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

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Research Effort[1]

- **Goals:**
  - ▶ analyze and model the ocean soundscape during rainfall at the northeast Pacific continental margin
  - ▶ compare results for different depths and with studies conducted in the open ocean
  - ▶ analyze the dependence of the noise level on rain rate and wind speed

- **Data:**
  - ▶ acoustic and meteorological data from Ocean Observatories Initiative (OOI)
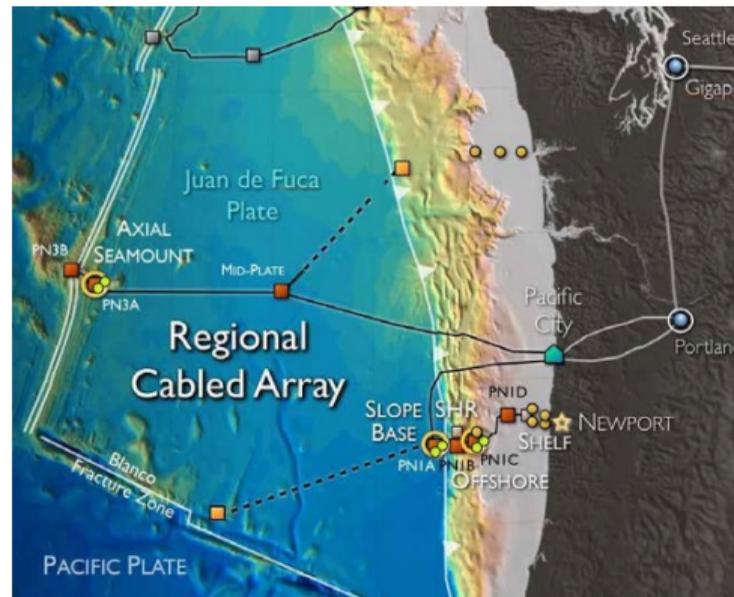

Figure from: Ocean Observatories Initiative (https://oceanobservatories.org/image-gallery/, Credit: University of Washington)

[1]Schwock & Abadi, "Characterizing Underwater Rain Noise in the Northeast Pacific Continental Margin" *The Journal of the Acoustical Society of America*, in review
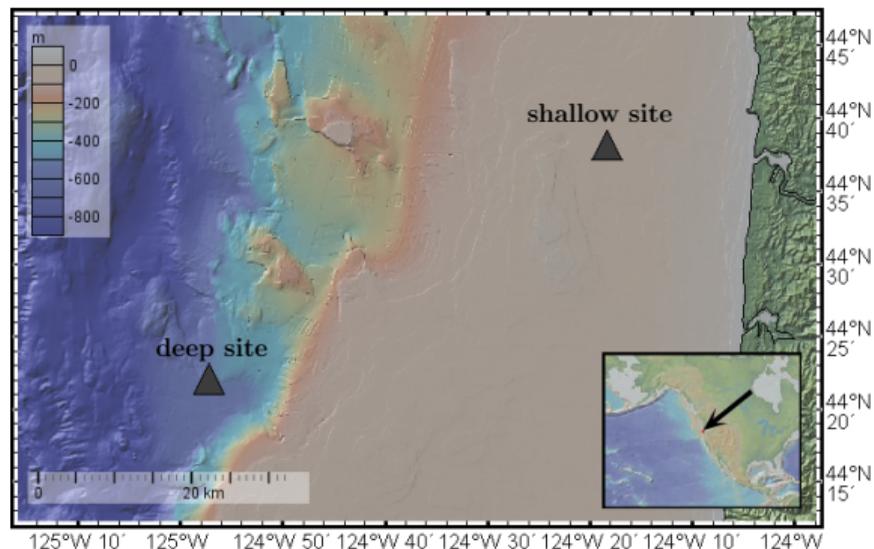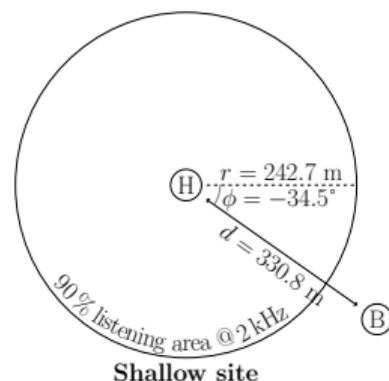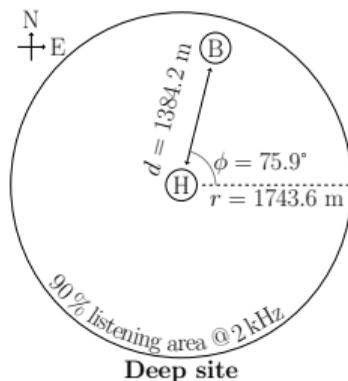
Measurement Setup

