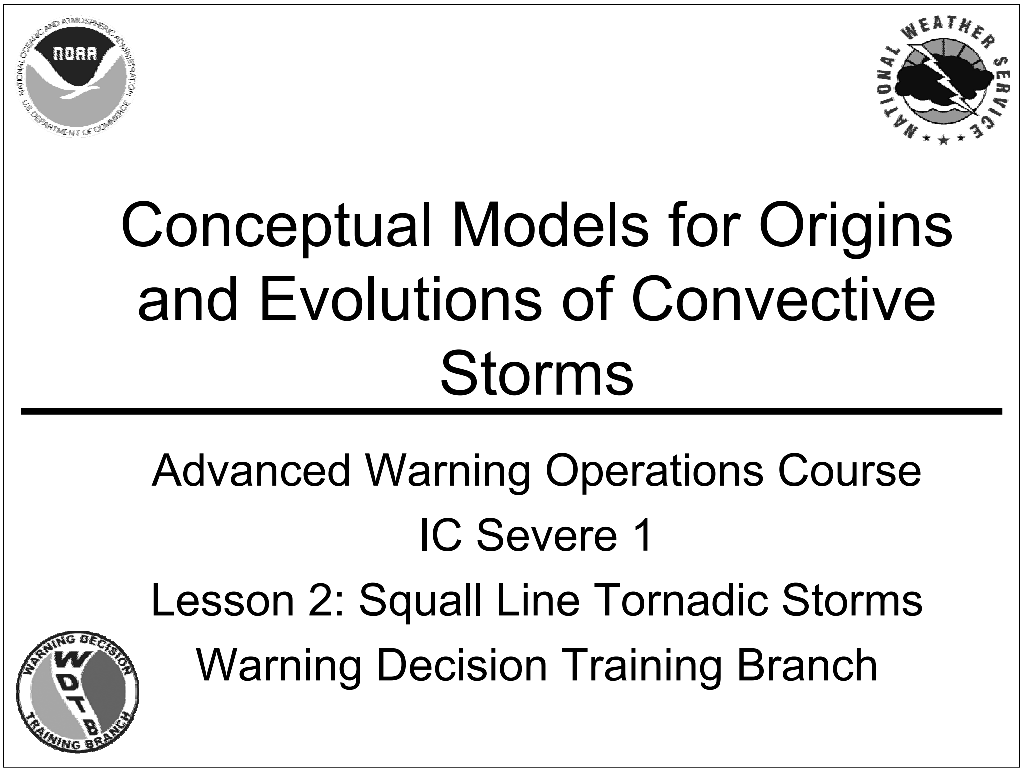



The title for the instructional component (IC) is “**Conceptual Models for Origins and Evolutions of Convective Storms** . This is the first IC in the AWOC Severe Track. Lesson 2 will be on conceptual models for squall line tornadic storms.

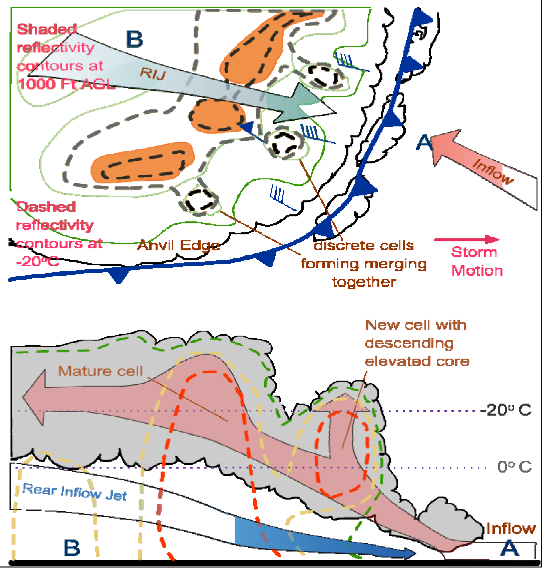
## Lesson 2 Learning Objectives

1. Identify characteristics of a severe linear squall line (SQLN).
2. Identify characteristics of SQLN tornado development process.
3. Describe how line-end vortices develop.

