ATMO 352
Severe Weather and Mesoscale Forecasting
Spring 2007
Laboratory #12: Forecasting Supercells with Significant Tornadoes and The Day-1 Convective Outlook

Section 501, Thursday 4-19-07

DUE: Part I - at the beginning of the next lab session (4-26-07)
Part II (team forecast) - by the end of the current lab session.

1. Introduction: The Central Oklahoma Tornado Outbreak of May 3, 1999

On May 3, 1999, multiple supercell thunderstorms produced many large and damaging tornadoes in central Oklahoma during the late afternoon and evening hours. Some of these storms were killers, including the tornadoes which moved through and/or near Dover, Shawnee, Perry and Bridge Creek, and the Moore and southern Oklahoma City metropolitan areas. Additional tornadoes also hit areas in south central Kansas, eastern Oklahoma and northern Texas, with over 70 tornadoes being observed across the region. Figure 1 below shows a detailed map of significant tornadoes in and around the Oklahoma City area. Figure 2 offers a slightly expanded view of the tornado outbreak, including an F4 over Wichita, Kansas.

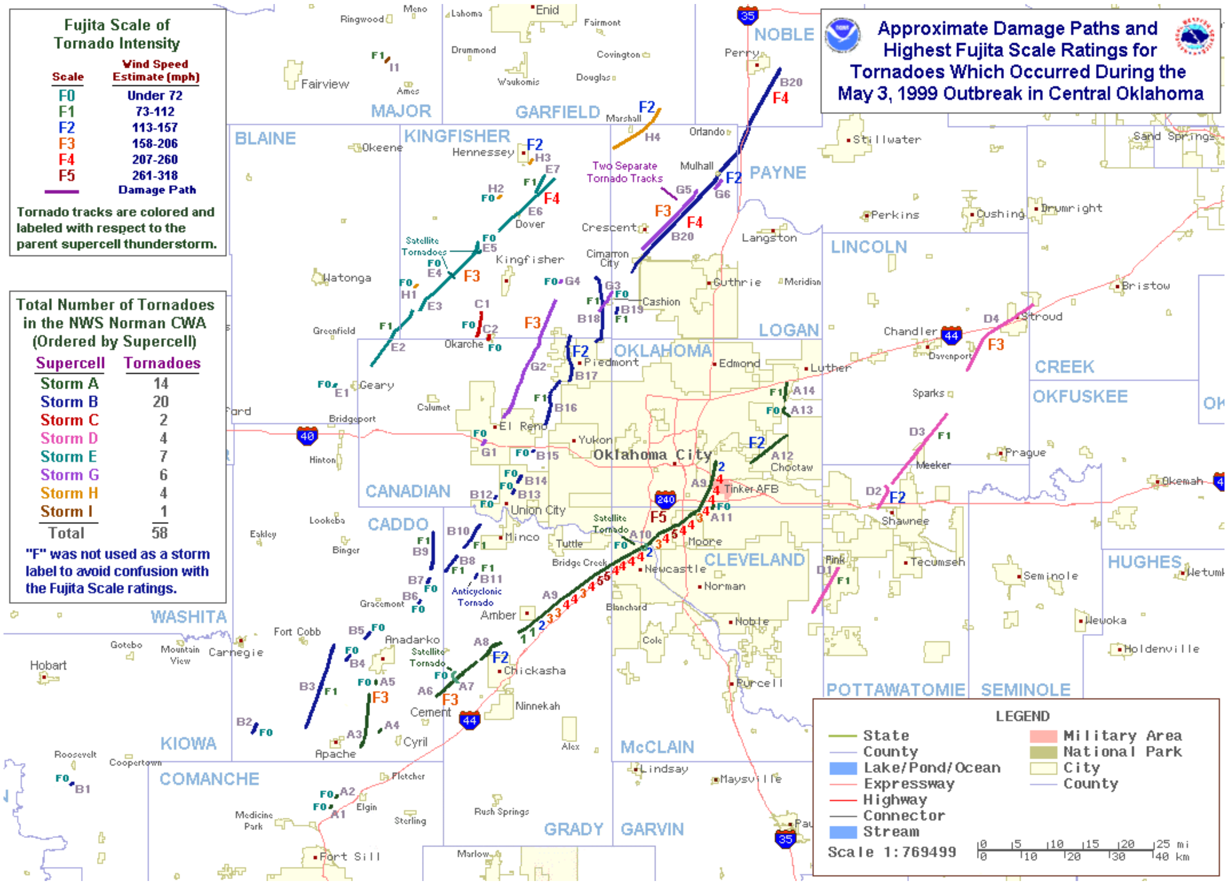


Figure 1. Location and F-scale intensity of damage paths for tornado outbreak on 3 May 1999 over and nearby Oklahoma City.

