PARTNERING RESEARCH, EDUCATION, AND OPERATIONS VIA A COOL SEASON SEVERE WEATHER SOUNDINGS PROGRAM

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Projects that partner research, education, and operations offer mutually beneficial opportunities to improve our knowledge and forecasting of unique, local meteorological challenges while providing professional development opportunities for up-and-coming meteorologists.

Environments exhibiting large magnitudes of vertical wind shear and limited instability are commonly referred to as high-shear, low-CAPE (HSLC) environments. Convection within these environments represents a significant forecasting challenge for operational meteorologists at the Storm Prediction Center (SPC) and local National Weather Service (NWS) Weather Forecast Offices (WFOs), exemplified by the high false alarm rates and low probabilities of detection of tornado watch and warning products in this portion of the parameter space (Dean et al. 2009; Dean and Schneider 2012; Anderson-Frey et al. 2016). The difficulties presented by these environments include the following:

- small spatial and, at times, temporal scales of convection and associated rotation when compared to higher CAPE convection (e.g., Davis and Parker 2014);
- a relatively low conditional probability of producing severe weather (Dean and Schneider 2008);
- atypical climatology compared to conventional severe weather climatology, including a large fraction of nocturnal and cool season events (e.g., Thompson et al. 2012; Sherburn and Parker 2014; Sherburn et al. 2016);[1]
- a relatively high percentage of tornadoes within quasi-linear convective systems (QLCSs; Smith et al. 2012; Thompson et al. 2013; Davis and Parker 2014);
- poor skill of traditional severe weather forecasting parameters (Guyer and Dean 2010; Sherburn and Parker 2014); and
- rapid environmental evolution prior to convection that is often poorly depicted by conventional guidance and analyses (King et al. 2017).

Recent research has improved our ability to distinguish between severe and nonsevere HSLC convective environments by establishing the discriminatory skill of low-level lapse rates, low-level shear vector magnitudes, and synoptic-scale and

[1] Note that the HSLC environments referred to herein are typically coupled with large low-level moisture content and low lifted condensation levels (LCLs). Drier, high-LCL HSLC environments also pose a challenge for forecasters, particularly across the plains and Intermountain West.

mesoscale forcing for ascent (Sherburn and Parker 2014; Sherburn et al. 2016; King et al. 2017). However, targeted observations and verification of model forecasts for these events are essentially nonexistent, which continues to limit the skill of short-term forecasting and nowcasting operations.

To address these gaps, an ongoing collaborative project at North Carolina State University (NCSU) is aimed toward increasing the number of near-storm observations in HSLC environments. Nearly 50 radiosondes have been launched in the vicinity of HSLC convection since early 2016, considerably increasing the number of observations of the near-storm HSLC environment. In addition to the research and operational objectives, this project provided a unique extracurricular experience for students in the NCSU Sounding Club, who served as the primary operators of the radiosonde system and were instrumental in the dissemination of the resultant data to collaborators at the Raleigh, North Carolina, WFO. Here we review the preliminary results from two cases, as well as the synergistic relationship between research, educational, and operational outcomes realized by this project.

PROJECT OVERVIEW. *Operations and radiosonde system overview.* NWS WFOs typically collect twice-daily soundings at 0000 and 1200 UTC from NWS rawinsonde observation (raob) locations across the country. In Virginia and the Carolinas, the NWS raob locations include Greensboro (GSO) and Newport (MHX), North Carolina; Blacksburg (RNK) and Washington–Dulles (IAD), Virginia; and Charleston (CHS), South Carolina. In some circumstances, WFOs and some NWS national centers—such as the SPC or the National Hurricane Center—will request supplemental soundings from the NWS raob locations. In contrast, the sounding effort at NCSU is less routine, with targeted operations initiated by local researchers based on several factors, including the likelihood of severe HSLC convection, the availability of personnel, and the budgeting of remaining expendables. However, there have been instances in which NWS meteorologists have worked directly with researchers prior to HSLC convection events to discuss the potential for supplemental soundings and/or to determine specific preferred observation times.

The soundings described herein are launched approximately 105 km east-southeast of the closest NWS raob site (GSO) on the campus of NCSU in Raleigh. In typical HSLC convective environments, the Raleigh location is climatologically closer to the warm sector, in a region of greater surface buoyancy, with a correspondingly greater risk of severe weather. Furthermore, soundings taken at times other than the standard synoptic observations (i.e., 0000 and 1200 UTC) can provide forecasters with additional critical information. For example, numerical simulations of several HSLC severe weather events by King et al. (2017) revealed that rapid destabilization was common within 3 h of the occurrence of severe weather, usually within spatially narrow regions on the order of tens of kilometers. King et al. (2017) recommended monitoring observations within intervals shorter than synoptic times ahead of the convective threat area as a necessity to appropriately identify the threat in a rapidly changing HSLC environment; the current project helps to realize these recommendations.

The decision of whether to conduct an intensive observation period (IOP) on a given event was typically made in the preceding 24–48 hours; however, "HSLC watches" were typically issued several days in advance, providing sufficient time to organize volunteers for each launch. Start and end times of IOPs, along with a desired launch frequency, were determined by NCSU researchers, who communicated via text or phone with the designated sounding club representative for the given event. "Go" and "no go" decisions were based upon subjective assessment of available guidance, including output from convection-allowing models and the SPC's convective outlooks, while timing of operations was determined by observations, short-term model guidance, and availability of resources and personnel. General meteorological requirements for a

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The abstract for this article can be found in this issue, following the table of contents.
DOI:10.1175/BAMS-D-17-0186.1

In final form 18 September 2018

go decision included an expected HSLC environment (CAPE ≤ 1,000 J kg^{-1} and 0–6-km bulk shear magnitude ≥ 18 m s^{-1}), high confidence in the development of convection, and at least a marginal risk for severe weather based on SPC's convective outlook. These criteria led to some "false alarm" IOPs (i.e., convection occurred but was nonsevere) but few misses. An IOP ended when observational trends suggested a decreasing threat for severe convection and/or convection moved downstream of the area.

The HSLC sounding project utilized GRAW DFM-06 radiosondes with a GRAW GS-E receiver, along with associated GRAWMET software. The sounding system had limited mobility; as a result, all operations for this project were conducted on the top floor and rooftop of Jordan Hall on the campus of NCSU (Fig. 1). Prior to each launch, surface observations were gathered from the rooftop using a Kestrel handheld weather and wind sensor and quality controlled against local North Carolina Climate Retrieval and Observations Network of the Southeast (CRONOS) database mesonet observations. This launch site does result in a loss of data in the lowest 10–20 m AGL; however, observations taken from the roof were generally comparable to nearby surface stations, so the sampled near-surface environments were deemed to be representative. However, surface wind observations were typically replaced with the CRONOS mesonet observations because of near-surface winds being frequently blocked by portions of the building.

