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43PM-Wx-0191 **Date: 13 April 2020**

Subject: National Weather Service TDWR Surveys for Tornado and Severe Thunderstorm Warning Guidance

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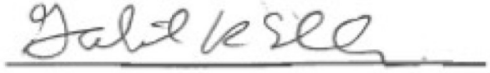
Approved by: 

This material is based upon work supported by the National Oceanic and Atmospheric Administration under Air Force Contract No. FA8702-15-D-0001. Any opinions, findings, conclusions or recommendations expressed in this material are those of the author(s) and do not necessarily reflect the views of the National Oceanic and Atmospheric Administration.

EXECUTIVE SUMMARY

This report offers the full responses from National Weather Service (NWS) forecasters to a pair of questions regarding Terminal Doppler Weather Radar (TDWR) usage in operations: "Do you find that TDWR is regularly used for tornado (severe thunderstorm) warning guidance in your office?" The answers to both questions were a resounding "yes," with near-ubiquitous support for TDWR data in the warning guidance process. A summary of the responses is provided, including the raw responses from each office surveyed.

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1. INTRODUCTION

The National Weather Service (NWS), Federal Aviation Administration (FAA), and Department of Defense (DOD) maintain a fleet of 143 Weather Surveillance Radar-1988 Doppler (WSR-88D) weather radars (Figure 1) and 44 Terminal Doppler Weather Radars (TDWR; Figure 2) across the contiguous United States (CONUS). As part of the Multifunction Phased Array Radar (MPAR) (MPAR; Weber at al. 2007), NextGen Surveillance and Weather Radar Capability (NSWRC) (NSWRC; Cho 2015), and Spectrum Efficient National Surveillance Radar (SENSR) (SENSR; Hondl and Weber 2019) programs, the cost-benefit relationship of additional radars and/or different network designs has been explored several times in the literature (Kurdzo and Palmer 2012; Cho and Kurdzo 2019; Cho and Kurdzo 2020a; Cho and Kurdzo 2020b; Kurdzo and Cho 2020). Since the radar beam both broadens and rises in height above the Earth's surface at farther ranges, one could postulate that additional "gap-filler" radars and/or an optimized network design based on modern population changes and climatology could yield benefit for the Nation.

