UNDERWATER CHANNEL CHARACTERIZATION FOR SHALLOW WATER MULTI-DOMAIN COMMUNICATIONS

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Jay Patel, Mae Seto

Faculty of Engineering,

Dalhousie University, Canada

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Outline

- Introduction
- Background
- Methodology & Demo
- Simulation and Results
- Conclusion
- References

Problem definition for research project

- Simulation of an underwater acoustic channel with environmental parameters supplied to Bellhop to predict performance of an underwater channel, simulations focussed on Bedford Basin, Canada - shallow water with muddy bottoms at various water depths.

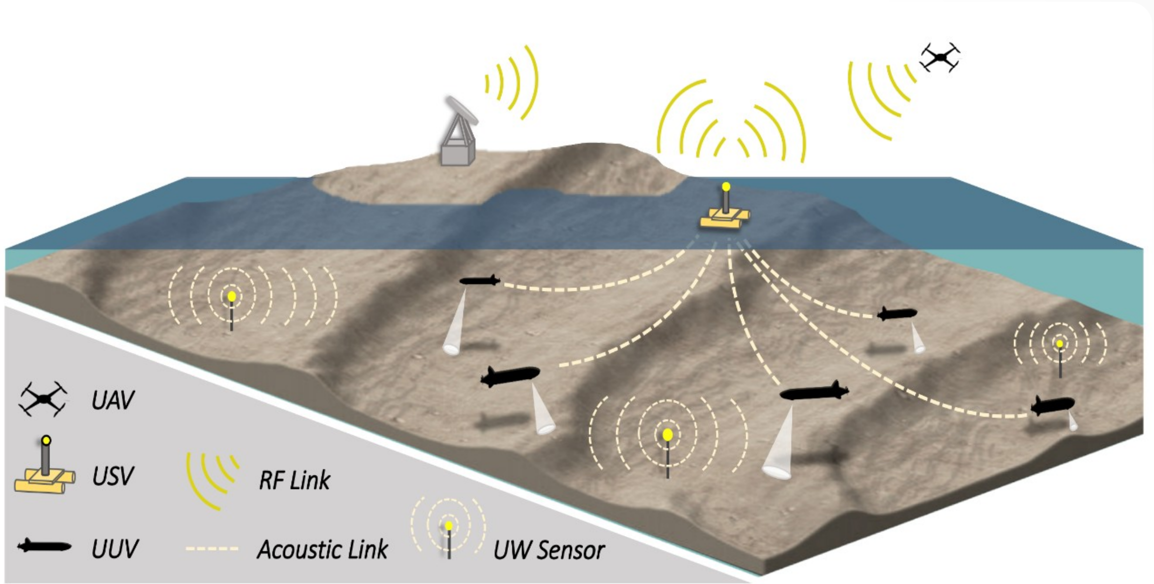


Figure 1: Robotic multi-vehicle collaboration – above and below water [7]

solution: Bellhop modeling

- Provides an estimated operating range and depth for UUV+ deployment for simulations on multi-domain marine robots communications for above and below-water surveillance and characterization of floating marine objects.[1]

+ unmanned underwater vehicle

Simulation objectives (1 / 2)

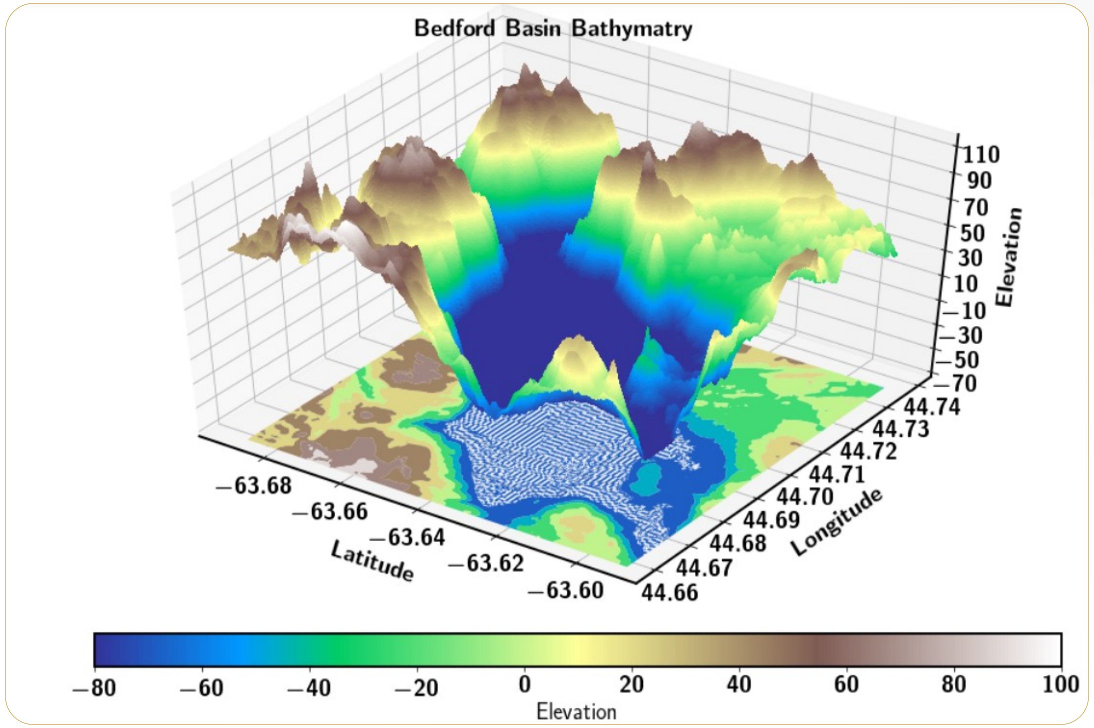


Figure 2: Bathymetry of Bedford Basin - Halifax, Canada

- concept of operation: heterogeneous marine robots (unmanned underwater vehicle (UUV), unmanned surface vehicle (USV), and unmanned aerial vehicle (UAV)) collaboratively acquire situational awareness on a floating target

- analyze impact of channel characteristics on underwater communications

Simulation objectives (2 / 2)

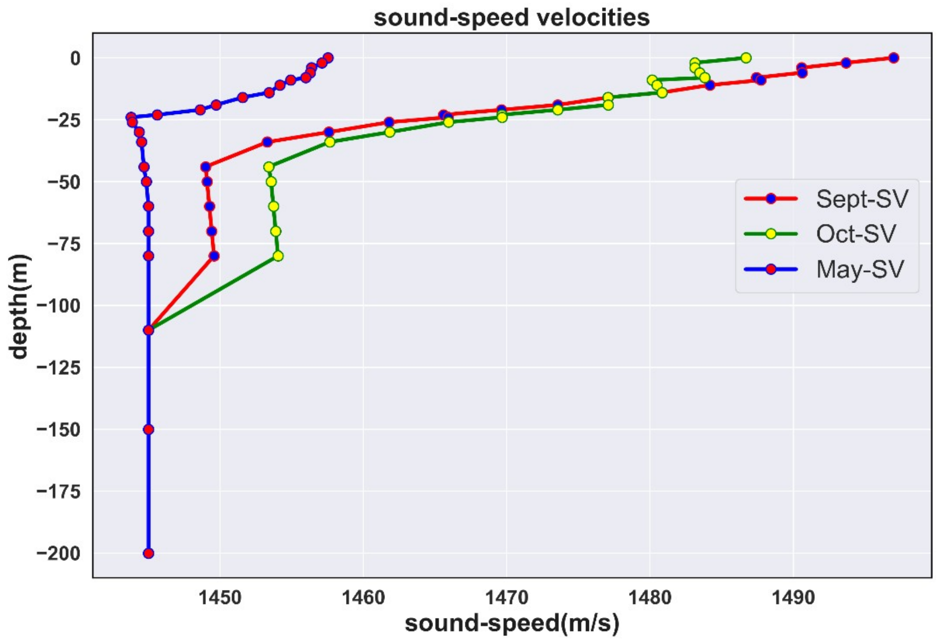


Figure 3: sound-speed profile of Bedford Basin used for simulation test cases

- prior to deploying robots, predict communication system performance
- provide guidance on best physical layout to deploy underwater vehicles
- provide estimates on parameters for link budget calculation

