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On the usage of composite parameters in High-Shear, Low-CAPE environments

Keith D. Sherburn* and Matthew D. Parker
Department of Marine, Earth, and Atmospheric Sciences, North Carolina State University, Raleigh, North Carolina

1. Introduction

Environments characterized by large deep-layer shear vector magnitudes but marginal instability (i.e., high-shear, low-CAPE, or "HSLC" environments) are a subject of increasing research. Such environments have a relatively low conditional probability of severe convection (Dean et al. 2009) but potentially significant threats to life and property (e.g., Sherburn and Parker 2014a). These factors contribute to low skill of Storm Prediction Center tornado watches compared to higher CAPE environments (Dean and Schneider 2008; Dean and Schneider 2012), and the diurnal and annual maxima for severe HSLC convection correspond to time periods associated with poor tornado and severe thunderstorm warning skill (e.g., Brotzge et al. 2011).

A more thorough review of the literature associated with HSLC severe convection is provided by Sherburn and Parker (2014b, this conference). The present work is focused on a composite approach to typical environmental ingredients. The goals of this work were a) to provide forecasters with a general overview of synoptic scale and mesoscale features associated with severe and non-severe convection, highlighting any distinguishing differences between the two and b) evaluate the typical spatial patterns of composite parameters associated with HSLC significant severe tornadoes and reports versus nulls. These maps provide additional guidance when addressing the difficult challenge of identifying potentially severe HSLC environments.

2. Methodology

Composite maps were generated for 26 HSLC significant tornado reports, 39 HSLC significant wind reports, and 75 HSLC nulls (defined here as in Sherburn and Parker 2014a; i.e., unverified warnings) using the National Centers for Environmental Prediction's North American Regional Reanalysis (NARR) dataset, which has an approximate 0.3° grid spacing and 3 h temporal resolution. Events and nulls across the Southeast and Mid-Atlantic U.S. were selected from the development dataset of Sherburn and Parker (2014a). The maps were created in a report-relative sense, meaning that the NARR data nearest (temporally) to the report or null were used to plot a 40° by 40° latitude/longitude box surrounding the report for each case. After creating report-relative maps for each respective hour associated with either a significant severe report or null, the maps were averaged over all hours to create composites. In the event that more than one significant severe report or null occurred within the three-hour time window surrounding each dataset (i.e., 90 minutes prior to 90 minutes after analysis time), the report or null that occurred nearest to that time was utilized in the respective storm-relative map.

Once the composite maps were created, we examined the mean upper-level, low-level, and surface patterns associated with both HSLC severe convection and non-severe convection. Additionally, composite maps of composite forecasting parameters, such as the Significant Tornado Parameter (STP; Thompson et al. 2012), Energy Helicity Index (EHI; Davies 1993), Vorticity Generation Parameter (VGP; Rasmussen and Blanchard 1998), Craven-Brooks significant severe parameter (Craven and Brooks 2004), and the newly-developed Severe Hazards in Environments with Reduced Buoyancy parameter (SHERB; Sherburn and Parker 2014a) were created to identify the spatial relationship of enhanced values of these parameters to the locations of severe reports and nulls.

3. Results

a. General mass and momentum fields

HSLC convective events—both those that are associated with significantly severe convection and those associated with non-severe convection—occur just downstream of a 500 hPa trough axis, with a slightly less-amplified and westward-displaced trough observed in the null cases (Figure 1). A broad 300 hPa jet is depicted from the trough axis northeastward, with a jet streak localized upstream of the composite significant tornado report (Figure 1a). Comparatively, the strongest 300 hPa winds are displaced just north and west of the composite significant wind report (Figure 1b) and somewhat farther northwest for the nulls (Figure 1c). Strongly veering winds are observed in all three cases from the surface to 500 hPa, consistent with warm air advection and suggesting synoptic-scale ascent. Additionally, in each case, the composite jet streak is in the base or on the downstream side of the trough, which would suggest the trough is lifting.

All three composites show a closed surface low centered northwest of the reports or nulls, with a surface trough and likely cold front extending southwestward (Figure 2). As with the upper-level trough, the surface low is displaced farther northwest of the reports than the corresponding low in the significant tornado or significant wind composites (cf. Figures 2a, 2b, 2c). The surface low is also weaker in the null cases, though this may be a consequence of the differing sample sizes, as

**Corresponding author address*: Keith Sherburn, Department of Marine, Earth, and Atmospheric Sciences, North Carolina State University, Raleigh, NC 27695-8208

discussed further in Section 4. All three composites are characterized by high levels of 2 m relative humidity, but the significant wind composite reflects slightly lower relative humidity in the vicinity of the reports than in significant tornado cases (cf. Figures 2a, 2b).

Lower-level composite maps (Figure 3) show similarities to upper-level and surface features, with each composite characterized by an 850 hPa trough upstream of the reports and nulls and a potent low-level jet focused near the location of the reports and nulls. As with the surface and upper-level troughs, the null 850 hPa trough is displaced slightly west when compared to the significant severe composites. In addition, the low-level jet and 850 hPa moisture convergence are weaker in the null composite than either the significant tornado or significant wind composites. Significant tornadoes are characterized by the strongest 850 hPa jet (approaching 60 kt) and moisture convergence, which matches well with anecdotal evidence from forecasters.

b. Sounding indices and composite parameters

Thermodynamically, the environment is fairly similar in the immediate vicinity of the reports or nulls in each case (Figure 4). While the mean MLCAPE near the significant tornadoes is higher than either the significant winds or nulls, all three composite points lie on the northern edge of a CAPE gradient. Likewise, the reports and nulls are on the northern flank of a CIN gradient. Meanwhile, the reports and nulls occur within a region of enhanced storm-relative helicity (SRH) values, with the highest values located northeast of the composite report and null locations.

