16A.3A SYNOPTIC CHARACTERISTICS OF WIDESPREAD SIGNIFICANT SEVERE THUNDERSTORM WIND EVENTS

Andrew R. Wade*
Cooperative Institute for Severe and High-Impact Weather Research and Operations (CIWRO), Norman, OK
NOAA/NWS/NCEP Storm Prediction Center, Norman, OK

Brian J. Squitieri
NOAA/NWS/NCEP Storm Prediction Center, Norman, OK

Israel L. Jirak
NOAA/NWS/NCEP Storm Prediction Center, Norman, OK

1. INTRODUCTION

The National Weather Service Storm Prediction Center (SPC) is moving toward an operationally applicable derecho definition and accompanying quantitative criteria, drawing from and attempting to unify several landmark derecho studies (Squitieri 2024, Squitieri et al. 2025a). This proposed definition emphasizes widespread, verifiable significant severe (33+ m s^{-1}) wind gusts. In keeping with the phenomenological definition in Corfidi et al. (2016), derechos are produced by cold pool-driven, forward-propagating mesoscale convective systems (MCSs). That is, despite the classification of strongly forced squall lines as serial derechos in some past works, the proposed definition would exclude such events.

The primary difference between this set of derechos and the sets used in past climatological and environmental studies is that these derechos are considerably rarer: 71 derechos from 2003–2023 inclusive (3.4 per year), compared to 12.3 per year in Coniglio et al. (2004), 14.2 in Guastini and Bosart (2016), etc. In such past works, particularly Coniglio et al. (2004) and Guastini and Bosart (2016), derechos were found in a wide range of synoptic patterns and flow orientations: ridge, trough, and zonal patterns, and southwesterly, westerly, and northwesterly flow. These span virtually all patterns in which adequate instability and vertical shear for MCS organization might be colocated. It is not clear, however, whether restricting derechos to a rarer and more intense subset of MCS wind events might also narrow the range of synoptic settings that support them. Furthermore, despite their omission from the proposed derecho definition on phenomenological grounds, cool-season squall lines can occasionally meet even the strictest criteria for significant severe wind production, with corresponding impacts. We are also interested in how these events fit into the range of synoptic patterns.

*Corresponding author: Andrew R. Wade, andrew.wade@noaa.gov

2. DATA AND METHODS

71 derechos were confirmed in the 2003–2023 period using the algorithmically identified and tracked MCS dataset of Wade et al. (2023), with additional manual quality control of derecho candidates. This matches the period of SPC's surface objective analysis (SFCOA; Bothwell et al. 2002) archive. Another 32 events were identified that met wind-based derecho criteria but were not associated with MCSs moving faster than the environmental mean wind. MCS motion was objectively estimated as the median 15-minute centroid-to-centroid motion, with spatial limitations on the expansion/motion of the

convective line, over the middle two-thirds of MCS life. The environmental mean flow was represented by SFCOA's 0–6-km AGL pressure-weighted mean wind, sampled before the convective line's arrival near the midpoint of the event.

For each event, a 2000 x 2000-km subset of 500-hPa heights centered on the first wind report in the event was extracted from SFCOA. The height field was smoothed using a 7 x 7-gridpoint (40-km grid spacing) mean. The heights, their zonal and meridional first derivatives, and their zonal second derivative were combined into a principal component analysis (e.g., Pearson 1901) using the scikit-learn Python package (Pedregosa et al. 2011). The first two principal components (PC1 and PC2), with 37 and 12 percent explained variance respectively, were retained. PC1's physical significance is apparent via its correlations with each of the component fields (Fig. 1): it is a rough proxy for the degree of synoptic amplification or forcing. Low heights (upper left panel; typical of the cool season), large positive zonal gradients (upper right panel; typical of the downstream side of an amplified trough), large negative meridional gradients to the south-southwest of the event (lower left panel; typical of an ejecting speed maximum within a trough upstream), and heights transitioning from convex to concave in the zonal direction (lower right panel; typical of the downstream side of a highly amplified trough) are all associated with small PC1. The opposite features, characteristic of weakly forced warm-season events in modest zonal or northwest flow, are associated with large PC1. PC2 is not so easily conceptualized, but it was retained for its use in separating certain clusters of synoptic patterns, seen in the following section.