Bedford Basin bathymetry used for simulation cases

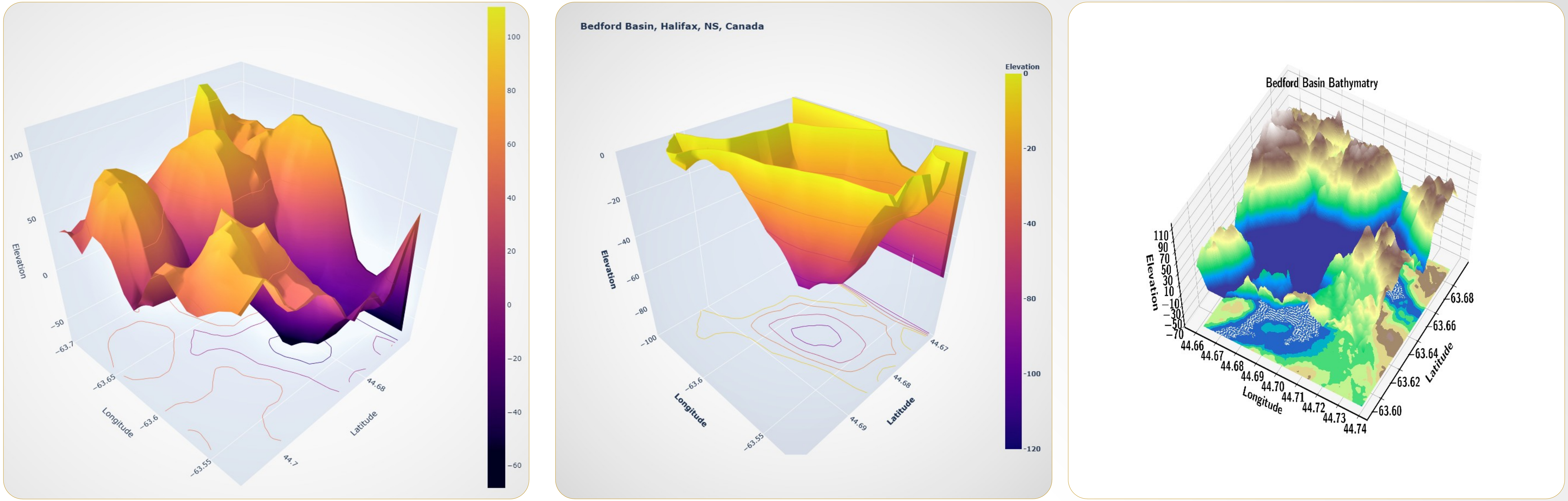


Figure 4: Detailed Bathymetry of Bedford Basin - Halifax, NS, Canada

Relevant References from Literature Survey

Table 1: relevant literature survey

Sr No	Title	Authors	Published in
1.	Simulation and experimentation platforms for underwater acoustic sensor networks: Advancements and challenges[1]	Hanjiang Luo, KaishunWu, Rukhsana Ruby, Feng Hong, Zhongwen Guo, and Lionel M. Ni.	ACM Comput. Surv. 50, 2, Article 28 (May 2017), 44 pages
2.	Analysis of Simulation Tools for Underwater Sensor Networks (UWSNs) [2]	Nayyar A., Balas V.E.	Bhattacharyya S., Hassanien A., Gupta D., Khanna A., Pan I. (eds) International Conference on Innovative Computing and Communications. Lecture Notes in Networks and Systems, vol 55. Springer, Singapore, March 2019
3.	A CDMA-based Medium Access Control for UnderWater Acoustic Sensor Networks[3]	D. Pompili, T. Melodia and I. F. Akyildiz	IEEE Transactions on Wireless Communications, vol. 8, no. 4, pp. 1899-1909, April 2009
4.	Comparative analysis of routing protocols for under-water wireless sensor networks[4]	Hala Jodeh, Aisha Mikkawi, Ahmed Awad, and Othman Othman.	Proceedings of the 2nd International Conference on Future Networks and Distributed Systems (ICFNDS '18). ACM, New York, NY, USA, Article 33, 7 pages.
5.	Embedded systems for prototyping underwater acoustic networks: The DESERT Underwater libraries on board the PandaBoard and NetDCU[5]	I. Calabrese, R. Masiero, P. Casari, L. Vangelista and M. Zorzi,	2012 Oceans, Hampton Roads, VA, 2012, pp. 1-8.

Methodology (1 / 3)

- Custom MATLAB based GUI+ is being used collaboratively for simulation of various test cases.

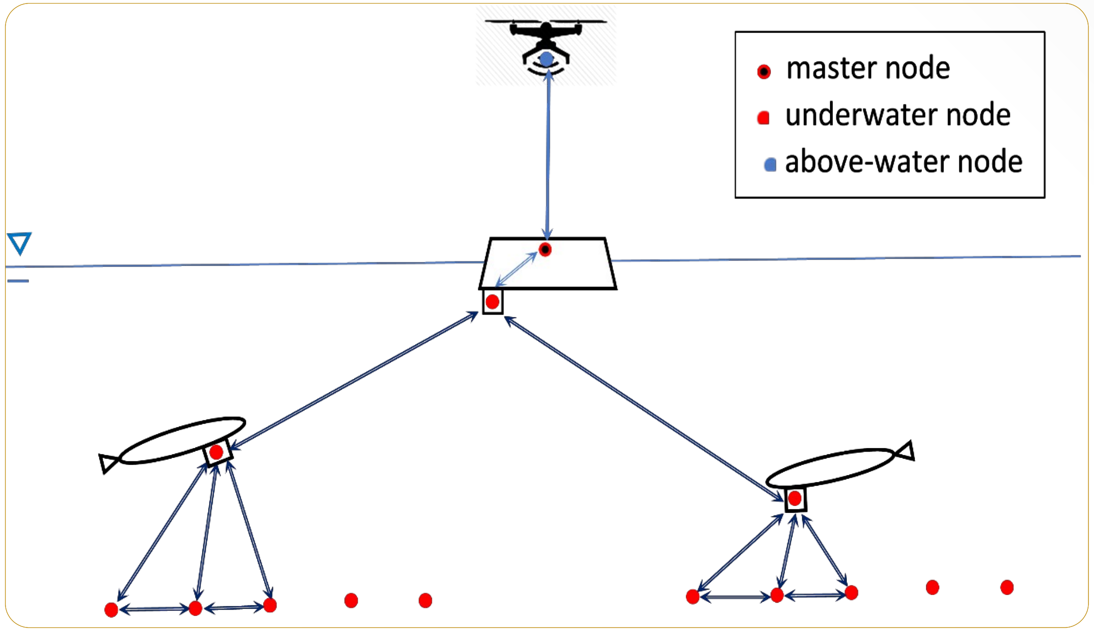


Figure 5: Heterogeneous marine sensor network architecture

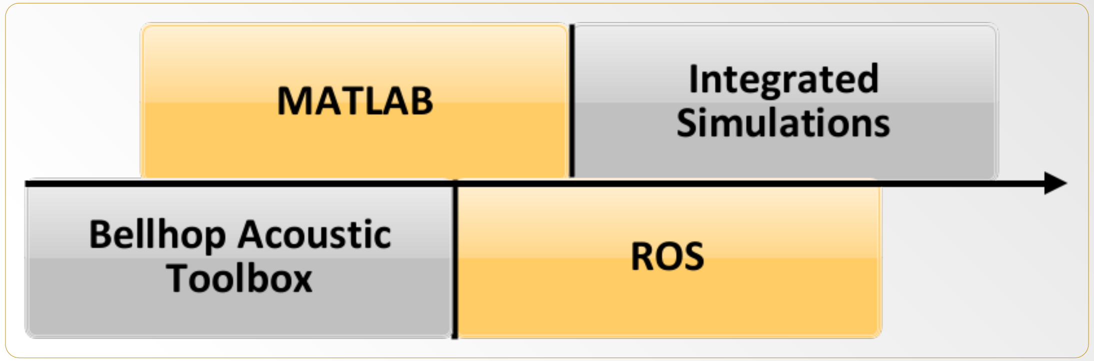


Figure 6: Software framework

Methodology (2 / 3)

- GUI used MATLAB App building Toolbox, planning to open source it soon to the community.

