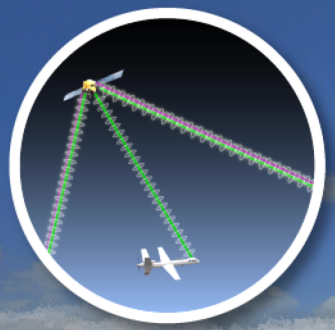






Radar Surveillance Volume for Phase 1 UAS's Alerting Timeline

Gilbert Wu

Seungman Lee

Background

- On March 6th, SC-228 selected a Detect-and-Avoid Well Clear (DWC) for non-cooperative aircraft (previously called DWC2)
  - The non-coop DWC and Phase 1 DWC yield comparable safety metrics such as the NMAC risk ratio and loss of DWC ratio

DWC	Γ_{mod} (sec)	HMD* (ft)	h* (ft)
Non-Coop	0 sec	2200 ft	450 ft
Phase 1	35 sec	4000 ft	450 ft

- There is a desire to raise the maximum UAS speed in the DAA MOPS from 200 kts KTAS to 291 kts KTAS (equivalent to 250 kts IAS)

Objective

- Investigate the combined effects of
  - Applying the non-coop DWC in place of the Phase 1 DWC
  - Increasing the maximum UAS speed to 291 kts

  on the required radar's surveillance volume for supporting the DAA alerting timeline for the Phase 1 UAS

Fast Time Simulation Schedule

Simulation Type		Low C-SWaP Operations	Phase 1 Operations
Unmitigated	Truth Tracks	NASA Briefing Mar. 2019	NASA Briefing Jun. 2019
	Noisy Tracks	NASA TBD	
Mitigated	Truth Tracks with a Simple Phase 1 Pilot Model	Lincoln Lab Briefing Mar. 2019	Cal Analytics Briefing Mar. 2019
	Noisy Tracks with an improved Pilot Model	NASA Oct. 2019	

Simulation Results

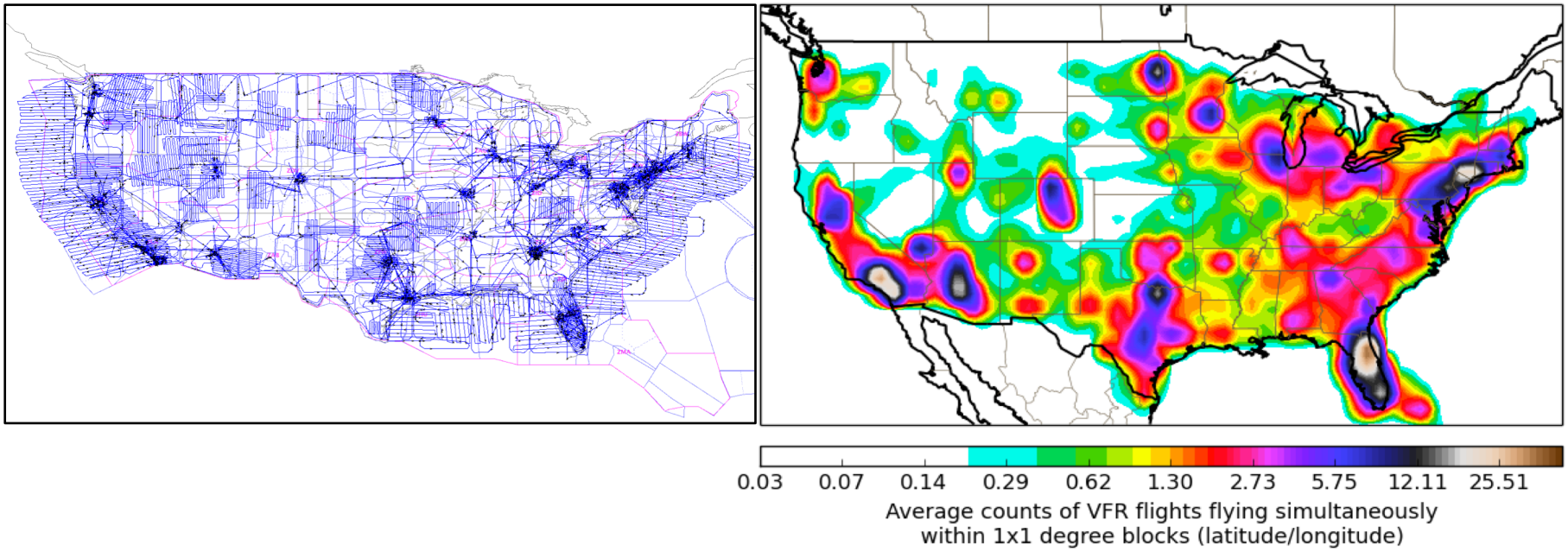
1. NASA encounter set

2. Stressing case alerting timeline

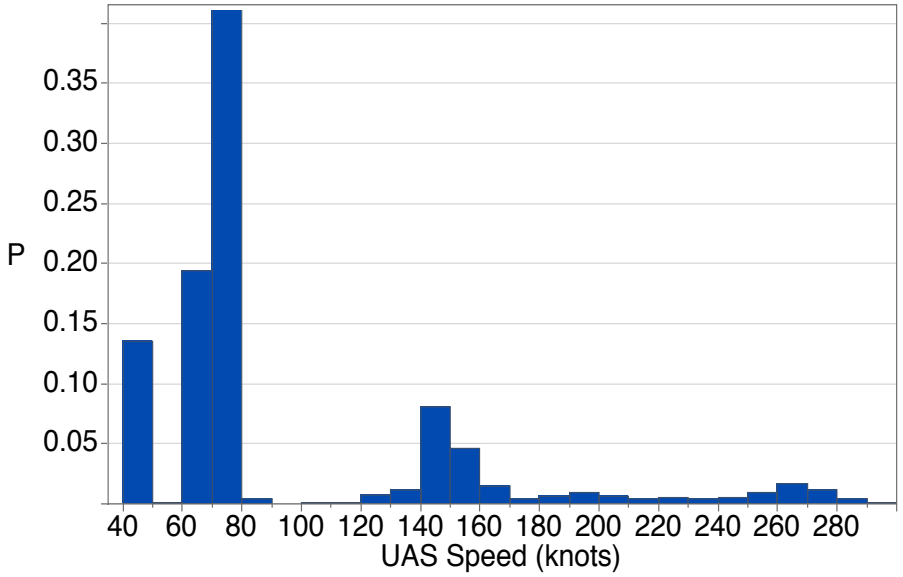
NASA encounter set

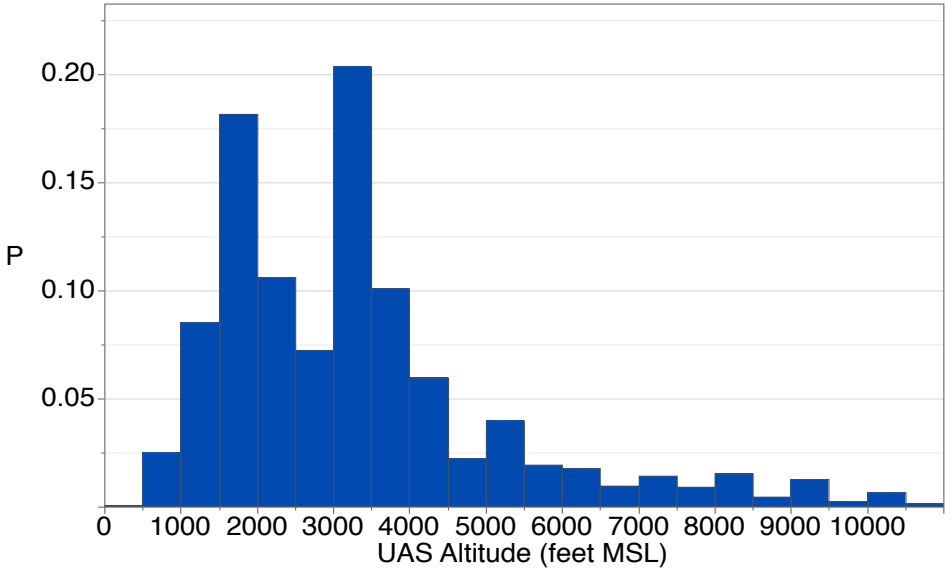
Encounter Set

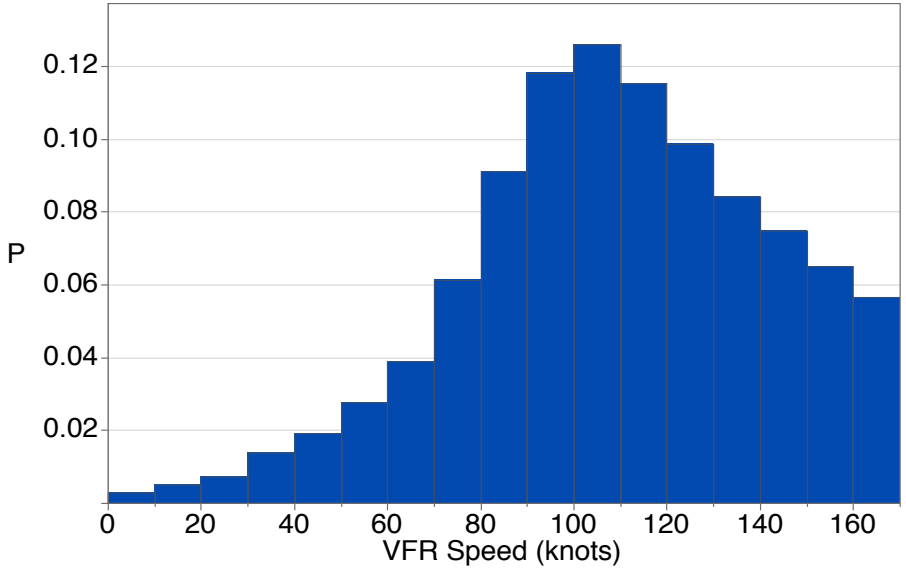
- 17,100 hours of projected UAS mission trajectories in one day overlaid with each of 21 days' radar recorded visual flight rules (VFR) traffic
- Only encounters between 500 ft AGL and 10,999 ft MSL are analyzed

