The October 23, 2017 Quasi-Linear Convective System Weather Event Simulation Facilitator's Guide

Warning Operations Course: Severe Curriculum

NWS/OCLO/Warning Decision Training Division

July 2018

1. Event Overview

This is a severe weather event simulation featuring a Quasi-Linear Convective System (QLCS) that swept through the Greenville-Spartanburg, South Carolina Forecast Office (GSP) County Warning Area (CWA) on the afternoon and evening of October 23, 2017. The QLCS was part of an outbreak of severe weather reports from a long line of severe storms extending from the western Carolinas to Virginia, spawning some unusually, long-track QLCS tornadic storms, widespread damaging winds, and flooding (see Fig. 1). Primary severe weather impacts from the QLCS in the GSP CWA on October 23, 2017 were damage to structures along 10 tornado tracks (see example in Fig. 2), and thousands of power lines and trees down from widespread wind damage.

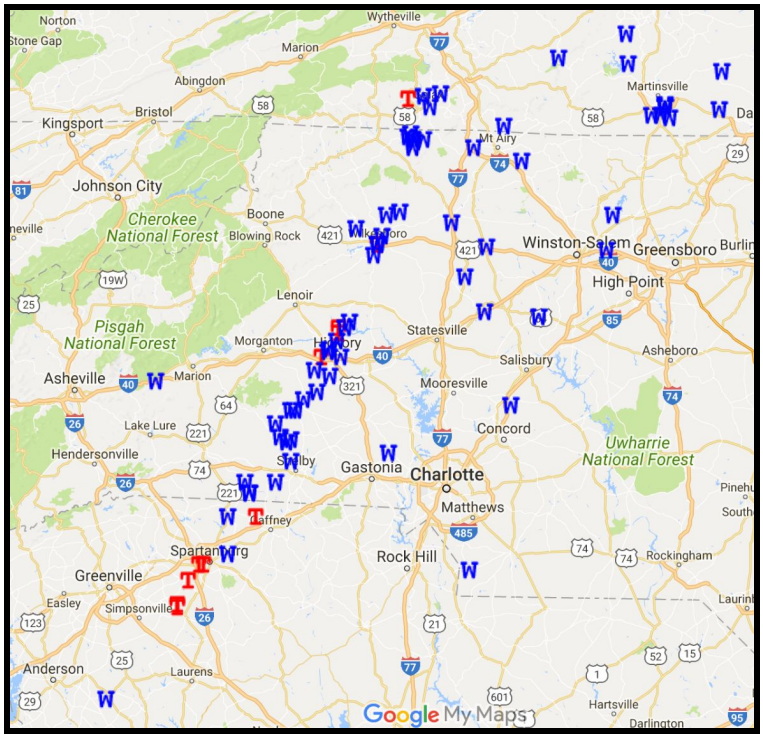


Figure 1: SPC reports for October 23, 2017 (zoomed-in to show reports in the GSP CWA.)

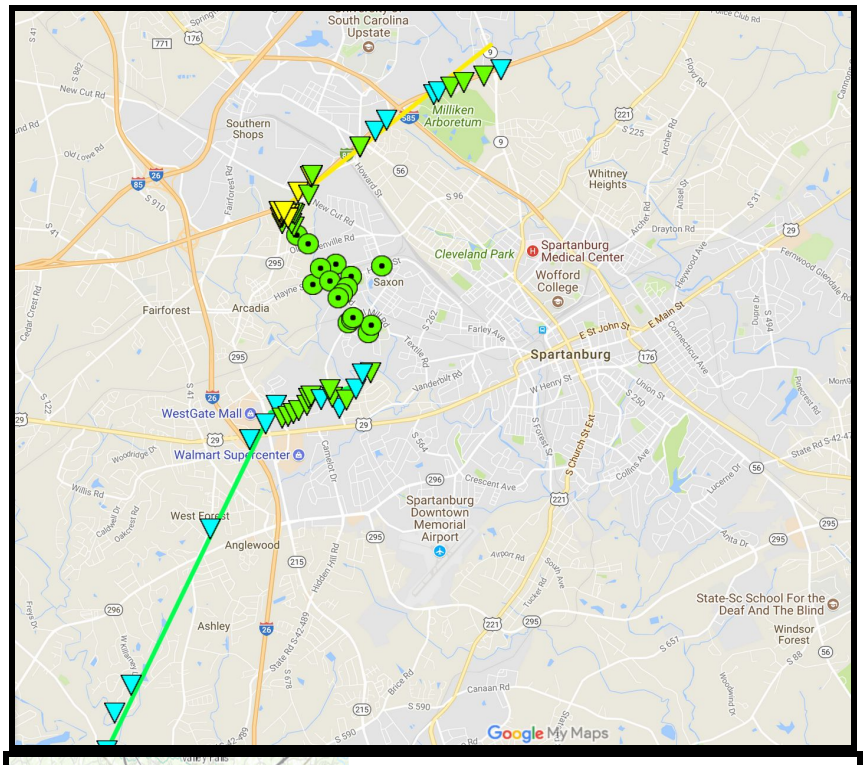


Figure 2. A portion of the storm damage paths including two tornadoes that tracked west of Spartanburg, SC on Oct. 23, 2017.

Figure 3. EF2 tornado damage at the Polysols Inc. facility on the northwest side of Spartanburg, SC at approximately 19:11Z on 23 October, 2017.

An example of some of the damage surveyed along the Spartanburg, SC tornado track is seen in Figure 3. This weather event simulation is intended to improve severe warning decision making skills for NWS meteorologists dealing with challenges from predicting QLCS tornadoes and their related impacts. The simulation is intended to be

used with the Weather Event Simulator WES-2 Bridge (W2B) Workstation version 17.1.1 or later.

2. Simulation Data Summary

Note the date/time details for this simulation as follows:

Simulation Data Time Range: 18:00Z 23 Oct 2017 to 20:30Z 23 Oct 2017
Case Data Time Range: 12:00Z 23 Oct 2017 to 01:00Z 24 Oct 2017

Part 1: Threat Assessment and DSS
(18:00Z) (Case Review Mode)

Part 2: Storm-scale Intensification to Tornado Debris Signature (TDS)
(18:00 - 19:39Z) (Simulation Modes)

Part 3: QLCS Evolution (optional)
(19:30 - 20:30Z) (Simulation Mode)

3. General Simulation Instructions

A. **User Instructions:** Students with their training offers may choose to complete all or parts of the simulation to gain the desired performance benefits.
B. **Performance Objectives:**
   Given a WES simulation, for a specified WFO County Warning Area (CWA), the trainee should be able to demonstrate the ability to:
   1. Analyze near-storm environment weather data to evaluate storm hazards (tornado, severe hail/wind) in the GSP CWA and integrate analysis into the warning decision process.
   2. Use the Three Ingredients Method to identify areas where mesovortex genesis and intensification are favored in a QLCS for effective warning decisions.
   3. Analyze real-time data including multi-radar multi-sensor system (MRMS) products with GSP WSR-88D, GOES-16, ENI lightning, and surface obs) to evaluate current and near future potential for convectively induced severe winds, hail and tornadoes.

4. Issue effective warnings that maximize lead time and reduce unnecessary false alarm area that meet specifications of National Weather Service Instruction 10-511 and guidelines from WDTD training.
5. Provide Decision Support Services (DSS) feedback to core partner questions regarding storm evolution.

4. WES-2 Bridge Setup and Case Installation Instructions/Controls

Please refer to the **WOC FY18 Severe Simulation Installation Guide** which contains the instructions to install the case, as well as the **WOC FY18 Severe Simulation Start Guide** which contains the instructions for starting up the simulation. Both of these documents are provided on the installation disc.

Make sure you have your WES-2 Bridge (W2B) workstation updated to Build 17.1.1 (or later) of AWIPS-2 and WES-2 Bridge.

For this particular type of simulation, here are some useful reminders:

- Ensure your EDEX_00 is started to guarantee the full functionality of the WESSL-2 Script.
- Make sure you click on the **Load Macro** on the desktop which will configure your simulation for the correct time, set up the correct WESSL-2 simulation script, and remove archived GSP Warnings.
- Make sure you click on "**PLAY**" from the Simulation Control Window (this window might be covered up by another window).
- Make sure you open a **Text Window (**to issue warnings from WarnGen).

Simulation participant responsibilities (for the trainee):

1) Analyze meteorological data starting at 18:00Z on 23 October 2017 to evaluate the severe (tornado, severe hail/wind) hazard potential.
2) Use the WOC Severe GSP WES-2 Simulation Answer Form to enter responses to questions pertaining to threat assessment, DSS, Three Ingredients Method analysis, Multi-Radar Multi-Sensor System analysis, and TDS identification.

3) Issue Tornado Warnings (TORs), Severe Thunderstorm Warnings (SVRs), and Follow-up Statements (SVSs) in the GSP CWA as needed from 1800Z to 2030Z.
4) Participate in a simulation debrief with your training facilitator to replay and review your warning performance and discuss actions for student improvement based on accomplishment of the performance objectives.
5) To obtain credit in the Commerce Learning Center (CLC), complete the 1-question quiz from the **WOC Severe Simulation - GSP** test item.

5. Case Data Details: WOC_Severe18_2017Oct23GSP (Case Size ~ 23 GB compressed)

Point	Grid	Radar	Satellite	Reports
METAR NLDN Lightning Raob	RAP13 RAP40 LAPS HRRR (to 00z)	KGSP KMRX KCAE TCLT MRMS (17-22z)	GOES-16 Center CONUS (17-20z) Mesoscale Center (17-23z)	Weather Event Simulator Scripting Language (WESSL) provides timed reports and injects to support warning decision process from 1800-2100z.

Available Procedures:

WOC_Severe18.xml (includes 4 useful procedures for Section 7)

RAC-FY18-GSPSevere.xml (includes around 30 useful bundles for threat assessment and storm interrogation)

Case Data Notes:

Radar data is available from 1700z to 2200z so you can modify the simulation data time range to accommodate different simulation times and periods for issuing warnings/statements. Make sure you set simulation end time to 2100z to enable all radar data to display through 2100Z which supports required WESSL and simulation questions.

This event occurred before the current placement and configuration of GOES-E CONUS. Thus, to access GOES-16 data for this case, under the Satellite Menu, select ***Imagery Channels***...***Center CONUS*** or ***Center Mesoscale 2***.

6. Threat Assessment, Hazard Evaluation, and DSS (Part 1 of Simulation)

A. Instructions

In this section, trainees will write a short-term (3-6 hour) severe convective forecast discussion. They can use all available data sources through 1800Z including SPC products, Mesoanalysis pages, High-Resolution Ensemble Forecast (HREF) output, and any AWIPS model products (such as QLCS/Wind Family) to assess the near-storm environment at 1800Z. In addition, trainees should analyze at least one proximity sounding ahead of the QLCS to evaluate parameters for expected severe hazards from 1800-2100Z. Students can use any pre-loaded AWIPS-2 procedures on CAVE to assess environmental hazards. Take advantage of the QLCS Tornado/Wind Environment Bundle from the NSEA Digital Cursor Readout volume menu. Students should use the **Simulation Answer Form** to input their assigned risk category for each severe hazard (tornado, severe hail, and severe wind). Finally, there will be two DSS questions that students will need to provide answers based upon their assessment.

B. Threat Assessment Summary at 1800Z

Trainees should the following severe weather ingredients and convective trends in the environment from assessing various AWIPS model products and SPC Mesoanalysis Pages.

1) A sharp, negative-tilt, shortwave trough evidenced at 500 mb (See Fig. 4) extending southeastward from a low in southern Indiana to central Georgia. Latest model forecasts indicate the trough is expected to lift rapidly northeast into the middle Appalachian Mountain region and then phase with an upstream, deeper mid-and upper-level trough by 24 hours over the Ohio and Tennessee River Valley Region.