These are the learning objectives for lesson 2. Squall line tornadoes account for up to 20% of all tornadic events nationwide (Tessendorf and Trapp, 2000). However, issuing warnings for squall line tornadoes is problematic.

# Conceptual Model of a Nonsevere Linear System

- Characteristics
  - Descending RIJ
  - No MARC, DCZ
  - Shallow sloping updraft over top of cold pool with numerous discrete cells merging into a line

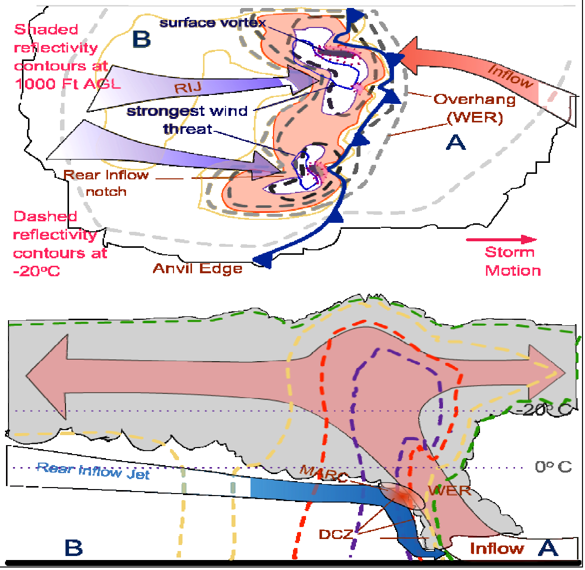



**From LaDue (2004)**

There will be more in IC 3 (storm interrogations) on this model. Essentially, the Rear-inflow Jet (RIJ) descends, due to cold pool imbalance with shear and lack of strong deep lifting along the gust front. Also, there could be insufficient storm-relative flow and/or surface based instability to feed the updrafts. There are no 3 dimensional features (line-end vortices, MARCs, DCZs, etc.) with these structures.

# Conceptual Model of a Severe Linear System

- Characteristics:
  - Relatively nondescending RIJ
  - MARC, DCZ
  - Front end echo overhang with linear BWER ahead of the surface gust front




**From LaDue (2004)**

Note position of surface vortex (potential tornadic development location) just south of inflow notch and north of RIJ , manifested on radar by a rear inflow notch. That is where the low level velocity couplet–shear signature should be located. Others features are the Mid-Altitude Radial Convergence (MARC) signature (Schmocker et al., 1996), which is often a precursor to the descent of the elevated RIJ. The MARC feature is characterized by persistent areas of enhanced convergence just downwind of high reflectivity cores along the leading edge of the convective line. Persistent areas of MARC > 25 m/s at 3 to 5 km above ground level (AGL) can provide lead time for first report of wind damage before a well –defined bow echo develops (See Severe IC 3 for more details).

The Deep Convergence Zone (DCZ) (Lemon and Burgess, 1992) represents a deep zone of laminar flow at the interface of an erect updraft and the edge of the RIJ (or in the case of a supercell , the Rear-Flank Downdraft). See Severe IC 3 for more details.

# Characteristics of SQLN Tornado Development Process

- 3 possible mechanisms at work
- Ambient vertical vorticity and horizontal convergence maximized in low-levels
- Nondescending tornadic vortex signatures (TVSs)

Squall line tornadoes account for up to 20% of all tornadic events nationwide (Tessendorf and Trapp, 2000). However, issuing warnings for squall line tornadoes is problematic. Supercell structures and attendant tornadoes are often observed during early stages of multicell systems when storms are still a bit isolated. During mature phase of squall line/multicell systems, supercells and their associated classical mesocyclone signatures generally are not identifiable, and in fact , are not considered important to the formation process . Thus, no clear relationship exists between midlevel line-end vortices that are located behind the leading-line convection and above the surface cold pool and subsequent tornadoes.