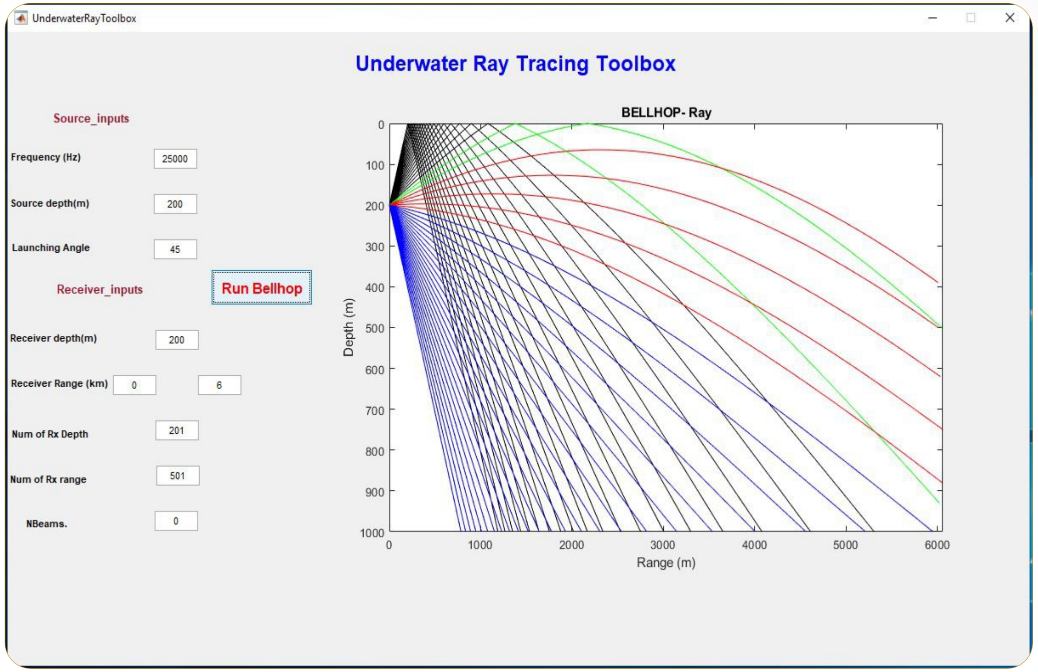


Figure 7: Ray Tracing from Underwater Ray Tracing Toolbox – MATLAB custom GUI +

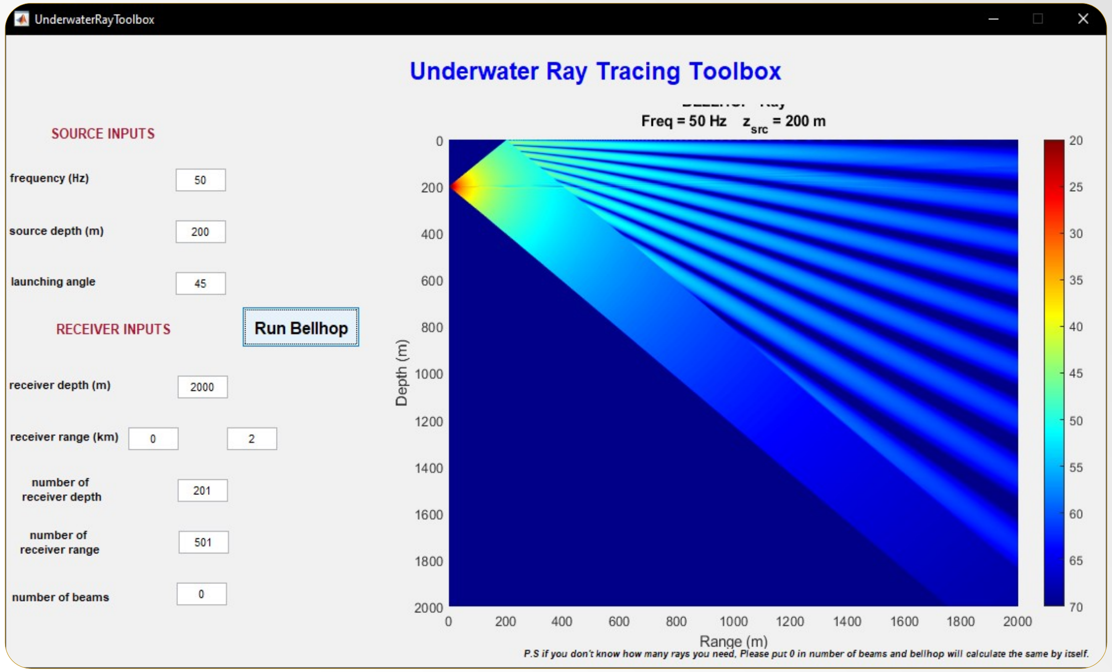


Figure 8: Transmission loss from Underwater Tracing Toolbox – MATLAB custom GUI +

Methodology (3 / 3)

- GUI used MATLAB App building Toolbox, planning to open source it soon to the community.

