

# Examining the relationship between atmospheric turbulence and metric variability at NASA Quesst Mission Phase 2 Dry Run

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# Acknowledgements

- NASA Quesst Phase 2 Dry Run team
- NASA Advanced Air Vehicles Program (AAVP) graduate fellowship program
- Will Doeblner

# NASA Quesst Phase 2 Dry Run

- Full-scale dry run with an F-15B
- June and July 2025
- Purpose: perform various test points to prepare for X-59
  - Limited flights
- ARray Instrumentation for Sonic Thump Observations in TurbuLence (ARISTOTLE)
  - Analyze variability due to atmospheric turbulence
  - What is the relationship between loudness variability and turbulence or other variables?



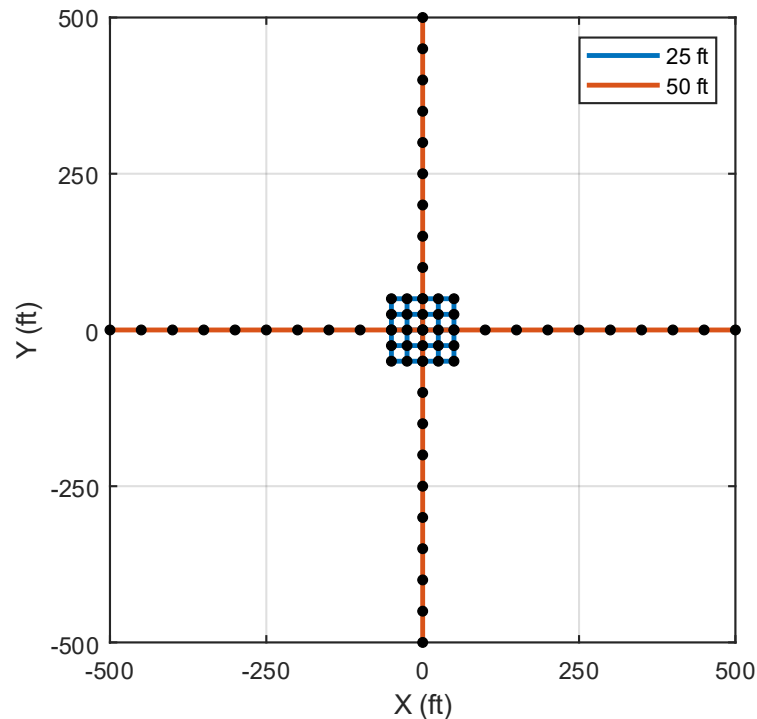
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# ARISTOTLE at Quesst Phase 2 Dry Run

- Measured 19 booms
- 4 trajectories



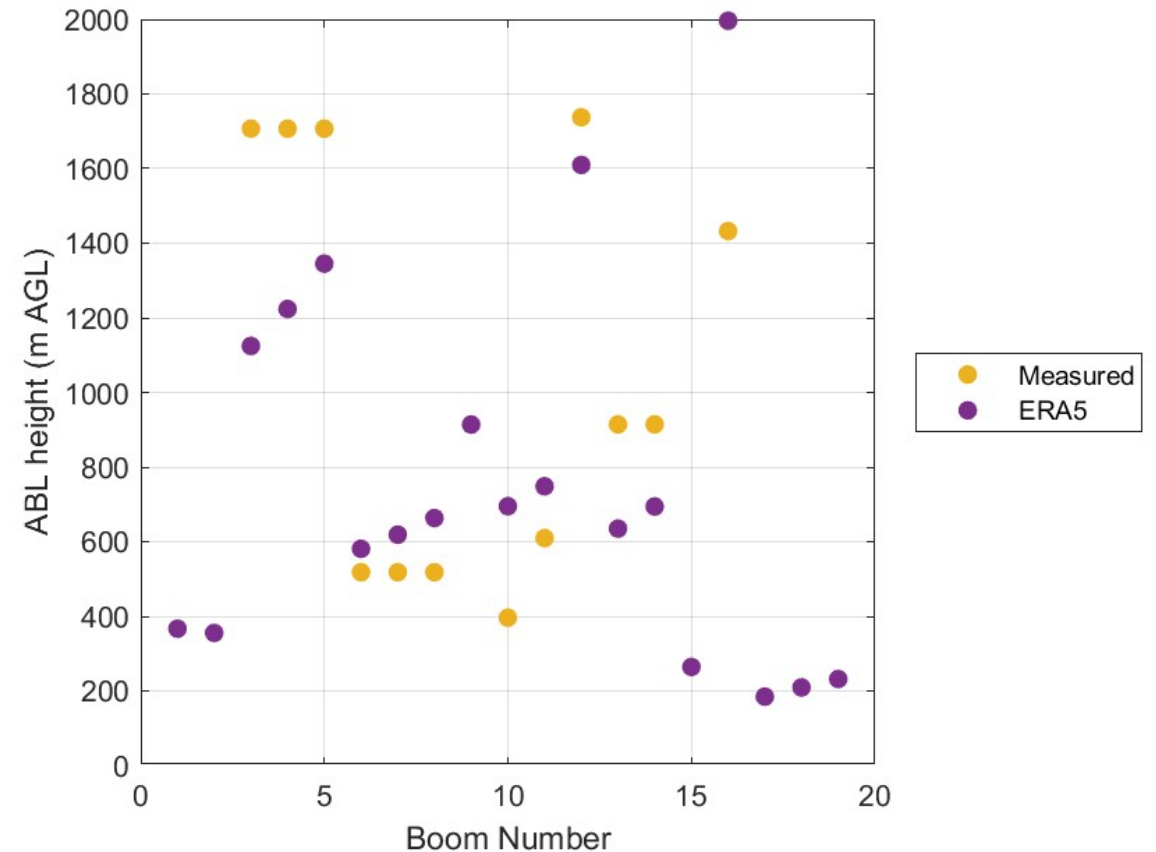
# Weather

- Surface weather
  - Temperature
    - Mean: 29.8°C
    - Range: 20.4 to 35.7°C
  - Humidity
    - Mean: 27.2%
    - Range: 12.1 to 51.5%
  - Wind speed and direction
    - Mean: 2.1 m/s
    - Range: 0.0 to 5.3 m/s

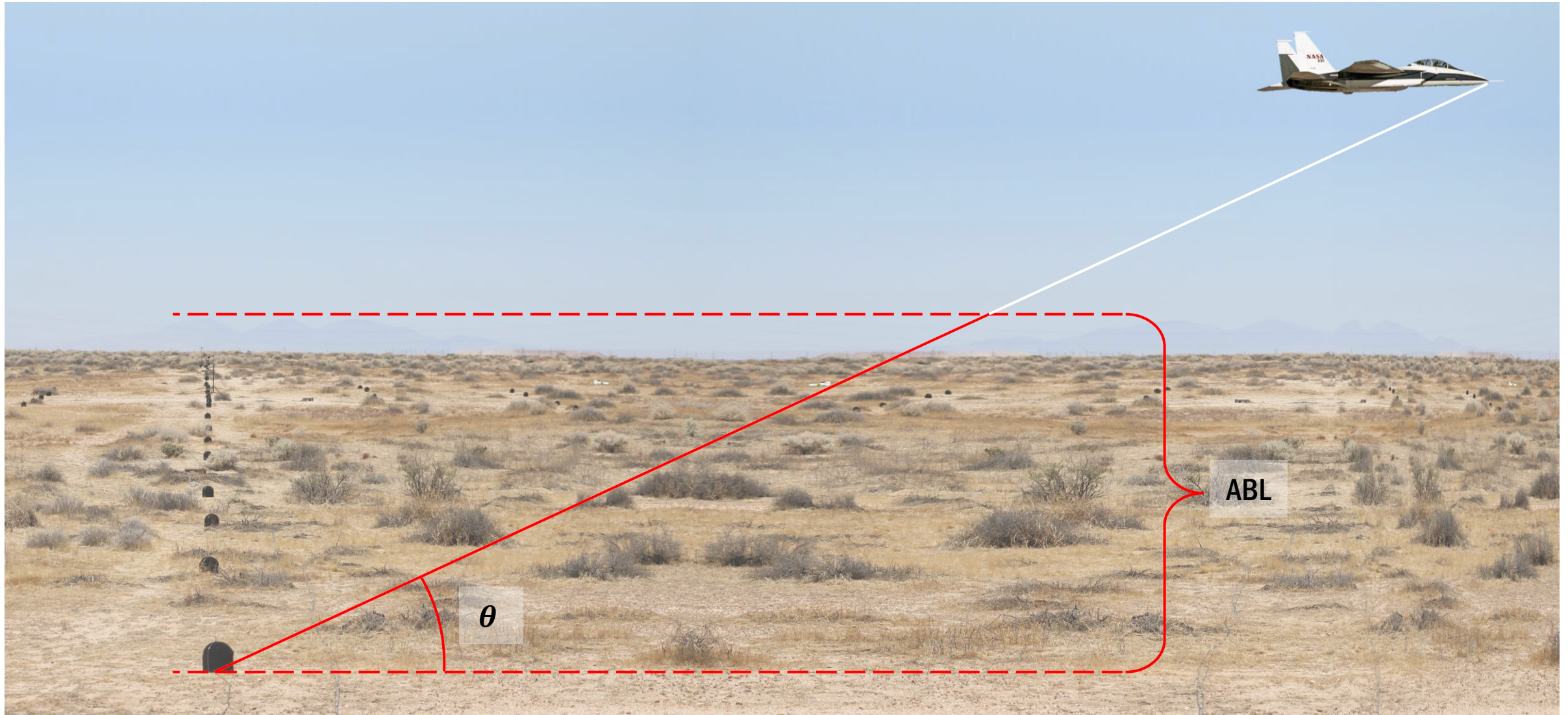


# Atmospheric Boundary Layer (ABL) heights

- Measured
  - Parcel method from weather balloon
  - Missing measured ABL heights for 7 booms
- ERA5
  - Maximum difference: 602 m
  - Mean absolute difference: 280 m
  - Use ERA5 in analysis
    - $\sigma_{\text{vector}}$  RMS difference: 0.06 m/s (ERA5 vs measured ABL heights)