Because CAPE is a substantial contributor to values of the STP, EHI, VGP, and Craven-Brooks significant severe parameter, values of these parameters are generally enhanced in a corridor extending from near the report locations towards the south-southwest (i.e., stretching into the CAPE axis), as shown in Figures 5-8. This pattern is also seen to an extent in the SHERBE (effective layer version; Figure 9), as the effective bulk wind difference is inherently dependent upon CAPE. Additionally, traditional composite parameter values are maximized in the case of significant tornadoes and see a considerable decrease for both significant wind and null cases. However, both of the SHERB parameters (effective version and 0-3 km shear version, the latter shown in Figure 10) are enhanced for both significant tornadoes and significant wind reports. Additionally, the maximum values of the SHERB parameters (particularly the SHERBS3) are more collocated with the locations of the reports than any of the parameters with CAPE as a constituent. It is worth noting that the STP, due to its CIN considerations, diminishes toward the south, away from the location of significant tornadoes, winds, and nulls.

c. Synthesis and interpretation

Our composite maps reveal that the synoptic-scale patterns and mesoscale features accompanying HSLC environments capable of producing significant severe convection are fairly similar to those that do not produce severe convection. Therefore, pattern recognition of familiar features highlighted within case studies of HSLC convective events may be insufficient when attempting to detect potentially severe environments. However, the composite features depicted herein are consistent with previous case studies of HSLC severe convection and are summarized in Section 4.

Because of the time offset of these data relative to the reports and nulls (i.e., up to 90 minutes before or after the respective report or null) and the relatively coarse resolution (approximately 32 km horizontal grid spacing), some otherwise distinguishing features may be smoothed or damped. Additionally, there is some uncertainty in how rapidly the environment evolves ahead of HSLC severe convection. In particular, CAPE and parameters with CAPE as a constituent were maximized to the south of composite report locations, with enhanced values extending northward towards the reports. Severe reports may occur in an environment where CAPE is minimal but a lack of inhibition and strong low-level shear aid in overcoming limited buoyancy to initiate and subsequently enhance convection through dynamic lifting; alternatively, these composite maps could be underestimating the degree of destabilization immediately ahead of significantly severe convection. Rapid environmental evolution, particularly in tornadic cases, is suggested by strong 850 hPa moisture convergence and strongly veering winds from the surface to 500 hPa. Further assessment of the capability of reanalysis or model data to accurately depict these rapid changes in the pre-storm environment is beyond the scope of this work but remains a gap in the knowledge base that requires future investigation. Based on the data presented herein, utilizing a product of lapse rates rather than CAPE appears more practically skillful when attempting to identify regions with the potential for significant severe HSLC convection.

4. Discussion and Conclusions

HSLC convective environments tend to be characterized by the following features:

- A potent upper-level trough
- An upper-level jet streak in the base or on the downstream side of the trough
- Strongly veering winds indicative of warm advection and synoptic-scale ascent
- A closed surface low and attendant cold front
- Plentiful near-surface moisture
- Intense low-level jet and moisture convergence
- A higher-CAPE, higher-CIN environment to the south
- High values of 0-3 km SRH

While there are differences in synoptic-scale and mesoscale features among the three composite samples shown, they remain fairly subtle, suggesting that additional tools may be necessary to adequately discriminate between HSLC environments capable of producing significant severe convection and those producing non-severe convection.

Composite forecasting parameters have been shown to exhibit some statistical skill at discriminating potentially severe and non-severe HSLC environments, particularly the SHERB parameters (Sherburn and Parker 2014a). Here, we examined their spatial patterns relative to composite significant tornado and wind reports and unverified warnings. The following key points emerged:

- The SHERB parameters are enhanced for both significant tornadoes and significant winds, with highest values near the location of the composite report
- Parameters with CAPE as a constituent (including the STP, 0-3 km EHI, 0-3 km VGP, and Craven-Brooks significant severe parameter) are highest for significant tornadoes, markedly diminishing for both significant wind events and nulls
- Values approaching or exceeding "traditional" operational thresholds for the EHI, VGP, and Craven-Brooks significant severe parameter remain south of the report locations, with the reports occurring on the "nose" of enhanced values
- Values of the STP remain low for even the significant tornado cases, with maximum composite values around 0.5, consistent with previous studies (e.g., Guyer and Dean 2010; Sherburn and Parker 2014a)

Although maximum values of many parameters are displaced to the south of the location of reports, these findings may yet provide some operational guidance. When a favorable synoptic-scale and mesoscale pattern presents maximized values of the SHERB parameters along with nearby upstream enhancements in traditional, CAPE-dependent composite forecasting parameters, significant HSLC severe weather appears to be common. Situational awareness may lead to an improved detection of potentially severe HSLC convective environments.

This work does not address the transition of convection from higher-CAPE to lower-CAPE environments (e.g., Davis 2013) or the evolution of HSLC environments preceding the occurrence of severe HSLC convection. These items are a subject of ongoing and future work (e.g., King and Parker 2014, this conference). Finally, this work represents a qualitative comparison between significantly severe and non-severe HSLC environments. A more quantitative approach, particularly in terms of the synoptic-scale and mesoscale features and their relative magnitudes and locations, could aid in pattern recognition and situational awareness during and in advance of these events. Future work will address this gap while expanding upon the number of fields and cases composited.

