EE0007822– NoiseSpotter: A cost-effective, real-time acoustic characterization and localization system

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Project Overview

Project Summary

NoiseSpotter® helps efficiently evaluate potential acoustic effects of marine energy (ME) projects. NoiseSpotter® **geolocates** sources of sound, allowing for the ability to discern ME device sounds relative to other confounding sounds in the environment, while providing location estimates of nearby marine mammals for **environmental mitigation** purposes. The NoiseSpotter® also measures acoustic **particle velocity** that can help address growing concerns about particle velocity effects on fishes and invertebrates.

Intended Outcomes

- A major outcome of this work is the development of a low-cost, **real-time** acoustic measurement system to monitor and characterize ME devices and ambient environmental sounds
- Characterization of ME noise requires distinguishing device sounds from ambient environmental sounds using **geolocation** techniques
- The final project product is a 3D array of acoustic particle velocity sensors coupled to a surface buoy for near real-time telemetry of acoustic data digests to a cloud-based server.

Project Information

Principal Investigator(s)

- Kaus Raghukumar
- Grace Chang
- Craig Jones

Project Partners/Subs

- Proteus Technologies
- Sandia National Labs
- Noise Control Engineering
- HT Harvey and Associates

Project Status

Sunsetting

Project Duration

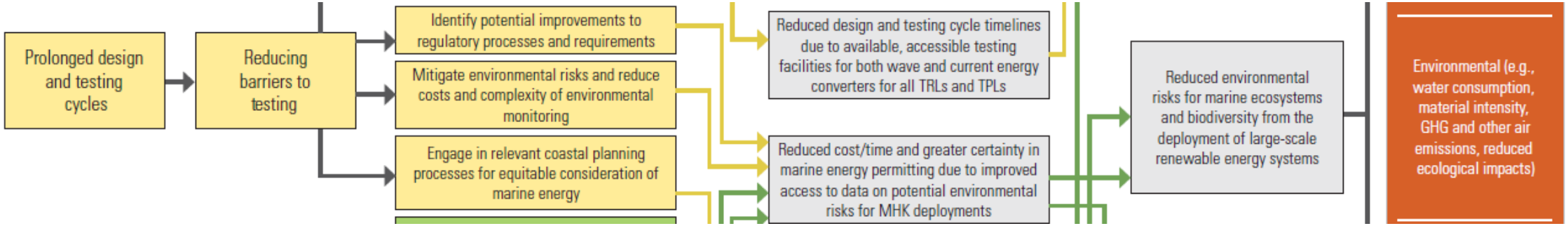
- December 2016
- December 2022

Total Costed (FY19–FY21)

$332,370

Project Objectives: Relevance

Relevance to Program Goals:

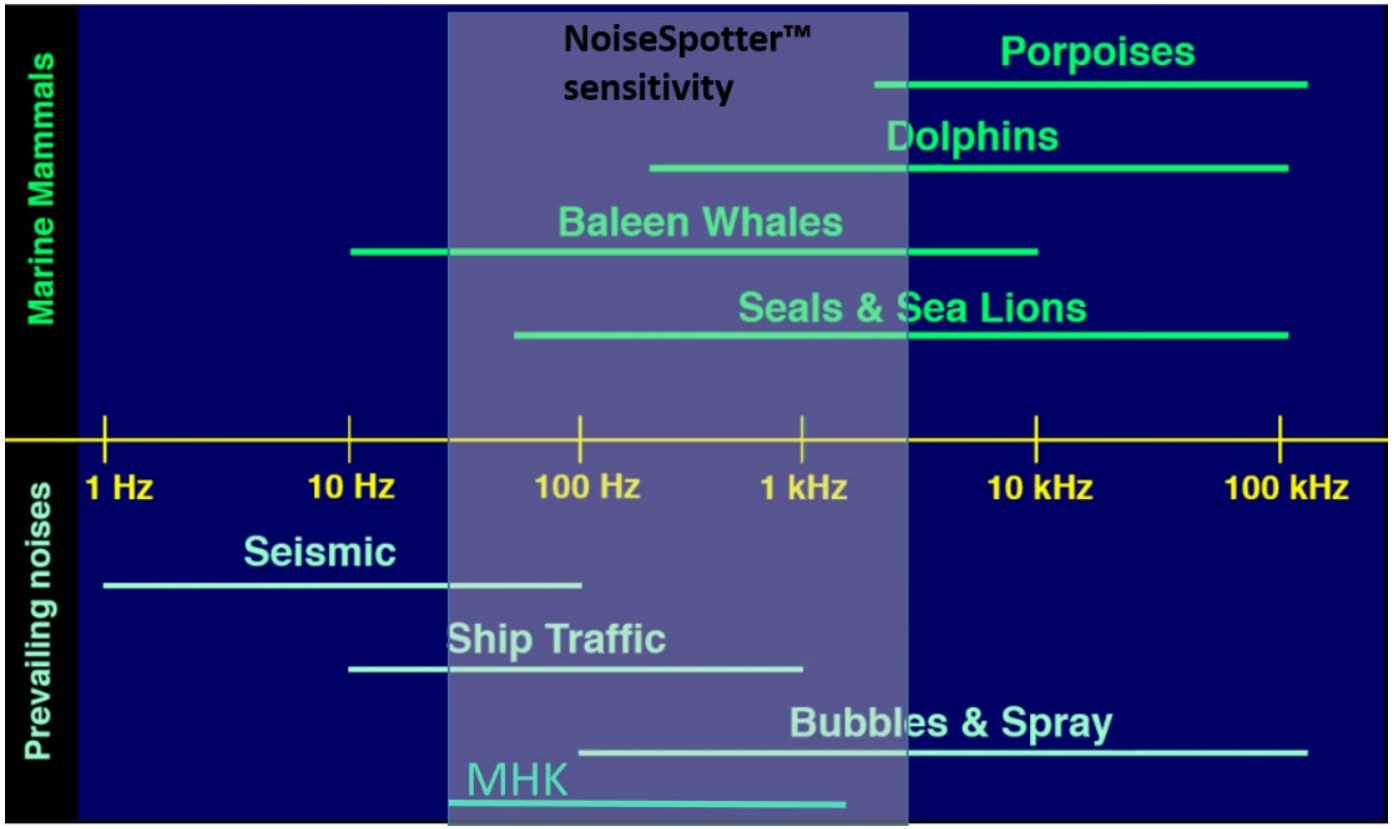


https://www.energy.gov/eere/water/multi-year-program-plan

The technology provides a technical basis for marine energy developers seeking to reduce environmental monitoring costs and **mitigate** concerns about the potential for ME device noise to alter marine mammal or fish behavior.

Project Objectives: Approach

- MHK sounds are low-intensity and overlap in frequency with other anthropogenic and natural sounds
- Implemented directional acoustic sensing to discriminate sounds of interest
- Implemented real-time telemetry to aid in rapid decision-making
- Modular and lightweight for easy deployment/recovery



Adapted from www.dosits.org

Project Objectives: Expected Outputs and Intended Outcomes

Outputs:

- A low-cost, **real-time** acoustic measurement system to monitor and characterize marine energy devices and ambient environmental sounds
- 3D array of acoustic particle velocity sensors coupled to a surface buoy for near real-time telemetry of acoustic data digests to a cloud-based server

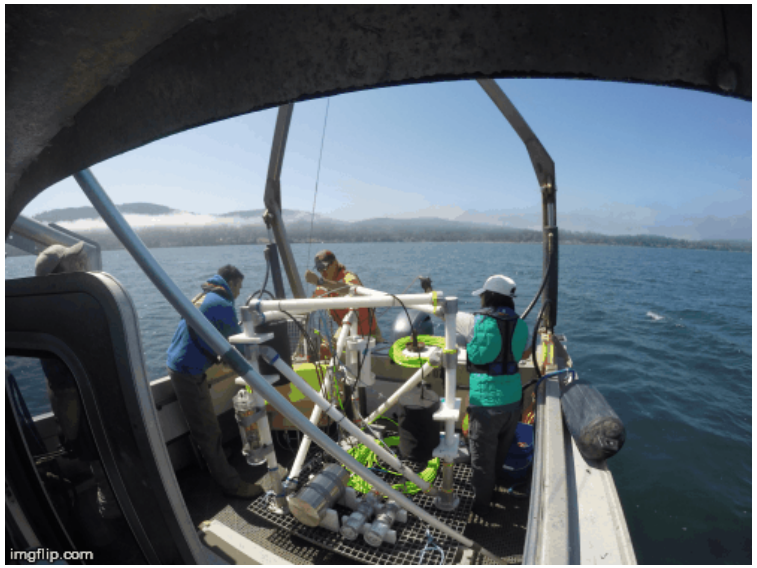
Outcomes:

- Developed a patented acoustic monitoring technology
- Directional characterization of sound from an operational WEC (CalWave)
- Characterization of acoustic particle motion from seismic surveys and its impact on the behavior of fishes and invertebrates.