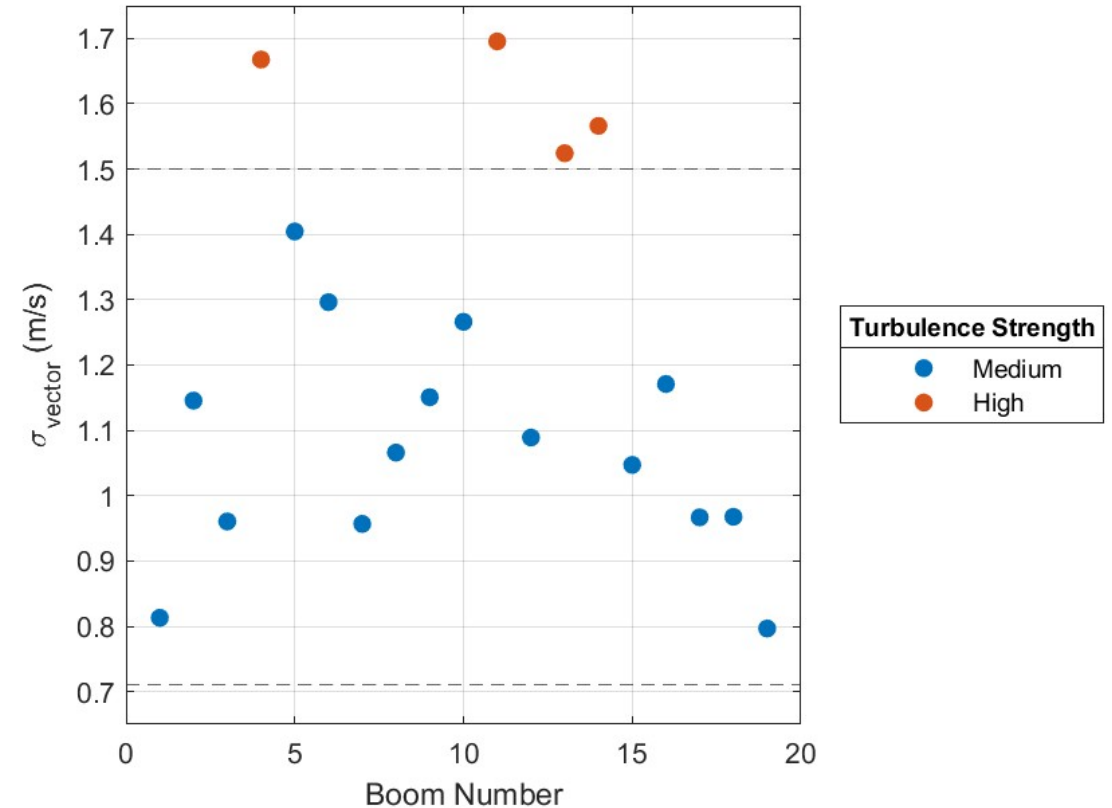


# Propagation distance through the ABL

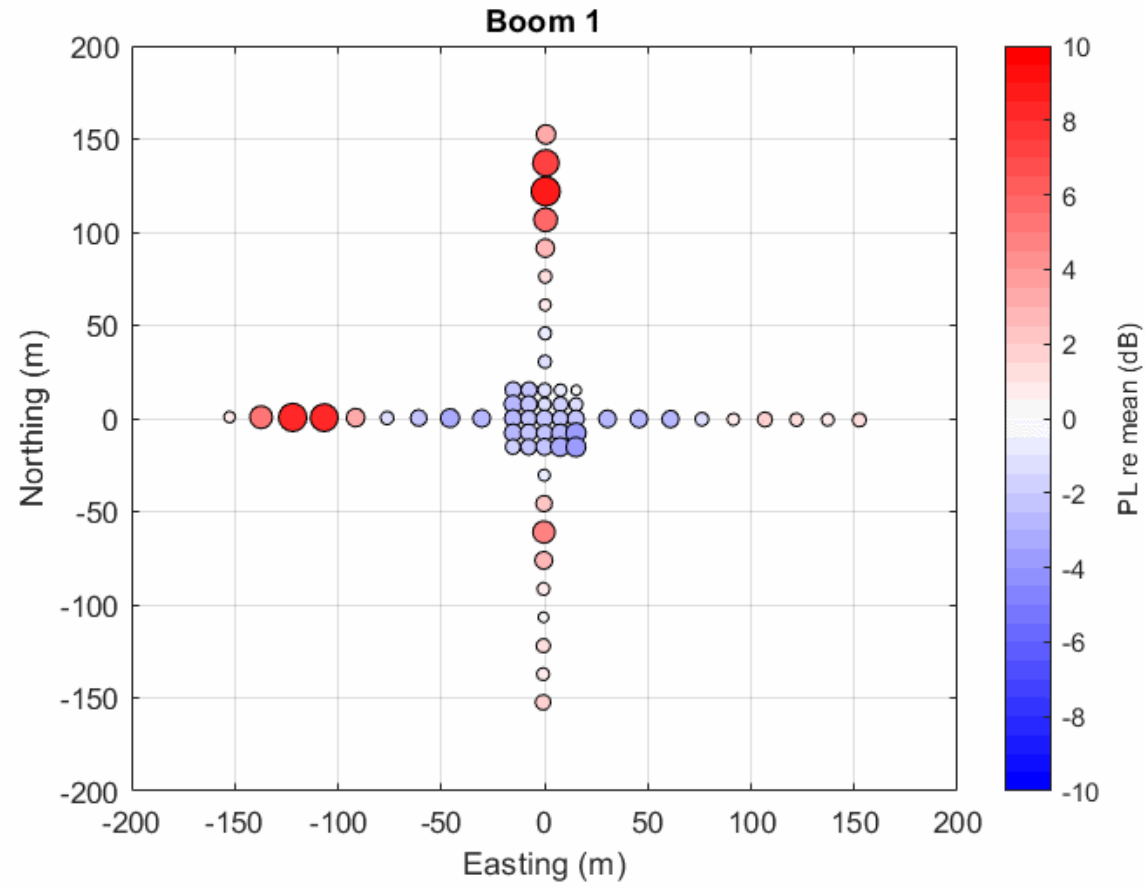


# Turbulence data

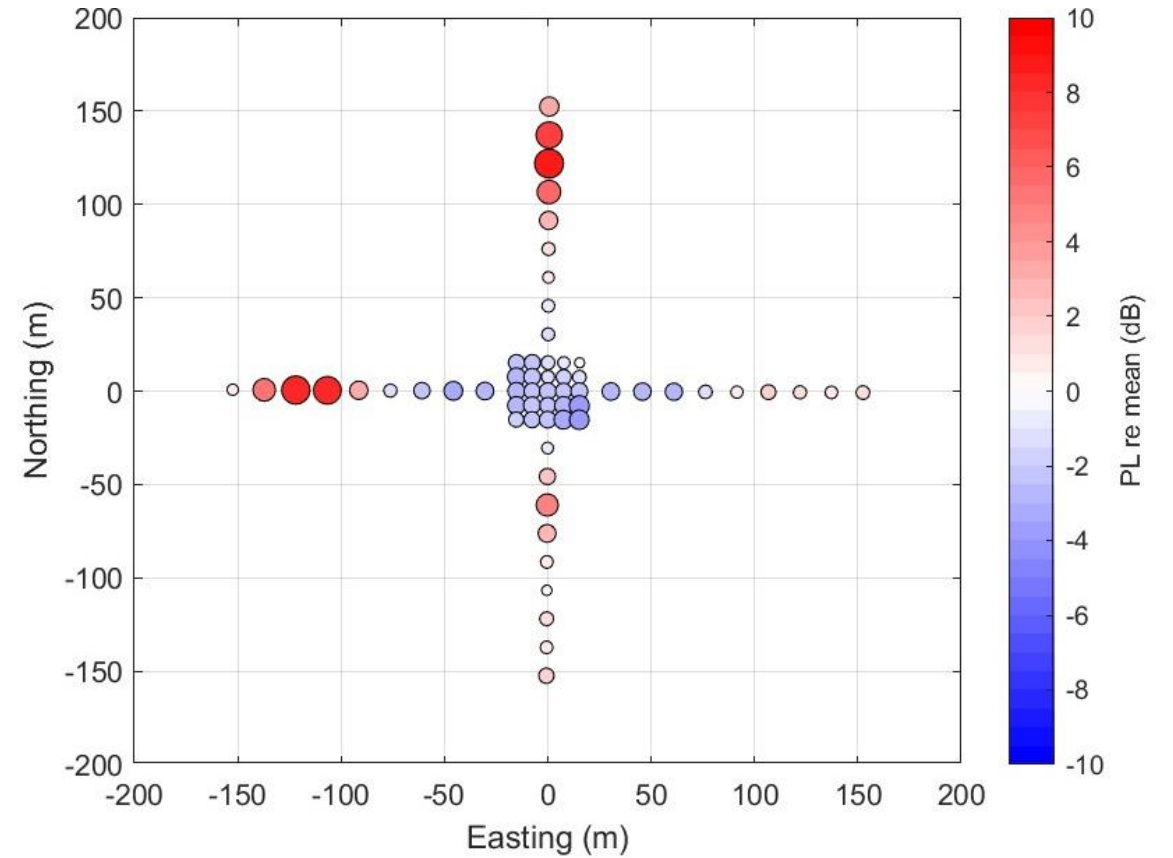
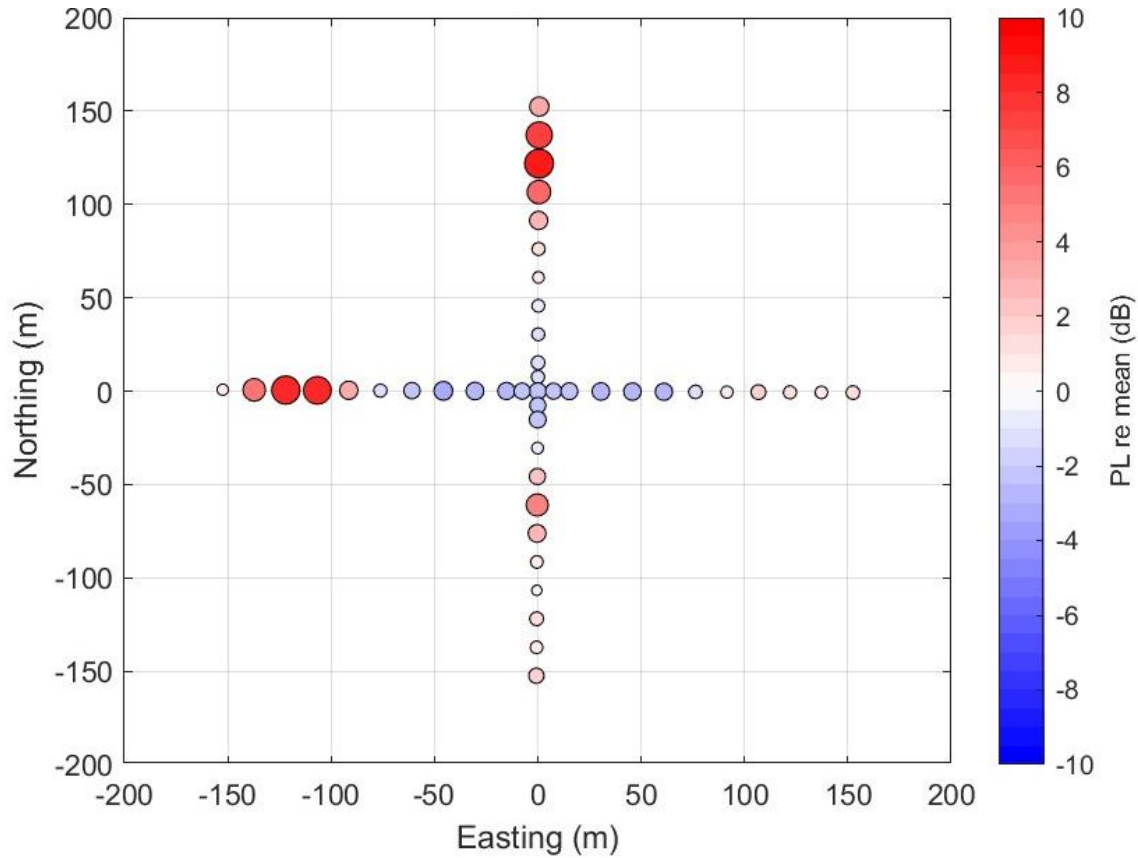
- Sonic anemometer located ~5 km NW of ARISTOTLE
- 10 min averages
- $\sigma_{\text{vector}}$ 
  - RMS velocity of turbulent field
  - $\sigma_{\text{vector}} = (3.0 u_*^2 + 0.35 w_*^2)^{1/2}$ 
    - $u_*$ : friction velocity
    - $w_*$ : mixed-layer velocity scale
  - Determines turbulence strength