ACKNOWLEDGEMENTS

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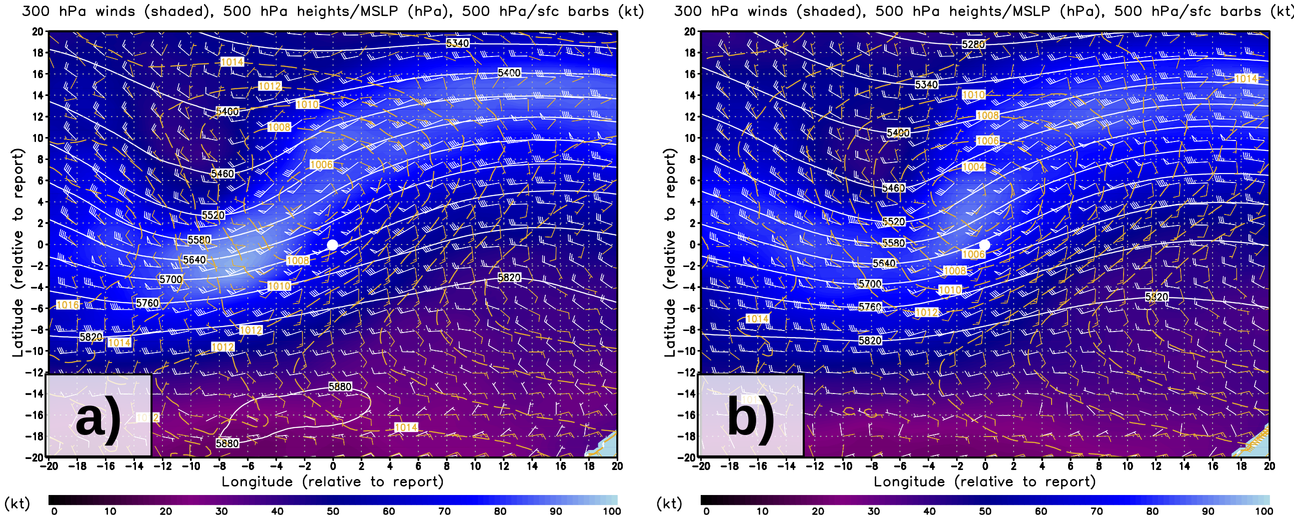


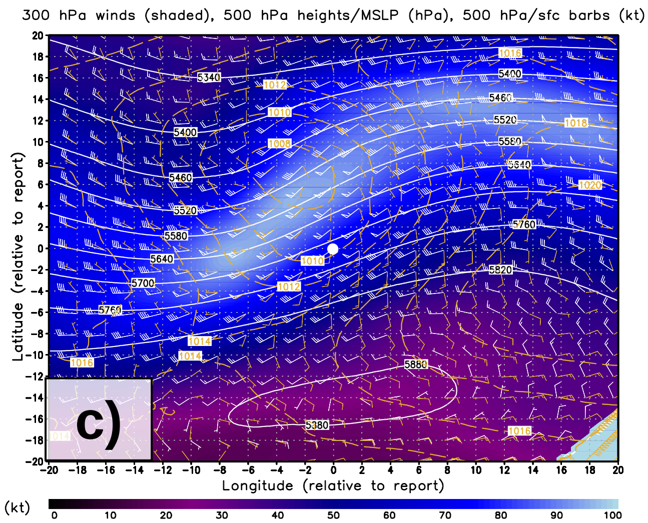


Figure 1. Composite maps depicting mean 300 hPa winds (kt, shaded), 500 hPa geopotential heights (m, white contours), mean sea-level pressure (hPa, gold dashed contours), 500 hPa wind barbs (kt, white), and 10 m wind barbs (kt, gold) for a) HSLC significant tornado reports, b) HSLC significant wind reports, and c) HSLC unverified warnings.