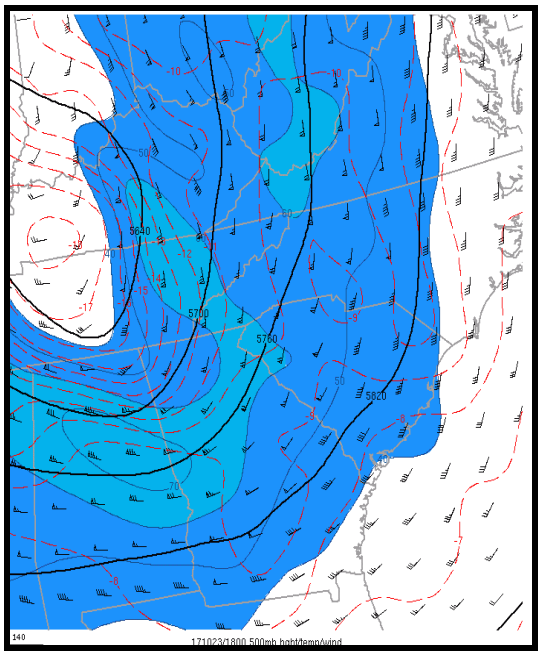


Figure 4. 1800Z 23 Oct 2017 500 mb heights, temps, wind (from spc.noaa.gov).

2) Impressive 850 mb height and wind fields at 1800Z with a jet axis of 50-60 kts winds from eastern Georgia into West Virginia transporting dewpoints > 15 deg C into western South Carolina (See Fig. 5).

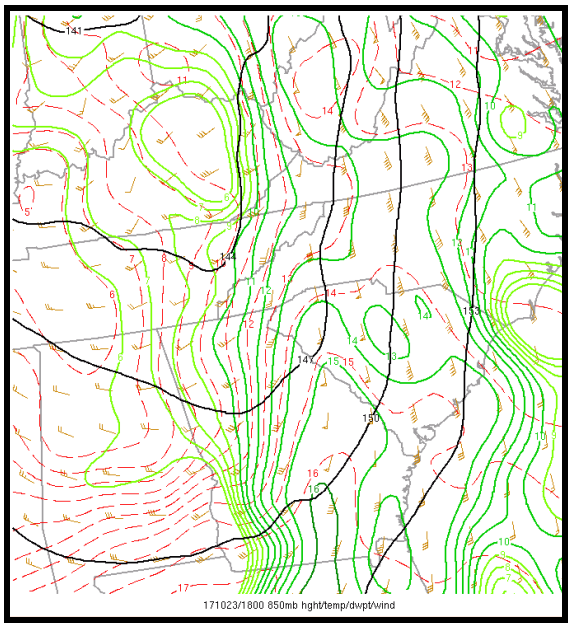


Figure 5. 1800Z 23 Oct 2017 850 mb heights, temps (dashed red lines), dew points (green lines), and wind (barbs) (from spc.noaa.gov)

3) Surface cold front extending southward from a low in extreme southwestern North Carolina through the western corner of South Carolina, central Georgia, the Florida Panhandle and into the eastern Gulf of Mexico (Fig. 6). The frontal boundary possesses a sharp, low- and mid-level moisture gradient as evidenced by the water vapor imagery despite a relatively weak, thermal contrast from west to east.

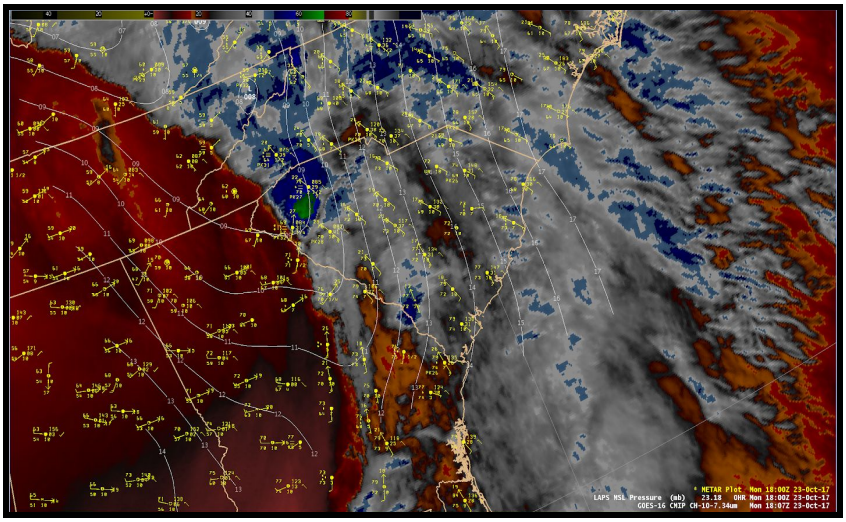


Figure 6. GOES-16 Channel 10 imagery overlaid with METARs and LAPS Mean Sea Level Pressure analysis at 1800Z.

Widespread clouds and precipitation are limiting surface heating ahead of the front. From the SPC Mesoanalysis Page, numerous thermodynamic and wind shear fields indicate an increasingly favorable severe storm environment developing across the GSP CWA including:

- Surface-Based CAPE (SBCAPE) of 500 J/kg to > 1500 J/kg along an axis from north to south axis extending from western North Carolina through central South Carolina
- LCL heights around 500 m AGL
- Effective Bulk Shear of 50-55 kts
- SRH (0-1 km) to 350 m2/s2 over western South Carolina
- STP (effective layer) ranging from 1 to a maximum of 3 over the South Carolina-Georgia border
- Lowest 3 km MUCAPE from 750-1500 j/kg, 0-3 km bulk shear vector 45-55 kts oriented from south to southwest (See Fig. 7).
- SHERBE > 1.0 over the entire CWA.

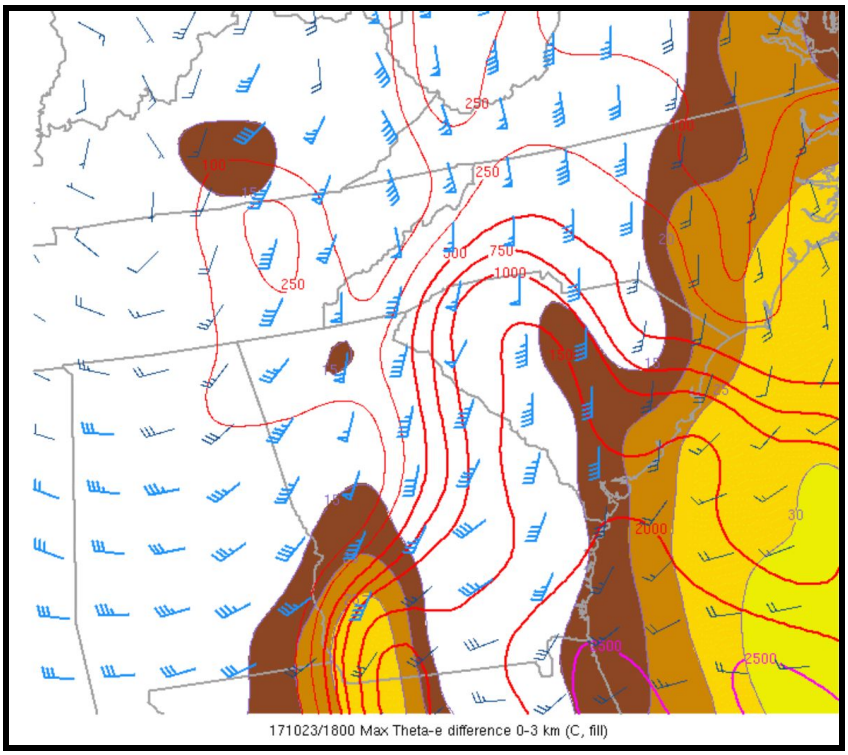


Figure 7. 1800Z 23 Oct 2017 Max lowest theta-e difference (contour filled in deg C), 0-3 km MUCAPE (J/kg red lines), 0-3 km vector shear (from spc.noaa.gov).

A representative proximity sounding ahead of the QLCS at point A (Fig. 8) from the RAP13 1800Z 00h forecast with convective parameters is shown in Figure 9.

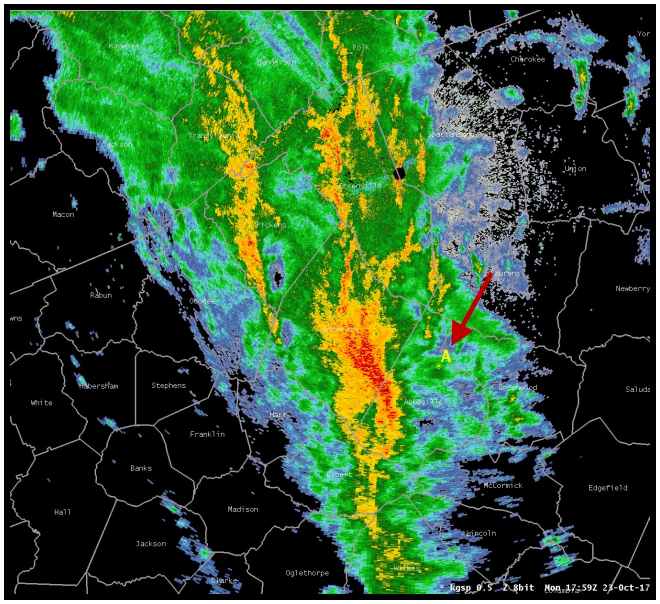


Figure 8. KGSP 0.5 deg Z at 1759Z showing location of point A used in the associated RAP13 proximity sounding.

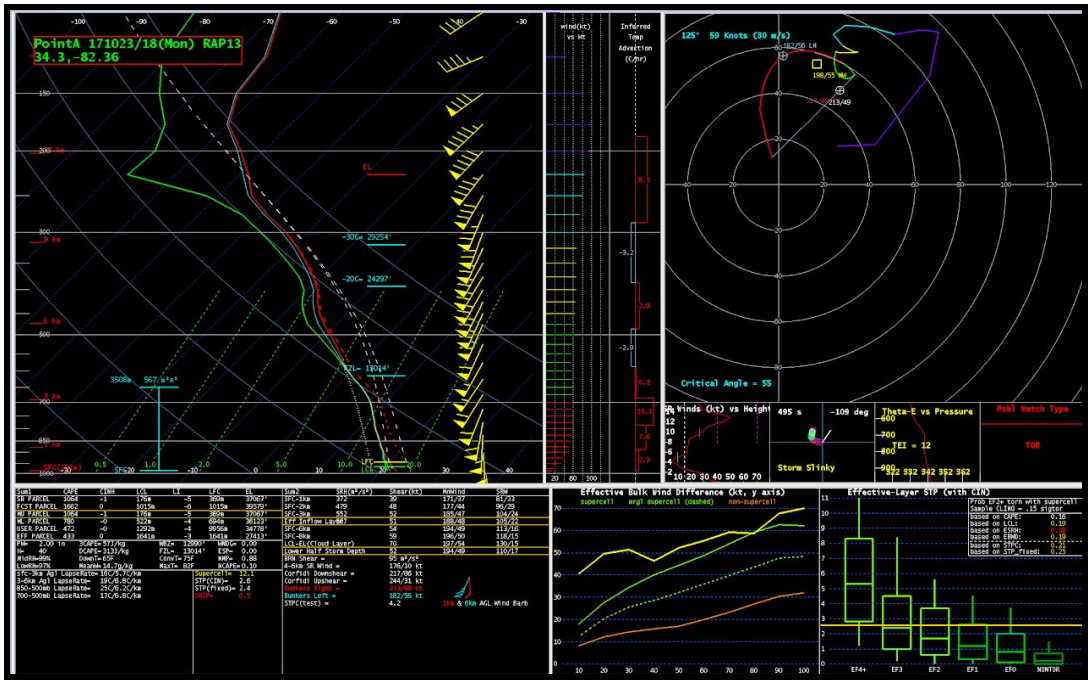


Figure 9. RAP13 00 HR forecast proximity sounding for 1800Z Mon Oct. 23, 2017, at point A, immediately ahead of the QLCS.

