Statistical Analysis and Modeling of Wind-generated Ocean Noise in the Northeast Pacific Ocean

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Research Effort

- **Goals:**
  - characterize and model the ocean soundscape for different wind speeds at the northeast Pacific continental margin
  - compare results for different depths and with studies conducted at other locations
  - analyze seasonal variations of ocean noise floor
- **Data:**
  - acoustic and meteorological data from Ocean Observatories Initiative (OOI)

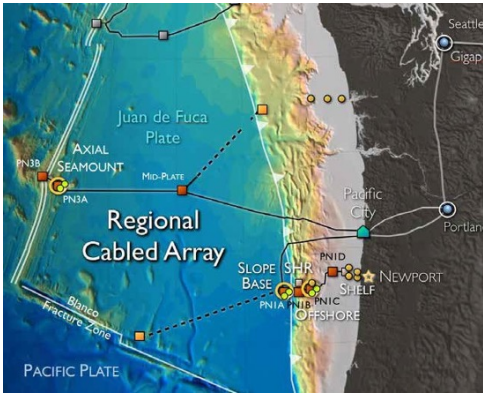
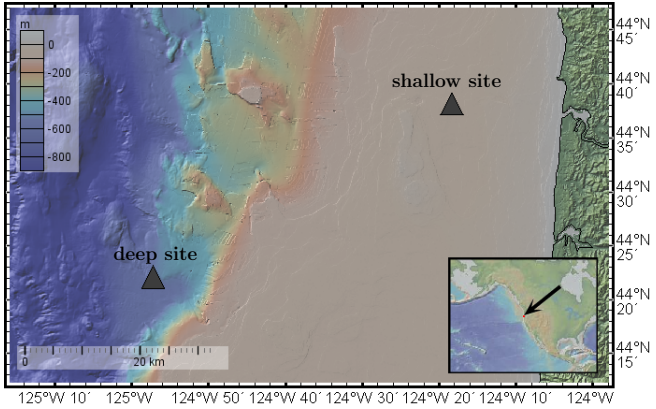


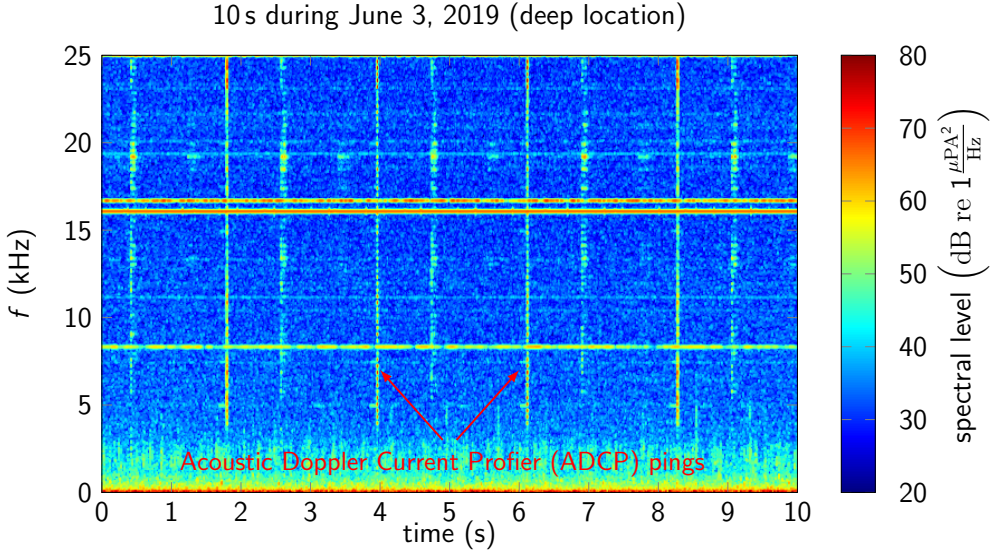
Figure from: Ocean Observatories Initiative (`https://oceanobservatories.org/image-gallery/`, Credit: University of Washington)

