63 Insights from Composite Environments of High-Shear, Low-CAPE Severe Convection

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ABSTRACT
Recent work has shown that severe high-shear, low-CAPE (HSLC) convection tends to occur in environments with stronger synoptic-scale forcing for ascent and larger low-level instability and vertical wind shear vector magnitude than its non-severe counterpart. Additionally, analyses and simulations of HSLC severe events show that rapid destabilization resulting from the release of potential instability and/or strong low-level theta-e advection may enhance apparently limited CAPE values on temporal (and potentially spatial) scales unresolvable by most numerical weather prediction models.
This paper supplements these recent findings with storm-relative composite maps and soundings from 2006-2011 HSLC severe report subsets segregated by report type and convective mode. In addition, these composites are compared to composite environments of false alarm tornado warnings. The goal of this work is to improve pattern recognition of HSLC severe convective events by presenting the typical spatial arrangements of several environmental ingredients. The ultimate aim is to increase (decrease) the associated relatively low (high) probability of detection (false alarm rate) of NWS tornado watches and warnings within HSLC environments by comparing severe event composites to those of non-severe events.

1. Introduction

A recent article by Sherburn et al. (2016) investigated the composite environments associated with severe and non-severe high-shear, low-CAPE (HSLC) convection. This paper acts as a supplement to Sherburn et al. (2016) by examining additional cases and subsets; the reader is referred to their manuscript for details on the general dataset and methodology, which will not be repeated here.

2. Methodology

a. Subsets

Two specific subsets were analyzed here: 1) Southeastern U.S. HSLC EF1 or stronger tornadoes against HSLC tornado warning false alarms, represented by 719 and 147 cases, respectively, and 2) Southeastern U.S. HSLC EF2 or stronger tornadoes against HSLC tornado warning false alarms, separated by convective mode.

Convective modes in subset 2) were broadly classified as discrete supercells (19 tornadoes, 7 false alarms), hybrid supercells (37 tornadoes, 15 false alarms), and quasi-linear convective systems (QLCSs; 44 tornadoes, 25 false alarms). Convective mode classification was manual and generally based upon the methodology of Smith et al. (2012). To be considered a supercell, approximately 50 kt (1 kt = 0.51 m s^{-1}) of rotational velocity was required based upon gate-to-gate inbound and outbound maxima for at least 30 minutes. Rotation was also required to extend from the radar's base scan to at least one-quarter of the storm depth. Hybrid supercells were those that showed characteristics of a prolonged mesocyclone but were embedded within a broader precipitation shield (i.e., an embedded supercell) or were marginal based upon the time and rotation constraints above. QLCSs were associated with shallow and typically brief mesovortices, though some longer-lived mesovortices were also observed, provided they did not meet the depth or strength requirements of an embedded supercell. Note that many cases lacked adequate radar data or were too ambiguous to assign a specific convective mode.

b. Data

As in Sherburn et al. (2016), composites were produced relative to tornado reports or false alarm warnings using North American Regional Reanalysis (NARR; Mesinger et al. 2006) data. HSLC tornadoes were from 2006-2011, while false alarm tornado warnings were from October 2006-April 2011.

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3. Results

a. Tornadoes vs. false alarm tornado warnings

The general findings of Sherburn et al. (2016), who investigated HSLC EF1 or greater tornado warnings *and* significant (65 kt or greater) wind reports against HSLC false alarm tornado *and* severe thunderstorm warnings, hold when eliminating straight-line winds and false alarm severe thunderstorm warnings. Namely, there is an increase of synoptic-scale forcing for ascent at all levels in tornadoes when compared with false alarms. Composite upper-level jet streaks are stronger (Fig. 1, top row), particularly upstream of the mean tornado report, where the associated mid-level vorticity maximum is also stronger (Fig. 1, second row). Low-level convergence is considerably more intense for tornadoes, while the 850 hPa baroclinic zone is in closer proximity to the mean tornado (Fig. 1, third row). Finally, the associated composite surface cyclone and implied cold front are both stronger in the tornado case (Fig. 1, bottom row). The tornadoes also appear to occur farther within the cyclone's "warm sector", given the low's positioning to the north-northwest, rather than the west-northwest, of the composite center. This is supported by the composites of the 10-m wind field (Fig. 2, middle row). Shear vector magnitude (Fig. 3) and storm-relative helicity (Fig. 2, bottom row) are also notably higher in tornado events when compared to false alarm tornado warnings, particularly in the lower troposphere (Fig. 3, third row). However, surface-based CAPE (Fig. 1, bottom row) and lifted condensation levels (LCLs; Fig. 2, top row) are generally comparable in the vicinity of the mean tornado and false alarm tornado warning, suggesting their overall utility as discriminatory tools may be limited.