The sounding analysis from the RAP forecast sounding at 1800Z shown in Fig. 9 suggests the following hazard risk assessment in the vicinity of point A, which is representative of the near-storm environment on the inflow side of the most active portion of the QLCS. Note the pros and cons of each hazard is based on parameter threshold guidance from the [WDTD All Hazards Decision Chart.]

C. All-Hazards Decision Chart Analysis Applied to GSP Forecast Sounding

1) Mesocyclonic and/or QLCS tornadoes: Enhanced Risk

Pros:	Cons:
Effective Layer Significant Tornado Parameter (STP (CIN)) = 2.6	
Effective Bulk Wind Difference (Lower Half Storm Depth Shear) = 52 kts	
Effective Inflow Layer Depth = 3508 m	
Effective Storm Relative Helicity (ESRH) = 567 m2/s2	
100-mb Mixed Layer Convective Inhibition (MLCIN) = 0 J/kg	
100-mb Mixed Layer Lifted Condensation Level (MLLCL) = 522 m	100-mb Mixed Layer Convective Available Potential Energy (MLCAPE) = 780 J/kg
0-3 km line normal bulk shear = 30-40 kts	
0-3 km MLCAPE = 150-200 J/kg	

2) Severe Hail: Marginal Risk

Pros (for ≥ 1″):	Cons:
Most Unstable Convective Available Potential Energy (MUCAPE) = 988 J/Kg	
Effective Bulk Wind Difference = 52 kt	
Pros (for sig hail ≥ 2″):	**Cons:**
700-500 mb lapse rates (LR7-5) = 6.8°C/km	Significant Hail Parameter (SHIP) = 0.5

Effective Bulk Wind Difference (EBWD) = 52 kt	Most Unstable CAPE (MUCAPE) = 988 J/kg
Surface to Equilibrium Level Bulk Shear (ShearEL) = 70 kt	

3) Severe Wind (horizontally driven): <u>Enhanced Risk</u>

Pros:	Cons:
Derecho Composite > 2	Downdraft Convective Available Potential Energy (DCAPE) = 313 J/kg
Slab-like lifting	Most Unstable Convective Available Potential Energy (MUCAPE) = 1064 J/kg
0-6 km mean wind = 198/55 kts	
EBWD = 52 kts	

D. Convective Allowing Model (CAM) Simulation Use

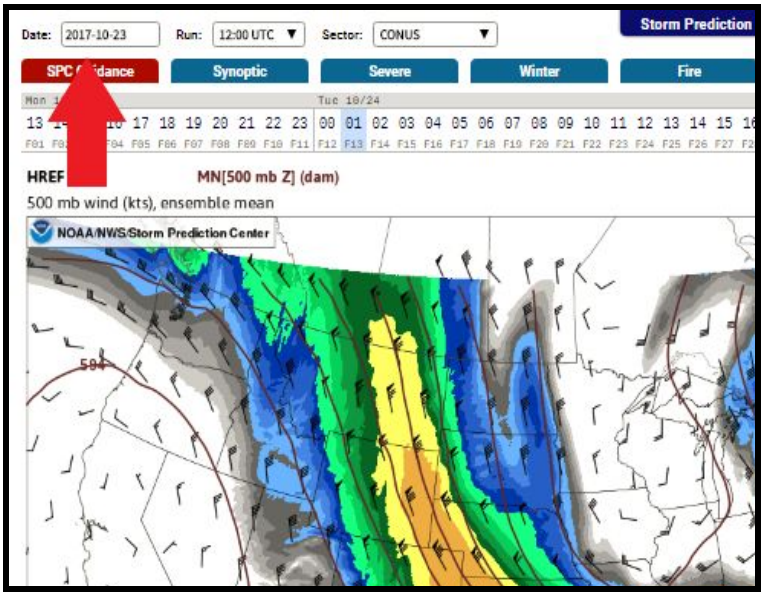
1) Instructions:

The student is expected to load the 12Z run from Oct. 23, 2017 using the **High-Resolution Ensemble Forecast Version 2 (HREFv2) Ensemble Viewer** found at http://www.spc.noaa.gov/exper/href/ to assess the following:

- Relevant synoptic and mesoscale features
- Near-storm environment
- Storm mode and intensity
- Event timing
- Location for severe hazard development

Notes: On your Firefox Browser, make sure to change the date/run of the ensemble viewer to **2017-10-23 12:00 UTC** to view appropriate archived case data (See Figure 10). The GSP CWA is best seen on the “Mid Atlantic” sector with the “NWS CWAs”

toggled on. More recent HRRR runs are also available for viewing in AWIPS/WES2-Bridge.



Include a brief summary of your HREF assessment to supplement your analysis of deterministic models and real-time observations in your answer for Question #1.

Figure 10. HREF V2 Ensemble Viewer

2) Summary of CAMs Ensemble Output

<u>Relevant synoptic and mesoscale features:</u>

A negatively-tilted trough and surface cold front will pass through the CWA from west to east during the 17 - 01z time frame. A low-level jet of 50-70 knots is forecast to develop ahead of the front during this time.

<u>Near-storm environment:</u>

This is a low-instability, high-shear environment. SBCAPE ahead of the front will most likely be > 500 J/kg but remain <1000 J/kg, with 1500 J/kg indicated as the max produced by the ensemble. Mean 0-3 km and 0-1 km SRH values ahead of the front range from 400 - 500 m^2/s^2 and 200 - 400 m^2/s^2, respectively.

<u>Storm mode and intensity:</u>

Ensemble members are in agreement that the convection will be linear, though the time-lagged members suggest it may be somewhat broken. Updraft Helicity (UH) swaths of >75 (m^2/s^2) are shown in some members, implying a possible QLCS tornado

threat. However, an ensemble max UH of 150 m^2/s^2 suggests the chance for strong tornadoes is minimal. Although this likely storm mode implies a strong wind threat, the ensemble max 10 meter wind speed remains <50 kts.

Event timing and location:

The ensembles suggest that the linear convection will likely move into the western part of the CWA from 14-15z and should move out of the eastern CWA by 00z. UH values suggest the stronger storms will occur between 18 - 00z across the eastern half of the CWA.

Question #1 for Trainee:

Based on the environmental assessment through 1800Z, including observations, SPC Mesoanalysis Pages, model forecast soundings and HREF output, briefly describe the risk of tornadoes, severe hail, and damaging winds expected in the GSP CWA for the next 3-6 hours (1800-0000Z). Focus on the specific hazards, timing, and impacts. Enter your answer via the **WOC Severe WES-2 Simulation Answer Form.**

E) Decision Support:

The next section provides an opportunity for simulation trainees to practice advising and interpreting Impact-Based Decision Support (IDSS) messaging techniques for threat assessment to help core partners for this particular event. There are two situations that will require a response from the trainee.

IDSS Situation #1: Call from Public School Superintendent

Immediately after completing your environmental analysis, you get a call from the Spartanburg Public Schools Superintendent. She says that she just heard a tornado watch was issued for the area and sees some storms on radar to the southwest. With schools under her jurisdiction expected to dismiss between 3:00 and 3:15 P.M. local time, she is wondering what times storms can be expected to hit the Spartanburg area and what impacts you expect with the storms. She can hold buses and keep students at the school if it looks like severe weather or tornadoes are expected. What do you tell her?

Best Answer: *"Thunderstorms are developing southwest of Spartanburg, and they may become severe. The main threats would be from damaging winds, and there is a chance that these storms could produce a tornado or two near the area. They also could produce some small hail, heavy rain, and of course, lightning. I would expect storms to arrive around 3 to 3:30PM."*

IDSS Situation #2: Greenville Main Street Event

Your office received a call from Greenville Main Street, a weekly outdoor event in Greenville. The event organizer wants guidance on when the severe thunderstorm threat will end, especially lightning, and expected winds to 30 mph or greater, tornadoes and flooding, due to tent setup.

Best Answer: "*By 2200Z, the back edge of the line of storms should be 40-50 miles east of GSP, temperatures will be dropping to low 60s with winds 10-15 mph."*

Trainee should evaluate current radar/satellite and CAMs/model output and use event thresholds as shown.

Edit	Duplicate	2018-03-22 15:00:00	2018-03-22 21:30:00	Greenville Downtown Alive	34.853;-82.398	Call for Lightning, wind 30 mph or greater, flooding, severe thunderstorms, tornadoes, heat inde: 100 or more. They will call operations the day before if they have any questions or would like a sh briefing leading up to the event.
Edit	Duplicate	2018-03-16 15:00:00	2018-03-16 22:00:00	Greenville Main St Friday	34.853;-82.398	Call for Lightning, wind 30 mph or greater, flooding, severe thunderstorms, tornadoes, heat inde: 100 or more. They will call operations the day before if they have any questions or would like a sh briefing leading up to the event.

7. Storm-Scale Intensification to Tornado Debris Signatures (TDSs)

Part 2 of Simulation: 18:00 - 19:39Z

Instructions: Trainee is expected to analyze real-time observational data including WSR-88D radars (KGSP), MRMS, GOES-16, ENI lightning, and model data to evaluate the current and short-term potential of convectively induced severe winds, hail and tornadoes, and issue warnings/statements as appropriate to convey the risk and impacts.

A. Three Ingredients Methodology Analysis

Objective: Trainee should apply the Three Ingredients Methodology to identify potential areas of mesovortex development and intensification to support warning decisions.

Recommended Procedures:

- **Three Ingredients (In WOC_Severe18.xml)**
    - **Plots HRRR 0-3 km line normal bulk shear vectors and arrows where magnitudes are >= 30 kts overlaid with 0.5 deg Z/V; turn sampling on to display actual shear values)**
- **kgsp 4 pnl Z/SRM/CC/ZdR (in WOC_Severe18.xml)**
- **kgsp 4-panel All-tilts (in RAC-FY18-GSPSevere.xml)**
- **kgsp WarnGen Z/V (in RAC-FY18-GSPSevere.xml)**

Recall from the WOC Severe Lesson, "Quasi-Linear Convective Systems: Mesovortex Recognition for Tornado Warnings", there are three criteria that favor mesovortex genesis and rapid intensification in a QLCS:

1) **The portion of a QLCS in which the system cold pool and ambient low-level shear are nearly balanced or slightly shear-dominant.**
2) **Where the 0-3 km line-normal bulk shear magnitudes are equal to or greater than 30 knots.**
3) **Where a rear-inflow jet (RIJ) or enhanced outflow causes a surge or bow in the line.**

Successful application of the method requires the co-existence of all three criteria (Fig. 11), in addition to the presence of several "confidence builders" and "nudgers" (Fig. 12), for issuing effective tornado warnings for a QLCS event.

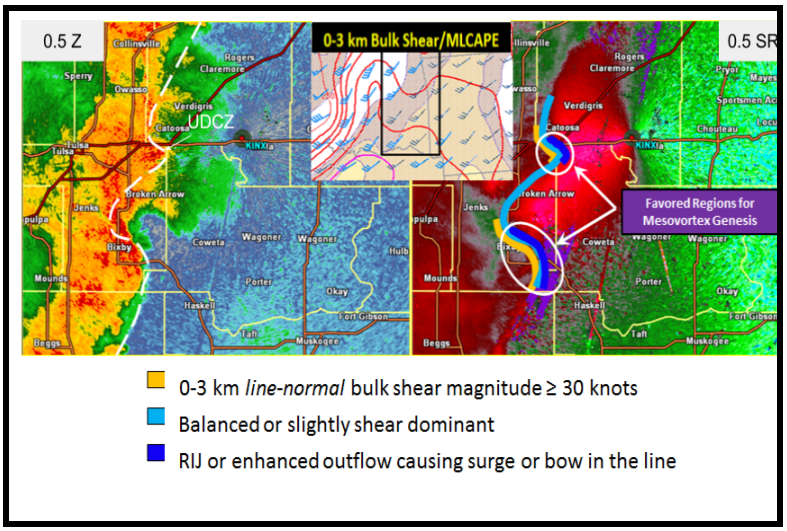


Figure 11. Example of application of Three Ingredients Method for a case used in the WDTD WOC Severe QLCS Mesovortex Recognition for Tornado Warnings Course.