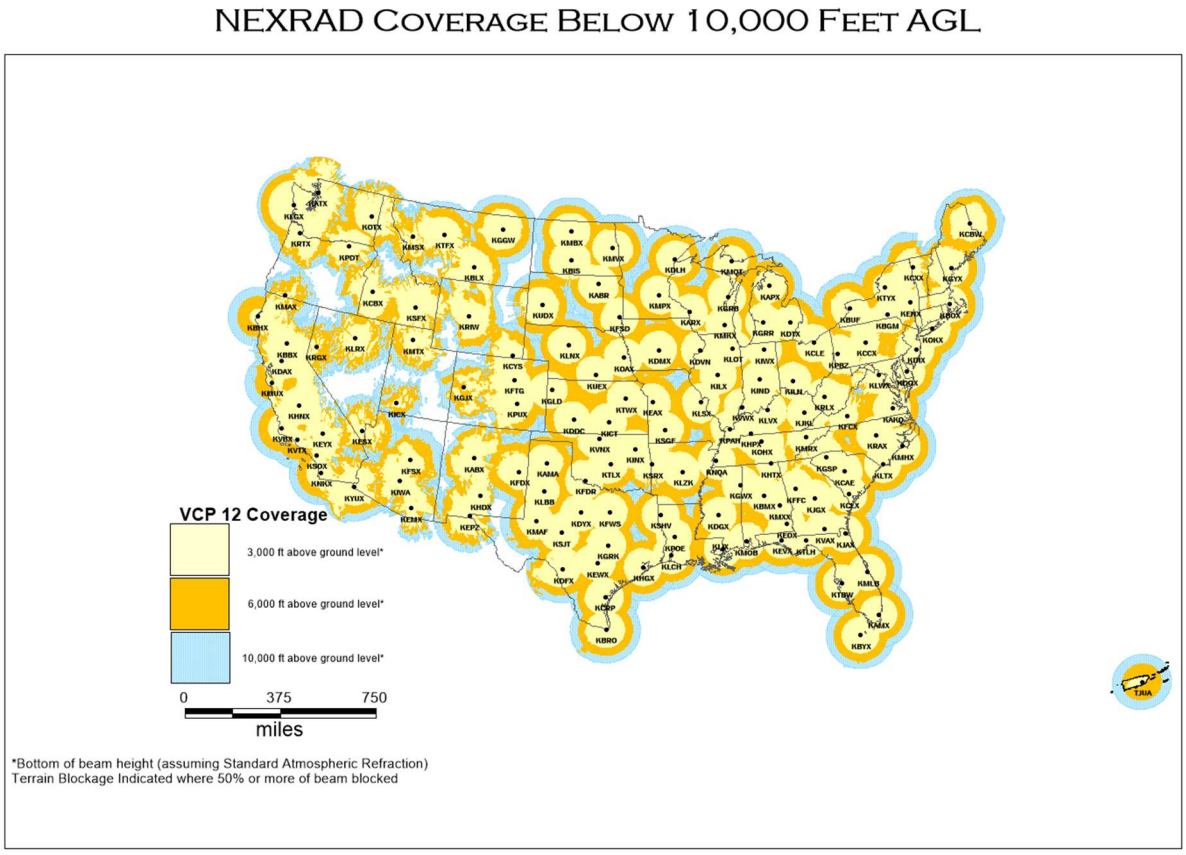

Figure 1: WSR-88D/NEXRAD coverage levels of the lowest beam in Volume Coverage Pattern (VCP) 12 across the CONUS.

In coordination with the SENSR effort, the National Oceanic and Atmospheric Administration (NOAA) National Severe Storms Laboratory (NSSL) tasked the Massachusetts Institute of Technology Lincoln Laboratory (MIT LL) to explore monetized benefits of CONUS radar network possibilities for tornadoes (Cho and Kurdzo 2019), severe thunderstorms (Cho and Kurdzo 2020b), and flash floods (Cho and Kurdzo 2020a). This analysis consisted of utilizing historical data along with the current WSR-88D network laydown in order to determine the monetized benefit of the current network. This benefit was then extended to hypothetical gap-filler exercises that showed where the most available benefit existed for additional radars. In the future, this benefit pool could be used for the planning of an entirely new weather radar network in the United States.

In order to properly determine benefit, we needed to know how useful the TDWR radars were to NWS forecasters and whether or not they should be included in the analysis. We focused on the tornado and severe thunderstorm warning problems, since TDWR is not a dual-polarimetric radar and operates at C band rather than S band, making it less useful for flood guidance. We generated two survey questions and sent the questions to a sampling of 12 NWS weather forecast offices (WFOs) and the NOAA/NWS Storm Prediction Center (SPC).

The summary of the responses is clear: the NWS WFOs see the TDWRs as indispensable for both the tornado and severe thunderstorm warning processes. Of course, many offices in the CONUS do not have a TDWR nearby. The offices queried in the survey that did have a TDWR within range claimed great appreciation for having the TDWR, due primarily to the "…faster scan times, lower elevation, and short wavelength…" (quote from the Milwaukee, Wisconsin WFO). The Wilmington, Ohio office, which has 3 TDWRs within their County Warning Area (CWA), went so far as to claim they *primarily* use the TDWRs for tornado warning guidance, and "heavily" rely on the TDWRs for severe thunderstorm warnings. The tornado question prompted numerous responses relating TDWR scan rates to the detectability of tornadoes in quasi-linear convective systems (QLCSs). These tornadoes are often rapid-spinup, short-lived, and short-lead-time situations that benefit strongly from the rapid scanning inherent in the TDWR scan strategy. The TDWR automatically goes into Hazard Scan mode whenever convective activity is detected. The Hazard Scan has a 2.5-minute volume scan period and a 1-minute update time for the lowest elevation cut.

It was clear that the TDWR network was useful to NWS forecasters and should be included in our analysis. This report lists the individual responses by WFO for both the tornado and the severe thunderstorm questions. This listing is provided as record of the information used in the MIT LL studies published in the literature.