b. Segregation by convective mode

Environments of discrete supercells supporting significant tornadoes are characterized by an intense approaching jet streak at 300 hPa, which is a feature absent from the corresponding false alarm tornado warning composite (cf. Figs. 4-5, top row, left column). Additionally, while there is not a clearly enhanced zone of 850 hPa convergence in the discrete supercell tornado composite, the 850 hPa trough is notably stronger (cf. Figs. 4-5, top row, middle column). The surface cyclone and warm sector are comparatively well-established in tornado cases within discrete supercells (cf. Figs. 4-5, top row, right column) and lie in similar positions relative to the composite centers as found in the EF1-plus tornado versus false alarm tornado warning composites explored above (cf. Fig. 1, bottom row and Figs. 4-5, top row, right column).

Hybrid supercell environments see similar differences in surface fields and CAPE (cf. Figs. 4-5, middle row, right column). Additionally, both upper-level divergence and lower-level convergence are notably stronger in tornadoes when compared to false alarms (cf. Figs. 4-5, middle row, left and middle columns). Although a similar intensity, the associated upper-level jet streak in the false alarms is shifted westward away from the composite center, suggesting the proximity to this feature is important.

As with discrete and hybrid supercells, QLCS environments supportive of HSLC significant tornadoes are characterized by a surface cyclone that is closer to the composite center and stronger than in the false alarm tornado warning composite (cf. Figs. 4-5, bottom row, right column). While upper-level divergence is comparable between the two composites (cf. Figs. 4-5, bottom row, left column), the according jet streaks are stronger in the tornado composite. Perhaps the most notable difference of the QLCS composites is the 850 hPa convergence, which is considerably greater in the tornado composite (cf. Figs. 4-5, bottom row, middle column).

Regardless of convective mode, *a recurring theme is the overlap of favorable environment and strong synoptic-scale forcing for ascent* at multiple levels within the tornado composites, one or more of which appear to be absent in the false alarm composites. This is encompassed nicely by the Modified Severe Hazards in Environments with Reduced Buoyancy parameter (MOSH), introduced by Sherburn et al. (2016) and shown in Figures 6 and 7 for discrete supercell and QLCS composites. The MOSH clearly demonstrates remarkable ability to discriminate between HSLC significant tornadoes and false alarm tornado warnings regardless of mode, albeit over a fairly small sample size.

4. Summary and Conclusions

This work supplements Sherburn et al. (2016), which investigated composite environments of high-shear, low-CAPE (HSLC) severe and non-severe convection. Rather than investigating both HSLC EF1 or greater tornadoes and significant winds against HSLC tornado and severe thunderstorm warning false alarms, this work only utilized tornadoes and tornado warning false alarms, while also segregating these datasets by convective mode.

Combined, these papers indicate that a key discriminating factor between severe and non-severe convection is the presence of strong synoptic-scale forcing for ascent at multiple levels collocated with a favorable convective environment. These features are present in all composite severe event subsets, but one or more of these features tend to be absent in the composite non-severe event. These factors are well represented by the Modified Severe Hazards in Environments with Reduced Buoyancy parameter (MOSH; Sherburn et al. 2016) and are shown in conceptual diagrams in Fig. 8.

