Quiet Vessel Initiative Final Report (2024): An Adaptive Physics-based Machine Learning Framework for Anthropogenic Noise and Ocean Soundscape (MELO) Project

Project Description

The MELO Project commenced development of a physics-based machine learning toolbox for the end-to-end mapping between the widely varying distributed noise sources and marine mammals and to demonstrate its application in an adaptive noise mitigation system.

Major achievements to date include:

- Configured Bellhop to generate under-water acoustic transmission loss data.
- Created a dataset, containing varying bathymetry for seamount profile.
- Validated the Bellhop (gaussian beam tracing) model with experimental data.
- Built a data-driven model for predicting underwater acoustic transmission loss.
- Trained the data-driven model to include prediction for varying bathymetry.
- Constructed a model problem simulating a ship voyage in 2D environment.
- Utilized particle swarm optimization algorithm to minimize the impact of radiated noise at a marine mammal's location.
- Submitted three papers containing results from the project to be published.
- Produced a review of the scientific literature outlining the auditory capabilities of marine mammals.
- Gathered acoustic data from a Canadian Coast Guard research vessel from hydrophones in Boundary Pass to validate the model.
- Convened experts from around North America (44 participants) for an interdisciplinary design workshop focused on developing innovative, holistic solutions to ship-source underwater noise and the impact on the marine environment.
- Published various project-related web content on the Clear Seas website and social media channels, including a workshop report, a research article on the data collection trip with the Canadian Coast Guard, and more.
- Planned second workshop to share results from the project and provide opportunities for interdisciplinary collaboration for late 2024 or early 2025.

There have been changes to the research approach and schedule of the MELO Project since being awarded QVI funding in 2022. In light of the tight timeframe for completion, the team has elected to validate the prediction capability of the noise toolkit using data from another QVI project, the Seaspan/Robert Allan electric tug project. This work is now ongoing and should be completed by the end of May 2024. The data collected from the CCGS Sir John Franklin, will be used to further validate the prediction capabilities after the end of the QVI project.

The project team identified additional future work to develop a database of experimental measurements to enhance interdisciplinary collaboration on research related to underwater noise. This task stemmed from discussions at the MELO Project Design Workshop in June 2023, where dataset availability and their application across organizations and disciplines was identified as a key challenge to developing innovative solutions to the impacts of underwater noise on marine mammals.

The MELO Project team will continue to work together to demonstrate the application of the toolkit in an adaptive noise mitigation system. To support the continued research into innovative solutions to underwater noise, Clear Seas is seeking additional funding for research activities and communication materials. Further investment into the MELO Project will allow the interdisciplinary team to build on the completed research tasks, broadening the scope of the project and advancing the development of the toolkit with additional data and a more robust framework.

The MELO Project team at the Design Workshop, hosted at UBC on June 1-2, 2023.

Performance Indicators

	ACTIVITY	ACTIVITY STATUS	NOTES
TASK 1 Develop the noise prediction toolkit	Acquire Multiphysics lab training data	COMPLETED	
	Perform CFD simulations with UBC tools for generating training data / physically accurate solutions	COMPLETED	
	Review Multiphysics lab architecture via literature review	COMPLETED	

	Assess novel ideas improving existing PBML tools at UBC	COMPLETED	Improved the model by integrating geometry of ocean bathymetry in architecture pipeline
	Train PBML models with training data acquired from experiments and simulations	COMPLETED	Results reported in OMAE conference paper
TASK 2 Demonstrate the software capabilities	Gather ship design details and plan experimental measurement campaign	COMPLETED	
	Acquire data through measurement campaign using CCGS vessel and Boundary Pass underwater listening station hydrophone	COMPLETED	Research campaign completed in August 2023 on the CCGS Sir John Franklin
	Process and analyze collected data	COMPLETED	Contracted JASCO to assist with the processing and analysis of acoustic data
	Compare underwater radiated noise predictions from PBML tool to existing CCG and hydrophone data	MODIFIED – IN PROGRESS (Estimated completion date: end of May 2024)	Shifted project plan to use vessel design plans and acoustic data from Seaspan tug first, with plans to address CCGS Sir John Franklin later in the project
TASK 3 Simulate smart adaptive noise mitigation	Obtain understanding of marine mammal response to broadband underwater radiated noise frequency spectrum	COMPLETED	
	Commence a parametric study of various marine vessel operation strategies with PBML to obtain benign ship underwater radiated noise	COMPLETED	
TASK 4 Mobilization of knowledge	Organize and host a workshop to present Project results of Marine Mammal Research Unit literature search with joint design session	COMPLETED	Hosted MELO Project Design Workshop in June 2023 at UBC
	Organize a workshop on the preliminary results of the vessel noise prediction and real-world noise measurements	COMPLETED	Workshop planned for end of 2024 / early 2025
	Publish Project results and share via communications platforms	COMPLETED	