- **Acoustic Data:**
  - two broadband icListen HF hydrophones, $f_s = 64\,\text{kHz}$
  - shallow site: 81 m depth
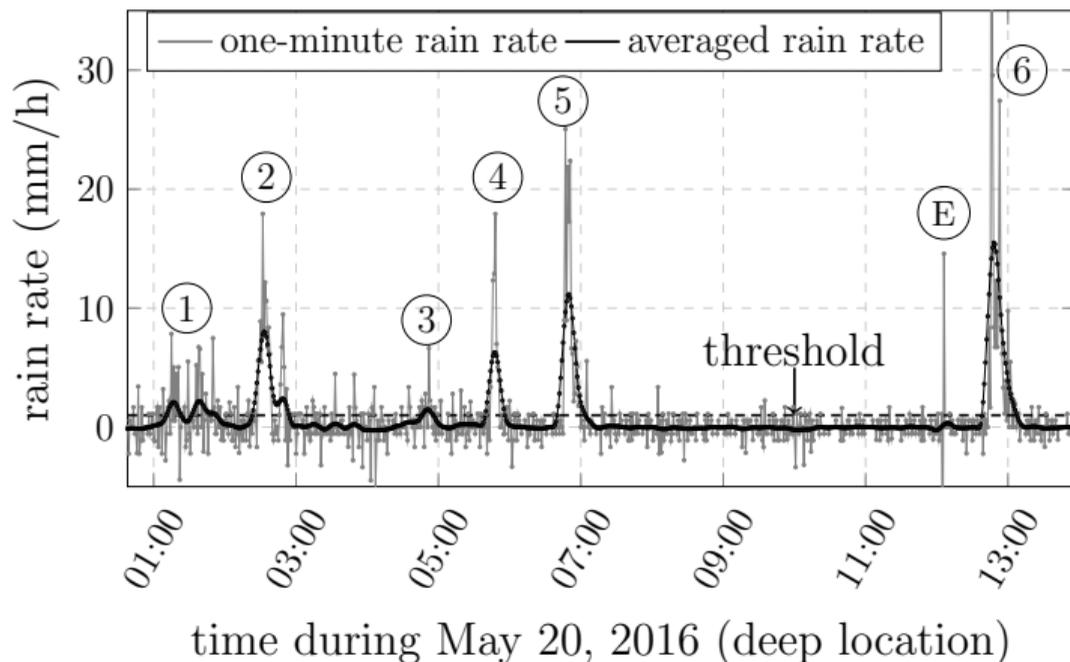 - deep site: 581 m depth
- **Meteorological Data:**
  - measured by surface buoys
  - collected every minute
- **Measurement Time:**
  - December 2015 - June 2019
  - $\sim$280 h of rain noise data

Deep site

Shallow site

Rain Event Detection

time during May 20, 2016 (deep location)
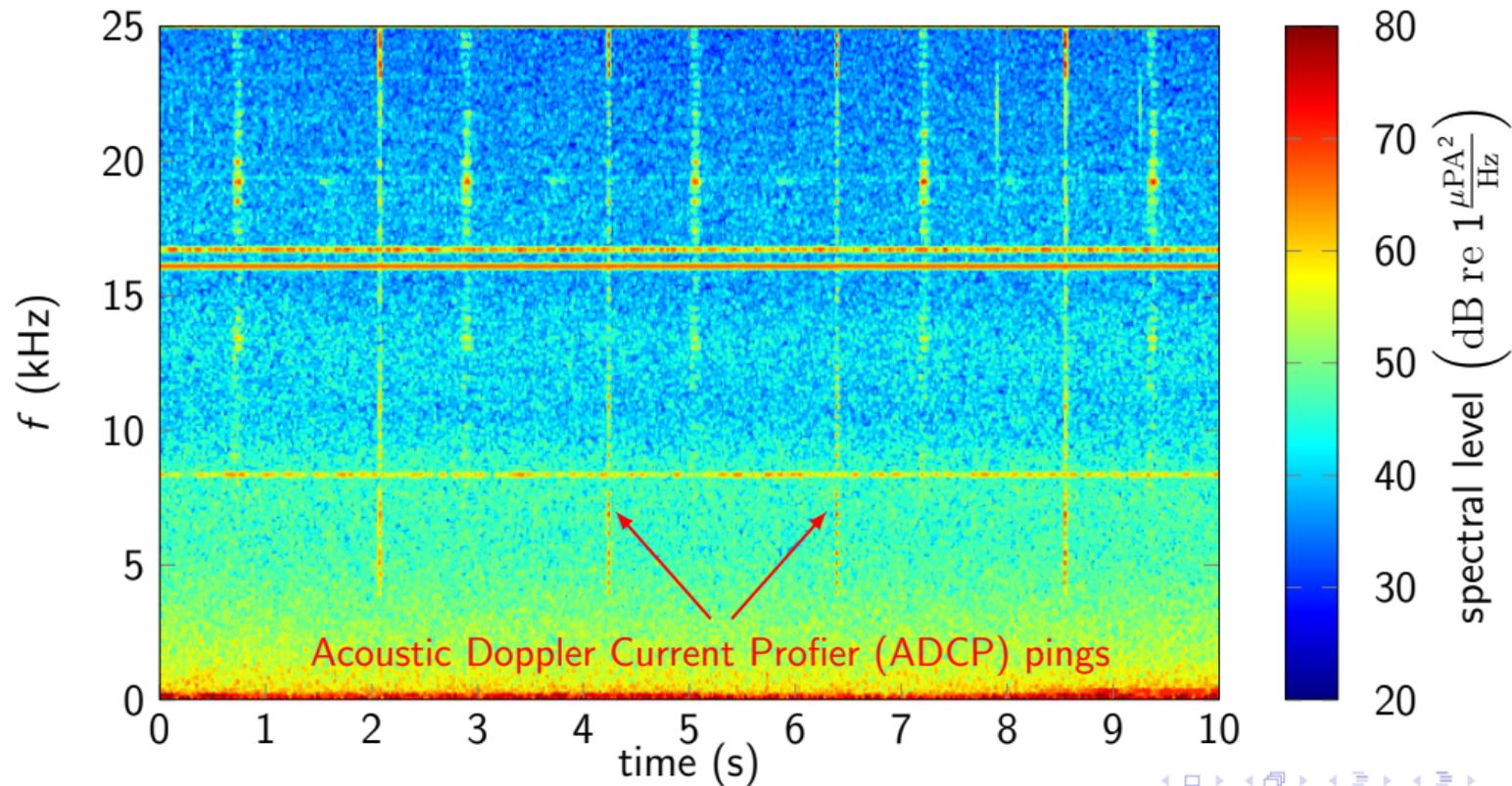
- 21-point Hann window moving average filter applied to one-minute rain rate to obtain averaged rain rate
- averaged rain rate used for rain event detection