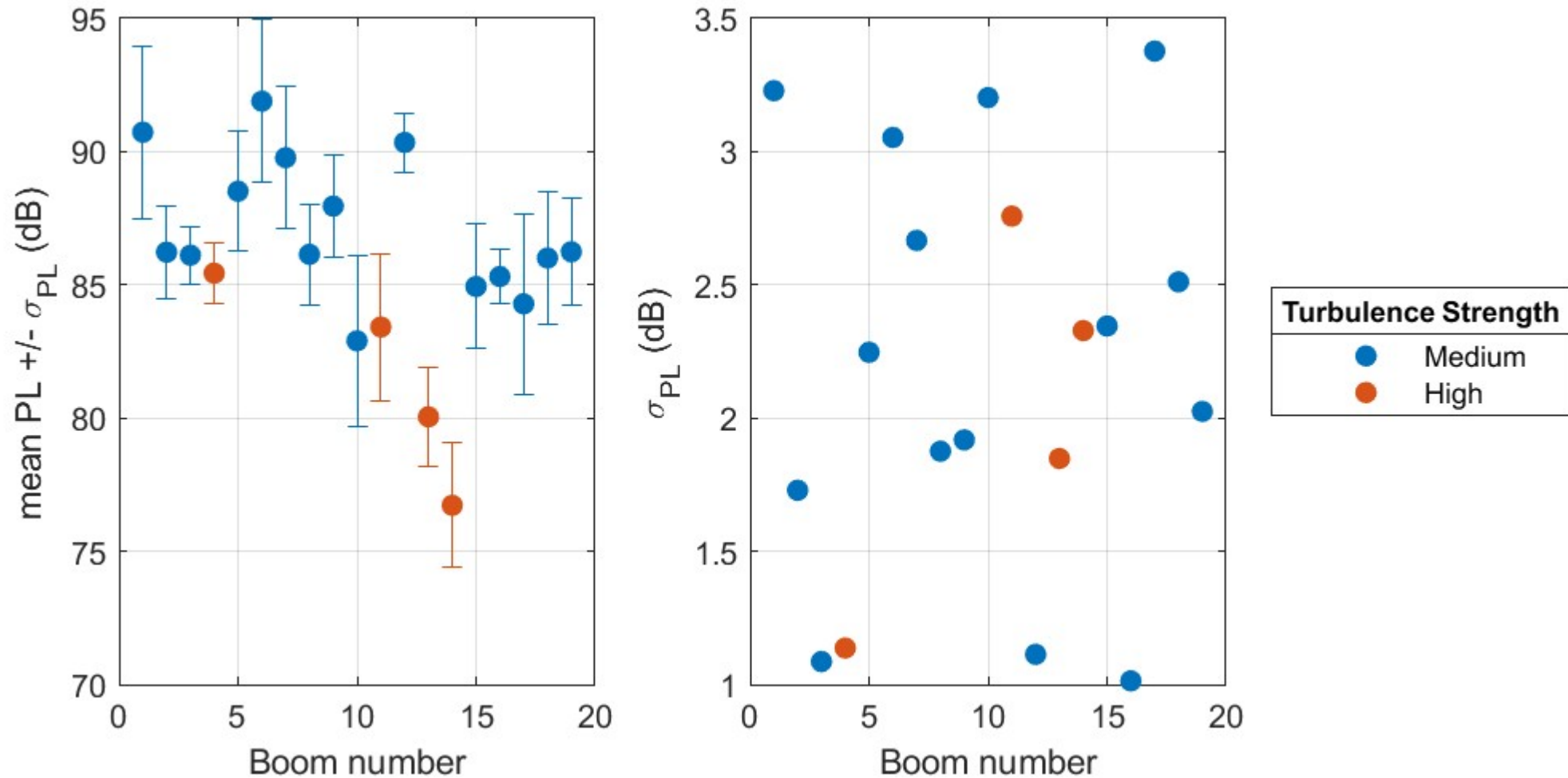
# PL across ARISTOTLE



# Data subset used in analysis

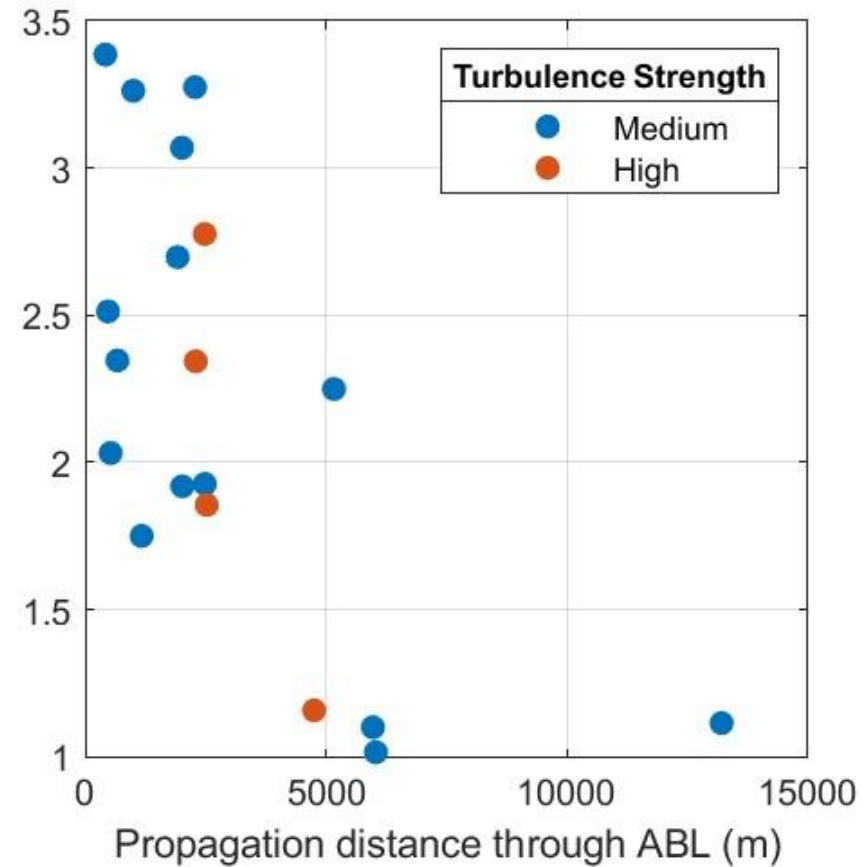
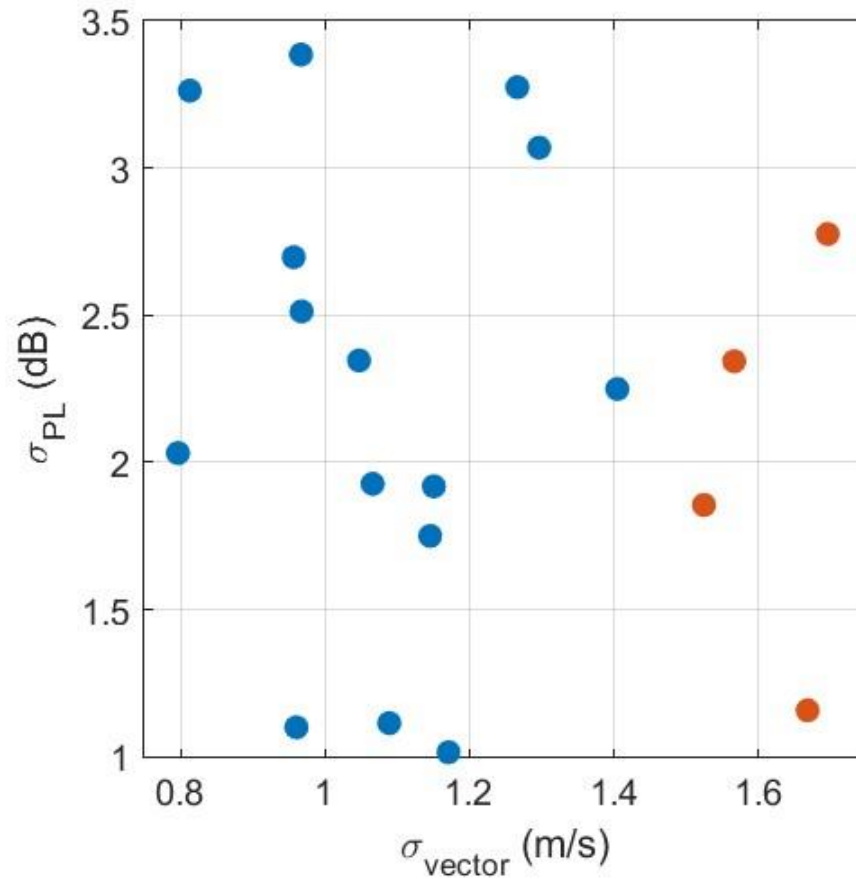