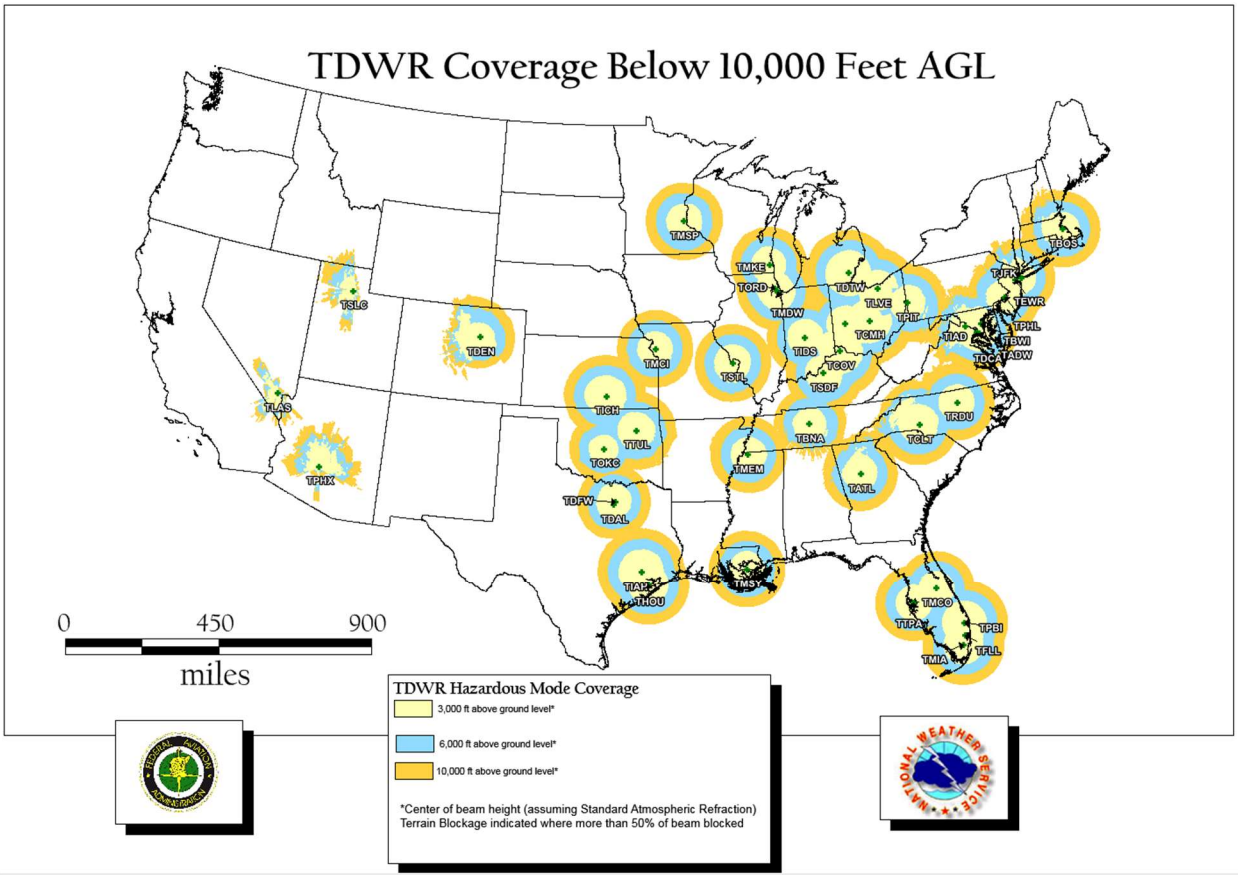

Figure 2: TDWR coverage levels of the lowest beam in hazardous mode across the CONUS.

2. TORNADO WARNING QUESTION AND RESPONSES

This question was sent to 12 WFOs, and the following WFOs responded:

- Tampa Bay, Florida
- Peachtree City, Georgia
- Topeka, Kansas
- Wilmington, Ohio
- Norman, Oklahoma
- Philadelphia, Pennsylvania
- Fort Worth, Texas
- Milwaukee, Wisconsin
- The NOAA/NWS Storm Prediction Center

The question, as asked, read: "Do you find that TDWR is regularly used for tornado warning guidance in your office?" The answers are listed below. They are lightly edited for typos and non-relevant information.