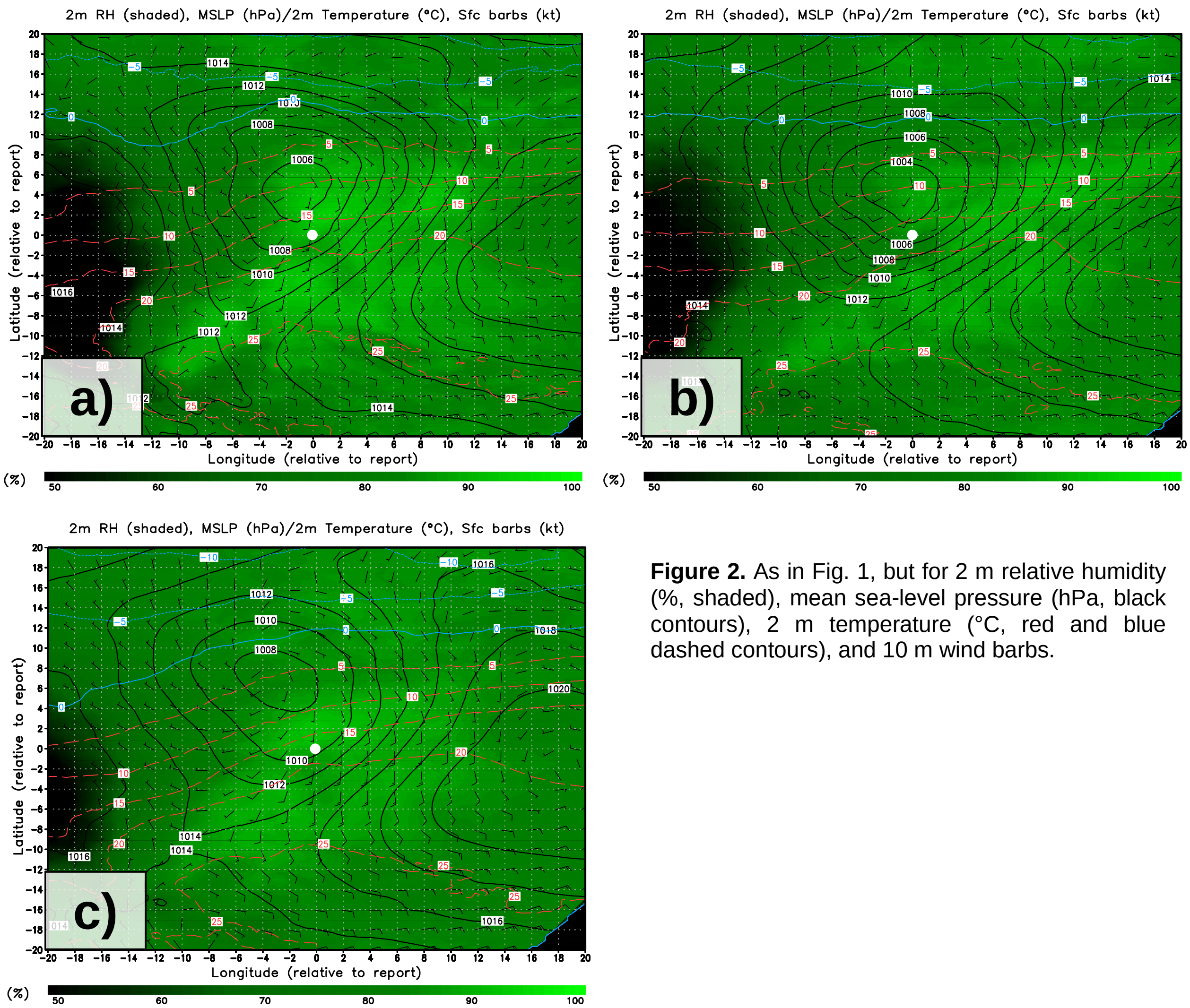


Figure 2. As in Fig. 1, but for 2 m relative humidity (%, shaded), mean sea-level pressure (hPa, black contours), 2 m temperature (°C, red and blue dashed contours), and 10 m wind barbs.

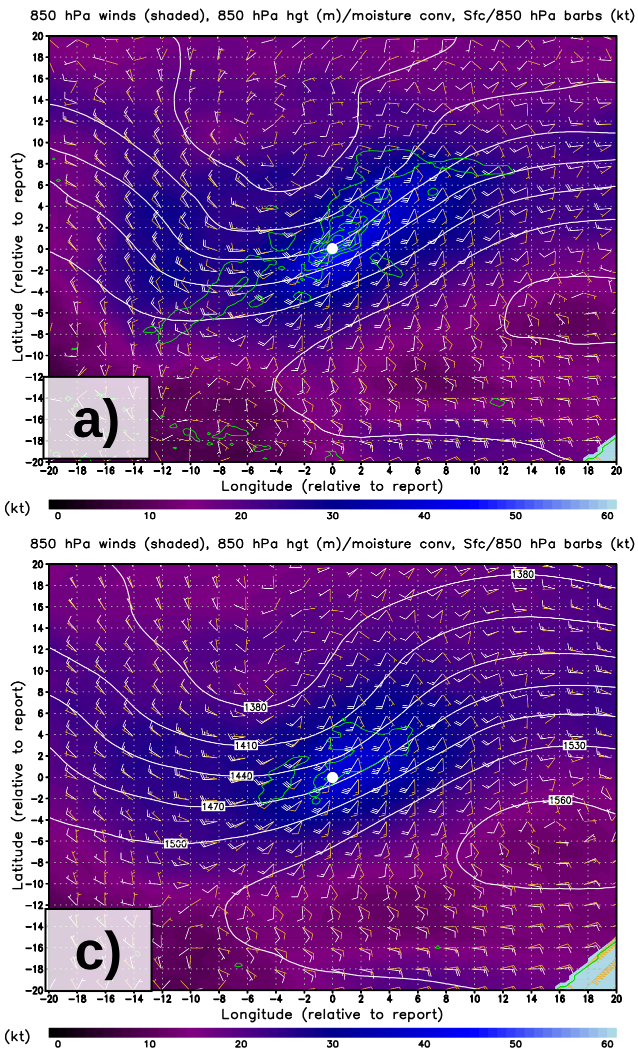


Figure 3. As in Fig. 1, but for 850 hPa winds (kt, shaded), 850 hPa geopotential heights (m, white contours), 850 hPa moisture convergence (1 x 10^{-7} s^{-1}, green contours), 850 hPa wind barbs (kt, white), and 10 m wind barbs (kt, gold).