Project Timeline

	FY2017 BP1				FY2018 BP2				FY2019-2021 BP3			
	Q1	Q2	Q3	Q4	Q5	Q6	Q7	Q8	Q9	Q10	Q11	Q12 - Q21
First round In-water testing plan												
Preliminary hardware design												
Baseline and initial testing with known source												
Technical and cost improvement plans												
Second round in-water testing												
Flow noise removal system development												
Data logger and power system hardware												
Location estimation algorithm development												
Integrated standalone NoiseSpotter powered with on-board storage tested in-water												
Technical and cost performance analysis update												
Finalize VSA design												
Real-time data telemetry software demonstration												
Creation of data digests on board NW												
Third round field testing in energetic environment at CalWave WEC												
Evaluation of quantitative metrics for baseline, initial, second round testing and state-of-the-art												
Final reporting												

- FY17-18
  - Demonstrated baseline and initial system performance
  - Developed and refined plans for performance and cost improvements
  - Designed and tested integrated NoiseSpotter® with low-power, low-noise data logger
  - Demonstrated location estimation using NoiseSpotter® data
- FY19-21
  - Conducted multiple operational deployments
  - Completed final project demonstration
  - Completed final technical and cost performance analysis
  - Published paper on NoiseSpotter® performance
  - Patented acoustic monitoring technology



Project Budget

Total Project Budget – Award Information		
DOE	Cost-share	Total
$746K	$200K	$946K

BP1 (12.1.16 – 11.30.17)	BP2 (12.1.17 – 11.30.18)	BP3 (through FY21) (12.1.18 – 9.30.21)	Total Actual Costs FY17–FY21
Costed	Costed	Costed	Total Costed
$210K (original) $184K (2019 Mod) $184K (actual)	$420K (original) $388K (2019 Mod) $388K (actual)	$315K (original) $373K (2019 Mod) $356K (actual)	$946K (original) $946K (2019 Mod) $928K (actual)

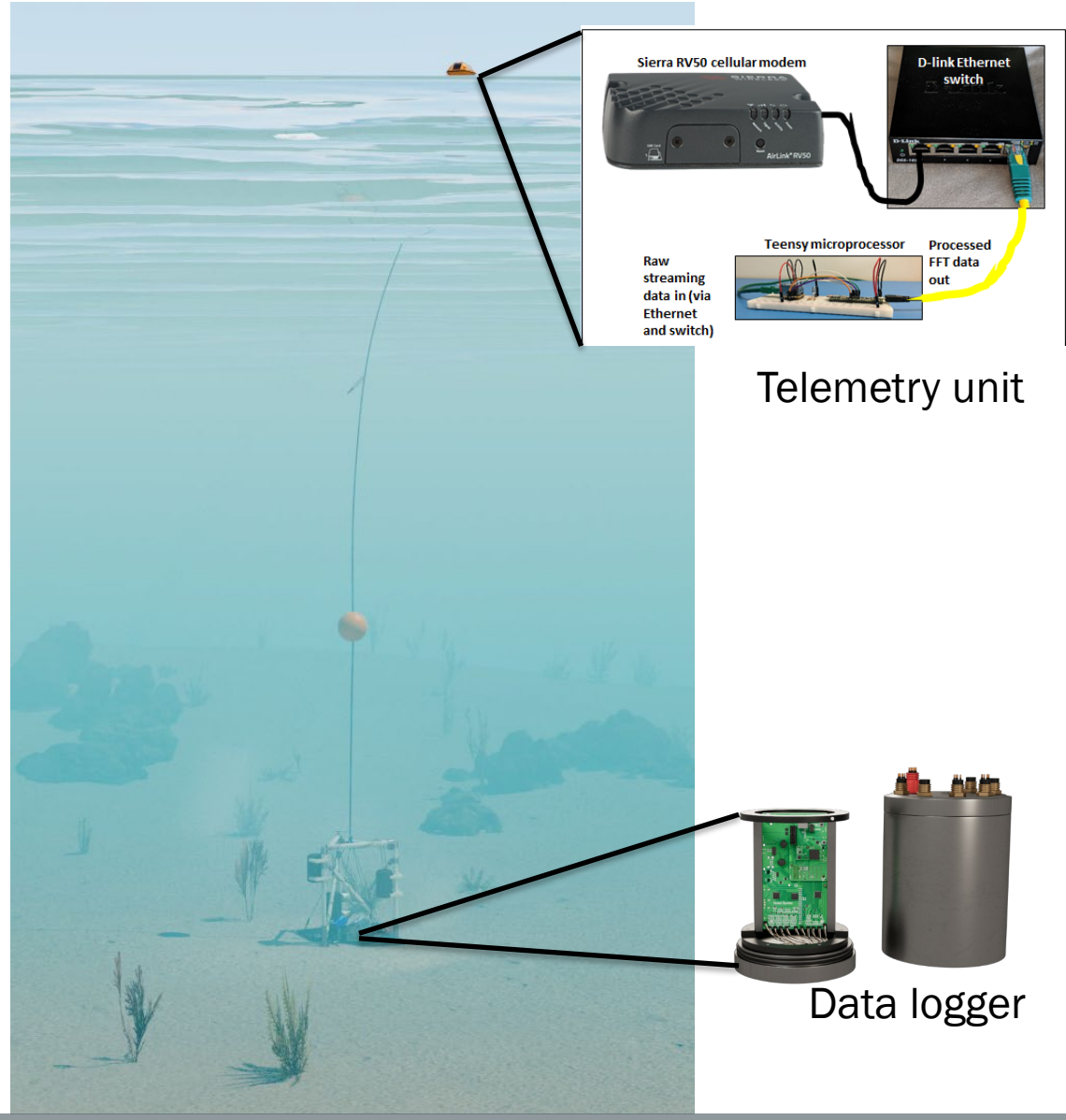
- Three ~12-month no-cost extensions were requested in September 2019, October 2020, and October 2021 to accommodate BP3 in-water field testing in an energetic environment with an operational wave energy converter (WEC).
- The first available opportunity for in-water field testing with an operational WEC was in November 2021 at Scripps Research Pier in San Diego, CA with the CalWave device.