While some specific features of interest were noted for particular convective modes here (e.g., an intense upper-level jet streak upstream of the composite HSLC discrete supercell significant tornado that is absent in the discrete supercell false alarm composite; much stronger low-level convergence in the tornadic hybrid supercell and QLCS environments compared to the false alarm composite environment), the general claims discussed in the prior paragraph hold regardless of convective mode. Thus, to reiterate, *forecasters should identify the regions where strong synoptic-scale forcing for ascent* and *a favorable environment overlap to identify potential locations for severe HSLC convection.*

Future work should address the relative roles each of these forcing mechanisms play in discriminating between severe and non-severe convection. Additionally, many subtleties not explored here—such as the orientations of shear vectors relative to boundaries and their role in determining convective mode—are worthy of further investigation.

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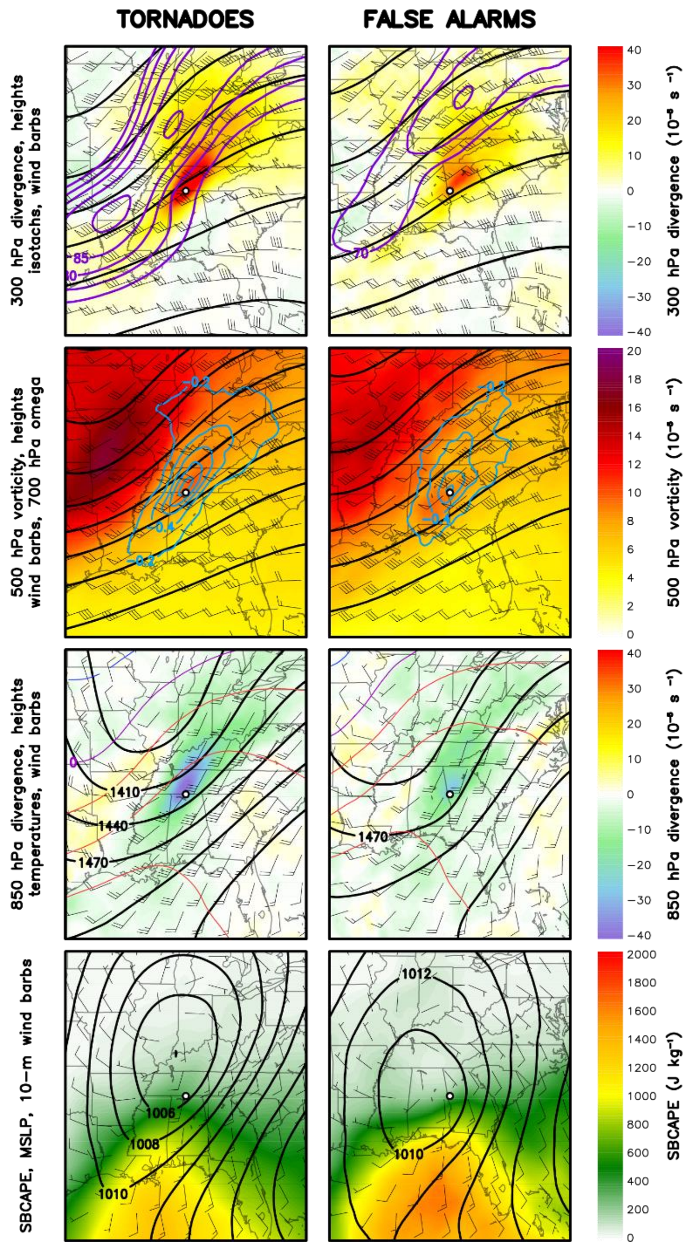

Figure 1. Mean (top row) 300 hPa divergence (shaded, 10^{-5} s^{-1}), geopotential heights (black contours, every 120 m), isotachs (purple contours, every 5 kt), and wind barbs (kt); (second row) 500 hPa absolute vorticity (shaded, 10^{-6} s^{-1}), geopotential heights (black contours, every 60 m), wind barbs (kt), and 700 hPa omega (blue contours, μbar s^{-1}); (third row) 850 hPa divergence (shaded, 10^{-5} s^{-1}), geopotential heights (black contours, every 30 m), temperatures (blue, red, and purple contours, °C), and wind barbs (kt); (bottom row) SBCAPE (shaded, J kg^{-1}), mean sea-level pressure (black contours, every 2 hPa), and 10-m wind barbs for (left) EF1 or greater tornadoes and (right) tornado warning false alarms. Maps are shown for a reference scale, with the white dot depicting the event-relative composite center point and the average latitude and longitude of each subset.