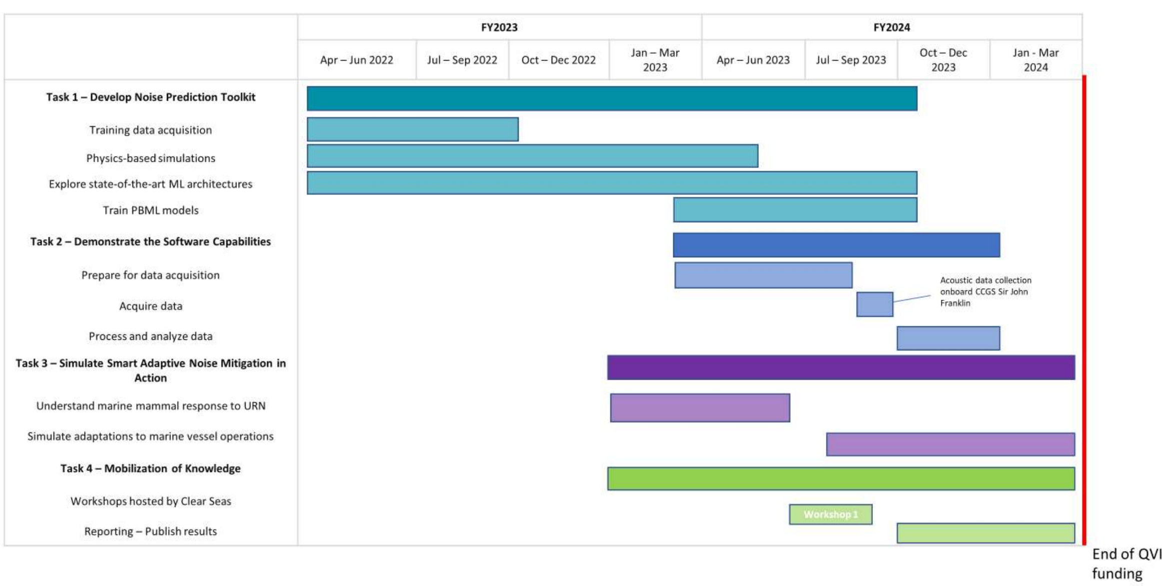
Project Outcomes

The MELO Project team has been trained in and contributed to identifying, testing, and developing technologies quiet vessel technologies and designs. The following metrics demonstrate this training and contribution:

Metric	Number	Description
# of participants that attended courses or workshops	44	There were 44 participants in the MELO Project Design Workshop hosted in June 2023 at UBC
# of individuals that received training or information	4	3 HQP (Zhi Cheng, Indu Kant Deo, Akash Venkateshwaran) and 1 project manager (Tessa Coulthard) received training or information related to underwater noise or quiet vessel technology

# of technologies developed (for example, literature reviews on Multiphysics lab architecture performed, simulation on smart adaptive noise mitigations, etc.)	9	Literature review of marine mammal sensitivity to underwater noise Literature review of PBML Literature review for integrating experimental data with machine learning Machine learning algorithm for sound propagation PyMELO: Python framework for generating sound propagation data RC-CAN: Deep-learning framework for sound propagration MOOF: Multi-Objective Optimization Framework Framework on the prediction of flow dynamics, cavitation, and hydroacoustics of full-scale marine propellers.
# of technologies evaluated	5	Bellhop Comparison between measurements and present simulation data regarding VP 1304 propeller Kraken (Normal mode solver for underwater acoustics) Nektar ++ (FEM-based underwater acoustics) PyTorch deep learning for underwater acoustics

