Characteristics of Tornadic and Nontornadic QLCS Mesovortices Observed Using Radar and Pod Data from PERiLS

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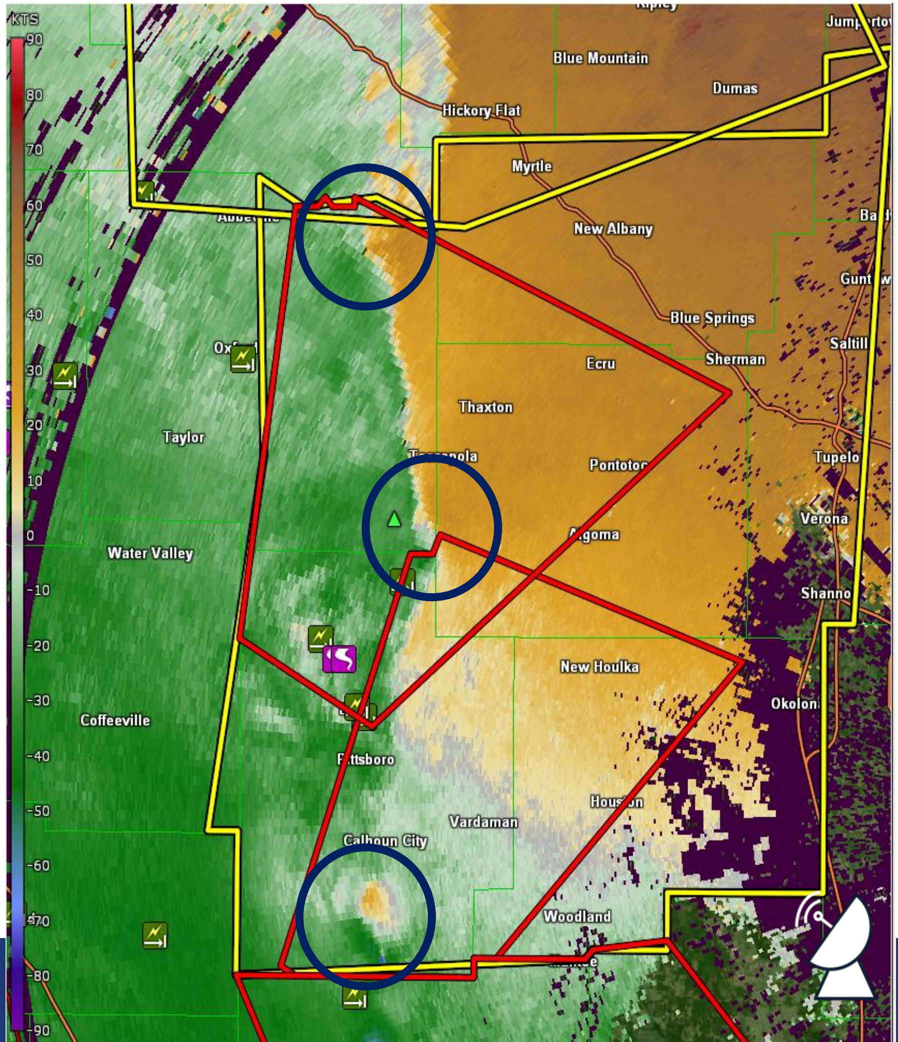
QLCS Tornadoes and the Trouble of Mesovortices

- Nowcasting quasi-linear convective system (QLCS) tornadoes is challenging (Trapp et al. 1999)
- QLCS tornadoes typically form within mesovortices (MVs)
  - Small-scale (< 10 km), convectively produced centers of vertical vorticity (Weisman and Trapp 2003)
- Not all MVs are tornadic (Trapp and Weisman 2003)
- Focusing on MVs at **low-levels**, which have been found in observational and modeling studies (Trapp and Weisman 2003; Atkins et al. 2005; Atkins and St. Laurent 2009a; Davis and Parker 2014)

Base velocity image depicting 3 MVs (circled) using the 0.5° scan from WSR-88D KGWX at 2235 UTC 30 Mar 2022 during PERiLS IOP2.



Research Questions

- My research focuses on the following objective of the PERiLS project:
  - To identify the characteristics and mechanisms that distinguish between tornadic and nontornadic QLCS MVs
- **Research Questions**

  1. How do radar-based characteristics differ between tornadic (TOR), wind-damaging (WD), and non-damaging (ND) MVs in QLCSs?
  2. What is the low-level structure of QLCS MVs?

Used WSR-88D and C-band on Wheels (COW) radar data along with in situ Pod data collected during PERiLS

C-band On Wheels (COW)

- Maintained by the Flexible Array of Radars and Mesonets (FARM) at UIUC
- "Quickly deployable" (Wurman et al. 2021)
  - Due to the long wavelength of radiation transmitted, a larger antenna is needed to still obtain a narrow beamwidth
    - Requires antenna assembly as opposed to fully mobile radars
  - Assembly to operations takes about 2.5 hours

COW Specifications	
Wavelength	C-band, 5 cm
Polarization	Dual-Pol, Dual-Frequency
Transmitter (kW peak)	2x 1000
Beamwidth	1.05°
Antenna diameter	3.8 m
Products	Z, V, SW, ZDR, Rho-HV, KDP (standard single and dual-pol products)
PRFs used in PERiLS	5400 Hz, 2160 Hz, both with stagger
Pulse Lengths used in PERiLS	0.5 µs, 0.667 µs
Gate Lengths used in PERiLS	75 m, 100m
Nyquist velocities used in PERiLS	67.5 m/s, 27 m/s
Maximum unambiguous ranges used in PERiLS	89 km, 148 km

Picture courtesy of Josh Aikins

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Manual Analysis of WSR-88D and COW Data

- Manually identified QLCS MVs from the PERiLS IOPs of 2022 and 2023
  - Utilized the **lowest elevation scan** (typically 0.5°) of the nearest Weather Surveillance Radar ‘88 Doppler (WSR-88D) using GR2 Analyst software
  - MVs had to pass through the COW’s domain
  - MVs had to be produced by a QLCS, defined as a continuous area of 35 dBZ radar reflectivity over at least 100 km at the lowest elevation scan (Smith et al. 2012)
  - Identified MVs by locating a thunderstorm wind damage report, a tornado report, or a tornado warning that didn’t produce a tornado (these make up the non-damaging cases) in/near the COW’s domain
    - Tracked the MV from its genesis to its decay
  - MV criteria (Smith et al. 2012)
    - Discrete circulation with a maximum dV ≥ 10 m/s (difference between the maximum outbound and minimum inbound velocities at a constant range) with a diameter ≤ 7 km

Manual Analysis of WSR-88D and COW Data

- Cataloged the following MV characteristics at each low-level velocity scan:

Longitude and latitude locations	Maximum rotational velocity (Vrot)
Maximum differential velocity (dV)	Diameter
Height above radar level (ARL)	Duration
Range from radar	

- To analyze MVs over their whole lifetimes, each MV was classified as tornadic (TOR), wind-damaging (WD), or non-damaging (ND) based on the damage report(s) or lack thereof that occurred over the entire lifetime of the MV
  - Subsequently, to analyze the pretornadic/predamaging period of a MV, each MV was classified based on the first damage report
- Repeated cataloging process of MV characteristics using the higher resolution COW radar data using Solo3