Measurement Setup

- **Acoustic Data:**
  - two broadband icListen HF hydrophones, $f_s = 64\,\text{kHz}$
  - shallow site: 81 m depth
  - deep site: 581 m depth
- **Wind Data:**
  - measured by surface buoys every minute
  - smoothen with 21-point Hann moving average filter
- **Measurement Time:**
  - September 2015 - June 2019
  - $\sim$11 400 h of wind noise data



Example of Acoustic Data



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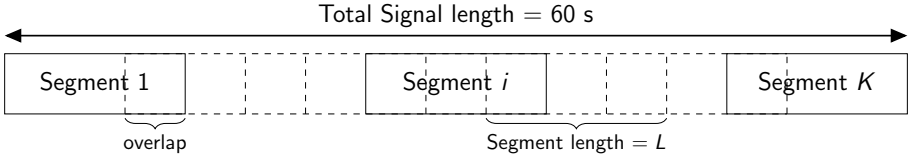

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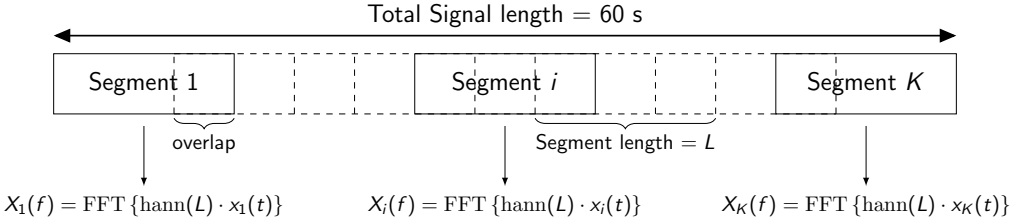

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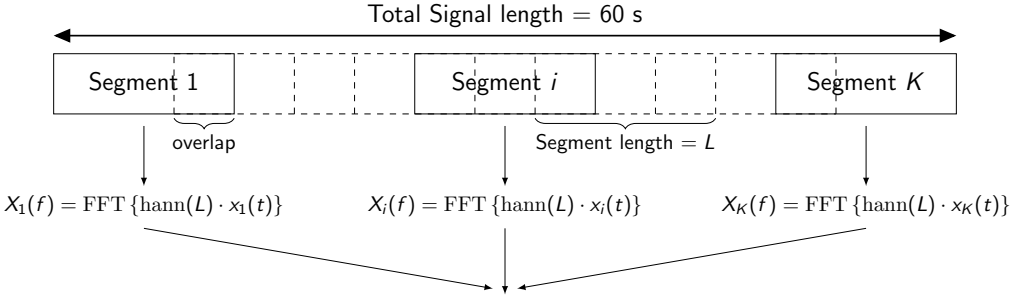

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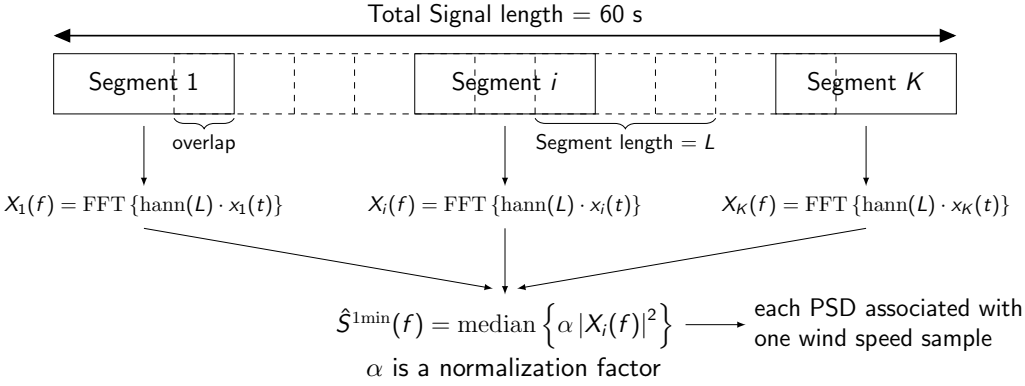