Updated Timeline of Project Activities



Task 1 Highlights: Toolkit development

Optimization of vessel operation considering mammal locations

For this project, an optimization framework was developed that reduces underwater radiated noise by mitigating the operation level of the ship (i.e., the speed of the ship). An ocean environment was modeled with randomly scattered marine mammals, where a ray-based approach was implemented for underwater noise modeling. A non-dominated sorting genetic algorithm was used to solve the optimization problem considering two contradicting objectives: total noise intensity levels and fuel consumption. The framework was demonstrated using real-world case studies. A conference paper and a journal paper comprising this work have been submitted to ASME and the Journal of Ocean Engineering, respectively.

Near-field noise prediction

The prediction framework of the near-field noise originating from marine propellers was developed based on the open-source computational fluid dynamics (CFD) software OpenFOAM. The involved methodology includes a standard dynamic Large Eddy Simulation (LES) model, the Schnerr-Sauer model for cavitation, and the Ffowcs-Williams-Hawkings (FW-H) method. We presented a comprehensive numerical investigation into the flow dynamics, cavitation patterns, and hydroacoustic propagation associated with a five-blade full propeller and further explored the potential mechanism underlying the propeller noise radiation. Both cavitating and non-cavitating conditions are considered in the present work.

Our modeling results, when compared to experimental data, validate the accuracy and reliability of our computational approach. In the cavitating configuration, the formation of cavitation occurs at the root and tip of the propeller blades, with the observation of a distinct double-helical pattern in the tip vortex cavitation. The trajectory analysis of the tip vortex showcases its evolution from discernible filaments to destabilization and eventual vortex breakdown.

Notably, the pressure fluctuations experienced on the propeller surface during cavitating conditions exhibit more pronounced variability compared to non-cavitating conditions. This intensified fluctuation amplifies the energy emitted by the noise source. Our comparative assessment of the sound pressure level (SPL) directionality confirms that the hydroacoustic power generated during cavitating scenarios surpasses that of non-cavitating instances in all directions, particularly evident in the downstream direction with an increase in SPL of up to 20 dB. The generation of sheet cavitation and tip vortex cavitation leads to the enhancement of monopole (loading) noise source, and the associated collapsing of vortices and bubbles in the wake contributes to broadband noise components. Additionally, the tonal components, at frequencies corresponding to harmonics of blade passing frequency, intensify owing to the close correlation between the structure of tip vortex cavitation and the blade passing.

The addition of the nozzle surrounding the marine propellers will suppress the cavitation generated from the propeller blades and also the accompanied noise sources. However, the presence of a nozzle will also bring the noise source. Generally, ducted propellers will have better performance on noise generation than non-ducted propellers.

Using the recently developed cavitation FSI solver, we also studied the coupled dynamics of flow-induced vibration and cavitation of cantilever flexible hydrofoils and explored the potential impact on hydro-noise sources. Our work involved the computation of three cases: a rigid hydrofoil without cavitation, a flexible hydrofoil without cavitation, and a flexible hydrofoil with cavitation. The comparative analysis indicated that the pressure fluctuations within the flow field are mainly affected by the tip vortex shedding, the trailing-edge vortex shedding, and the structural vibration. Among them, the tip vortex shedding and blade vibration are correlated to the intense peak (low-frequency tonal components) of the noise source, while the trailing-edge vortex shedding leads to broadband noise. We further analyzed the effect of sheet cavitation's appearance on the flow-solid interaction response. The results demonstrated that the shedding of sheet cavitation induces considerable periodic forces on the hydrofoil surface, which induces flutter-like response, dominates the blade vibration, and affects the pressure fluctuations in the flow field. The frequency of tonal components inside potential noise sources is consistent with those of cavitation shedding behaviors and structural vibration. It could be summarized that the cavitating behaviors and structural vibrations co-dominate the features of noise sources for propeller singing behavior. Moreover, there is also a reciprocal effect between cavitation structures and hydrofoil vibrations. The deformation and oscillation of hydrofoil will also in turn modify the vortex and cavitation shedding dynamics.