# Summary of acoustic measurements



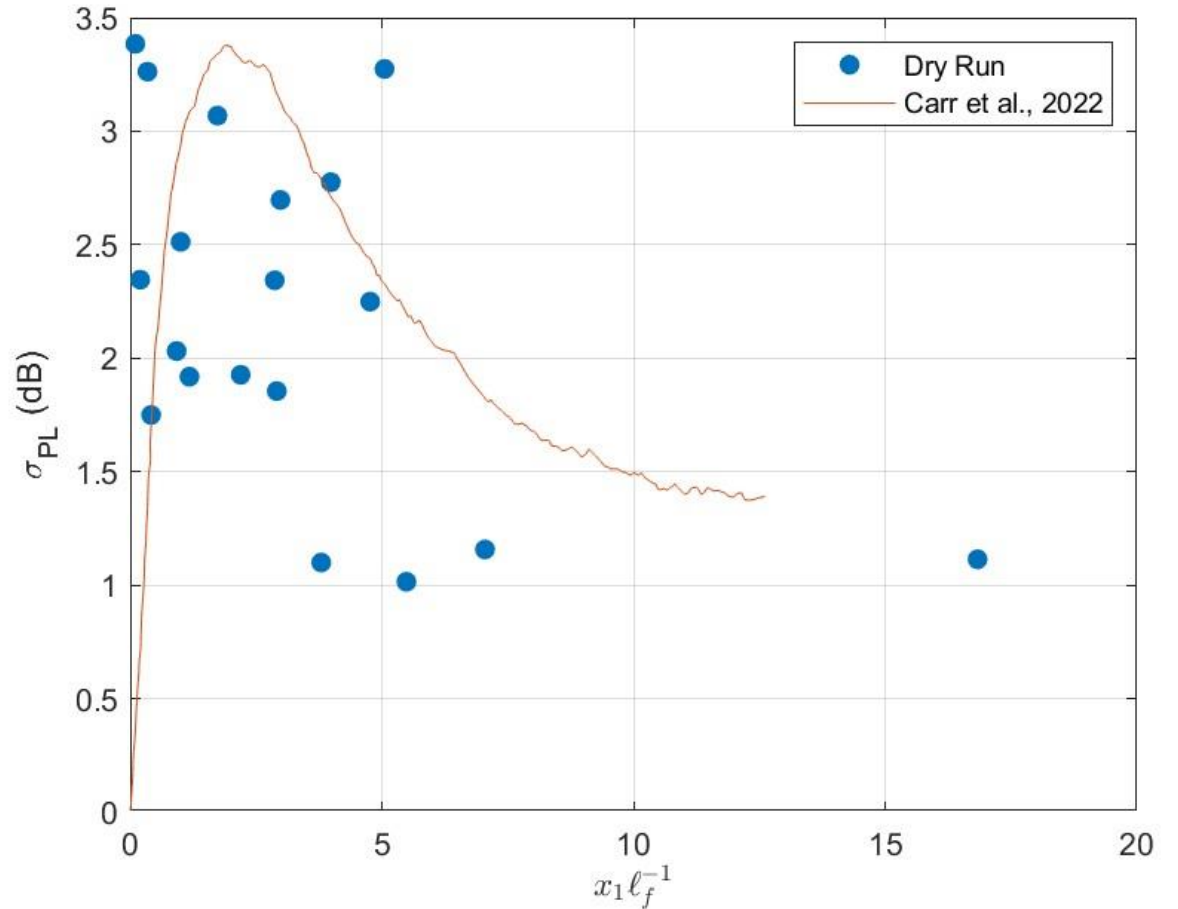
# Acoustic vs. turbulence data

# Relating $\sigma_{PL}$ to turbulence



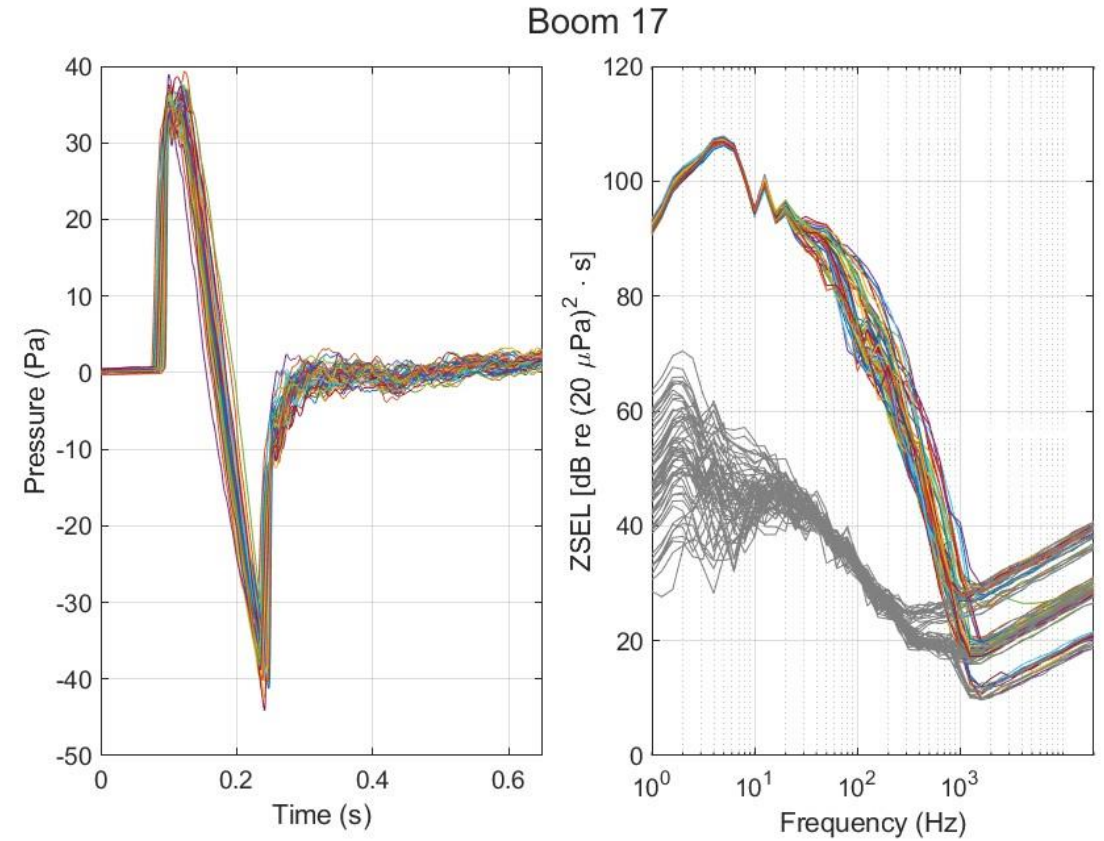
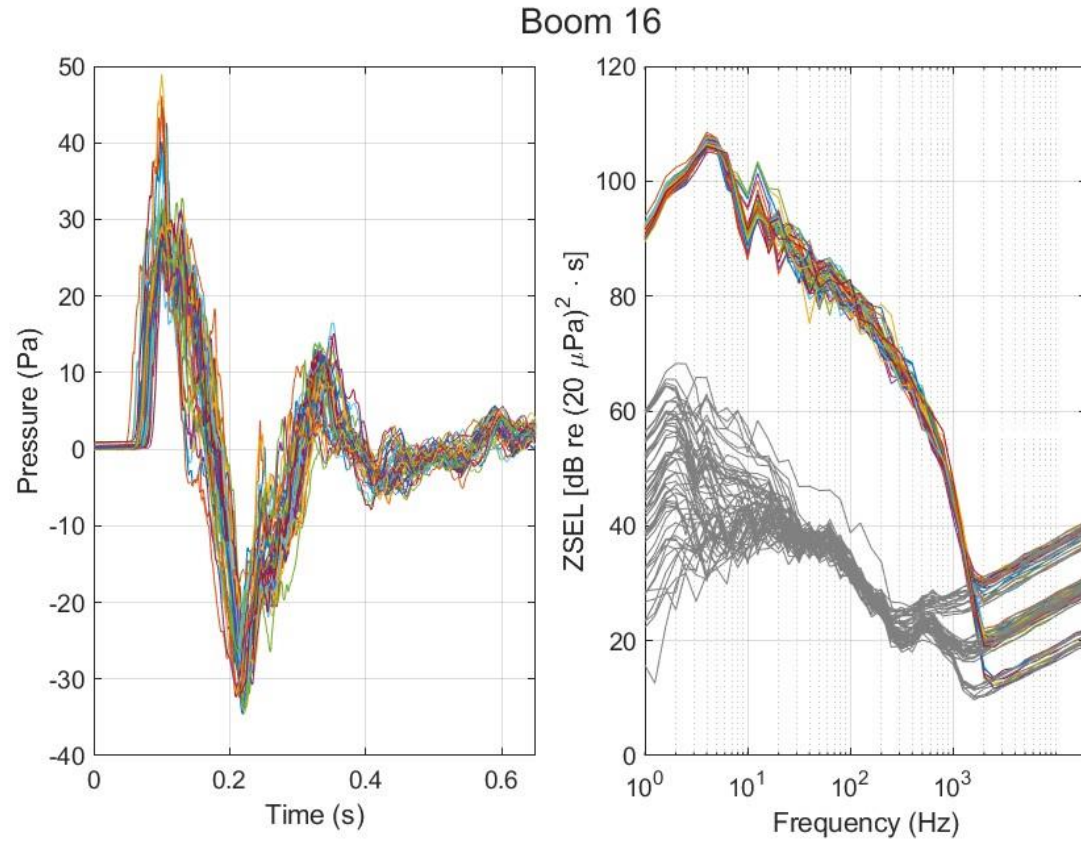
# Nondimensional propagation distance