Overview of PERiLS QLCS MVs

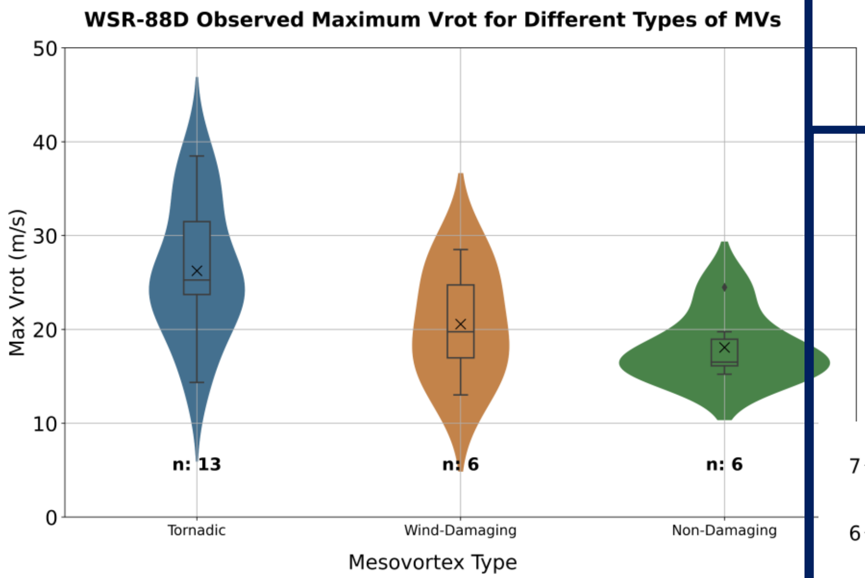
*Labeled by the damage associated with each MV over their entire lifetime

IOP#	IOP date(s)	IOP times	# of **WSR-88D** QLCS MVs that passed near/through the COW domain	# of **COW** QLCS MVs visible during ***some duration*** of each MV	# of **COW** QLCS MVs visible at the ***start of each MV before the first report/warning*** was issued	# of **COW** QLCS MVs visible during the ***whole duration*** of each MV
2	2022-03-30/31	1900 – 0220 UTC	8 total • 4 TOR, 3 WD, 1 ND	6 total • 3 TOR, 2 WD, 1 ND	5 total • 2 TOR, 2 WD, 1 ND	5 total • 2 TOR, 2 WD, 1 ND
3	2022-04-05	1300 – 1730 UTC	5 total • 4 TOR, 1 WD	4 total • 3 TOR, 1 WD	4 total • 3 TOR, 1 WD	1 total • 1 TOR
4	2022-04-13	1900 – 2130 UTC	5 total • 2 TOR, 1 WD, 2 ND	3 total • 1 TOR, 1 WD, 1 ND	1 total • 1 WD	0
2	2023-03-03	0400 – 1100 UTC	4 total • 1 TOR, 1 WD, 2 ND	4 total • 1 TOR, 1 WD, 2 ND	4 total • 1 TOR, 1 WD, 2 ND	4 total • 1 TOR, 1 WD, 2 ND
3	2023-03-24/25	2100 – 0230 UTC	2 total • 1 TOR, 1 ND	2 total • 1 TOR, 1 ND	0	0
4	2023-04-01	0000 – 0800 UTC	1 total • 1 TOR	1 total • 1 TOR	0	0
Total			**25**	**20**	**14**	**10**

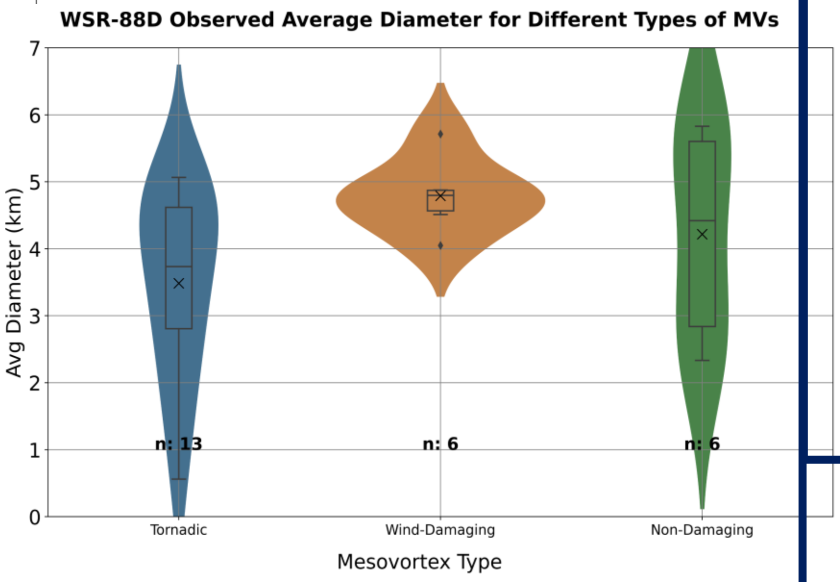
Out of the **13 tornadic QLCS MVs** observed by the WSR-88D network, **only 4 had positive warning-report lead times**

Entire Lifetimes of WSR-88D MVs

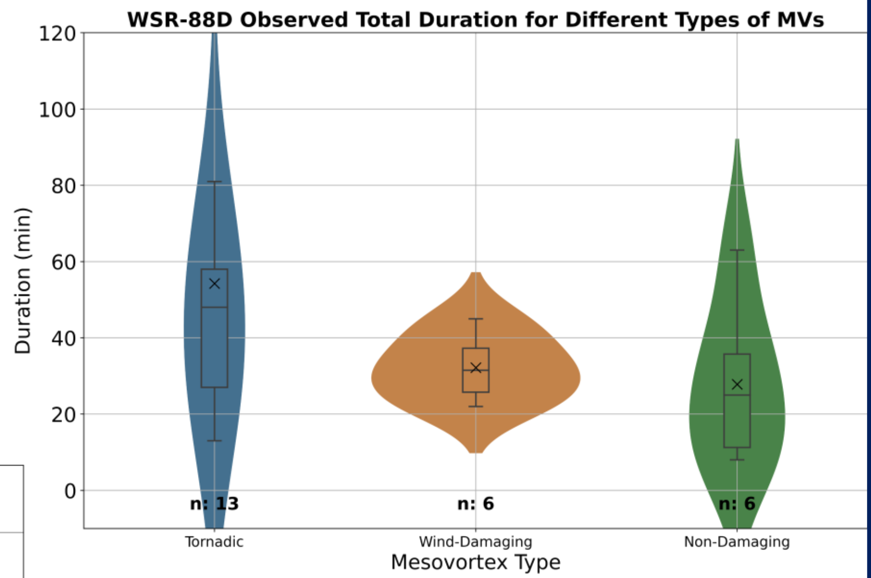
1. How do radar-based characteristics differ between TOR, WD, and ND MVs in QLCSs?



- TOR MVs have stronger Vrots



- TOR MVs generally have smaller diameters



- TOR MVs have longer lifetimes, but WD MVs also tend to be persistent

*Reminder: the MVs were analyzed using the lowest tilt of the radar

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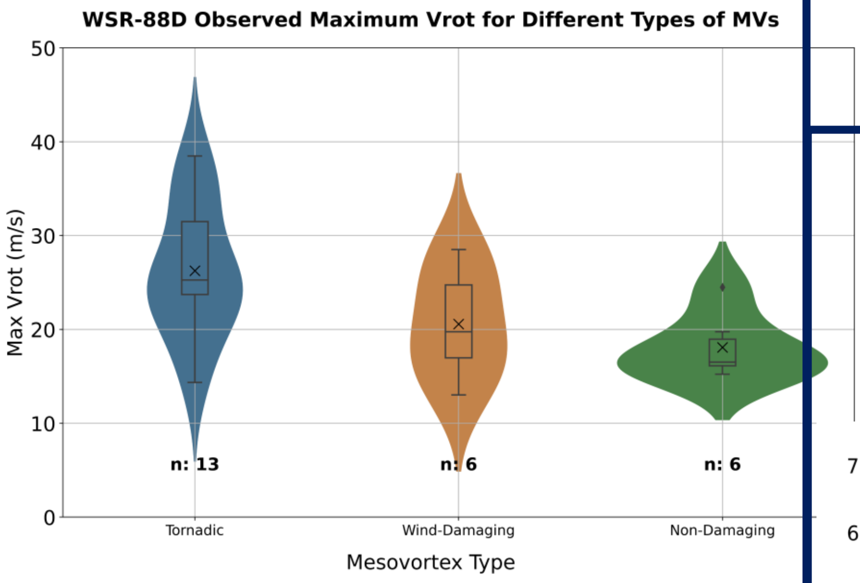