Near-surface winds are typically quite gusty during HSLC events, prompting adjustments to the launch process. For example, the balloon was inflated inside before being transported to the rooftop for radiosonde attachment and the subsequent launch. Once outside, several volunteers were often needed to shelter the balloon from wind and to hold it in place prior to launch; additional hands on the balloon also encouraged safety of the operators. Operations were not conducted on the rooftop during lightning, but some balloons were unintentionally launched into precipitation. Typically, ascent to the tropopause was complete within an hour of launch time, which allowed for hourly soundings through the depth of the tropopause when desired. Considering the rapid environmental evolution in HSLC events (King et al. 2017), an even smaller window between launches may be ideal to truly gauge the preconvective adjustments to the environment, particularly those occurring in the low levels. This may require a different sounding system or an alternative strategy altogether (e.g., tethersondes or remote sensing) in the future.

Between early 2016 and mid-2017, sounding operations were conducted for 12 HSLC convective events in central North Carolina (Table 1). Several of the sampled events were quite significant; two of them, each producing over 100 reports of damaging winds and tornadoes in the mid-Atlantic region, are profiled in the example events later in the article. The NCSU soundings are shared with WFO Raleigh in near–real time, thus supporting operational forecast

Fig. 1. Images from (a) nocturnal and (b) daytime sounding operations conducted by the NCSU Sounding Club during the HSLC sounding project. Credit to Rob Byron for the photo in (b).

and warning needs of NWS forecasters. During the sounding ascent, preliminary information such as the amount of low-level shear and a qualitative description of the sounding are communicated via social media posts. A more traditional and comprehensive display of the sounding observation is typically provided closer to the sounding termination when an image generated from the Sounding/Hodograph Analysis and Research Program in Python (SHARPpy; Blumberg et al. 2017) is created and shared. The image usually includes a skew T–log$p$ diagram, hodograph plot, and various derived parameters that are delivered via direct e-mail, a regional forecasting forum, and social media. While the NCSU soundings may be most relevant to WFO Raleigh given its location near the center of the Raleigh forecast area, these soundings have been viewed and used operationally by WFOs across the region.

Integration of education into the "research to operations" process. The NCSU Sounding Club, founded in 2014 by NCSU's student meteorology majors, provides students hands-on experience with sounding equipment and software while facilitating the application of concepts learned in the classroom. To ensure the sounding club's officers and members were thoroughly familiar with the sounding operations, the first few launches of each "season" were supervised by NCSU faculty and graduate students, who provided constructive training, feedback, advice, or other comments as necessary. Following this trial period, sounding operations were almost entirely led by the sounding club's officers, with other members assisting with launches.

The close relationship between researchers, students, and operational forecasters provides valuable experiential learning opportunities while meeting the needs of the researchers and forecasters. Notably, field work has been shown to produce more engaged students (e.g., Kolb 2014; Milrad and Herbster 2017) while enhancing their understanding of scientific principles (e.g., Knapp et al. 2006; Elkins and Elkins 2007; Godfrey et al. 2011; Barrett and Woods 2012; Hopper et al. 2013). This project further offers unique opportunities for real-time operational decision-making, as students often decided whether to continue operating during an event; such autonomy is a critical component of successful student involvement in field work (e.g., Rauber et al. 2007; Richardson et al. 2008; Godfrey et al. 2011; Hopper et al. 2013; Bell et al. 2015; Milrad and Herbster 2017). Additionally, the sounding club promotes professional growth for students, including providing networking opportunities with faculty, NWS personnel, and other local meteorologists.

Students and others who are not members of the sounding club still benefit from the HSLC project, as data have been used extensively in NCSU's mesoscale meteorology course and public presentations on southeastern severe weather. Additionally, while not discussed here, launches have also been conducted by the sounding club during winter weather events, for classroom activities at the university and for other outreach purposes. Overall, the training, participation, and subsequent use of sounding system data at NCSU have greatly enhanced student engagement in research, operations, outreach, and the curricula within closely related courses.

Table 1. List of events in which HSLC balloon operations were conducted.

Date	SPC outlook (central NC)	Tornado reports (central NC)	Wind reports (central NC)	Hail reports (central NC)	Balloons launched
3 Feb 2016	Marginal	0	8	0	3
24 Feb 2016	Moderate	7	64	18	6
31 Mar 2016	Marginal	0	0	0	1
1 Apr 2016	Marginal	0	0	0	1
30 Nov 2016	Marginal	0	0	0	1
8 Feb 2017	Marginal	0	0	1	6
1 Mar 2017	Slight	0	2	3	2
31 Mar 2017	Slight	0	2	1	3
3 Apr 2017	Slight	0	4	0	3
5–6 Apr 2017	Enhanced	0	4	2	5
1 May 2017	Enhanced	0	23	0	2
4–5 May 2017	Marginal	1	76	0	3

EXAMPLE CASES. *24 February 2016*. The 24 February 2016 event exemplified many of the typical features present in HSLC severe convective events (e.g., Sherburn et al. 2016): a coupled upper-level jet, including an approaching 120-kt (61.2 m s^{-1}) jet streak at 300 hPa (Fig. 2a) and a 100-kt jet streak at 500 hPa (Fig. 2b), as captured by morning radiosondes from the southeastern United States; a strong, closed low extending from 500 hPa down to the surface cyclone (Fig. 2b); widespread 850-hPa winds in excess of 50 kt (Fig. 2c); plentiful moisture and a strong baroclinic zone in the low levels (Fig. 2c); and an eroding cold air damming wedge (Bell and Bosart 1988) in the lee of the Appalachians (Fig. 2d). Given these telltale signs, in addition to low but sufficient CAPE, the event was fairly well forecast across the mid-Atlantic region, with the SPC issuing a moderate risk for severe weather across central and eastern North Carolina and an enhanced risk from northern South Carolina northward to southeastern Maryland (Fig. 3).

Sounding operations were conducted from approximately 1200 to 2100 UTC 24 February 2016. In addition, collaborators from the University of North Carolina at Charlotte contributed two early-morning radiosonde launches from their campus, while some regional WFOs contributed special 1500 and 1800 UTC soundings during the event (Table 2). During the IOP, the NCSU Sounding Club was responsible for each radiosonde launch, providing the club with valuable experience in a research-to-operations-driven framework. During balloon ascent and following the termination of each launch, images of the associated skew T–log$p$ diagrams were shared with operational forecasters at WFO Raleigh,[2] who used these data to assess operational model and

[2] During this event, skew T–log$p$ images of soundings launched by the University of North Carolina at Charlotte were also shared with WFOs Greenville–Spartanburg and Columbia, SC.