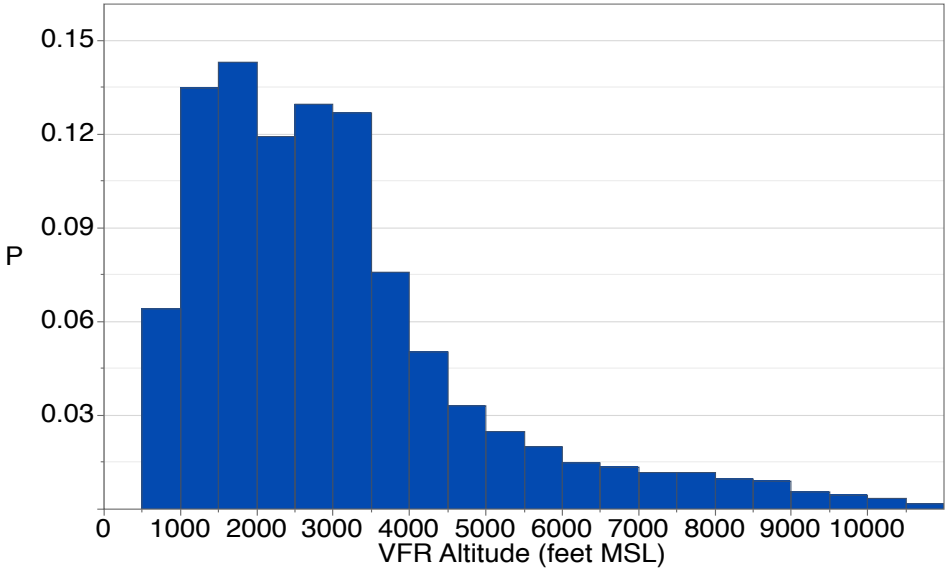


Speed and Altitude of UAS and VFR Traffic









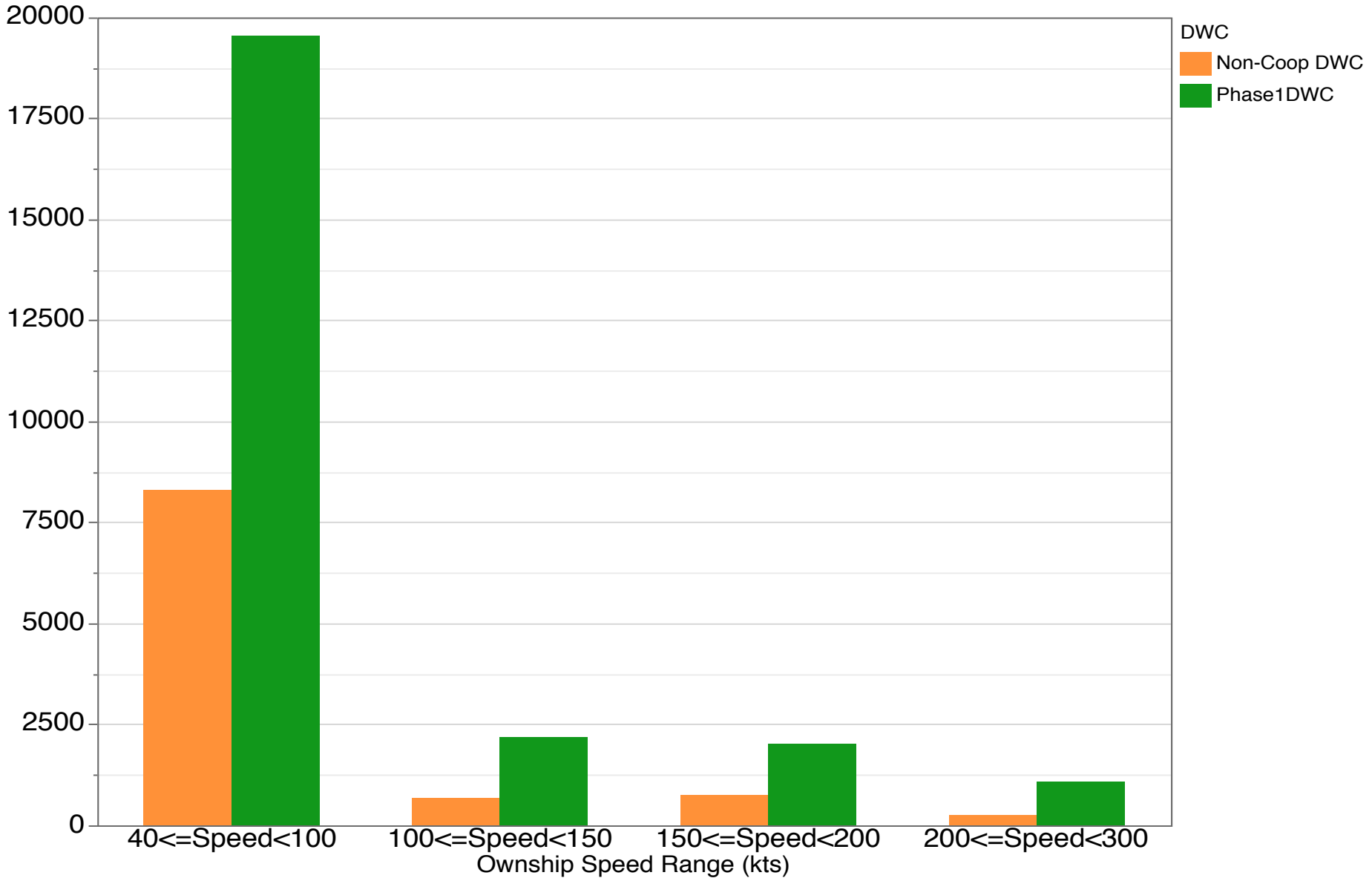
Encounter Statistics

- Total number of pairwise encounters with 21 days of traffic
  - 94,081
- Total number of NMAC: 505 Near Mid-Air Collisions

UA Speed Range (KTAS)	40 to 100 kts	100 to 150 kts	150 to 200 kts	200 to 291 kts
# Encounters	72667	9062	7040	5312

- Total number of LoDWCs
  - Non-coop DWC: 9958
  - Phase1 DWC: 24809
- All speeds referred on the following slides are KTAS

Number of LoDWC



Encounter Geometry Analysis at First Corrective Alerts

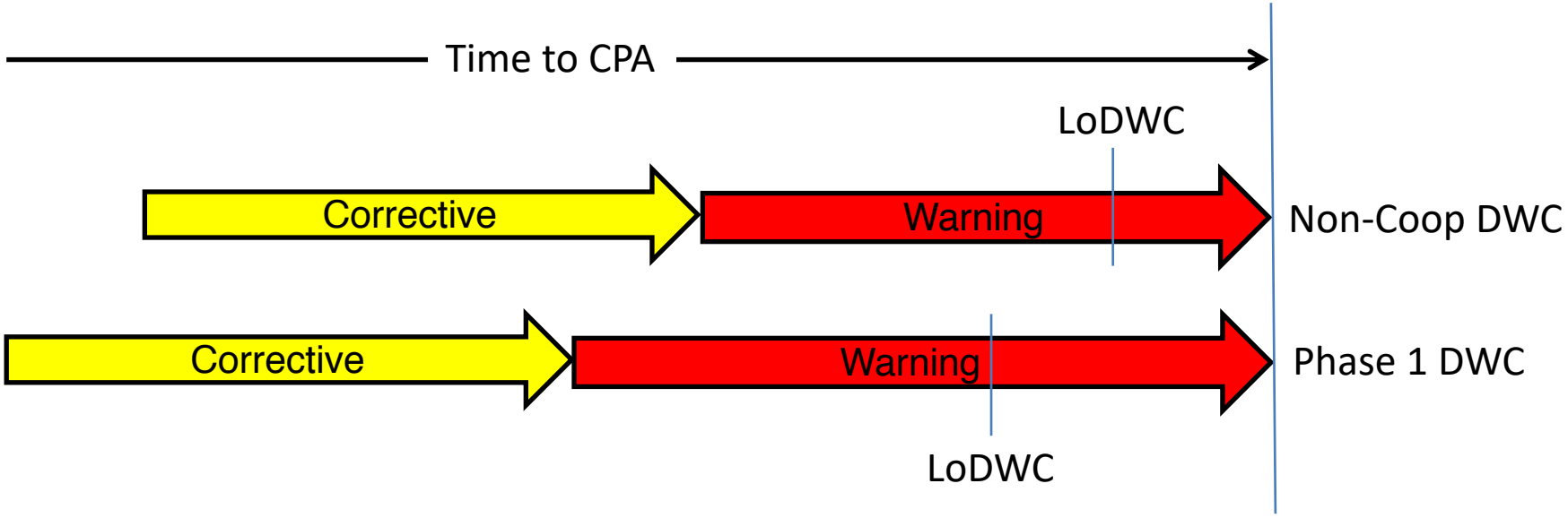
Open-Loop Fast-Time Simulation Setup

- Simulation platform
  - NASA's Java Architecture for DAA Extensibility and Modeling (JADEM)
- Surveillance volume for simulation
  - 8 nmi radar declaration range
  - +/-180 degrees of bearing angle (horizontal field of regard)
  - +/- 90 degrees of elevation angle (vertical field of regard)
- No sensor uncertainty
- Detect-And-Avoid (DAA) alerting and guidance system
  - Detect and AvoID Alerting Logic for Unmanned Systems (DAIDALUS)

Alerting and Maneuver Guidance Algorithm

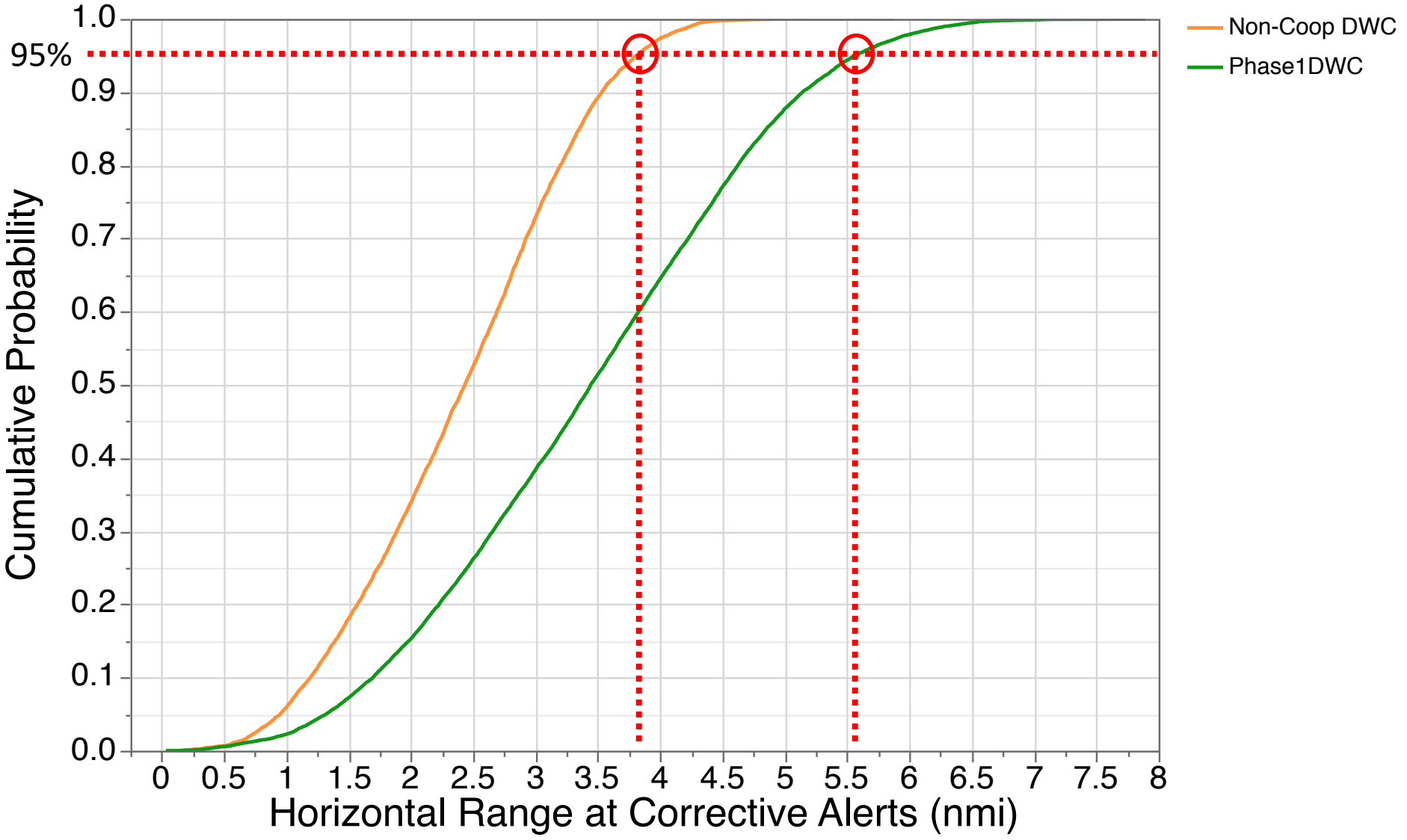
- Detect and AvoID Alerting Logic for Unmanned Systems (DAIDALUS) version 1.0

- DAIDALUS protects against a horiz-buffered DWC volume
  - Corrective alert 60 seconds before entering volume
  - Warning alert 30 seconds before entering volume

