An Investigation of Radar Signatures and Challenges Associated with Tornadic Storms in Pennsylvania at Distant Radar Ranges

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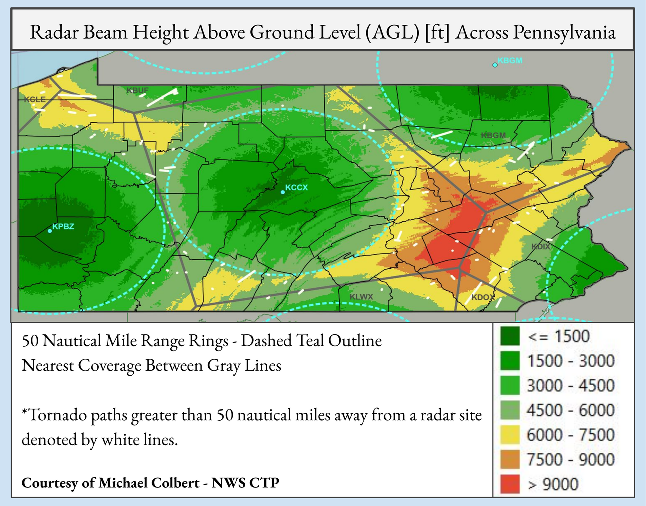
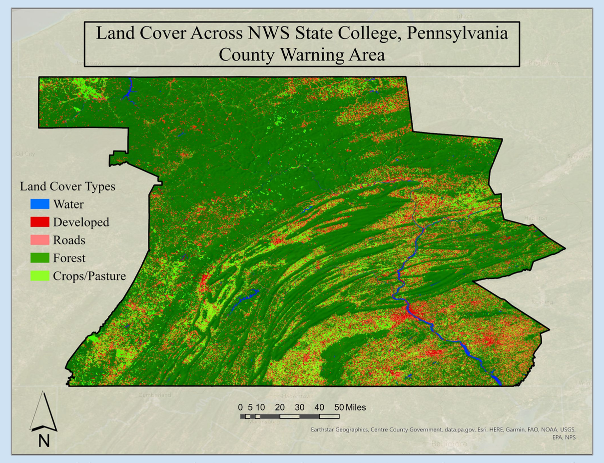
Introduction

In an operational lens, the decision to warn on tornadic storms is dependent on radar characteristics and storm-scale features outlined in national guidance. The distinctive topographic features and severe weather regimes of Pennsylvania, coupled with portions of County Warning Areas (CWA) in spots of poor radar coverage, can cause warning decisions to be rather difficult, especially at far radar ranges. Radar coverage in PA is split amongst 8 different radar sites. Tornadoes are often shallow and short-lived and a majority of reported tornadoes do not have an associated Tornadic Debris Signature (TDS). In an effort to address these concerns, a ten year dataset of confirmed tornadoes greater than 50 nautical miles from the nearest radar site was analyzed to propose a curated warning guidance unique to Pennsylvania tornadoes.



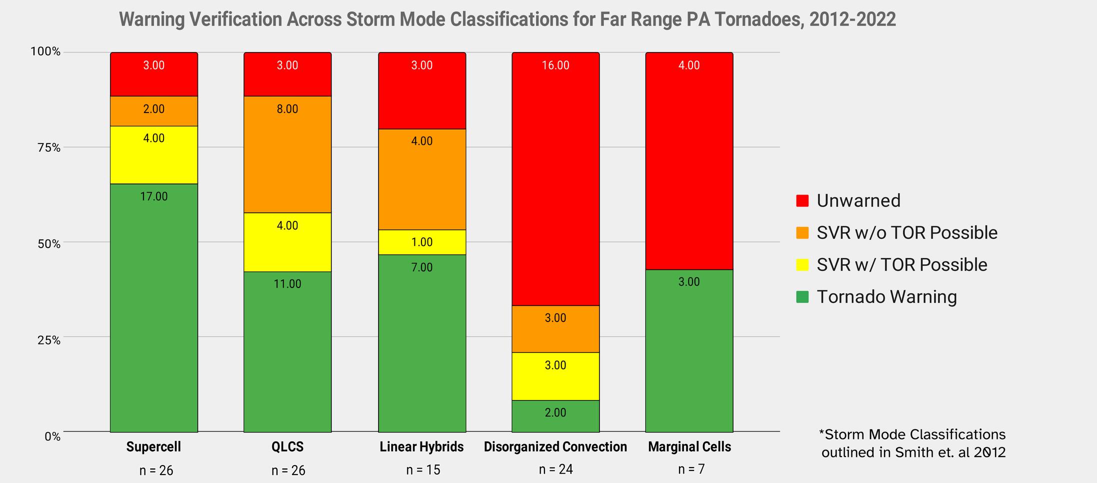


Created by Savannah Southward w/ USGS Landsat 8 ARD Tiles

Important Note: All tornadic circulations studied are from *reported* damage *confirmed* on surveys.