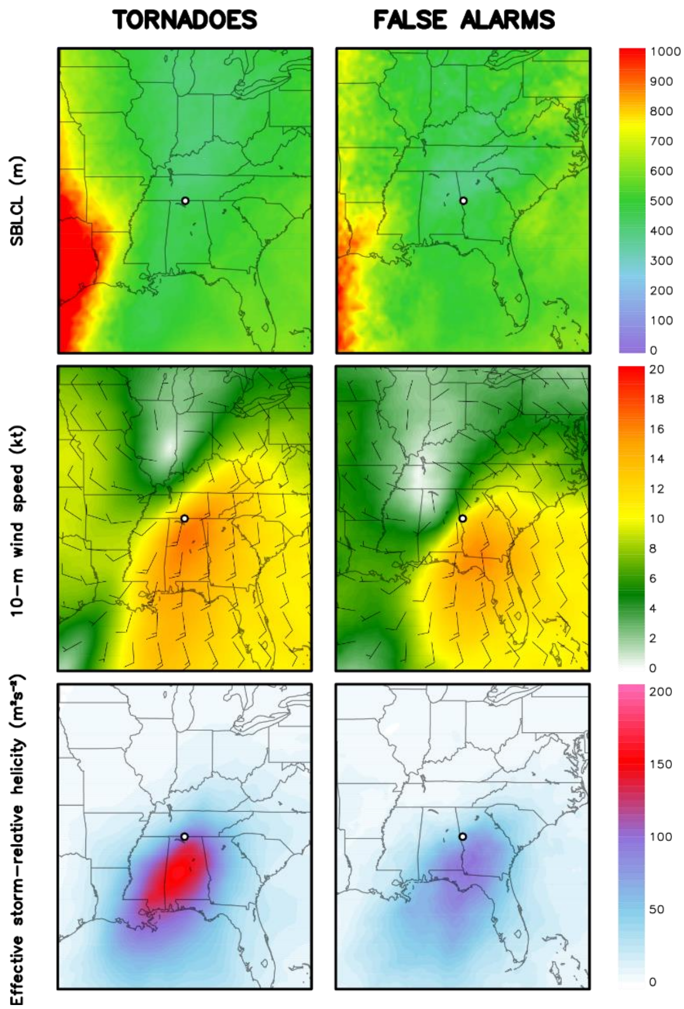

Figure 2. Mean (top row) surface-based lifted condensation level (shaded, m), (second row) 10-m wind speed (shaded, kt) and barbs (kt), and (bottom row) effective storm-relative helicity (shaded, $m^2 s^{-2}$) for (left) EF1 or greater tornadoes and (right) tornado warning false alarms. Maps are shown for a reference scale, with the white dot depicting the event-relative composite center point and the average latitude and longitude of each subset.