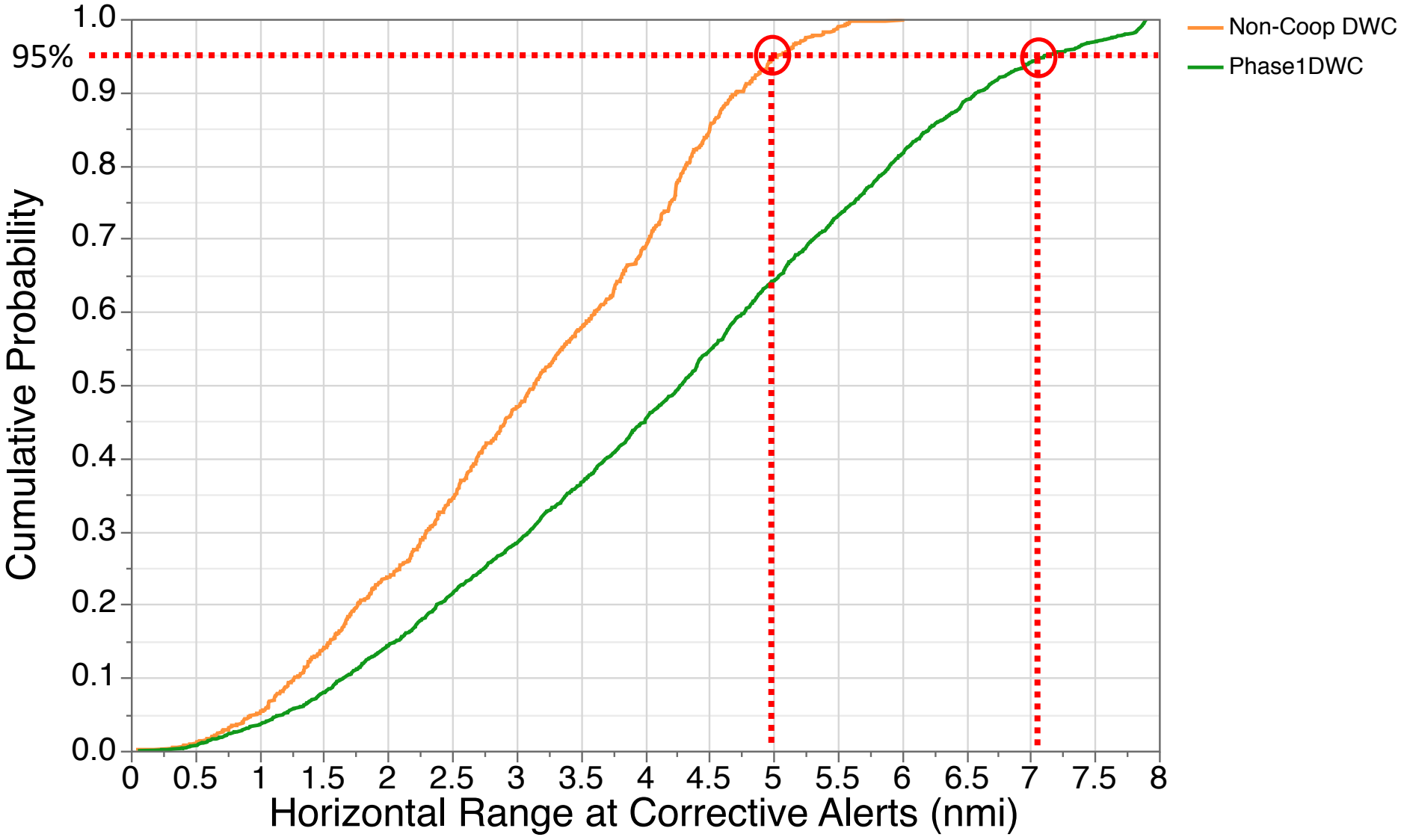


Range at First Corrective Alerts

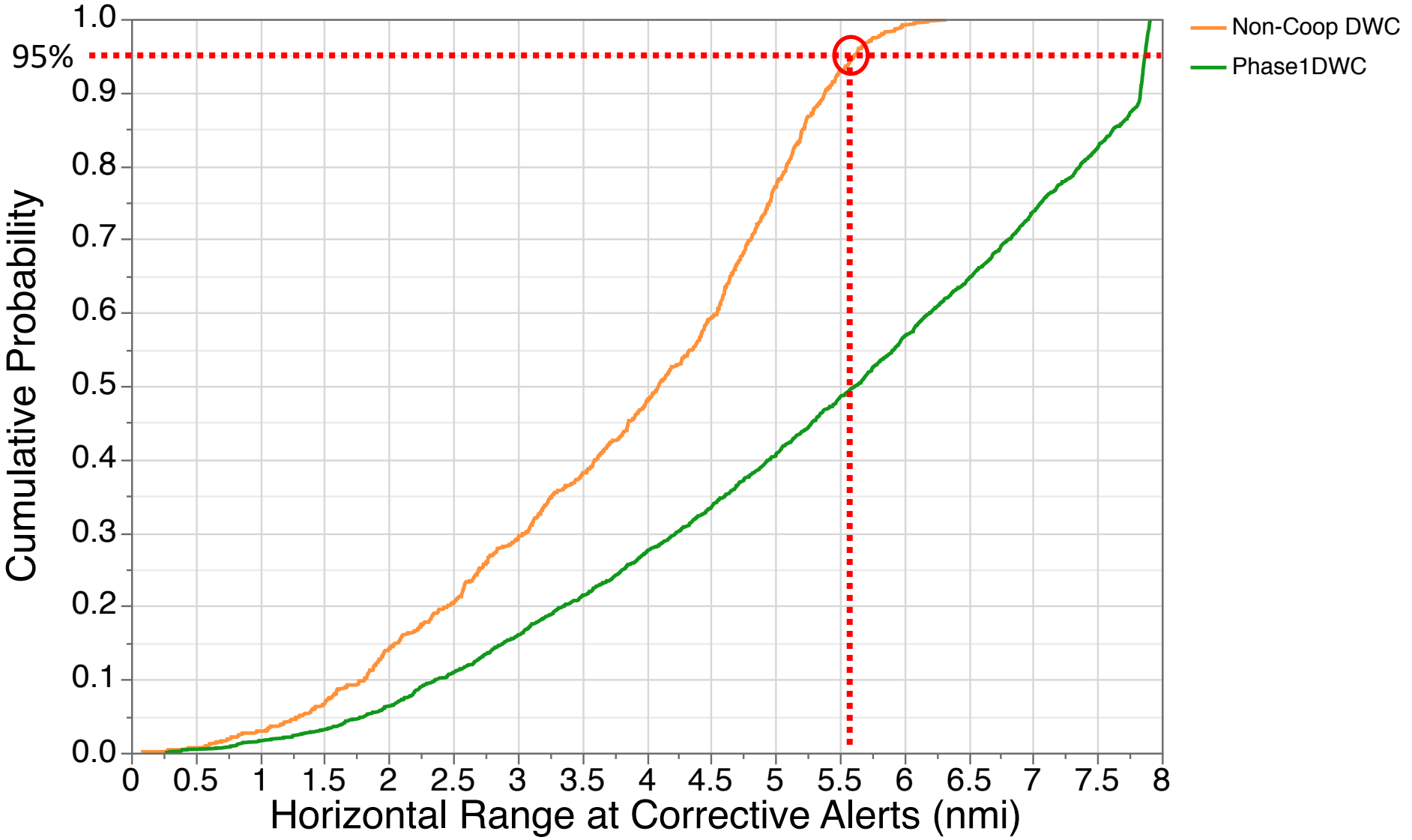
40 kts <= Ownship Speed < 100 kts



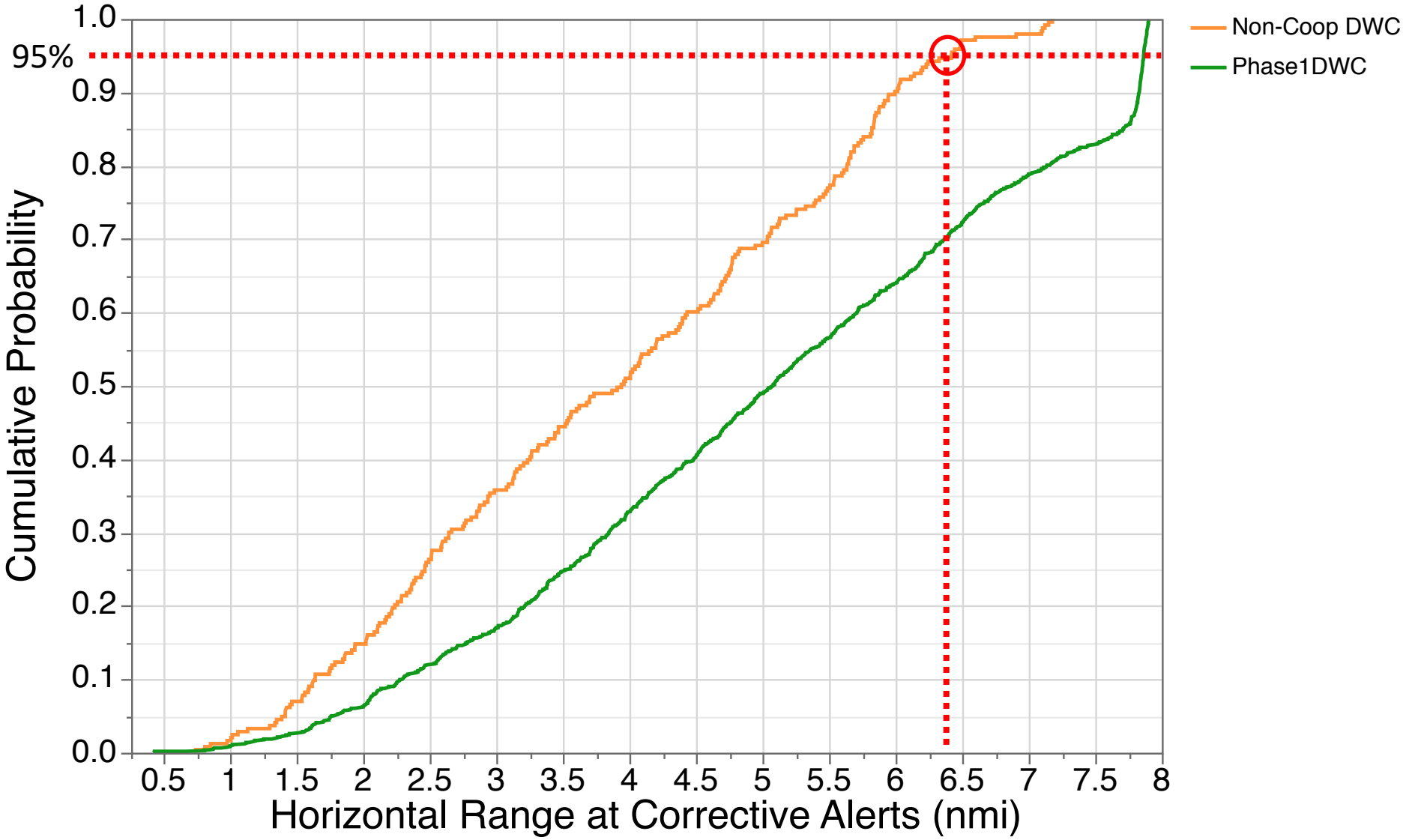
100 kts <= Ownship Speed < 150 kts



150 kts <= Ownship Speed < 200 kts



200 kts <= Ownship Speed < 291 kts



Range that Encloses 95% First Corrective Alerts

UA Speed Range	40 to 100 kts	100 to 150 kts	150 to 200 kts	200 to 291 kts
Range (nmi) with Non-Coop DWC	3.8	5	5.6	6.4
Range (nmi) with Phase 1 DWC	5.6	7.1	> 8	> 8

UA Speed Range	40 to 200 kts	40 to 291 kts
Range (nmi) with Non-Coop DWC	4.4	4.6
Range (nmi) with Phase 1 DWC	6.4	6.6

% First Corrective Alerts at Phase 1 Radar Range (6.7 nmi)