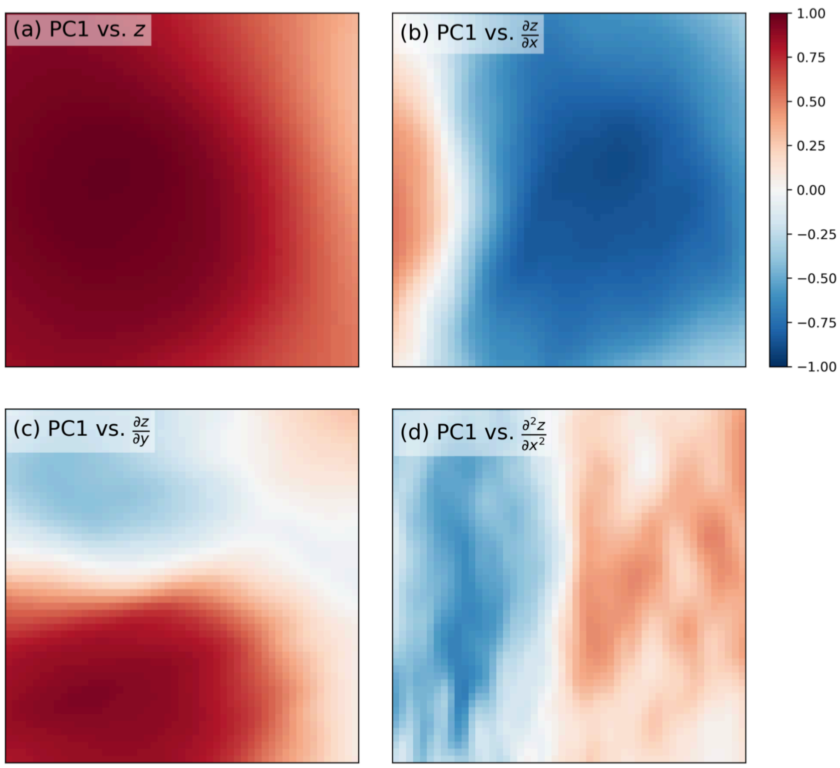

Fig. 1. Correlations of PC1 with (a) 500-hPa heights, (b) the zonal height gradient, (c) the meridional height gradient, and (d) the second zonal derivative of the height field, over a 2000 x 2000-km domain centered on event onset.

Initially, unsupervised techniques such as *k*-means clustering in the PC1-PC2 space were used with varying settings to explore objective clusters of synoptic patterns. This produced up to five clusters with recognizably distinct mean height patterns. However, many cases around cluster borders were classified counterintuitively. To subjectively improve individual classifications, each case was manually labeled as belonging to one of the five objectively identified patterns, and a logistic regression was fitted to the manual labels.