Tornado Warning Decision Confidence Builders & Nudgers
Descending RIJ/Reflectivity Drop
Enhanced Surge
Line Break
UDCZ Entry/Inflection Point
Paired front/Rear Inflow Notch
Boundary Ingestion
Front Reflectivity Nub
Contracting Bookend Vortex with Vr ≥ 25 kt
Tight/Strong Mesovortex (Vr ≥ 25 kt)
Tornadic Debris Signature (TDS)
Reflectivity Tag Intersecting a Surge
0-3 km MLCAPE ≥ 40 J/kg
Cell Merger/Reflectivity Spiking Near Surge
History of Tornadic Debris Signature (TDS)

Figure 12. Table showing tornado warning confidence builders and nudgers after Schaumann and Przybylinski (2012). The Updraft Downdraft Convergence Zone is denoted as UDCZ.

Effective use of the Three Ingredients Methodology requires a significant level of expertise as the ability to quickly judge radar features of rapidly evolving QLCS storm characteristics can be very difficult. Since learning is a process that requires prior knowledge, practice and contextual application, it may be necessary to run this part of the simulation multiple times to gain proficiency in using the Three Ingredients Methodology for optimum warning decision making skill.

Use this section of the simulation to:

- Improve the trainee's ability to recognize criteria using the Three Ingredients Method to help identify where and when tornadoes might develop to maximize lead time and reduce false alarms for QLCS warnings
- Practice radar product assimilation to speed up feature identification.

B) Three Ingredients Method Analysis from 1812-1851Z:

Time	Notable Features	Impacts
1812-1820Z	North of the apex of the bow, the 0-3 km line-normal bulk shear ≥ 30 kts 0-3 km CAPE > 40 J/kg ahead of the QLCS (from SPC Meso page) The UDCZ starts curling back into the updraft tower region which is an UDCZ entry point (See Fig. 13). Further south, the UDCZ is located along the immediate front edge of the updraft towers which implies a balanced cold pool/shear zone. Descending RIJ/Reflectivity drop signature shows up between 1812 and 1825Z in the trailing stratiform region. Reflectivity tags migrating north along the leading flank of the line and through the bow section.	Minimum criteria met for Three Ingredients, plus 3 confidence builders and 1 nudger for a Tornado Warning. Mesovortex genesis should be expected with the next 20 minutes or so. Warning Decision: Enough evidence for a SVR with tornado possible tag, based on favorable ingredients.
1820-1838Z	Small cells developing out ahead of the strongest part of the line west of	Up to 5 confidence builders/nudgers.

	Laurens between 1822Z and 1830Z and then merge back with the bow starting at 1833Z. Mid-level mesocyclone at 4K ft strengthens	Warning Decision: SVR with tornado possible tag, based on favorable evidence. Prepare to draw up first tornado warning.
1838-1846Z	Pronounced entry point developing at Point A (Figure 13) . Mid-level mesocyclone weakens slightly.	Warning Decision Options: (Good) SVR with tornado possible tag, based on favorable evidence. (Better) TOR based on increasing confidence of favorable ingredients.
1846-1849Z	Enhanced reflectivity surge develops at 1846Z just south of Point A. Mesovortex genesis rapidly takes place at 1846Z west of Woodruff.	Warning Decision: TOR within the SVR based on accumulated evidence of favorable ingredients. For sample polygon, see Figure 15)
1849-1851Z	Intensification and constriction of mesovortex. 120 kt delta-V at 0.5 deg tilt. Tornado Debris Signature (TDS)	Warning Decision: TOR SVS with “radar confirmed tornado” as basis. Optional: Considerable Tag
1854Z	TDS; first Tornado report comes in via spotter 4 NW of Woodruff.	Warning Decision: TOR SVS with spotter reported as basis

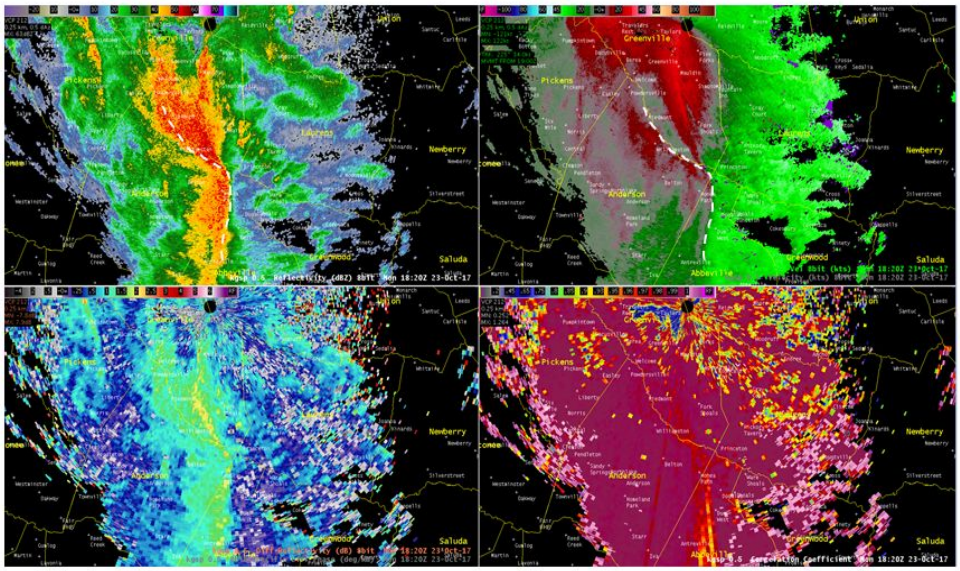


Figure 13. KGSP 4-panel at 1820Z with the following 0.5 deg products (clockwise): Z, SRM, CC, and ZDR. Updraft Downdraft Convergence Zone (UDCZ) annotated in dashed white.

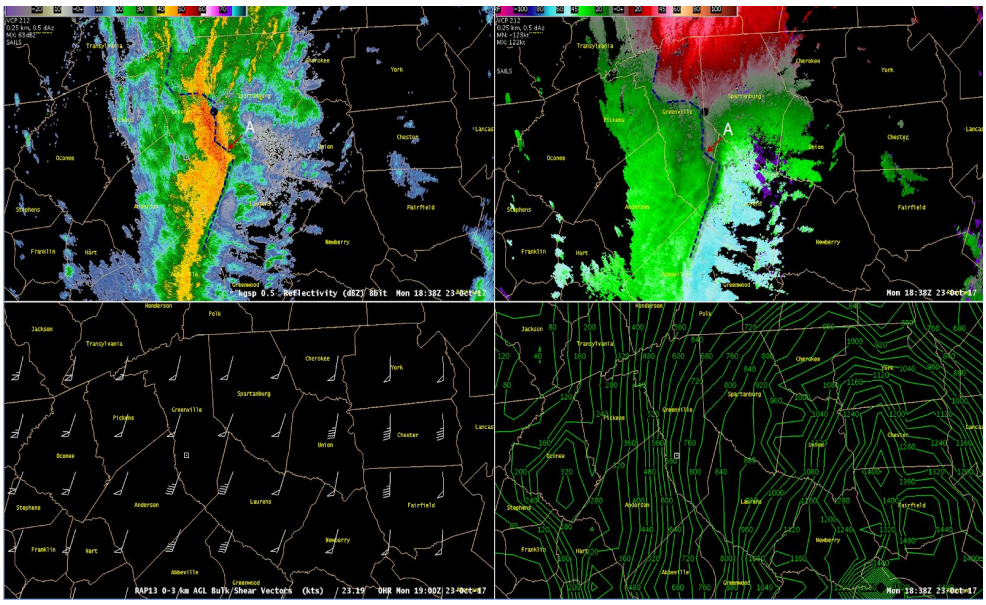


Figure 14. 4-panel product display at 1838Z showing (clockwise): KGSP 0.5 deg Reflectivity, 0.5 deg Base Velocity, MUCAPE (RAP13 1900Z 00h fcst), and 0-3 km AGL bulk shear vectors (RAP 1900 00h fcst). Updraft downdraft convergence zone (UDCZ) annotated in dashed blue.

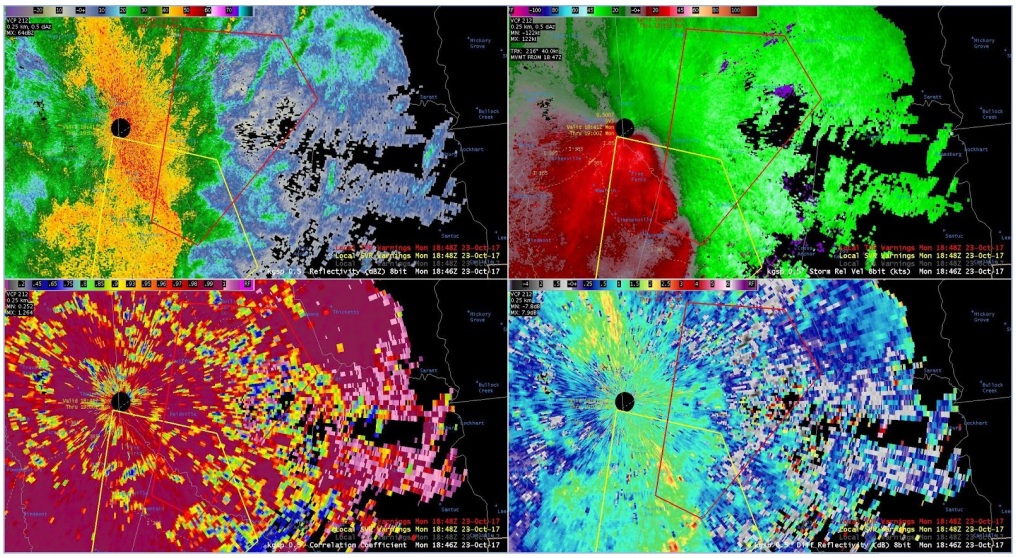


Figure 15. Proposed SVR and TOR polygons issued for GSP Simulation @ 1846Z.

C. Multisensor Temporal Analysis of QLCS Storm Structure Evolution (1800 - 1900Z)

The simulation is the first WOC Severe WES case that contains a full suite of multisensor data products including: Multi-Radar Multi-Sensor System (MRMS), GOES-16, and Total Lightning (ENI) products. This section is designed to help warning forecasters practice using these multisensor data sets to help determine which ones work best to support QLCS storm interpretation, threat motion, and hazard assessment for warning decisions. After completing Section B on the Three Ingredients Method, this section offers an option to dig even deeper into an analysis of severe storm structure and evolution of the QLCS from 1800-1900Z. If you want to to use this section, stop the simulation and go back play the simulation again starting at 1745Z and use the 9-panel multisensor products procedures to practice identifying updraft signature evolution in more detail.

As part of the exercise, the trainee should use the [2018 WOC Severe WES-2 Simulation Answer Form]() to assess what each multisensor product shows at various stages of storm structure evolution such as:

- Changes in upper-level updraft signature trends
- Changes in low-level velocity signatures
- Storm motion/mode changes
- Hazard assessment

Objectives: Using preloaded procedures of 9-panel GOES/Lightning/MRMS products and 9-panel KGSP all-tilts no flip Std env table, trainee should demonstrate the ability to identify updraft signatures, trends in storm motion and convective mode, and work to increase efficiency in using multisensor products for assessing trends in severe storm intensity to support effective warning hazard decisions.