End-User Engagement and Dissemination

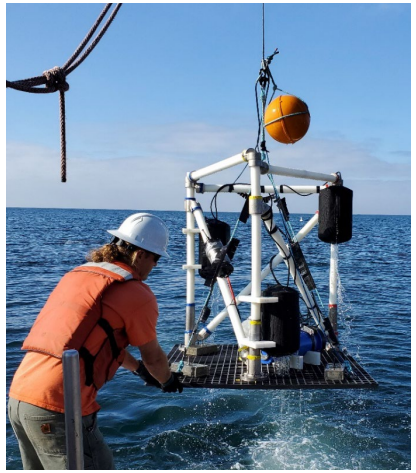
- NoiseSpotter® introduced to regulators and stakeholders at multiple conferences
  - Marine Energy Technology Symposium (2018, 2019)
  - Offshore Technology Conference (2019, 2020)
  - Underwater Acoustics Conference and Exhibition (2019)
  - European Wave and Tidal Energy Conference (2019)
  - Effects of Noise on Aquatic Life (2019)
  - Ocean Sciences Meeting (2020)
- Industry and regulator needs surveyed and addressed during MHK Alt Markets Workshop in December 2017. Survey goals:
  - Ensure NoiseSpotter® hardware and operations are appropriate for marine energy developers
  - Evaluate utility of data output for baseline site characterization and operational deployments
- NoiseSpotter® is patented technology (USPTO No. 11,156,734) and registered trademark (U.S. Trademark No. 6,442,313)
- NoiseSpotter® is currently offered as a service that includes deployment, recovery and delivery of QA/QC'ed data with optional analysis
- Interested clients include offshore wind service providers and the U.S. Navy

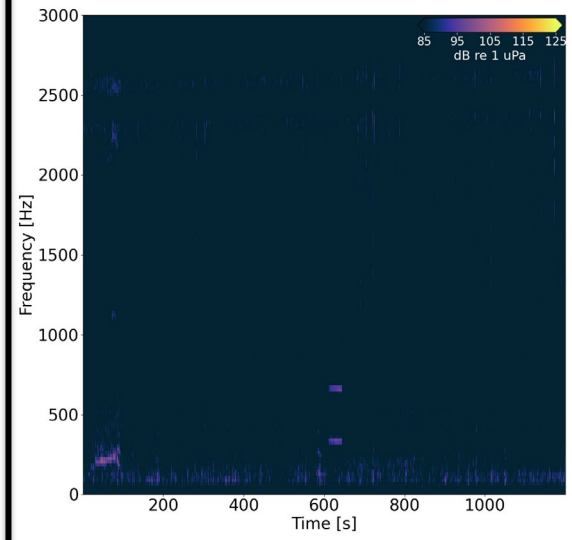
Performance: Accomplishments and Progress