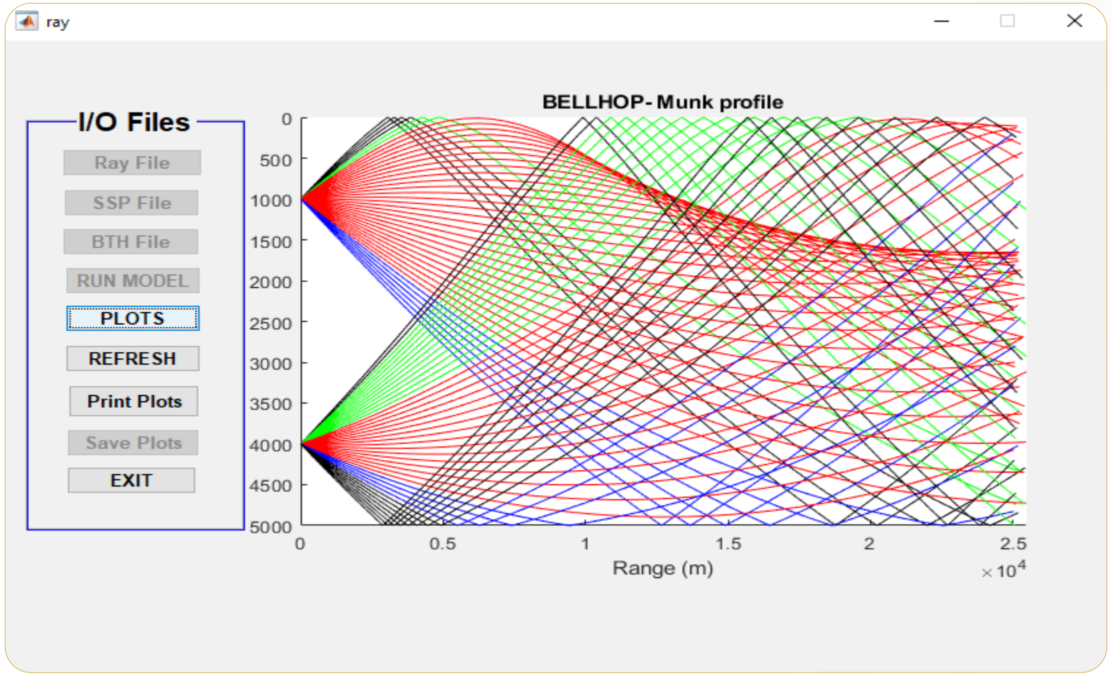


Figure 9: Ray Plotting using Underwater Ray Tracing Toolbox – Plotting Toolbox

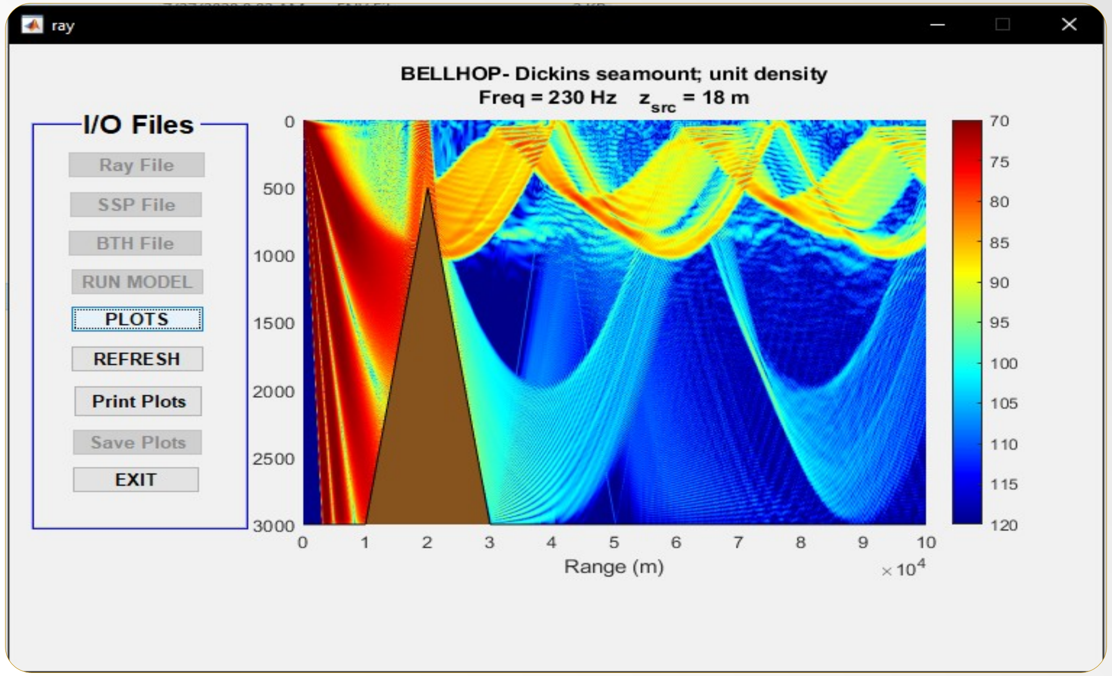


Figure 10: TL plotting using Underwater Ray Tracing Toolbox – Plotting Toolbox

File Structure

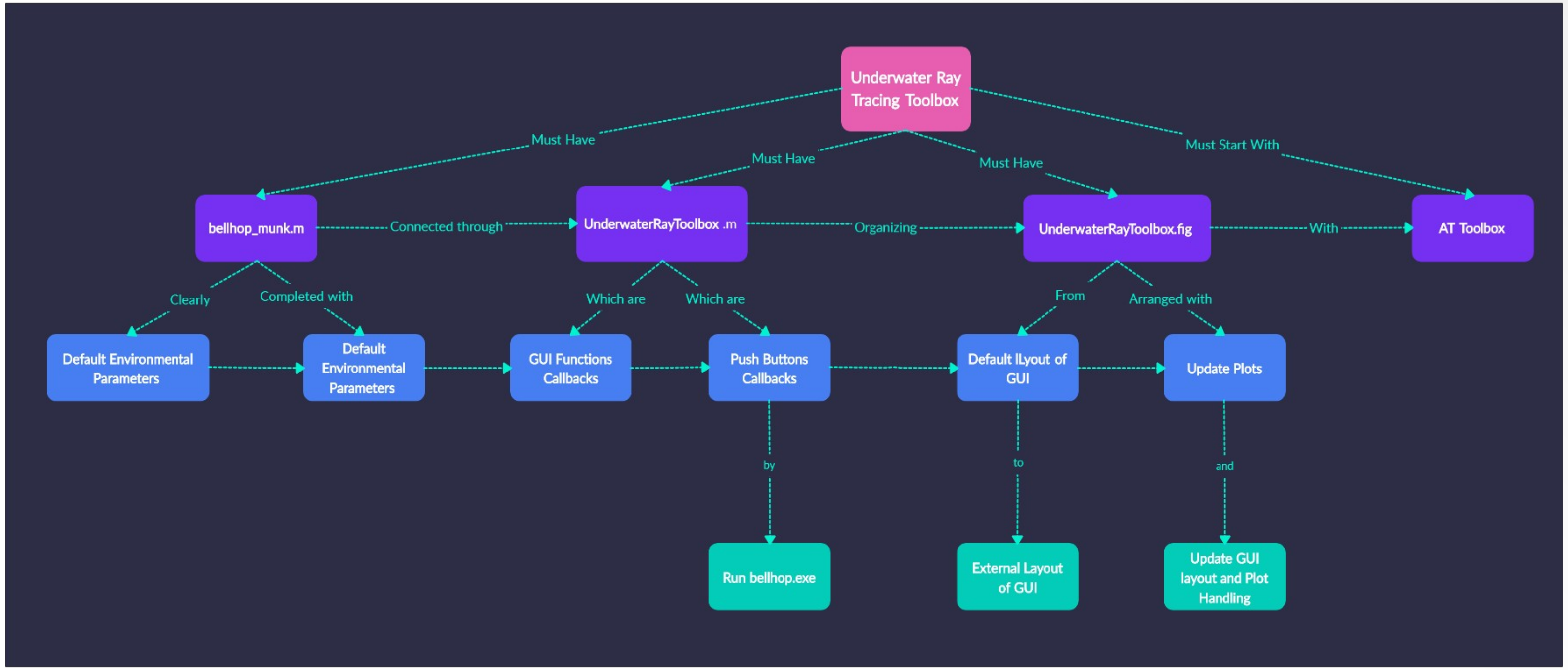


Figure 11: File structure of Underwater Ray Tracing Toolbox

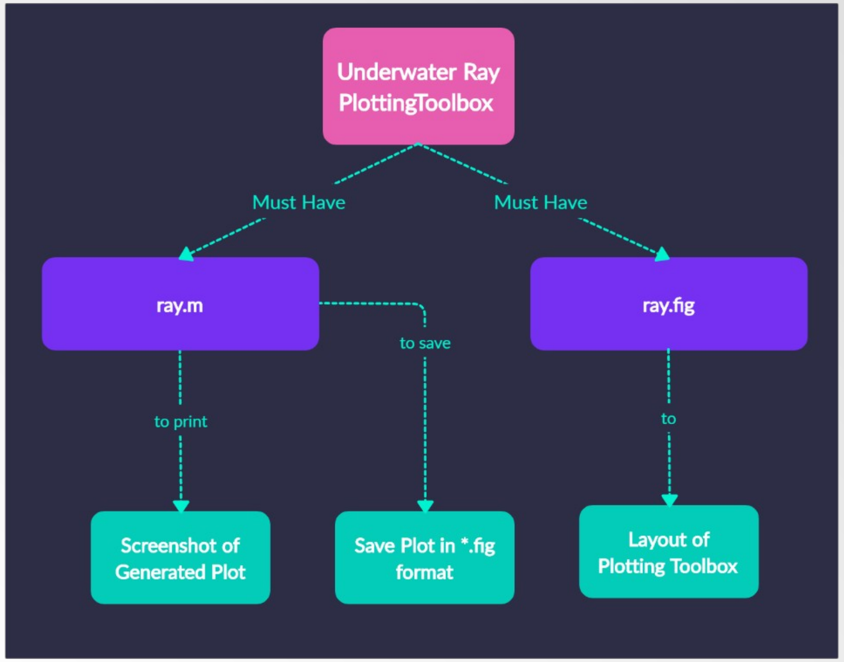


Figure 12: File structure of Underwater Plotting Toolbox

Bellhop Simulation Results (1 / 3)

Table 2: System parameters to simulate

parameter	value
frequency	25 kHz
water depth	50,100 m
range	0-6 km
USV uw modem depth	1.8 m
UUV depth	10 m

- from predicted transmission loss to determine the optimal range (function of water depth, UUV depth = 10 m)