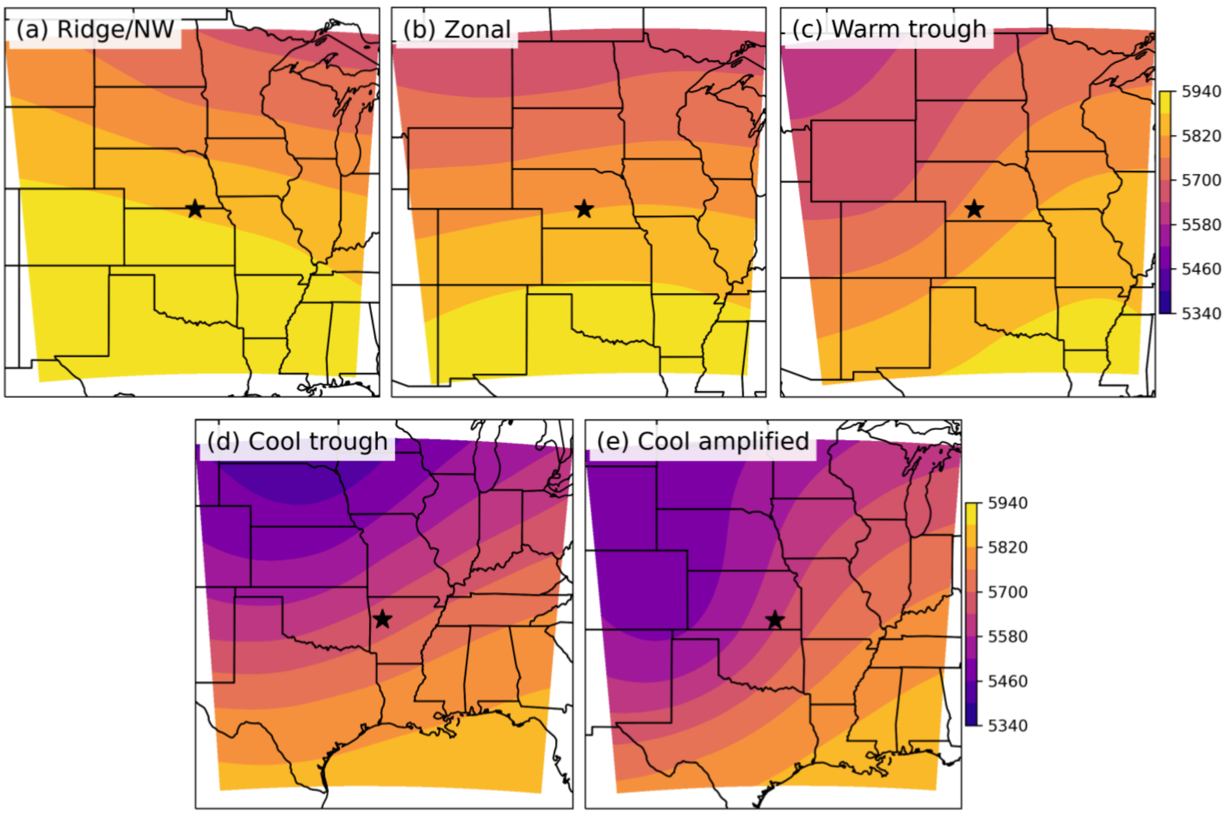

Fig. 2. Mean 500-hPa height fields (m) for each of five clustered synoptic patterns.

3. RESULTS

Mean height fields of the five clusters (Fig. 2), in order of increasing synoptic forcing/decreasing PC1, might be interpreted as (a) northwest flow around a ridge, (b) zonal flow, (c) a moderately amplified warm-season trough, (d) a progressive cool-season trough, and (e) a highly amplified cool-season trough. In the PC1-PC2 space (Fig. 3a), these do not generally follow natural breaks; rather, there is a more or less continuous spectrum of synoptic forcing/amplification associated with derecho-level wind events, and classifications at the edges of clusters are often debatable. Nevertheless, the directionality and especially the seasonality (Fig. 3b) of that spectrum are clear, from strongly synoptically driven cool-season events to weakly forced warm-season events. True derechos by the proposed definition, those produced by forward-propagating MCSs, tend heavily toward the latter end of the spectrum (Fig. 4).

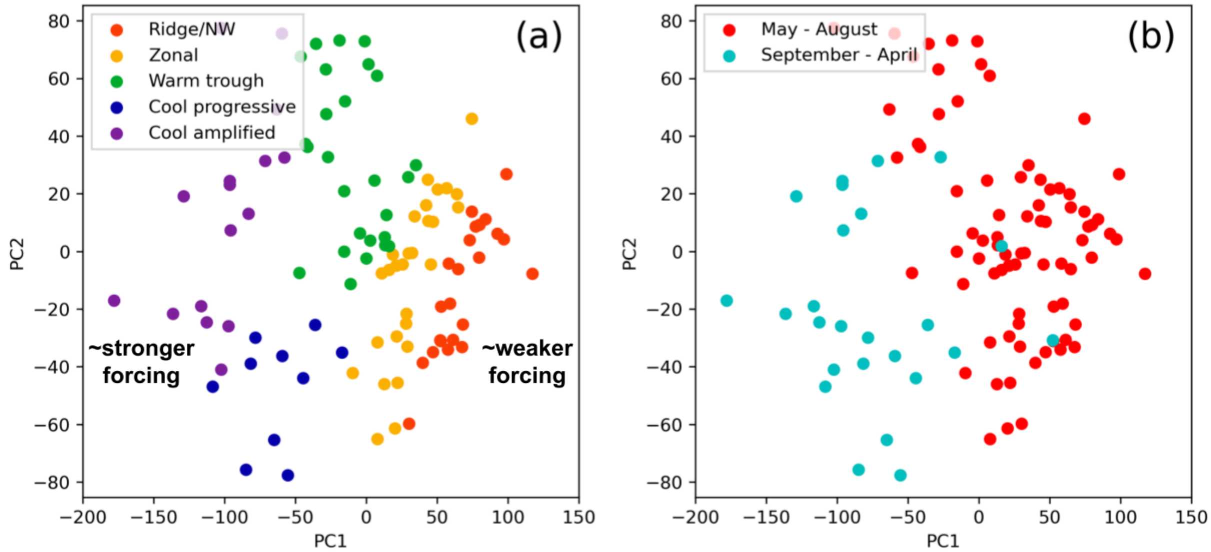

Fig. 3. (a) Synoptic patterns and (b) seasons of all 103 events meeting wind-based criteria for derechos, in the two-dimensional PC1–PC2 space.