Example of Acoustic Data

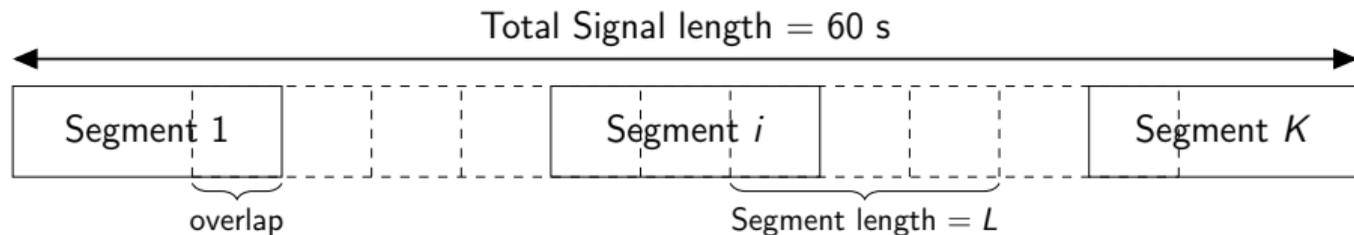10 s during rain Event 5 on May 20, 2016 (deep location)

Processing of Acoustic Data to Obtain Power Spectra

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$$\text{Total Signal length} = 60 \text{ s}$$

Segment 1   Segment i Segment K

overlap   Segment length $= L$

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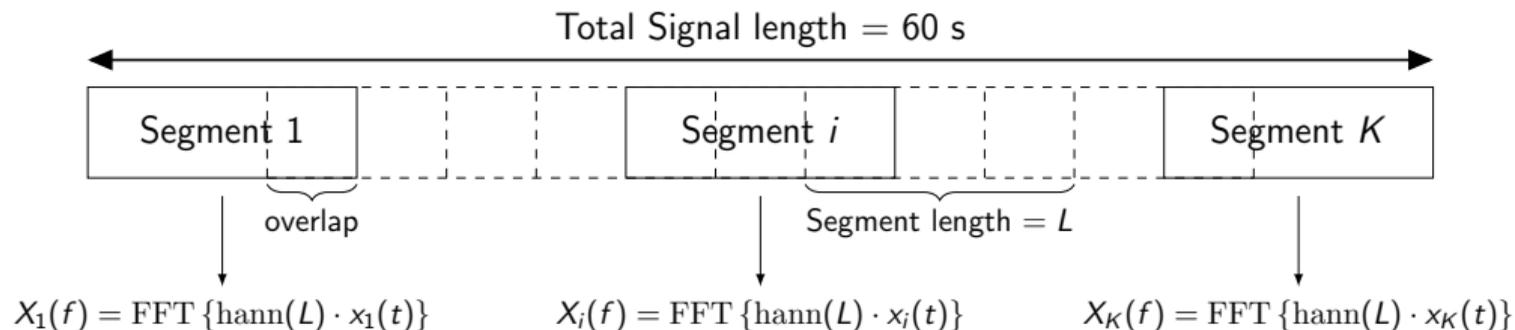
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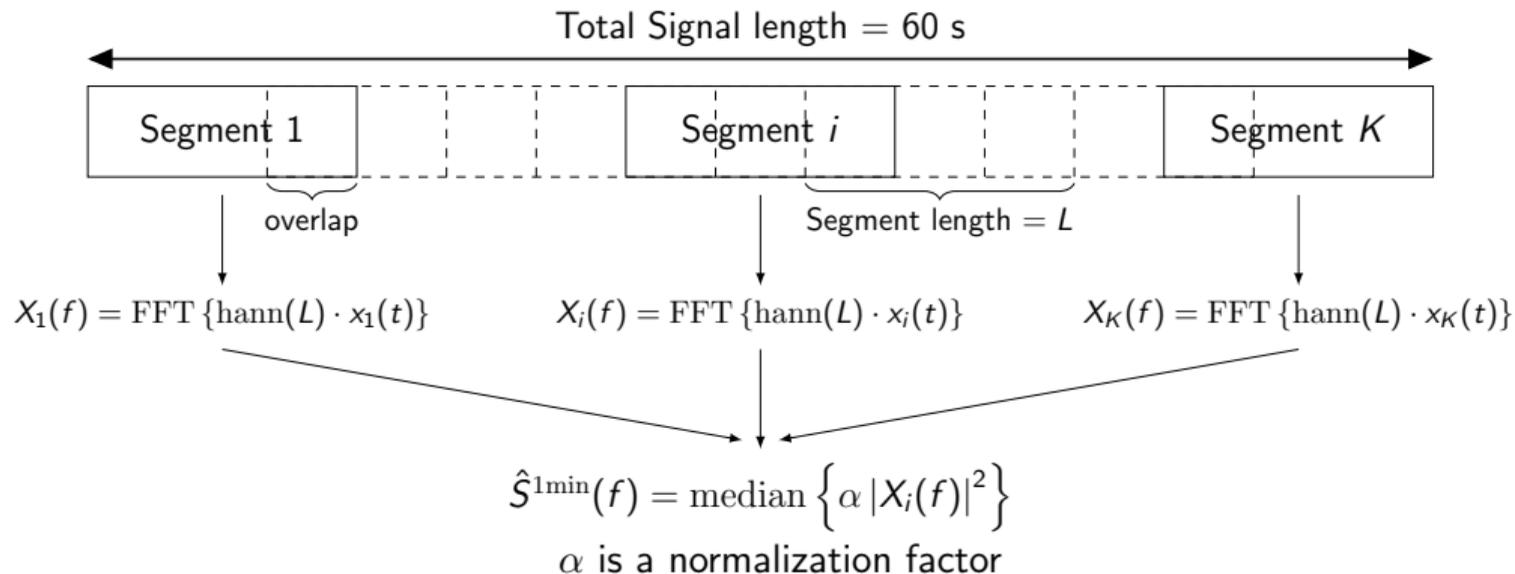
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$$\hat{S}^{1\min}(f) = \text{median} \left\{ \alpha \, |X_i(f)|^2 \right\}$$