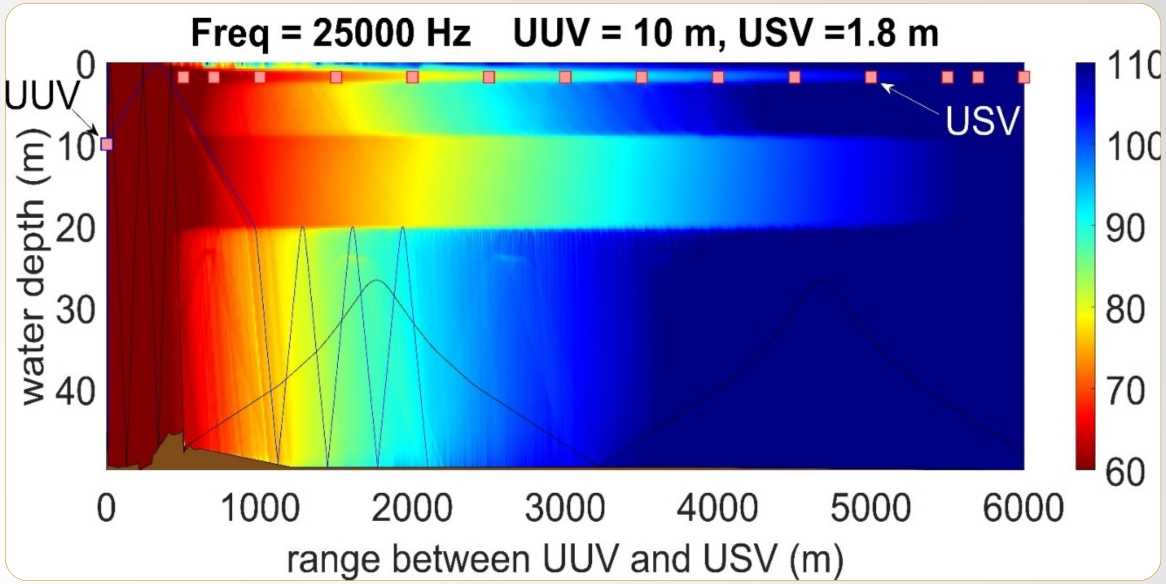


Figure 9: Ray Traced and TL with water depth = 50 m

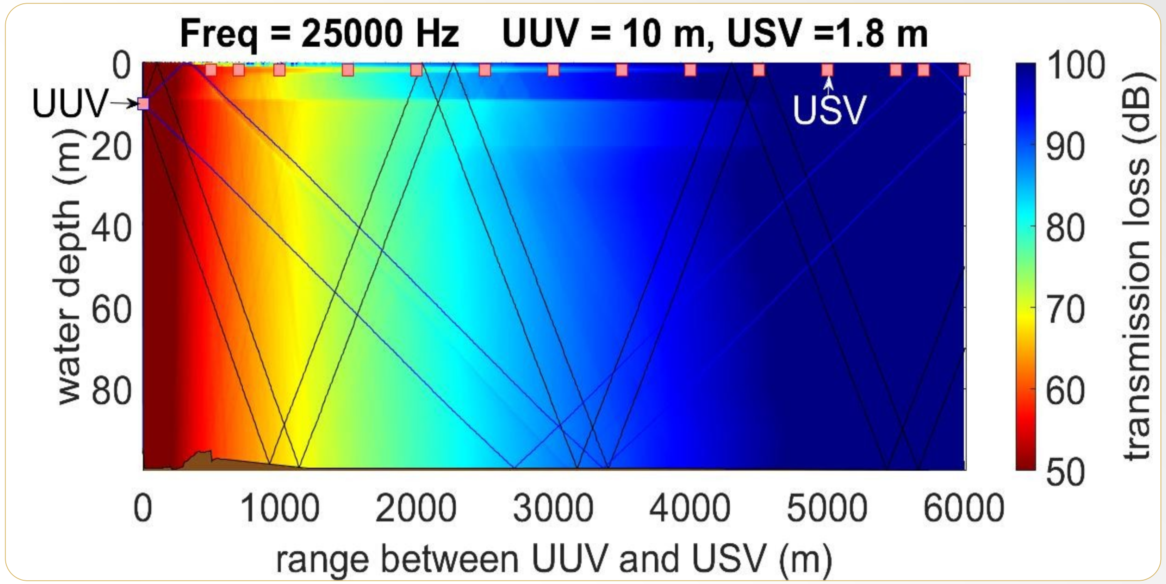


Figure 10: Ray traced and TL with water depth = 100 m

Bellhop Simulation Results (2 / 3)

Table 3: System parameters to simulate

parameter	value
frequency	25 kHz
water depth	150,200 m
UUV-USV range	0-6 km
USV uw modem depth	1.8 m
UUV depth	10 m

- from predicted transmission loss can determine the optimal range (function of water depth, UUV depth = 10 m), 0 – 6 km range)

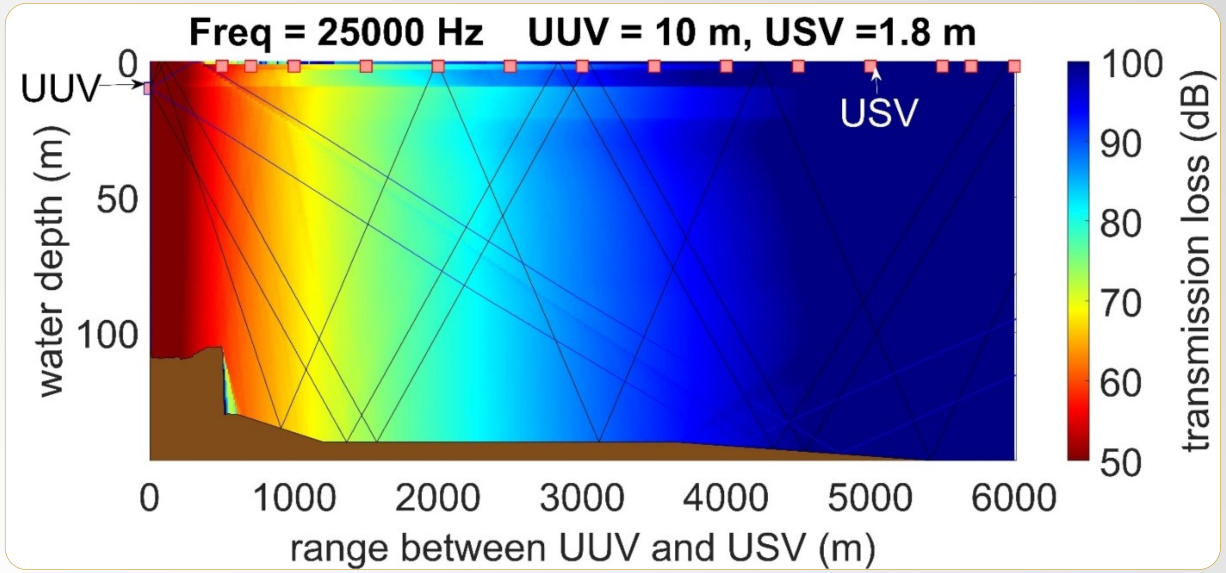


Figure 11: Ray Traced and TL with water depth = 150 m

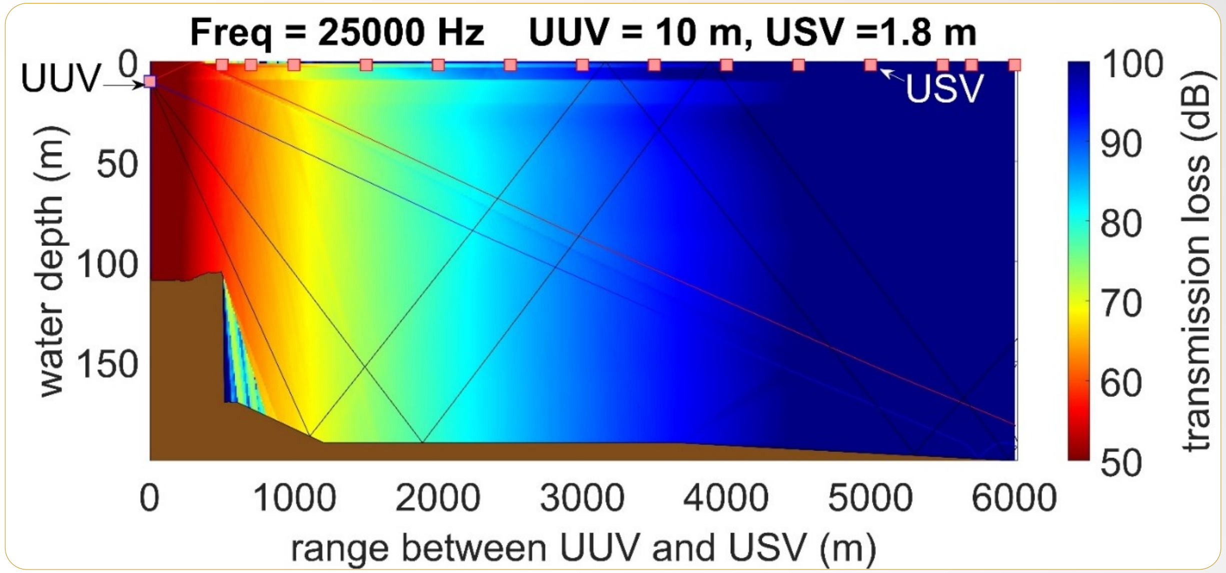


Figure 12: Ray Traced and TL with water depth = 200 m

Bellhop Simulation Results (3 / 3)

Table 4: System parameters to simulate

parameter	value
frequency	25 kHz
water depth	200 m
UUV-USV range	0-2.2 km
USV uw modem depth	1.8 m
UUV depth	3 m

- from predicted transmission loss can determine the optimal range (UUV depth = 3m, UUV-USV range = 0 – 2.2km)