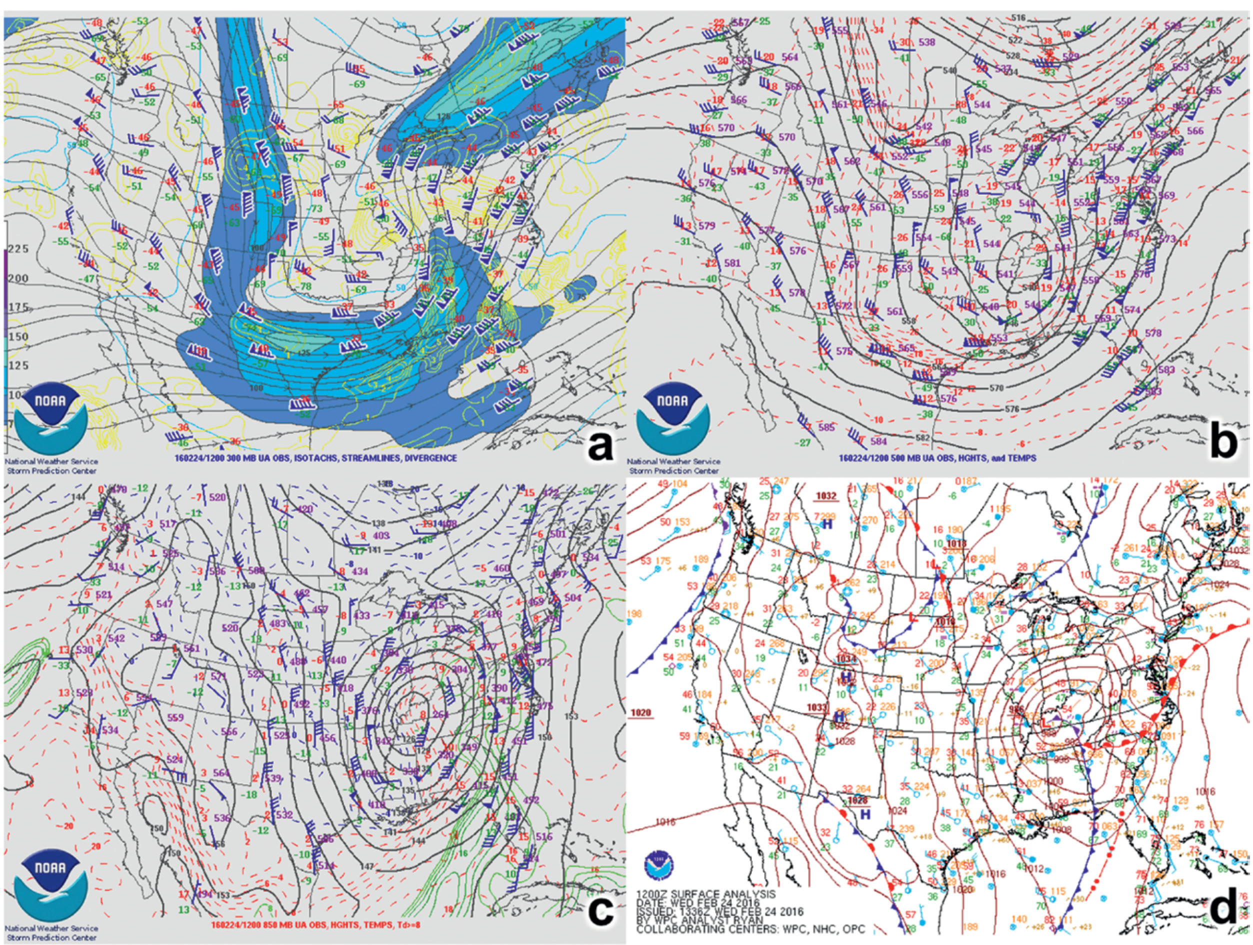


Fig. 2. At 1200 UTC 24 Feb 2016, (a) 300-hPa upper-air observations, isotachs, streamlines, and divergence; (b) 500-hPa upper-air observations, heights, and temperatures; (c) 850-hPa upper-air observations, heights, temperatures, and dewpoints; and (d) surface observations with subjective analysis. Plots (a)–(c) courtesy of the NOAA/NWS/SPC and (d) courtesy of the NOAA/NWS/Weather Prediction Center.

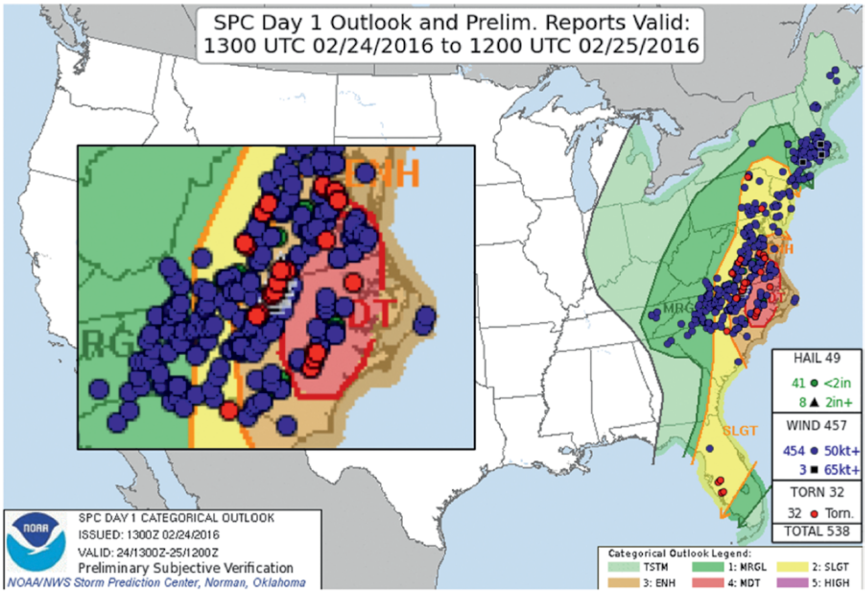


Fig. 3. SPC's day 1 convective outlook issued at 1300 UTC 24 Feb 2016, valid until 1200 UTC 25 Feb 2016, overlaid with preliminary local storm reports during that time. Inset: Zoomed to focus on North Carolina and Virginia.

analysis output in real time in support of nowcasting and warning operations.

The soundings, launched every one to two hours during the IOP, readily captured the environment's evolution during the event. Several rounds of showers and convection impacted central North Carolina during the morning and afternoon hours (Fig. 4), with some development occurring very close to the sounding site (e.g., Figs. 4a,b). Following a period of largely stratiform precipitation in the morning hours (Fig. 4a), low-level warming and moistening led to increasing instability during the morning and early afternoon hours (Figs. 5a,b), which supported the development of convection across central North Carolina (Fig. 4b). Behind the convection, layers of probable subsidence were evident in the sounding launched from NCSU (Figs. 5c,d), providing slight stabilization in the lower troposphere prior to the arrival of a broken line of supercells with a history of producing severe winds across the North Carolina Piedmont (Figs. 4c,d). As the environment stabilized, the low-level shear vector magnitude increased, with winds in the 500–1,000-m AGL layer increasing above 60 kt leading up to 2100 UTC (Figs. 5e,f). Given a continued favorable environment for the production of severe weather, it is no surprise that wind damage was observed across western portions of Raleigh. The line of thunderstorms weakened slightly as it moved east of Raleigh and subsequently produced only a few severe wind reports.