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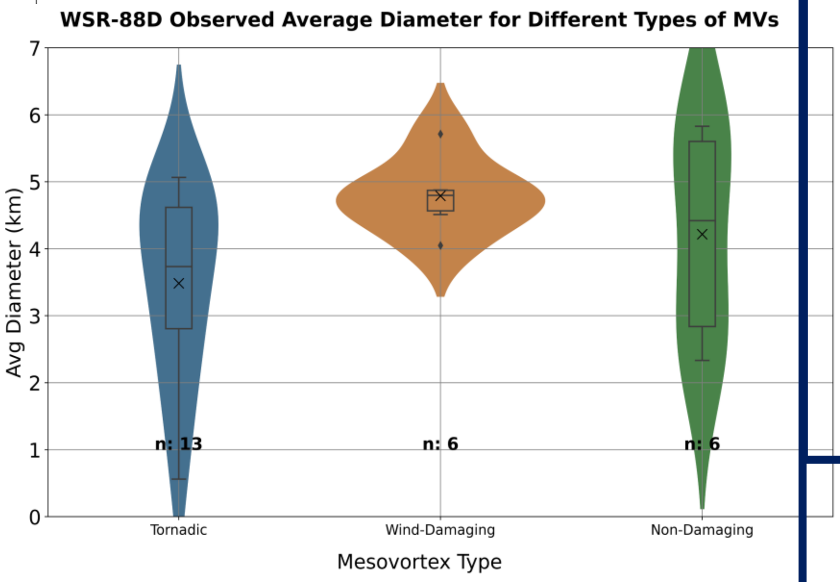

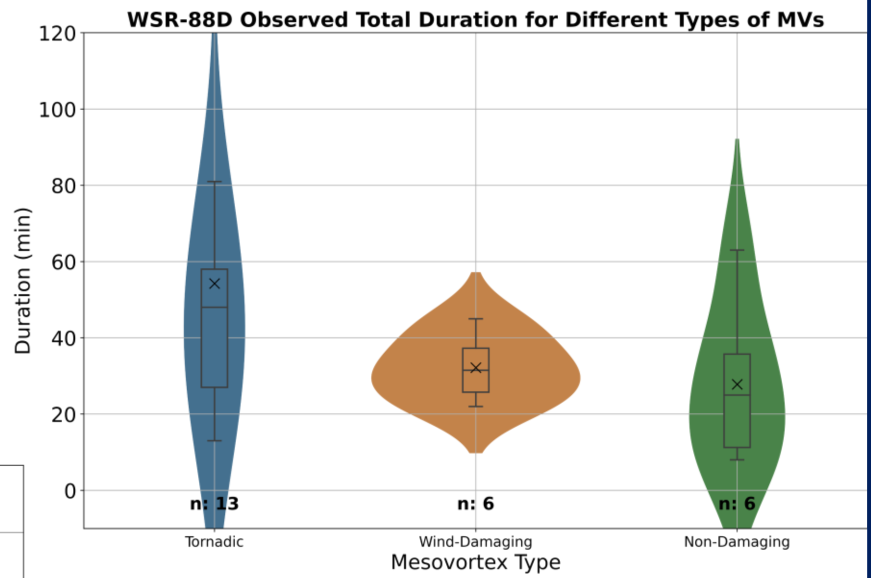

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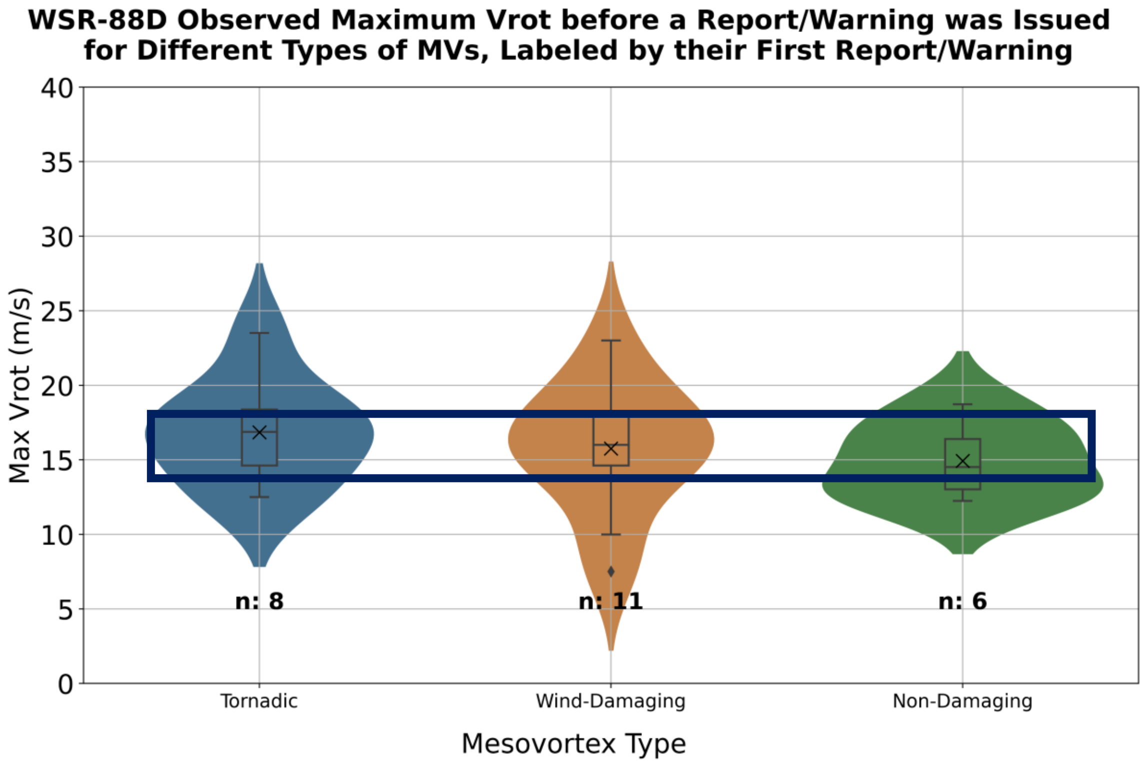
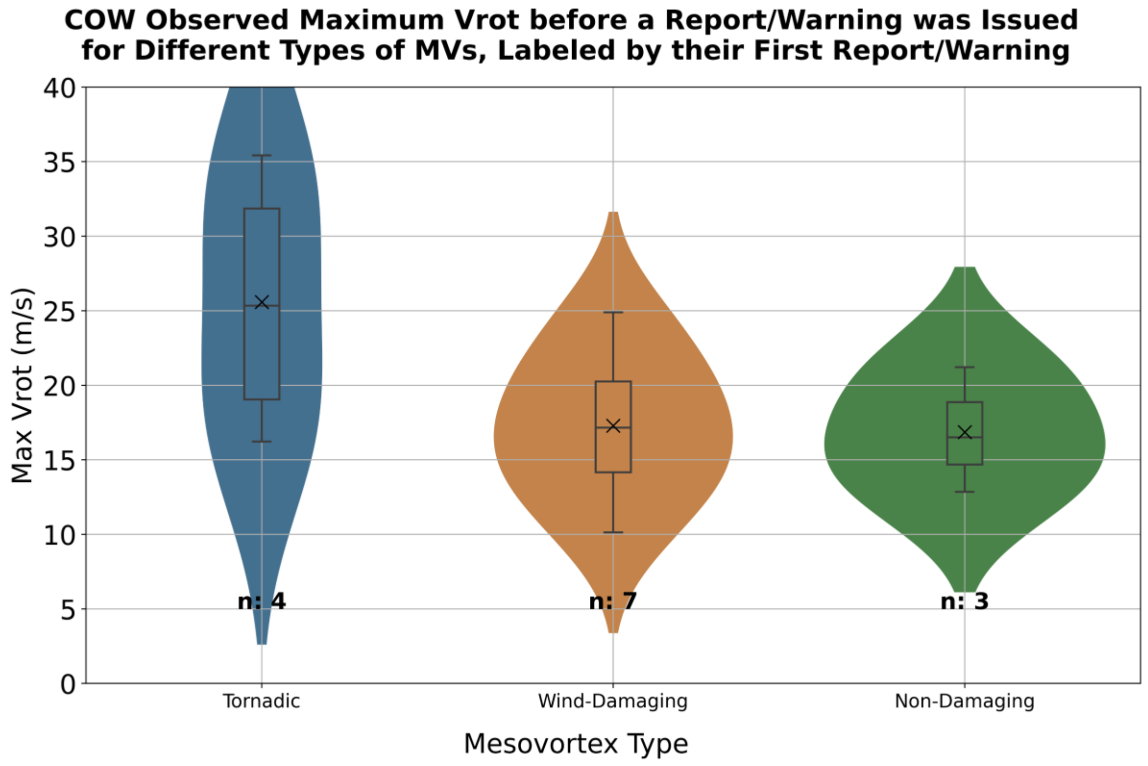
WSR-88D vs. COW MVs Before Reports: Vrot