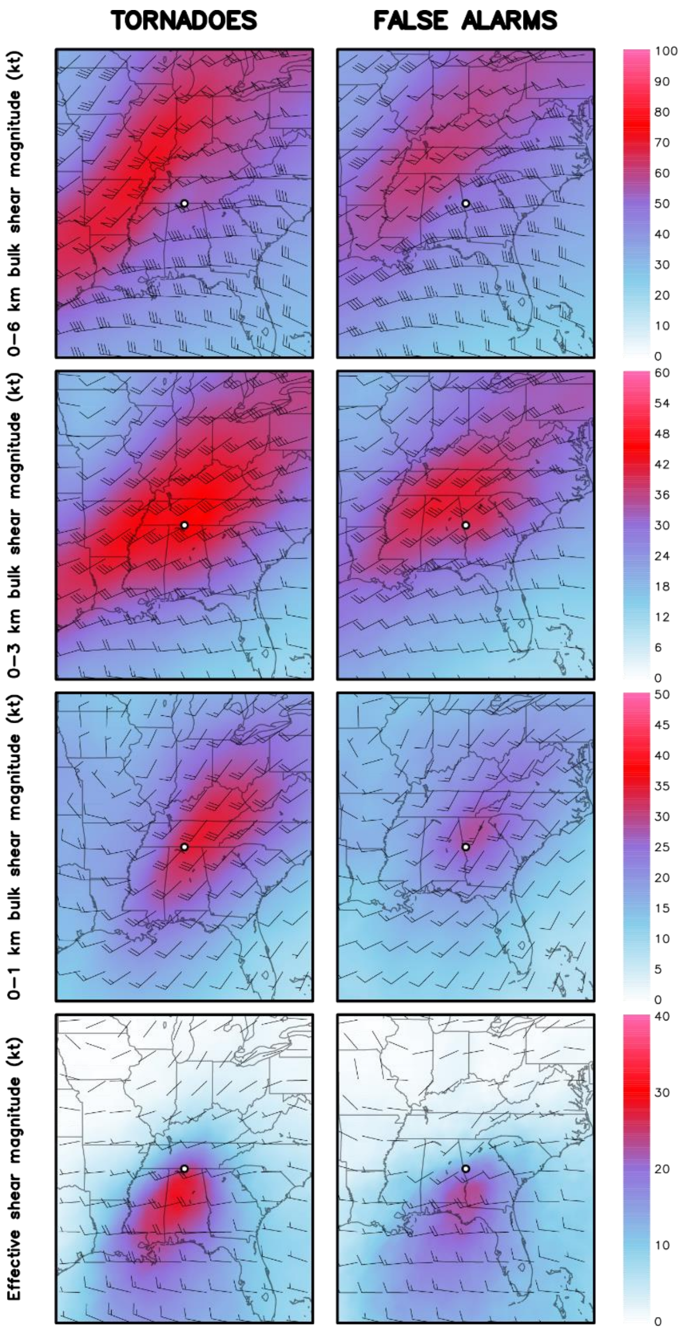

Figure 3. Mean (top to bottom) 0-6 km, 0-3 km, 0-1 km, and effective layer shear vector magnitude (kt) and wind barbs (kt) for (left) EF1 or greater tornadoes and (right) tornado warning false alarms. Maps are shown for a reference scale, with the white dot depicting the event-relative composite center point and the average latitude and longitude of each subset.