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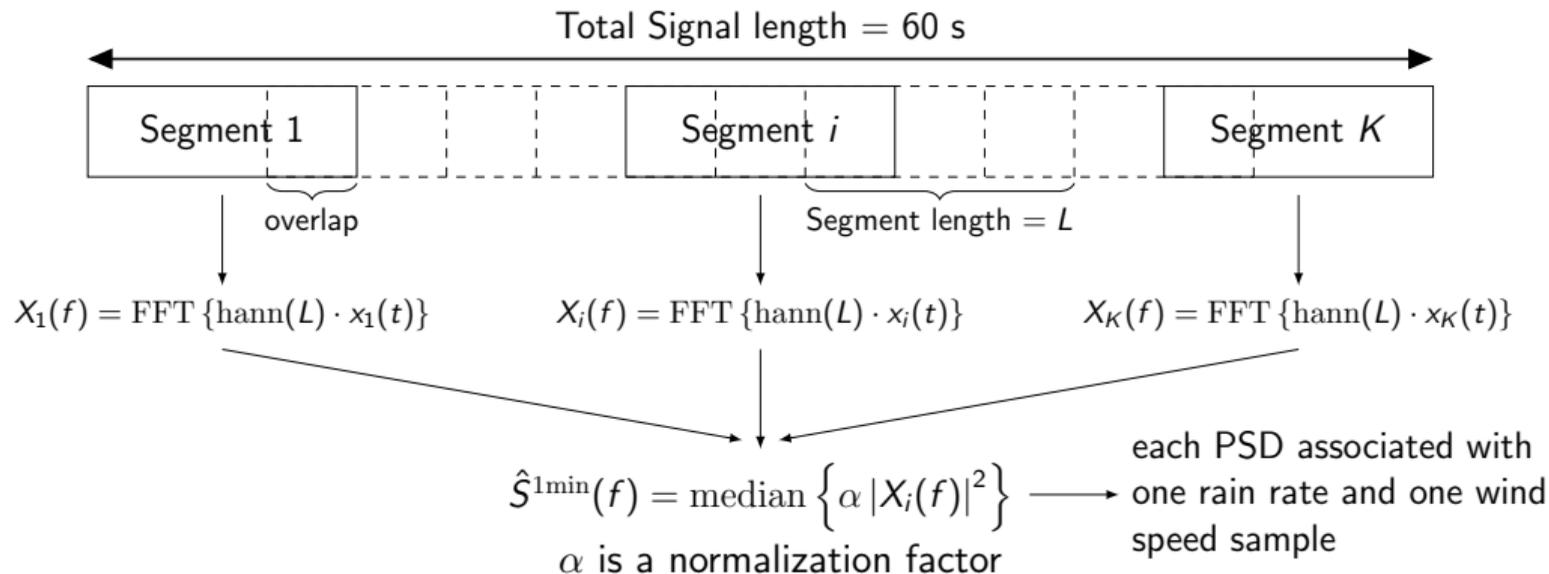
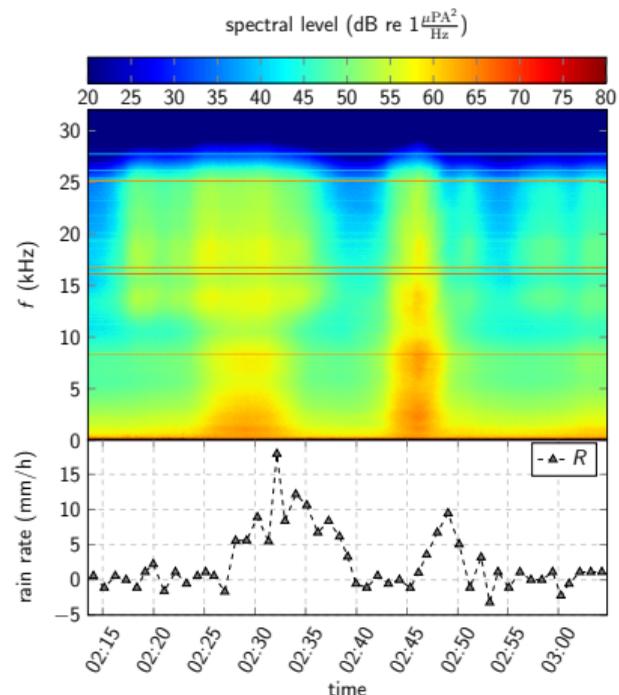# Processing of Acoustic Data to Obtain Power Spectra

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each PSD associated with one rain rate and one wind speed sample

