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

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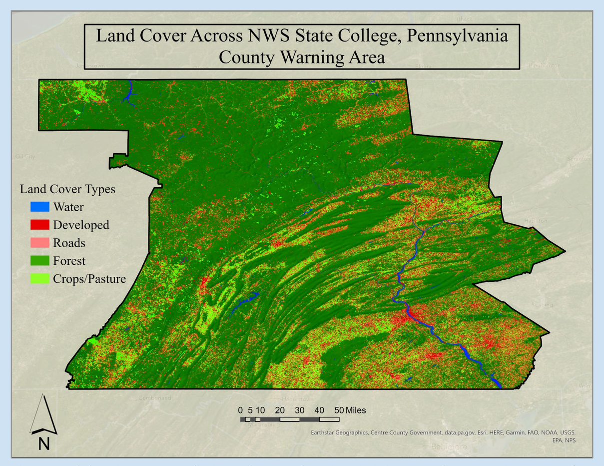
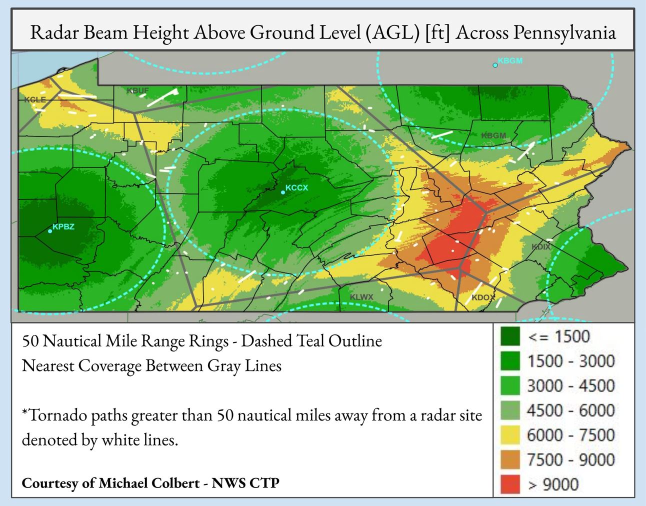
Introduction

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 the state in spots of limited low-level 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 curated warning guidance unique to Pennsylvania tornadoes.



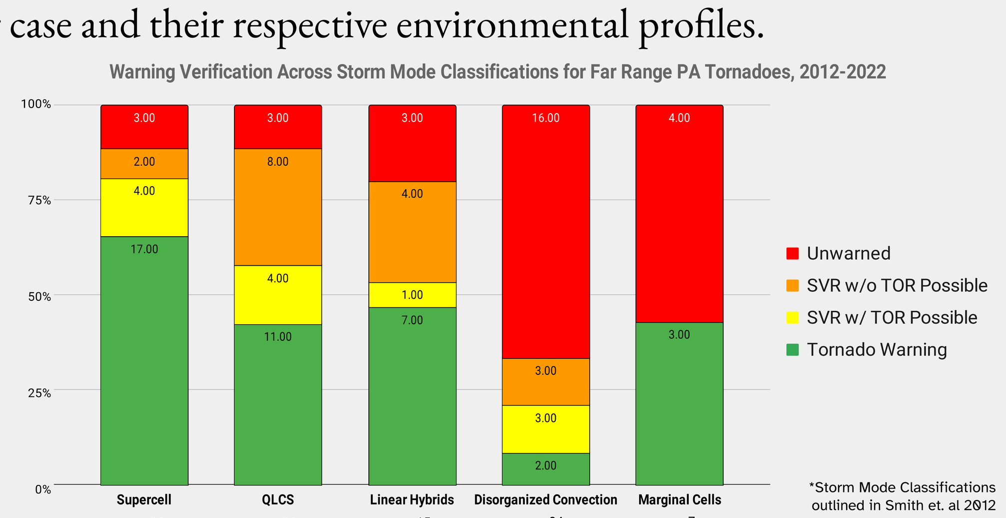
Created by Savannah Southward w/ USGS Landsat 8 ARD Tiles



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

Background

Using tornado warning criteria outlined by the Warning Decision Training Division (WDTD), we first examined our dataset's warning verification across 97 cases with 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 between 15 minutes prior to and 15 minutes after reported tornado touchdown were documented for each case 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

Proposed modifications to warning thresholds based on calculated statistics from the Pennsylvania tornado 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