- Propagation distance,  $x_1$
- Length scale,  $\ell_f$ 
  - Mean speed of sound,  $\bar{c}$
  - $\sigma_{\text{vector}}$
  - Longitudinal integral scale,  $L_f$ 
    - From sonic anemometer data
- Comparison to Carr *et al.* (2022)
  - Both have maximum  $\sigma_{\text{PL}}$  of  $\sim 3.5$  dB
  - Measurements do not reach a maximum  $\sigma_{\text{PL}}$  at a given  $x_1 \ell_f^{-1}$

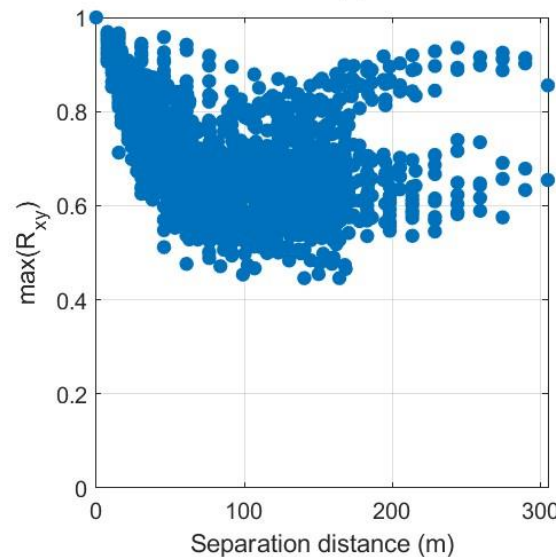
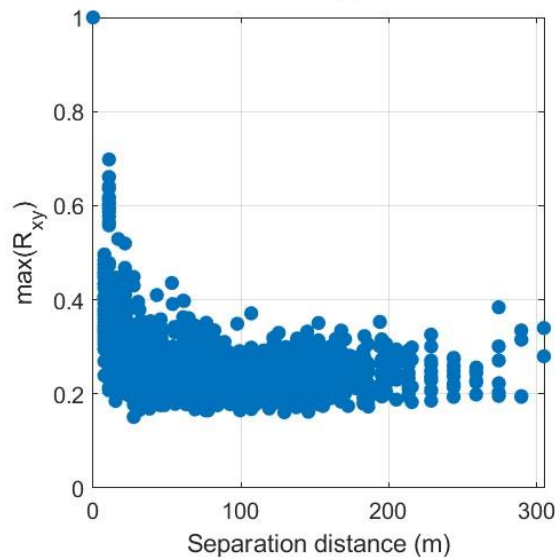
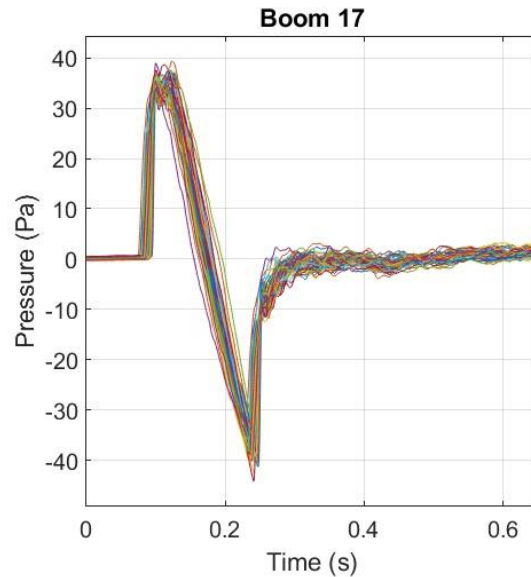
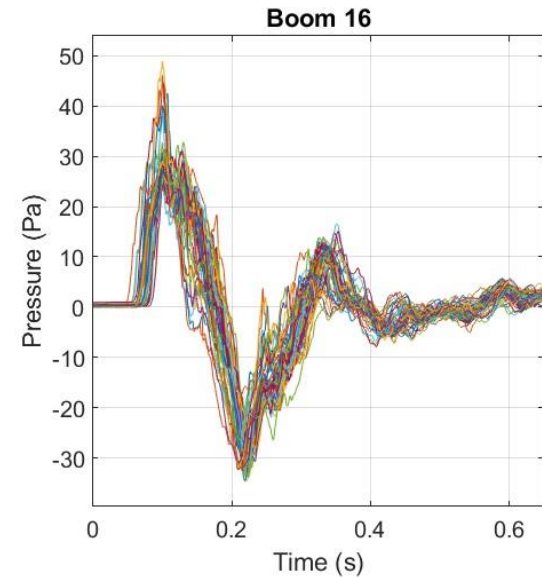


# Correlating turbulence parameters and PL variability with physical properties of the waveforms

# Booms with lowest and highest PL variability



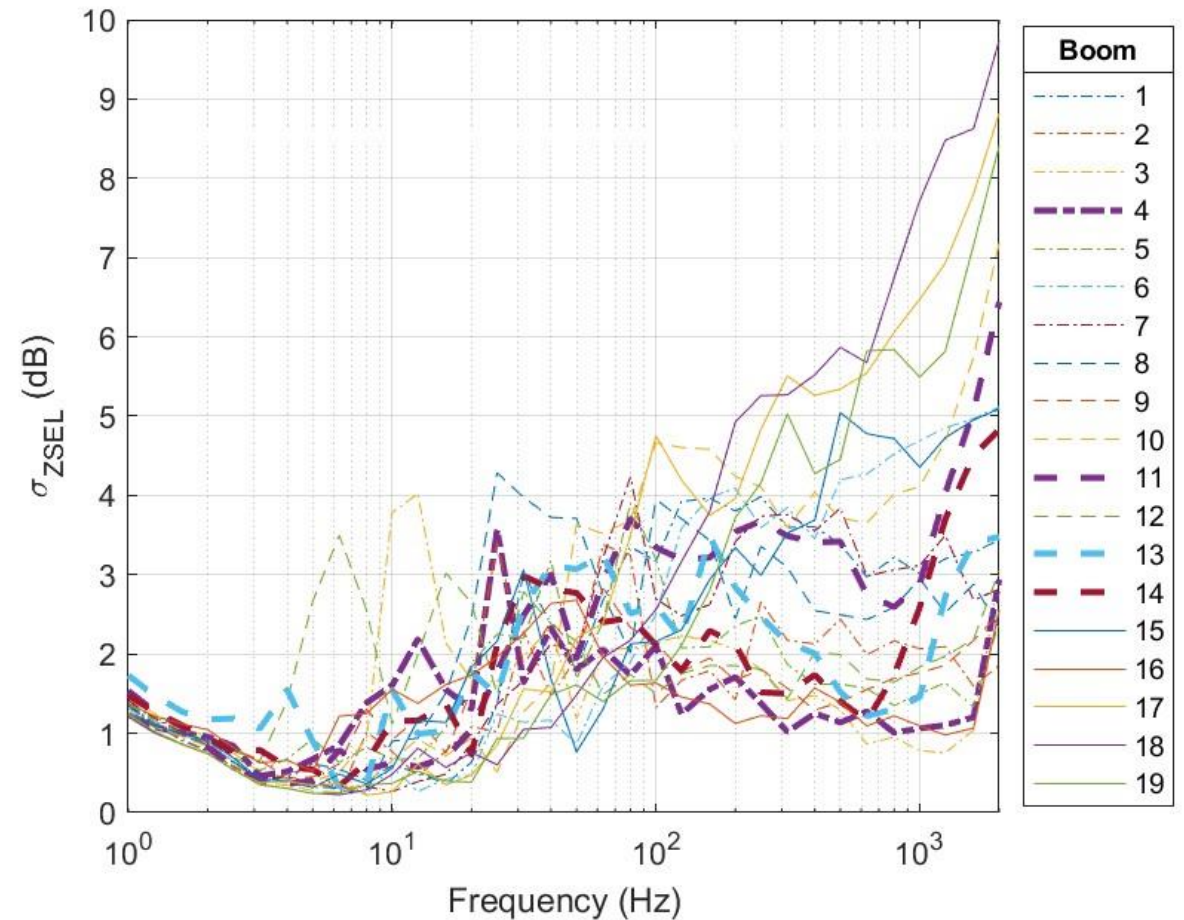
# Spatial correlation of waveform



- Measured waveforms
- Cross-correlation
  - A-weighted waveforms
    - How are high frequencies changing?
  - Correlation coefficients vary widely for different booms