- Little differentiation between the median max Vrot values and the separation of boxes in the WSR-88D data
- Better distinction in the COW data, likely due to less beam filling

WSR-88D



COW



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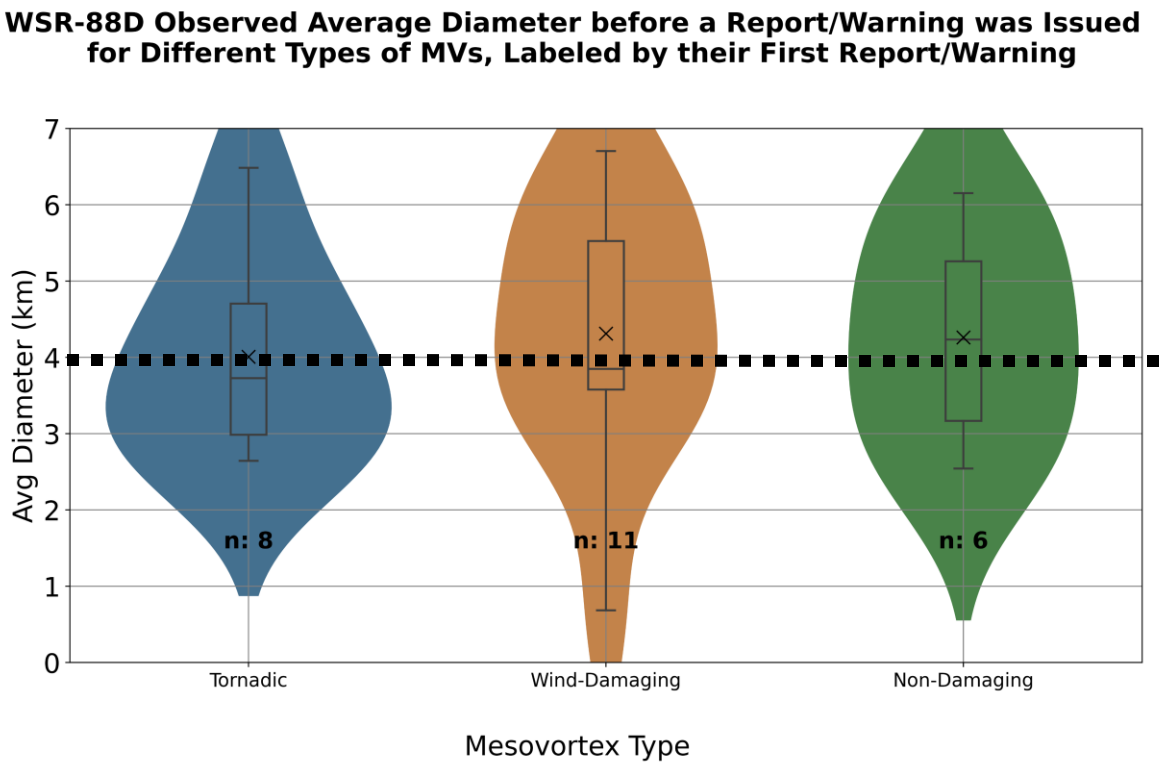
WSR-88D vs. COW MVs Before Reports: Diameter

- Over the whole period prior to a report/tornado warning, large overlap in MV diameters in the WSR-88D data
  - Greater differentiation seen when using the higher resolution COW radar data

WSR-88D



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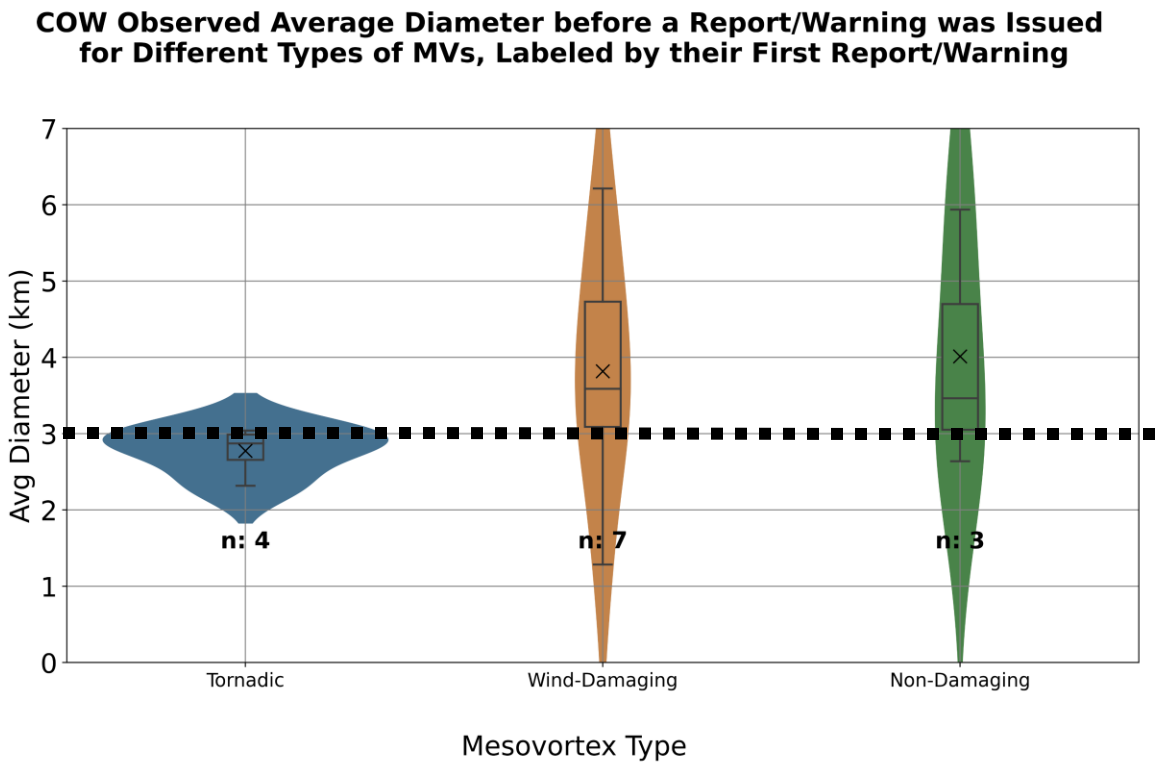