<u>Far-field noise propagation</u>

Over the past year, significant progress has been made in enhancing the predictive capabilities of deep-learning-based models for forecasting underwater radiated noise from shipping vessels in far-field scenarios. Traditional full-order models based on Navier-Stokes equations have limitations in such environments, especially with seamounts and varying bathymetry. However, recent advancements in reduced-order models based on deep learning have shown great promise, operating much faster than full-order simulations while maintaining accuracy.

Our project has focused on improving these models by modifying the network architecture. One key enhancement is the introduction of a novel range-conditional convolutional neural network that incorporates ocean bathymetry data into the input. This addition addresses a critical limitation in existing models, which often rely on auto-regressive prediction and lack information about far-field bathymetry.

The modified architecture has been rigorously tested on various scenarios, including a benchmark case involving far-field prediction over Dickin’s seamount. The results demonstrate the model's effectiveness in capturing transmission loss over a range-dependent, varying bathymetric profile.

Moving forward, this enhanced model has the potential to be integrated into an adaptive management system for underwater radiated noise. Such a system could provide real-time mapping between near-field ship noise sources and received noise at marine mammal locations, aiding in conservation efforts and reducing the impact of underwater noise pollution.

Task 2 Highlights: Vessel Noise Measurement Campaign

Acoustic Data Collection with the Canadian Coast Guard on the CCGS Sir John Franklin

At the beginning of August 2023, the MELO Project research team boarded the Canadian Coast Guard's research vessel, the CCGS Sir John Franklin, to gather acoustic data in the Salish Sea. Over two days, the vessel made 13 passes over an array of hydrophones located in Boundary Pass. With support from JASCO Applied Sciences, the hydrophone data were collected to validate the MELO Project team's computational model that can be used to predict the noise signature of vessels based on the operating parameters. This work helped the team determine if they can successfully predict the noise signature of the CCGS Sir John Franklin, based on their understanding of the ship, the speed, the oceanographic conditions, and other factors. In addition to collecting acoustic data through hydrophones, the research team also gathered oceanographic data and took measurements of machinery vibrations in the engine room. The MELO Project team is grateful for the in-kind support from the Canadian Coast Guard that made this research trip possible.

The CCGS Sir John Franklin, the research vessel that was used to gather acoustic data in Boundary Pass in August 2023.

A short blog post and video about the trip were created by one of Clear Seas' interns with the Indigenous Internship Program, Chanessa Perry, which can be found on the Clear Seas' website: https://clearseas.org/insights/a-day-in-the-life-on-a-coast-guard-research-vessel/

Task 3 Highlights: Understanding Marine Mammal Response to Ship Noise

Executive Summary of Literature Review of Marine Mammal Sensitivity to Anthropogenic Sound

Marine mammals have evolved to use sound both actively (sound production) and passively (sound reception) for a variety of critical life history behaviours. Marine mammals have differential hearing sensitivity at various frequencies. Mitigating the impact of sound produced by marine vessels is therefore reliant on minimizing sound production at critical frequencies. We produced a review of the scientific literature outlining the auditory capabilities of marine mammals for the purposes of practically guiding engineering design options to minimize potential impacts on marine mammals.

Audiograms are the classic manner of defining hearing sensitivities across frequencies, but they are available for only a limited number of marine mammal species. To simplify matters, the 132 extant species of marine mammals can be aggregated into 8 hearing groups (2 of which are concerned with in-air hearing and one of which is not found in local waters) based on similarities in the hearing profiles. However, audiograms do not accurately represent an animal's sensitivity to realistic mixed-tone signals. Instead, auditory weighting functions (which generally have a broader range of maximum sensitivity than audiograms) can be employed for each of these hearing groups. These weighting functions mathematically describe the relative sensitivity of defined groups of marine mammals to different frequencies of sound. Although the collective range among all marine mammals is quite extensive, individual hearing group weighting functions can be used to narrow down the frequencies of concern for anthropogenic noise for specific groups of marine mammals. These auditory weighting functions are a means of filtering the received levels into biologically meaning sound exposure levels by emphasizing areas of highest sensitivity and de-emphasizing the effect of frequencies outside of this range.