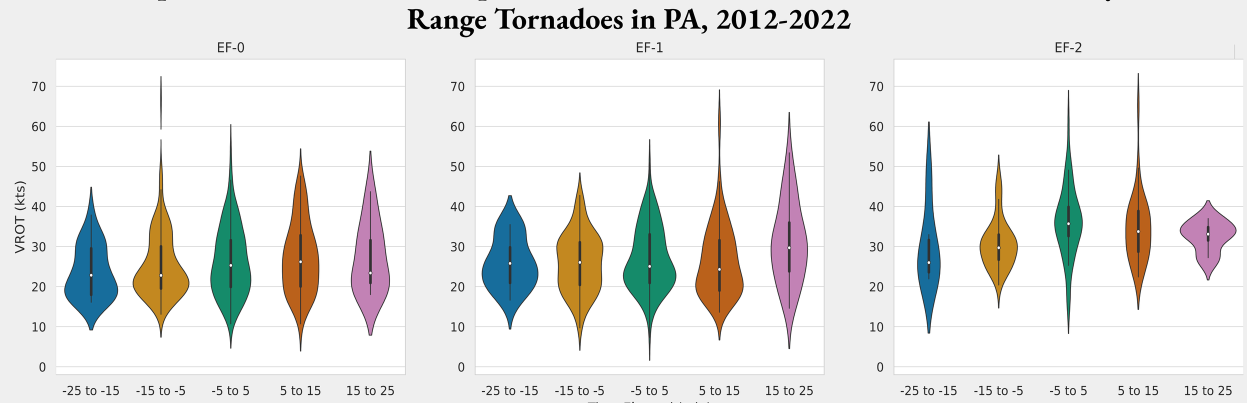


Fig. 1 - Rotational Velocity binned by time before and after tornado touchdown, separated by EF-0, EF-1, and EF-2.

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

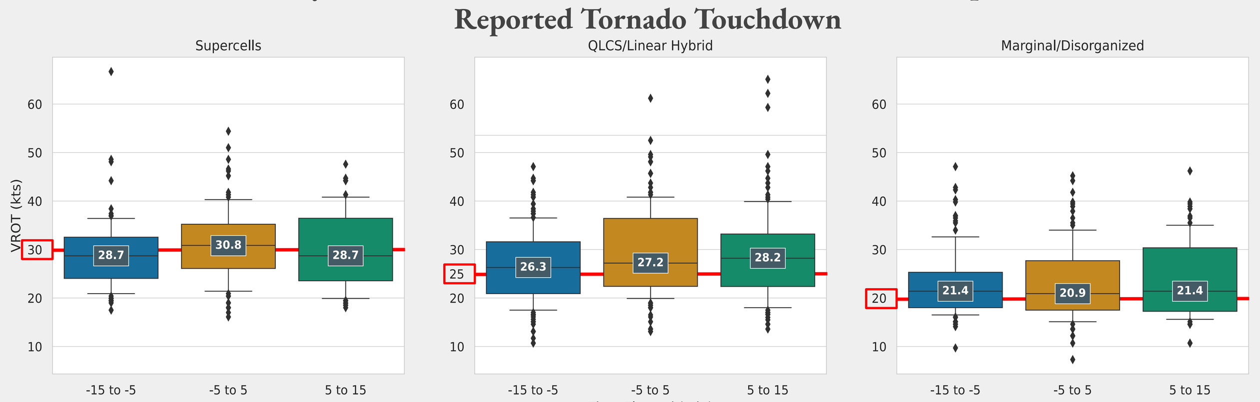


Fig. 2 - Rotational Velocity binned by time before and after tornado touchdown, separated by storm mode classification. **Red lines** denote the baseline WDTD threshold suggested for Tornado Warnings.

When counting QLCS Event Confidence Builders & Nudgers, suggested warning guidance is as follows:
- 0-1 → SVR
- 1-4 → SVR w/ TOR Possible
- 3+ → TOR

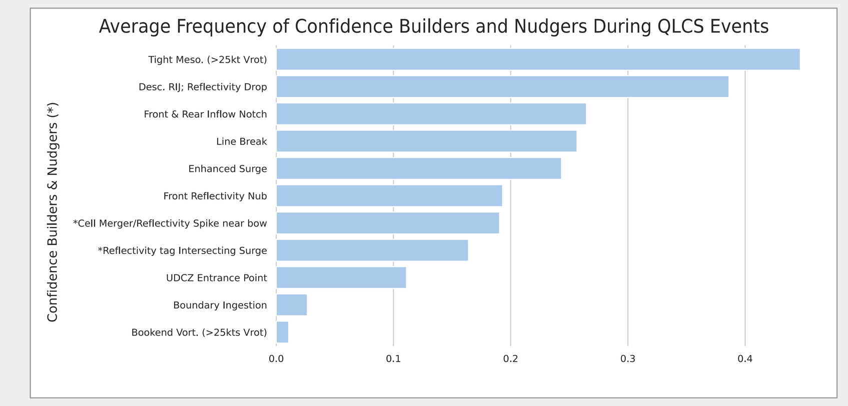


Fig. 3 - Occurrences of QLCS Confidence Builders and Nudgers as outlined by the WDTD.