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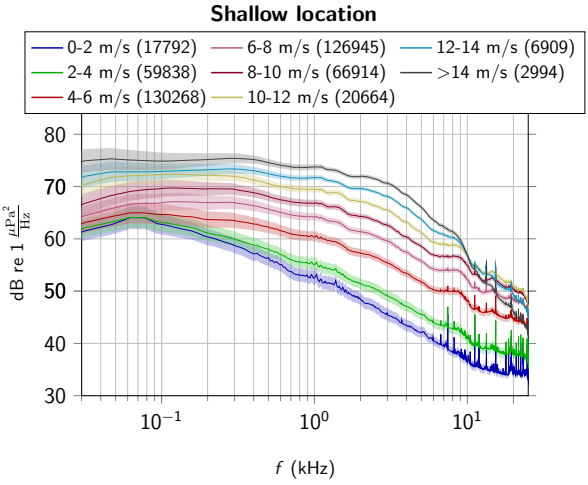
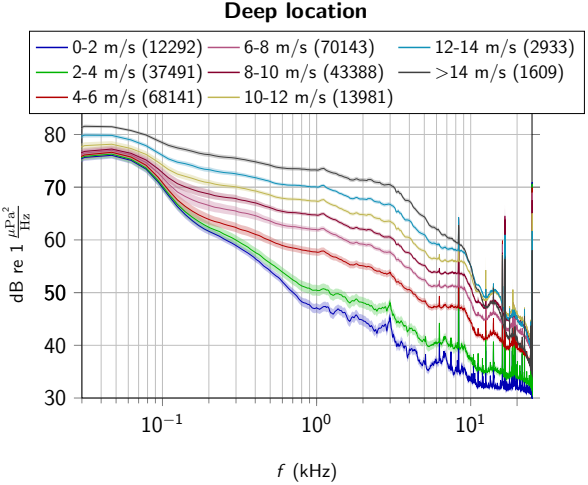
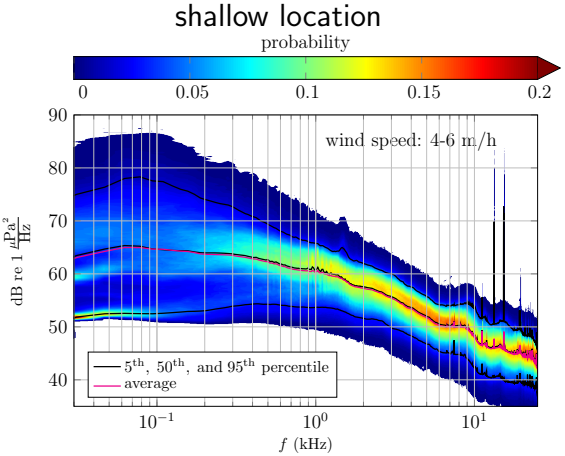
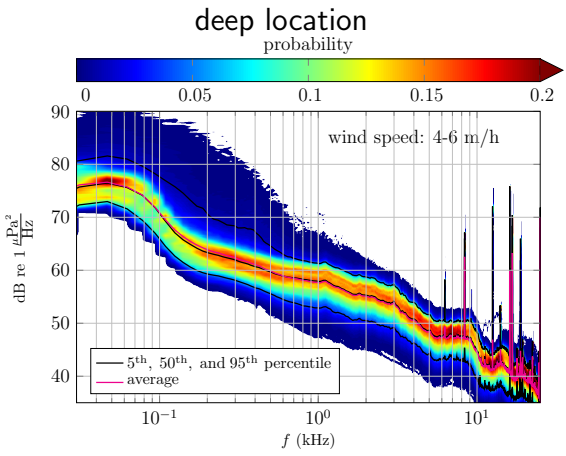
PSDs for different wind speeds





