Tornado events, fatalities, injuries, and property damage related to NEXRAD radar coverage in the era of polygon warnings

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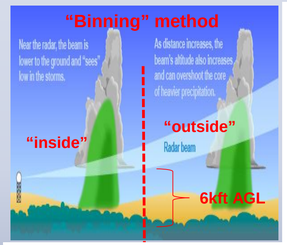
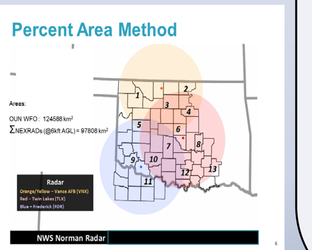
How does NWS warning performance vary with radar coverage? Evaluate NWS tornado warning-polygon performance in terms of 2008-2016 NEXRAD network coverage of warned/unwarned events, injury- and fatal-events, and property damage.

Method

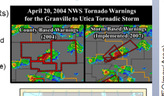
Two radar coverage methods are applied. (1) Partition 12296 events warned/unwarned inside range implied by NEXRAD bottom-of-the-beam (b-o-b) height of 6 kft AGL ("binning"). (2) Compute percent area coverage per WFO under 6 kft b-o-b height ("area"). Both include beam clutter and obstruction at each radar site.



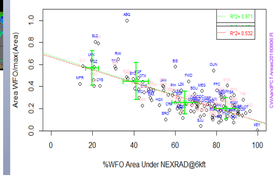


Dataset – Local Storm Reports

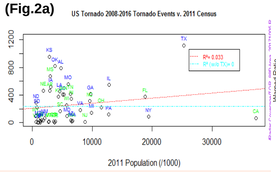
- NWS Local Storm Reports (LSRs) 2006-2016+
  - 2008 - adoption in of warning "polygons" (replacing county-sized areas)
  - Over 12000 TOR events (2006-2016; 2006-2007 used old F-scale)
  - Over 30,000 FF events (2008-2016)
- NEXRAD (N=134) and TDWR (N=45) coverage radii at 6 kft bottom-of-beam range
  - "Shape files" used for each WSR-88D and TDWR site
- NWS 2007-2017 event data
  - Used to analyze TOR and FF partial-event warnings (PEWs)



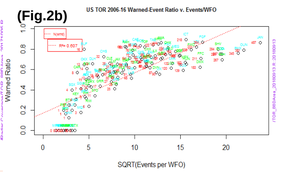
(Fig.1)



(Fig.2a)



(Fig.2b)

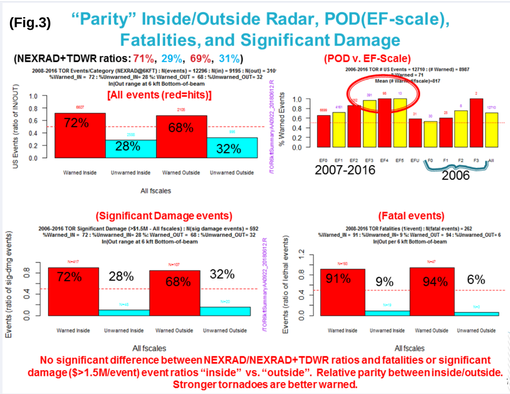


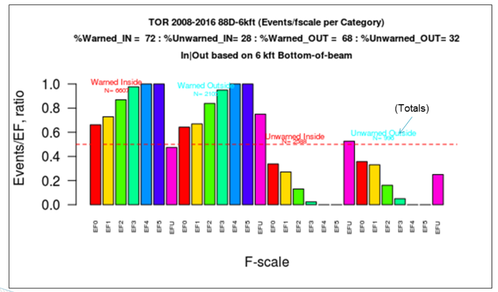
(Fig. 1): Relative size of WFO v. %area covered. Largest WFOs have less coverage. (Fig. 2a) Event counts increases with population (Census 2011), slope is statistically significant. One state (TX) can change the relationship obtained (blue dotted line). (Fig.2b): Warned ratio increases rapidly with number of events (N½).

Abbreviations / Notes:
NEXRAD = Next-Generation Weather Radar
Polygon: event area with vertices conforming to actual feature instead of a county.
Implemented in Oct 2007.
WFO = NWS Weather Forecast Office

I. Tornado event "binning" @6 kft NEXRAD beam height

(Fig.3) "Parity" Inside/Outside Radar, POD(EF-scale), Fatalities, and Significant Damage





(Fig. 4)

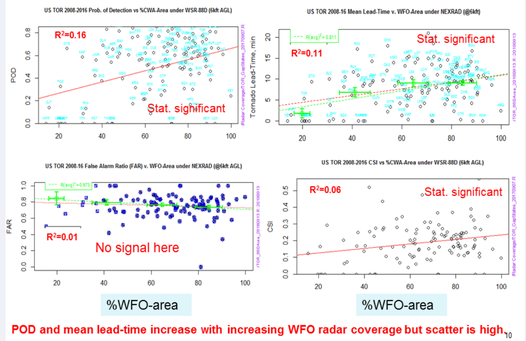
No significant difference between NEXRAD/NEXRAD+TDWR ratios and fatalities or significant damage ($>1.5M/event) event ratios "inside" vs. "outside". Relative parity between inside/outside. Stronger tornadoes are better warned.

Violent tornadoes are warned at higher ratios either inside or outside than weaker ones. Larger counts of EF0s recorded inside than outside.