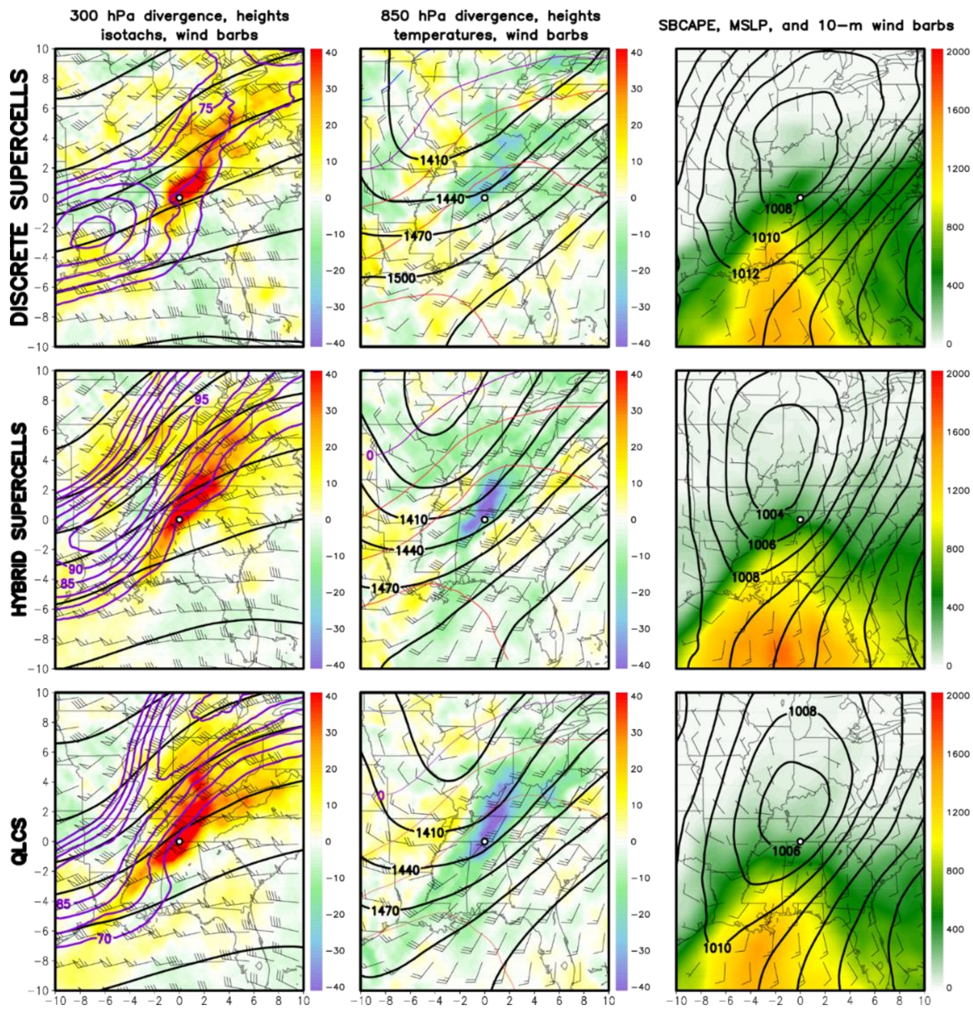

Figure 4. Mean (left column) 300 hPa divergence (shaded, 10^{-5} s^{-1}), geopotential heights (black contours, every 120 m), isotachs (purple contours, every 5 kt), and wind barbs (kt); (middle column) 850 hPa divergence (shaded, 10^{-5} s^{-1}), geopotential heights (black contours, every 30 m), temperatures (blue, red, and purple contours, °C), and wind barbs (kt); (right column) SBCAPE (shaded, J kg^{-1}), mean sea-level pressure (black contours, every 2 hPa), and 10-m wind barbs for HSLC EF2 or greater tornadoes within (top) discrete supercells, (middle) hybrid supercells, and (bottom) QLCSs. Maps are shown for a reference scale, with the white dot depicting the event-relative composite center point and the average latitude and longitude of each subset.