Spectral Probability Density for 4 - 6 m/s Wind Speed

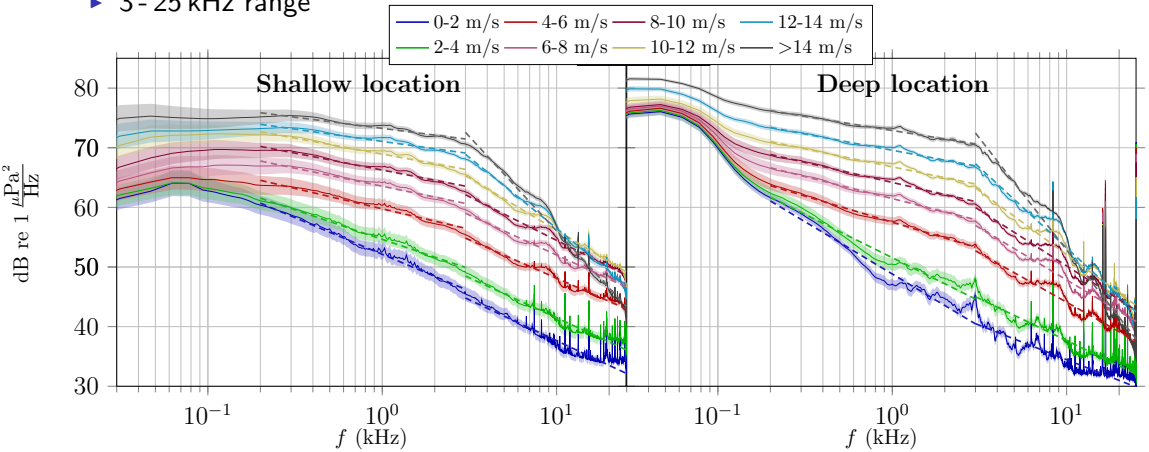




- 90 % of spectral levels within 9 dB (shallow), 7 dB (deep) range for $f \geq 3\,\mathrm{kHz}$

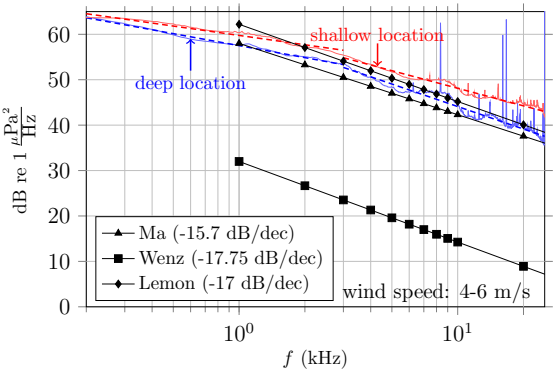
Modeling of Wind Noise

- Linear regression $\mathrm{SPL}(f) = s \cdot \log_{10} f + o$ in:
  - 200 Hz - 3 kHz range
  - 3 - 25 kHz range



Comparing Spectral Level with Other Measurements

- shallow: $s_{3-25\,\mathrm{kHz}} = -12.9\,\mathrm{dB/dec}$
- deep: $s_{3-25\,\mathrm{kHz}} = -16.5\,\mathrm{dB/dec}$
- Ma[1]: tropical Pacific Ocean ($\sim 40\,\mathrm{m}$ depth)
- Wenz[2]: deep and shallow ocean (open ocean and coastal environment)
- Lemon[3]: continental shelf (Queen Charlotte Sound, $\sim 250\,\mathrm{m}$ depth)



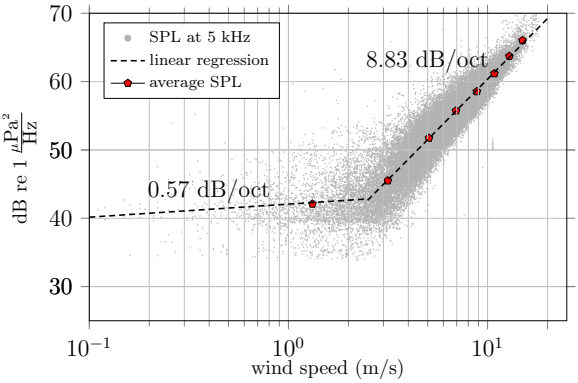
[1]Ma, B. B., Nystuen, J. A., & Lien, R.-C. (2005). Prediction of underwater sound levels from rain and wind. *The Journal of the Acoustical Society of America, 117*(6), 3555–3565.

