Acoustic Monitoring of Ocean Surface Wave Spectra with Autonomous Underwater Gliders

This research is supported by the National Science Foundation Navigating the New Arctic grant #1839063

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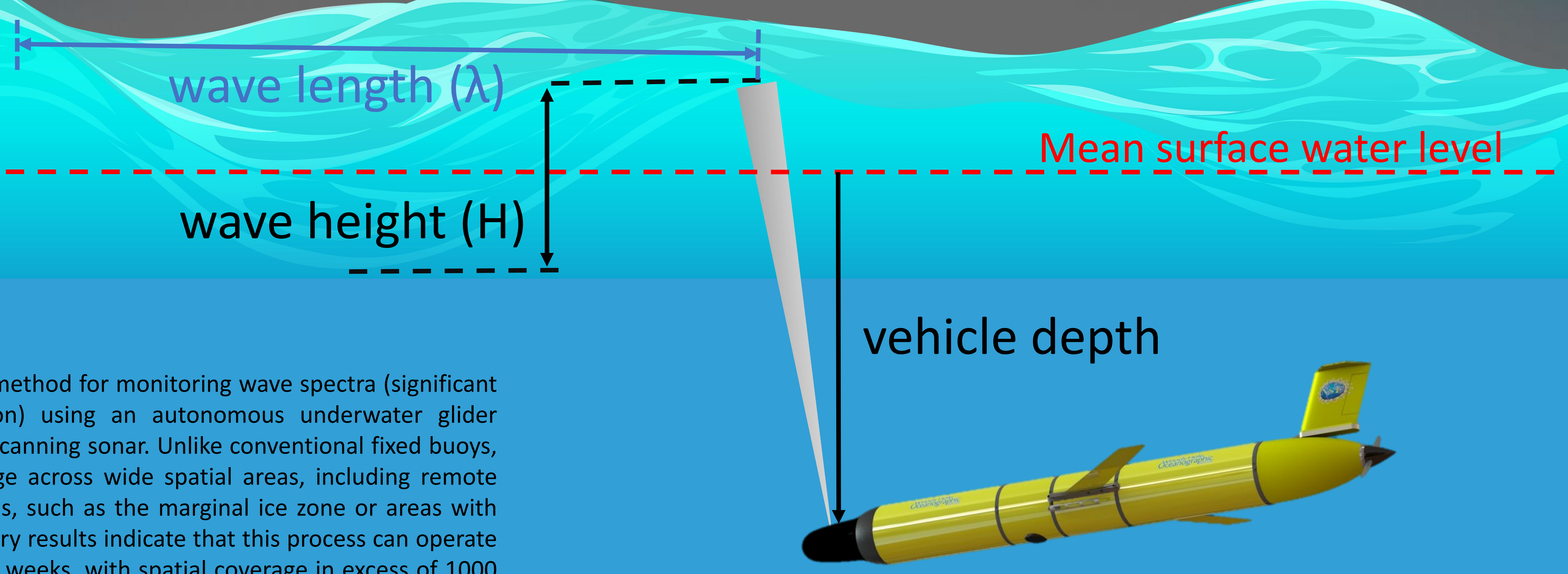


Abstract:
We present a new, low-cost method for monitoring wave spectra (significant height, period, and direction) using an autonomous underwater glider equipped with a low power scanning sonar. Unlike conventional fixed buoys, this method enables coverage across wide spatial areas, including remote and difficult to access regions, such as the marginal ice zone or areas with extreme sea states. Preliminary results indicate that this process can operate continuously for durations of weeks, with spatial coverage in excess of 1000 km. Information gathered from these observations are potentially useful for understanding mechanisms of ice advance/retreat and coastal erosion.