Analysis-hour soundings from the High-Resolution Rapid Refresh (HRRR) model were broadly able to depict changes in the observed environment quite well, as shown in the sounding comparisons of Fig. 5. However, minor differences, particularly in low levels, resulted in some changes to shear vector magnitudes and mixed-layer CAPE (MLCAPE; Fig. 6a). Overall, the convective environment as analyzed by the SPC surface objective analysis (SFCOA; i.e., mesoanalysis; Bothwell et al. 2002) was largely consistent with the

Table 2. List of supplementary soundings on 24 Feb 2016 across the southeastern and mid-Atlantic regions.

Launch time (UTC)	Source and launch location
1204	North Carolina State University, Raleigh, NC
1230	University of North Carolina at Charlotte, Charlotte, NC
1400	National Weather Service, Greensboro, NC
1437	North Carolina State University, Raleigh, NC
1440	University of North Carolina at Charlotte, Charlotte, NC
1659	North Carolina State University, Raleigh, NC
1700	National Weather Service, Blacksburg, VA
1700	National Weather Service, Charleston, SC
1700	National Weather Service, Greensboro, NC
1700	National Weather Service, Newport, NC
1700	National Weather Service, Sterling, VA
1843	North Carolina State University, Raleigh, NC
1944	North Carolina State University, Raleigh, NC
2047	North Carolina State University, Raleigh, NC

sampled NCSU soundings. Differences between the SFCOA and observations were most pronounced in the MLCAPE fields, which tended to be lower in the observed soundings (Fig. 6a), likely as a result of decreased saturation in the lowest 1 km. Shear vector magnitudes and storm-relative helicity values were generally similar, particularly when compared to the HRRR-analyzed fields (Fig. 6).

Although the immediate preconvective environment was not sampled in this particular case, the NCSU soundings allowed for real-time comparison to analyses and short-term model fields. Supplemental observations could be particularly useful in these events where strong large-scale forcing may produce multiple rounds of convection across the same general area over the course of several hours. In such situations it is difficult to assess how the atmosphere is responding to, and recovering from, convection in real time without a new sample of the environment. Therefore, supplemental soundings could be very beneficial to subsequent warning operations.

5 May 2017. Despite exhibiting many of the traditional features of HSLC severe convective events that were noted in the 24 February 2016 case, the 5 May 2017 severe event, which occurred from approximately 0600 to 1200 UTC on 5 May, was relatively poorly forecast based on SPC's convective outlook, particularly when compared to the preceding example. The initial day 1 outlook for the event suggested only a marginal risk for severe weather throughout the period, though a slight risk was added over portions of southeastern North Carolina and eastern South Carolina at the 0100 UTC update (Fig. 7). Between 0000 and 0600 UTC 5 May, a broad zone of mostly stratiform precipitation crossed central North Carolina from southwest to northeast (Fig. 8). The environment across central North Carolina preceding this area of precipitation, as sampled by an NCSU sounding, showed very limited CAPE but large low-level shear and significant low-level hodograph curvature (Fig. 9). A subsequent sounding, which happened to be the last one launched during the IOP,

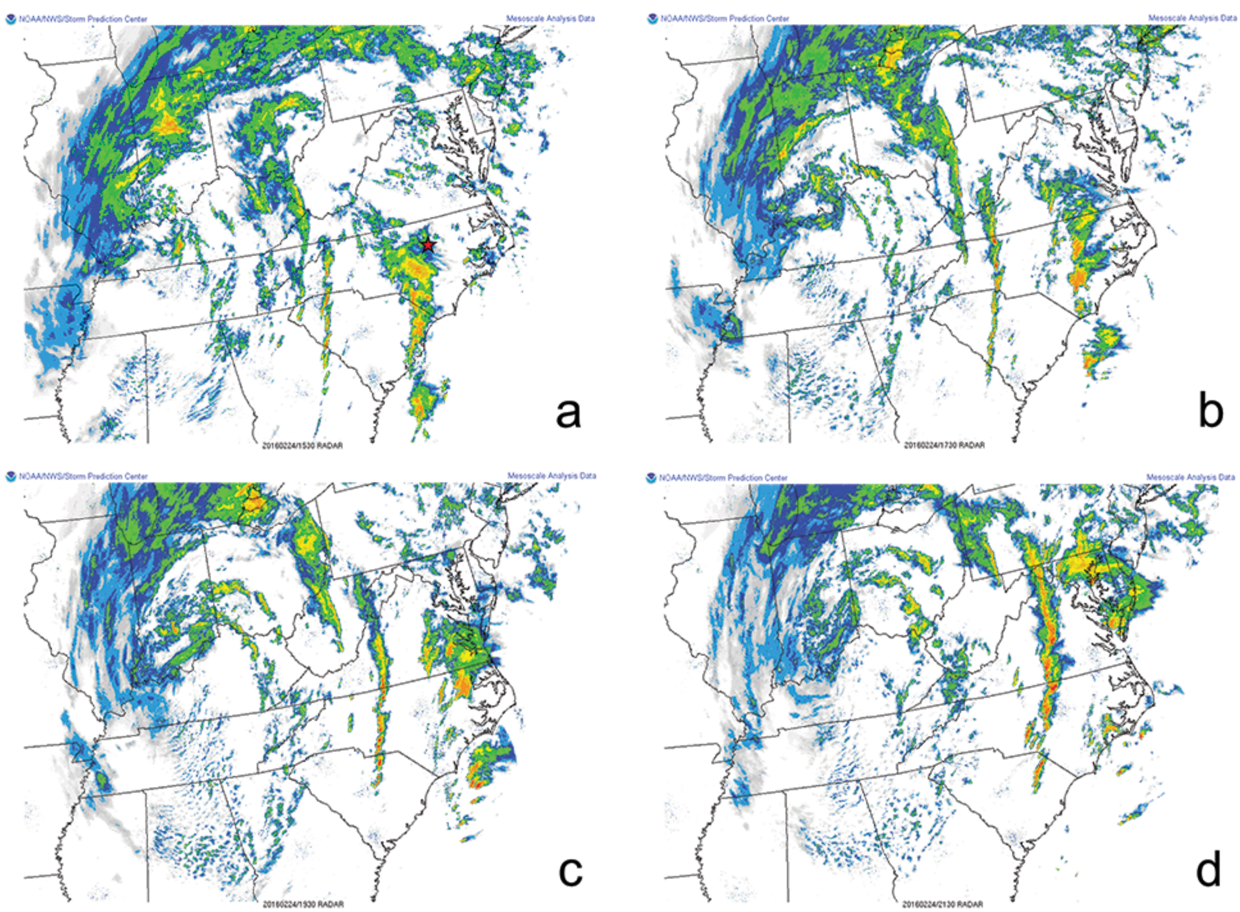


Fig. 4. East-central regional radar composite valid at (a) 1530, (b) 1730, (c) 1930, and (d) 2130 UTC 24 Feb 2016 via the SPC's mesoanalysis. Approximate sounding launch location is shown as red star in (a).