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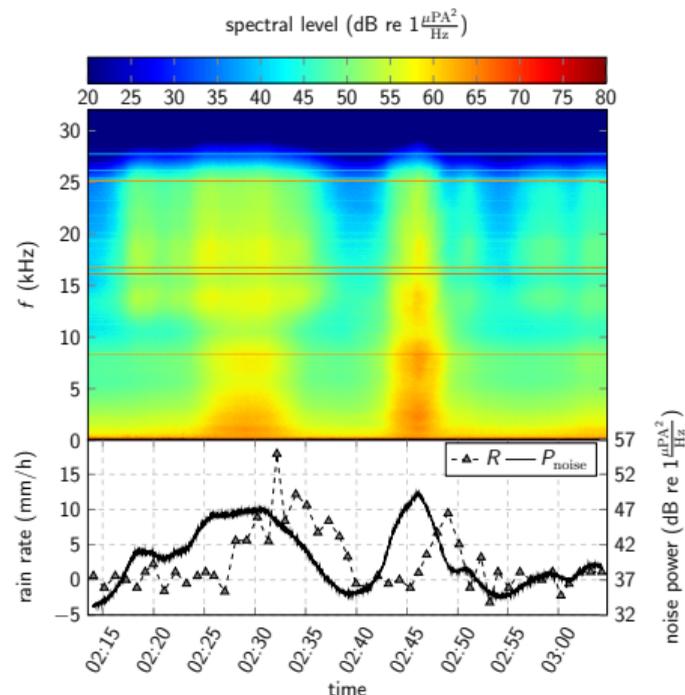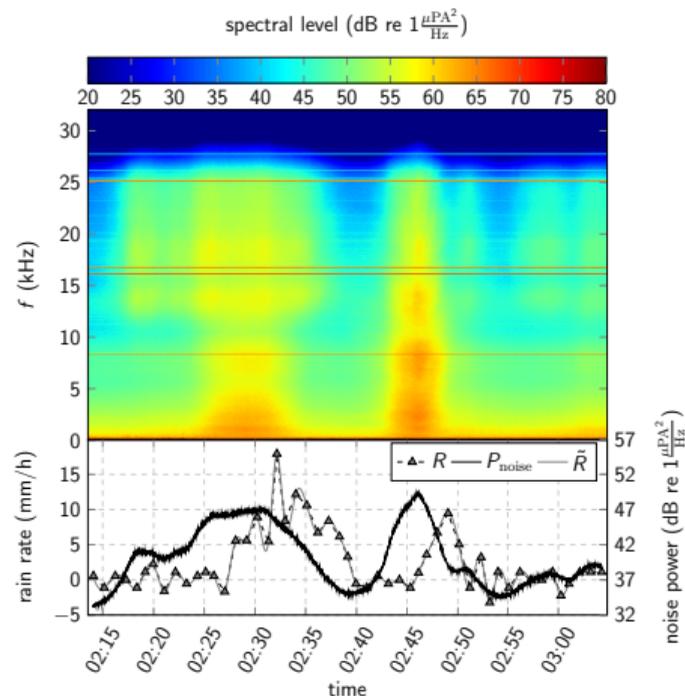
Matching Acoustic and Meteorological Data

- acoustic pattern does not always match rain rate pattern → offset
- estimate and eliminate offset:

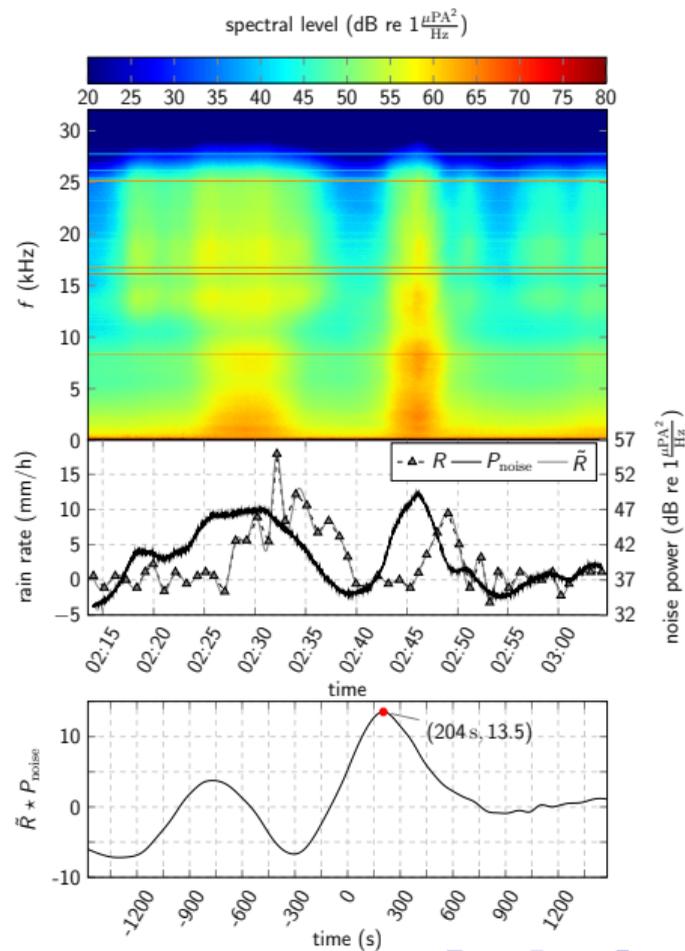spectral level (dB re $1\frac{\mu\mathrm{PA}^2}{\mathrm{Hz}}$)

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$$P_{\mathrm{noise}}(k) = \frac{1}{L} \sum_f 10 \log_{10}\left(\hat{S}^{1s}(f,k)\right)$$