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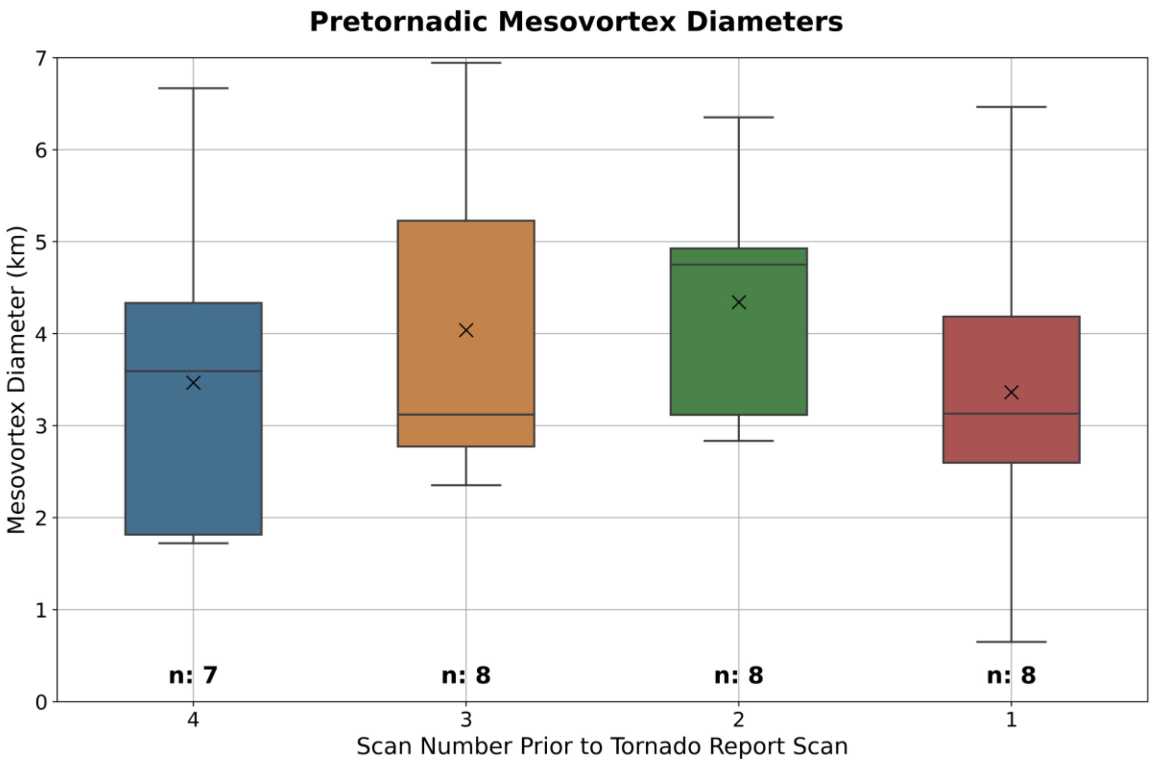
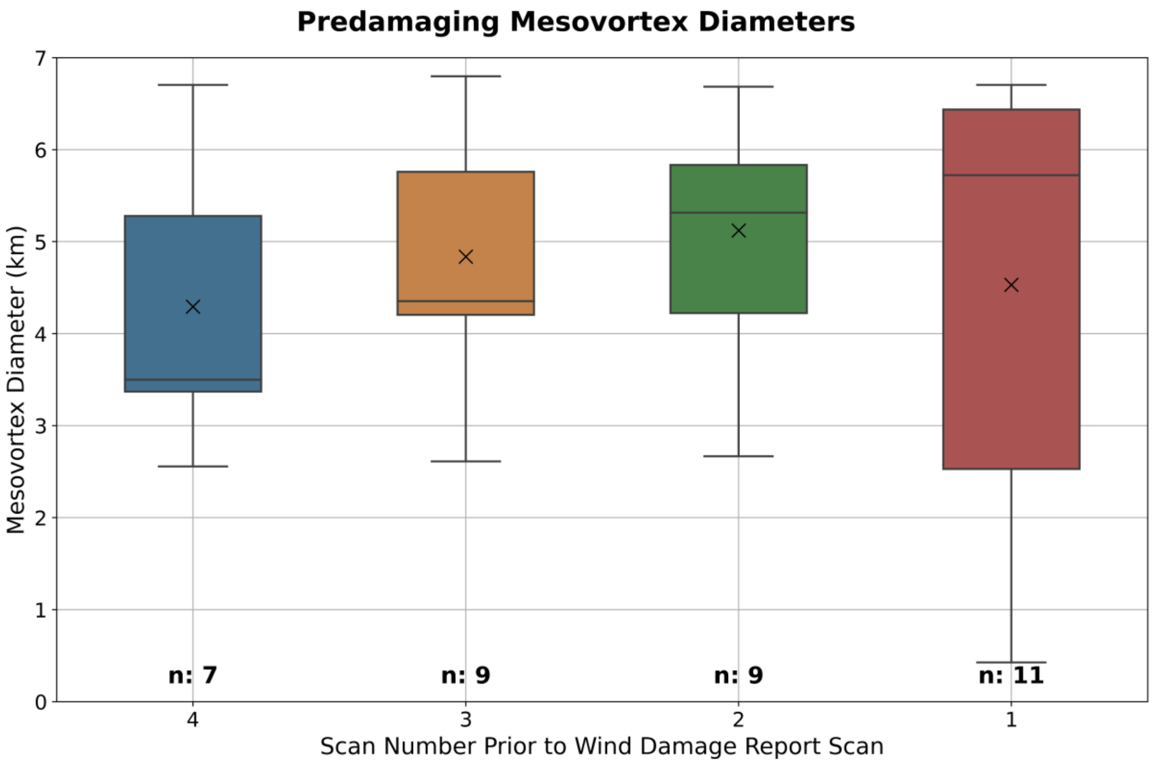
Pretornadic and Predamaging MV Diameters

- Some distinction in MV diameters between TOR and WD MVs in the few scans prior to damage