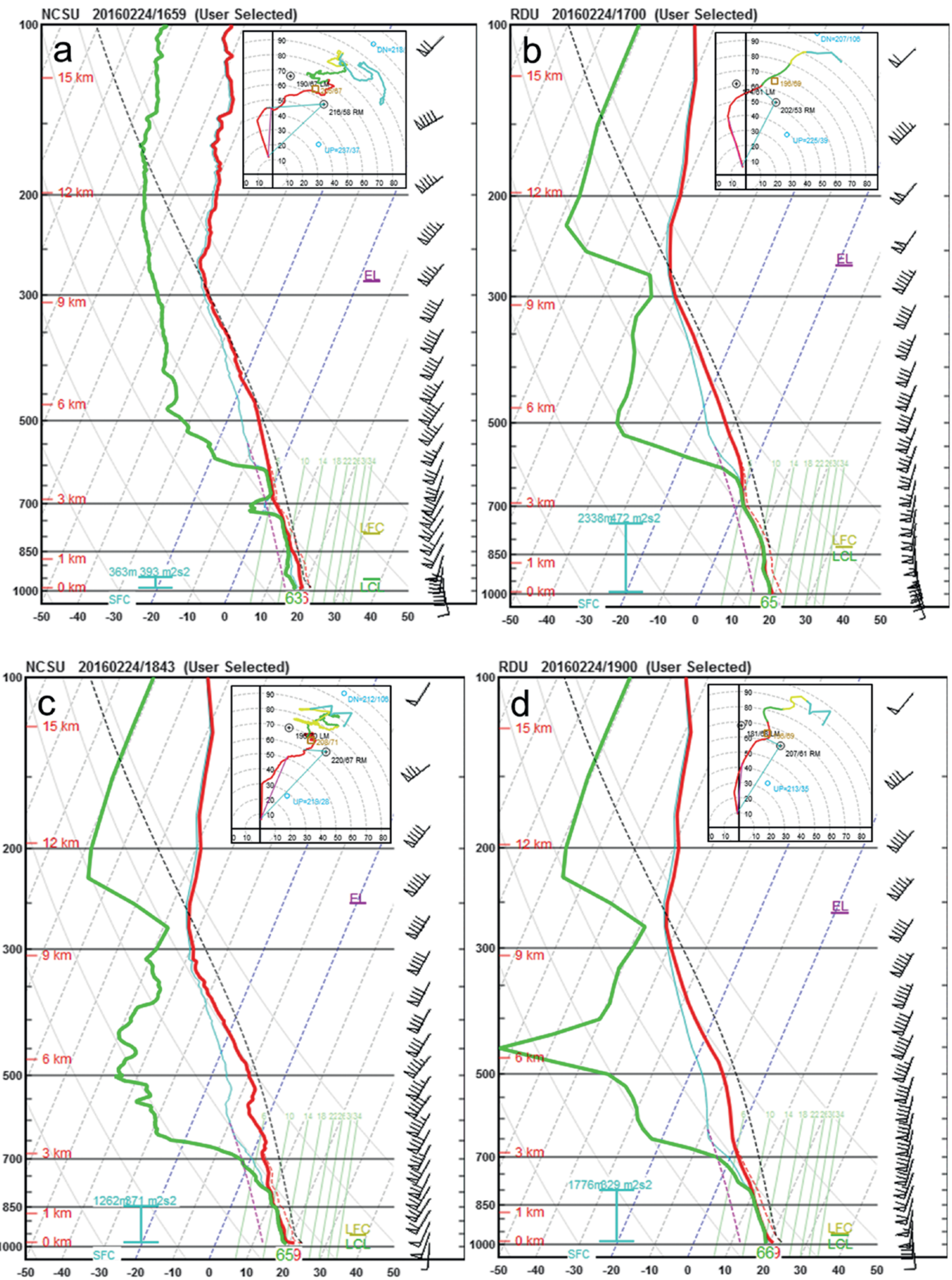


Fig. 5 (continued on next page). **Comparisons between (a),(c),(e) observed soundings launched from NCSU and (b),(d),(f) modeled soundings from the HRRR near Raleigh–Durham International Airport (RDU) at approximately (a),(b) 1700, (c),(d) 1900, and (e),(f) 2100 UTC 24 Feb 2016.**

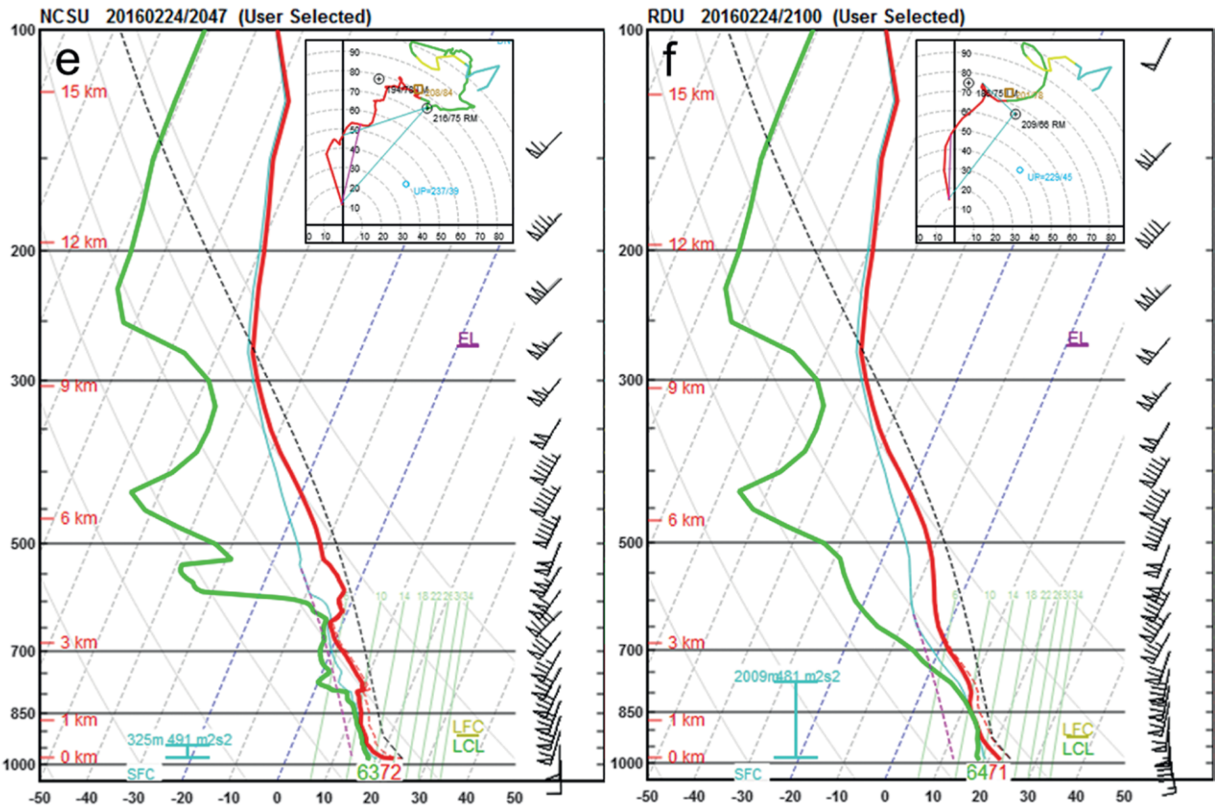


Fig. 5. Continued.

was unintentionally launched into this precipitation shield, rendering it unrepresentative of the ambient environment.