Numerical simulations and radar observations suggested that there were 3 possible mechanisms related to squall line tornado production. They all involve dependencies on strong (> 20 m/s) low-level shear (in lowest 2-5 km) and updraft which produces vertical vorticity in low-levels and a tornado vortex signature which develops and intensifies rapidly in low levels first as opposed to supercells (Weisman and Trapp, 2003).

## Formation Mechanisms for SQLN Tornadoes

1. Horizontal shearing instability
   - Similar to nonsupercell processes (along leading edge of gust front)
2. Tilting of horizontal vorticity at intersection of a bow echo with preexisting boundary
3. Tilting of crosswise vorticity by convective-scale downdrafts
   - Tornadic Quasi-Linear Convective Systems (QLCS)

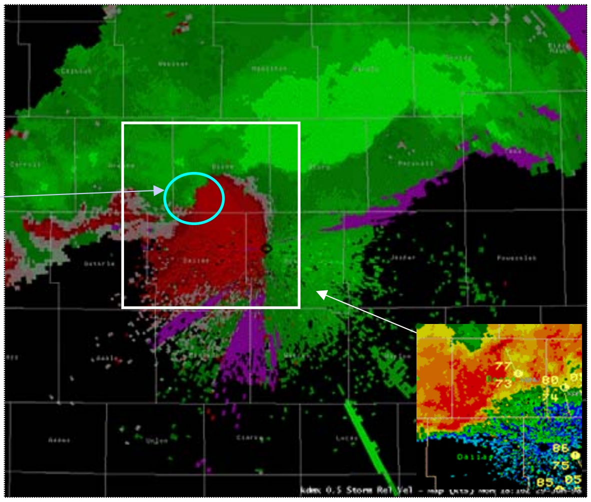
All of these are possible tornadic development mechanisms at work in SQLNs, but research remains uncertain as to which actually occurs in reality. The first mode occurs when horizontal shear vorticity is stretched locally by a vigorous updraft which is being enhanced by convergence and system-relative flow along the gust front. These vortices are usually short-lived.

2nd mode is tilting of horizontal vorticity at intersection of a bow echo with preexisting boundary (Przybylinski, 1995), or tilting upward of easterly shear. This is similar to supercell process but there is typically no long-lived rotating updraft above the low-level vortices associated with squall lines and bow echoes.

The third mode is downward tilting of westerly shear (Weisman and Trapp , 2003). This formation process, modeled in detail with numerical simulations (Weisman and Trapp (2003) includes the generation of both midlevel and low-level mesovortices via tilting of crosswise vorticity rather than streamwise vorticity (typical supercell process). The mesovortex associated with this type of QLCS develops a larger circulation with time than a supercell mesocyclone.

# Example 1

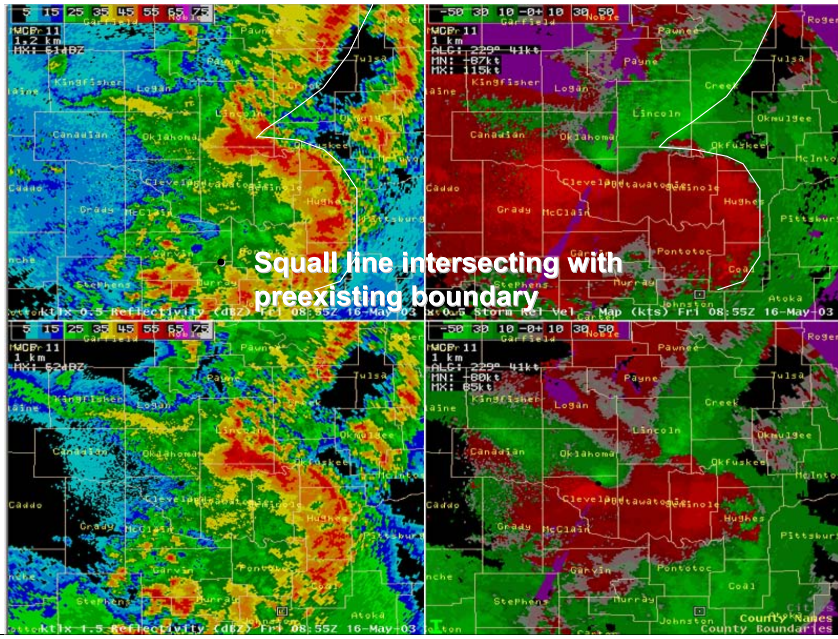
- "Kink" in the gust front signifies a mesovortex developing rapidly along squall line
- Likely location for a brief tornado or enhanced wind damage



This is from the 29-June 98 DMX WES case.