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.
Preferred Values are denoted in WDTD materials and are directly compared to the 50th percentile values obtained from the analysis.

Supercells

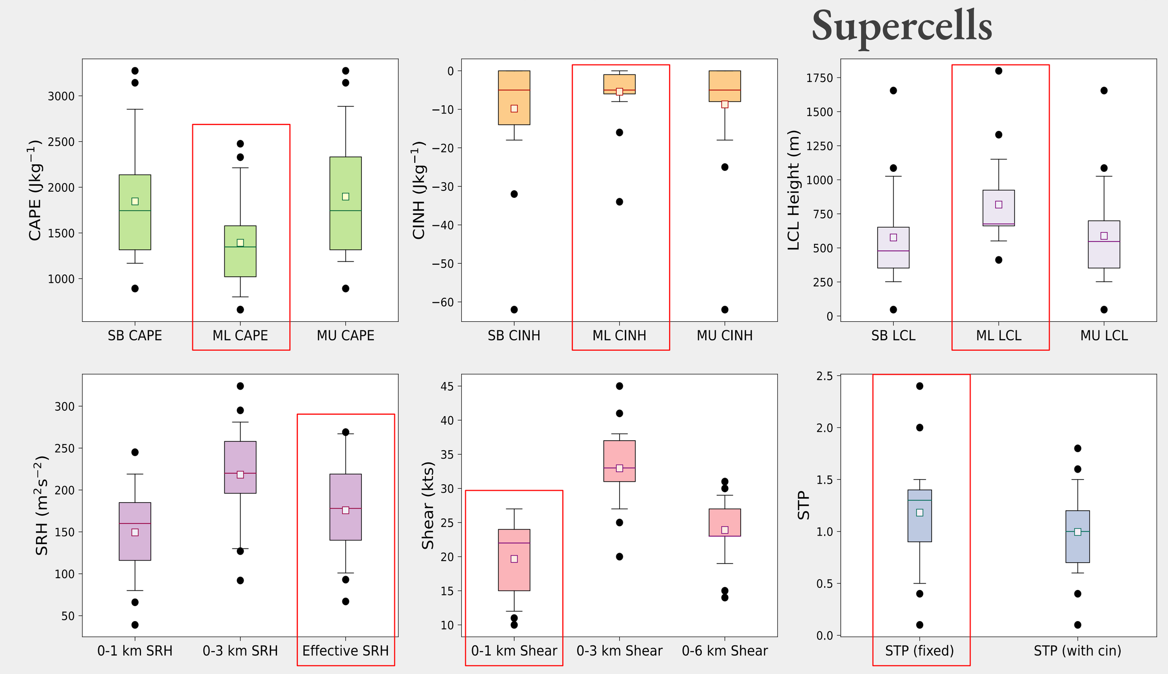


Fig. 4 - Box and Whisker plots of Supercell environmental parameters obtained from nearest RAP reanalysis sounding site.