Closer to tornadogenesis

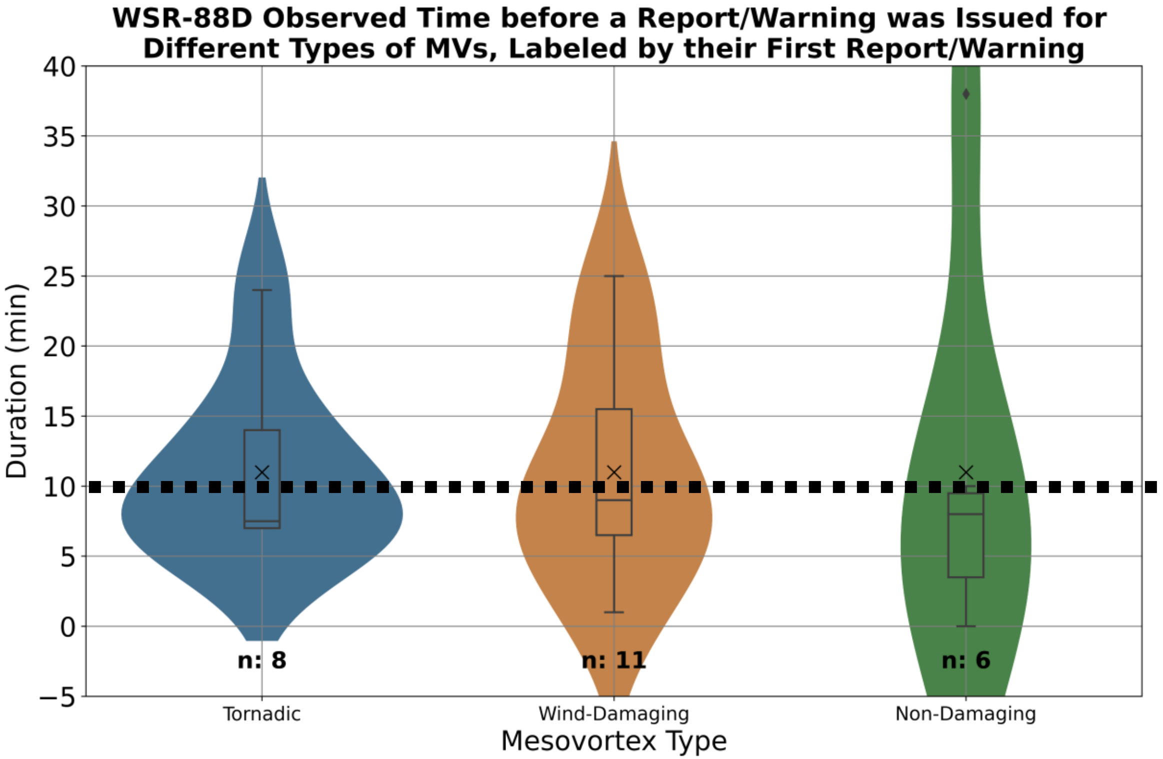


Closer to wind damage

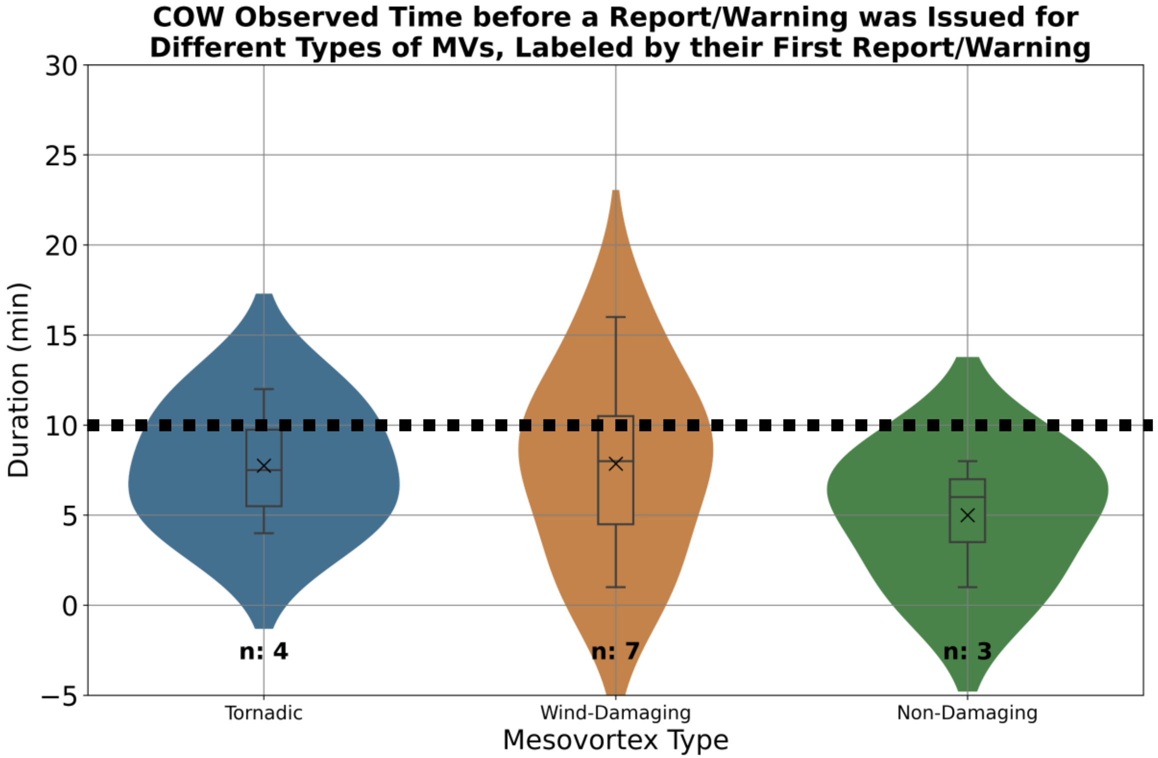
WSR-88D vs. COW MVs Before Reports: Time

- Often ≤ 10 minutes between the time a MV forms and when it produces damage or a warning is issued

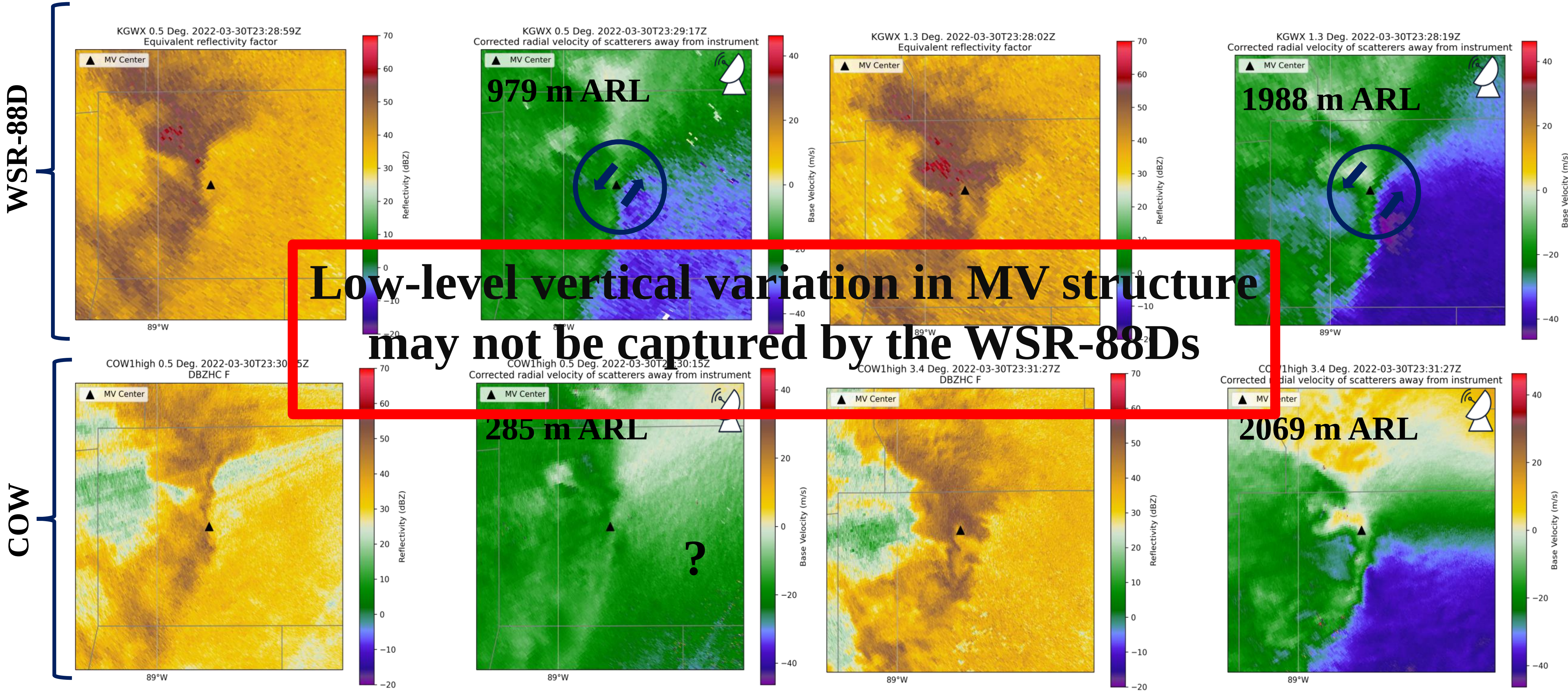
WSR-88D



COW



What is the Low-Level Structure of MVs?