Brief F1 tornadoes and extreme wind damage were reported as the line swept into Des Moines area.

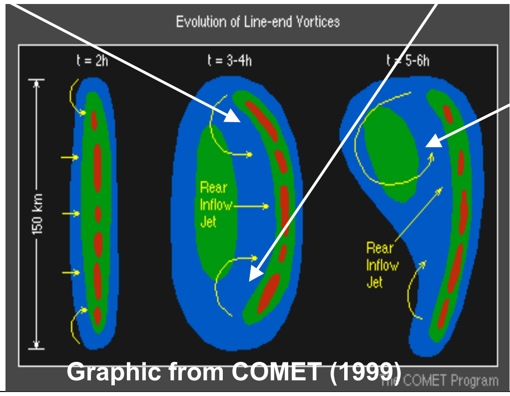
# Example 2




There's a loop with this example. The F1 tornado briefly touched down in SE Lincoln Co. (very near the intersection of the squall line with the SW-NE boundary), approximately 14 min after this radar image.

# How Line-end Vortices Develop

- Line-end vortices (or bookend vortices) typically develop over time (2-4 hours) along any portion of line (ends, breaks, other - where strong updraft/shear exists).
- Northern member cyclonic, southern member anticyclonic.



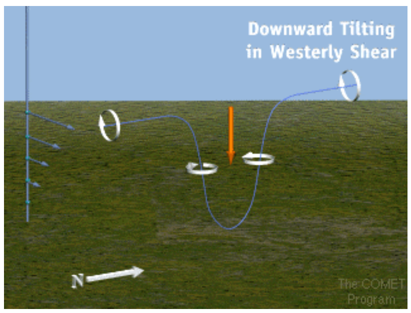

Graphic from COMET (1999)

- Cyclonically rotating vortex tends to become stronger and larger due to midlevel convergence and Coriolis forcing.

In the numerical simulations presented in the MCS module (http://meted.ucar.edu/convectn/mcs/), the line-end vortices developed 2-4 hrs. into the lifetime of the convective system, just behind the zone of active convection. The northern vortex had cyclonic rotation while the southern end of the line rotated anticyclonically. The northern member is the one that usually is stronger and longer- lasting and can enhance the RIJ sufficiently to help spin up a tornado. Note that bookend vortices are downdrafts - tornadic circulations along squall lines form typically along the leading edge of the system outflow or when the outflow intersects a pre-existing boundary.

# How Line-end Vortices Develop

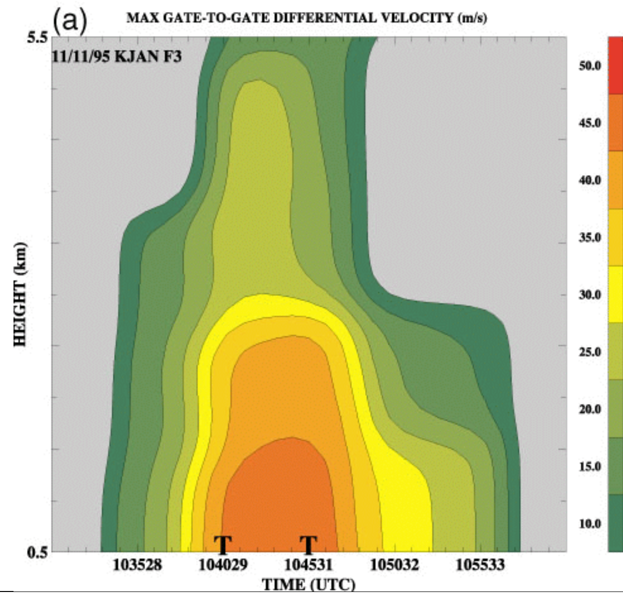
- A new conceptual model by Weisman and Trapp (2003)
- Downward tilting of westerly shear