Background

Using criteria outlined by the Warning Decision Training Division (WDTD), we first examined our dataset's warning verification across various storm mode classifications. This provided a baseline for improvements to be later determined in the analysis of each radar case and their respective environmental profiles.



Methodology

With materials from WDTD's Radar Applications Course, radar variables from each case 15 minutes prior to and post reported tornado touchdown were recorded using GR2Analyst. To analyze the environmental conditions, Rapid Refresh (RAP) soundings were examined.

Radar Data — Downloaded WSR-88D data closest to storm via AWS S3 Buckets & analyzed variables in GR2Analyst:

- Mesocyclone Diameter [nm]
- Rotational Velocity (VROT) [kts]
- Azimuthal Shear (AzShear) [k s^{-1}]
- Gate to Gate Shear [kts]
- Normalized Rotation (NROT)
- Range from Radar [nm]
- Beam Height Above Ground Level (AGL) [ft]

Environmental Data — Obtained Rapid Refresh (RAP) Soundings through SHARPpy: Sounding and Hodograph Analysis Toolkit.

Results — Revised thresholds of National Warning Guidance based on calculated statistics from the dataset.

Results

Radar Analysis

Plots generated using the 10th and 90th Percentile

Time Elapsed Prior to and Post Reported Tornado Touchdown vs. Rotational Velocity for Far Range Tornadoes in PA, 2012-2022

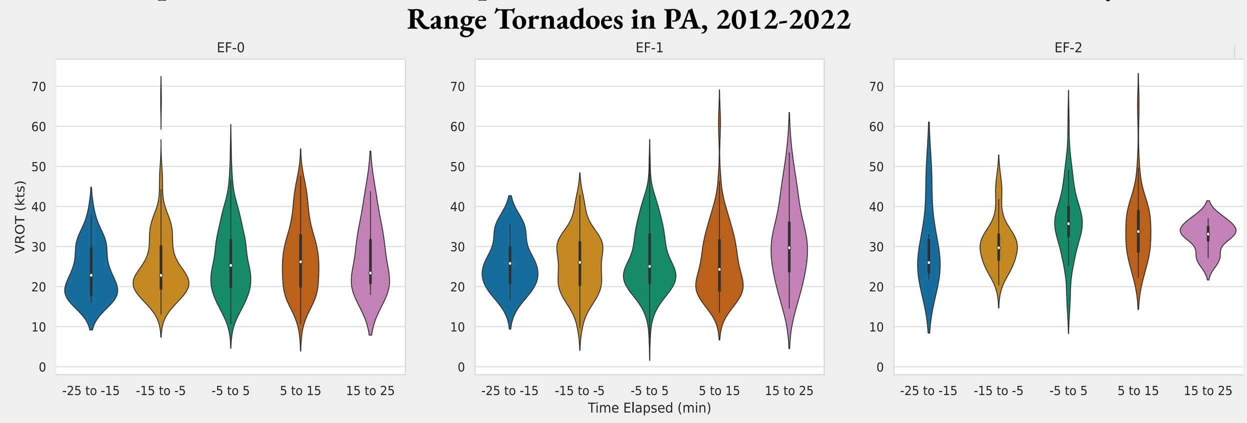


Fig. 1 - Rotational Velocity binned by time before and after tornado touchdown, separated by EF-0, EF-1, and EF-2.

Rotational Velocity Thresholds Across Storm Mode Classification Groups Prior to and Post Reported Tornado Touchdown