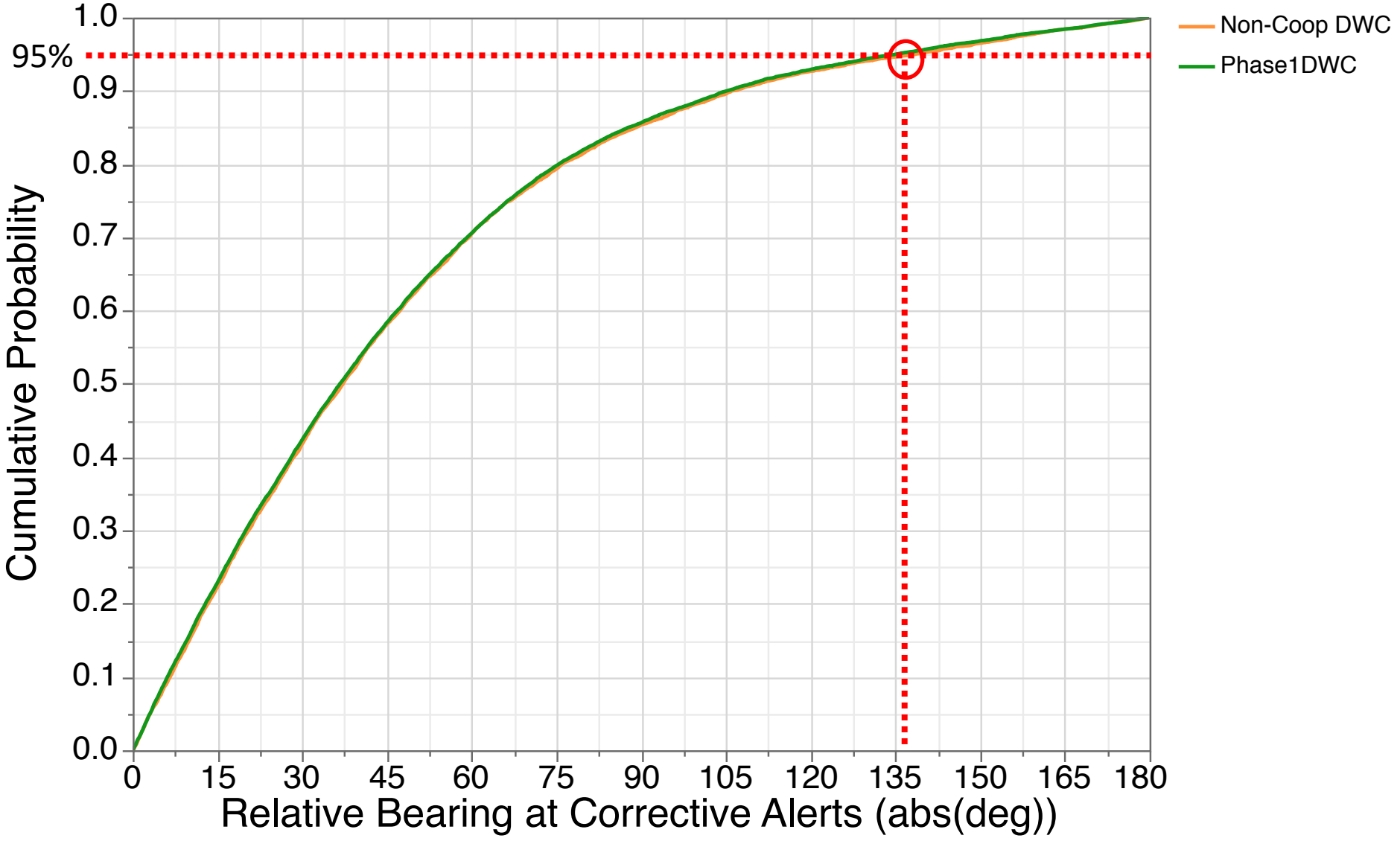
At 6.7 nmi

UA Speed Range	40 to 100 kts	100 to 150 kts	150 to 200 kts	200 to 291 kts
% with Non-Coop DWC	100	100	100	98
% with Phase 1 DWC	100	90	67	75

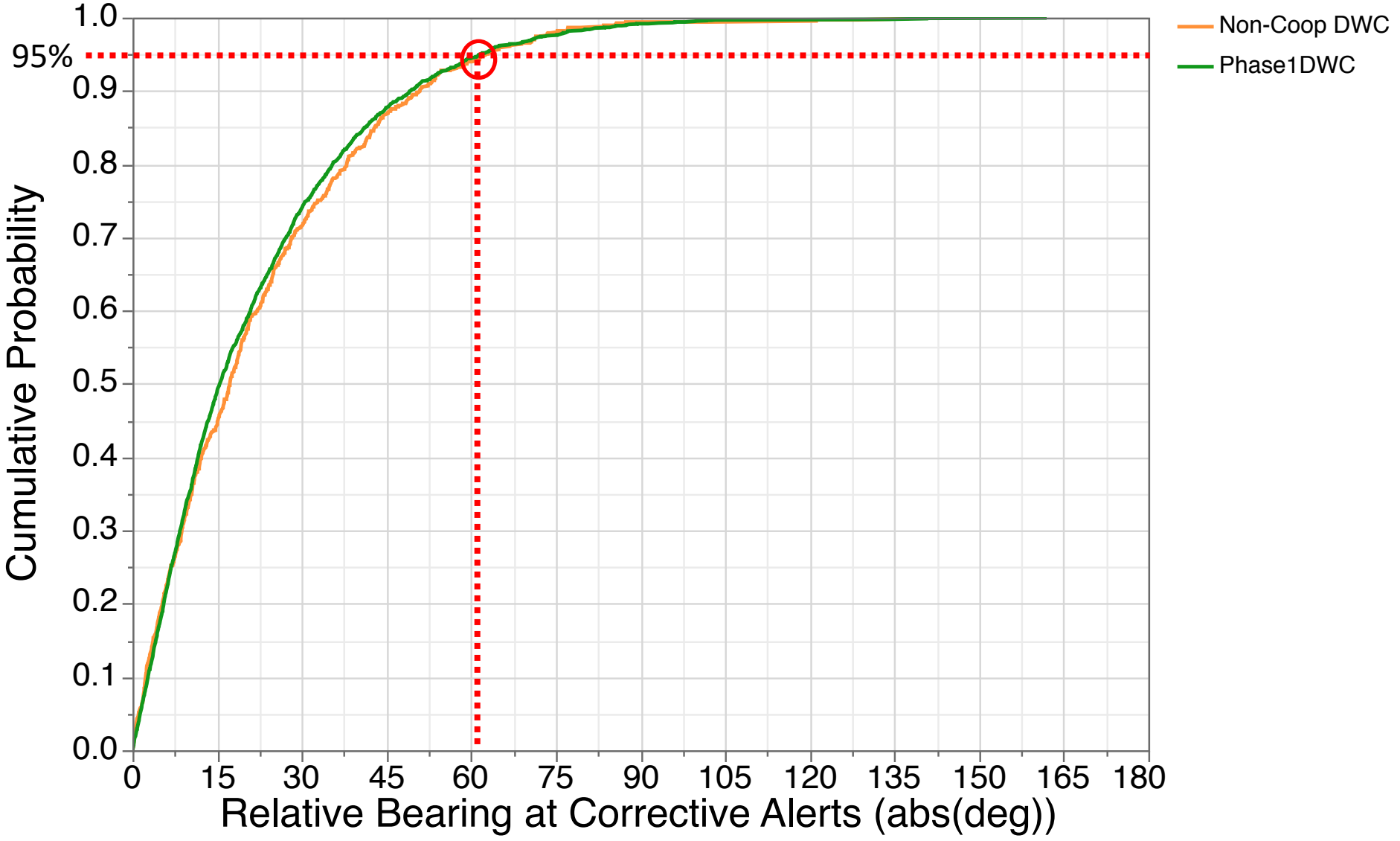
4.8 nmi encloses 67% first corrective alerts for non-coop DWC