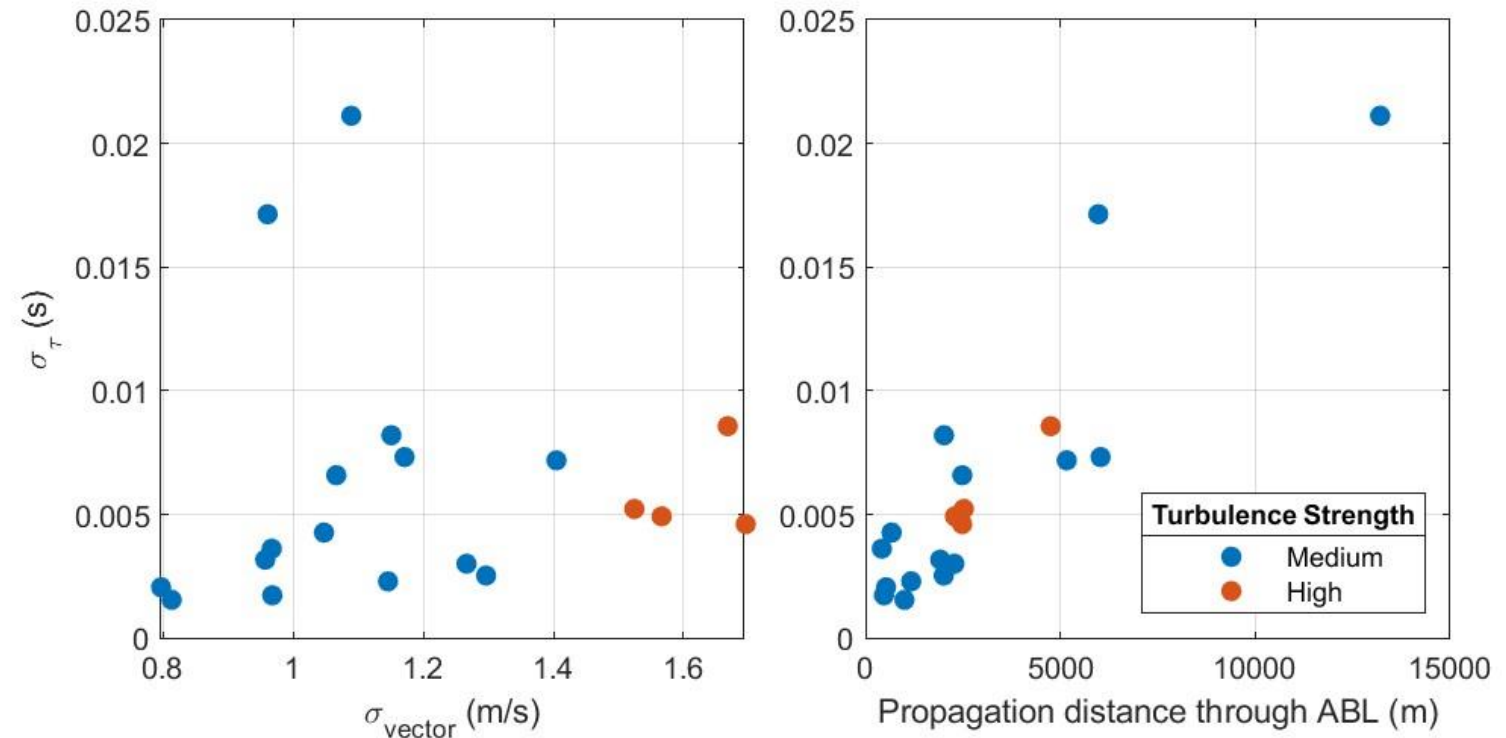
# Variation in SEL across frequency bands

- Standard deviation of sound exposure level (SEL) for each 1/3 octave band
  - Boom with high turbulence: bolded
- $\sigma_{ZSEL}$  increases at higher frequencies for the high turbulence cases and for the booms with greater PL variability



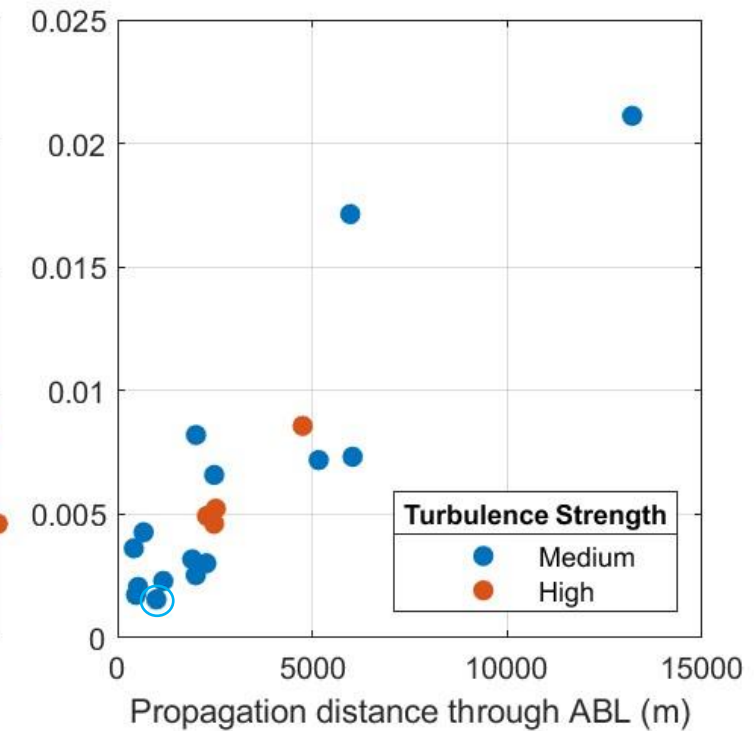
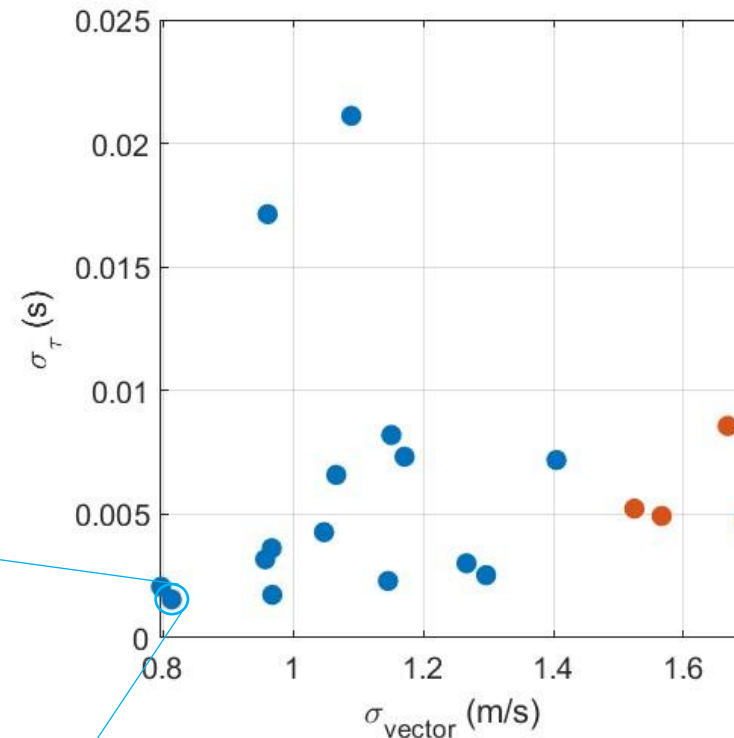
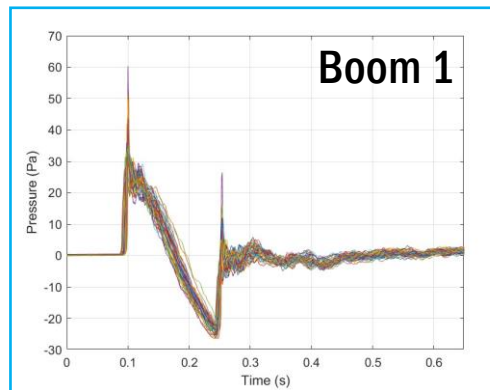
# Rise time

- Calculated the rise time,  $\tau$ , of the sonic boom recorded by each microphone
  - 10% to 90% of the maximum overpressure
- Computed the standard deviation of rise time,  $\sigma_{\tau}$ , for each boom



