifting, lee side convergence, channeling, and wake effects. Investigation of the terrain associated with each genesis region, as well as an understanding of the ridge top flow, allows the identification of the predominant mechanisms activating these regions (Barker and Banta, 1985). A variety of severe weather can occur with mountain convection, including significant tornadoes (Evans and Johns, 1996).

2. Desert

Over the southwestern United States thunderstorms tend to occur either in association with baroclinic disturbances in the late fall, winter, and spring or during the summer monsoon season. Mesoscale features such as the Gulf of

California surge and diurnal wind circulations near complex terrain, influence the development and evolution of convection (Stensrud 1996).

3. Sea Breeze/Lake Breeze

Without the effects of topography, a sea/lake breeze forms as very frontal like in nature and reflecting the shape of the coastline. Sufficient surface convergence is the primary focusing mechanism responsible for development of precipitation as the boundary moves inland. Many studies have been accomplished on this warm season phenomena, most recently Kelly et al., (1998) concluded for undisturbed east coast sea breeze days, the K index was found to best discriminate thunderstorm days from other days.

B. **Climatology**

There are a number of resources for severe weather climatology available . In Missouri, Hatch (1996) did a county by county severe weather analysis over 100 years for the Springfield, MO County Warning Area (CWA). His paper is at **http://www.crh.noaa.gov/sgf/papers/svrtxt.htm**. Darkow (1996) also did an extensive analysis of tornado climatology for Missouri for the years 1916 through 1994.

Additional tornado climatology on a national scale can be found in Otsby (1993), Livingston and Schaefer (1993), and Concannon, et al., (2000).

While, climatological knowledge of severe local storm events is useful in the overall evaluation of the severe weather threat, the atmosphere on any given day may not conform to the statistical normal (Sturtevant, 1995).

10. SEVERE WEATHER STABILITY INDICES

Instability is a critical factor in severe weather development. Severe weather stability indices can be a useful tool when applied correctly to a given convective weather situation. However, great care should be used when applying these empirical indices because they simply cannot be applied to every weather situation and must always be applied in conjunction with other parameters.

A number of indices are tied to specific pressure levels which may (or may not) be representative of a particular convective weather situation. Soundings must be looked at as a whole. Stations at high elevations make some indices irrelevant. Local adaptations must be made at such stations and are not discussed here. One must also consider the fact that sometimes the upper air sounding itself may not even be representative of the overall synoptic situation.

Severe weather indices only indicate the potential for convection. There must still be sufficient forcing for upward motion to release the instability before thunderstorms can develop. A zero lifted index is sufficient for severe weather development if the dynamics are very strong. On the other hand, when the lifted indices are -8 or less, severe weather can occur with very weak upper air support Hales (1996). Also be aware of a strong capping inversion inhibiting updrafts.

A. **K Index (K)** (George, 1960)

se rate along with the amount and vertical extent of lowâ€‘level moisture in the atmosphere.

K Index	TSTM Probability
<15	0%
15-20	<20%
21-25	20-40%
26-30	40-60%
31-35	60-80%
36-40	80-90%
>40	near 100%

B. **Lifted Index (LI)** (Galway, 1956)

The LI is a measure of potential instability from the surface to 500 mb. Lift a parcel with an average mixing ration and dry adiabat in the lowest 100 mm of the sounding. It is very similar to the Showalter Index (see below), but better considers available low level moisture below 850mb.

= Is the measured air temperature at 500 mb (deg C)
= The temperature (deg C) of an average air parcel lifted from the surface to 500mb.

Lifted Index (LI)	**Instability**
0 to 3	Stable. Weak convection possible with strong lifting or forcing mechanism
0 to -3	Marginally Unstable
-3 to -6	Moderately Unstable
-6 to -9	Very Unstable
< -9	Extremely Unstable

C. **Showalter Stability Index (SSI)** (Showalter, 1953)

The SSI is a measure of the potential instability in the 850mb to 500 mb layer. The SSI is unrepresentative if the available low level moisture occurs below 850mb.

= Is the measured temperature (deg C)at 500 mb
= the temperature (deg C) of an air parcel lifted moist adiabatically from the 850 mb LCL.

SSI	**Stability**

+1 to +2	Stable. Weak convection possible if strong lift present
0 to -3	Moderately Unstable
-4 to -6	Very Unstable
< -6	Extremely Unstable

D. **Total Totals (TT)** (Miller, 1972)

The Total Totals Index consists of two components: Vertical Totals (VT) and Cross Totals (CT). VT represents static stability between 850 mb and 500 mb. The CT includes the 850 mb dewpoint. As a result, TT accounts for both static stability and 850 mb moisture. However, TT would be unrepresentative in situations where the lowâ€‘level moisture resides below the 850 mb level. If a significant capping inversion is present, convection will be inhibited even with a high TT.

Total Totals	**Thunderstorm Chances**
45 to 50	Thunderstorms possible
50 to 55	Thunderstorms more likely (some severe)
55 to 60	Severe thunderstorms likely

E. **Sweat Index (Severe Weather Threat Index–SWEAT)** (Miller, 1972)

The SWEAT Index evaluates the potential for severe weather by examining both kinematic and thermodynamic information into one index. Parameters include lowâ€‘level moisture (850 mb dewpoint), instability (Total Totals Index), lower and middleâ€‘level (850 and 500 mb) wind speeds, and warm air advection (veering between 850 and 500 mb). Unlike the K Index, the SWEAT index should be used to assess severe weather potential, not ordinary thunderstorm potential.

The last term in the equation (the shear term) is set to zero if any of the following criteria are not met: 1) 850 mb wind direction ranges from 130 to 250 degrees, 2) 500 mb wind direction ranges from 210 to 310 degrees, 3) 500 mb wind direction minus the 850 mb wind direction is a positive number, and 4) both the 850 and 500 mb wind speeds are at least 15 kts. No term in the equation may be negative; if so, that term is set to zero.

SWEAT over 300	Potential for severe thunderstorms
SWEAT over 400	Potential for tornadoes

These are guidance values developed by the U.S. Air Force. Severe storms may still be possible for SWEAT values of 250â€‘300 if strong lifting is present. In addition, tornadoes may occur with SWEAT values below 400, especially if convective cell and boundary interactions increase the local shear which would not be resolved in this index. The SWEAT value can increase significantly during the day, so low values based on 1200 UTC data may be unrepresentative if substantial changes in moisture, stability, and/or wind shear occur during the day.

F. **Deep Convective Index (DCI)**(Barlow, 1993)

The DCI attempts to combine the properties of equivalent potential temperature (Qe) at 850 mb with instability. Values of roughly 30 or higher indicate the potential for strong thunderstorms. Ridge axes of DCI seem to be a good indicator of location for thunderstorm development given the presence of forcing mechanisms.

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