Recommended Procedures:

- **kgsp 9 pnl All-tilts No flip (in RAC-FY18-GSPSevere.xml)**
- **kgsp 9 pnl MRMS/ENI/GOES-16 (in WOC_Severe18.xml) (See Figure 16 for panel product labels)**

1) Multisensor Analysis Summary

Period	Key Summary Points
1745-1800Z	Rapid cell growth along a convergence line in favorable tornado environment
1800-1815Z	Deep updraft surge occurring over low-level gust front
1815-1822Z	Tall echo phase of the bow echo. Azimuthal shear increasing, lightning jump occurring, rear, low reflectivity notch forming through a deep layer behind the apex of the bow. 3 ingredients for mesovortex formation coming together (gust front constrained under updraft, strong line-normal 0-3 km shear, and bowing segment).
1822-1835Z	Deep updraft signatures declining thus signaling end of tall echo phase of bow echo lifecycle. Hail and lightning threat decreasing but wind and tornado threat remaining the same.
1835-1845Z	Upper level updraft strength stabilizing in mature bow echo stage, low-level mesovortex forming.
1845-1852Z	Rapid mesovortex strengthening, tornado vortex signature (TVS) forms (1848Z)

1852-1900Z	Tornado, accompanied by a TVS with TDS, tracks to the NNE.

2) Detailed Multisensor Analysis for each period:

1745 - 1800Z:

Upper-level updraft trends	Storm Motion/Mode	Hazard Assessment
• Z increasing at -10C • 50 dBZ thickness above melting became positive • VII (3- 7 kg/m**2) • MESH increasing • GOES-E CTT falling from -60 to -66 C • Very few lightning flashes • 50 dBZ height rose from 13-18.6 kf ASL • Zdr column height rose from .5 C level @1743Z to -6 C level @1759Z • Midlevel mesocyclone formed ~1750Z and strengthened to Vr=30kts by 1759Z.	• **Following MRMS VII maximum: tracking** from 236 deg @ 41kt (right of mean wind/Bunker's right-motion) • New cell growth on south side of multicell is encouraging rightward motion. • Area of interest is an intensifying ordinary cell embedded in a heavy precip line along a gust front. • Onset of midlevel circulation suggests conversion to supercell. This is the time to watch out for a surge in gust front at later time but none seen now.	• CG Lightning - Low threat now but increasing as updraft increases. • Large Hail - Low Minimal depth of 50 dBZ above 0 C, low MESH indicate little potential for large hail production. • Severe Wind - Low Updraft growth is cause for concern for generating downbursts. Environment doesn't suggest severe downbursts, however, outflow surge could reorient gust front orientation to allow for mesovortex formation. • Tornado - Low concern increasing for future. - No mesovortex observed at this time. But updraft surge is first step in process to generate a mesovortex. If gust front orientation changes to more cross-shear then tornado threat could rise.
Low-level velocity signatures (up to 4kft AGL)		
• No real features of note in V. • Rotation tracks show typical gust front shear < .006 s-1. • KGSP all-tilts show strengthening shear along the gust front but no mesovortices.		

1800 - 1815Z

Upper-level updraft trends	Storm Motion/Mode	Hazard Assessment
• Continued increasing at -10C • Reflectivity at -10C up to 55 dBZ • 50 dBZ thickness above 0C is up to 8 kft from 5kft • VII up to 12 kg/m^2 from 6 • MESH up to 0.4" from 0.2 • GOES-E CTT leveling out near -66C from -64 • ENI lightning 5 min flash density (5km grid) up to 10 from 1 or 2 • KGSP alltilts: 50 dBZ height briefly reached 23 kft @1809Z and held steady @1815Z • Zdr column reached to -5 C @1809 and steady thereafter • Updraft assuming a comma shape, even with shape of inbound side of meso. **Low-level velocity signatures (up to 4kft AGL)** • MRMS low-level azimuthal shear increased incrementally in last 10 min at .013 s^{-1}. This shear is still somewhat linear but is at the head of a bowing segment	• Still moving roughly 235º at 40 kts, both right of Bunker's right-moving and 0-6 km mean wind. • Cell with quasi-supercellular characteristics in motion and a midlevel mesocyclone but embedded in a line and increasingly taking on the shape of a bow echo. The line orientation north of the apex is allowing ~30º forward 0-3 km line-normal shear along the northern half.	• CG Lightning - Threat increasing as updraft increases in size. • Large Hail - Still low. MESH is <<1" and environment doesn't point to strong future threat. • Severe Wind - Increasing due to localized outflow surge. Some post-gust front radial winds from KGSP are 50kts but typically these don't reach the surface except in downburst. Downburst mechanisms are weak given environment. • Tornado - Increasing with low-level shear exceeding .01 s^{-1} with improving line-normal shear north of bow apex and favorable environment. No mesovortex formed by 1815Z and thus not significant.

1815 - 1822Z

Upper-level updraft trends	Storm Motion/Mode	Hazard Assessment
• Peaked in growth according to VII as it fell a bit from its peak in 1818z at 18 kg/m2. • MESH also peaked and has decreased a bit • GOES-E 10.3 micron cloud top temp dropped 1 deg C to -67 C but this drop is slower than before 1815z • KGSP all-tilts shows Zdr column size less but 50 dBZ still >20 kft AGL • MRMS 50 dBZ thickness above melting level decreased some. • Midlevel mesocyclone persists. **Low-level velocity signatures (up to 4kft AGL)** • Azimuthal shear has increased to .015 s-1 from .010. • Shear is still linear along the gust front.	• Based on VII, the motion shifted left and now is 229 deg 47 kts. This is more in line with Bunker's. • Bowing segment now well-defined at low-levels with a persistent set of supercell features aloft, including motion. • The rear low reflectivity notch also appears in the -10 C reflectivity, 50 dBZ thickness, and in derivative products like VII and MESH, indicating deep layer of ascent. • Updraft tendency suggests we've gone through the tall echo phase of the bow.	• CG Lightning - Threat is considerable as updraft and intracloud lightning has peaked. Most of the CG activity is within the precipitation core left of the apex following storm motion. • Large Hail - Threat is still low as MESH peaked at 0.5" and latest VII, 50 dBZ thickness also showed decline in last few minutes. • Severe Wind - Threat has stabilized. Outflow surge has resulted in a bow but still question about 50 kt post-gust front radial winds reaching the surface. Consider though the high Kdp (>5 deg/km) at 10 kft AGL may show enough melting small hail to drive a downdraft to ground. • Tornado - Threat is stabilized for now with low-level azimuthal shear around .016 s^{-1}.

1822 - 1835Z

Upper-level updraft trends	Storm Motion/Mode	Hazard Assessment
• Decline in upper-level updraft strength signaled most clearly by decline in VII, MESH, 50 dBZ thickness above 0C, reflectivity at -10C, and GOES-E 10.3micron CTT. • However, 3-6 km azimuthal shear increased during this time and low-level azimuthal shear remained steady. • These latter signatures, and a strongly convergent gust front underneath the deeper updraft indicate low-level updraft signatures remain strong. • KGSP velocity doesn't show the localized azimuthal velocity couplet of before. • Other KGSP updraft signatures becoming difficult to discern due to cone of silence and steep elevation angles.	• The VII peak indicates motion stabilized at 229 47 kts. • The bow echo continues but enters its later mature stage as deep updraft weakens. • Lost midlevel signals of a supercell incl motion.	• CG Lightning - Threat has declined as tall echo phase of bow ended. • Large Hail - The threat, never significant, has declined. • Severe Wind - Some decline in KGSP radial winds indicates more uncertainty in the threat. Overall, the bow echo structure suggests some potential for severe winds. • Tornado - Threat seems to have eased a bit. Low-level MRMS azimuthal shear is steady around .016 s^{-1} but do not see the tight focused shear segment along apex of gust front in KGSP radial velocity.
Low-level velocity signatures (up to 4kft AGL)		
• 0-2km Azimuthal shear remains nearly steady at .015 s-1. • Shear along gust front remains strong from KGSP though maybe a little lower than 1815-1822Z.		

1835 - 1845Z (See Figure 16)

Updraft intensity assessment	Low-level velocity assessment	Hazard Assessment
• Conflicting signals • Psbl new updraft forming right of old one • 50 dBZ thickness above 0C, VII, MESH, and reflectivity at -10C show little trend (steady updraft strength) • ENI total lightning density, GOES-E 10.3 micron CTT, indicate weakening updraft. • Decline in upper level core preceded changes to lightning density prior to 1835 UTC. • Increase in VII, reflectivity at -10C, 50 dBZ thickness above 0C, over an area of tightening low-level azimuthal shear to the right of the bow apex • Low-level updraft signatures remain strong with strong azimuthal shear at low- and midlevels and the gust front remained under the deep updraft • KGSP midlevel updraft signatures are missing because of cone of silence issues but lower scans show updraft intensification in same area that MRMS showed. • Low-level front inflow notch and improvement in azimuthal velocity difference in the 4 - 8 kft AGL range suggests better updraft signatures in this layer.	• 0-2km MRMS Azimuthal shear remains nearly steady at .015 s-1. • Convergence along gust front remains strong • KGSP Base V indicates a mesovortex forming at, or just right of the bow apex at 4-8 kft AGL. • While azimuthal shear remained the same, it became concentrated in this mesovortex. • Lowest tilt in KGSP also indicates a larger pool of angular momentum surrounding the area underneath the mesovortex. That is a streamer of outbounds expanding left, and in front, of a similar zone of inbounds ahead of the shear max.	• CG Lightning: Threat has stabilized even though intracloud lightning density continued to decline. Other deep updraft signatures have stabilized, especially reflectivity at -10 C and thus lightning threat should stabilize. • Large hail: Insignificant as deep updraft signatures are too weak. • Severe wind: This threat remained the same, significant and still worth of a severe warning. • Tornado: Threat is increasing as a mesovortex is forming even with the maximum low-level azimuthal shear steady around .016 s^{-1}.

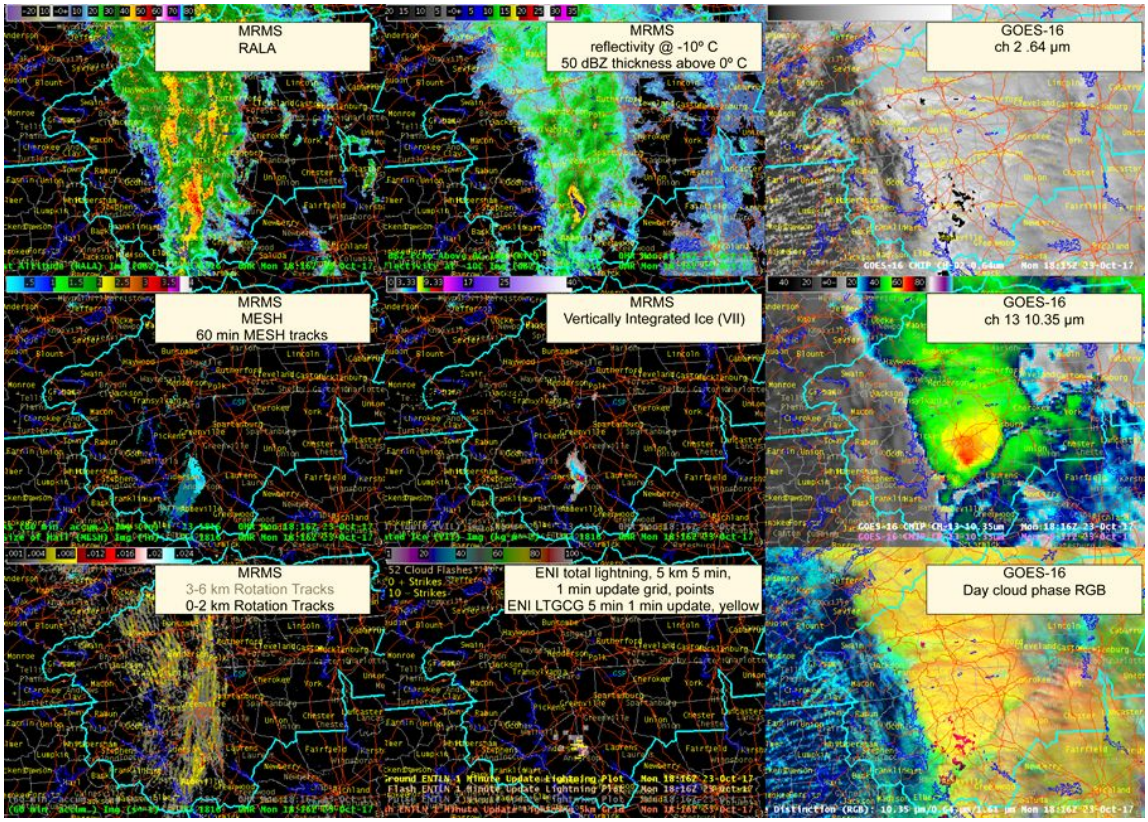


Figure 16. 9-panel image of MRMS/Ltg/GOES products used for Part C of the simulation (1845Z).