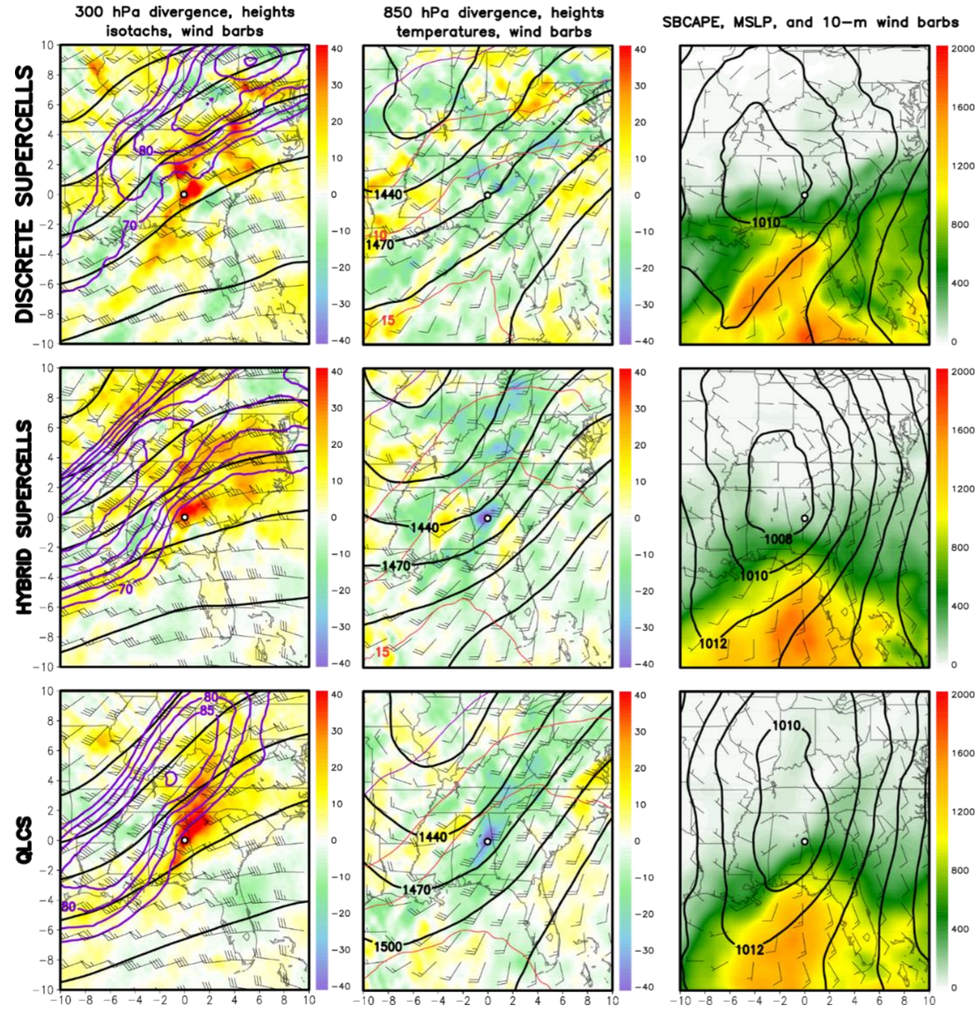

Figure 5. As in Fig. 4, but for HSLC tornado warning false alarms.

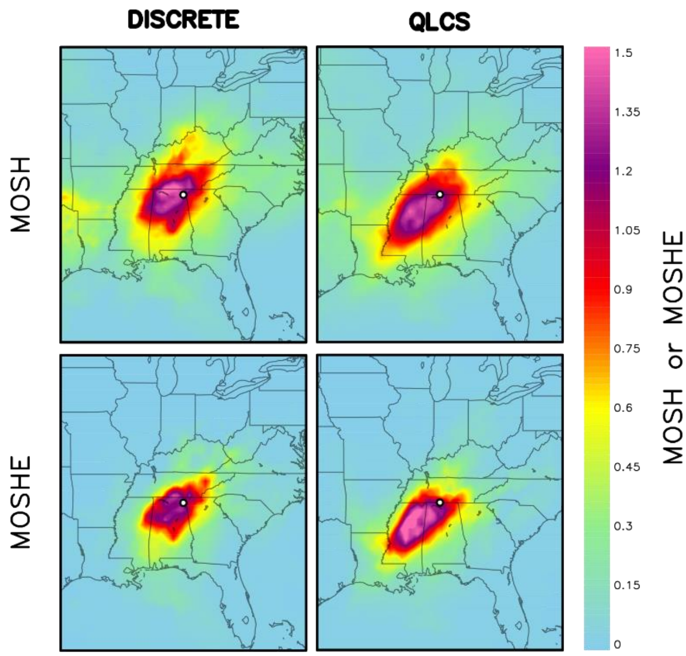

Figure 6. Modified Severe Hazards in Environments with Reduced Buoyancy parameter (MOSH; top) and its effective-layer version (MOSHE; bottom) for HSLC EF2 or stronger tornadoes associated with discrete supercells (left) and QLCSs (right).

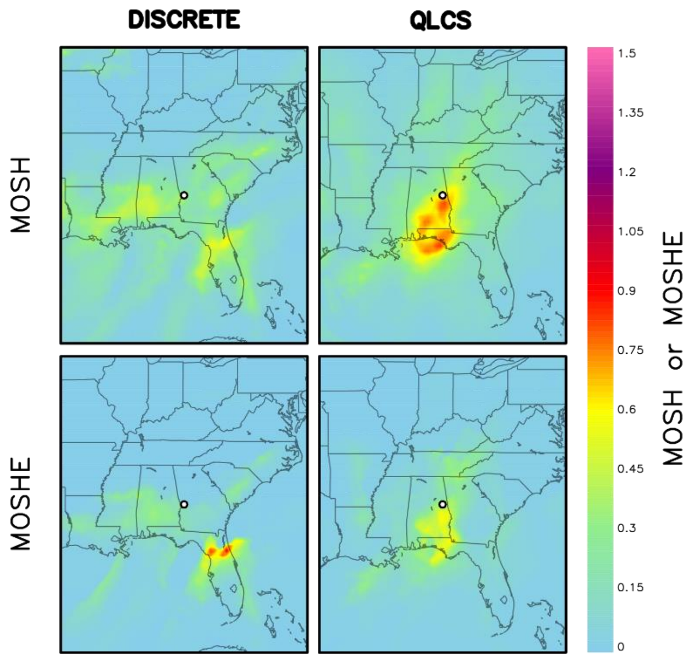

Figure 7. As in Fig. 6, but for HSLC tornado warning false alarms.