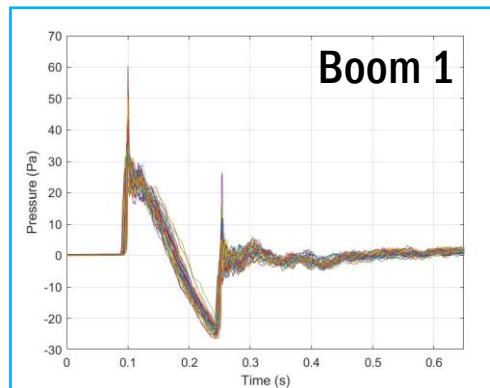
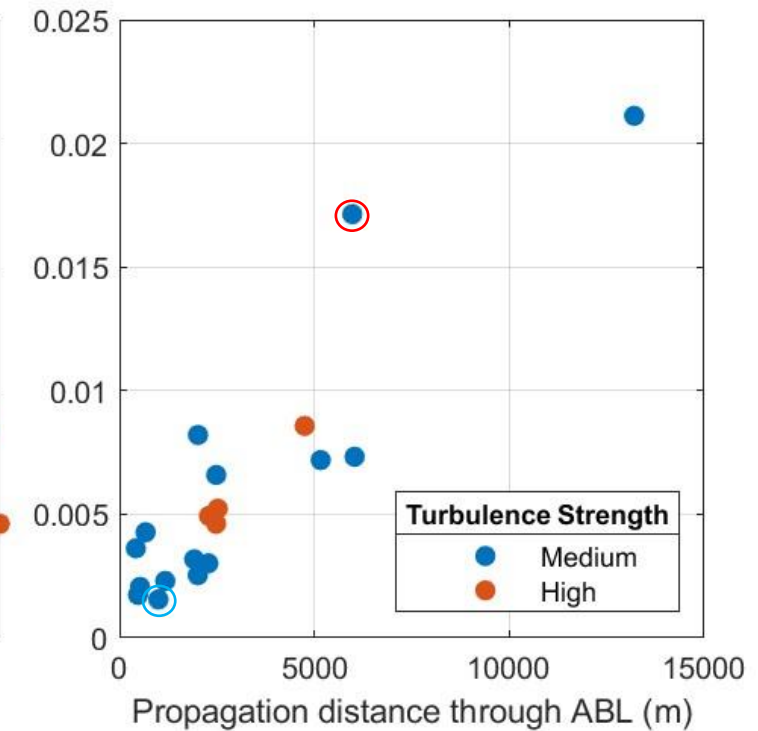
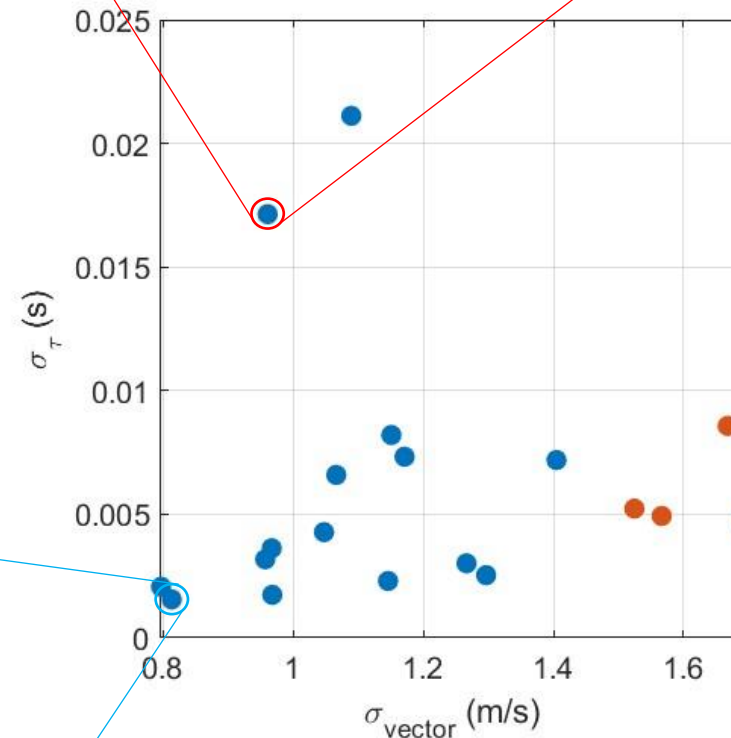
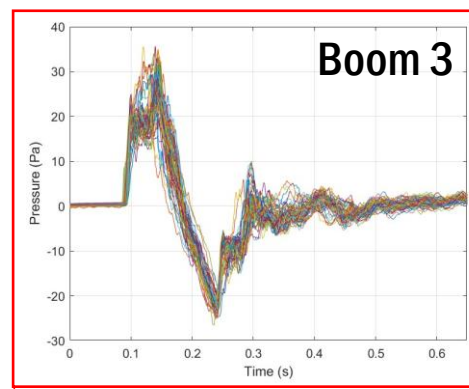
# Rise time, $\tau$

- $\sigma_\tau$  tends to increase with  $\sigma_{\text{vector}}$  and propagation distance
  - Rise time standard deviations tend to increase with propagation distance (Averiyanov *et al.*, 2011)



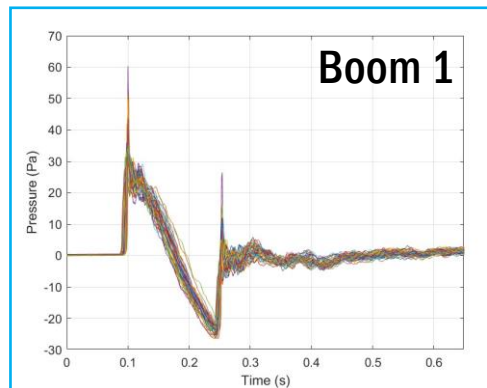
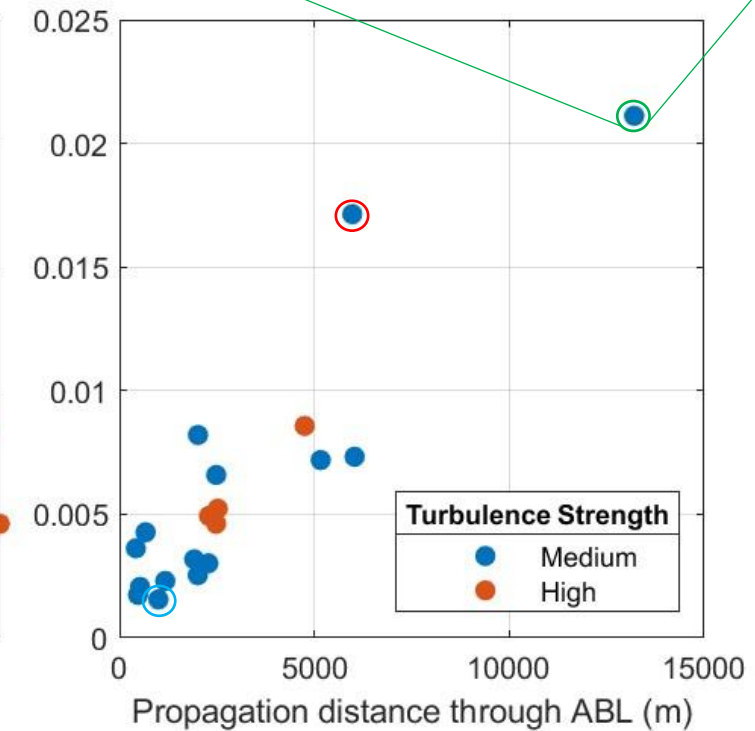
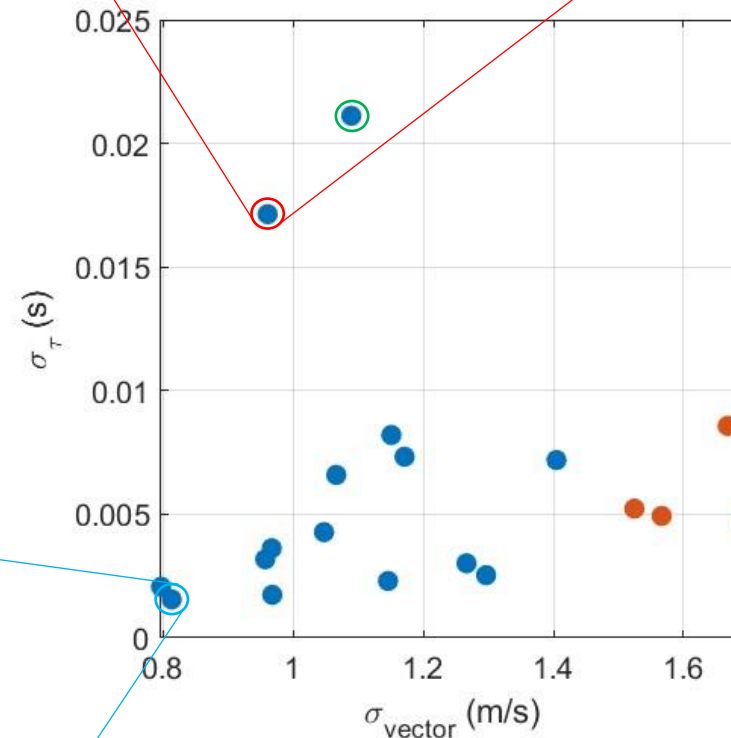
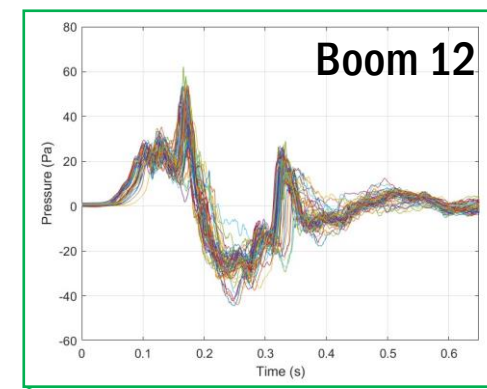
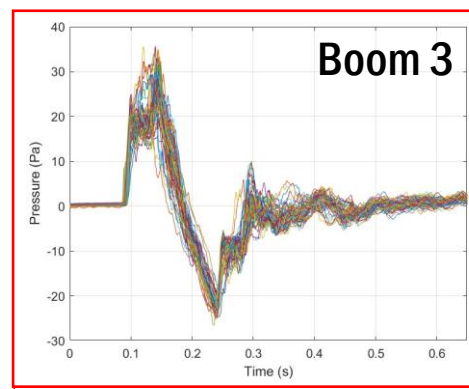
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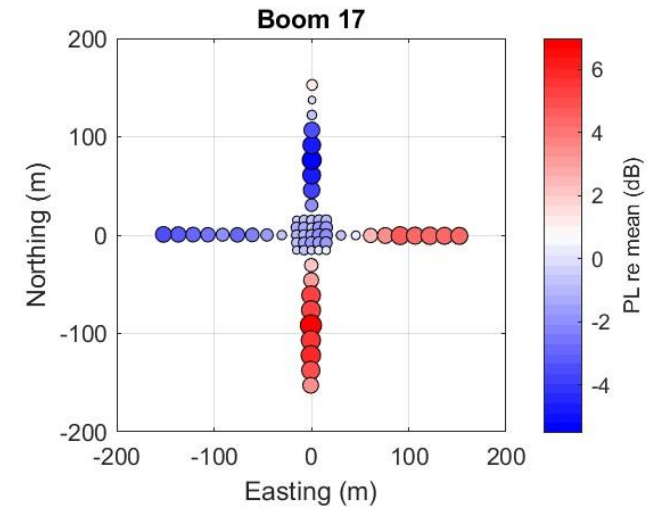
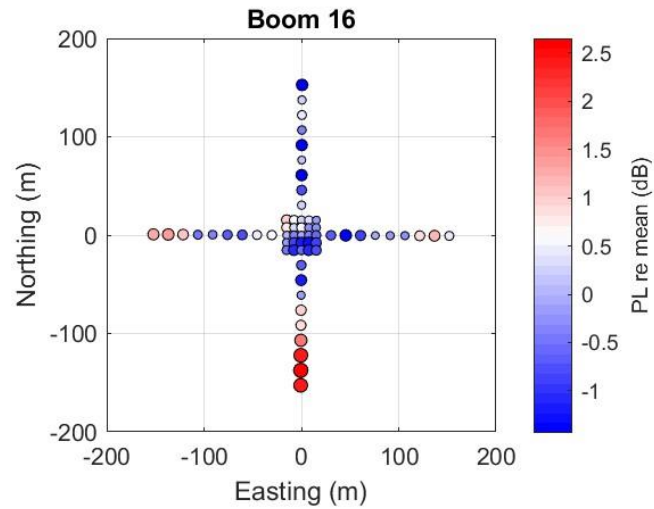