During the 0000–0600 UTC period, a broken QLCS became organized over central South Carolina and eastern Georgia, leading to the development of a few tornadoes and reports of straight-line wind damage prior to 0300 UTC across eastern South Carolina. As the QLCS evolved and crossed North Carolina and Virginia (Fig. 8), widespread straight-line wind damage and seven enhanced Fujita scale (EF) 0 and EF1 tornadoes were reported from 0600 to 1200 UTC. The QLCS continued to produce damaging winds and tornadoes from far eastern North Carolina northward into Maryland through approximately 1400 UTC 5 May before weakening.

The earlier NCSU sounding (Fig. 9) and SPC SFCOA fields (Fig. 10) revealed a very low CAPE but strongly sheared environment throughout the overnight period, including in the vicinity of early-morning tornadoes across North Carolina and Virginia (Fig. 10). However, the tornadoes shown here may have occurred near a nose of higher instability, with analyses suggesting the upstream environment was increasingly unstable. As noted by King et al. (2017), narrow bands of destabilization may not be resolvable in models or analyses with coarse spatial or temporal resolutions. Forecasters have come to realize that the ability to directly sample and observe these environments is critical in the near-term forecast and warning decision-making process. Thus, supplemental sounding operations should target expected zones of rapid, localized destabilization ahead of severe HSLC convection—potentially based upon observations of locally higher equivalent potential temperature (θ_e) immediately ahead of a cold front or outflow boundary—to assess the potential for the SFCOA and other guidance to adequately depict and quantify them. By doing so, supplemental soundings could fill a crucial gap in the real-time assessment of rapidly evolving HSLC environments and their ability to produce severe weather.

During this particular event, sounding operations were shortened because of concerns of atmospheric stabilization following the stratiform precipitation over central North Carolina early in the overnight period and other nonmeteorological factors, including a lack of staffing and expertise resulting from the academic calendar (final exams were ongoing, affecting the availability of student volunteers) and travel. As a result, operations concluded by 0500 UTC, a few hours prior to the arrival of severe

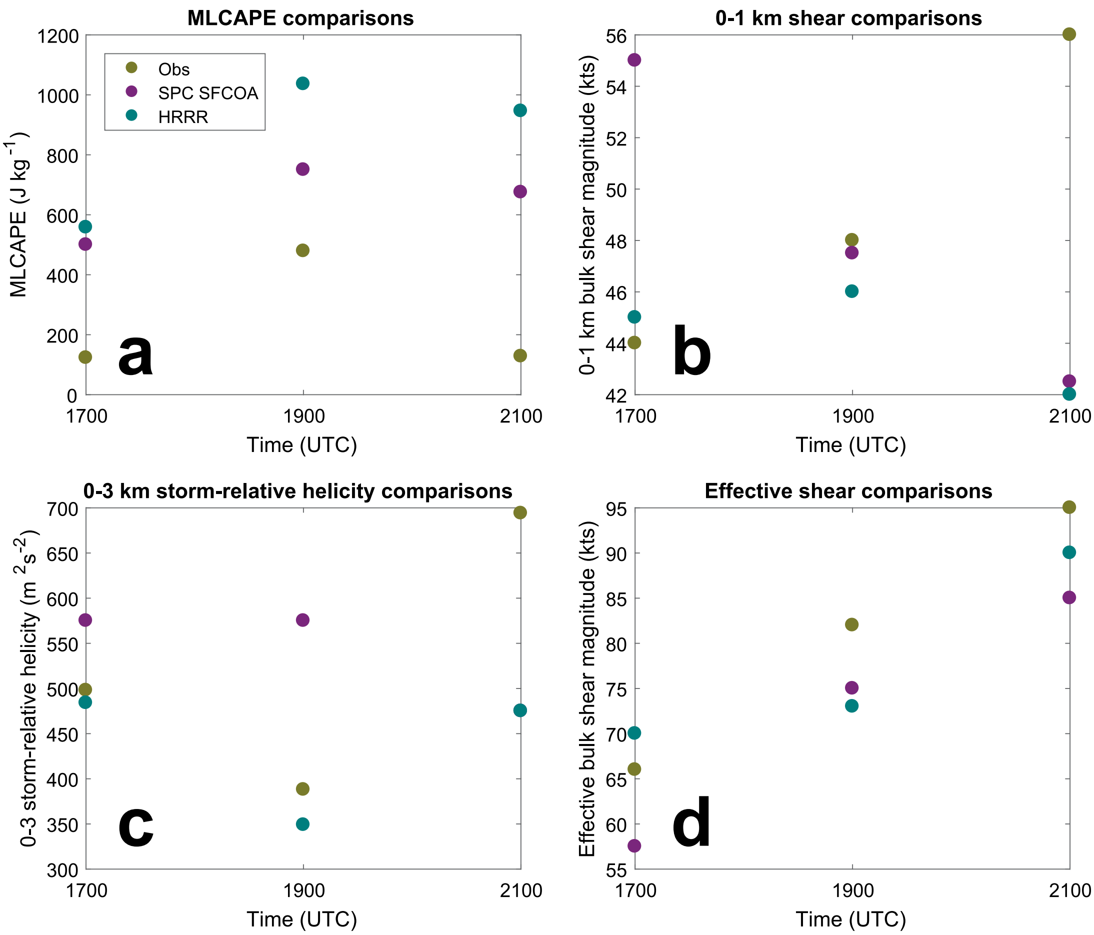


Fig. 6. Comparisons of (a) MLCAPE, (b) 0–1-km shear vector magnitudes, (c) 0–3-km storm-relative helicity, and (d) effective shear vector magnitudes (Thompson et al. 2007) for NCSU soundings (Obs), the SPC SFCOA, and analysis-hour HRRR at 1700, 1900, and 2100 UTC 24 Feb 2016.