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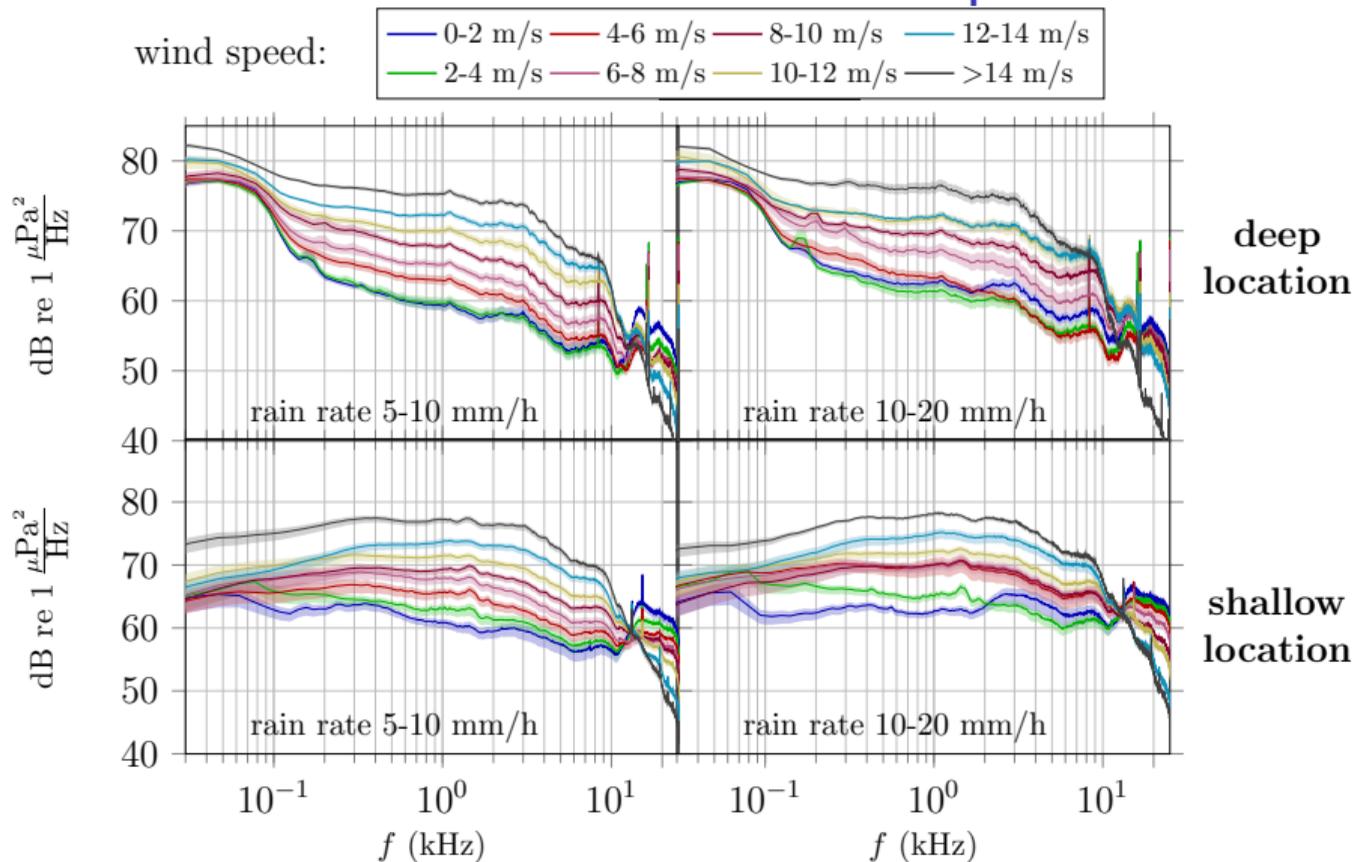- estimate and eliminate offset:
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  - compute offset

  $$\text{offset} = \underset{k}{\text{argmax}}\left(\tilde{R} \star P_{\text{noise}}\right)(k)$$

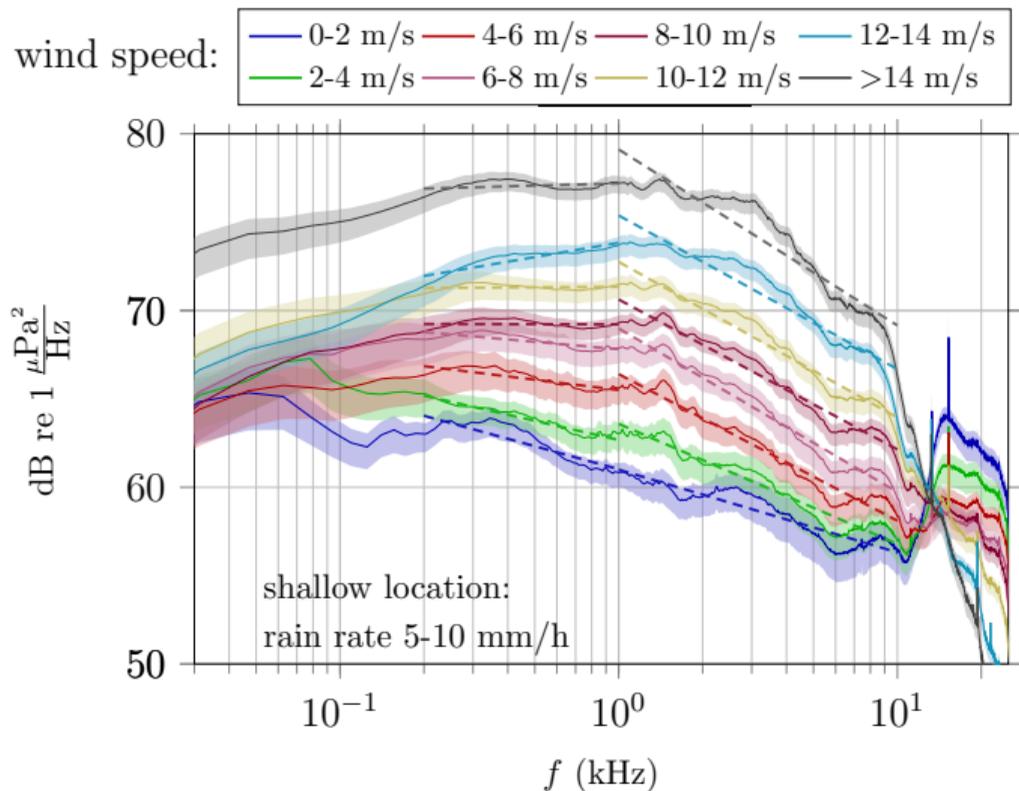spectral level (dB re $1\frac{\mu\text{PA}^2}{\text{Hz}}$)