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

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

ML LCL
- Preferred Value: <1000 m
- Dataset Value: <700 m

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

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

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

QLCS & Linear Hybrid

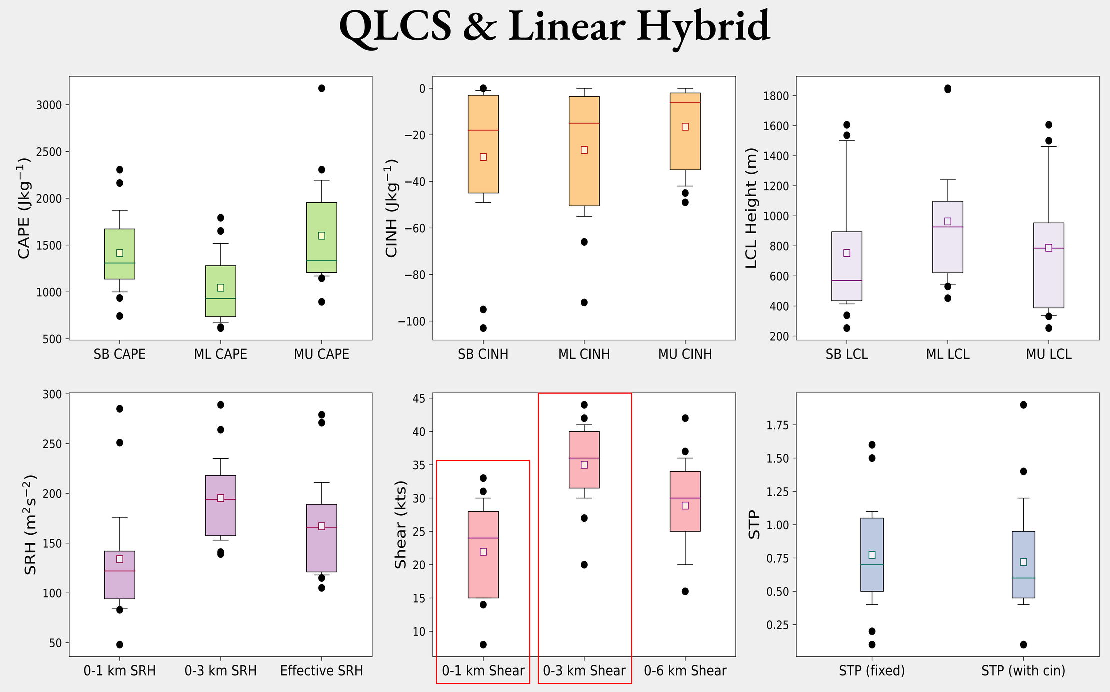


Fig. 5 - Box and Whisker plots of QLCS & Linear Hybrid environmental parameters obtained from nearest RAP reanalysis soundings site.

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

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

Marginal & Disorganized

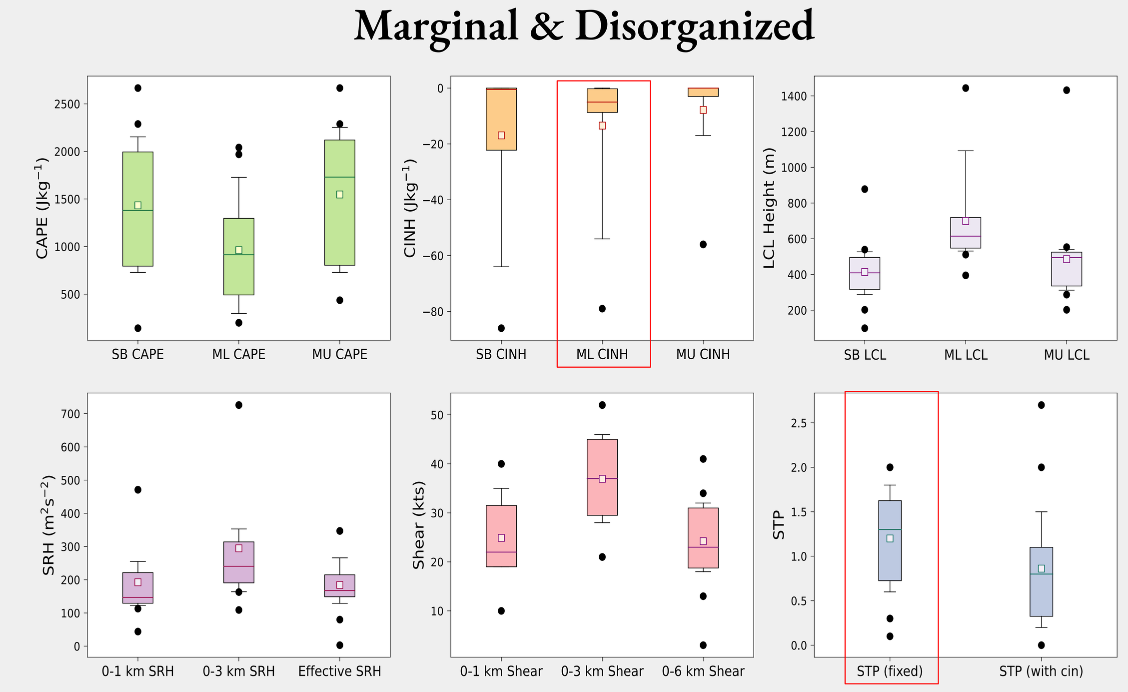


Fig. 5 - Box and Whisker plots of Marginal & Disorganized environmental parameters obtained from nearest RAP reanalysis soundings site.

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

STP (fixed)
- 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.
    - This project is dedicated towards increasing the POD. Another study will have to be conducted to assess the impact on FAR.
- 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 analysis is necessary to determine if those thresholds are beneficial to forecasters in warning ops.

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 do not take False Alarm Cases into account.

Acknowledgements

This project was completed through the NOAA Ernest F. Hollings Undergraduate Scholarship Program. I extend my utmost gratitude to the Hollings Team and my mentors, Michael Colbert & Michael Jurewicz. Thank you to all the staff at NWS CTP for an amazing summer internship!

AMS 2024
AMERICAN METEOROLOGICAL SOCIETY
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