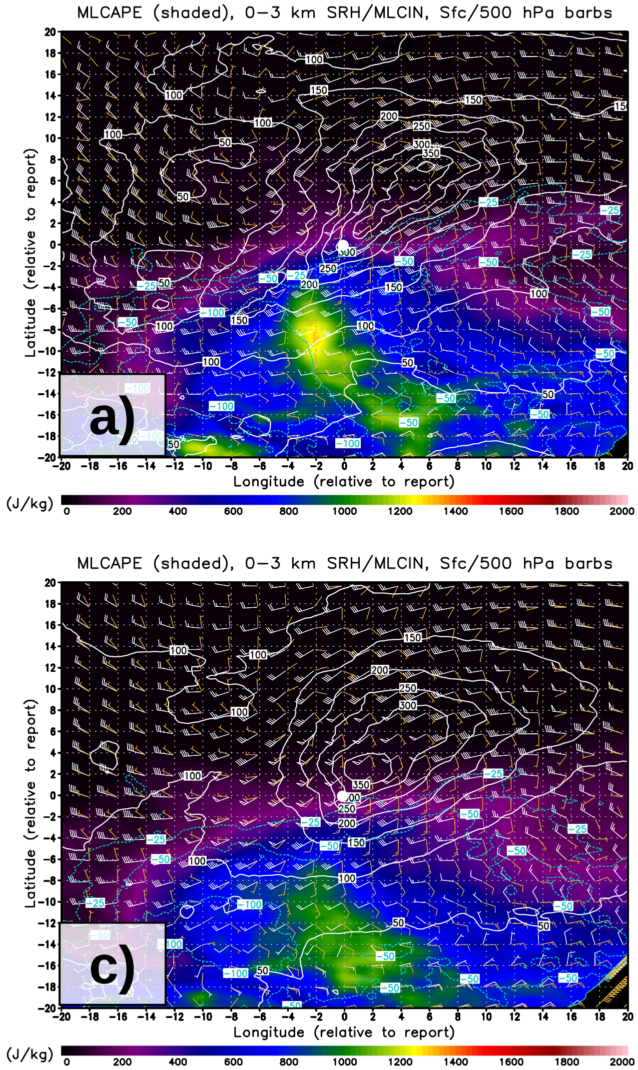


Figure 4. As in Fig. 1, but for MLCAPE (J kg^{-1}, shaded), 0-3 km storm-relative helicity (m^2s^{-2}, white contours), MLCIN (J kg^{-1}, teal dashed