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DEPARTMENT OF COMMERCE
RESEARCH PERFORMANCE PROGRESS REPORT (RPPR)

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AWARD INFORMATION

1. Federal Agency: NOAA
2. Federal Award Number: NA17NWS4680002
3. Project Title: Understanding Fundamental Processes and Evaluating High-Resolution Model Forecasts in High-Shear Low-CAPE Severe Storm Environments
4. Award Period of Performance Start Date: 07/01/2017
5. Award Period of Performance End Date: 06/30/2022

PRINCIPAL INVESTIGATOR/PROJECT DIRECTOR

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REPORTING INFORMATION

Signature of Submitting Official:

16. Submission Date and Time Stamp:
17. Reporting Period End Date: 06/30/2022
18. Reporting Frequency:
    - ○ Annual
    - ● Semi-Annual
    - ○ Quarterly
19. Report Type:
    - ○ Not Final
    - ● Final

RECIPIENT ORGANIZATION

20. Recipient Name: North Carolina State University
21. Recipient Address: Raleigh, North Carolina 27695
22. Recipient DUNS: 042092122
23. Recipient EIN: 56-6000756

ACCOMPLISHMENTS

24. What were the major goals and objectives of this project?

a) Improve short-term prediction and situational awareness of high-shear low-CAPE (HSLC) scenarios by more thoroughly understanding the quality of convection-allowing model (CAM) numerical weather prediction (NWP) forecasts. Surveys confirm that forecasters are already using these tools, despite limited documentation of their strengths and weaknesses in HSLC environments. To accomplish this specific aim we proposed to perform observational verification of CAM NWP performance (archived operational CAM ensemble output and case study simulations) during HSLC events vs. nulls.

b) Improve HSLC nowcasting and warning operations by advancing the understanding of tornadogenesis and the associated interpretation of HSLC radar imagery. Forecasters have indicated that a major gap in understanding hinders this process. To accomplish this specific aim we proposed to perform idealized simulations of HSLC convective storms, within which we will study the dynamical processes at work and compare them to pseudo-radar measurements of the simulated storms.

c) In addition to the two preceding, originally proposed goals, a subsequent development has been to objectively characterize the various synoptic and mesoscale patterns accompanying HSLC convection, and relate these patterns to distributions of local storm reports (LSRs).

25. What was accomplished under these goals?

goal a) Graduate student Chase Graham sought to assess the predictive skill of severe convection by the High-Resolution Ensemble Forecast (HREF) system. In order to keep the scope of his MS thesis study manageable, we focused on using the ensemble-maximum updraft helicity as the predictive quantity, and we evaluated this against the storm report database (for tornadoes and several wind). Efforts were hampered by changes in the HREF system over the years, and limitations of using storm reports for verification. A sample of 144 6-h cool-season time periods over three seasons was analyzed, using both a neighborhood method (Fractions Skill Score, FSS) and traditional contingency-table statistics (presented using performance diagrams). While overall HREF skill was rather low, we found that a threshold of 35 m2/s2 showed the greatest skill, despite a high false-alarm ratio. When scores were stratified by storm report activity, skill increased, which offers some hope that high-impact cases are more skillfully predicted.

goal b) Graduate student Levi Lovell studied a HSLC QLCS from 25 February 2018, which had an early-in-life period with primarily non-tornadic vortices and a late-in-life period with many tornadic vortices. His work included a great deal of preliminary sensitivity analysis, followed by a production run using the WRF model. The WRF model was nested down to 200 m grid spacing and both the non-tornadic and tornadic phases were reasonably represented. He characterized the vortices in the WRF simulation via a statistical analysis, and also studied the dynamics of the vortices via a vortex line analysis. Finally, he characterized the environments of the non-tornadic vortices in the WRF to determine whether environmental ingredients could be used to operationally discriminate between the vortices. This was established via both a statistical analysis and via idealized numerical simulations using the mean tornadic and non-tornadic soundings to initialize simulations within the CM1 model.