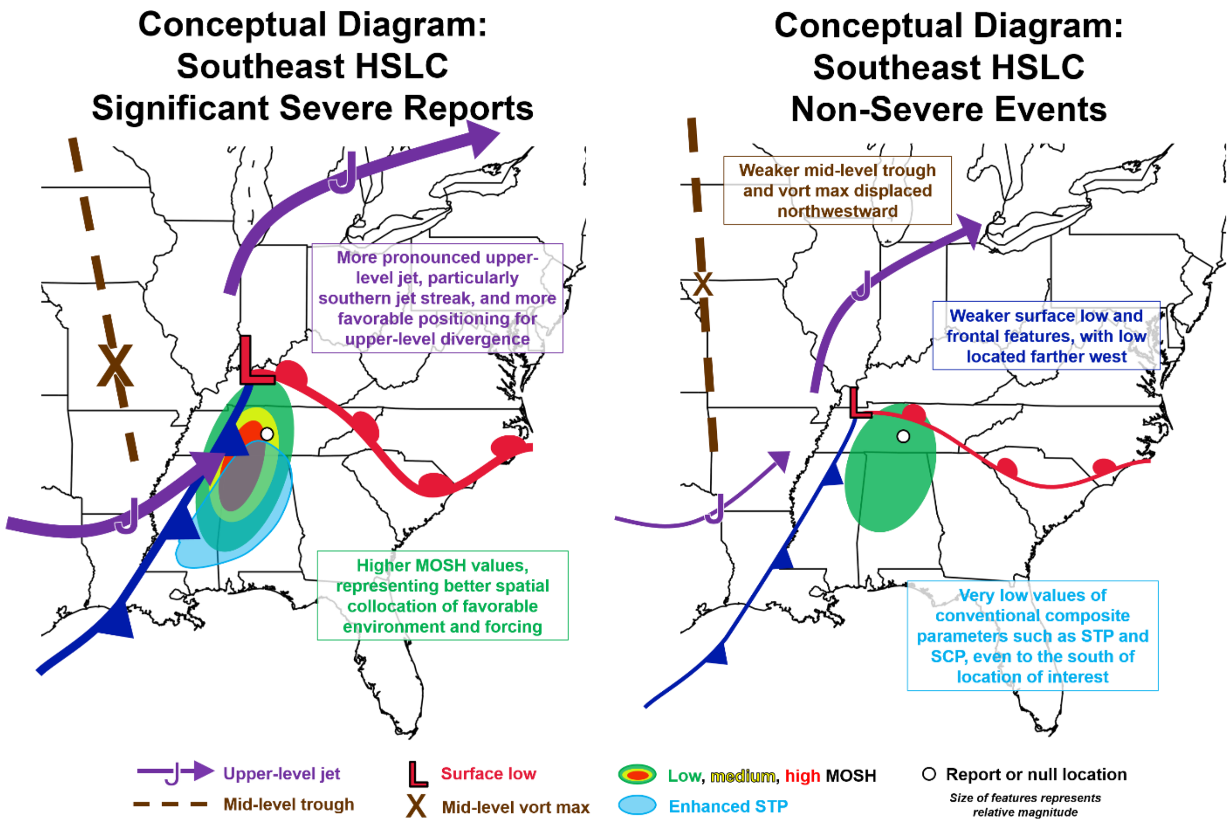

Figure 8. Conceptual models for composite HSLC significant severe (EF2 or stronger tornadoes and 65 kt or stronger winds) event (left) and non-severe event (right). “STP” refers to the Significant Tornado Parameter (e.g., Thompson et al. 2012), while “SCP” refers to the Supercell Composite Parameter (Thompson et al. 2004). Size of features are meant to represent their relative strength (e.g., surface low depicted by red “L” is larger in severe event conceptual model, consistent with a typically stronger surface cyclone in those cases).