Auditory weighting functions can also be used to construct noise exposure functions that can be used to calculate received noise exposure levels that describe the biologically effective received sound exposures. These received sound exposure levels take into account the power and frequency spectrum of the noise (at the receiver not the source), the duration of the exposure, as well as the auditory capability of the animal. Calculating received sound exposure levels are required to estimate the onset of a given physiological or behavioural effect. In theory, noise exposure functions can be constructed for any potential physiological or behavioural impact of noise, but reliable data is mostly available for temporary and permanent threshold shifts in hearing. Other areas of concern are the auditory masking of signals (e.g., communication).

The review noted that many of the hypothesized negative effects of ship noise on marine mammals are context-specific (e.g., dependent upon age, season, or reproductive status). Despite such complications, there is sufficient information to provide a framework on the relative severity of different observed behavioural changes, and their effects on various life history functions. In addition, the review highlighted that when considering the effect of specific anthropogenic sound on observable short-term changes in physiology, behaviour, or sound production on marine mammals, it is important to remember that they do not necessarily reflect the long-term effects of sound exposure. The population consequences of acoustic disturbance (PCAD) model is a conceptual framework linking anthropogenic sound exposure to physiological and behavioural responses to biologically significant, population-level effects.

Finally, it was noted that the identification of potential characteristics of acoustic conflict are important, even if absolute levels/frequencies are not known. Similarly, mitigation measures based on basic principles of physics and biology – and aided by expert elucidation – will likely contribute to biologically significant changes in the impact of vessel noise.

Task 4 Highlights: Mobilization of knowledge

<u>MELO Project Design Workshop (June 2023)</u>

On June 1-2, 2023, the MELO Project team organized a design workshop at the University of British Columbia. Over two days of presentations, discussions, and breakout group collaboration, the MELO Project Design Workshop brought experts together to share knowledge and discuss different pathways to solving issues related to underwater noise. Exchanging knowledge with other researchers is an essential part of the MELO Project's methodology, and hosting the design workshop is one way the team is engaging with experts across disciplines. The workshop was planned to provide opportunities for constructive dialogue and brainstorming on innovative topics, such as:

- Leveraging technologies from different disciplines in order to develop new solutions to reduce marine mammal disturbance from underwater noise
- Understanding how artificial intelligence in the form of machine learning can be used to process data more efficiently, for example in order to predict noise in real-time onboard vessels; and
- Exploring how to improve our understanding of the sensitivity and response of marine mammals to underwater noise using data gathered by ships, hydrophones and other observation methods.

As a key component of the MELO Project, the design workshop was planned to bring together experts across different fields and gain feedback on the MELO Project's methodology. Invitations to attend the workshop were sent out to people around the world whose work or research focused on ship design, marine biology, underwater acoustics, and other areas. Speakers were invited based on their expertise in specific fields or on recommendation from other experts. Efforts were taken by the team to ensure representation from different disciplines in speakers and participants. Approximately 40 people attended the workshop, with a mix of students, academics, public servants, industry representatives, and one person who worked for a coastal First Nations community.

The first day of the workshop aimed to bring a shared understanding across disciplines of issues and opportunities related to underwater noise. Seven speakers, from both academia and industry, gave presentations on their research area of interest. The speakers intentionally focused on trying to deliver their ideas and presentation content in a way that was accessible to all workshop participants, regardless of one's expertise in the topic. Each presentation session included a discussion period where workshop participants could pose questions or prompt conversations among the group. As part of the first day, the MELO Project team presented the preliminary results of their work, including the results of a literature review on marine mammal responses to underwater noise and a session on advances in the computational modelling of ship noise.

The second day of the workshop included facilitated sessions which aimed to form connections with others, discuss opportunities for innovation, and identify knowledge gaps in different research areas. Participants were separated into smaller breakout groups of 10-12 people and guided through two exercises. The objective of these breakout sessions was to co-develop design systems to account for the different interactions occurring between ocean users and inhabitants. In addition to the breakout sessions, the MELO Project team demonstrated the initial functionality of the analysis toolkit.