Bearing at First Corrective Alerts

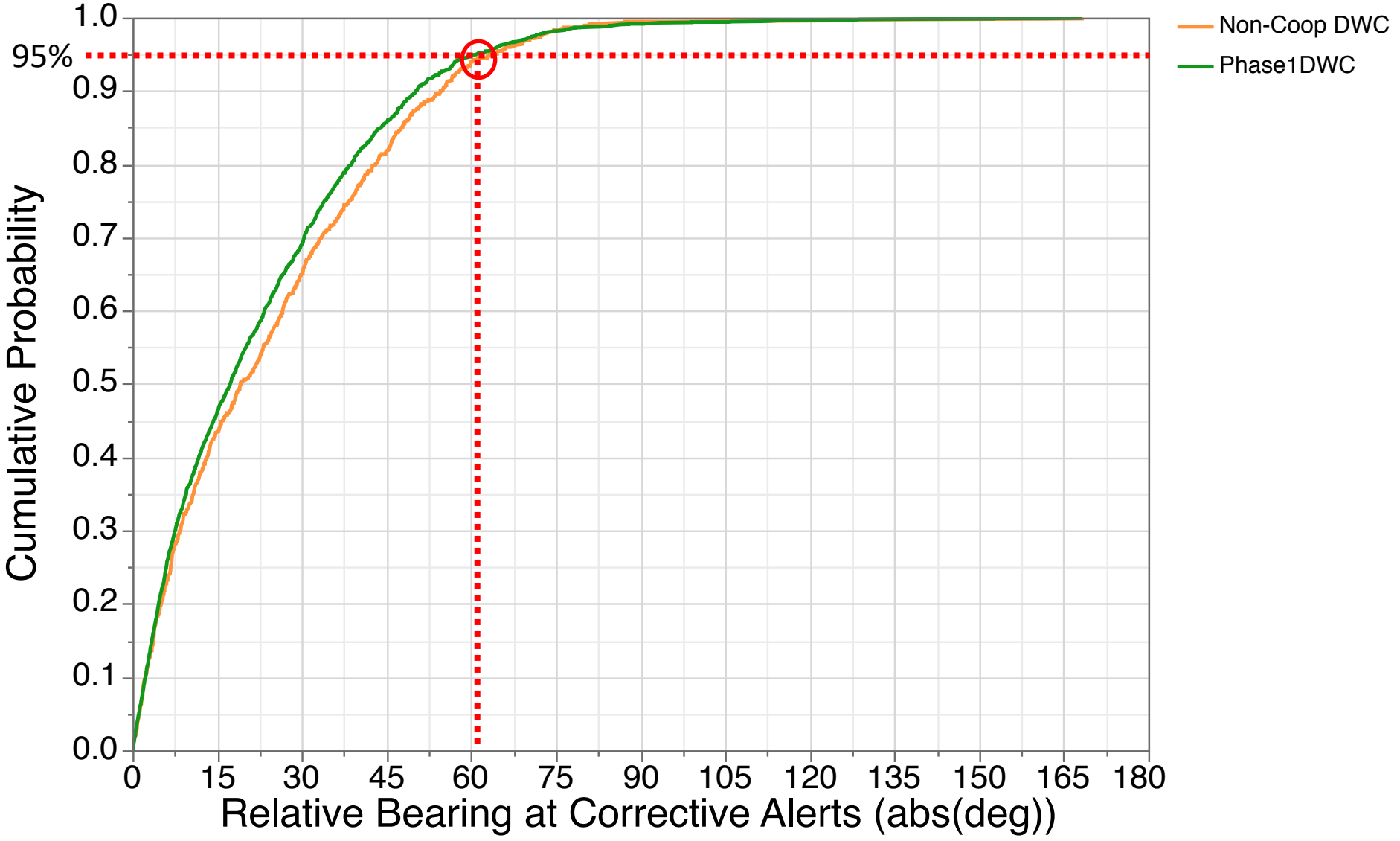
40 kts <= Ownship Speed < 100 kts



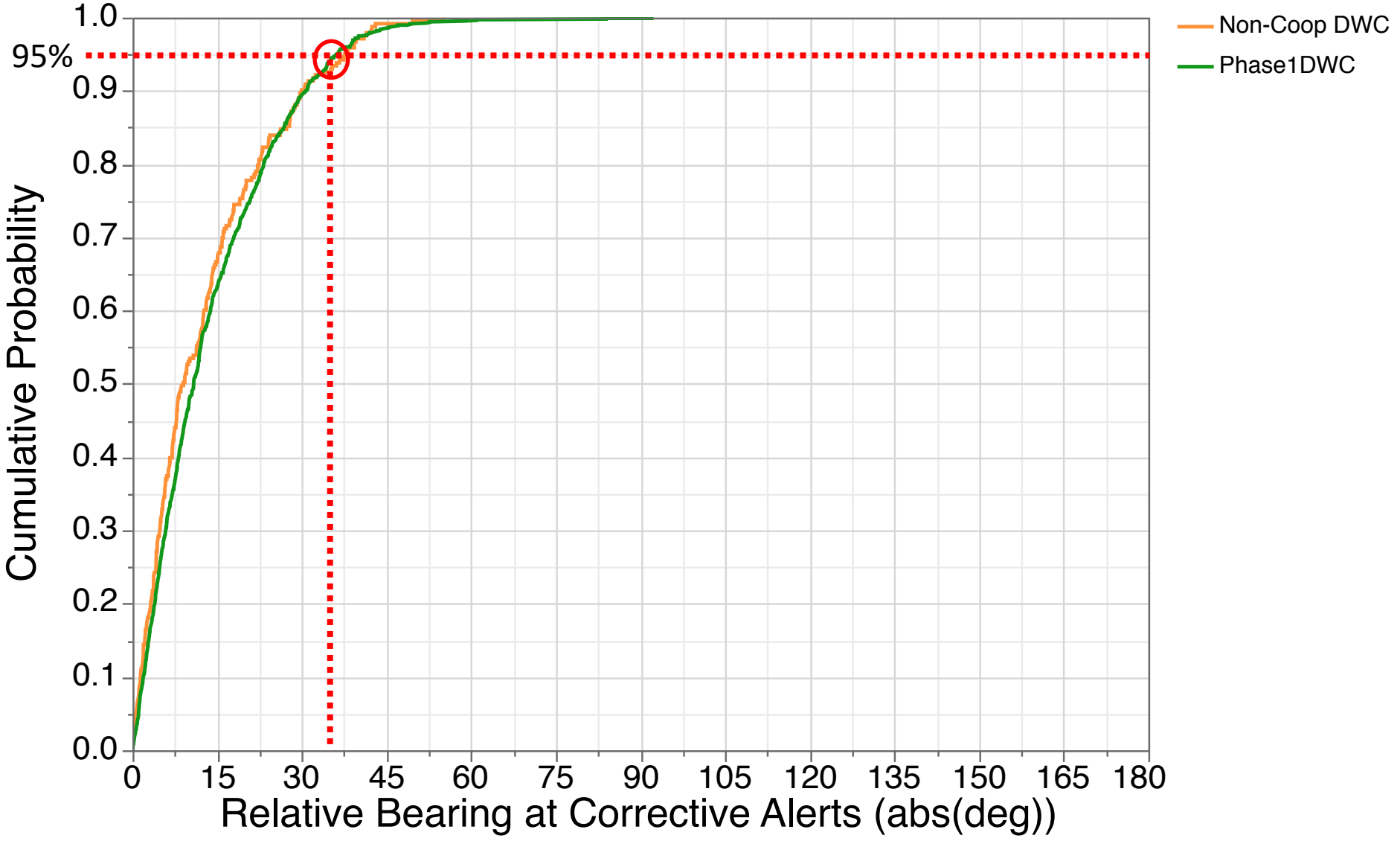
100 kts <= Ownship Speed < 150 kts



150 kts <= Ownship Speed < 200 kts



200 kts <= Ownship Speed < 291 kts



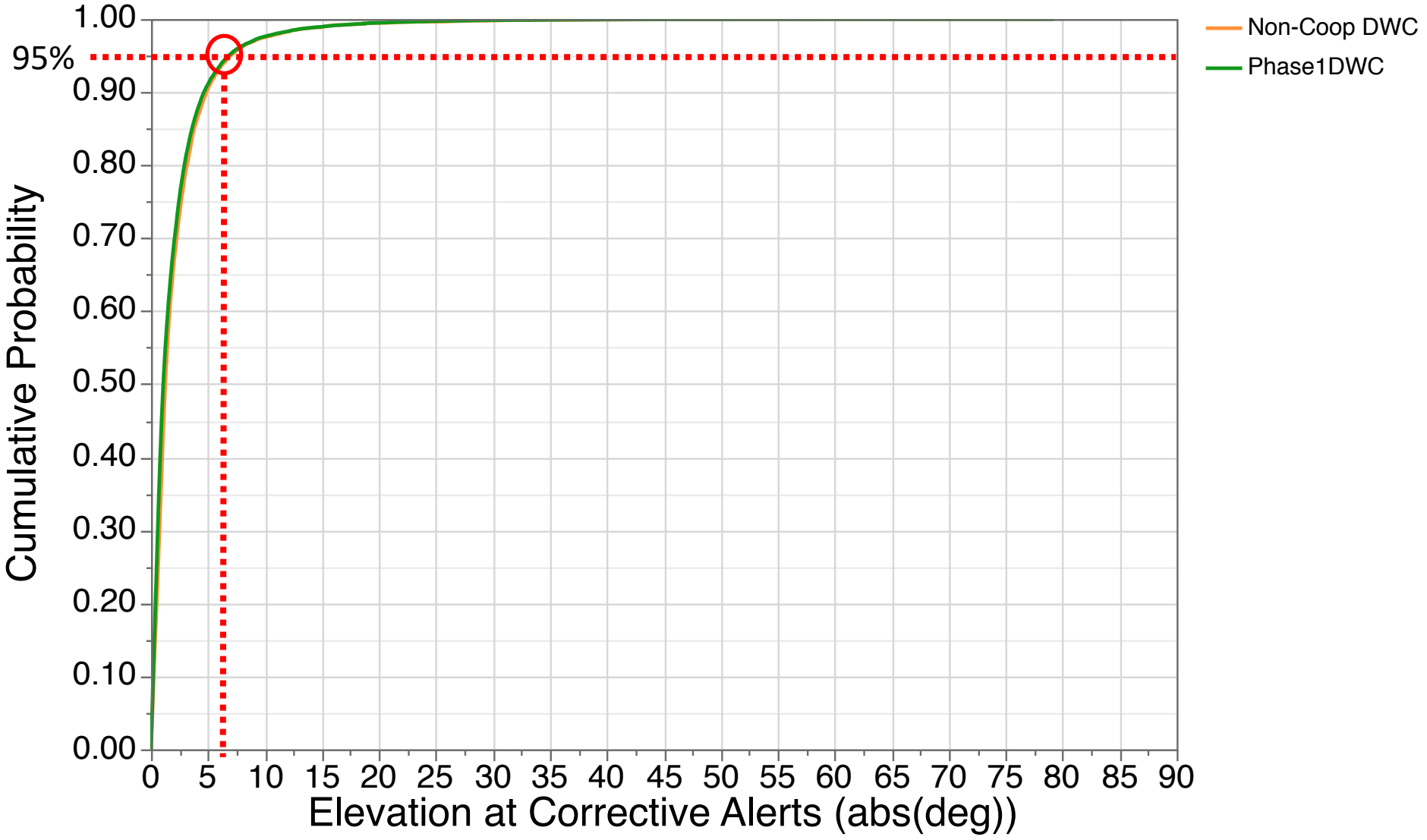
Bearing Range that Encloses 95% First Corrective Alerts

UA Speed Range	40 to 100 kts	100 to 150 kts	150 to 200 kts	200 to 291 kts
Bearing Range (deg) with Non-Coop DWC	138	63	64	38
Bearing Range (deg) with Phase 1 DWC	135	62	61	36

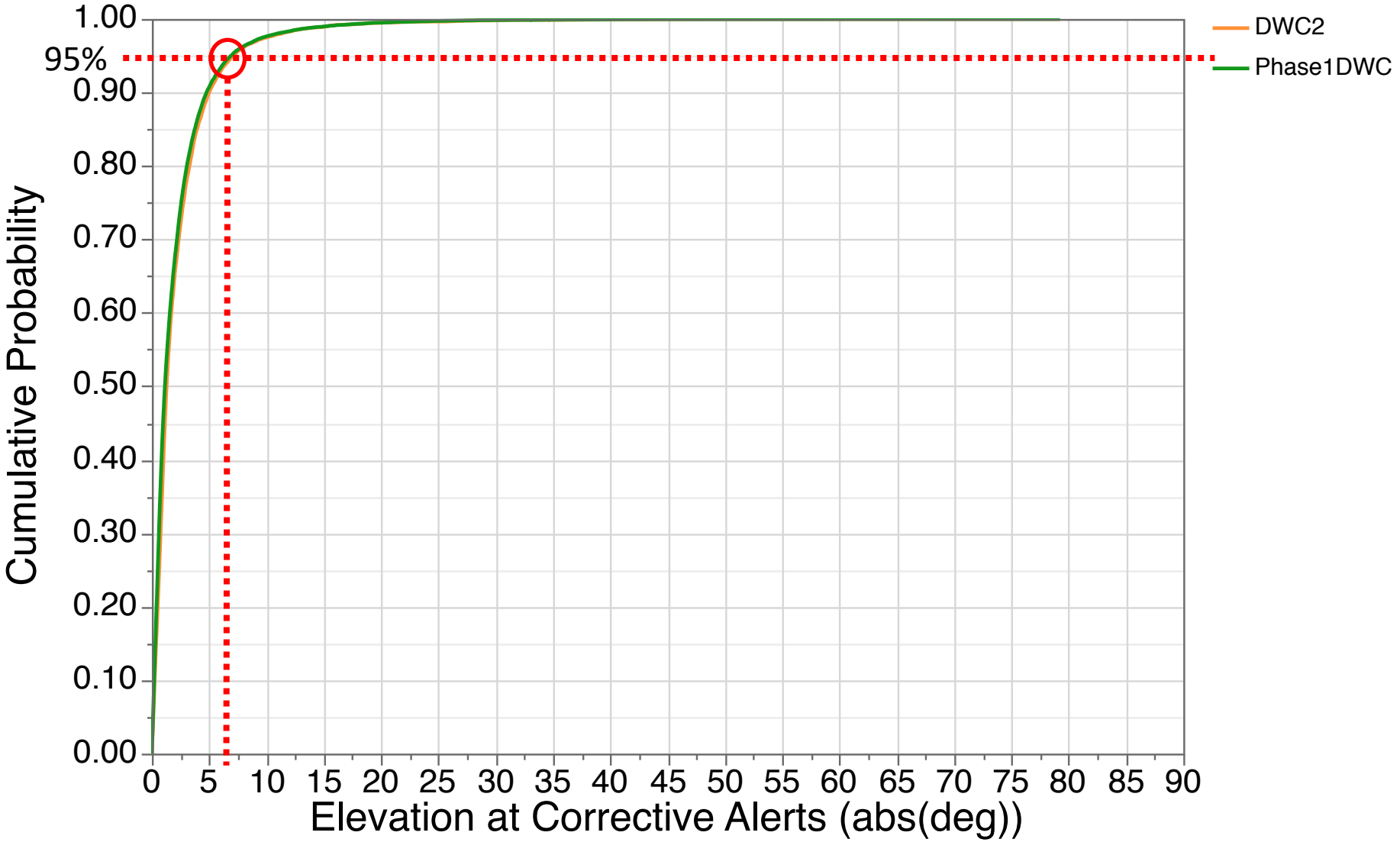
UA Speed Range	40 to 200 kts	40 to 291 kts
Bearing Range (nmi) with Non-Coop DWC	131	130
Bearing Range (nmi) with Phase 1 DWC	127	126

Elevation at First Corrective Alerts

40 kts <= Ownship Speed < 200 kts



40 kts <= Ownship Speed < 291 kts

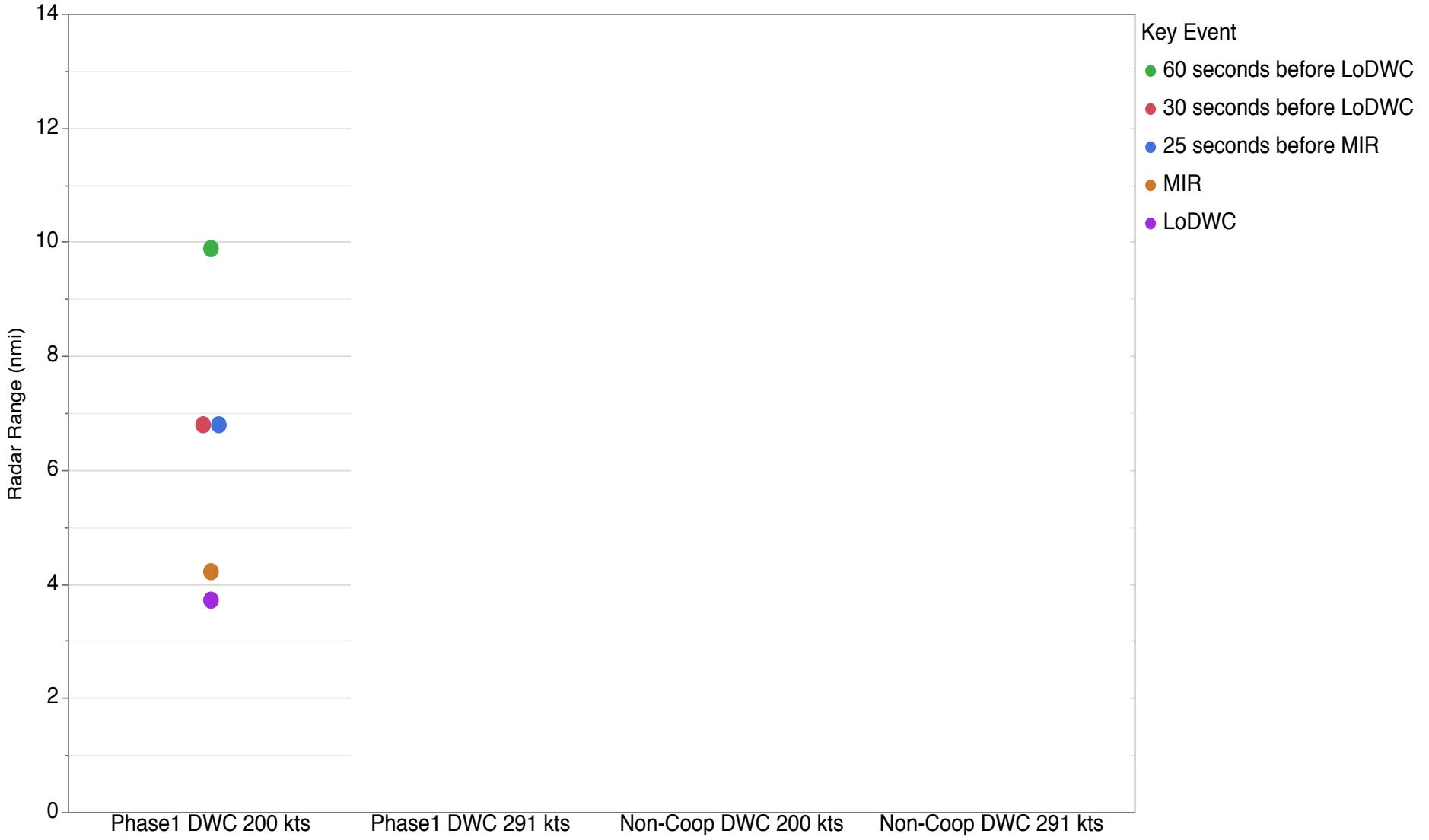


Stressing Case Alerting Timeline

High Closure Rate Head-On Encounter

- Intruder speed: 170 kts
- UA speed: 200 kts or 291 kts
- DWC: Phase 1 DWC or Non-cooperative DWC
- DAIDALUS configuration
  - 30 sec warning alert before LoDWC
  - 60 sec corrective alert before LoDWC
  - Turn rate 3 deg /sec for computing maneuver initiation range (MIR)
  - No buffer in the alerting volume
- Events
  - First corrective alert
  - 25 seconds before MIR (Phase 1 radar range criterion)
  - First warning alert
  - MIR
  - LoDWC