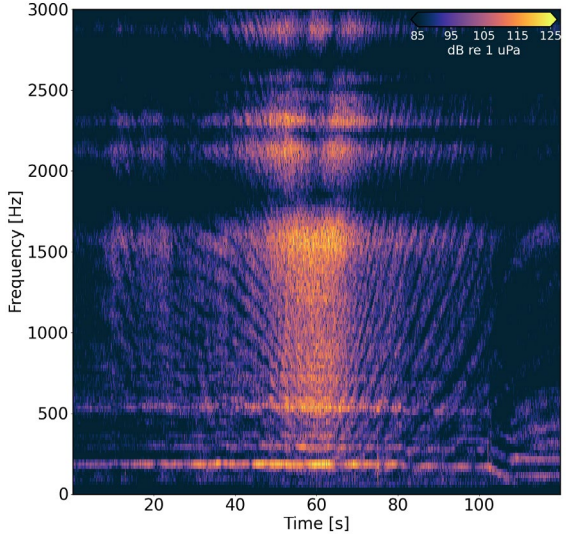
- Vector sensor array with real-time telemetry
  - 3D pressure and particle motion measurements
  - Acoustic characterization and source localization
  - *Data digests transmitted in real-time with <5% data drop-out*
- Tested and validated in multiple environments
  - Tidal regions (velocities of 3-5 knots/1.5- 2.5 m/s)
  - Wave-rich regions (wave heights 2 m @ 15 s)
  - 200 m water depth (no telemetry), 75 m (with telemetry)
- Technical specifications
  - Frequency range (50 Hz to 3 kHz)
  - *Sampling frequency (20 kHz, 16-bit depth)*
  - *Array spacing (1 m horizontal, 25 cm vertical)*



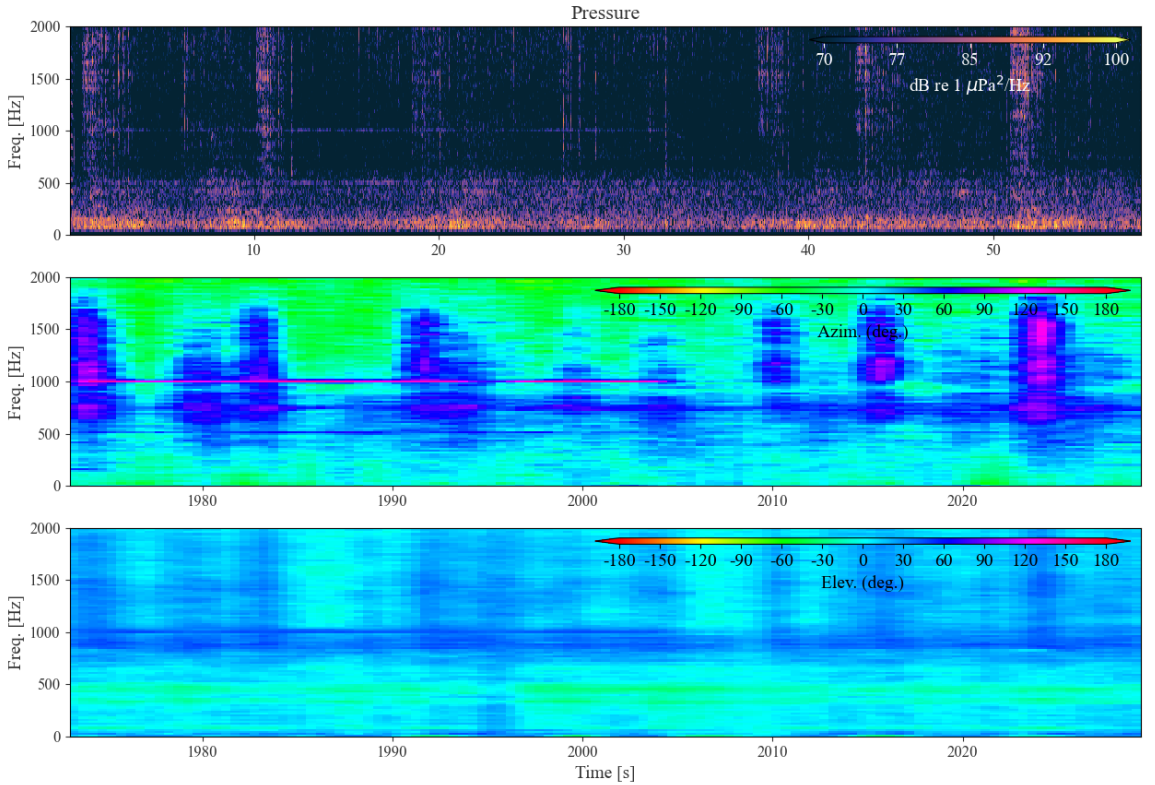
Performance: Accomplishments and Progress (cont.)