Tampa Bay, Florida

"…we do have a TDWR located at the north end of Tampa Bay. It is used regularly when storms are near the bay, especially for waterspout detection and strong marine downbursts. Of course, TDWR comes with several caveats. Data is often messy and/or incomplete and NWS offices don't really control if or when they are taken down for maintenance."

Peachtree City, Georgia

"…I would say for us in Hartsfield-Jackson Atlanta International Airport (ATL) we routinely use it during warning operations, especially around the ATL metro. In fact, it was the only source we had during the missed tornado / tornado warning at Hartsfield-Jackson Airport this past spring. It captured a very small velocity couplet right over the airport when looking back at the data, whereas Weather Surveillance Radar-1988 Doppler in Peachtree City, GA (KFFC) (which is not too far away) had nothing. While I would still say that we use the WSR-88Ds MUCH more when issuing tornado warnings, our TDWR is very useful in many cases, particularly squall lines in our area. I'd say include TDWRs in your analysis if you can!"

Topeka, Kansas

"Terminal Doppler Weather Radar in Kansas City, MO (TMCI) does clip a few of our Nebraska counties. I have not personally had the opportunity to use the TDWR for tornado warning guidance, but I imagine that on the rare occasions that we have tornadic storms within range of the radar that we would use it."

Wilmington, Ohio

"…we are very fortunate to have 3 TDWRs, Terminal Doppler Weather Radar in Dayton, OH (TDAY), Terminal Doppler Weather Radar in Covington, KY (TCVG), Terminal Doppler Weather radar in Charlotte, NC (TCMH) in our CWA. And yes, we heavily rely on them for issuance of tornado warnings. I would say we issue more tornado warnings based on TDWR than we do from our WSR-88D (KILN). Given that many of our tornadoes are spawned courtesy of QLCSs (and therefore have very quick spin-ups and lifespans), TDWR data is constantly used in the warning decision process for our office."

Norman, Oklahoma

"We absolutely use TDWR to assist with tornado warning decisions. It's been a great tool in numerous events close to metro Oklahoma City.

"We use TDWR data on a regular basis when there is the potential for tornadic storms close to the radar. There is utility in sampling closer to the storm—especially for QLCS/non-supercell tornado events."

Philadelphia, Pennsylvania

"I have used TPHL more times than I count to either help verify what the WSR-88D was showing rotation-wise or just straight up warning based solely off its signatures. TDWRs helped a lot too on Maryland's eastern shore using either Terminal Doppler Weather Radar in Baltimore, MD (TBWI) or Terminal Doppler Weather Radar in Andrews Air Force Base, MD (TADW). Same can be said for Terminal Doppler Weather Radar in Newark, NJ (TEWR). Again, these terminal dopplers have become an amazing asset to warning operations, just wish the FAA wasn't so quick to take them down for maintenance without realizing how much that degraded our services."

Fort Worth, Texas

"This is something we make aggressive use of for warning decisions at the Fort Worth WFO. The high temporal and spatial resolution of these systems is paramount in fast-evolving tornadic events like those spawned by QLCSs. I think this is where the TDWRs shine for us when it comes to tornado warning guidance; while we can usually "see" and track the big ones well enough from the WSR-88D, it's nice having the finer detail from way down low with the TDWRs when small and low-level mesocyclones are a threat. Obviously, we have to make due with increased velocity dealiasing failures, attenuation, and beam blockage, but I'd still put the TDWRs up there on the "must-have" list for tornado warning guidance. […] being able to spot very small vortices underneath the 0.5-deg WSR-88D scan provides incredible utility so close to a major population center."

Milwaukee, Wisconsin

"…it is mainly a source of supplemental information during severe weather operations. The most common use would be to get a different perspective on storm structure if the WSR-88D's data is being

contaminated by a three-body scatter spike (TBSS), etc. Given the relatively close proximity of the TDWR and WSR-88D, the TDWR would only make a significant difference in a select number of cases. Plus, the TDWR is located about 10 nm from Lake Michigan, meaning about 40% of its coverage area is over the lake, and thus of little use."