Range at Key Events



Conclusion

- Non-coop DWC requires less surveillance range for supporting the same alerting timeline
  - 6.4 nmi for Phase 1 DWC, 4.4 nmi for non-coop DWC, to detect 95% first Corrective alerts
  - 6.7 nmi for Phase 1 DWC, 4.3 nmi for non-coop DWC, to detect intruder 25 seconds before MIR for stressing case
- When maximum UAS speed is raised to 291 kts, if combined with non-coop DWC, the Phase 1 radar still provides more than enough range.
  - 6.6 nmi for non-cooperative DWC, to detect 95% first Corrective alerts
  - 5 nmi for non-cooperative DWC, to detect intruder 25 seconds before MIR for stressing case
- Bearing distribution varies greatly with the UAS speed
  - +/- 131 degrees bearing to detect 95% first Corrective alerts for UAS between 40 kts and 200 kts
  - 130 degrees if the maximum UAS speed is raised to 291 kts
- Phase 1 radar MOPS's +/- 15 degrees elevation is more than enough to detect 95% first Corrective alerts for UAS

Future Work

- NASA fast-time simulation 3 with DAA maneuvers and sensor uncertainties
  - Experiment plan in preparation, will brief to SC-228 soon
  - Data collection from July to August 2019
- NASA flight test 6 using Honeywell's low C-SWaP DAPA Lite radar
  - Data collection from September to December 2019
- NASA HITL for low C-SwaP operations
  - Data collection in September 2019
- Surveillance requirement analysis
  - Analyses in Appendices B, C and D of DO-366 for low C-SWaP sensors (Q4 2019)
  - Analyses in Appendices B, C and D of DO-366 for the Phase 1 radar (if necessary)



Backup Slides

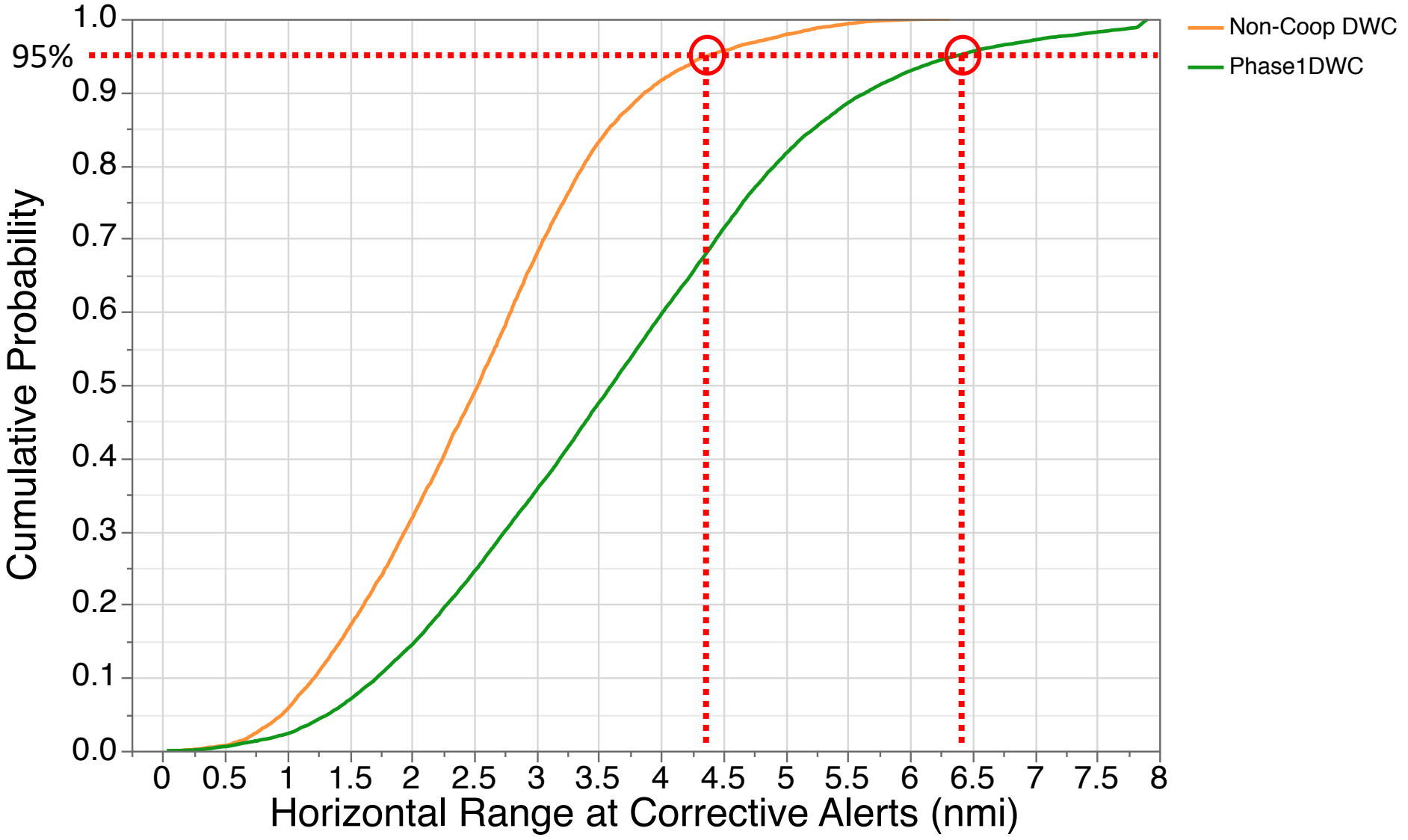
UAS Mission Flight Data Set

- The proposed UAS flight data sets were identified and developed by Intelligent Automation Inc. (IAI) in collaboration with NASA ARC.
  - Subject matter experts
  - Socio-economic analysis
  - Literature reviews
  - Stakeholder community inputs
- Total 19 UAS missions with approximately 26,500 flights over a 24-hour period.
- Flight data set for each mission consists of a set of flights that have altitude, speed, aircraft type, origin airport, destination airport, takeoff times, and waypoints.

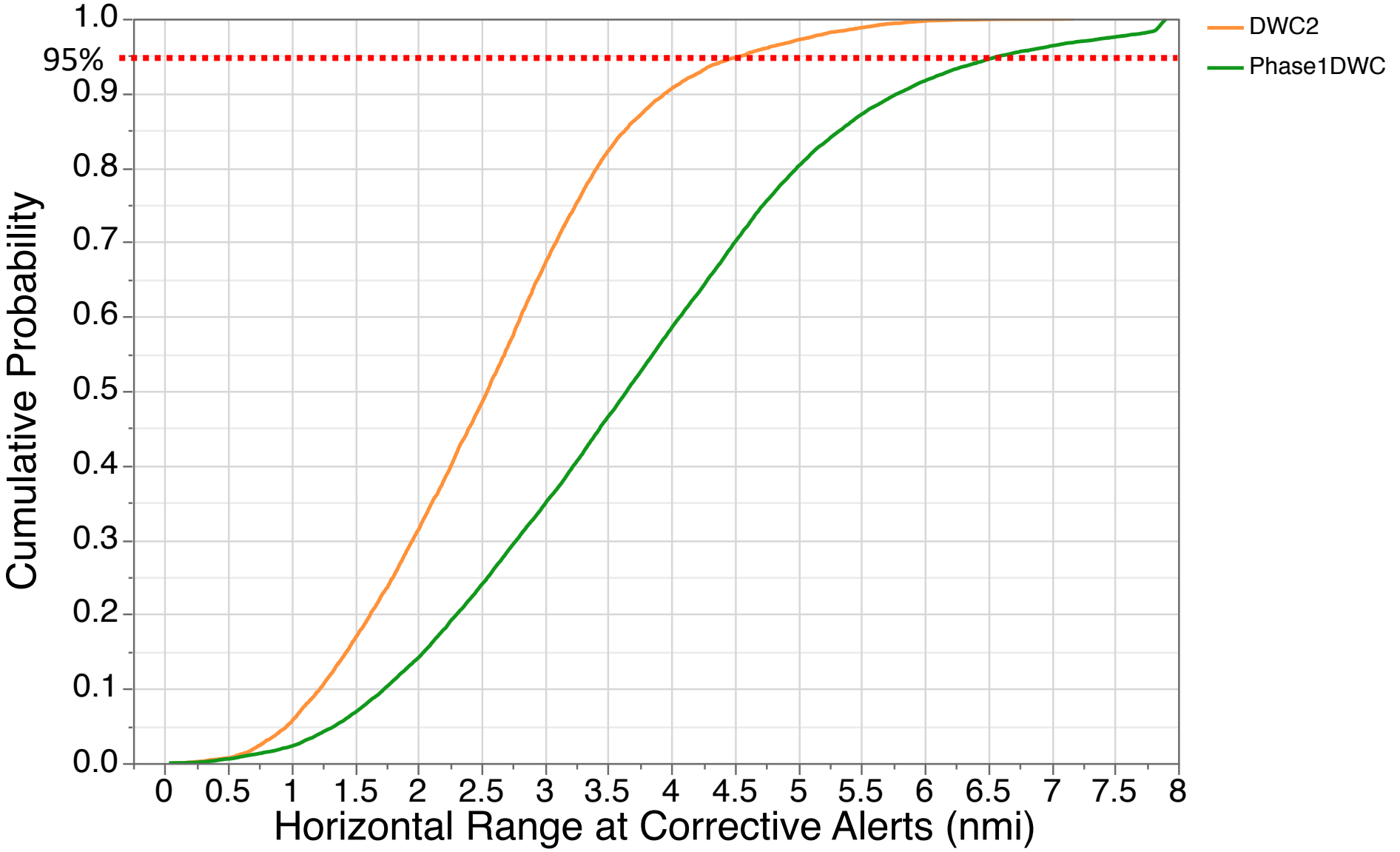
Characteristics of UAS Missions

Mission Type	Unmanned Aircraft	Cruise Altitude	Cruise Speed (KTAS)	Flight Pattern
Aerial Imaging and Mapping	Aerosonde Mk 4.7	3000 ft. AGL	44 to 51	Radiator-grid pattern
Air Quality Monitoring	Shadow (RQ-7B)/NASA Sierra	4k,5k, and 6k ft. AGL	74 to 89	Radiator-grid pattern
On-Demand Air Taxi at Low Altitude	Cirrus SR22T	6k-11k MSL	153 to 166	Point-to-Point
On-Demand Air Taxi at High Altitude	Cessna Mustang	11k-32k MSL	156 to 340	Point-to-Point
Airborne Pathogen Tracking	Shadow (RQ-7B)/NASA Sierra	3k ft., 5k ft., to 10k ft. AGL	72 to 97	Radiator-grid pattern
Border Patrol	Predator-B (MQ-9)	5k ft., 10k ft., and 15k ft. AGL	129 to 173	Radiator-grid pattern
Cargo Delivery	Cessna 208	7k, 8k, 9k, 10k ft MSL	137 to 172	Point-to-Point
Flood Inund. Mapping	Aerosonde Mk 4.7	4,000 ft. AGL	46 to 51	Grid pattern
Flood Stream Flow	Aerosonde Mk 4.7	4,000 ft. AGL	46 to 51	Grid pattern and/or along stream direction
Law Enforcement	Aerosonde Mk 4.7	3,000 ft. AGL	44 to 51	Three types of pattern: 1) grid pattern, 2) random, 3) outward spiral
Maritime Patrol	Global Hawk (RQ4A)	5,000 ft. to 35,000 ft. AGL	151 to 321	Radiator-grid pattern
News Gathering	Aerosonde Mk 4.7	1,500 ft. and 3,000 ft. AGL	44 to 51	Random-path: e.g., police-chase; Circular orbit:
Point Source Emission	Shadow (RQ-7B)/NASA Sierra	3,000 ft. AGL	72 to 80	Round-the-clock
Spill Monitoring	Shadow (RQ-7B)/NASA Sierra	3,000 ft. to 10,000 ft. AGL	72 to 93	Radiator-grid pattern
Strategic Wildfire Monitoring	Predator-B (MQ-9)	31,000 MSL	209	Grid pattern
Tactical Fire Monitoring	Shadow (RQ-7B)/NASA Sierra	3,000 ft. AGL	72 to 75	Circular flight path following the perimeter of a wildfire
Traffic Monitoring	Shadow (RQ-7B)/NASA Sierra	1,500 ft. AGL	58 to 84	Geo-spatial monitoring flight path
Weather Data Collection	Global Hawk	5,000 ft. to 35,000 ft. AGL	151 to 321	Radiator-grid pattern
Wildlife Monitoring	Aerosonde Mk 4.7	3,000 ft. AGL	44 to 51	Radiator-grid pattern