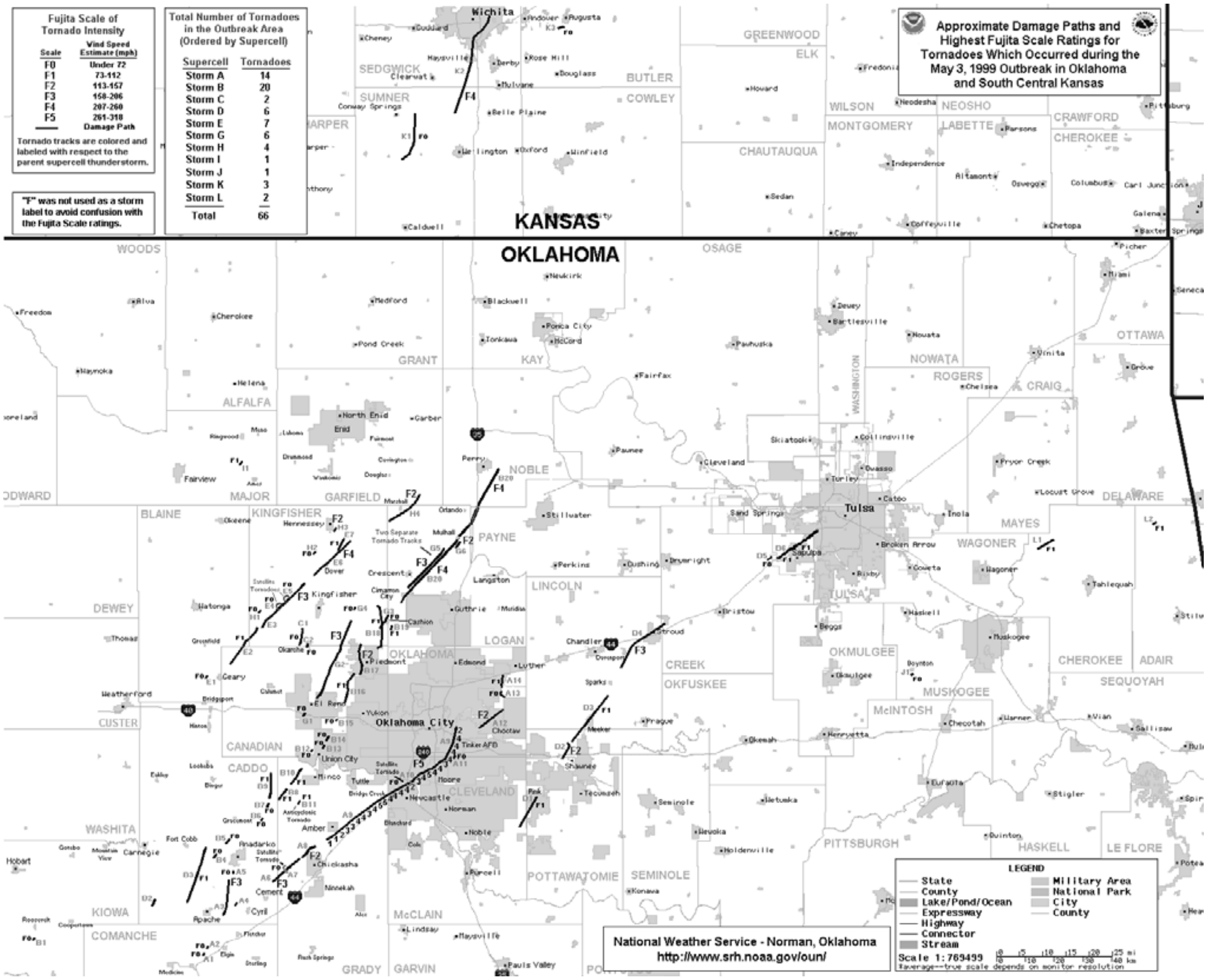


Figure 2. Same as Figure 1 except for an expanded region.

In lecture and past labs, we have seen the utility of CAPE, deep layer shear, bulk Richardson Number and other traditional stability parameters for forecasting storm type (i.e., supercell versus multicell) and severity. Forecasting a violent tornado outbreak presents new challenges and requires new techniques. To this end, we will investigate two new parameters – storm relative helicity (SRH) and energy helicity index (EHI). We will also re-visit some known parameters to investigate their utility in differentiating between tornadic and non-tornadic supercells, with an emphasis on violent tornadoes.

2. **Storm Relative Helicity (SRH)**

Since tilting of environmental vorticity initiates updraft rotation according to at least one theory of tornadogenesis, a measure of the potential for updraft rotation can be obtained from streamwise vorticity or the component of the 3-D vorticity vector in the direction of the storm relative inflow. A related quantity, the storm relative helicity (SRH), is proportional to streamwise vorticity and the strength of the flow feeding the updraft (i.e., the storm relative inflow). A mathematical expression for the SRH is

$$SRH = \int_{0}^{h} \left(\vec{V} - \vec{C}\right) \bullet \vec{w}\, dz = -\int_{0}^{h} \hat{k} \bullet \left(\vec{V} - \vec{C}\right) \times \frac{\partial \vec{V}}{dz}\, dz$$

where V is the environmental horizontal velocity (ground-relative), C is the storm motion, and *w* is the *horizontal* vorticity vector (Davies-Jones et al. 1990). The units are $m^2\ s^{-2}$. The equation above says that SRH is minus twice the signed area swept out by the storm relative wind vector between 0 and h on a hodograph diagram (e.g., Figure 3). The integration is over the inflow layer of the storm from 0 km to some depth h (typically 1 to 3 km). SRH is computed by NSHARP over 2 and 3 km layer depths. There is research that suggests that SRH is a very useful tool for differentiating non-tornadic supercells from tornadic supercells. Recent research suggests that SRH over the 0-1 km layer may be the most useful for tornado forecasting (Rasmussen 2003; Weather and Forecasting). Unfortunately, NSHARP does not compute SRH over this layer.