(Fig. 3): Ratios of warned/unwarned events inside and outside of 6 kft b-o-b range (~ 165 km or ~72% max range). About 75% of all events occur inside. There is parity to within 4% between events warned inside (72%) and outside (68%), and between events unwarned inside (28%) and outside (32%). Fig. 9 in Brotzge and Erickson (2010), *Tornadoes Without NWS Warning,* has 26% unwarned tornado events inside 150 km, 2% less than in (3) above. Likewise, their mean unwarned event ratio between 150-200 km range is about 32%, within 1% of outside/unwarned in (3). Therefore, there is compatibility with tornado warned ratios with distance even though our data is larger and more recent. The binning here counts all events within the prescribed range. There is near parity in the ratios of 592 events with significant damage (>$1.59M mean damage/event) and in 262 fatal events (bottom right). Adding TDWR coverage results in nearly identical ratios ±1%. (Fig. 4): Weak tornadoes (≤ EF2) account for 95% of the total and have smaller warning ratios than intense ones. A few F-scale events after 2006 also have similar warned/unwarned ratios. (EFU = undefined)

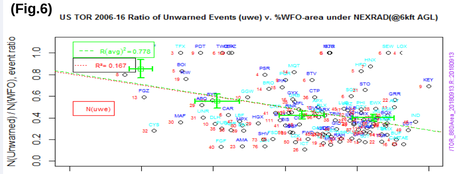
II. Performance metrics v. WFO-area covered by NEXRAD @6kft

(Fig. 5) TOR Performance v. %WFO-area NEXRAD coverage @ 6 kft – POD, lead time, FAR, CSI & v. %area-WFO

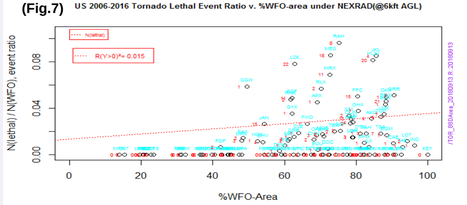


POD and mean lead-time increase with increasing WFO radar coverage but scatter is high.

(Fig.6)

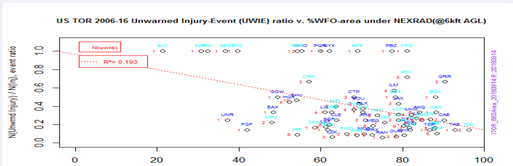


(Fig.7)

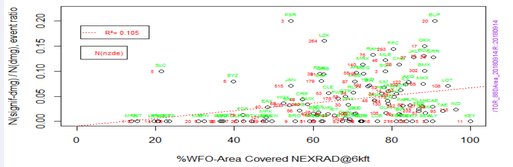


(Fig. 5): Linear fits to traditional performance metrics of probability of detection (POD), lead time, false alarm ratio (FAR), and critical success index (CSI); fits based on quarter-area means (green dotted lines) as in previous studies. Both fits show similar slopes but scatter is not overt in means (giving high R²). FAR fit is not statistically significant. Fits vary as expected but note large scatter. (Fig. 6): Fit to ratio of 3723 unwarned to events/WFO v. area under NEXRAD @6kft is statistically significant (unwarned events increase with coverage, like events v. population). (Fig. 7): Fit to non-zero ratios of lethal (N=271, deaths=1093) to all 12710 events/WFO is not statistically significant (p=0.4). Injury-event ratios increase with coverage like population.

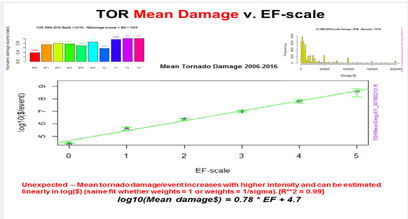
(Fig.8)



(Fig.9)



(Fig.10)



Unexpected – Mean tornado damage/event increases with higher intensity and can be estimated linearly in log($) (same fit whether weights = 1 or weights = 1/sigma). [R^2 = 0.99]
*log10(Mean damage$) = 0.78 * EF + 4.7*

(Fig.8): Linear fit to ratio of 193 unwarned injury-events to 982 WFO injury events has statistically significant slope but low R². (Fig.9): Fit to ratio of 557 significant out of 7078 damage events has statistically significant positive slope but low R². (Fig.10): Tornado-intensity damage model of mean log (damage $)/event v. EF-value is estimated with a log-linear fit. Error bars are "sigmas" of the means. Damage and damage probability (> $0) increase with intensity.

Conclusions

Near parity seen between warned/unwarned events inside and outside of 6 kft AGL bottom-of-beam range and per EF-level to within ±4%, unchanged with added TDWR coverage (to within 1%).

- **POD, lead time, and CSI metrics increase linearly with NEXRAD coverage albeit with high scatter. FAR is insensitive to radar coverage variations.**
- **Unlike unwarned event ratio, slope of fatal-event ratio increases with more coverage but has marginal statistical significance.**
- **Significant damage event ratio increases with more coverage, like injury and lethal event ratios. Mean damage per event can be estimated with log-linear fit. Population may play a role in both damage and fatal event ratios.**
- **There is large scatter in the data causing weak dependence of many metrics on radar coverage. Linear fit represents best-case scenario. Area coverage is not the primary explanation of coverage variation in metrics. Skill is very sensitive to number of events and appears to be the more significant factor.**