goal b) Graduate student Andy Wade studied the processes occurring in HSLC supercells using very high resolution idealized simulations (grid spacings of 100 m) based on a HSLC tornado outbreak from 31 March 2016 (observed during VORTEX-Southeast). His analysis focused on the dynamics controlling the shallowness and transience of tornadic vortices (which present major operational challenges) as well as the generation of vorticity in storms with very weak cold pools in HSLC environment. These processes were highlighted via a comparison to a well-known higher-CAPE tornado outbreak in the Southeast (the 3 April 1974 Super Outbreak).

goal c) Graduate student Trevor Campbell used an unsupervised neural network approach known as Self-Organizing Maps, or SOMs, to seek differences in HSLC synoptic and mesoscale patterns. One related goal of this work was to identify patterns that differentiate high- and low-activity convection events. Specific meteorological patterns exhibited only slight variations within the HSLC convection subclass, strongly resembling those documented in previous literature: a strong surface cyclone accompanied by a deep upper-level trough and a northward extending tongue of instability. The presence of lower-tropospheric wind shear, near-surface theta-e advection, and the release of potential instability showed marked distinctions across different SOM nodes. No one variable consistently demonstrated differences in the distribution of severe weather activity across patterns. Assessing the meteorological patterns associated with the upper and lower quartiles of severe weather occurrence indicated that the release of potential instability was consistently associated with higher-impact events in comparison to other convective ingredients. A HSLC composite parameter identified in earlier research was effective in depicting HSLC severe convection in high-impact events. However, instances of variability in the spatial location or maximum values of this parameter were found in events in which the parameter did not align with the distribution of severe weather. These differences were most heavily influenced by variables representing the release

26. What opportunities for training and professional development has the project provided?

-Graduate student Andy Wade advanced his numerical modeling and data analysis skills and had active interaction with the operational community. Upon graduation with his PhD degree in 2020, he joined the NOAA workforce as an NWP researcher with SPC/CIWRO in Norman, OK.
-Graduate student Levi Lovell advanced his numerical modeling, coding, and statistical analysis skills. Upon graduation with his M.S. degree in 2020, he took a job with a private sector company doing big data science.
-Graduate student Chase Graham gained valuable data analysis skills. Upon graduation with his MS degree in 2021, he joined the NOAA/NWS workforce as a forecaster at the Louisville, KY office.
-Graduate student Trevor Campbell expanded his skill set using machine-learning and data analysis methods. He has successfully defended his MS thesis, and will officially graduate in December 2022. He has taken a job with a private sector company doing meteorology and data science.
-Two undergraduate students, Lauren Getker and Hunter Camp, developed Python and AI skills by working on coding projects to display real-time data and to generalize SOM codes to work on both real-time and reanalysis data.

27. How were the results disseminated to communities of interest?

-The major findings of this project were shared with the NWS Eastern Region via a webinar on 21 July, 2022. We also held regular meetings with the MIC and SOO of NWS WFO-Raleigh, NC, and held periodic CSTAR regional update calls/webinars.
-Two peer-reviewed journal articles have been published:
Wade, A. R., and M. D. Parker, 2021: Dynamics of simulated high-shear low-CAPE supercells. J. Atmos. Sci., 78, 1389-1410.
Lovell, L. T., and M. D. Parker, 2022: Simulated QLCS vortices in a high-shear low-CAPE environment. Wea. Forecasting, 37, 989-1012.
-Chase Graham's MS thesis, entitled Verification of Convection-Allowing NWP in Southeastern US High-Shear, Low-CAPE Environments, is available here: https://www.lib.ncsu.edu/resolver/1840.20/39034.
-Trevor Campbell defended his MS thesis on 20 July 2022. The thesis should be available in final form from NCSU libraries soon, and we expect to develop it into a peer-reviewed journal article.
-Related conference presentations included:
Wade, A. and M. D. Parker, 2018: High-shear low-CAPE supercell simulations. 29th Conference on Severe Local Storms, AMS, 22-26 October, Stowe, VT.
Wade, A., and M. D. Parker, 2019: Dynamics of simulated high-shear low-CAPE tornadic supercells. 18th Conference on Mesoscale Processes, AMS, 29 July – 1 August 2019, Savannah, GA.
Graham, C. S., and G. M., Lackmann, 2020: Verification of Convection-Allowing NWP in High-Shear, Low-CAPE Environments. 30th Conference on Weather Analysis and Forecasting (WAF)/26th Conference on Numerical Weather Prediction (NWP), AMS, 13-16 January 2020, Boston, MA.
Campbell, T. A., and G. M. Lackmann, 2021: Predictability of High-Shear Low-CAPE Convection with the HREF. 31st Conference on Weather Analysis and Forecasting (WAF)/26th Conference on Numerical Weather Prediction (NWP), AMS, 24-27 January 2021, Houston, TX.