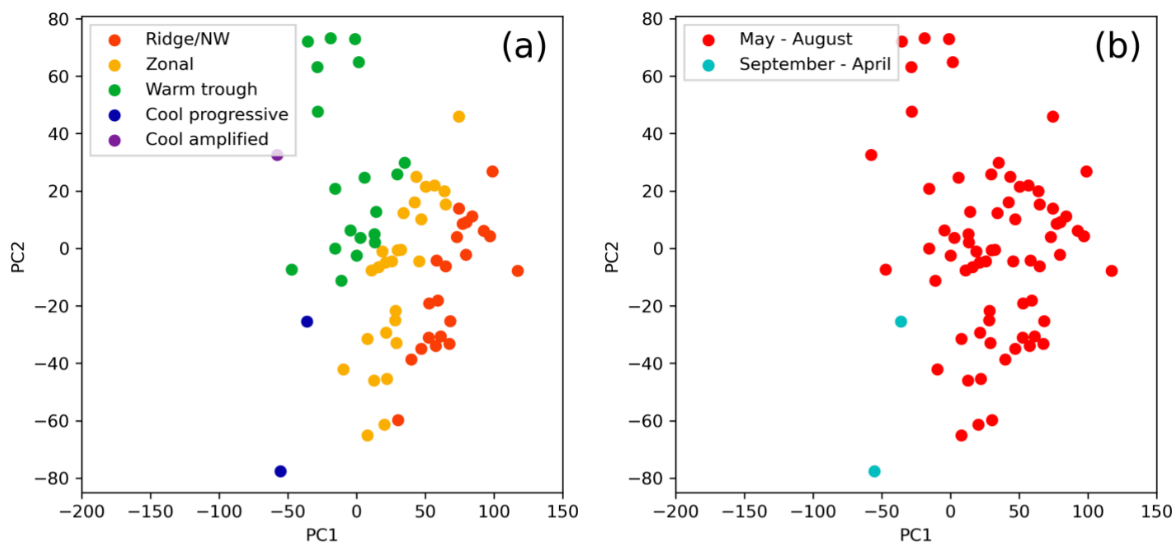

Fig. 4. As in Fig. 3, but for derechos only, i.e., the 71 events associated with forward-propagating MCSs.

Geographically, tracks of many cool-season events cluster rather tightly, moving northeastward from origins around the Arklatex and Southern Plains (Fig. 5). This cluster vanishes when forward-propagating MCSs are required (Fig. 6), leaving three apparent geographic regimes for derechos. The classical Corn Belt–Midwest corridor experiences many derechos, some with very long paths, in northwest and zonal flow. The Southern Plains maximum, while somewhat more localized, hosts a variety of patterns; large north-to-south components of motion are more common there than elsewhere. The Northern Plains–Upper Midwest regime experiences more warm-season trough-associated derechos than most other areas and, curiously, recorded no ridge/northwest flow derechos in the study period.

4. CONCLUSIONS

Enforcing higher criteria for significant severe wind to obtain a rarer, more intense set of derechos does *not* limit the range of their synoptic settings. Numerous derechos occur in ridging/northwest flow patterns, in zonal flow, and downstream of warm-season troughs. Comparable wind events with strong external forcing, generally in the cool season, occur downstream of large-scale troughs of varying amplitude.