Introduction:

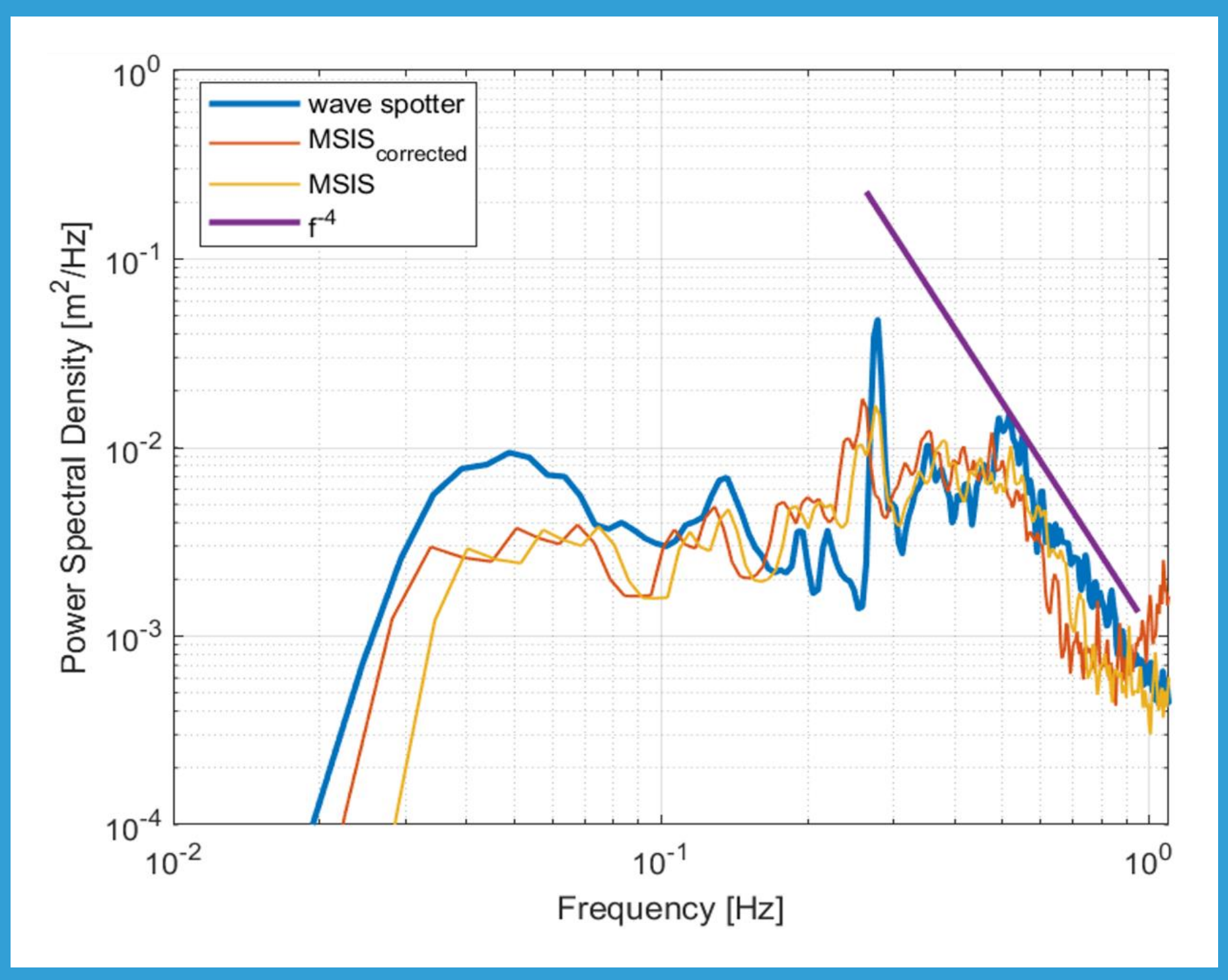
Ocean wave spectra characterization is important for understanding heat and momentum transfer at the air-sea interface during seasonal ice advance and retreat in marginal ice zones (MIZ)[1]. Conventional measurements are limited to surface buoys and ice tethered profilers, which can be costly to operate and provide limited spatial coverage. Additionally, because these systems measure the direct physical interaction of the platform with sea surface, factors such as the fundamental frequency of oscillation can alias the measurement process. An autonomous underwater glider (AUG) equipped with a mechanically scanned imaging sonar (MSIS) can minimize these limitations by observing wave spectra while traveling at a safe depth below the ocean surface during storms or in areas of ice cover.