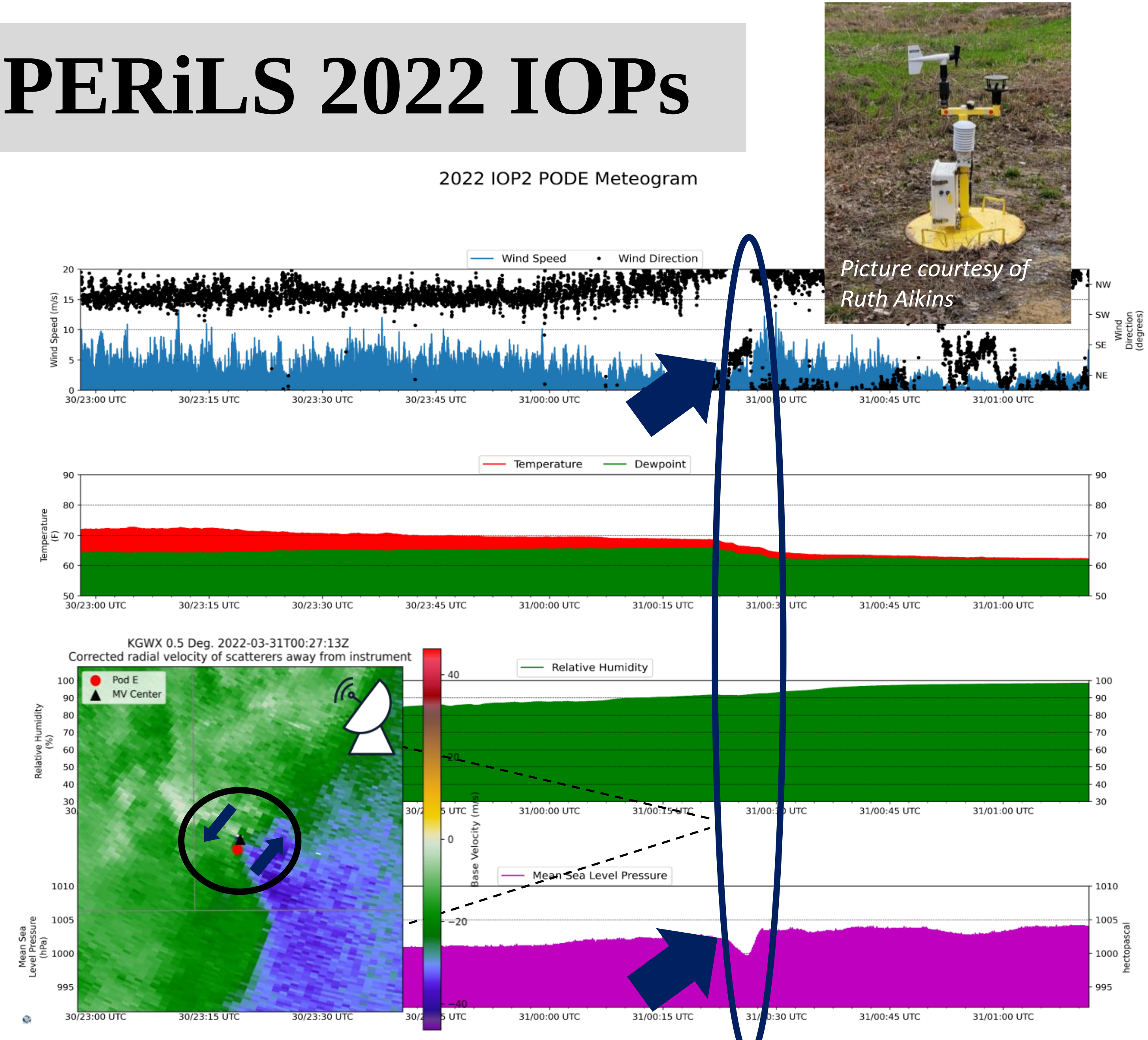


Low-level vertical variation in MV structure may not be captured by the WSR-88Ds

MV formed at 2225 UTC → Produced tornado at 2232 UTC → Tornado warned at 2317 UTC → Dissipated at 2343 UTC