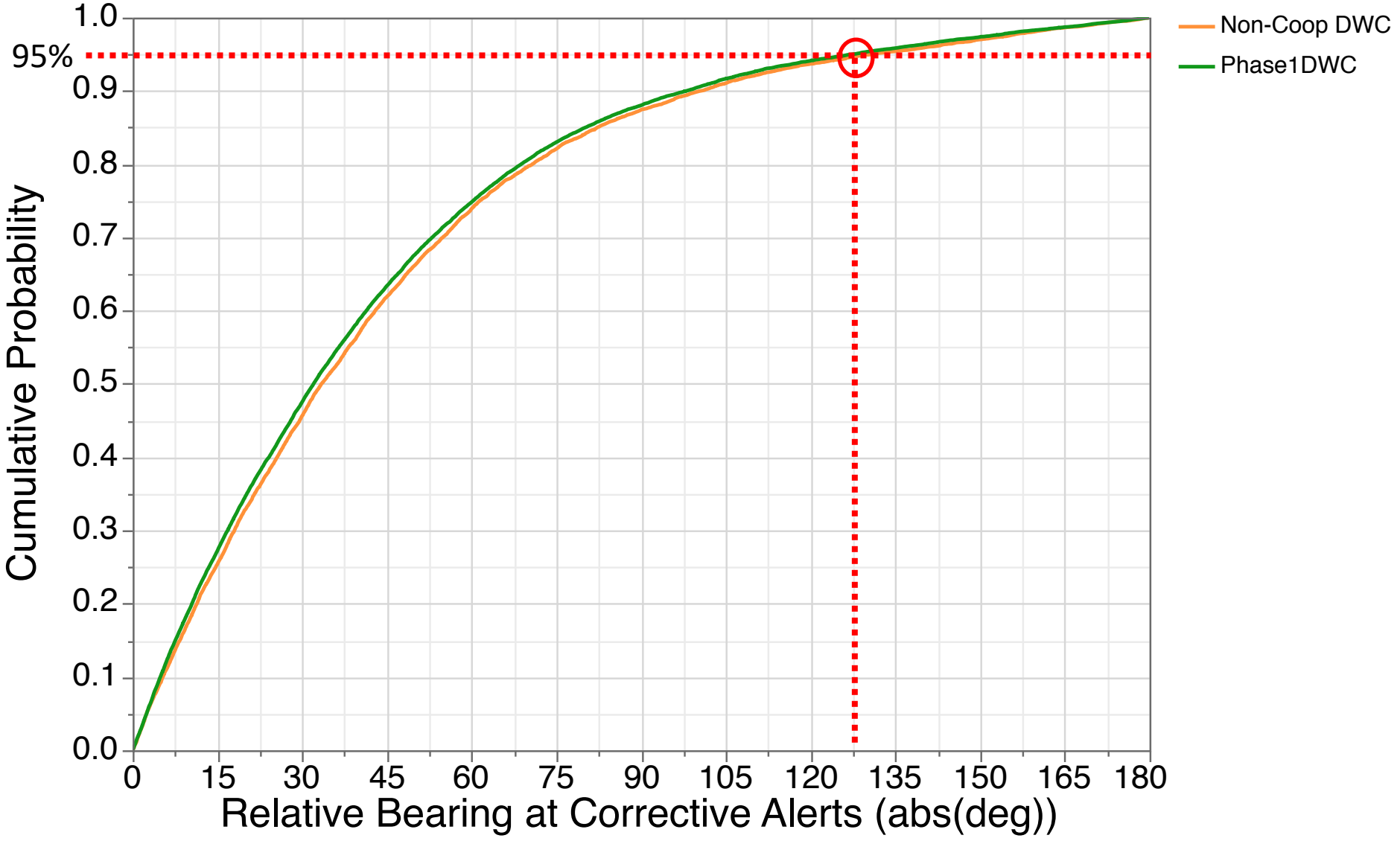
40 kts <= Ownship Speed < 200 kts



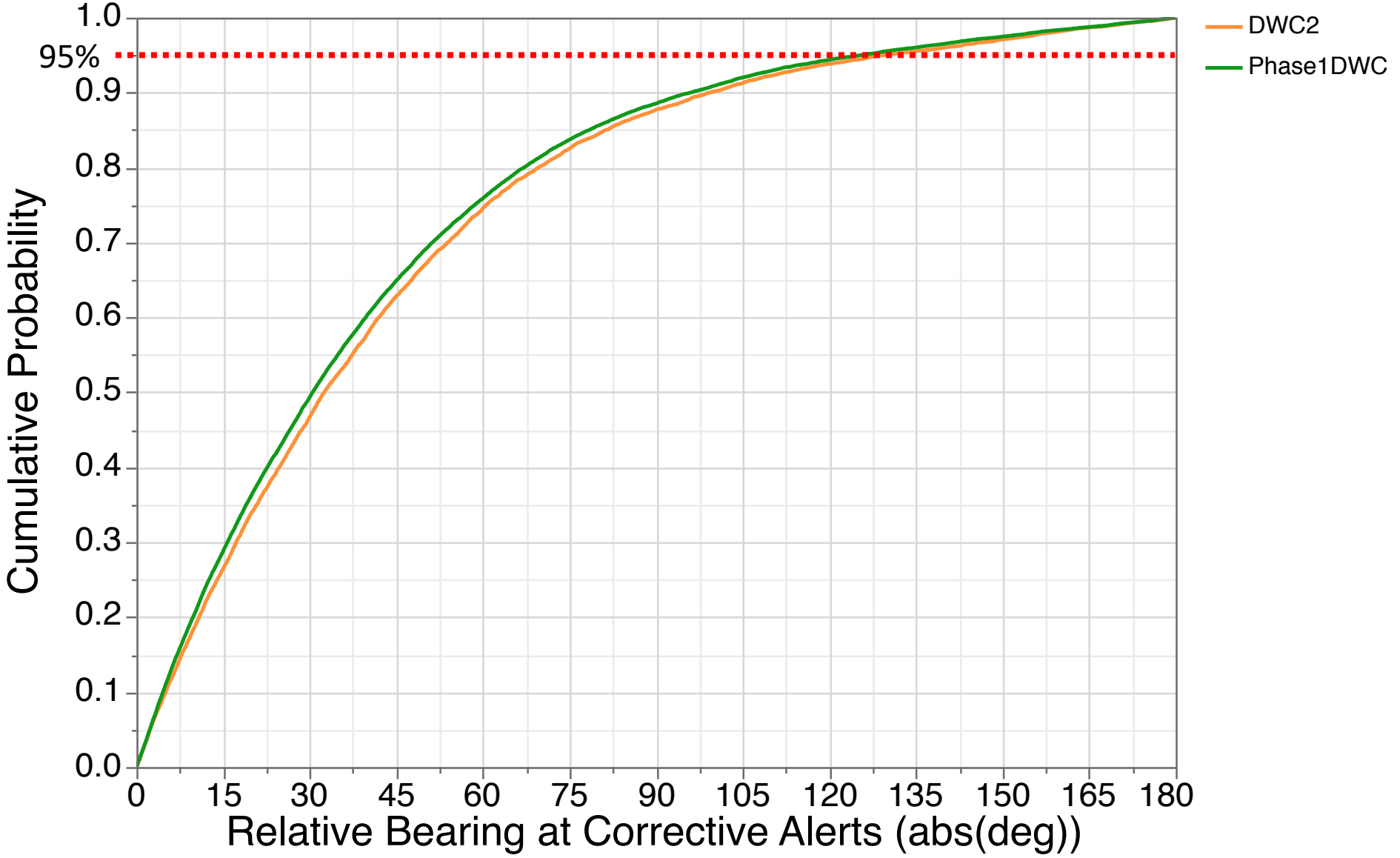
40 kts <= Ownship Speed < 291 kts



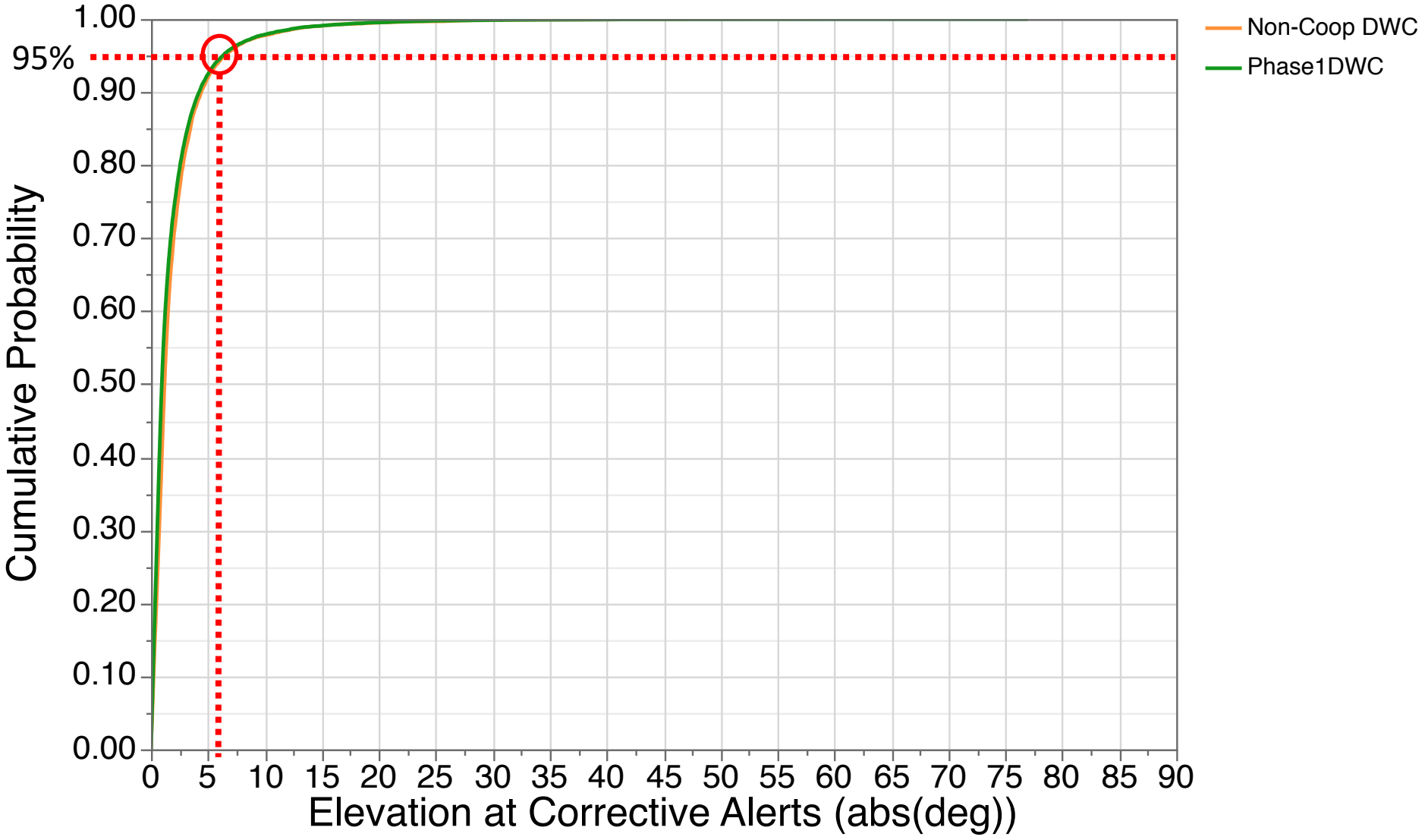
40 kts <= Ownship Speed < 200 kts



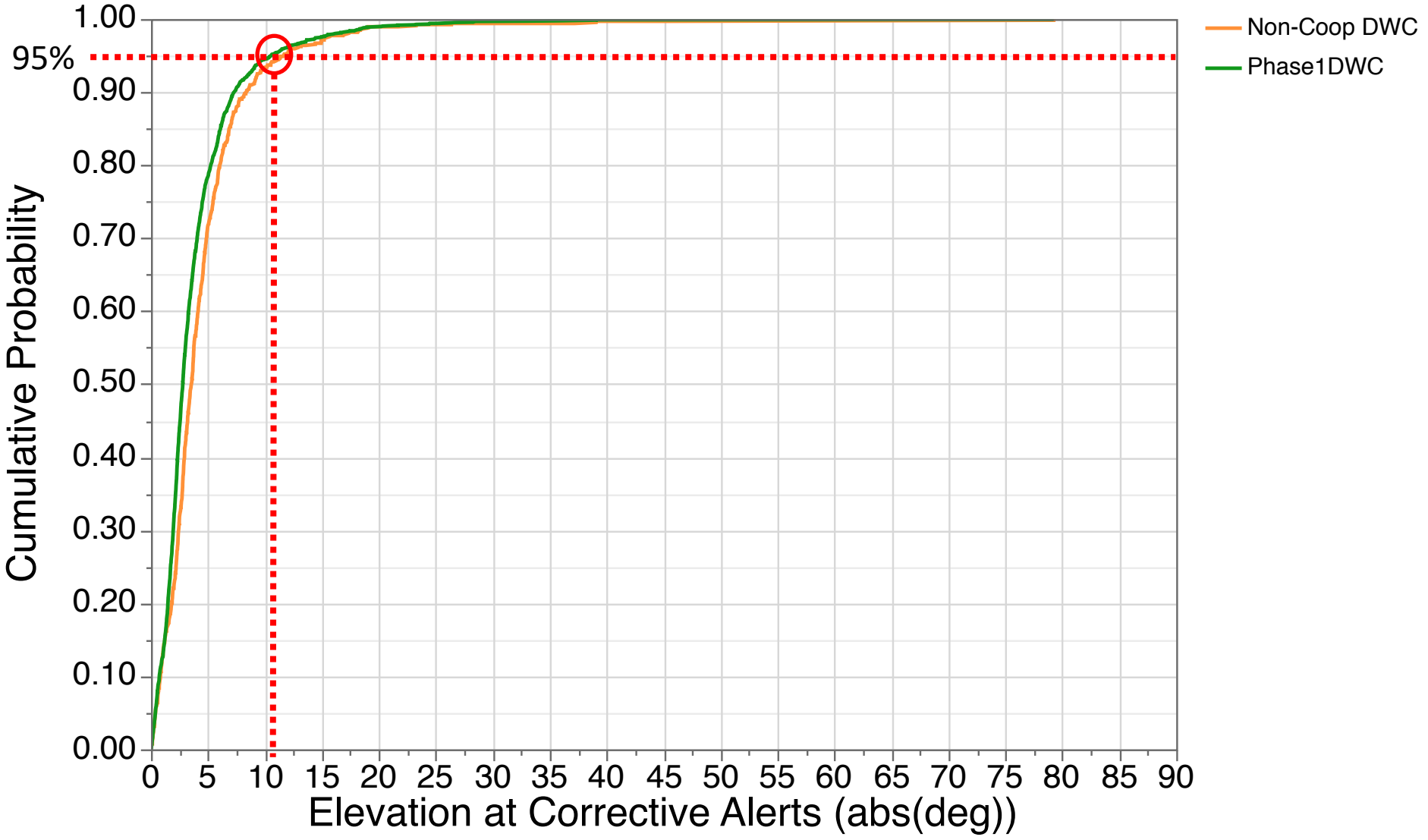
40 kts <= Ownship Speed < 291 kts



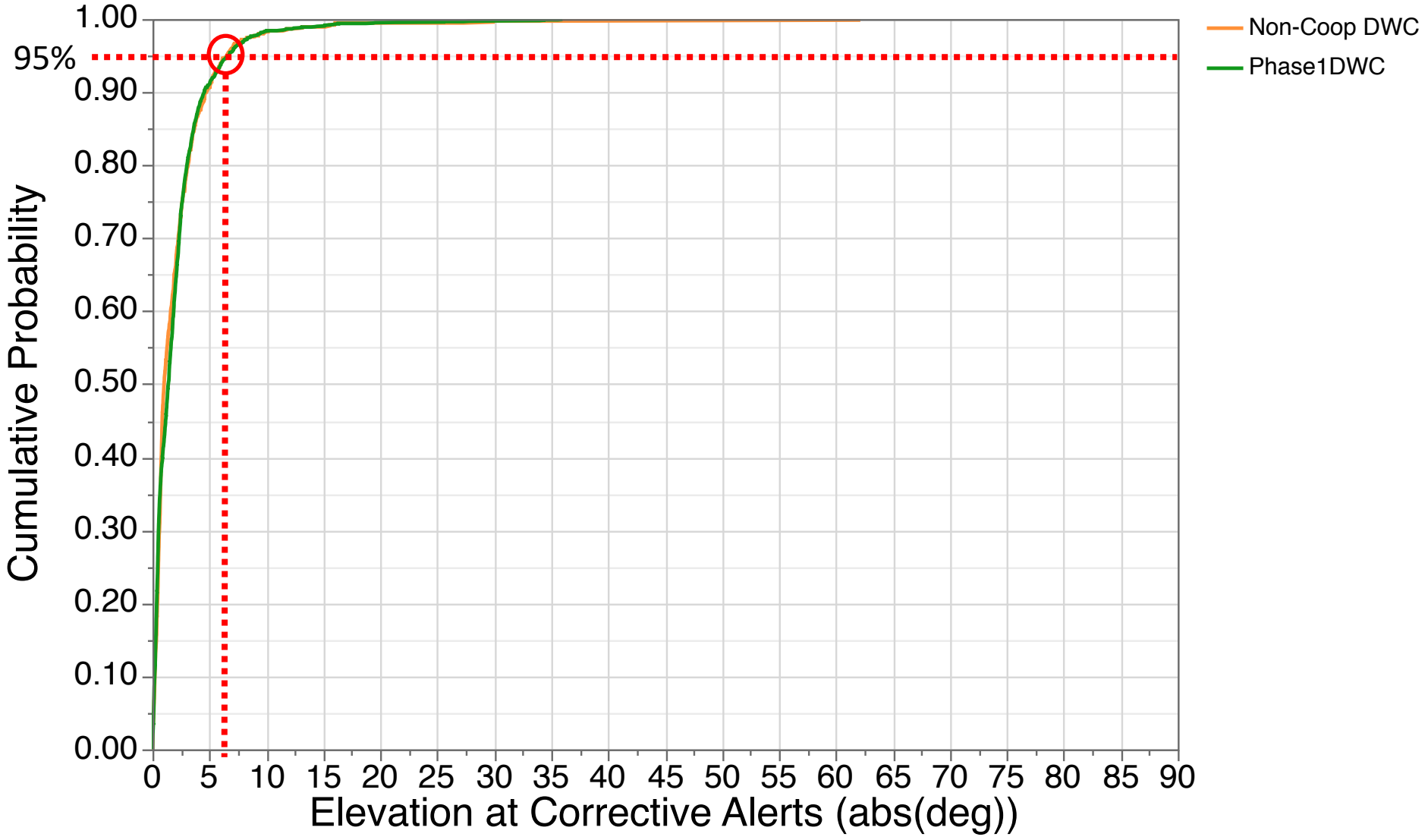
40 kts <= Ownship Speed < 100 kts



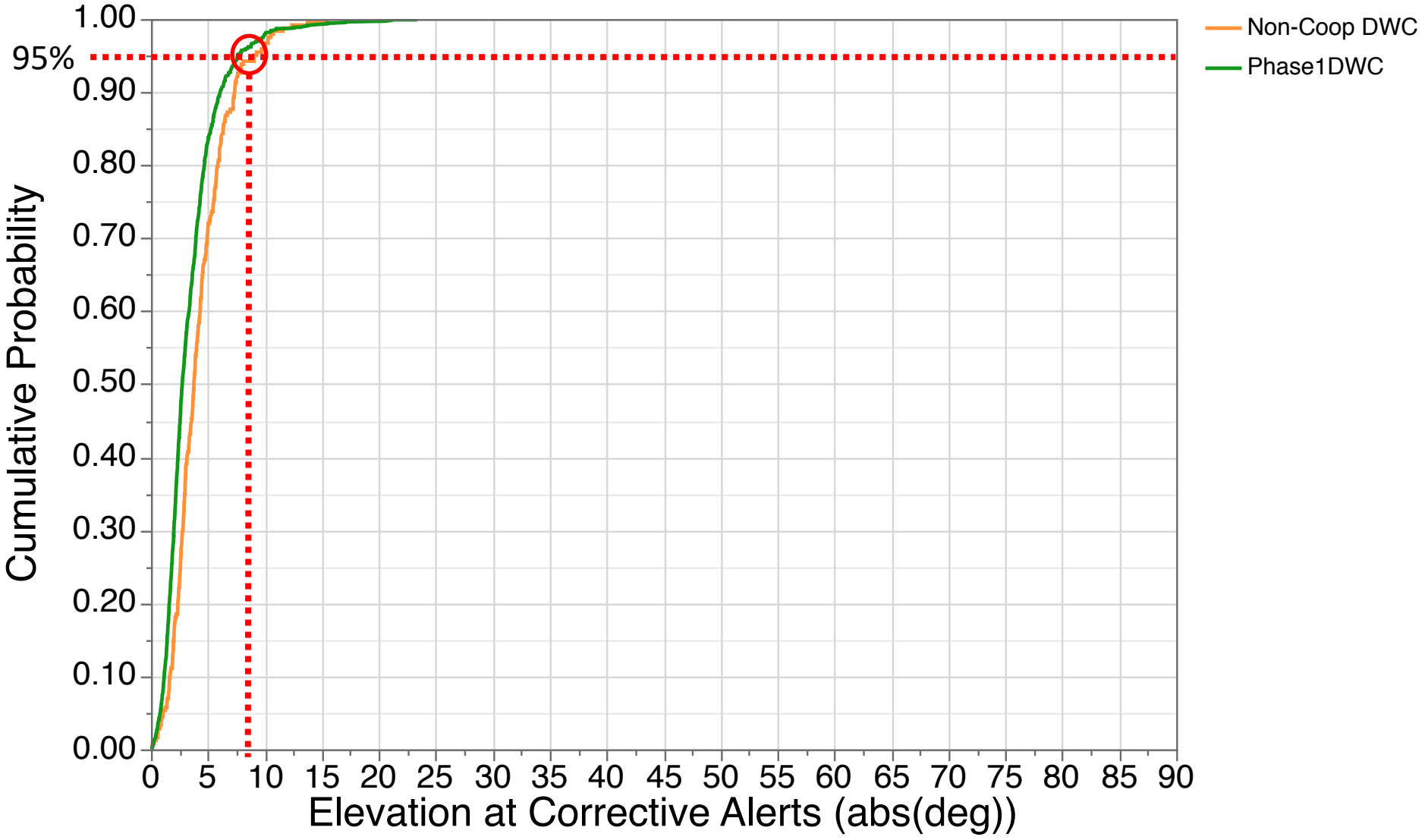
100 kts <= Ownship Speed < 150 kts



150 kts <= Ownship Speed < 200 kts



200 kts <= Ownship Speed < 291 kts



Elevation Range that Encloses 95% First Corrective Alerts

UA Speed Range	40 to 100 kts	100 to 150 kts	150 to 200 kts	200 to 291 kts
Elevation Range (deg) with Non-Coop DWC	6.5	12	6.6	9.2
Elevation Range (deg) with Phase 1 DWC	6.3	11	6.7	7.6

UA Speed Range	40 to 200 kts	40 to 291 kts
Elevation Range (nmi) with Non-Coop DWC	7.0	7.1
Elevation Range (nmi) with Phase 1 DWC	6.8	6.9