NoiseSpotter® Measurements - CalWave



Performance: Accomplishments and Progress (cont.)

Technical Performance Analysis

Technical Performance Category	Final Score	Target Score
Detection frequencies	2 20 Hz – 20 kHz broadband, 50 Hz – 3 kHz particle motion	2 40 Hz to 5 kHz
Detection sensitivity	1 -194 dB – 230 dB	1 -194 dB – 230 dB
Ambient noise removal	1 Beamforming methods across multiple sensors suppresses incoherent ambient noise	1 Coherent processing across multiple sensors suppresses incoherent ambient noise
Horizontal flow noise removal	1 Flow noise shields reduce flow noise by >15 dB at <200 Hz and <1 dB signal loss at >200 Hz	2 Flow noise reduction of 2 dB at <200 Hz and <1 dB signal loss at >1 kHz
Vertical flow noise removal	1 <5° movement in pitch, roll, and yaw. Shock-mounted sensor configurations; bottom-mounted platform configuration	1 <5° movement in pitch, roll, and yaw. Shock-mounted configuration decouples buoy from surface wave motions
Data logger noise	2 NoiseSpotter® signals comparable to broadband acoustic recorder (BAR)	2 NoiseSpotter® signals comparable to BAR
Signal losses	0 <2 dB signal loss	0 <2 dB signal loss
Data quality	0 Zero dB degradation in signal to noise ratio	0 Zero dB degradation in signal to noise ratio
Clock	0 All sensors synchronized to GPS clock during start-up; all three sensors are logged synchronously	0 All sensors synchronized to GPS clock

0- no issue

5- moderate issue

10- severe issue

Performance: Accomplishments and Progress (cont.)