Storm Prediction Center

"While I don't issue warnings at SPC, I do get to see tornado warnings issued from every office across the CONUS. From what I've noticed, TDWRs do occasionally provide useful velocity data that wouldn't otherwise be seen by the WSR-88D network. Specifically, I've seen this multiple times along the Florida Peninsula for mainly land-falling tropical systems, and in western North Carolina with TCLT where there is a bit of a radar hole otherwise. Prior to the Supplemental Adaptive Intra-Volume Low-Level Scan (SAILS) era, TDWR velocity data had much higher temporal resolution than the WSR-88Ds, so I believe offices would often use them to get better looks at velocity couplets in between WSR-88D scans."

3. SEVERE THUNDERSTORM WARNING QUESTION AND RESPONSES

This question was sent to 12 WFOs, and the following WFOs responded:

- Miami, Florida
- Tampa Bay, Florida / Norman, Oklahoma (forecaster had been at both)
- Peachtree City, Georgia
- Topeka, Kansas
- Wilmington, Ohio
- Charleston, West Virginia
- Milwaukee, Wisconsin
- The NOAA/NWS Storm Prediction Center

The question, as asked, read: "Do you find that TDWR is regularly used for severe thunderstorm warning guidance in your office?" The answers are listed below. They are lightly edited for typos and non-relevant information.

Miami, Florida

"Absolutely the Miami International Airport (MIA), Fort Lauderdale Hollywood International Airport (FLL), and Palm Beach International Airport (PBI) TDWRs provide vital information for issuing severe thunderstorm warnings. No question about it."

Tampa Bay, Florida / Norman, Oklahoma

"…TDWRs were used heavily in Norman and Tampa. Norman for convective wind events and tornadoes/tornadogenesis, and in Tampa, as the TDWR was near Tampa Bay, it was especially useful in detecting waterspouts and damaging winds from marine thunderstorms."

Peachtree, Georgia

"Yes, with a loose definition of regularly (maybe more like occasionally?). Our TDWR is most often used more as a nudge in marginal cases. The TDWR is great for providing enhanced resolution of radial velocities in and near the Atlanta Metro. The temporal resolution and low-level scanning are often used to answer specific questions a forecaster may have that a WSR-88D may not adequately provide. Are there meso-beta rotations along a line of wind shear at low-levels? What's a radial velocity closer to the ground around the ATL metro area with an incoming squall line? What's the radial divergence from downbursts from popcorn thunderstorms in the summer? While certainly not the main source of information with severe thunderstorm warning issuance, it can help provide some clarity in very specific circumstances."

"I would say from my experience in Atlanta, TDWR was routinely used for severe weather guidance and radar operations, but the S band was still the dominant resource for warning guidance. For me personally, and also from what I've seen from others, TDWR is commonly used, but often used as a supplement with the WSR-88Ds"

Topeka, Kansas

"For severe thunderstorm warning guidance, I do not know of a situation that we explicitly used the TDWR out of TMCI. I don't see it being a useful hail tool at the moment given the lack of dual-polarimetric data, limited vertical slices, and overlapping coverage by our WSR-88Ds. It could be useful for wind guidance in our far northeast, though with the typical W-E or SW to NE progression of complexes through our area, the warning decision will have likely been made for the remainder of the CWA before it enters the domain of TMCI. I used the TDWR to review a tornado case in 2018 that happened to occur within the range of TMCI. TMCI was better able to resolve the updraft downdraft convergence zone (UDCZ) of the bowing line while KTWX picked up the tornadic debris signature (TDS)."

Wilmington, Ohio

"…given that we have 3 TDWRs with fairly good spatial coverage, yes we rely heavily on them for issuance of severe thunderstorm warnings as well. This is especially the case for high downdraft convective available potential energy (DCAPE) / strong wind potential environments. TDWR data is constantly used in the warning decision process for our office."