1845 - 1852Z

Upper-level updraft trends	Storm Motion/Mode	Hazard Assessment
• Deep updraft signature forms ~1845Z over the peak low-level shear. • Signature is first visible in VII, Z at -10C, and 50 dBZ thickness above 0C. • Then GOES-16 10.3 micron imagery detects overshoot and dropping CTT (parallax corrected) by 1848 Z. This delay is likely because the updraft had to punch anvil before revealing itself by satellite. • ENI total lightning also indicated a few discharges in this new updraft but density remained very low. **Low-level velocity signatures (up to 4kft AGL)** • 0-2km Azimuthal shear rapidly increased to .02 s^{-1} and became shaped like a comma with the peak values in the comma head. • 3-6 km Azimuthal shear remained unchanged. • Classic bottom-up mesovortex evolution common with QLCSs. The first sign of a tightening mesovortex was at 1846Z in the KGSP 0.5deg tilt at 11nm@151deg. This feature extended up 7.3 kft (6.4 deg) before washing out and developed coincident with a sharp counterclockwise pivot of gust front orientation to become more normal to 0-3 km shear. This mesovortex is embedded in a larger region of a convergent pool of flow with high angular momentum.	• Tracking is more difficult. At this point VII has become more difficult. • Low-level azimuthal shear peak appears more continuous in the last 15 minutes. Its motion is roughly 217 at 48kt. Given tornado concerns, tracking this feature is most appropriate. • This is still a mature bow but new updraft growth right of the apex is clouding clean appearance.	• CG Lightning - Deep updraft signatures are weak and thus this threat continues low. • Large Hail - Insignificant as deep updraft signatures are too weak. • Severe Wind - Severe wind threat becoming focused on mesovortex formation and thus may not be a threat separate from that of the tornado. • Tornado - Threat is very high. Mesovortex intensification and TVS formation under a local deep updraft surge suggested tornado conditions. Tornado debris signature appears at 1851Z 0.5 deg and extends to 7kft AGL during the course of this volume scan.

1852-1900Z

Storm Motion/Mode	Hazard Assessment
• QLCS featuring a TDS is tracking to the NNE; becoming embedded in a comma head of rain indicating visibility problems for those trying to spot the threat from the ground.	• Ongoing tornado means frequent SVS updates with rain wrapped tornado call to actions. This tornado has the indications of producing EF2 or greater damage based on the low-level rotational velocity, and intensity of the TDS. Messaging should appropriately reflect this threat.

D. Tornado Debris Signature Evolution (1830-1939Z)

There are multiple Tornado Debris Signatures (TDSs) evident in this QLCS simulation so we have summarized the location, timing, and structure of these features for the purpose of practicing TDS feature identification and integration into warning products and services.

Objective: Use WSR-88D base data to identify and track QLCS TDS characteristics for the purpose of evaluating feature location, structure and movement to use in tornado warning products and decision support services.

Recommended Procedure:

- **kgsp 4 pnl All-tilts (in RAC-FY18-GSPSevere.xml)**

TDS #1: Spartanburg County, SC

TDS #1 begins roughly 4 miles WNW of Woodruff (34.78, -82.08) at 1851Z. While not very clear at the 0.5 degree scan, if one goes up one tilt, this TDS is clearly visible at 0.9 degrees and continues to a height of roughly 6,000 ft AGL (6.4 degree tilt). The TDS becomes very visible at the lowest (0.5 degree) tilt with the 1854Z SAILS tilt, which is the next scan. By 1856Z which is the next full scan, the TDS continues and is clearly visible with very low CCs and ZDR also dropping out. At this time, the TDS extends upwards to approximately 8,000 ft AGL (8.0 degree tilt).

As the tornado continues, a clear TDS remains visible at the 1901Z tilt, with the TDS extending upwards to the 10.0 degree tilt to approximately 11.5kft AGL.
The TDS remains visible with the 1904Z and 1907Z scans but becomes hard to distinguish with the 1909 SAILS tilt as ground clutter and the lack of upper tilts makes it difficult to identify debris.

TDS #2: Spartanburg County, SC

At 1912Z, a new TDS is visible to the left of the track of the first TDS. This TDS is roughly 4 miles WNW of Spartanburg in Spartanburg County, SC (34.97, -81.98). TDS #2, like the final scans of the previous TDS, is mixed in with ground clutter at the 0.5 degree scan. However, if one looks aloft, the TDS is much clearer at the 0.9 degree scan and continues to a height of approximately 6.5kft AGL (4.0 degree scan) before it becomes difficult to distinguish. This TDS continues until the 1920Z scan, at which point the CC values increase into the 0.85+ range and spread out, indicating lofted debris being spread out by winds. While not a TDS from this point forward, debris continues to be displayed in CC through at least the 1933Z scan.

TDS #3: Cherokee County, SC and Cleveland County, NC

A new TDS (35.13, -81.72) is evident on the 1936Z 0.5 degree radar scan (See Figure 17 with sample warnings overlaid). This TDS continues until the 1942Z radar scan, at which point it dissipates with just some lofted debris evident by increased values of CC. Only one of the all-tilts product is available during the timeframe of this TDS (1939Z), where debris is distinguishable upwards to ~ 5.2kft AGL.

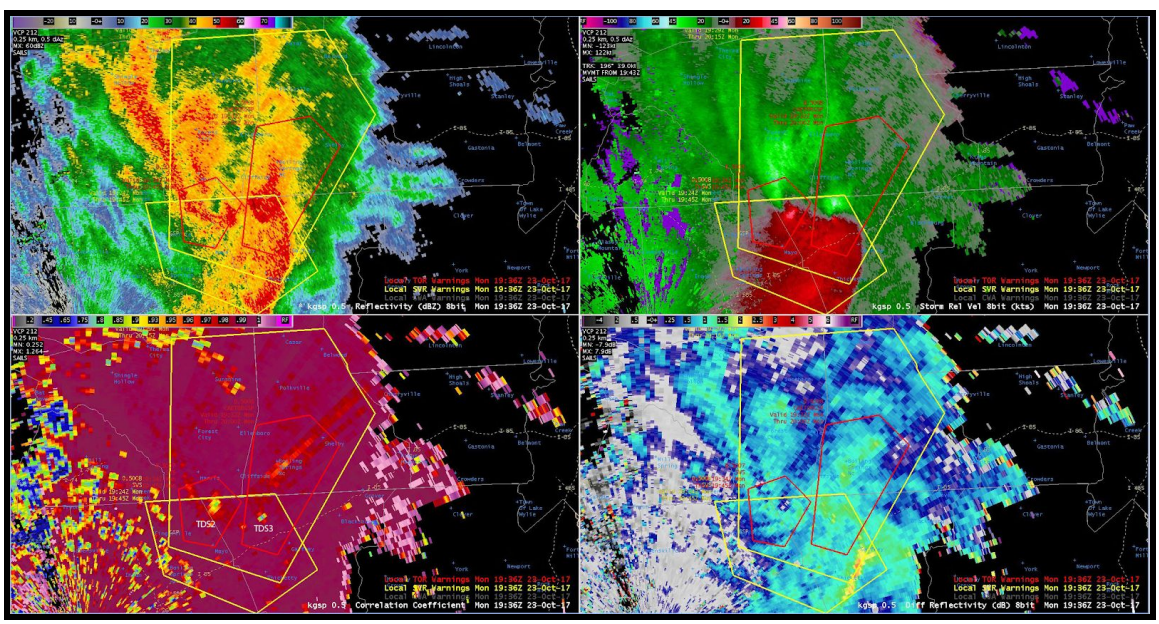


Figure 17. KGSP 4-panel at 1936Z 0.5 deg (Z, SRM, ZDR, CC) showing locations of TDS#2 and TDS#3 with recommended warnings overlaid.

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8. Part 3: QLCS Evolution

1930 to 2030Z

Meteorological Summary:

During this period, the bookend vortex at the northern part of the QLCS occludes and moves NNW of the mean QLCS line motion and the entire feature moves into North Carolina and detaches bit from the lower bowing structures. Meanwhile, the UDCZ continues to reorient itself due to the dominant shear region of the northern part of the QLCS and by 1936Z is oriented from west to east across extreme southern Rutherford and Cleveland Counties (See Figure 15) . There are two simultaneous mesovortices tethered to the UDCZ at the beginning of this phase of the simulation moving northward and producing rain-wrapped tornadoes from northern Cherokee County SC and southern Rutherford County, NC. Radar interrogation of the mesovortices are becoming more difficult with time due to range resolutions issues as the features are > 40 nm NNE of the radar. The eastern-most tornadic mesovortex in Cleveland County, NC continues to cause sporadic damage with mostly trees and powerlines down from 1941-2011Z. The western-most tornadic mesovortex continues to draw back further into the trailing stratiform rain region but continues to do damage all the way into Catawba County NC with mostly trees, power lines and roof damage reported. The simulation facilitator can choose to have the trainee complete this section optionally for additional practice of issuing warnings for a mature QLCS. The simulation should end at 2030Z.

9. Summary

Quasi-Linear Convective System (QLCS) tornadoes pose substantial challenges to operational forecasters owing to the rapid development and detection difficulties related to radar sampling limitations. Often times, development of the mesovortex features occurs below the lowest tilt of the radar beam. In this particular case from October 23, 2017 in the GSP CWA, the evolution of particular features of interest, such

as the development and intensification of tornadic mesovortices and associated tornado debris signatures were close enough for sufficient radar sampling which afforded detailed examination. This somewhat unique situation provides an opportunity for warning forecasters to be able to train to improve skills in feature recognition and detection for this challenging events.

After facilitating this simulation, it is very important to confer with the trainee to go back and replay and review areas where competency in mastering the simulation objectives were difficult. As part of the debriefing process, it is a good idea to use the storm data listing below to verify warnings issued during the simulation and examine situations where warning polygons could have been issued earlier and/or had areas trimmed back. In addition, evaluate the number and timeliness of follow-up statements. It may be necessary for the trainee to complete the simulation multiple times to gain proficiency at issuing warnings for QLCS tornadoes. If there are gaps in knowledge or understanding during this process, consider reviewing sections of the Radar and Applications Course (RAC) as well as the QLCS Curriculum in WOC Severe.

10. Storm Data

Storm Data and Unusual Weather Phenomena - October 2017

Location	Date/Time	Deaths & Injuries	Property & Crop Dmg	Event Type and Details

GEORGIA, Northeast

HART COUNTY --- 1.8 SW NUBERG [34.25, -82.92]

	10/23/17 12:00 EST	0	Thunderstorm Wind (EG 50 kt)
	10/23/17 12:00 EST	0	Source: Public

Public reported trees blown down on Woodland Way.

A band of rain showers moved across northeast Georgia during the late morning and early afternoon along and ahead of a strong cold front. An isolated damaging wind event occurred in the Piedmont.