Technical Performance Analysis

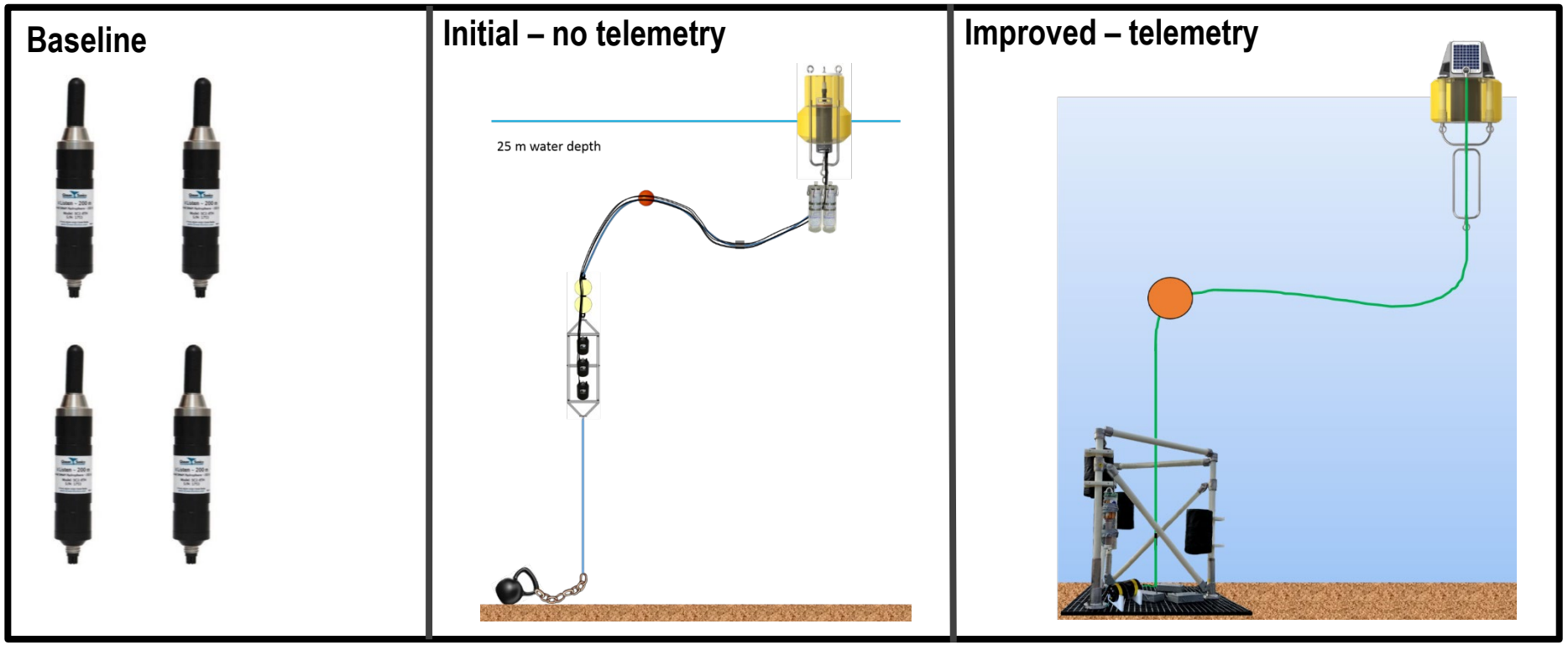
Technical Performance Category	Final Score	Target Score
Location estimation accuracy	1 Bearing estimates to within 2 m	4 Bearing estimates <100 m
Data presentation and interpretation	1 Data digests @ 140 kB/digest for decision-making	1 Short data digests for decision-making; peak exceedance levels, RMS sound pressure, location estimates
Onboard data storage	1 2 TB	1 48 GB/day @ 25 kHz for 40 days
Data communication	2 >10 Mb/s throughput, cellular range: coastal, <1% data drop-outs, automatic data queuing, automatic system re-establishment	2 6 kb/s transmission of key data metric digest, satellite range: unlimited, <1% data drop-outs, automatic data queuing, automatic system re-establishment
Power budget	3 3.6 W; however NoiseSpotter® is designed with custom rechargeable 516 Ahr battery packs	3 2 W of electrical power including acoustic sensors, analysis, storage
Operations	4 2 personnel and vessel assistance (e.g., A-frame) for deployment/recovery	2 2 personnel for deployment/recovery; no vessel assistance
Operational duration	1 Autonomously for 35+ days	2 Autonomously for 7 days
Operational environments	0 Any: inland waters, harbors, surf zone, coastal ocean, open ocean; low to high energy	0 Any: inland waters, harbors, surf zone, coastal ocean, open ocean; low to high energy
Cost	2 <$35,000	2 <$35,000

0- no issue

5- moderate issue

10- severe issue

Performance: Accomplishments and Progress (cont.)



Cost performance analysis:

Baseline (broadband autonomous hydrophone)