Charleston, West Virginia

"...I used the Columbus, Ohio TDWR quite a lot. This was partially due to its location on the western flank of our CWA, where it was great as a gap filling radar between Wilmington and us. Perry County, Ohio was a bit of a trouble spot for us... it was one of those odd counties in a CWA that sticks out away from everything else. Columbus was great for detecting exactly where wind shifts were within storms, and was used to time squall line gust fronts as they approached from the west. General non-severe outflow, thin lines and fronts were great to see on it too. I would say that it was used for wind vastly more than hail during my time there. Often, we were in situations where Wilmington would have a warning up against us, then the storm would cross briefly through our CWA in Perry County, then out the other side into Pittsburgh's CWA. TCMH was quite helpful for any wind severe operations over there."

Milwaukee, Wisconsin

"WFO Milwaukee (MKX) does use the TMKE radar on a fairly regular basis during potential severe thunderstorm events affecting the Milwaukee metro area. The focus is on wind potential, as the faster scan times, lower elevation, and shorter wavelength make it very useful for microburst detection (of course, that's the whole point of the TDWRs). I've never seen anyone use it for hail, given that the WSR-88D is so superior in that application."

Storm Prediction Center

"Similar to my response regarding tornado warnings, it is my perception/opinion from a national perspective that most offices use TDWRs for severe thunderstorm warnings. I've seen multiple instances of offices referring to TDWRs when collaborating internally on chat software about both severe thunderstorm and tornado warnings adjacent to a neighboring office (whether to issue downstream of an existing warning, matching up when both offices decide to warn simultaneously, etc...).

I've also experienced several occasions when I'm questioning why an office has issued a severe thunderstorm warning. I often realize that there's a TDWR nearby, pull it up, and see 40-50+ kt inbound/outbound velocities that aren't as readily apparent using just the WSR-88D network. From what I've observed, the use of TDWRs seems to be more common with wind rather than hail."

4. CONCLUSIONS

As demonstrated in the survey responses, we have concluded from this small sampling of NWS WFOs that the TDWR is a valuable asset for both tornado and severe thunderstorm warning guidance. For tornadoes, rapid spinups such as those in QLCSs are a primary use case. For severe thunderstorms, wind is the primary use for TDWRs (as opposed to hail). We conclude that incorporating the TDWR into our benefit analyses was the proper course of action.

GLOSSARY

ATL	Hartsfield-Jackson Atlanta International Airport
CONUS	Contiguous United States
CWA	County Warning Area
DCAPE	Downdraft Convective Available Potential Energy
DOD	Department of Defense
FAA	Federal Aviation Administration
FLL	Fort Lauderdale Hollywood International Airport
KFFC	Weather Surveillance Radar-1988 Doppler in Peachtree City, GA
KILN	WSR-88D
MIA	Miami International Airport
MIT LL	Massachusetts Institute of Technology Lincoln Laboratory
MKX	WFO Milwaukee
MPAR	Multifunction Phased Array Radar
NOAA	National Oceanic and Atmospheric Administration
NSSL	National Severe Storms Laboratory
NSWRC	NextGen Surveillance and Weather Radar Capability
NWS	National Weather Service
PBI	Palm Beach International Airport
QLCSs	Quasi-Linear Convective Systems
SAILS	Supplemental Adaptive Intra-Volume Low-Level Scan
SENSR	Spectrum Efficient National Surveillance Radar
SPC	Storm Prediction Center
TADW	Terminal Doppler Weather Radar in Andrews Air Force Base, MD
TBSS	Three-Body Scatter Spike
TBWI	Terminal Doppler Weather Radar in Baltimore, MD
TCMH	Terminal Doppler Weather radar in Charlotte, NC
TCVG	Terminal Doppler Weather Radar in Covington, KY
TDAY	Terminal Doppler Weather Radar in Dayton, OH
TDS	Tornadic Debris Signature
TDWR	Terminal Doppler Weather Radar
TEWR	Terminal Doppler Weather Radar in Newark, NJ
TMCI	Terminal Doppler Weather Radar in Kansas City, MO
UDCZ	Updraft Downdraft Convergence Zone
WFOs	Weather Forecast Offices
WSR-88D	Weather Surveillance Radar-1988 Doppler

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