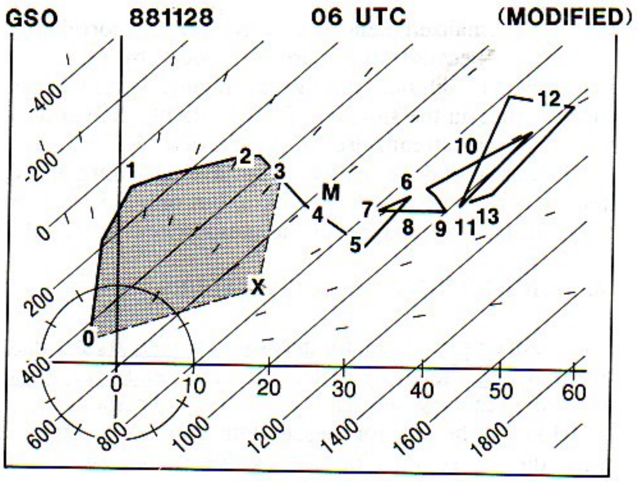


Figure 3. Hodograph for Raleigh, NC F4 tornado environment on Nov 28 1988. Speed circles are every 10 $m\ s^{-1}$ and dashed lines every 10°. Numbers along hodograph indicate height AGL in km. Large X and M indicate storm motion and mean wind between surface and 200 mb. The storm relative helicity (SRH) in the lowest 3 km is minus twice the shaded area (which is negative because the storm relative wind turns clockwise with height). Straight lines parallel to 0 to 3 km shear vector are contours of helicity for this hodograph, given a storm motion vector. The SRH was 719 $m^2\ s^{-2}$ for this hodograph for a storm motion of 240° at 20 $m\ s^{-1}$. Adapted from Davies-Jones et al. (1990, 16th Severe Local Storms).

Some ranges of SRH (0-3 km) associated with different F-scale tornadoes that have been presented in the literature - F0: 66 $m^2\ s^{-2}$; F1: 140 $m^2\ s^{-2}$; F2: 196 $m^2\ s^{-2}$; F3: 226 $m^2\ s^{-2}$; F4: 249 $m^2\ s^{-2}$ (Kerr and Darkow 1996). Another study suggests that 200 $m^2\ s^{-2}$ is a useful threshold in SRH (0-3 km) for identifying supercells with significant tornadoes (Rasmussen and Blanchard 1998, Weather and Forecasting). More recently, Rassmussen (2003) found that SRH *from 0-1 km* (SRH_{0-1}) of 120 $m^2\ s^{-2}$ was the optimal threshold for differentiating tornadic from non-tornadic supercells. In reality, there is some overlap between the SRH associated with tornadic and non-tornadic supercells. Finally, note that SRH is very sensitive to the estimation of supercell storm motion (see Bunkers et al. 2000, Weather and Forecasting).

3. Energy Helicity Index (EHI)

The Energy Helicity Index (EHI) is used operationally for supercell and tornado forecasting. Since tilting of horizontal vorticity must be followed by stretching by the updraft for tornadogenesis, EHI combines SRH and CAPE (related to updraft by parcel theory) and is defined as:

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

where SRH is from 0-3 km (unless otherwise stated) and CAPE is standard surface based. EHI appears to be a very effective discriminator for significant tornadoes. Increasing values from 1.0 to 3.0 and higher correspond to increasing probability of tornadic supercells (Rasmussen and Blanchard 1998). According to Rasmussen (2003), an EHI *from 0-1 km* (EHI_{0-1}) of 0.7 is the optimal threshold for differentiating tornadic from non-tornadic supercells. According to Rasmussen (2003), EHI_{0-1} and SRH_{0-1} are the most effective forecast parameters for distinguishing tornadic from non-tornadic supercells, followed by LCL and CIN as discussed in the next section. Although NSHARP does not provide 0-1 km values, you can obtain current and forecasted EHI_{0-1} and SRH_{0-1} from various online web pages (e.g., SPC Forecast Tools page (http://www.spc.noaa.gov/exper/).

4. LCL and CIN as value-added tornado discriminators

When used in combination with other parameters such as SRH and EHI, recent research has shown that LCL and CIN can be effective discriminators of tornadic (significant tornadoes here) and non-tornadic supercells. In situations where supercells are already expected, significant tornado potential tends to be associated with *low* values of LCL (e.g., ≤ 800 m AGL) (Rasmussen and Blanchard 1998; Rasmussen 2003). LCL's above 1200 m AGL are associated with decreasing likelihood of significant tornadoes. Interestingly, recent research suggests that supercells, which produce significant tornadoes, are characterized by *low* CIN (e.g., ≤ 16 J kg^{-1}) (Rasmussen and Blanchard 1998; Rasmussen 2003). This study showed that 75% of (significant) tornadic supercells were associated with CIN < 21 J kg^{-1} while 60% of non-tornadic supercells had higher values than this. The physical and dynamical connection between low CIN and low LCL and significant tornadoes is currently a matter of speculation and debate and is therefore an active area of research (Rasmussen 2003). One can hypothesize that "low LCLs favor formation of significant tornadoes because they somehow alter the rear-flank downdraft and outflow character of supercells" (Rasmussen 2003). Large CIN may be associated with a lowered probability of significant tornadoes either because 1) "supercells occurring with large CIN could be 'elevated' storms that draw inflow from a potentially buoyant layer above the boundary layer; these storms are thought to be relatively less likely to produce tornadoes" or because 2) "the presence of large CIN in soundings associated with thunderstorms would tend to indicate that the thunderstorms are being strongly forced by local low-level convergence (e.g., by a cold front, outflow). Local strong forcing could imply that storms would tend to be organized into larger-scale convective systems rather than isolated supercells that are more favorable for tornadoes" (Rasmussen and Blanchard 1998).