contours), 10 m wind barbs (kt, white), and 500 hPa wind barbs (kt, gold).

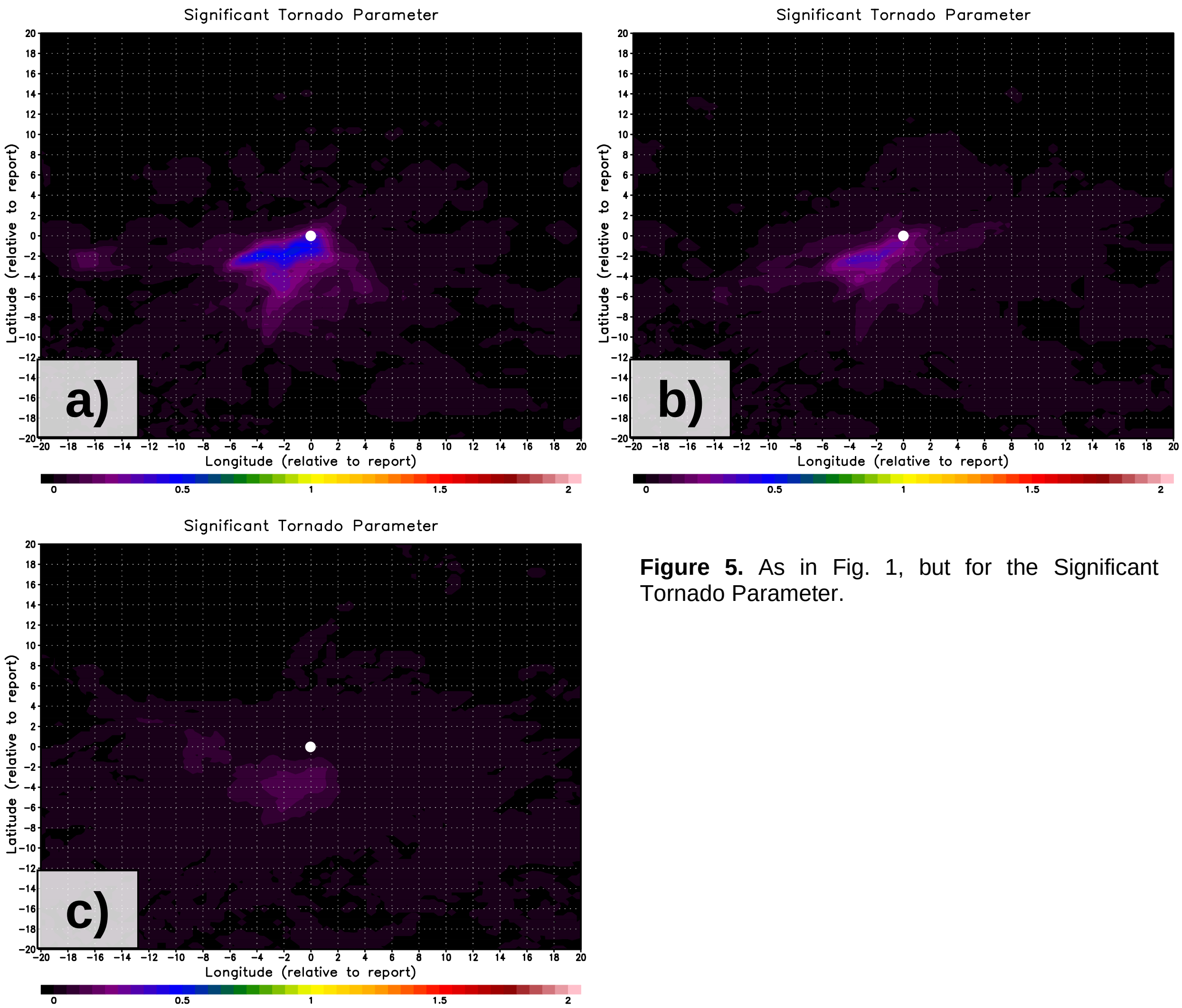
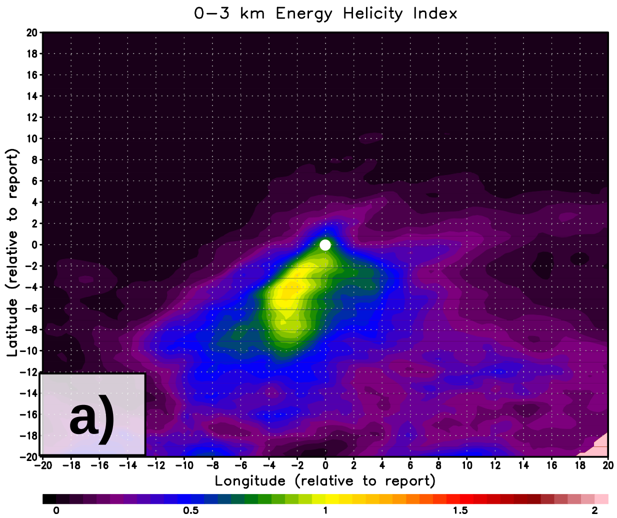
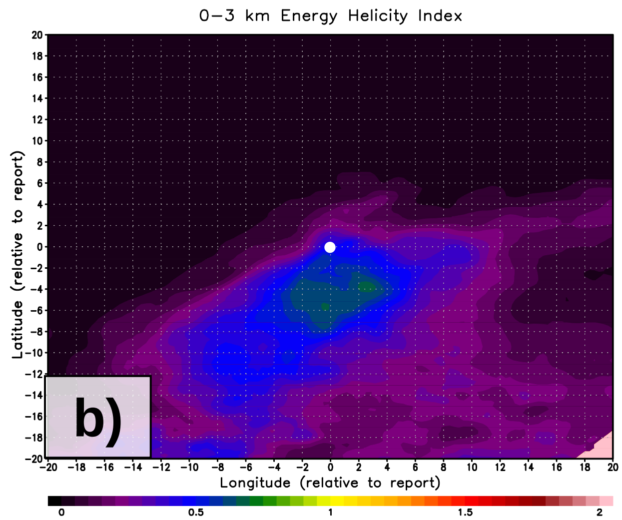