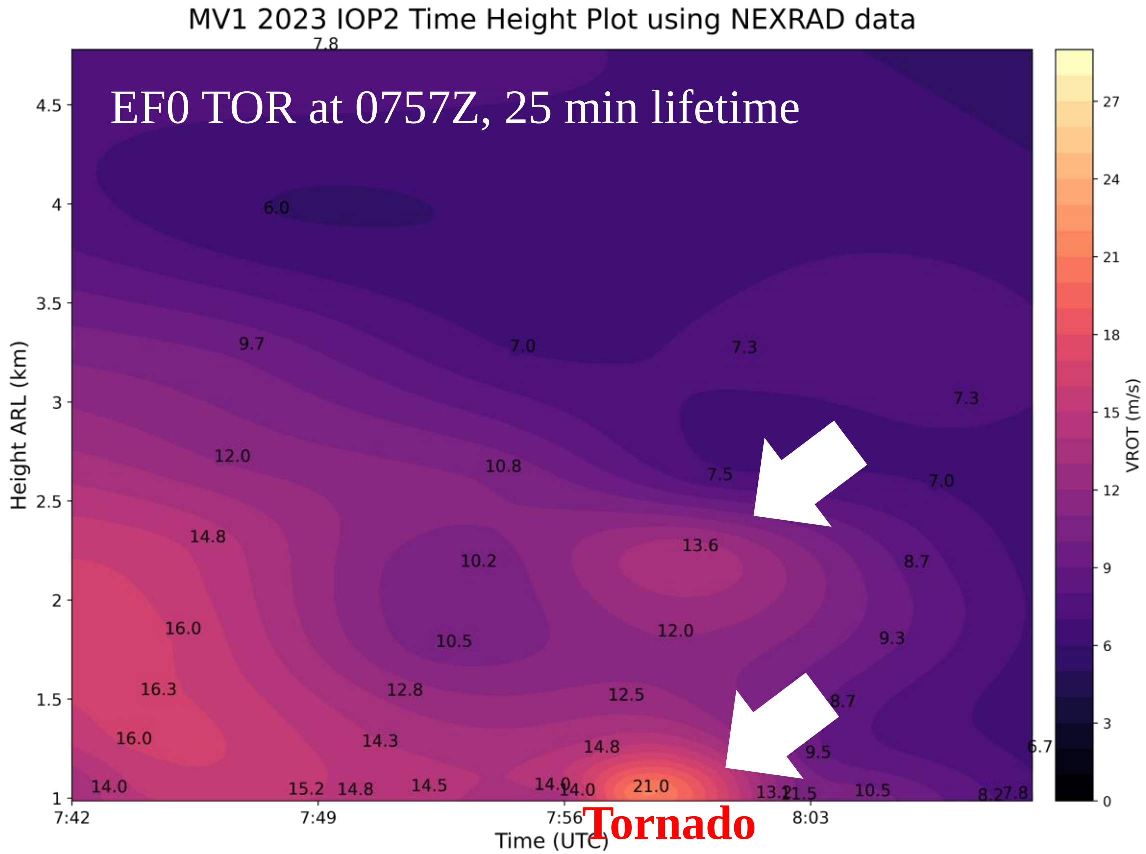
In-Situ Pod Data from PERiLS 2022 IOPs

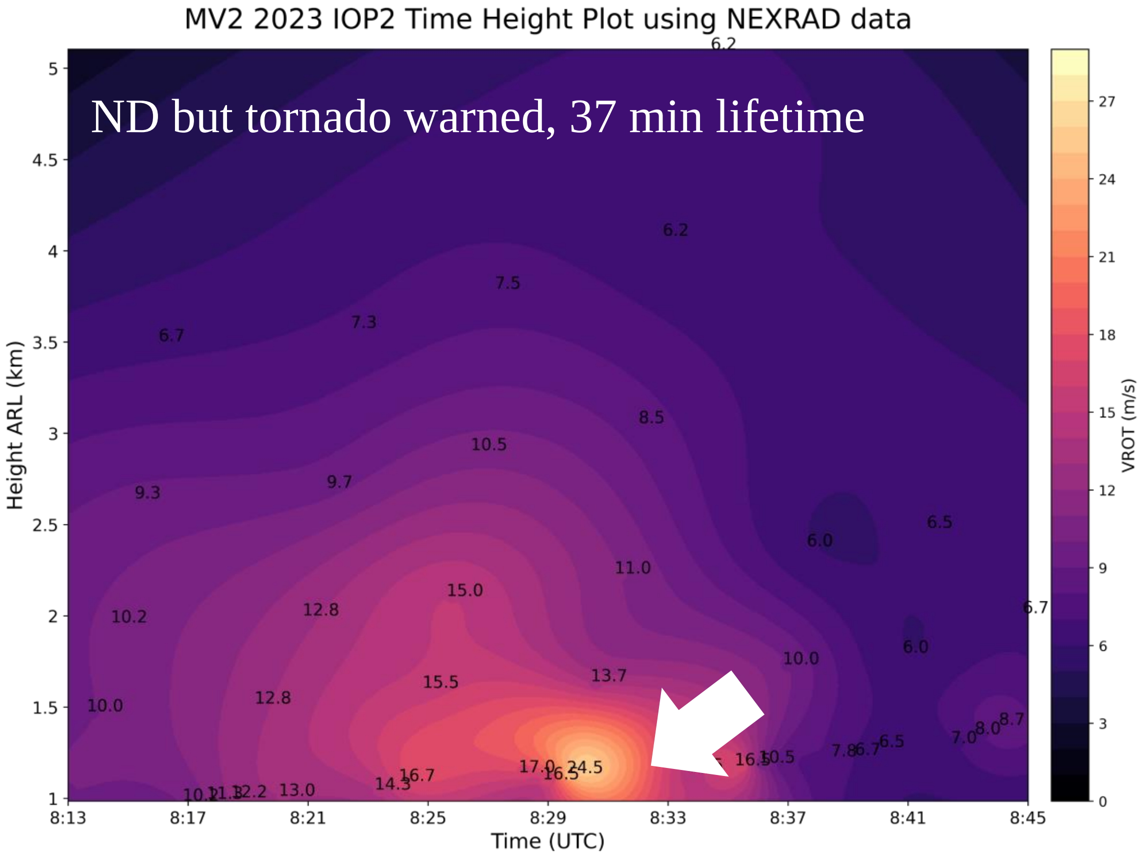
- A MV was considered to have intercepted a Pod if its center came within 5 km of the Pod
- 3 QLCS MVs intercepted 6 Pods when viewed from the lowest scan of the nearest WSR-88D
  - None of the MVs were actively producing damage at the time of intercept
- When a MV passes over the pods, there is usually:
  - A pressure drop, 2.1 mb on average
  - A shift in the wind direction
  - An increase in wind speed, but limited to 13 m/s or less



Time-Height Profiles of Vrot for a TOR and a ND MV

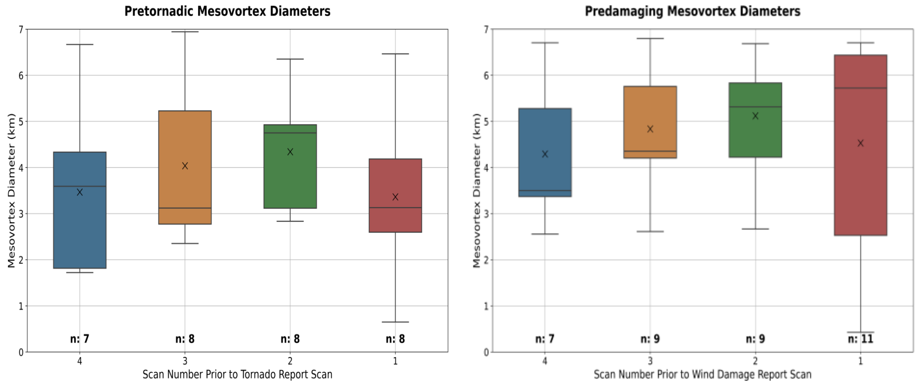
- At the time of tornadogenesis, low-level and "mid-level" circulations were present
  - MV had a greater vertical extent
- Exhibited a stronger max Vrot than the TOR MV
- However, the low-level circulation was not co-located with a circulation aloft at its peak intensity

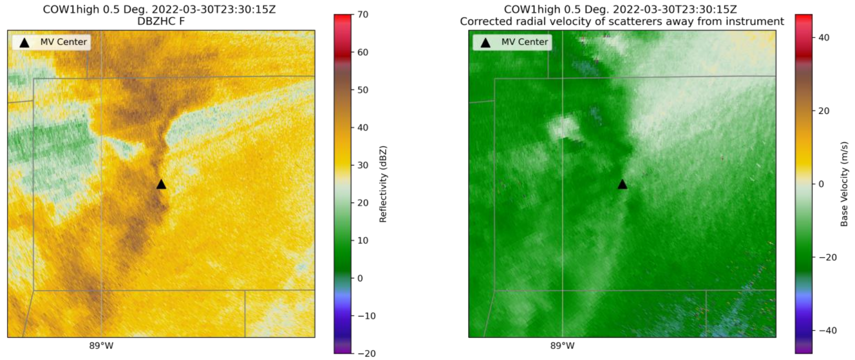


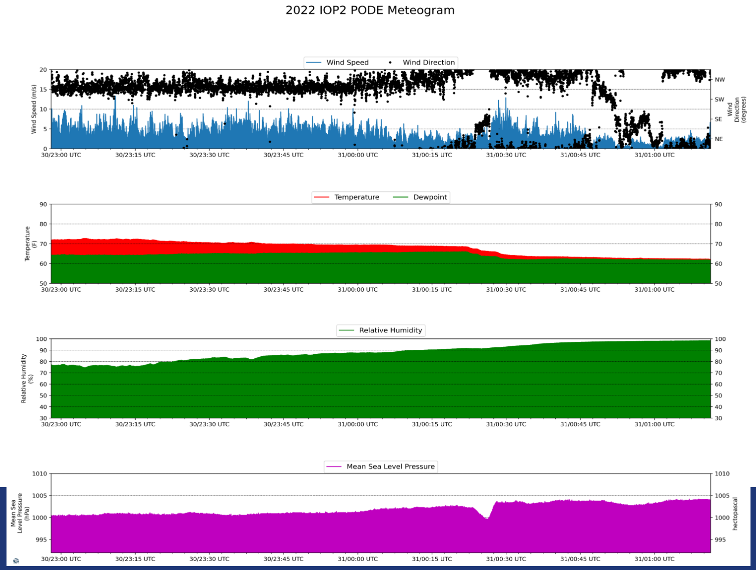


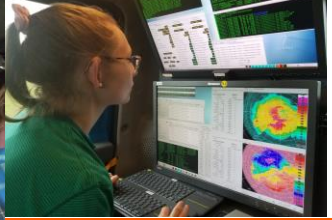
Conclusions

- TOR and WD MVs have similar Vrots and diameters when analyzed over the whole period prior to the first report/warning
    - However, TOR MVs typically have smaller diameters in the few scans prior to tornadogenesis when compared to WD MVs
- Evidence that there is significant vertical variation in low-level MV structure from COW radar and in-situ Pod data that may not be captured by WSR-88Ds
- For MVs that intercepted Pods, a maximum wind gust of 13 m/s was observed, and most of the Pods observed a decrease in pressure
- Time-height profiles of Vrot displayed that the TOR MV was associated with a "mid-level" circulation/was deeper at the time of tornadogenesis









Acknowledgements

- Advisors, Jeff and Steve, for their unwavering support and research guidance
- Committee member and mobile radar guru, Karen Kosiba
- Josh Aikins and Paul Robinson for FARM data QC
- FARM Family and PERiLS Project
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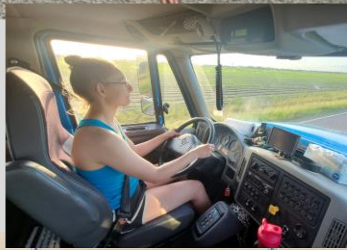
- Keith Sherburn and Charles Kuster for discussions about this work
- Funding agencies: PERiLS NSF Grant (NSF AGS 2020462), NSF GRFP
- Research group mates, past and present
- Family and friends



Questions? Comments? **Thanks for attending!**

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