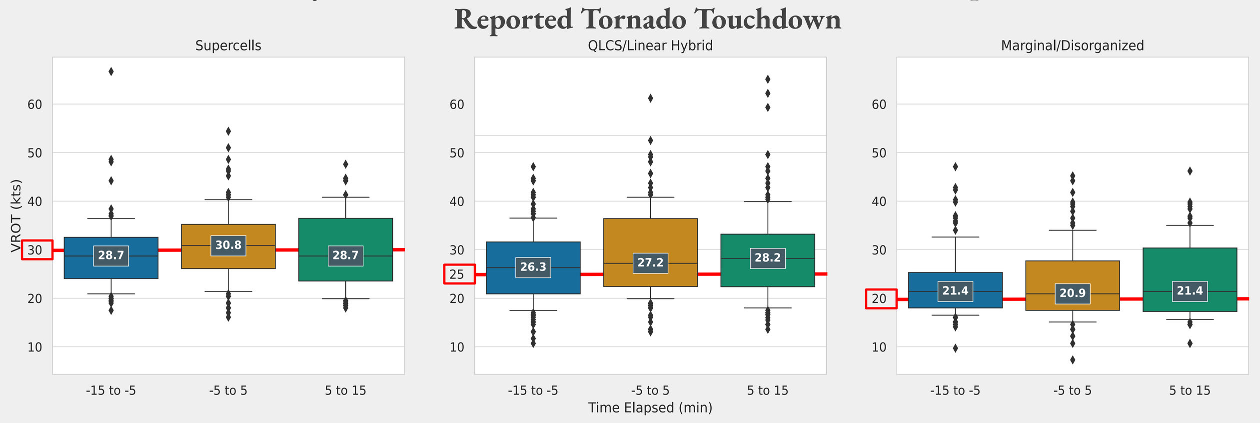


Fig. 2 - Rotational Velocity binned by time before and after tornado touchdown, separated by storm mode classification.

When counting QLCS Event Confidence Builders & Nudgers, suggested warning guidance is as follows:

- 0-1 → SVR
- 1-4 → SVR w/ TOR Possible
- 3+ → TOR

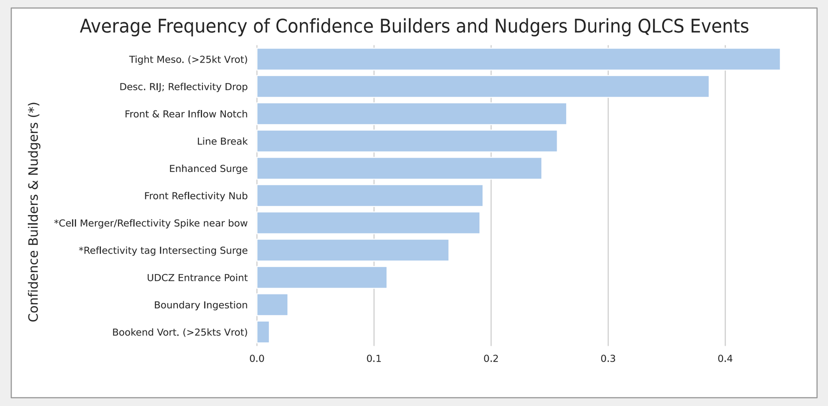


Fig. 3 - Occurrences of QLCS Confidence Builders and Nudgers as outlined by the WDTD.

Radar analysis showed that overall, around 67% of cases had ≥3 Confidence Builders/Nudgers present prior to each reported tornado, with 44% of cases having 4+ present.

- Despite occurrences of Range Folding disrupting criteria based on numeric values, the most frequent and reliable Builders/Nudgers point towards the *Tight Mesocyclone and Descending Rear Inflow Jet*.

Environmental Analysis

Plots generated using the 10th and 90th Percentile (Whiskers).
Median and Mean values are represented by the line and square within the box, respectively.