In this lab, we will investigate the environment associated with the 3 May 1999 tornado outbreak over OK and KS to determine whether any of these or previously studied parameters appear to be useful indicators of where significant tornadoes might occur.

Part I, Forecasting Significant Tornadoes (65 points)

1. (45 points) Use NSHARP to fill out Table 1 below for the upper-air sounding sites in the central United States, which surround the OK/KS region. Use data from 00 UTC on 4 May 1999. Remember that you must point NSHARP to the archived data (i.e., filter on the following directory path "/h/metr352/cases/Oklahoma_May3/upperair/"). See earlier lab NSHARP directions if you are having trouble accessing the data.
2. (20 points) Discuss the significance of your results for forecasting the occurrence of tornadic supercells. What forecasting parameter or combination of parameters in Table 1 seem to be most associated with the tornado outbreak location in central OK to south-central KS. Which parameters were least useful in isolating this area? Discuss/speculate regarding "why".

Part II, The Current Day I Convective Outlook - Team Forecasting Exercise (35 points)

1. (*10 points*) **Team Forecasting Exercise**: For the current DAY 1 situation, use the map below (next page) to provide your forecast of severe weather. In the area identified during lab, mark any 1° X 1° box in which you believe that *severe* weather will occur during the forecast period (i.e., about 1 hour after end of lab to the end of the DAY 1 forecast period or 2230 UTC to 1200 UTC next day). Also write the **number** of forecast boxes in which you expect severe weather to occur (i.e., count your marks). Hand in one team forecast.