Method:

The MSIS transducer is aimed vertically upward and swept rapidly (~1 second) across a narrow (±5 °) angle to record sea surface elevation while submerged. This time series information is co-registered vehicle pose (e.g., depth, heading, pitch, and roll). The instantaneous vertical difference between the MSIS transducer's depth (relative to mean surface level) and the insonified water surface is used to estimate wave height (H). The projected peak-to-peak distance (accounting for AUG velocity) is calculated wave length (λ), and AUG velocity corrected time between peaks is wave period. Conversion of this time series data into a frequency domain enables wave power spectral density analysis. Doppler-induced wave spectra frequency peak shifts relative to direction of MSIS transducer rotation indicates direction wave front propagation.

Results:

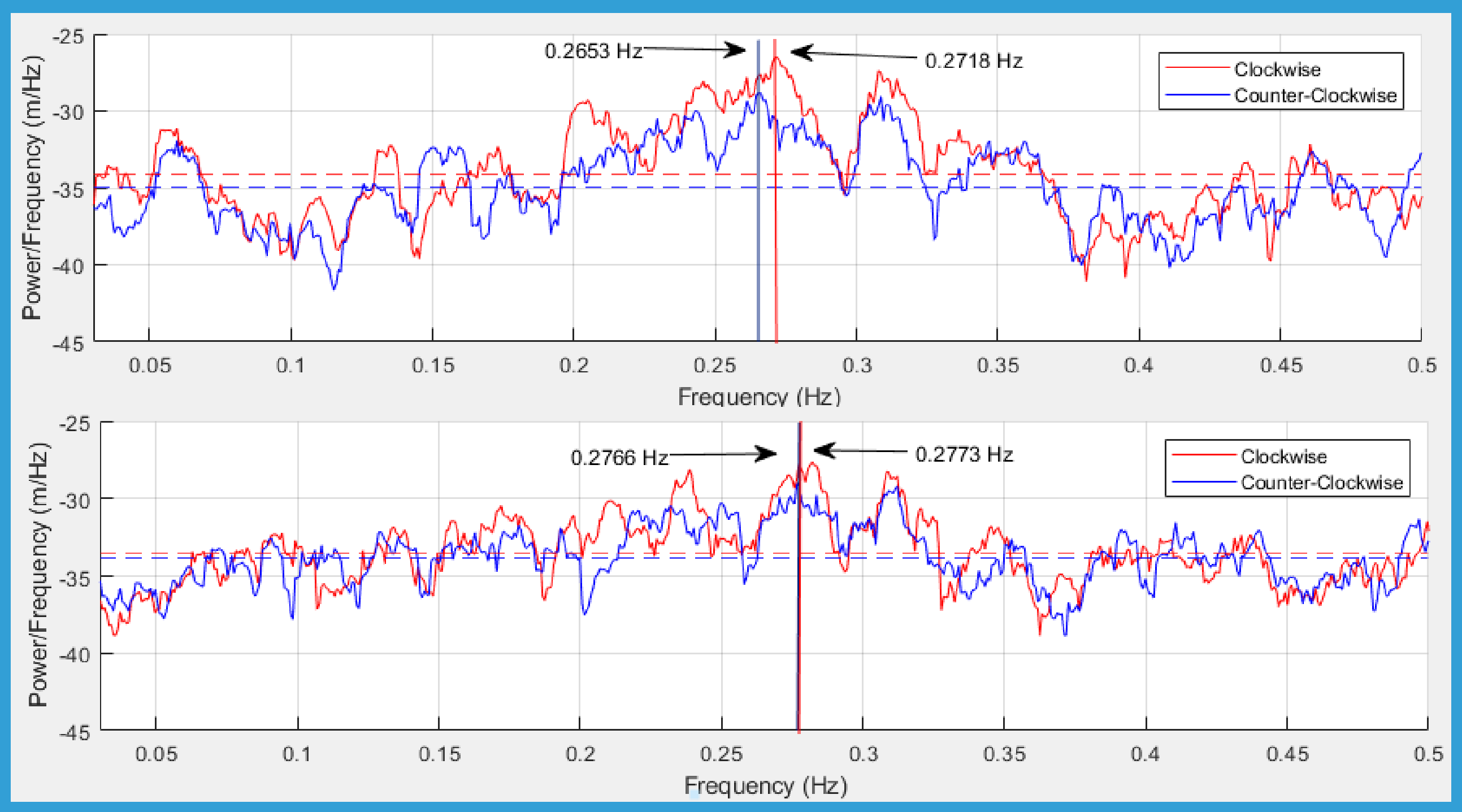
AUG-sonar characterization of bulk parameters, including significant wave height (H_s), peak frequency (f_p), and mean wave direction (θ_m) are in close agreement with independent observations using a conventional wave buoy sensor.. Comparison of wave spectra show similar peak amplitudes and frequencies.