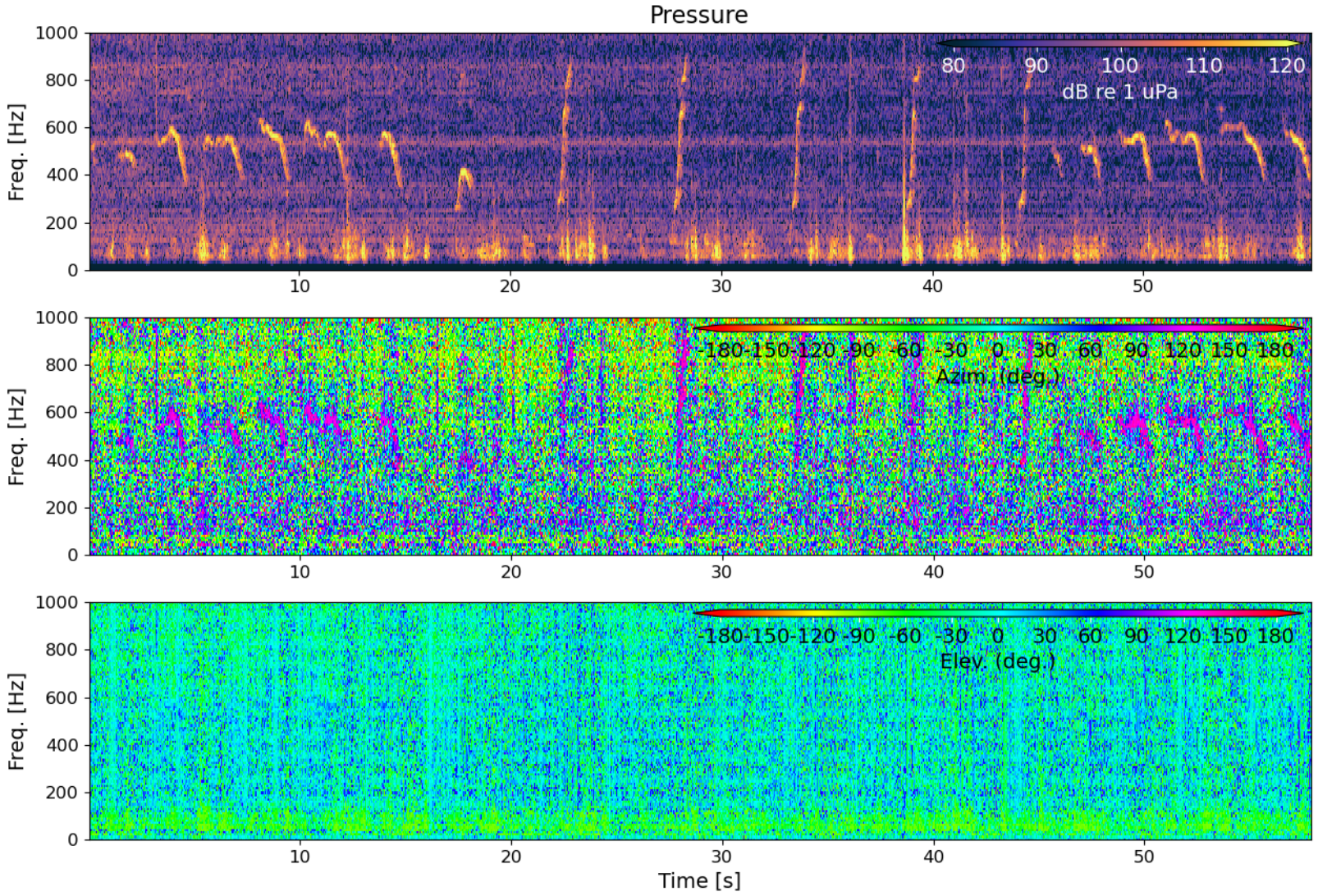
Initial (NoiseSpotter®, no telemetry): 20% savings over baseline

Improved (NoiseSpotter® with telemetry): 50% savings over baseline

Performance: Accomplishments and Progress (cont.)

- U.S. Patent No. 11,156,734 and U.S. Registered Trademark No. 6,442,313
- NoiseSpotter® is the only commercial particle motion sensor array with real-time telemetry
- Peer-reviewed publications:
  - Chang, G., G. Harker-Klimeš, K. Raghukumar, B. Polagye, J. Haxel, J. Joslin, F. Spada, and G. Staines. 2021. Clearing a path to commercialization of marine renewable energy technologies through public-private collaboration. Front. Mar. Sci., 8, 669413. doi: 10.3389/fmars.2021.669413.
  - Raghukumar, K., G. Chang, F. Spada, and C. Jones. 2020. A vector sensor-based acoustic characterization system for marine renewable energy. J. Mar. Sci. Eng. 8(3):187. doi:10.3390/jmse8030187.
  - Raghukumar, K., G. Chang, F.W. Spada, and C.A. Jones. 2019. NoiseSpotter: A rapidly deployable acoustic monitoring and localization system. D. Vicinanza et al. (eds), Proc. of the 13th European Wave and Tidal Energy Conference, Naples, Italy.
  - Raghukumar, K., G. Chang, F. Spada, C. Jones, J. Spence, S. Griffin, and J. Roberts. 2019. Performance characteristics of a vector sensor array in an energetic tidal channel. pp. 653–658. J.S. Papadakis (ed), Proc. of the Fifth Underwater Acoustics Conference and Exhibition, Crete, Greece.
  - Raghukumar, K., G. Chang, F.W. Spada, and C.A. Jones. 2019. Performance characteristics of the NoiseSpotter: An acoustic monitoring and localization system. A. Cooper and P. Gibbs (eds), Offshore Technology Conference, Houston, TX. doi:10.4043/29425-MS.

NoiseSpotter® Operational Measurements - ONR



Q&A