Figure 5. As in Fig. 1, but for the Significant Tornado Parameter.





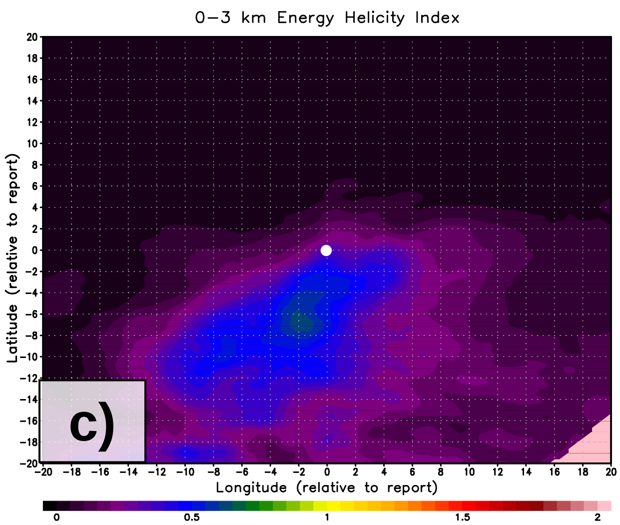


Figure 6. As in Fig. 1, but for the 0-3 km Energy Helicity Index.

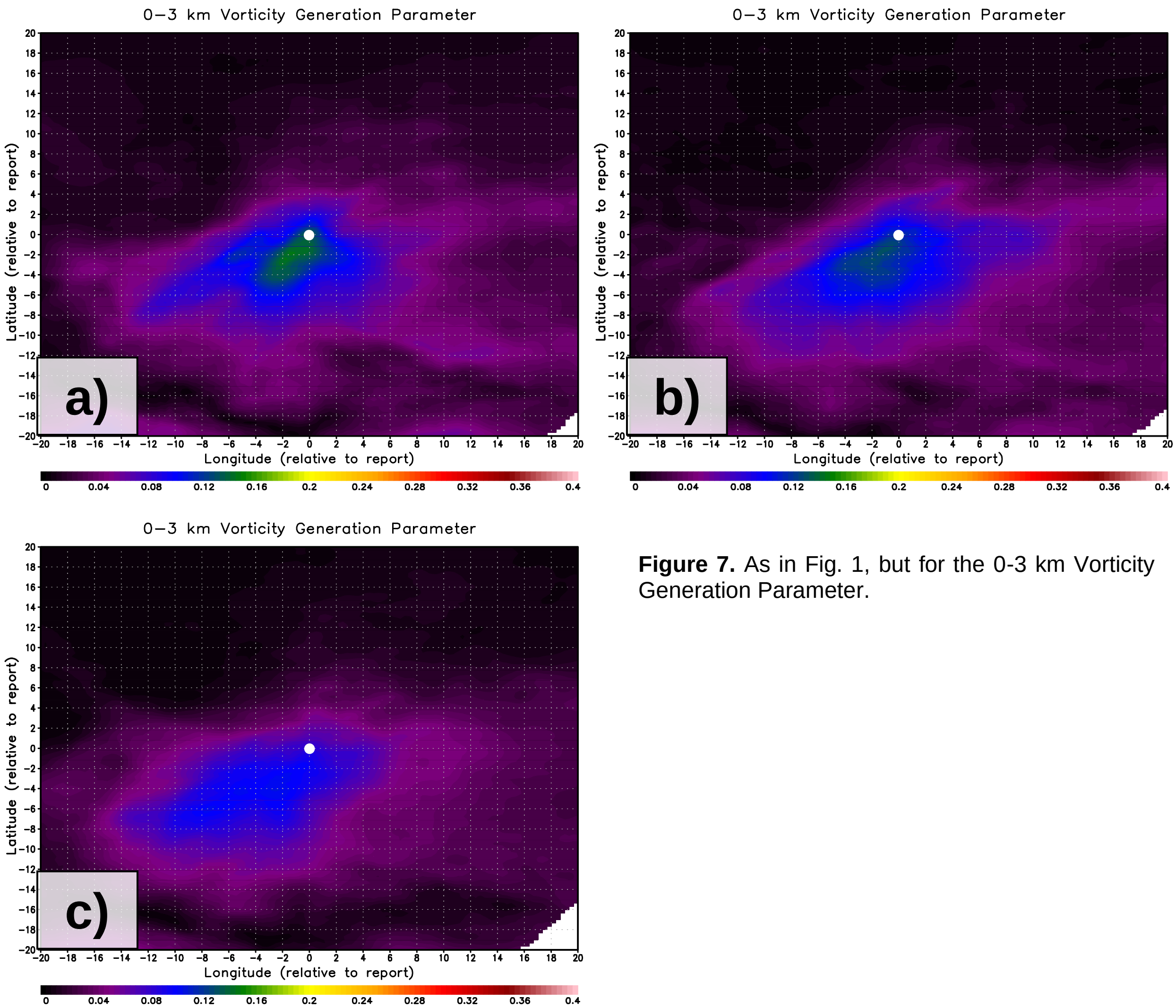
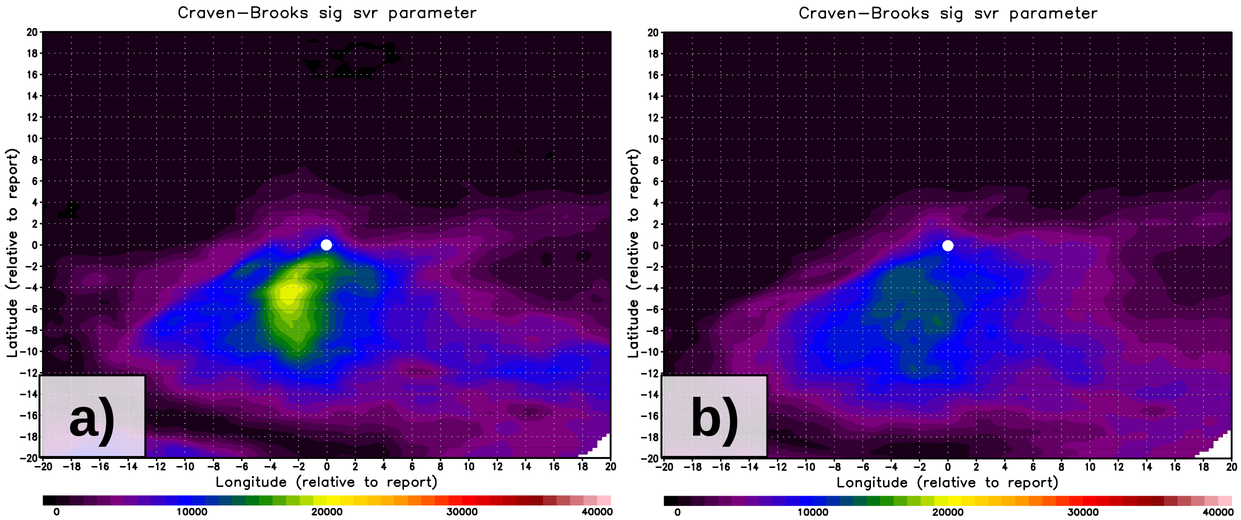


Figure 7. As in Fig. 1, but for the 0-3 km Vorticity Generation Parameter.



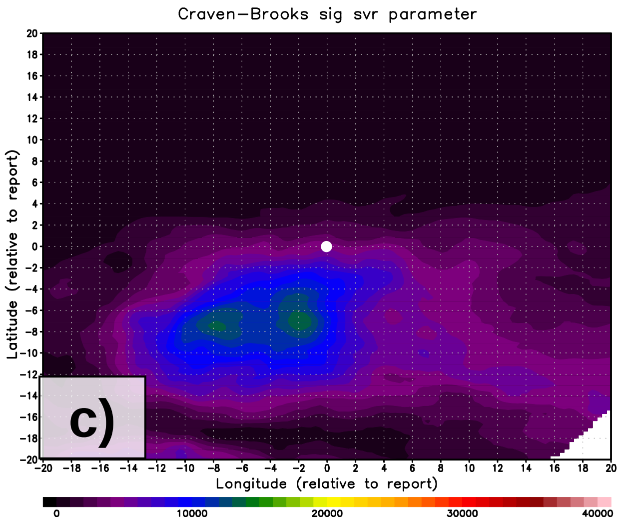


Figure 8. As in Fig. 1, but for the Craven-Brooks significant severe parameter.