Power spectral density plots of wave spectra generated from Field Trials (MSIS) closely match contemporaneous observations using a conventional SAFOR wave spotter buoy (see table at right), and the theoretical dissipation of wave energy as f^{-4}. Doppler shifts caused by vehicle motion are corrected with vehicle dead reckon velocity estimates ($\text{MSIS}_{\text{corrected}}$) [2].

Bulk parameter	MSIS	Wave Buoy	Discrepancy
H_s (m)	0.244	0.257	5.1%
$T_{p\ max}$ (s)	2.88	2.71	-6.1%
$f_{p\ max}$ (Hz)	0.375	0.413	9.2%
$T_{p\ weighted}$ (s)	2.31	2.24	-2.9%
$f_{p\ weighted}$ (Hz)	0.434	0.461	5.9%

Significant wave height (Hs), Peak Period (Tp), and Peak Frequency (fp) calculated from the AUG sonar method [2]. Results are within 10% of values recorded using a conventional wave buoy. *Bulk parameters are calculated using the energy integral with frequency bounds 0.1 –→ 1.0 Hz. Peak frequency and period are calculated using the max-ordinate method.*



Example of wave spectra generated from dockside trials. Trial 1 (top) was conducted with the MSIS oriented ESE and visually confirmed to be perpendicular to the wave front. Trial 2 (bottom) was conducted with the MSIS oriented SSW and parallel to the wave front [3]. The more pronounced Doppler shift in the major peak at approx. 0.27 Hz (*Tp* ≈ 3.7s) indicates that the dominant wave front energy was traveling toward the starboard direction of the MSIS during Trial 1 (i.e., a dominant SSW wave front).

Conclusion:

AUG-sonar characterization of surface wave motion provides a low cost method for improving understanding of momentum transfer which is important for forecasting storms, ice cover evolution, coastal flooding and erosion. This capability is potentially applicable for helping coastal communities respond to changing Arctic conditions.

Cited sources:

[1] S. Zippel and J. Thomson. "Air-sea interactions in the marginal ice zone Air-Sea interactions in the Marginal Ice Zone." *Elementa: Science of the Anthropocene* 4 (2016).
[2] G. Burgess *"In-situ* Characterization of Sea State with Improved Navigation on an Autonomous Underwater Glider" S.M. Thesis, MIT-WHOI, 2022.
[3] G. Burgess, P. Ventola, R. Camilli "Got Ice?-A Statistical Approach to Marking Sea Ice and Atmospheric Conditions with a Low-Powered Imaging Sonar." *2020 IEEE/OES Autonomous Underwater Vehicles Symposium (AUV)*. IEEE, 2020.