PSDs for Different Rain Rates and Wind Speeds

Modeling of Rain Noise

- linear regression in:
  - 200 Hz - 1 kHz range
  - 1 - 10 kHz range

$$\mathrm{SPL}(f) = s \cdot \log_{10} f + o$$

wind speed: 0-2 m/s, 2-4 m/s, 4-6 m/s, 6-8 m/s, 8-10 m/s, 10-12 m/s, 12-14 m/s, >14 m/s
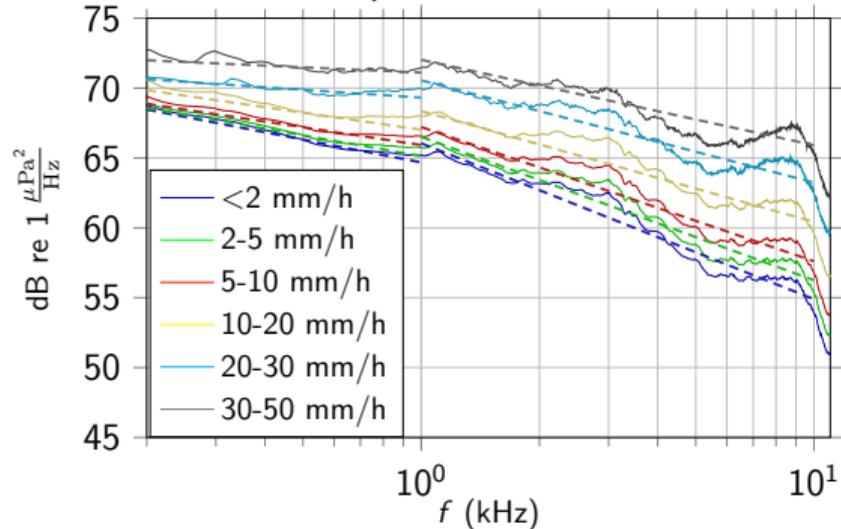
shallow location: rain rate 5-10 mm/h

Summary Spectra
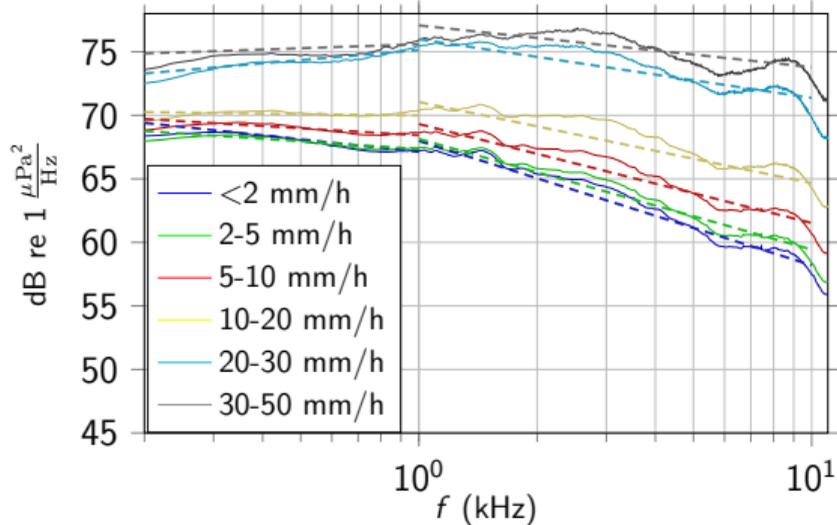
shallow location · deep location
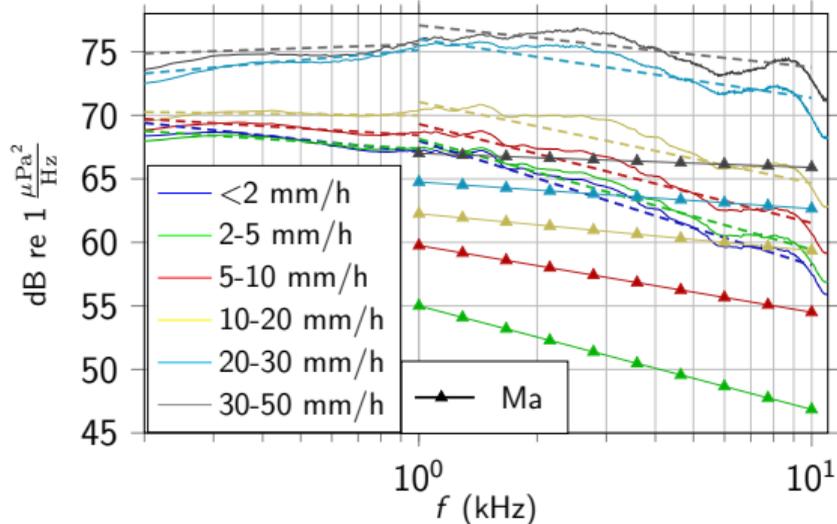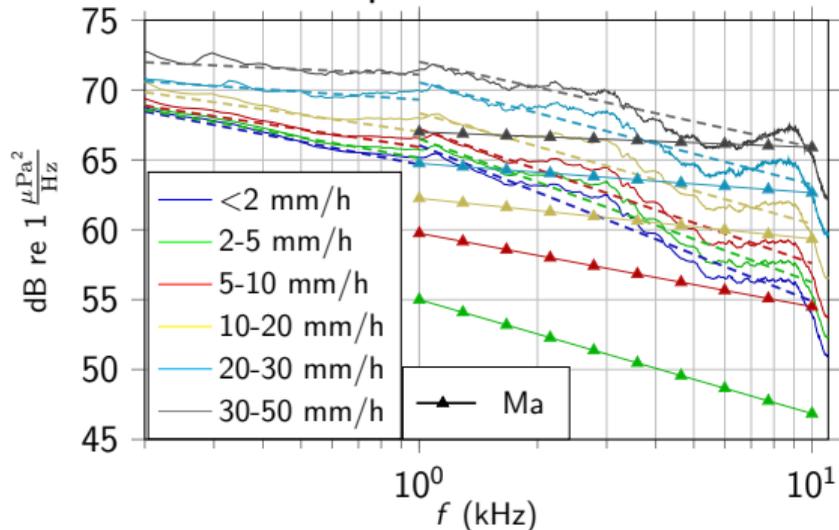
- spectral levels are averages over all wind speed categories