[2]Wenz, G. M. (1962). Acoustic Ambient Noise in the Ocean: Spectra and Sources. *The Journal of the Acoustical Society of America, 34*(12), 1936–1956.

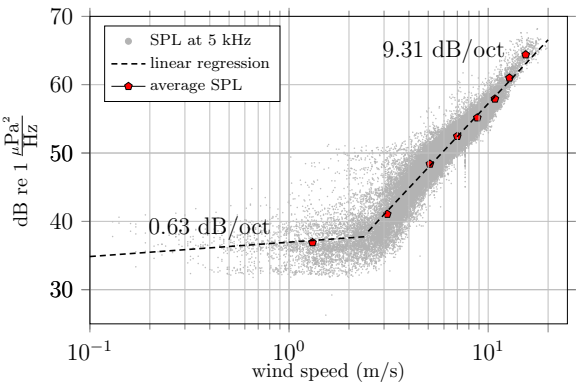
[3]Lemon, D. D., Farmer, D. M., and Watts, D. R. (1984), Acoustic measurements of wind speed and precipitation over a continental shelf, *J. Geophys. Res., 89*(C3), 3462–3472.

Spectral Level at 5 kHz vs. Wind Speed

shallow location



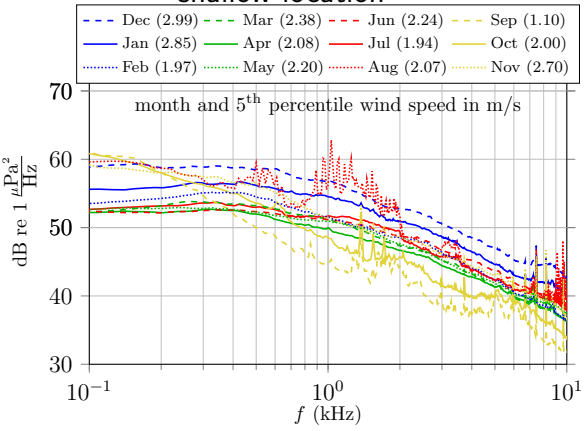
deep location



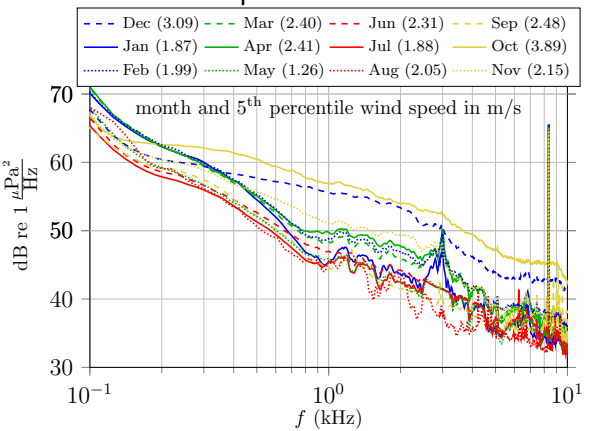
- 2 linear regression models:
  - wind speed: 0 - 2.5 m/s (no whitecaps or breaking waves)
  - wind speed: >2.5 m/s

Seasonal Analysis of Noise Floor – 5$^{\text{th}}$ Percentile PSDs

shallow location



deep location



- noise floor can vary by > 10 dB over seasons
- very high 5$^{\text{th}}$ percentile wind speed $\longrightarrow$ high spectral level
- some month have lower spectral level than expected (shallow: Oct; deep: Jun, Sep)

Conclusions

- **Key Findings:**
  - wind noise spectral level at the northeast Pacific continental margin can differ from open ocean measurements
  - linear regression slopes depend on wind speed and frequency range
  - strong linear relation of spectral level at 5 kHz over logarithmic wind speed
  - noise floor shows seasonal dependence not solely explained by wind speed
- **Future Work:**
  - find out which acoustic features show the strongest correlation with different wind speeds
  - use machine learning to estimate wind speeds from acoustic data
- **Related Talk:** ASA Fall 2020 – 1pAOb4: Statistical Analysis and Modeling of Rain-generated Ocean Noise in the Northeast Pacific Ocean