28. What do you plan to do during the next reporting period to accomplish the goals and objectives?

N/A

PRODUCTS

29. Publications, conference papers, and presentations

The main products and presentations are reported under item 27. NCSU defense presentations were also delivered by all 4 graduate students who worked on this project.

30. Technologies or techniques

Development of automated HSLC case identification algorithm, successful implementation of SOM software to HSLC cases.

31. Inventions, patent applications, and/or licenses

N/A

32. Other products

N/A

Attach a separate document if more space is needed for #6-10, or #24-50.

PARTICIPANTS & OTHER COLLABORATING ORGANIZATIONS

33. What individuals have worked on this project?

PIs Matthew D. Parker and Gary M. Lackmann
M.S. students Chase Graham, Trevor Campbell, and Levi Lovell
Ph.D. student Andrew Wade
Undergraduate students Lauren Getker and Hunter Camp (part time May and June 2022)

34. Has there been a change in the active other support of the PD/PI(s) or senior/key personnel since the last reporting period?

No.

35. What other organizations have been involved as partners?

We have received assistance from personnel at the NOAA/NWS Storm Prediction Center (SPC) and have met with personnel from the NOAA/NWS Weather Forecast office in Raleigh, NC. Our case-identification work has benefited from input from Dr. Keith Sherburn (NWS), and an initial SOM code was provided by Dr. Maria Molina of NCAR; both have actively supported our work.

36. Have other collaborators or contacts been involved?

Same as item 35.

IMPACT

37. What was the impact on the development of the principal discipline(s) of the project?

It is probably too early to answer this question, but two publications are out, and another is in development. Beyond our NOAA webinar on 7/21/2022, we will remain in contact with our NWS collaborators to amplify and implement our operationally useful outcomes. The studies of tornadogenesis by Levi Lovell and Andy Wade have important warning implications, including highlighting the need for a more dense radar network for HSLC convection.

38. What was the impact on other disciplines?

N/A

39. What was the impact on the development of human resources?

The students supported by this grant have benefited substantially, and two of those who have graduated are now working in NOAA/NWS (Andy Wade at SPC/CIWRO in Norman, OK and Chase Graham at NWS-WFO Louisville, KY).

40. What was the impact on teaching and educational experiences?

Dr. Parker has included new materials from Levi Lovell and Andy Wade in his undergraduate Mesoscale Meteorology course and graduate courses Atmospheric Convection and Mesoscale Dynamics. Dr. Lackmann is incorporating SOM results into his Synoptic Meteorology course.

41. What was the impact on physical, institutional, and information resources that form infrastructure?

The case-identification and SOM algorithms developed for this project are broadly useful in meteorological analysis.

42. What was the impact on technology transfer?

N/A

Attach a separate document if more space is needed for #6-10, or #24-50.

43. What was the impact on society beyond science and technology?

Our hope is that this new knowledge will lead to improved forecasts, warnings, and thus public safety.

44. What percentage of the award’s budget was spent in foreign country(ies)?

0%

CHANGES/PROBLEMS

45. Changes in approach and reasons for change

None.

46. Actual or anticipated problems or delays and actions or plans to resolve them

Funding was originally made available through NCSU in mid-late summer 2017, which was well after the period during which we could recruit incoming August 2017 graduate students for the project. Therefore, the beginning of work was delayed. We ran behind by this amount for most of the project, and the COVID-19 pandemic did nothing to help us catch up. For this reason, we requested no-cost extensions as needed to complete research tasks.

47. Changes that had a significant impact on expenditures

Despite the delays described under item 46, spending allocations closely followed the original budget. Due to much less travel during the COVID-19 pandemic, we were able to rebudget some travel funds toward additional student support.

48. Significant changes in use or care of human subjects, vertebrate animals, biohazards, and/or select agents

None.