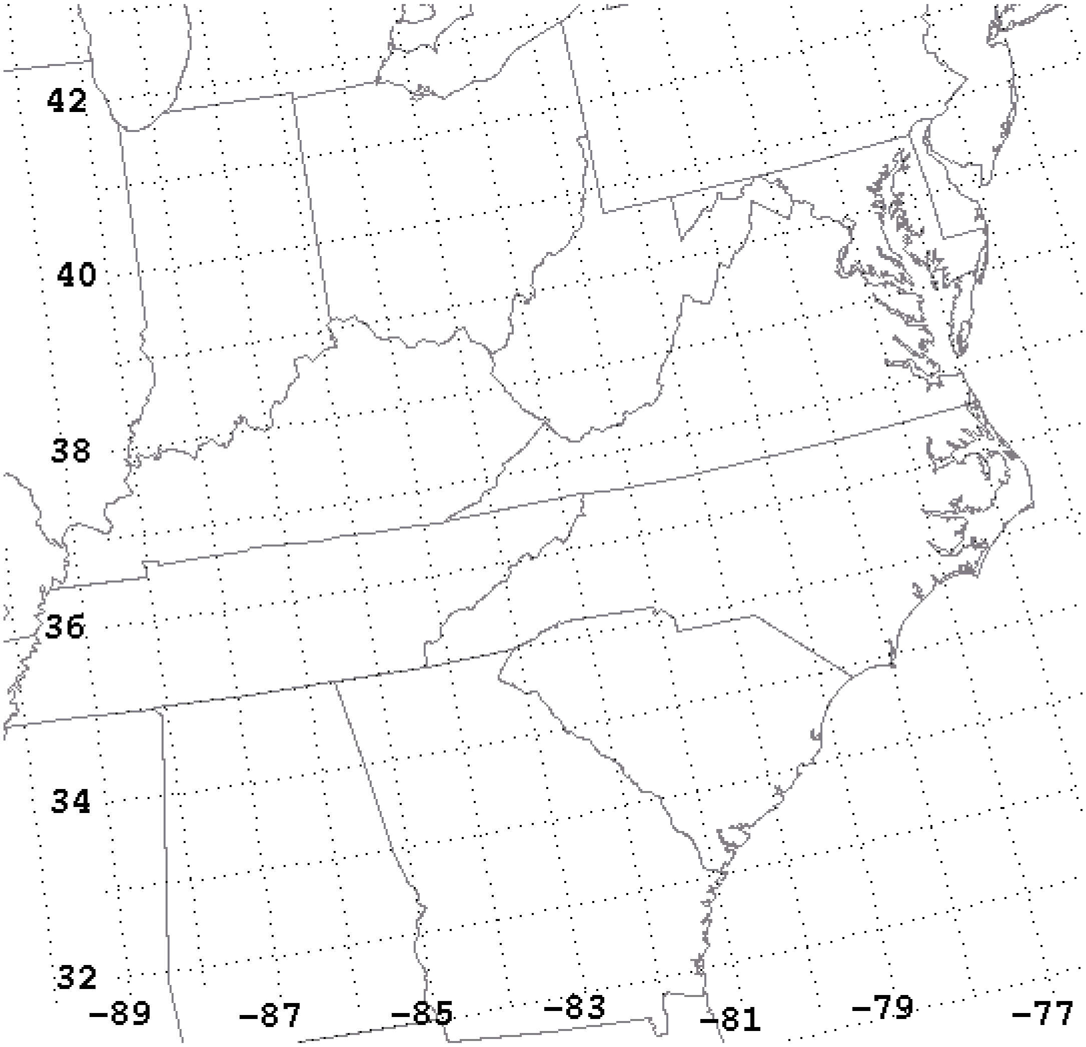
Your team forecast, along with the current SPC Day 1 convective outlook, will be skill scored against preliminary severe storm reports from SPC. Any team that beats SPC's skill score automatically gets 14 points (i.e., 4 bonus points for this question). Otherwise, the top ranked team receives 10 points, the 2nd place team receives 8.5 points, the 3rd place team receives 7 points, and the 4th place team receives 5.5 points.

2. (*25 points*) On the back of the forecast map, please write a succinct but complete summary (paragraph or bullet form is fine) of the forecast problem(s) of the day, including the synoptic-to-mesoscale features, forecast parameters, and/or physical processes that support your severe weather forecast above. Be **specific and quantitative** when you can (e.g., don't just say "high CAPE and high shear" – give some values with units!) Hand in the forecasting sheet with forecast summary by the end of the lab period.

Table 1. 4 May 1999, 00 UTC NSHARP parameters

Sounding Site	**MLCAPE** **($J\ kg^{-1}$)**	**CIN** **($J\ kg^{-1}$)**	**LCL** **(m)**	**Deep Layer (SFC-6 km) shear** **($m\ s^{-1}$)**	**MLCAPE * 0-6 km Shear** **($m^3\ s^{-3}$)**	**BRN Shear** **($m^2\ s^{-2}$)**	**BRN**	**SRH (0-2 km)** **($m^2\ s^{-2}$)**	**SRH (0-3 km)** **($m^2\ s^{-2}$)**	**EHI (0-3 km)**
TOP										
DDC										
SGF										
AMA										
OUN										
LZK										
MAF										
FWD										
SHV										

MLCAPE: Mixed Layer Convective Available Potential Energy
CIN: Convective Inhibition
LCL: Lifted Condensation Level
BRN: Bulk Richardson Number
SRH: Storm Relative Helicity
EHI: Energy Helicity Index



FORECASTED SEVERE BOXES: ________________