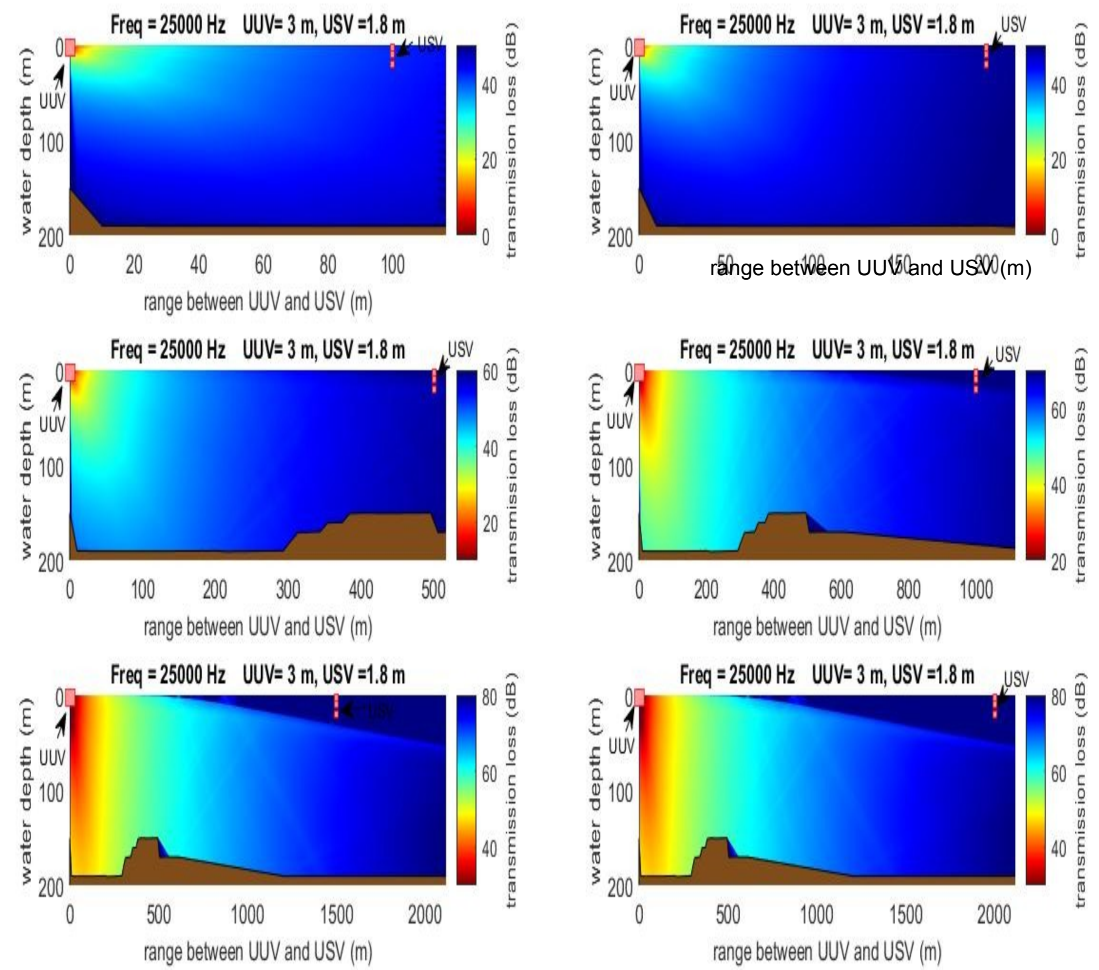
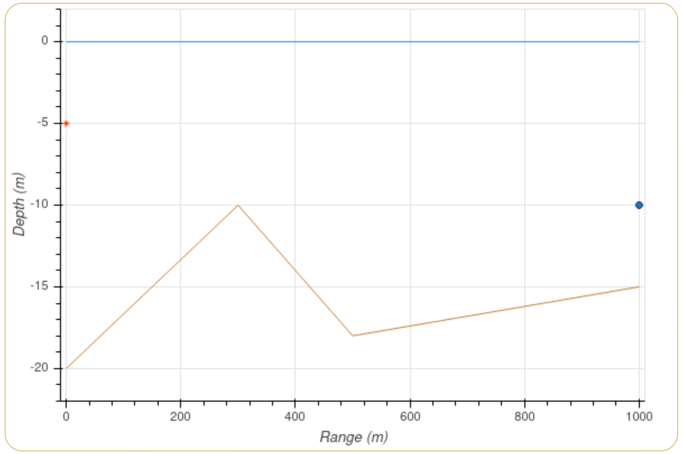
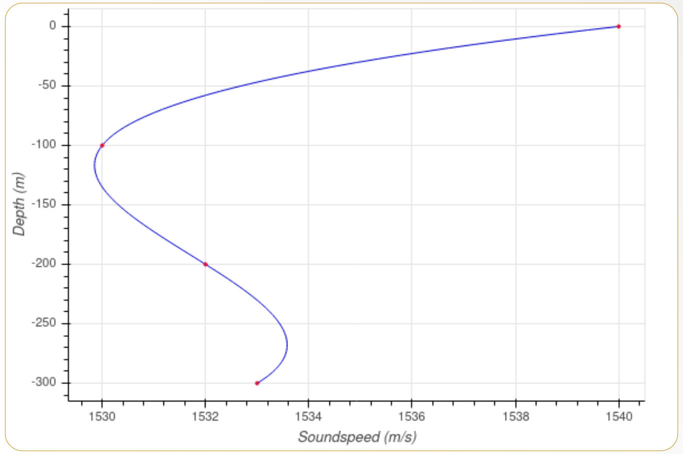
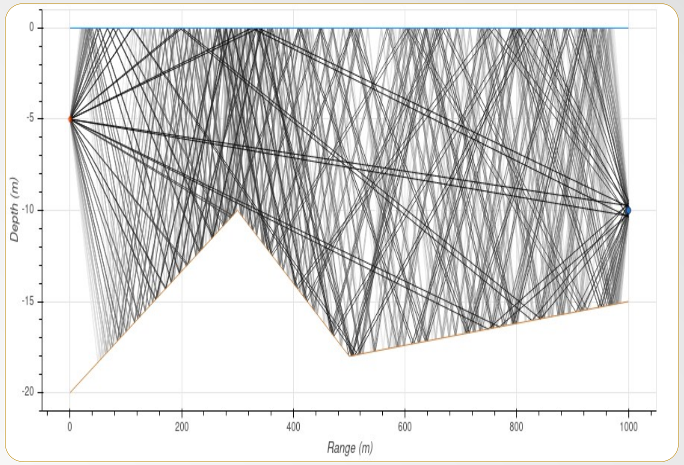


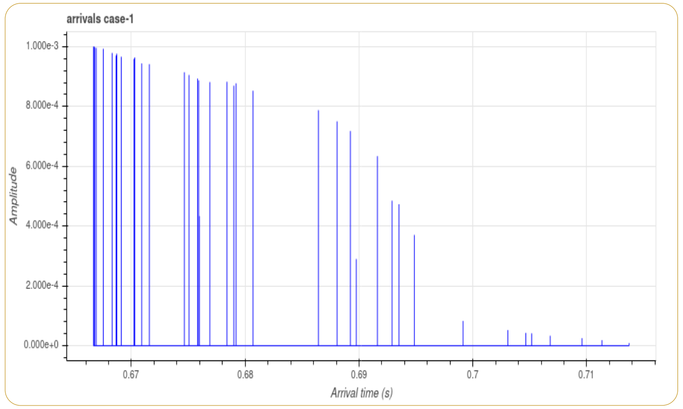
Figure 13: Transmission loss at water depth = 200 m starting from top left corner - for ranges: i) 100 m; ii) 200 m; iii) 500 m; iv) 1 km; v) 1.5 km, and vi) 2.2 km

More test cases explored using ARLPY toolbox (1 / 5)









	time_of_arrival	angle_of_arrival	surface_bounces	bottom_bounces
1	0.713725	-21.603680	13	13
2	0.711335	20.415777	13	12
3	0.706794	-19.402731	12	12
4	0.704646	18.202858	12	11
5	0.689760	-12.739491	9	9
6	0.694861	-17.684189	10	10
7	0.692903	16.470312	10	9
8	0.689241	-15.407454	9	9
9	0.679002	9.650291	7	6
10	0.676894	-8.537592	6	6