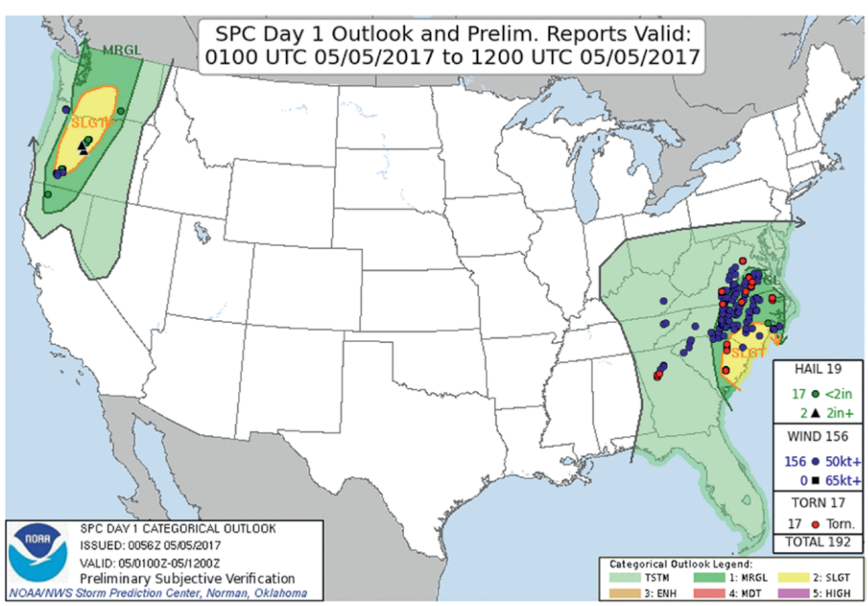


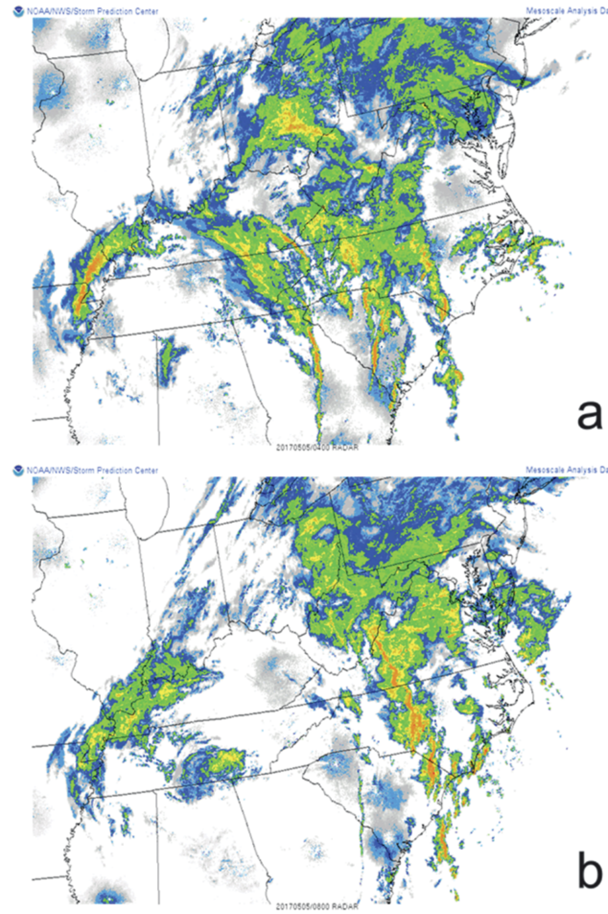
Fig. 7. SPC's day 1 convective outlook issued at 0100 UTC 5 May 2017, valid until 1200 UTC, overlaid with preliminary local storm reports during that time.

convection in central North Carolina and before any appreciable preconvective destabilization may have occurred. Regardless, forecasters at the Raleigh WFO found utility in the soundings. For example, during the early-morning hours of 5 May, Raleigh WFO forecaster M. Strickler shared the following assessment of the severe weather potential during the upcoming 6–12 hours with NWS partners—including emergency managers, media, and other WFOs—via the NWSChat communication tool:

> (1:25:09 AM) nws-michael.strickler: Convection across central NC has remained devoid of lightning thus far. Nonetheless, weak instability and the character and strength of (particularly the low level) shear—depicted in both mesoanalysis data and NCSU sounding club RAOBs—has supported the development of multiple showers that have exhibited relatively impressive circulations.

Although operations were limited to a period well before the arrival of severe convection, and thus did not capture any substantial destabilization ahead of it, this particular event again revealed that all available supplemental observations of the prestorm environment are of utmost importance to operational meteorologists. In this case sounding data allowed for real-time assessment of numerical weather prediction guidance, lending confidence to operational meteorologists in their near-term forecasts and nowcasts. This suggests that increased supplemental sounding observations could lead to more accurate forecasts in future events.

In addition to the operational forecast and nowcast considerations, this event provided student volunteers from the sounding club a glimpse into severe weather operations during an unconventional period. Overnight sounding



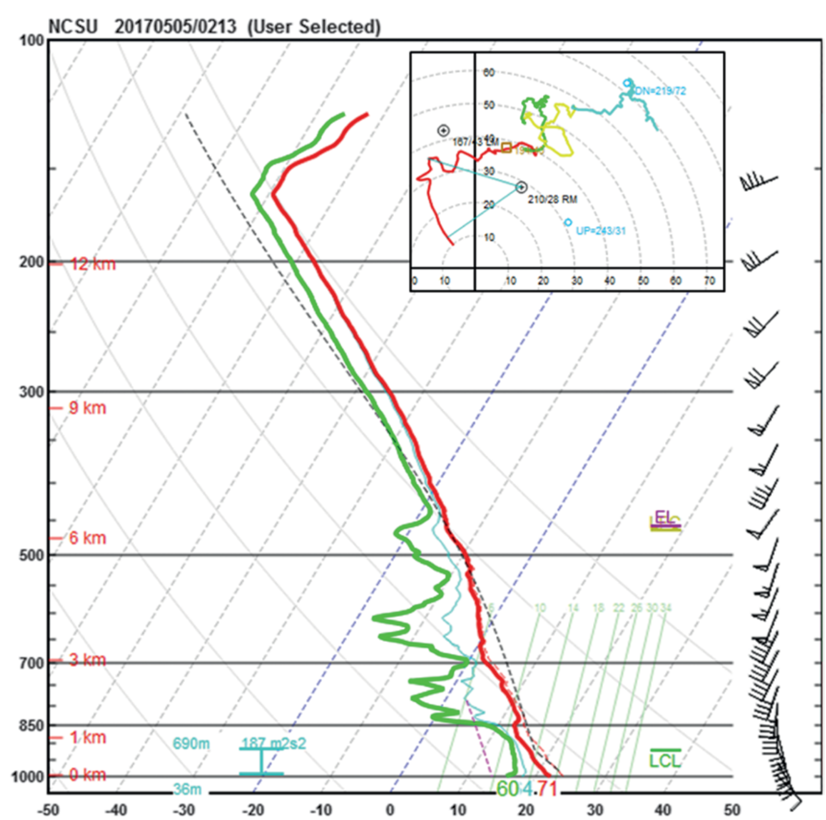


Fig. 8 (top right). East-central regional radar composite valid at (a) 0400 and (b) 0800 UTC 5 May 2017 via the SPC's mesoanalysis.

Fig. 9 (bottom right). Observed sounding launched from NCSU at 0213 UTC 5 May 2017.

