The Effects of Vertical Wind Profiles on Derecho Producing Mesoscale Convective Systems

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Introduction & Background

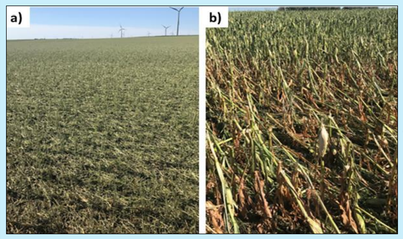


Figure 1: Both damage photos (a and b) from Aug. 10, 2020. A is soybeans and b is corn, both ripped from the ground by severe winds (Squitieri et al. 2023a)

Derechos are a major windstorm caused by a series of destructive downbursts associated with a mesoscale convective system (MCS). These storms can cause billions of dollars in damage to the regions they propagate over, with the Aug. 10, 2020, causing $11 billion in damage (Bell et al. 2022; Squitieri et al. 2023a).

After a 100-year hiatus in derecho research, Dr. Robert Johns and Dr. William Hirt wrote the original definition and criteria for a derecho based on consecutive severe wind gusts (50kts). The research discussed here focuses on high-end derechos with hurricane force winds (64kts). This is stricter criteria than Johns and Hirt 1987 and the current classification criteria proposed by Corfidi et al. in 2016, (This research's full criteria is listed in 'Additional Information' [a]).

There is currently discourse about how derecho producing mesoscale convective systems (DMCS) are able to maintain their intensity:

- RKW: Interactions between the cold pool, 0-3 km shear, and updrafts combine to create DMCSs (Rotunno et al. 1988) [b].
- Coniglio: Combination of high atmospheric instability and strong vertical wind shear, with a cold pool and feedback loop present (Coniglio et al. 2004).

The discourse above leads to our hypothesis:

- Stronger mid-level shear and faster propagation tilt updrafts up-shear, promoting front-to-rear flow and enhancing hydrometeor-rear inflow jet interaction, increasing latent cooling (Squitieri et al. 2023b). This leads to more intense downdrafts, strengthening the cold pool and increasing surface wind intensity.

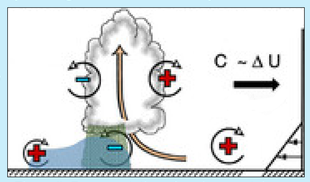


Figure 2: Representation of environmental vorticity balancing the updraft. (Rotunno et al. 1988)

Methods

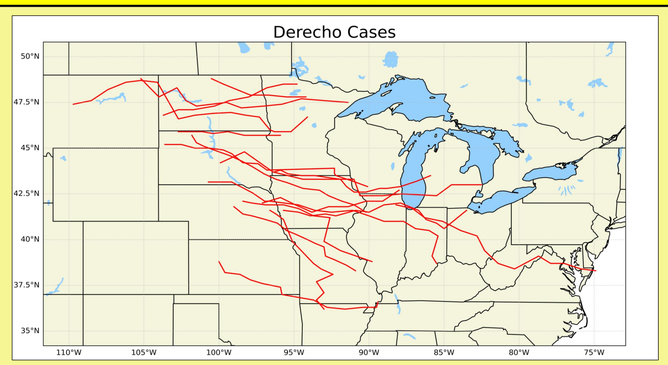


Figure 3: Paths of the DMCSs on a latitude/longitude map of the United States, highlighting region of interest.

- Dataset focuses on cold-pool driven MCSs in weakly forced environments (progressive derechos) in the Midwest US.
- DMCS and Null cases (NDMCS) from 2000-2022 were selected.[d]
- Analysis done at hourly increments for each individual case with SPC objective reanalysis data just ahead of MCS apex.
- Storm motion calculated using the Corfidi down shear vector, which adds low-level wind to the mean wind.[e]

Results

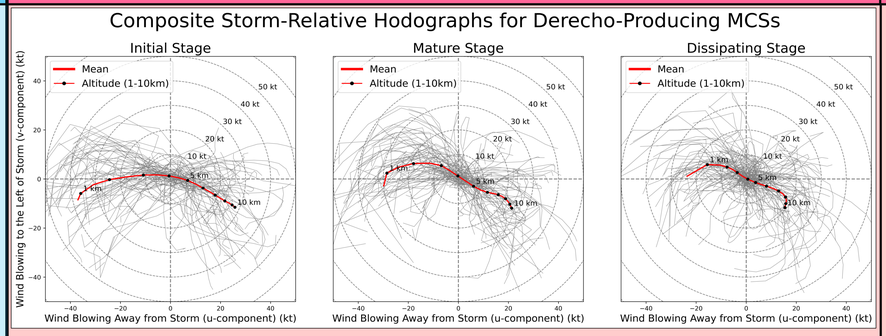


Figure 4: Hodographs during the lifecycle of DMCSs. Grey lines are individual cases from the dataset.

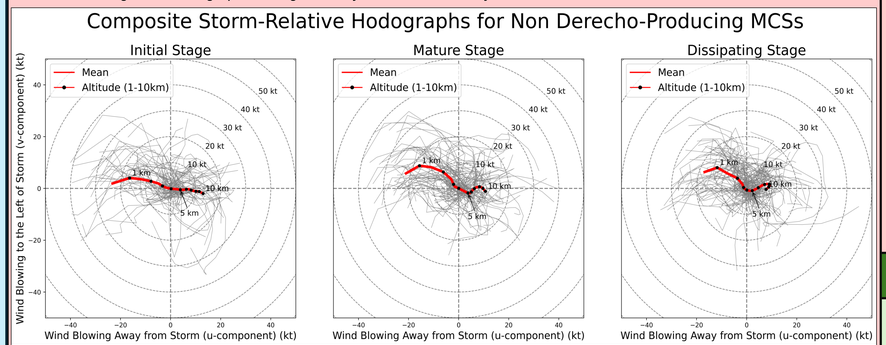


Figure 5: Hodographs during the lifecycle of NDMCSs. Grey lines are individual cases from the dataset.