Supercells

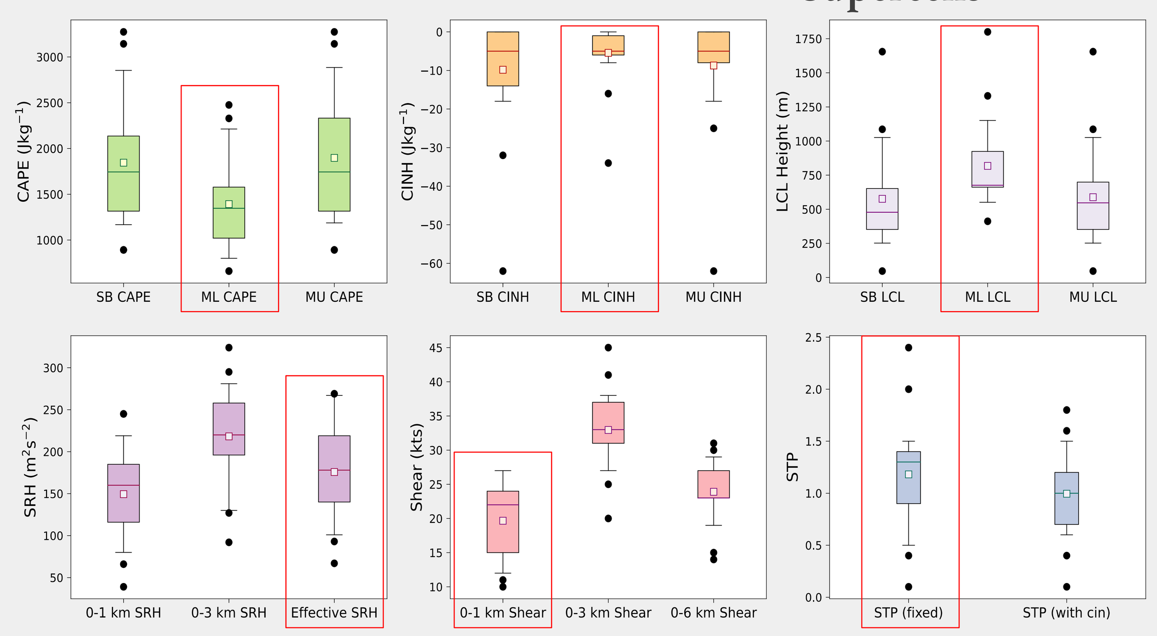


Fig. 4 - Box and Whisker plots of Supercell environmental parameters obtained from nearest RAP reanalysis sounding site.

Preferred - 50th Percentile:

<u>ML CAPE</u>
- Preferred Value: >1500 J kg^{-1}
- Dataset Value: >1400 J kg^{-1}

<u>ML CINH</u>
- Preferred Value: <-50 J kg^{-1}
- Dataset Value: <-5 J kg^{-1}

<u>ML LCL</u>
- Preferred Value: <1000 m
- Dataset Value: <700 m

<u>Effective SRH</u>
- Preferred Value: >150 m^2s^{-2}
- Dataset Value: >175 m^2s^{-2}

<u>0-1 km Shear</u>
- Preferred Value: >20 kts
- Dataset Value: >23 kts

<u>STP (fixed)</u>
- Preferred Value: >1
- Dataset Value: >1.35

QLCS & Linear Hybrid

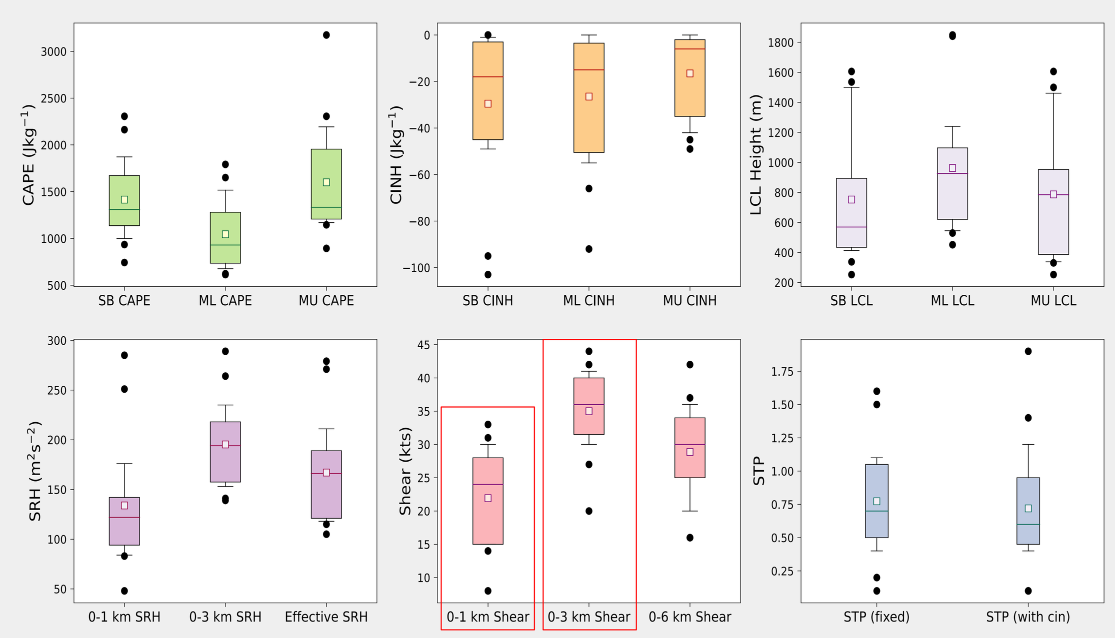


Fig. 5 - Box and Whisker plots of QLCS & Linear Hybrid environmental parameters obtained from nearest RAP reanalysis soundings site.