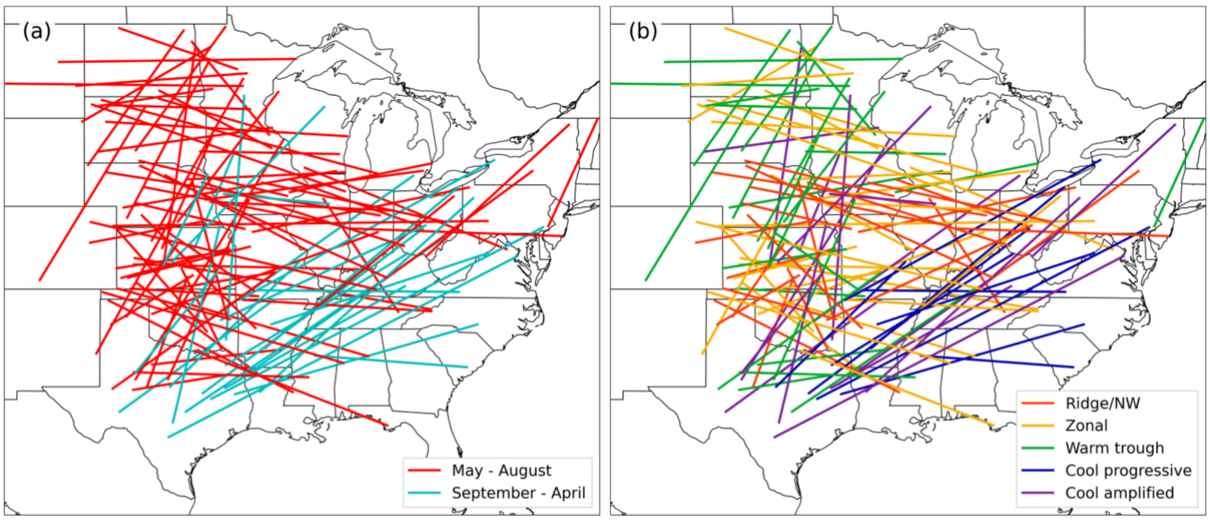

Fig. 5. Tracks of the 103 events meeting wind-based derecho criteria by (a) synoptic pattern and (b) season. Tracks were defined as the longest line transecting the convex hull of wind reports and oriented within 30 degrees of MCS motion.

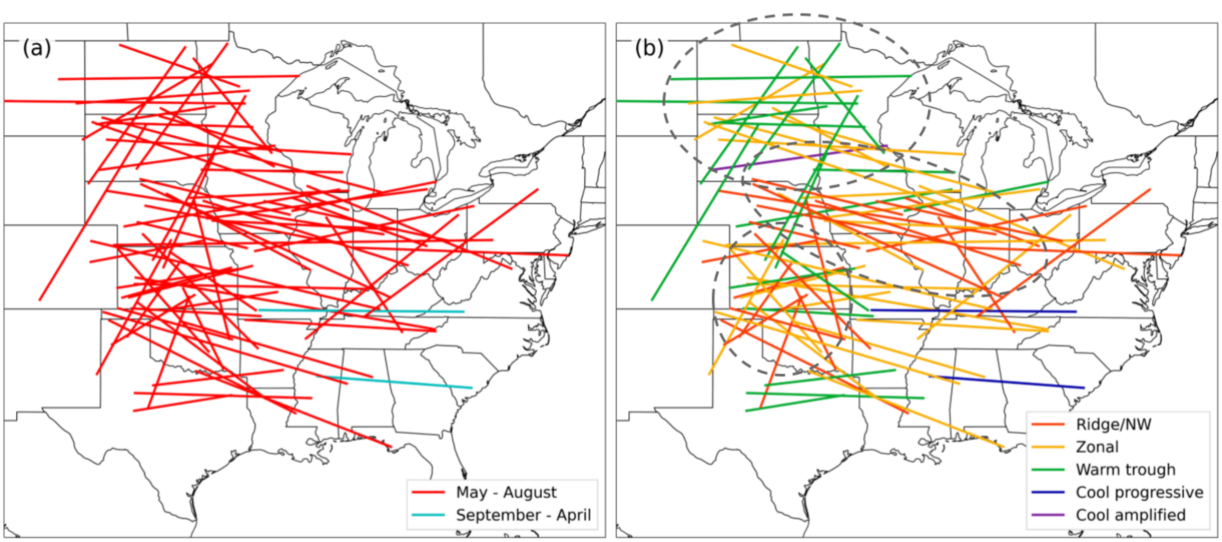

Fig. 6. As in Fig. 5, but for derechos only, i.e., the 71 events associated with forward-propagating MCSs. Suggested geographic regimes are indicated with dashed ovals.

While archetypal progressive derechos and wintertime squall lines mark opposite ends of a spectrum, there is not necessarily a clear break between them, but a continuous range of moderate synoptic forcing/amplification and of MCSs' forward propagation relative to the mean wind. There are three rough geographic regions with different distributions of synoptic patterns for derechos: the Corn Belt–Midwest, the Southern Plains, and the Northern Plains–Upper Midwest.

Ongoing work is using these synoptic stratifications to compare mesoscale inflow environments of derecho-producing MCSs to those of weaker MCSs in similar patterns. Ultimately, relationships among synoptic patterns, inflow parameters, and MCSs' production of significant severe wind are intended to inform modeling and forecasting of conditional wind intensity (Jirak et al. 2024) at SPC.

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