After the workshop, a survey was sent out to participants encouraging them to share feedback on their experience of the design workshop. The survey included the following prompts:

Do you agree, disagree, or are neutral towards the following statements:

- The workshop was an effective way to bring together interdisciplinary expertise in the field of ship source underwater radiated noise and the impact on marine mammals.
- The workshop allowed attendees to develop a common understanding of the gaps and opportunities for more research and other solutions in this field.
- The workshop helped attendees begin to develop innovative solutions to the underwater noise problem.
- This workshop was relevant to my research, work, or personal interests.
- The speaker presentations (Day 1) were diverse, interesting, and appropriate for the workshop topic and objectives.
- I made connections with new people who could help advance my research, work, or personal interest in this field.
- I would like attend another MELO Project Design Workshop if it was offered in the future.

Other questions that allowed for multiple choice or free-form text responses were also included in the survey:

- Did you find the location of the workshop suitable?
- Did you find the size of the workshop suitable?
- Do you have any thoughts to share about the workshop experience?
- Do you have any other suggestions on what we could improve on?

Overall, the responses to the survey were positive, and highlighted the benefits of bringing together a multidisciplinary group to tackle the complex challenges of reducing the impacts of underwater noise. Some participants provided feedback that there was not enough time to dive into discussions on specific topics, and others mentioned the need to extend the invitation to an even broader audience (i.e., vessel operators, whale watchers, fishermen) if another workshop was hosted.

For a full summary of the workshop presentations, discussions, and key takeaways, read the workshop report: https://clearseas.org/wp-content/uploads/REP-MELO-Workshop-Report-EN_1-1.pdf

Lessons Learned

The MELO Project team encountered and overcame both technical and conceptual challenges as the project progressed. For the CFD prediction of near-field noise, there were three main difficulties: mesh construction; computational instability; and extreme requirements of computational resources. In the actual practice, the mesh problem was solved by constantly adjusting the meshing strategy. Then the computational instability was maintained by tuning the numerical scheme and controlling the time step. The computational resource requirements were temporarily met by balancing back and forth between two supercomputing resources, Compute-Canada and Sockeye.

The prediction of far-field noise faced several significant challenges in accurately forecasting noise emanating from shipping vessels. The complex environmental factors, including seamounts and varying bathymetry, posed difficulties for generating accurate sound propagation data. Additionally, current deep-learning models struggled with predicting long-term wave propagation and forecasting noise levels in remote locations. To overcome these challenges, the project developed a new network architecture that incorporates ocean bathymetry data and developed a novel range-conditional convolutional neural network. This approach seeks to improve the model's predictive capabilities and enable real-time mapping between near-field ship noise sources and received noise at marine mammal locations. The other significant challenge was obtaining accurate sound speed profile in the boundary pass during the experimental trial and near field source level of the CCGS John Franklin.

The optimization toolbox had significant challenges, primarily in mathematically defining the problem as a multi-objective optimization problem with constraints. This involved developing models to accurately represent the intricate relationship between ship speed, underwater noise levels, and fuel consumption and integrating everything together. Upon formulating the problem, applying genetic algorithms to solve it raised difficulties in achieving convergence and ensuring the smoothness of solutions. Strategies such as parameter tuning and normalization were employed to address these challenges and effectively construct the Pareto front. Additionally, the framework's task of modeling the propagation of noise from ships through the ocean environment posed substantial computational challenges. Simulating the transmission loss at every ship location across all frequencies required intensive computations. Since the transmission loss varies based on the proximity and location of each marine mammal, compiling this data for an extensive range of frequencies and potential mammal positions became the most time-intensive aspect of the study.

The team has also faced some broader challenges inherent to a complex, multidisciplinary research project. Because team members were coming together from a range of academic backgrounds and technical skill levels, reaching a common understanding and designing a cohesive research approach that includes all perspectives took time. The integration of diverse expertise from the research team has contributed to its unique success and was only possible through effective communication between team members and a willingness to collaborate and learn from each other.