<u>0-1 km Shear</u>
- Preferred Value: >25 kts
- Dataset Value: >**23 kts**

<u>0-3 km Shear</u>
- Preferred Value: >30 kts
- Dataset Value: >**35 kts**

Marginal & Disorganized

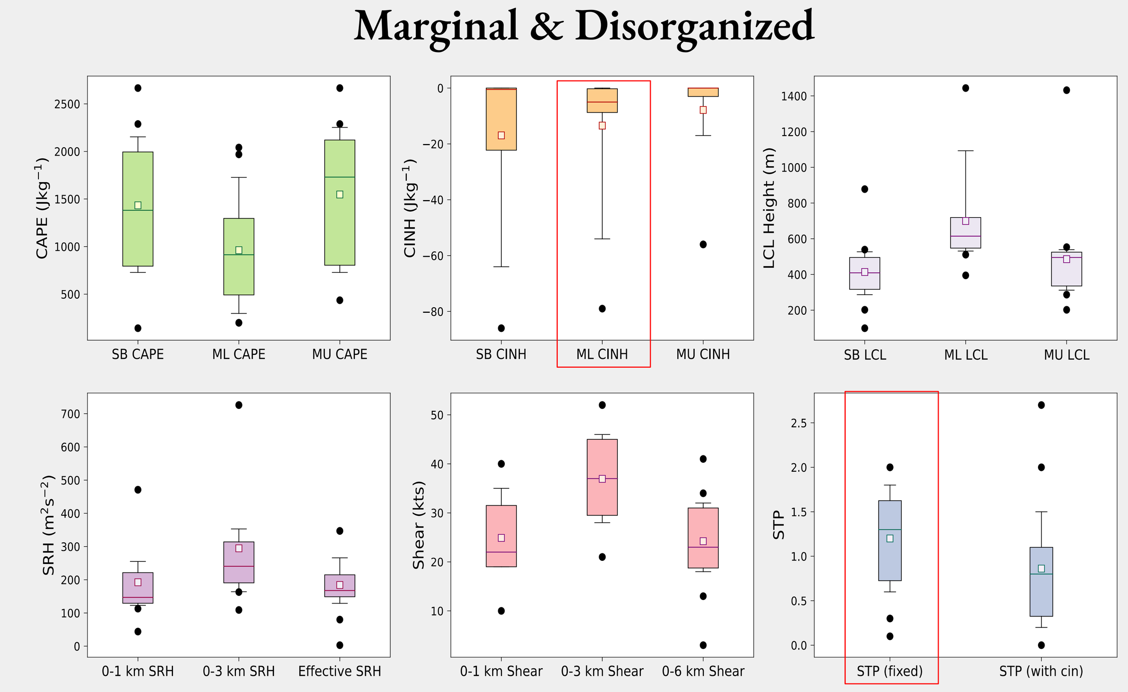


Fig. 5 - Box and Whisker plots of Marginal & Disorganized environmental parameters obtained from nearest RAP reanalysis soundings site.

<u>ML CINH</u>
- Preferred Value: < -25 J kg^{-1}
- Dataset Value: < **-10 J kg^{-1}**

<u>STP (fixed)</u>
- Preferred Value: >1
- Dataset Value: >**1.25**

Discussion & Conclusions

- Proposed refinements to warning guidance includes lowering all thresholds across storm mode classifications to ideally catch 75% of tornado occurrences within the far range.
  - Since POD and False Alarm Ratio (FAR) have a direct negative impact on each other, these revisions will cause an uptick in FAR.
    - However, this project is dedicated towards increasing the POD.
- Other radar variables such as Azimuthal Shear and Gate to Gate Shear were examined, but were not discussed in this presentation due to no criteria outlined within WDTD guidance.
  - Further discussion will be necessary to determine if those thresholds are beneficial to forecasters during the warning process.

Recommendations

Based on the 25th Percentile from the Far Range Dataset

Supercells
- VROT: >**25 kts**
- ML CAPE: >**1000 J kg^{-1}**
- ML CINH: <**-5 J kg^{-1}**
- ML LCL: <**900 m**
- Effect. SRH: >**145 m^2s^{-2}**
- 0-1 km Shear: >**15 kts**
- STP (fixed): >**0.90**

QLCS/Linear Hybrids
- VROT: >**22 kts**
- 0-1 km Shear: >**15 kts**
- 0-3 km Shear: >**32 kts**
- Total Number of
- Confidence Builders & Nudgers*:
  - **0-1 → SVR**
  - **1-2 → SVR w// TOR Possible**
  - **3+ → TOR**

**If environment is favorable*

Marginal/Disorganized
- VROT: >**17 kts**
- ML CINH: <**-10 J kg^{-1}**
- STP (fixed): >**0.75**

Disclaimer: These refinements <u>do not</u> take False Alarm Cases into account.

Acknowledgements

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