Note in the flash graphic counter-rotating vortices which develop below the horizontal vorticity streamlines which are bent downward. The (red) one to the south rotates cyclonically and is stronger, and longer lasting than the anticyclonically (purple) rotating one. Also, note Coriolis Force (CF) effects get stronger with time - actually the graphic tries to imply the impacts of midlevel convergence in the presence of the CF squall line which acts to strengthen the cyclonic vortex with time. This forcing helps to produce the asymmetric evolution that characterizes most long lasting MCSs.

# Nondescending TVS Paradigm

- Mode prevalent in QLCSs
- The T is tornado time
- Short lead times to max velocity differentials and tornado




Trapp et al. (1999)

The non-descending TVS paradigm is found in QLCS structures. The mode of development is bottom-up from crosswise vorticity that is tilted by storm scale downdrafts (Trapp et al., 1999).

# Summary

- Review the objectives

The 3 objectives are:

1) Identify characteristics of a severe linear squall line (SQLN)
2) Identify characteristics of SQLN tornado development process
3) Describe how line-end vortices develop.

The test over IC 1 will include a few questions on this Lesson’s objectives.

# References

- See handout list or AWOC Severe Track web page

See the reference list.

**Severe Track IC 1**
**Lesson 2 References**

COMET, 1999: Mesoscale Convective Systems: Squall Lines and Bow Echoes. Online training module, http://www.meted.ucar.edu/convectn/ mcs/index.htm.

Evans, J. S. and C. A. Doswell III, 2001: Examination of Derecho environments using proximity soundings. Wea. Forecasting, 16, 329-342.

Lemon, L. R., and D. W. Burgess, 1992: Supercell associated deep convergence zone revealed by a WSR-88D. Preprints, *26th Conf. on Radar Meteorology,* Norman, OK, Amer. Meteor. Soc., 206–208.

Przybylinski, R. W., 1995: The bow echo: Observations, numerical simulations, and severe weather detection methods. *Wea. Forecasting,* **10,** 203–218.

Schmocker, G. K., R. W. Przybylinski, and Y.-J. Lin, 1996: Forecasting the initial onset of damaging downburst winds associated with a mesoscale convective system (MCS) using the mid-altitude radial convergence (MARC) signature. Preprints, *15th Conf. on Weather Analysis and Forecasting,* Norfolk, VA, Amer. Meteor. Soc., 306–311.

Tessendorf, S. A., and R. J. Trapp, 2000: On the climatological distribution of tornadoes within quasi-linear convective systems. Preprints, 20th Conf. on Severe Local Storms, Orlando, FL, Amer. Meteor. Soc., 134-173.

Thompson , R.L. , R. Edwards, J. A. Hart, K. L. Elmore, and P. Markowski, 2003: Close proximity soundings obtained from the Rapid Update Cycle. Wea. Forecasting, 18, 1243-1261.

Trapp , R. J., E. D. Mitchell, G. A. Tipton, D. W. Effertz, A. I. Watson, D. A. Andra, and M. A. Magsig (1999): Descending and nondescending tornadic vortex signatures detected by WSR-88Ds. Wea. Forecasting, 14, 625-639.

____, and M. L. Weisman, 2000: Preliminary investigation of tornadogenesis within quasi-linear convective systems. Preprints, 20th Conf. on Severe Local Storms, Orlando, FL, Amer. Meteor. Soc., 273-276.

TWG, 2002: Tornado Warning Guidance. Web page, http://www.wdtb.noaa.gov/resources/PAPERS/twg02/index.html

Weisman, M. L., and R.J. Trapp, 2003: Low-level mesovortices within squall lines and bow echoes. Part I: Overview and dependence on environmental shear, Mon. Wea. Rev., 131, 2779-2803.