Communications Highlights

Research papers

A multi-objective optimization framework for reducing the impact of ship noise on marine mammals (2024). Akash Venkateshwaran, Indu Kant Deo, Jasmin Jelovica, Rajeev K. Jaiman. https://arxiv.org/abs/2402.02647

Zhi Cheng, Suraj Kashyap, Brendan Smoker, Giorgio Burella, Rajeev Jaiman, MODELING OF HYDROACOUSTIC NOISE FROM MARINE PROPELLERS WITH TIP VORTEX CAVITATION, proceedings of the OMAE 2024, 43rd International Conference on Ocean, Offshore Arctic Engineering, June 9–14, 2024, Singapore

Zhi Cheng, Rajeev Jaiman, FLOW-INDUCED VIBRATION OF FLEXIBLE HYDROFOIL IN CAVITATING TURBULENT FLOW, proceedings of the OMAE 2024, 43rd International Conference on Ocean, Offshore Arctic Engineering, June 9–14, 2024, Singapore

UBC sustainability website: Event page for Rajeev Jaiman's talk on the MELO Project (October 2023): https://sustain.ubc.ca/events/advanced-models-and-solutions-mitigating-impact-ship-noise-marine-mammals

Web content created highlighting the MELO Project research on the Clear Seas website

- Project page: https://clearseas.org/research/melo-project-smart-adaptive-solutions-to-underwater-noise/
- Press release news article: https://clearseas.org/news/turning-down-the-volume-how-artificial-intelligence-could-cut-ship-noise/
- Workshop report: https://clearseas.org/wp-content/uploads/REP-MELO-Workshop-Report-EN_1-1.pdf
- Research article: https://clearseas.org/insights/a-day-in-the-life-on-a-coast-guard-research-vessel/
- YouTube short video of research trip on CCGS Sir John Franklin for social media: https://www.youtube.com/watch?v=jGMuU67EsaA

News article reach

- Turning down the volume: how artificial intelligence could cut ship noise https://www.hellenicshippingnews.com/turning-down-the-volume-how-artificial-intelligence-could-cut-ship-noise/#google_vignette
- UBC engineers want to save whales from drowning… in noise https://news.ubc.ca/2022/12/15/ubc-engineers-want-to-save-whales-from-drowningin-noise/

- Canadian researchers study ways to reduce underwater noise pollution https://www.hindustantimes.com/world-news/canadian-researchers-study-ways-to-reduce-underwater-noise-pollution-101671613562658.html
- Engineers work to quiet the ocean https://www.asme.org/topics-resources/content/engineers-work-to-quiet-the-ocean
- B.C. researchers aim to clear up acoustic smog impacting endangered killer whales https://www.nationalobserver.com/2022/12/19/news/researchers-aim-clear-acoustic-smog-impacting-endangered-killer-whales
- Can whales be saved from harmful noise pollution? These B.C. engineers think so https://www.coastreporter.net/local-news/can-whales-be-saved-from-harmful-noise-pollution-these-bc-engineers-think-so-6260773
- UBC researchers studying AI to reduce sea noise for whale https://vancouver.citynews.ca/2022/12/15/ubc-researchers-studying-ai-to-reduce-sea-noise-for-whales/
- Quieting the propeller and cutting underwater noise https://www.rivieramm.com/news-content-hub/news-content-hub/quieting-the-propeller-and-cutting-underwater-noise-74799
- West coast engineers aim to clear up acoustic smog impacting endangered killer whale https://cortescurrents.ca/west-coast-engineers-aim-to-clear-up-acoustic-smog-impacting-endangered-killer-whales/
- Turning down the volume: how artificial intelligence could cut shipnoise https://www.seaandjob.com/turning-down-the-volume-how-artificial-intelligence-could-cut-ship-noise/
- UBC team harnesses AI in effort to make quieter ships https://vancouversun.com/news/local-news/ubc-team-harnesses-ai-in-effort-to-make-quieter-ships
- Turning down the volume: how artificial intelligence could cut ship noise https://cyprusshippingnews.com/2023/06/06/turning-down-the-volume-how-artificial-intelligence-could-cut-ship-noise/