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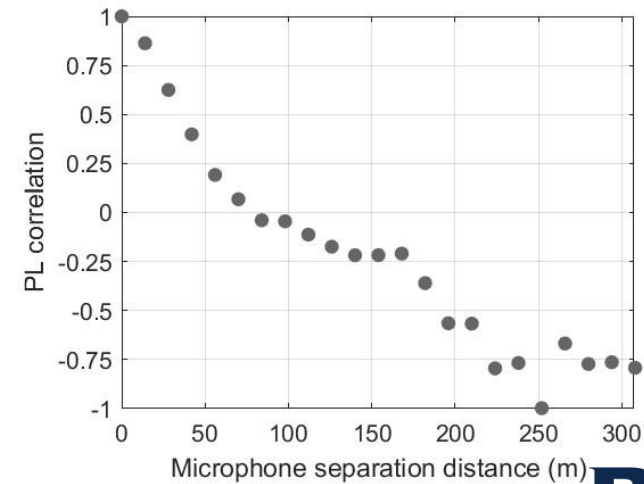
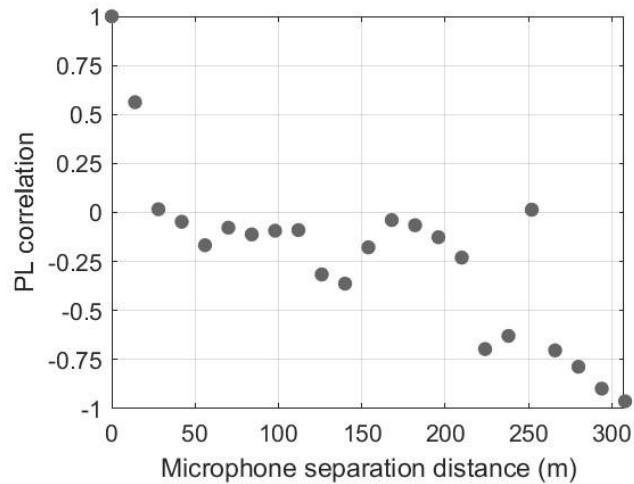
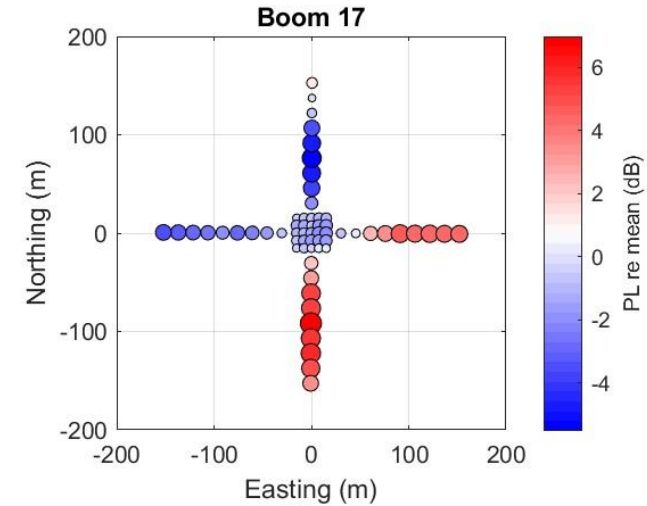
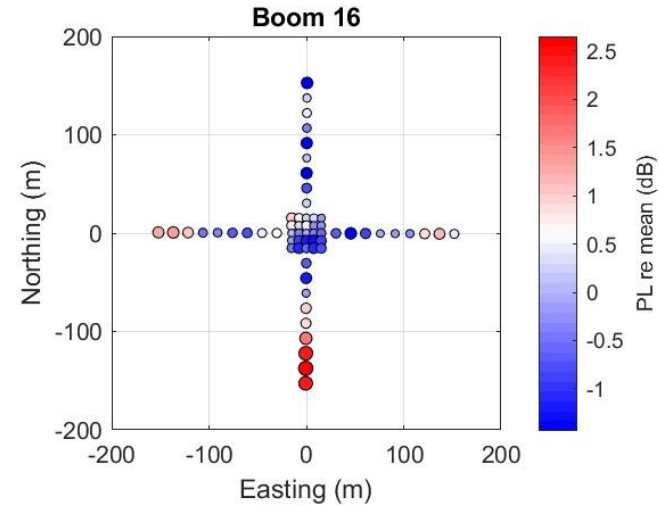
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# Pearson correlation coefficient for PL

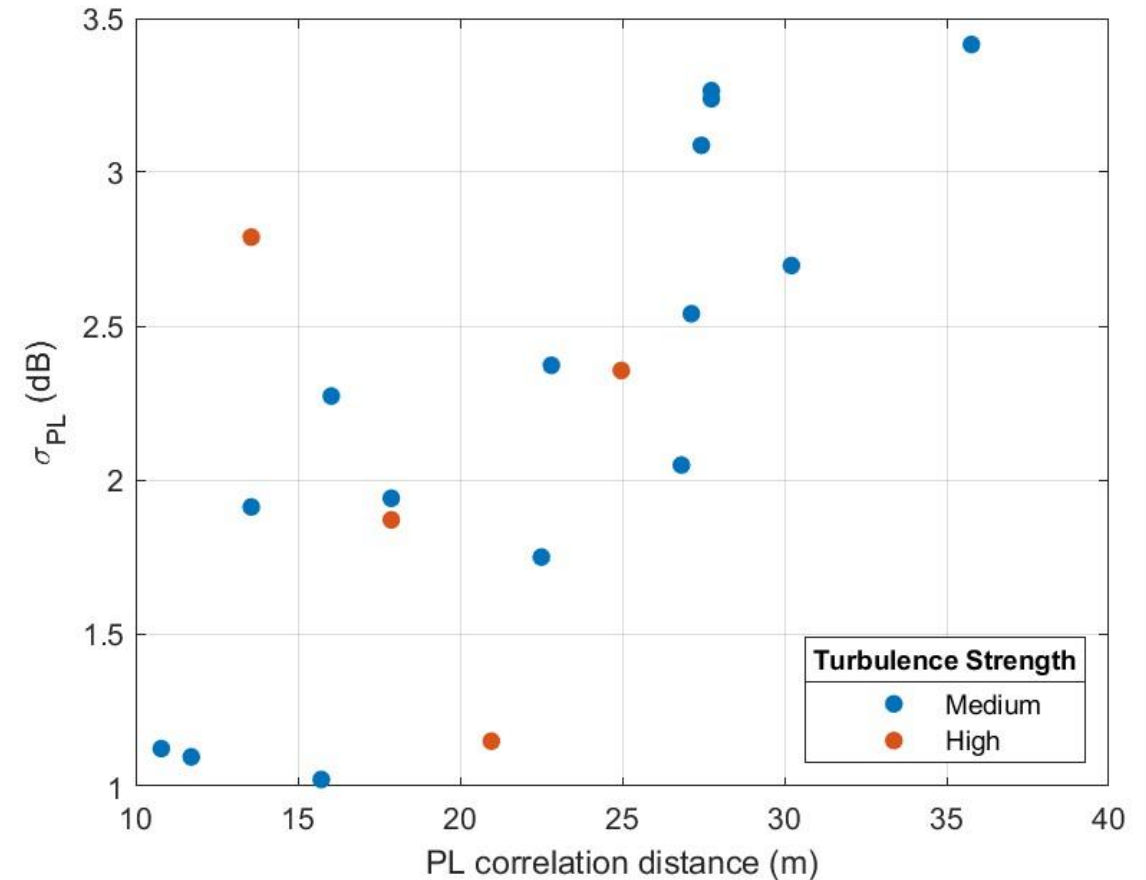


# Pearson correlation coefficient for PL



# $\sigma_{PL}$ vs microphone separation distance

- Separation distance where Pearson correlation coefficient = 0.5
  - Partially correlated
- No trends with turbulence strength
- Booms with larger  $\sigma_{PL}$  values typically had larger PL correlation distances



# Conclusions

- No clear trends between PL variability across the array and turbulence strength or propagation distance
- Maximum variability
  - Max  $\sigma_{PL}$  around 3.5 dB
    - Similar to Carr et al., 2022 results
- $\sigma_{\tau}$  tends to increase with  $\sigma_{\text{vector}}$  and propagation distance
- Challenges
  - Similar turbulence conditions throughout measurement
  - Turbulence conditions at ARISTOTLE may differ from sonic anemometer location
- Recommendations
  - Fly at different times of year or different times of day
  - Deploy sonic anemometer at ARISTOTLE
    - Planned for X-59 measurements



NASA/Jim Ross