- Substantial elongation of the mean profile above 5km in the DMCS cases.
- Mean profile of NDMCS cases exhibited weaker winds above 5km.
- This suggests DMCS profiles are characterized by stronger speed shear in the upper-levels.
- The difference appears strongest during the initial stage.

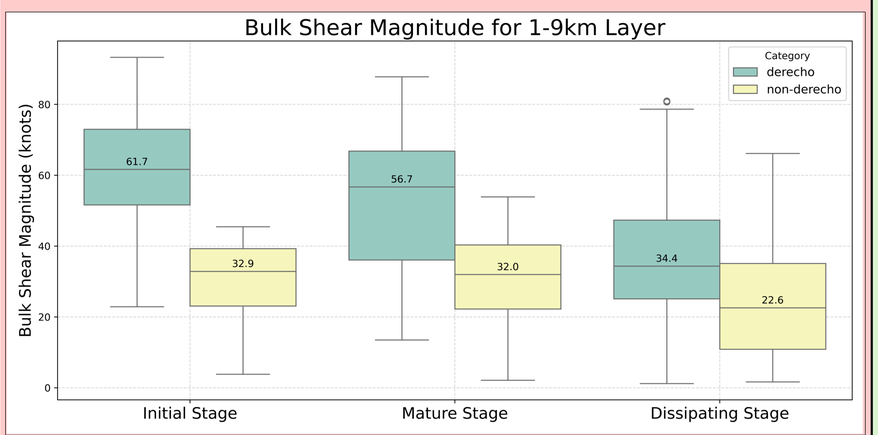
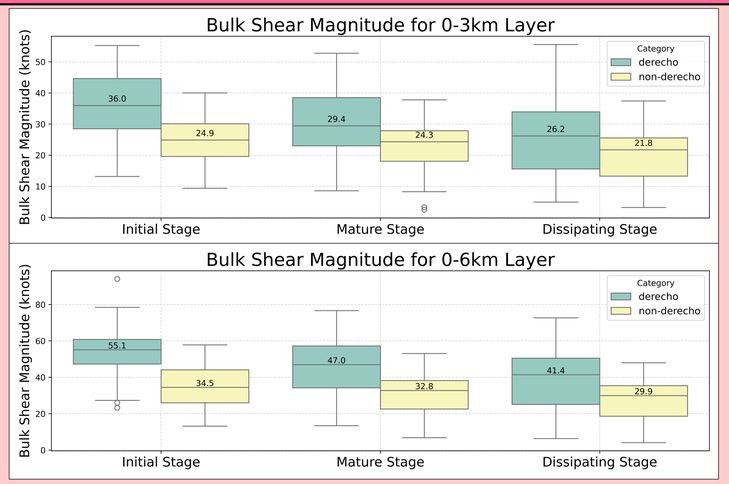


Figure 6: Median Bulk Shear in the 1-9km layer during the three stages of an MCSs lifecycle.

- The 1-9km bulk shear magnitude demonstrates the differences in upper-level winds particularly well.[f]
- The data is distributed in a relatively normal fashion.
- A **p-value of $1.65 \cdot 10^{-5}$** indicates the relationship is unlikely to be coincidental.
- A **correlation coefficient of 0.5267** indicates the relationship is moderately strong.
- A **t-test value of 12.604** indicates a significant difference in mean values.
- Differences are largest at the initial stage and values converge with time.

Results (Continued)



Figures 7 & 8: Median bulk shear magnitude for MCS lifecycles.

- Differences in other layers affirm previous studies.
- The 0-3km bulk shear demonstrates the importance of RKW balance.
- The 0-6km bulk shear agrees with Coniglio's findings.

Conclusions & Future Work

- Significant differences in upper-level winds suggest low-level shear is not the only factor for DMCS maintenance.
- Results align with our hypothesis with upper-level winds affecting downdraft and surface wind strength
- Environment similarities between DMCS and NDMCS environments confirm significance of upper-level winds.
- Correlation is strongest at initial stage, where upper-level winds are likely environmental



Figure 9: Photo of the derecho from July 5, 2022, which tracked from South Dakota to Indiana. (Photo: Parker Alvstad)

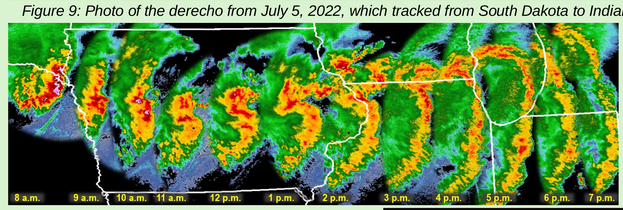


Figure 10: Radar lapse of the Aug. 10, 2020, derecho. Times are in CDT. (NWS Chicago)

Future Work

- Study thermodynamic effects on DMCS maintenance.
- Research climate oscillations to check for correlations with derecho intensity and frequency.
- Study ensemble relationship between multiple factors.

Additional Information