Summary Spectra

shallow location — deep location

spectral levels (dB re 1 $\frac{\mu Pa^2}{Hz}$) versus f (kHz), with curves for rain rate categories: <2 mm/h, 2-5 mm/h, 5-10 mm/h, 10-20 mm/h, 20-30 mm/h, 30-50 mm/h, and Ma.

- spectral levels are averages over all wind speed categories
- triangle lines are linear regression results for same rain rate categories from Ma et al. (2005)[1] measured in the tropical Pacific Ocean (deployment depth: 20 - 98 m)

[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.
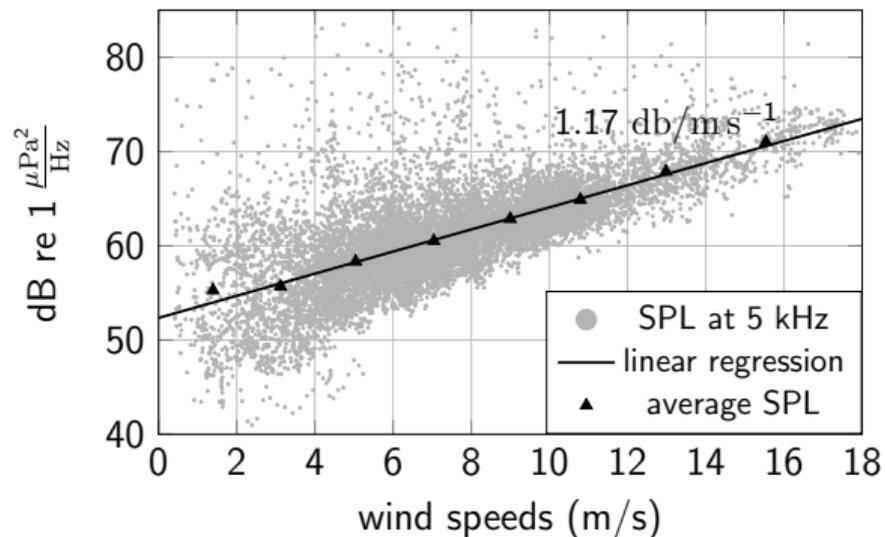
Spectral Level at 5 kHz vs. Rain Rate and Wind Speed

shallow location
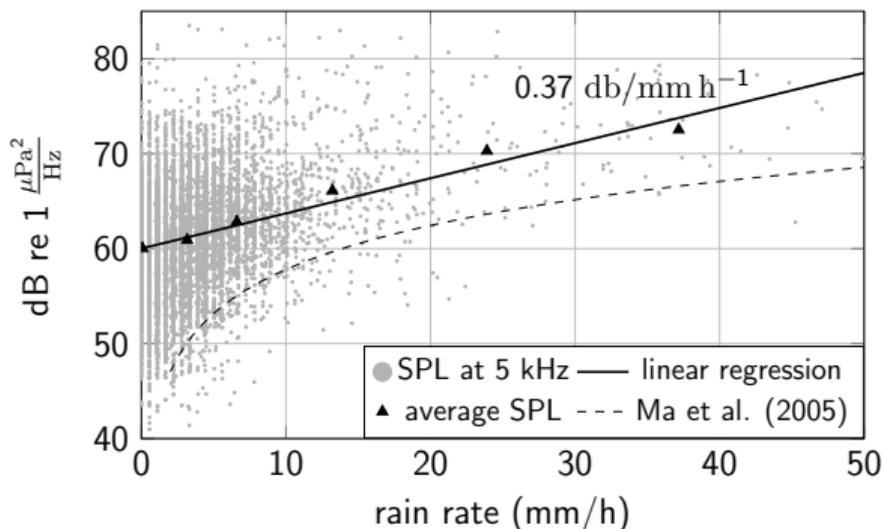
shallow location

- large sampling variability, especially for low rain rates

- strong linear relation for wind speeds above 3 m/s

Conclusions

- **Key Findings:**
  - different rain rates and wind speeds result in different spectral characteristics
  - rain noise level at the northeast Pacific continental margin differ significantly from open ocean measurements
  - the large variability of the spectral level for a specific rain rate along with the strong wind speed dependency make an acoustic conversion challenging
- **Future Work:**
  - find out which acoustic features show the strongest correlation with different rainfall rates
  - use machine learning to estimate rain rates from acoustic data
- **Related Talk:** ASA Fall 2020 – 4aAOb3: Statistical Analysis and Modeling of Wind-generated Ocean Noise in the Northeast Pacific Ocean