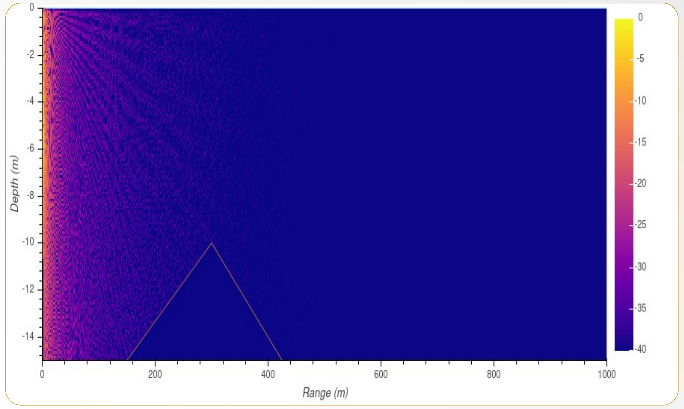
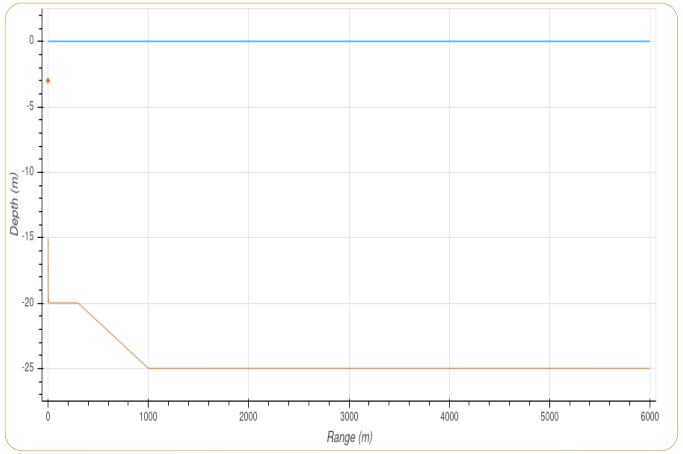
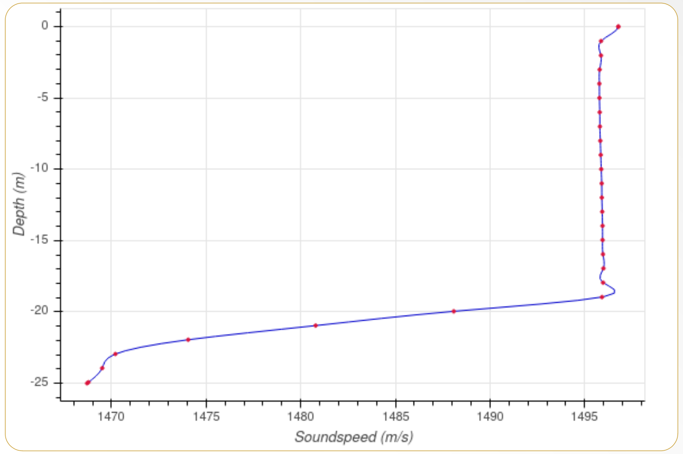
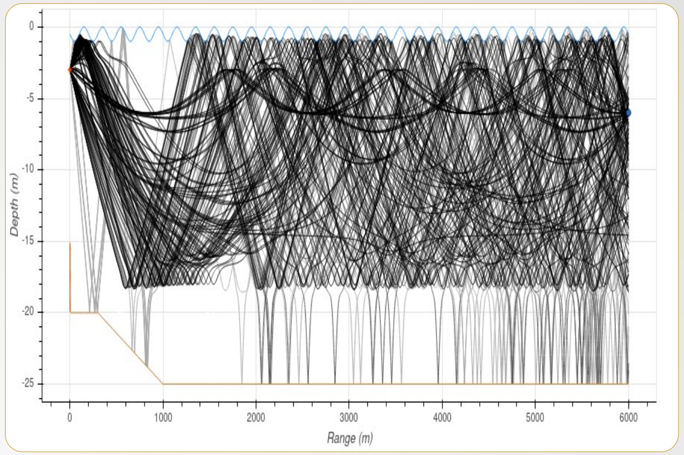


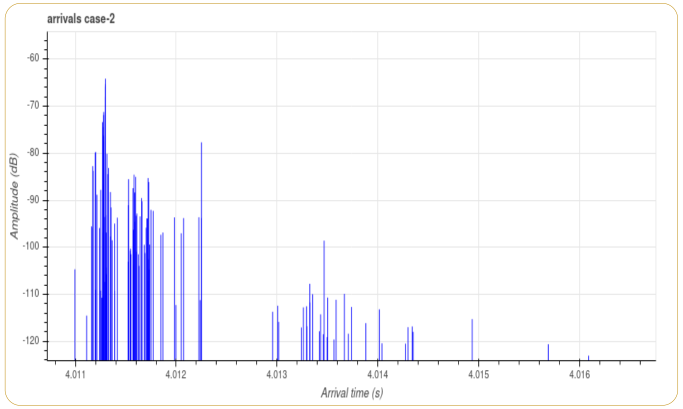
Figure 14: For water depth = 20 m; Tx=5m; Rx= 10m starting from top left corner - i) UW-env; ii) SSP; iii) Eigen rays; iv) arrivals; v) information of first 10 arrivals, and vi) coherent TL [9]

More test cases explored using ARLPY toolbox (2 / 5)









	time_of_arrival	angle_of_arrival	surface_bounces	bottom_bounces
1	0.713725	-21.603680	13	13
2	0.711335	20.415777	13	12
3	0.706794	-19.402731	12	12
4	0.704646	18.202858	12	11
5	0.689760	-12.739491	9	9
6	0.694861	-17.684189	10	10
7	0.692903	16.470312	10	9
8	0.689241	-15.407454	9	9
9	0.679002	9.650291	7	6
10	0.676894	-8.537592	6	6

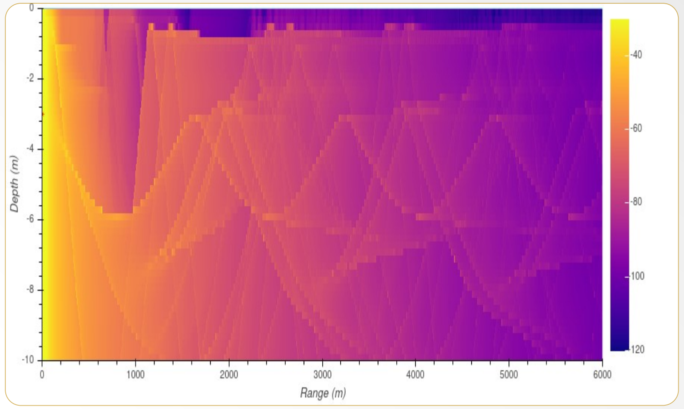
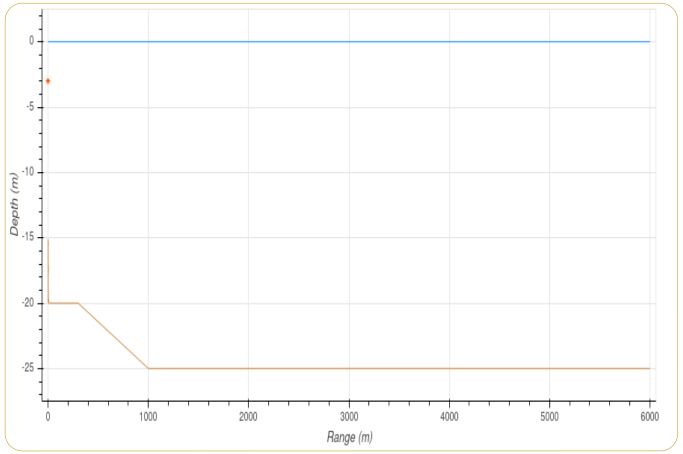
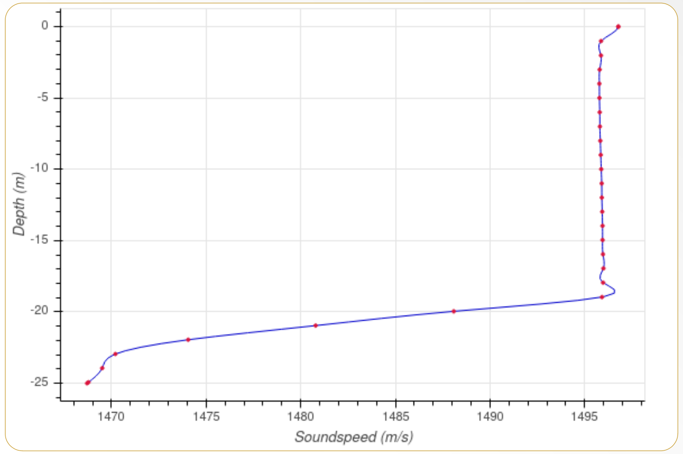
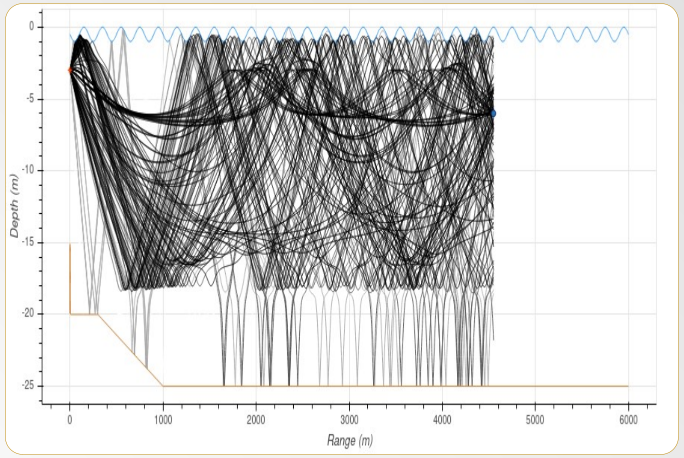


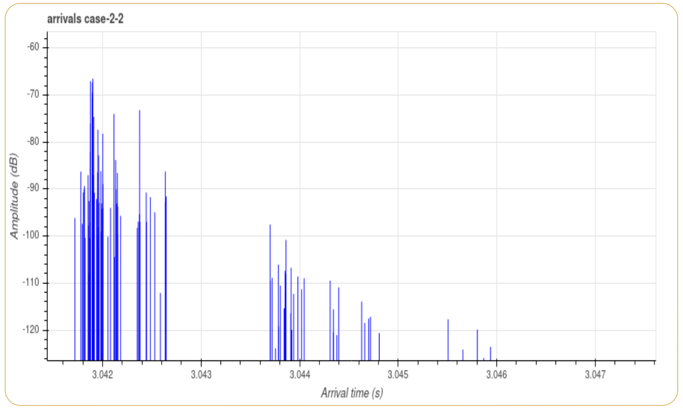
Figure 15: For water depth = 20 m; Tx=3m; Rx= 10m starting from top left corner - i) UW-env; ii) SSP; iii) Eigen rays; iv) arrivals; v) information of first 10 arrivals, and vi) incoherent TL [9]