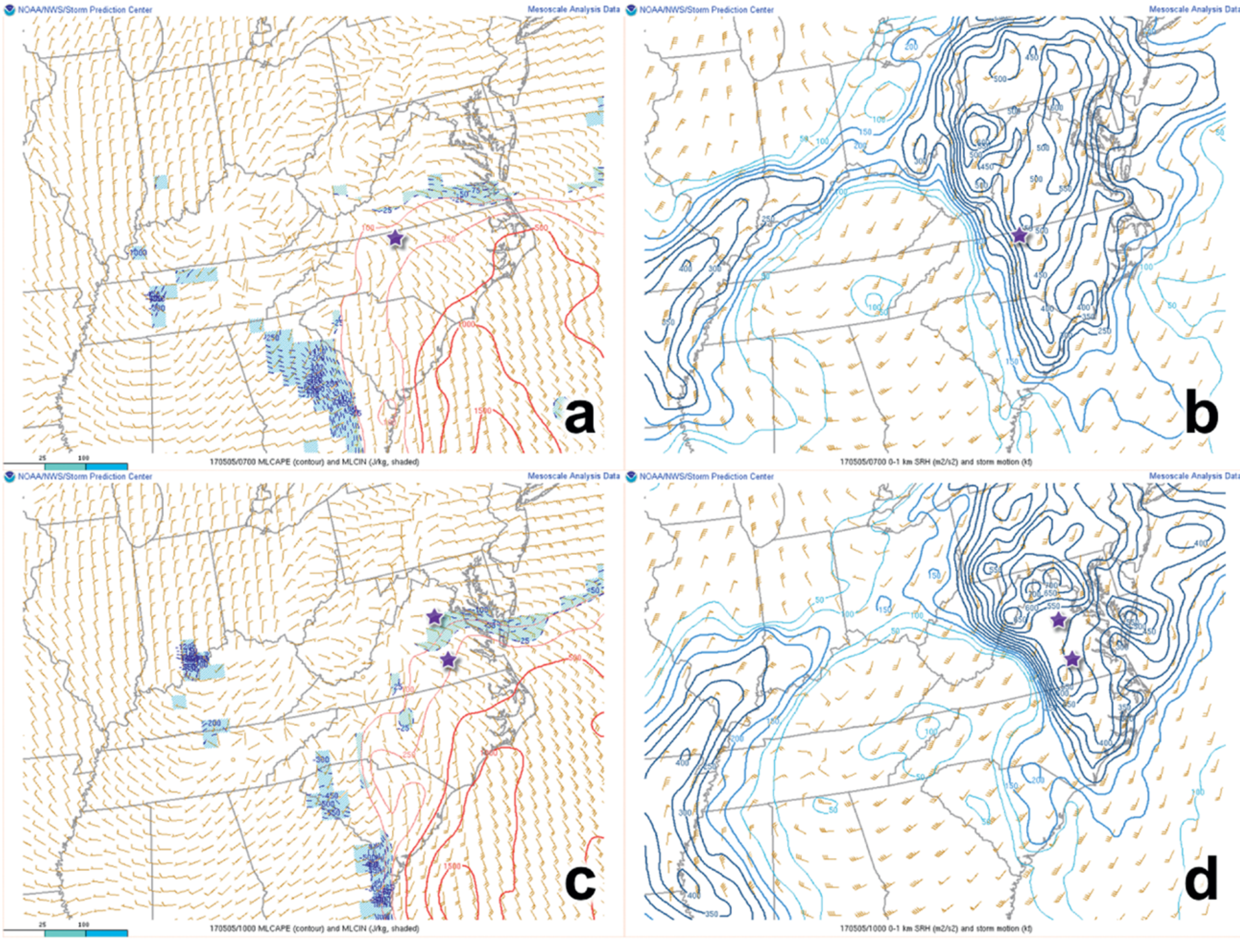


Fig. 10. From 5 May 2017, analyzed (a),(c) MLCAPE (contoured; J kg^{-1}) and convective inhibition (shaded; J kg^{-1}) and (b),(d) 0–1-km storm-relative helicity (m^2 s^{-2}) and storm motion vectors (kt) for (a),(b) 0700 and (c),(d) 1000 UTC via the SPC's surface objective analysis (i.e., mesoanalysis). Purple stars indicate approximate locations of tornadoes within the surrounding hour.

operations offer unique physical and occupational challenges, including fatigue and darkness in the launch area. This particular event offered the students experience that would be difficult to match outside of a larger-scale research project or an operational position at the NWS.

DISCUSSION AND CONCLUSIONS. Despite recent climatological and modeling studies that have improved our knowledge of high-shear, low-CAPE (HSLC) severe convective environments, they remain a considerable operational forecasting challenge, particularly in the Southeast, Ohio Valley, and mid-Atlantic regions. This paper has provided an overview of ongoing efforts to expand the number of observations in the vicinity of HSLC severe convection. In addition to research and operational benefits, this project has further incorporated volunteers from North Carolina State University (NCSU)'s student-run sounding club to provide educational and professional development opportunities via practical hands-on experiences outside the classroom.

The HSLC soundings program was primarily conceived as a research effort to greatly increase the number of measurements of the near-storm environment in these poorly understood severe weather outbreaks. But, the project has also evolved into a mutually beneficial collaborative relationship between NCSU and the regional WFOs that contributes to valuable experiential learning for students and a positive impact on citizens via improved forecasts and warnings. While the NCSU Sounding Club was not created to support operational meteorology, a program such as this provides increased opportunities for hands-on experiences making meaningful measurements. The critical data that they collect have found their way into a stream of information that is delivered to operational forecasters—including warning decision-makers—and key external NWS partners, such as media and emergency managers. These efforts could be largely duplicated within the numerous other organizations that take sounding observations across the region and country. In recent years, upper-air sounding efforts in the Southeast have been conducted by the University of North Carolina at Asheville; the University of North Carolina at Charlotte; the University of Alabama in Huntsville; Simmons Army Airfield in Fort Bragg, North Carolina; Redstone Arsenal in Huntsville, Alabama; and the National Oceanic and Atmospheric Administration (NOAA) Atmospheric Turbulence and Diffusion Division Laboratory in Oak Ridge, Tennessee, among others. Nationwide, there are many other universities and organizations with similar capabilities. Continuing to expand this partnership of research, education, and operations across the country would be mutually beneficial to all components of the weather enterprise, as it engenders greater student engagement and could lead to more rapid progress in solving a variety of regional forecasting challenges.

ACKNOWLEDGMENTS. The funding for the 50 research soundings purchased to begin the HSLC soundings project was provided by the National Science Foundation through the Early-Concept Grants for Exploratory Research (EAGER) program under Grant AGS-1530258. The authors thank all members of the NCSU Sounding Club and the Department of Marine, Earth, and Atmospheric Sciences who dedicated their time to balloon launches over the course of this project. Additionally, we would like to particularly thank Dr. Markus Petters from NCSU, who acquired the sounding system used throughout this project and advised the NCSU Sounding Club from its origins. Further, we would like to acknowledge the student volunteers at the University of North Carolina at Charlotte who participated in the launches of 24 February 2016 for their time and effort. Funding for the soundings launched at UNC Charlotte was provided by a faculty research grant. We would also like to acknowledge three anonymous reviewers, Mr. Jeff Waldstreicher, and Dr. Matt Bunkers, whose comments and suggestions on earlier versions of the manuscript greatly benefited the final article. Finally, the authors thank regional and national collaborators within the high-shear, low-CAPE CSTAR projects from which this idea emerged (NOAA Grants NA10NWS4680007 and NA14NWS4680013).

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