NORTH CAROLINA, Southwest

MCDOWELL COUNTY --- 3.8 ESE NEBO [35.70, -81.87], 0.8 N DYSORTVILLE [35.61, -81.88], 3.7 SW DYSORTVILLE [35.56, -81.93], 1.2 SSW GLENWOOD [35.60, -81.99], 0.9 SW NEBO [35.71, -81.94], NEBO [35.72, -81.93]

	10/23/17 14:15 EST	5K	Flash Flood (due to Heavy Rain)
	10/23/17 17:30 EST	0	Source: Emergency Manager

EM reported flash flooding developed across eastern McDowell County after 3 to 4 inches of rain fell across the area, mostly within a couple of hours. Several small streams overflowed their banks and flooded adjacent roads in the southern part of the county, including Katy Creek, Moores Branch, and Stanfords Creek. Closer to Nebo, the main problem stream was Mud Creek, which flooded portions of Dixie Dr, South Creek Rd, Harmony Grove Rd, and Gilbert Byrd Rd. Additionally, Shadrick Creek flooded part of Highway 126.

MITCHELL COUNTY --- 1.3 N ALTAPASS [35.90, -82.03], 1.6 SSE ESTATOE [35.88, -82.11], 0.8 W TOECANE [36.02, -82.19], 1.5 NNW CLARRISSA [36.04, -82.13]

	10/23/17 14:30 EST	3K	Flash Flood (due to Heavy Rain)
	10/23/17 17:00 EST	0	Source: 911 Call Center

County comms reported multiple streams overflowing their banks and flooded/closed roads in Mitchell County after 3-4 inches of rain fell across the county, mostly over the span of a few hours.

RUTHERFORD COUNTY --- 3.5 SSW CLIFFSIDE [35.18, -81.80], 3.5 NE CLIFFSIDE JCT [35.30, -81.72]

	10/23/17 14:40 EST	0.10M	Tornado (EF1, L: 9.44 mi , W: 100 yd)
	10/23/17 14:47 EST	0	Source: NWS Storm Survey

This tornado moved into Rutherford County from Cherokee County, SC near the intersection of Camp Ferry Rd and State Line Rd. The tornado moved northeast, initially paralleling Highway 221 A (just to its west). In addition to the uprooting and snapping of numerous trees, some structural damage occurred in the
Cliffside area , with windows blown out of a school while trees fell on several structures. The tornado crossed Highway 221 A in the vicinity of the Broad River, then roughly paralleled Highway 120 to the Cleveland County line. Some of the most significant damage occurred in the vicinity of the intersection of Highways 120 and 74, where a camper was overturned and a man was thrown 15-20 yards with no significant injuries. Overhead doors also collapses at a warehouse building at this location.

CLEVELAND COUNTY --- 5.1 SSW BOILING SPGS [35.18, -81.71], 4.8 SSW BOILING SPGS [35.18, -81.70]

	10/23/17 14:41 EST	0	Tornado (EF0, L: 0.28 mi , W: 100 yd)
	10/23/17 14:42 EST	0	Source: NWS Storm Survey

A weakening tornado moved into Cleveland County from Cherokee County , SC between Twin Bridges Rd and McCraw Rd. The tornado blew down multiple trees and large limbs before dissipating shortly after crossing into North Carolina.

CLEVELAND COUNTY --- 1.3 WNW MOORESBORO [35.30, -81.72], 1.0 ESE POTTVILLE [35.41, -81.63]

	10/23/17 14:47 EST	0.10M	Tornado (EF0, L: 9.11 mi , W: 100 yd)
	10/23/17 15:02 EST	0	Source: NWS Storm Survey

This tornado crossed into Cleveland County from Rutherford County in the vicinity of the Highway 120/ Ellenboro Rd intersection, snapping and uprooting numerous trees as it moved northeast toward Polkville. A small frame home was shifted off its foundation on Rehobeth Church Rd near the intersection of Crowder Rdige Rd. It was also in this area that the tornado appeared to make a slight jog to the right, moving in more of a north/northeast direction toward Polkville, where trees were blown down on several homes.

CLEVELAND COUNTY --- 0.8 S MOORESBORO [35.29, -81.70], 1.0 ESE LAWNDALE [35.41, -81.56]

Storm Data and Unusual Weather Phenomena - October 2017

Location	Date/Time	Deaths & Injuries	Property & Crop Dmg	Event Type and Details
	10/23/17 14:48 EST		50K	Thunderstorm Wind (EG 60 kt)
	10/23/17 15:07 EST		0	Source: NWS Storm Survey

NWS storm survey and other sources reported downburst damage to the east of a tornado path in Cleveland County, from Mooresboro to Lawndale. Numerous trees were blown down in this area, some of which fell on homes.

CLEVELAND COUNTY --- 0.8 E LAWNDALE [35.42, -81.57], 2.5 NW TOLUCA [35.55, -81.51]

	10/23/17 15:08 EST	0.10M	Tornado (EF1, L: 9.19 mi , W: 100 yd)
	10/23/17 15:15 EST	0	Source: NWS Storm Survey

Nws survey found the path of a tornado that touched down near Lawndale, resulting in structural damage as uprooted and snapped trees fell on houses. The tornado continued northeast, with sporadic trees downed along its path, with a slight uptick in structural damage near Belwood, again due to trees falling on homes. The tornado passed into Lincoln County in the Toluca community near Highway 10.

LINCOLN COUNTY --- 2.5 NW TOLUCA [35.55, -81.51], 3.5 NNW TOLUCA [35.57, -81.49]

	10/23/17 15:18 EST	0	Tornado (EF1, L: 1.50 mi , W: 100 yd)
	10/23/17 15:22 EST	0	Source: NWS Storm Survey

NWS storm survey followed the damage path of a tornado that began near Lawndale in Cleveland County into extreme northwest Lincoln County. The tornado blew down multiple trees and tree limbs as it passed near the intersection of Highways 10 and 18, then crossed into Catawba County in the vicinity of Willis Rd.

CATAWBA COUNTY --- 4.0 W PROPST XRDS [35.63, -81.45], 1.2 W HICKORY [35.73, -81.34]

	10/23/17 15:20 EST	10K	Thunderstorm Wind (EG 65 kt)
	10/23/17 15:35 EST	0	Source: NWS Storm Survey

Nws storm survey found an extensive area of downburst damage across western Catawba County, generally along and near Old Shelby Rd in the southwest part of the county, northeast to Hickory. Numerous trees were uprooted or snapped in this area. At least one home was damaged by falling trees on the south side of Hickory.

CATAWBA COUNTY --- 7.3 WSW PLATEAU [35.57, -81.49], 6.2 W PLATEAU [35.59, -81.48]

	10/23/17 15:22 EST	0	Tornado (EF0, L: 1.65 mi , W: 100 yd)
	10/23/17 15:26 EST	0	Source: NWS Storm Survey

NWS storm survey found that a tornado that began near Lawndale in Cleveland County moved northeast, passing through extreme northwest Lincoln County, then into Catawba County in the vicinity of Willis Rd. The tornado blew down numerous trees as it moved northeast across southwest Catawba County before lifting in the vicinity of Mull Rd and Old Shelby Rd.

BURKE COUNTY --- 2.8 SW BURKE CHAPEL [35.64, -81.50], 0.9 NW (HKY)HICKORY MUNI AR [35.74, -81.39]

	10/23/17 15:24 EST	0	Thunderstorm Wind (EG 70 kt)
	10/23/17 15:35 EST	0	Source: NWS Storm Survey

Nws storm survey found an extensive area of downburst damage across eastern Burke County, generally in the area between Miller Bridge Rd and the Catawba County line, northeast across Hildebran to the area around the Hickory Regional Airport . Numerous trees were uprooted and snapped in this area.

AVERY COUNTY --- 1.4 NNE PLUMTREE [36.05, -82.01], 1.2 N PLUMTREE [36.05, -82.02], 0.9 SSW ROARING CREEK [36.06, -82.03], 0.6 ESE ROARING CREEK [36.07, -82.01], 0.9 SW FRANK [36.06, -82.01], 1.0 S ROARING CREEK [36.05, -82.02]

	10/23/17 15:30 EST	1K	Flash Flood (due to Heavy Rain)
	10/23/17 17:00 EST	0	Source: River/Stream Gage

A stream gauge on the Toe River exceeded established flood stage in western Avery County after 3 to 4 inches of rain fell in the basin, with much of that falling in only a couple of hours. Low-lying areas near the gauge were flooded, including a portion of Blue Bell Ln, just off Highway 19E.

GASTON COUNTY --- 0.8 WNW STANLEY [35.36, -81.11]

	10/23/17 15:30 EST	20K	Thunderstorm Wind (EG 40 kt)
	10/23/17 15:30 EST	0	Source: Law Enforcement

Law enforcement reported a tree was blown down on a home at Summerow Rd and Mauney Rd.

BURKE COUNTY --- 1.1 NNW (HKY)HICKORY MUNI AR [35.74, -81.39], 1.5 N (HKY)HICKORY MUNI AR [35.75, -81.38]

	10/23/17 15:37 EST	1.50M	Tornado (EF2, L: 1.00 mi , W: 300 yd)
	10/23/17 15:40 EST	0	Source: NWS Storm Survey

Storm Data and Unusual Weather Phenomena - October 2017

Location	Date/Time	Deaths & Injuries	Property & Crop Dmg	Event Type and Details

NWS storm survey found the path of a strong tornado that began at the Hickory Regional Airport . A hangar at the airport was destroyed and several aircraft flipped. The tornado moved northeast to Winkler Park, damaging part of L.P. Frans stadium before moving into Catawba County. Numerous trees were also blown down in this area.

CALDWELL COUNTY --- 3.5 SSE GRACE CHAPEL [35.77, -81.36], 2.2 SE DUDLEY SHOALS [35.85, -81.35]

	10/23/17 15:37 EST	10K	Thunderstorm Wind (EG 70 kt)
	10/23/17 15:46 EST	0	Source: NWS Storm Survey

Nws storm survey found an area of extensive downburst damage across extreme southeast Caldwell County, near the Alexander County line. Numerous trees were blown down in this area, while several outbuildings were damaged, some heavily.

CATAWBA COUNTY --- 1.5 NNW LONGVIEW [35.75, -81.38], 4.3 N HICKORY [35.79, -81.33]

	10/23/17 15:40 EST	0.50M	Tornado (EF1, L: 3.87 mi , W: 1300 yd)
	10/23/17 15:44 EST	0	Source: NWS Storm Survey

NWS storm survey found the path of a tornado that began at the Hickory Regional Airport in Burke County moved into Catawba County near Highway 321, moving northeast along the Caldwell County line/Catawba River. Although the tornado was in a weakening state as it moved into Catawba County, it also widened to more than a half mile. Widespread tree damage occurred, with many trees falling on homes, vehicles, and smaller structures. The tornado either dissipated near Lake Hickory, or abruptly changed direction to more of a northerly direction as it crossed into extreme southeast Caldwell County.

CALDWELL COUNTY --- 2.5 ESE GRACE CHAPEL [35.80, -81.34], 2.4 E GRACE CHAPEL [35.82, -81.34]

	10/23/17 15:44 EST	0	Tornado (EF1, L: 0.76 mi , W: 750 yd)
	10/23/17 15:46 EST	0	Source: NWS Storm Survey

NWS storm survey found a tornado path across extreme southeast Caldwell County. This was either the continuation of a tornado that moved across extreme northwest Catawba County that made a dramatic change in direction from NE to almost due north, or was a new tornado that developed after that one dissipated. (This was difficult to ascertain due to the presence of the lake). The tornado blew down numerous trees along its path across a small part of Caldwell County before moving into Alexander County in the vicinity of Hubbard Rd .

ALEXANDER COUNTY --- 0.6 E BETHLEHEM [35.83, -81.31], 2.2 NE BETHLEHEM [35.85, -81.29]

	10/23/17 15:45 EST	0	Thunderstorm Wind (EG 55 kt)
	10/23/17 15:48 EST	0	Source: Broadcast Media

Media and Ham Radio operator reported numerous trees blown down by straight line winds about one mile east of a tornado path. This included locations around Highway 127 and Heritage Farm Rd and Teague Town Rd.