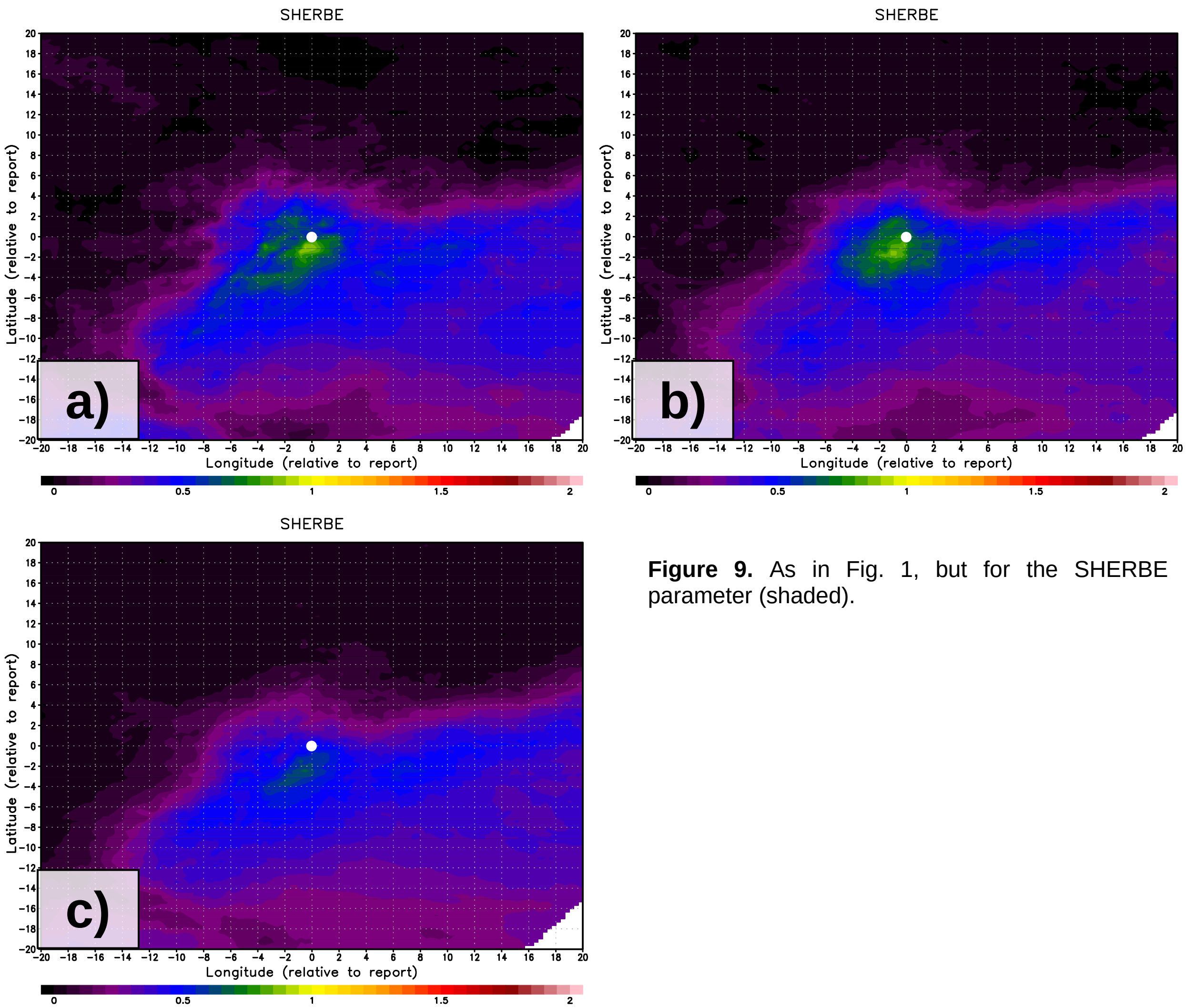


Figure 9. As in Fig. 1, but for the SHERBE parameter (shaded).

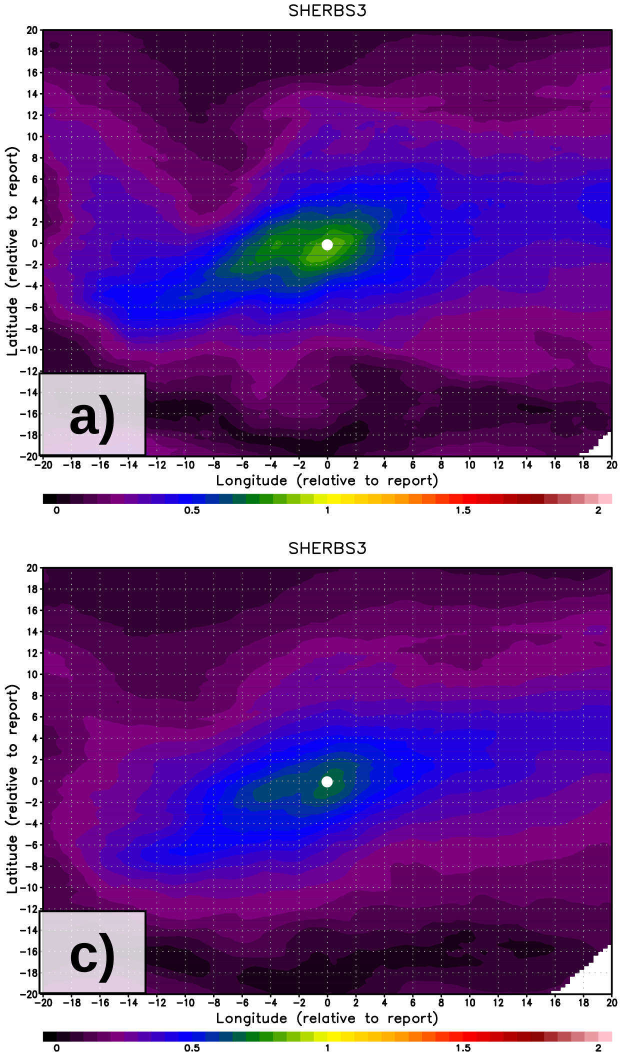


Figure 10. As in Fig. 1, but for the SHERBS3 parameter (shaded).