49. Change of primary performance site location from that originally proposed

None.

PROJECT OUTCOMES

50. What were the outcomes of the award?

Results from Andy Wade include the following. It appears that the cold pool in the low-CAPE supercells are considerably weaker (due to moister environments and weaker updrafts). This may impact the potential for storm-scale baroclinic generation of horizontal vorticity (negatively), but also the potential for outflow parcels with vertical vorticity to be easily lifted and stretched (positively). Sticknet observations seem to support this finding of weaker cold pools (perhaps only 1-2 K temperature deficits). Notably, much of the baroclinity that is present in these storms is associated with hydrometeor loading, not thermal perturbations.Low-CAPE supercells are not only shallower because of lower environmental equilibrium level (EL) heights. The weak positive buoyancy in these environments is particularly susceptible to entrainment, such that low-CAPE storms have tops that are considerably below their ELs (this is in contrast to high CAPE storms). Strong upward dynamical accelerations in the lowest levels are replaced by strong downward dynamical accelerations in the mid-levels, as air rises above the low-level mesocyclone's pressure minimum. The primary difference in high-CAPE supercells is that there is sufficient positive buoyancy to offset these downward dynamical accelerations (unlike in low-CAPE storms). Intense vortices in low-CAPE supercells are preceded by dramatic intensification of the updraft roughly 1 km above the ground (a similar feature is also seen in the highly-publicized simulations of Leigh Orf). What is distinctive is that the vertical structures of the vortices are amazingly shallow. Air parcels rise up through the vortices from the surface, but stagnate at 1.5-2 km AGL. Indeed, at the time of vortex-genesis, the vertical velocities generally weaken above the 1.5 km level. This explains in part the operational radar detection and warning problem; low-CAPE supercells may have elusively shallow vortex signatures even if neither the tropopause nor cloud tops are unusually low.

Results from Levi Lovell include the following. In simulations of low-CAPE QLCSs, most surface vortices are short-lived and weak, but stronger vortices can occur. These tend to be deeper and longer-lived. Surface vortices are associated with common reflectivity features like gust front cusps, line breaks, and embedded supercells… but so are nulls. Hence, reflectivity features are likely not useful for discriminating high impact from null vortices. Small changes in environmental parameters are statistically significant and do appear to influence QLCS intensity, but these differences are so small that they are probably not of practical use to forecasters. The most distinctive feature of high impact vortices is their superposition of large updraft velocity very close to the ground along with large vertical vorticity very close to the ground. Null vortices tended only to have midlevel updrafts and vorticity. This implies that frequent radar scanning of very low altitudes is likely the best tool available for detection.

Results from Chase Graham demonstrate added value from CAM ensembles in predicting HSLC severe convection, and suggest that lower-threshold UH values, such as 35 m2/s2, may be optimal in the anticipation of HSLC severe weather. His work also highlights the need for reforecasts for future high-resolution ensemble forecast systems.

Results from Trevor Campbell demonstrate the importance of potential instability release in HSLC convection, and confirm that the vast majority of HSLC severe convection takes place in close proximity to a cold front. This suggests that the role of frontal circulations may play a significant role in HSLC convection. By examining upper and lower quartile events, differences in lower-tropospheric wind shear were very modest, while differences in potential instability release and near-surface theta-e advection were much more pronounced.

Attach a separate document if more space is needed for #6-10, or #24-50.

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DEMOGRAPHIC INFORMATION FOR SIGNIFICANT CONTRIBUTORS (VOLUNTARY)	
Gender: ● Male ○ Female ○ Do not wish to provide	Ethnicity: ○ Hispanic or Latina/o ● Not Hispanic or Latina/o ○ Do not wish to provide
Race: ○ American Indian or Alaska Native ○ Asian ○ Black or African American ○ Native Hawaiian or other Pacific Islander ● White ○ Do not wish to provide	Disability Status: ○ Yes ☐ Deaf or serious difficulty hearing ☐ Blind or serious difficulty seeing even when wearing glasses ☐ Serious difficulty walking or climbing stairs ☐ Other serious disability related to a physical, mental, or emotional condition ● No ○ Do not wish to provide

Attach a separate document if more space is needed for #6-10, or #24-50.