ALEXANDER COUNTY --- 1.4 SW BETHLEHEM [35.82, -81.34], 3.7 SW ALL HEALING SPGS [35.90, -81.32]

	10/23/17 15:46 EST	0	Tornado (EF1, L: 5.72 mi , W: 500 yd)
	10/23/17 15:51 EST	0	Source: NWS Storm Survey

NWS storm survey found the path of a tornado that initially straddled the Caldwell/Alexander County line, roughly paralleling Icard Ridge Rd as it moved almost due north across far western Alexander County . Numerous trees were uprooted and snapped. The tornado path was lost in the vicinity of Caldwell Pond Rd, just south of Highway 64. However, additional tornado damage was found several miles away along Highway 64. The area between these two points was heavily wooded and largely inaccessible, but based upon the almost due north orientation of this damage path, and the more northeast orientation of the damage along Highway 64, they are treated as separate events.

ALEXANDER COUNTY --- 1.1 WSW ALL HEALING SPGS [35.92, -81.29], 6.2 WNW VASHTI [36.02, -81.21]

	10/23/17 15:54 EST	0	Tornado (EF1, L: 8.17 mi , W: 200 yd)
	10/23/17 16:02 EST	0	Source: NWS Storm Survey

NWS storm survey found a path of a tornado across northwest Alexander County . This could have been the continuation of a tornado path that began across the southwest part of the county and straddled the Caldwell County line. However, the path of that tornado was lost in a heavily wooded area east of Caldwell Pond Rd and south of Highway 64. This tornado path began along Highway 64 in the Ellendale community and moved northeast, uprooting or snapping numerous trees along a fairly continuous path. The path was lost along Seth Deal Rd, about a mile west of Highway 16 and a mile south of the Wilkes County border. Two days after the event, a utility worker was killed after part of a tree that he cut fell on him.

DAVIE COUNTY --- 1.9 SW CALAHALN [35.90, -80.70]

	10/23/17 16:24 EST	0	Thunderstorm Wind (EG 50 kt)
	10/23/17 16:24 EST	0	Source: County Official

County comms reported a couple of trees blown down near County Line Rd and Highway 901.

IREDELL COUNTY --- 1.5 NNE HOUSTONVILLE [36.02, -80.76]

Storm Data and Unusual Weather Phenomena - October 2017

Location	Date/Time	Deaths & Injuries	Property & Crop Dmg	Event Type and Details
	10/23/17 16:24 EST		0	Thunderstorm Wind (EG 50 kt)
	10/23/17 16:24 EST		0	Source: County Official

County comms reported multiple trees blown down along Harmony Highway.

DAVIE COUNTY --- 3.8 SSE MOCKSVILLE ARPK ARPT [35.87, -80.42]

	10/23/17 16:50 EST		0	Thunderstorm Wind (EG 50 kt)
	10/23/17 16:50 EST		0	Source: County Official

County comms reported a few trees blown down at Tadpole Trail and Highway 64.

UNION COUNTY --- 0.6 E WAXHAW [34.92, -80.74]

	10/23/17 16:50 EST		0	Thunderstorm Wind (EG 50 kt)
	10/23/17 16:50 EST		0	Source: County Official

County comms reported multiple trees and power lines blown down in the Waxhaw area.

ROWAN COUNTY --- 1.3 WSW CHINA GROVE ARPT [35.54, -80.55]

	10/23/17 16:55 EST		0	Thunderstorm Wind (EG 50 kt)
	10/23/17 16:55 EST		0	Source: County Official

County comms reported multiple trees blown down east of China Grove, including on Backwoods Ln.

A band of rain showers along and ahead of a strong cold front quickly intensified during the afternoon across Upstate South Carolina, then moved quickly northeast into the North Carolina foothills and far western Piedmont. Multiple severe and/or tornadic thunderstorms developed within the line, with multiple tornadoes, some of which were quite strong, reported across the area. This was the second tornado outbreak to impact the this area in just over two weeks, and for the most part, the same counties that were impacted on October 8th were once again affected on the 23rd. Meanwhile, moderate to heavy rain falling throughout the morning hours, followed by a brief period of intense rainfall associated with the band of rain showers resulted in areas of flooding and flash flooding near the eastern escarpment of the Blue Ridge.

SOUTH CAROLINA, Northwest

ANDERSON COUNTY --- 2.3 SW HONEA PATH [34.43, -82.41]

	10/23/17 13:16 EST		0	Thunderstorm Wind (EG 50 kt)
	10/23/17 13:16 EST		0	Source: Public

Public reported trees blown down on Will Hanks Rd. Also a report of minor structural damage in this area.

SPARTANBURG COUNTY --- 2.1 ENE CRESCENT [34.78, -82.08], 0.9 ESE ARCADIA [34.94, -81.99]

	10/23/17 13:52 EST		50K	Tornado (EF1, L: 12.68 mi , W: 100 yd)
	10/23/17 14:10 EST		0	Source: NWS Storm Survey

NWS storm survey found the path of a tornado that began near the intersection of Highway 101 and Neilson Rd. The tornado moved north/northeast uprooting and snapping numerous trees along Greenpond Rd and Switzer Green Pond Rd. Some structural damage was also noted to homes in this area, mainly minor roof damage and damage to gutters and siding. The path of the tornado was lost in the area around Pearson Rd and pine Hills Rd, where it entered a heavily wooded valley near the Tyger River , but dual pol radar data indicated the tornado likely continued through this area. The track was picked up again in the area between Bethany Church Rd and Highway 290. Many downed trees were observed from that area northeast toward Reidville Rd, where damage became less intense and more sporadic. The tornado continued northeast to near the I-26/Highway 29 intersection, where the path made an eastward jog. Numerous trees were snapped and uprooted in neighborhood off Highway 29 just east of Westgate Mall. Although a distinct tornado path was lost in this area, extensive Straight-line wind damage continued downstream of the tornado path.

SPARTANBURG COUNTY --- 0.8 SW UNA [34.97, -81.99], 1.7 NW WHITNEY [35.00, -81.95]

	10/23/17 14:12 EST		1M	Tornado (EF2, L: 3.02 mi , W: 350 yd)
	10/23/17 14:18 EST	1	0	Source: NWS Storm Survey

Storm Data and Unusual Weather Phenomena - October 2017

Location	Date/Time	Deaths & Injuries	Property & Crop Dmg	Event Type and Details

Nws survey found that a second, more intense tornado touched down on the northwest side of Spartanburg, along Business 85 near Spartanburg Community College. The tornado reached its peak intensity almost immediately upon touching down, as a warehouse building near the intersection of Spring St and Simuel Rd suffered extensive damage, with the collapse of an exterior wall, and much of the roof removed. Multiple trailers were damaged or destroyed and several cars flipped in a parking lot at an adjacent business at
Garrett Rd and Spring St. A person who sought shelter in a glass booth under a metal awning structure at this location was hospitalized with burst ear drums due to the extreme change in air pressure. A warehouse building also lost much of its roofing here. The tornado continued east/northeast, paralleling Business 85, snapping trees along New Cut Rd, and collapsing a wall at another warehouse style building on Buffington Rd. The tornado appeared to weaken considerably from this point, with damage primarily limited to downed trees and limbs until the path ended near the intersection of Business 85 and Highway 9.

SPARTANBURG COUNTY --- 0.9 SW SAXON [34.94, -81.98], 0.8 SW UNA [34.97, -81.99]

	10/23/17 14:12 EST	10K	Thunderstorm Wind (EG 65 kt)
	10/23/17 14:15 EST	0	Source: NWS Storm Survey

NWS storm survey found an extensive area of primarily straight-line wind damage across the Saxon community, between the end of one tornado path that ended in the vicinity of Westgate Mall, and another tornado that began along Business 85 across from Spartanburg Community College. This appeared to be the result of very strong inflow into the developing second tornado, although the dissipating first tornado may have intermingled with the strong inflow winds.

SPARTANBURG COUNTY --- 2.4 SSE CHESNEE [35.12, -81.85]

	10/23/17 14:29 EST	0	Thunderstorm Wind (EG 50 kt)
	10/23/17 14:29 EST	0	Source: Amateur Radio

Ham radio operator reported multiple trees blown down in the area around the intersection of Highway 221 and Thompson Rd.

CHEROKEE COUNTY --- 8.8 W GRASSY POND [35.14, -81.83], 8.0 WNW GRASSY POND [35.18, -81.80]

	10/23/17 14:33 EST	5K	Tornado (EF1, L: 3.28 mi , W: 150 yd)
	10/23/17 14:40 EST	0	Source: NWS Storm Survey

NWS Storm survey found the path of an EF1 tornado that began about 1 mile southeast of Chesnee near the Cherokee/Spartanburg county line. Damage associated with this tornado was largely confined to uprooted and snapped trees as it moved northeast, crossing Highway 11, Keg Town Mill Rd, and N Green River Rd before crossing into Rutherford County in North Carolina near Camp Ferry Rd. However, a couple of outbuildings were also damaged.

CHEROKEE COUNTY --- 3.4 WSW GRASSY POND [35.11, -81.73], 3.9 NNW GRASSY POND [35.18, -81.71]

	10/23/17 14:36 EST	0.25M	Tornado (EF2, L: 4.58 mi , W: 150 yd)
	10/23/17 14:41 EST	0	Source: NWS Storm Survey

NWS storm survey found the path of a strong tornado that touched down near the intersection of Farmington Rd and Meadowview Rd, with damage initially confined to downed trees. The tornado moved north/northeast to the
intersection of Fairview Rd and Highway 11, where two homes sustained EF2 damage, with much of the roofs of both homes removed. The tornado appeared to weaken northeast of this location, with damage confined mainly to minor structural damage and downed trees and power lines until it reached the area near the intersection of Furnace Mill Rd and Robb School Rd. A frame home slid off its foundation on W Diesel Dr, resulting in virtual destruction of the home. The path of the tornado through this area was less than 1000 ft west of a short track tornado that impacted the area around Robb School Rd and Twin Bridge Rd on October 8th 2017. The tornado weakened again from there, with damage confined to downed trees and tree limbs as it moved into Cleveland County between Twin Bridges Rd and McCraw Rd.

A band of rain showers along and ahead of a strong cold front quickly intensified during the afternoon across Upstate South Carolina. Multiple severe and/or tornadic thunderstorms developed within the line, with multiple tornadoes, some of which were quite strong, reported across the area. This was the second tornado outbreak to impact the Upstate in just over two weeks, and for the most part, the same counties that were impacted on October 8th were once again affected on the 23rd. In fact, a Cherokee County tornado from the 23rd passed within several hundred feet of an event that occurred on the 8th.

11. Credits

Chris Spannagle (WDTD/CIMMS)	Case data collection, WESSL creation, SPC meso pages, TDS analysis, internal review and testing
Alex Zwink, Dale Morris (WDTD/CIMMS)	WES-2 Bridge simulation case installation, data trimming, install script development, documentation and testing
Brett Roberts (SPC)	HREF Archive page
Bill Martin (SOO, WFO GSP)	Case archive and storm damage track/images
Barb Mayes-Boustead (WDTD)	WFO data retrieval, hazard assessment, warning decision analysis, polygon recommendations
Jim LaDue (WDTD)	Multi-sensor data analysis, hazard assessment
Phil Ware (WFO OUN)	Lightning data analysis
Jason Schaumann (WFO SGF)	Three Ingredients Method analysis, QLCS Tornado AWIPS procedure bundle
John Gagan (SOO, WFO MKX)	Three Ingredients Method analysis
Austin Harris (WDTD/CIMMS)	CAMs analysis, internal review and testing
Robert Prentice (WDTD)	NSHARP forecast sounding parameter evaluation, internal review
Paul Schlatter (SOO, WFO BOU)	Simulation external review and testing
Aaron Ward (WFO AMA)	Simulation external review and testing
Kelly Thomason, Jill Hardy (WDTD)	Packing and shipping