More test cases explored using ARLPY toolbox (3 / 5)









	time_of_arrival	angle_of_arrival	surface_bounces	bottom_bounces
1	4.014346	-1.034714	5	2
2	4.014340	-1.537412	4	2
3	4.014350	-1.540428	4	2
4	4.014299	-1.430534	3	2
5	4.012225	0.533211	3	0
6	4.011868	0.462791	3	0
7	4.012073	-0.796780	2	0
8	4.015337	-2.752173	4	2
9	4.013325	-1.327790	3	1
10	4.013497	3.561893	4	1

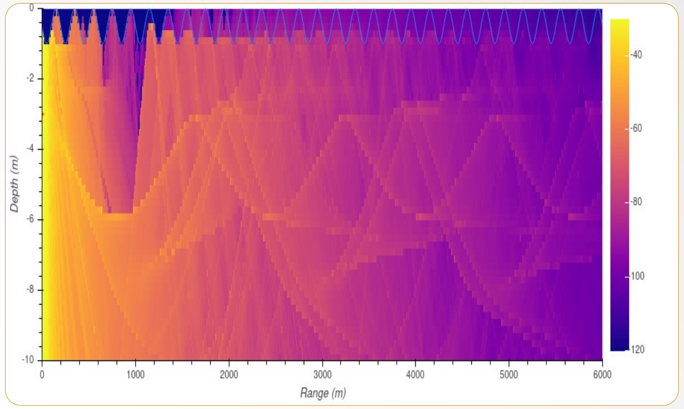
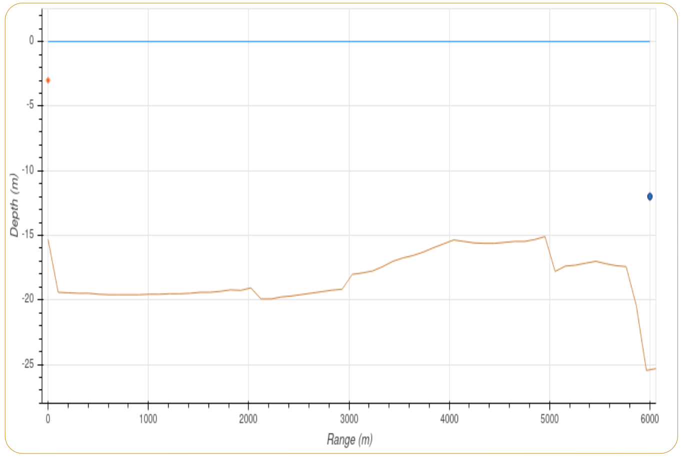
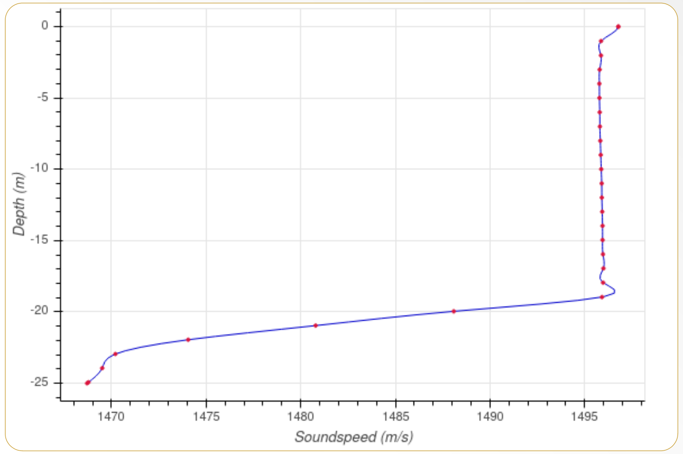
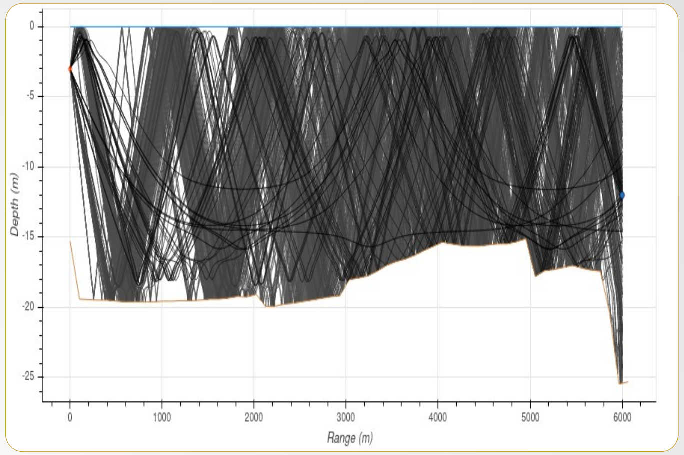


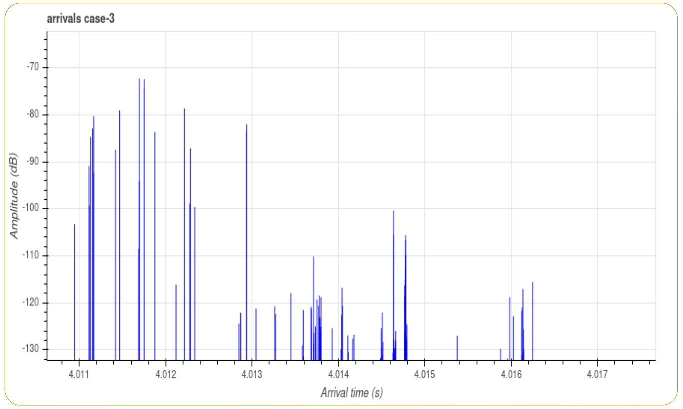
Figure 16: For water depth = 20 m; Tx=3m; Rx= 6m starting from top left corner - i) UW-env; ii) SSP; iii) Eigen rays; iv) arrivals; v) information of first 10 arrivals, and vi) incoherent TL [9]

More test cases explored using ARLPY toolbox (4 / 5)









	time_of_arrival	angle_of_arrival	surface_bounces	bottom_bounces
1	3.047335	-1.200291	5	3
2	3.044719	-1.453743	3	2
3	3.044808	2.633330	4	2
4	3.042637	1.496444	2	0
5	3.042485	-1.132180	2	0
6	3.042647	1.280771	2	0
7	3.044397	-1.503683	3	1
8	3.045672	-1.199286	4	2
9	3.043702	-1.373687	3	1
10	3.043853	0.308503	3	1

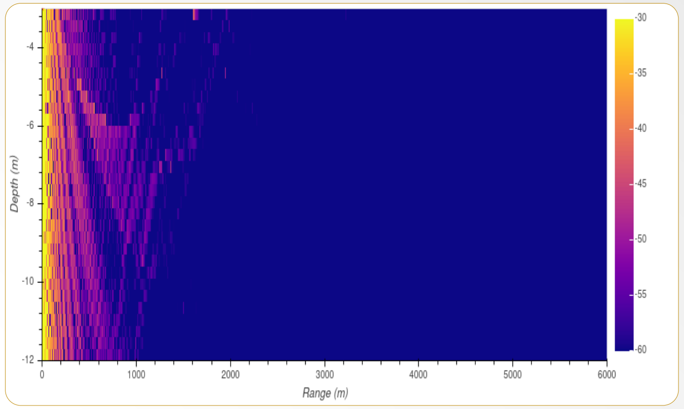
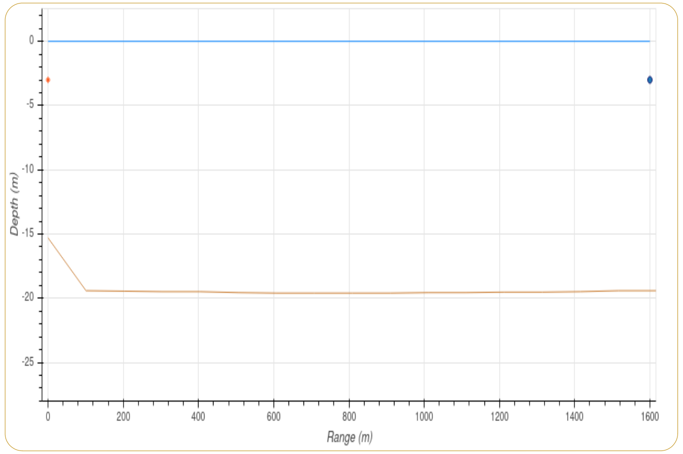
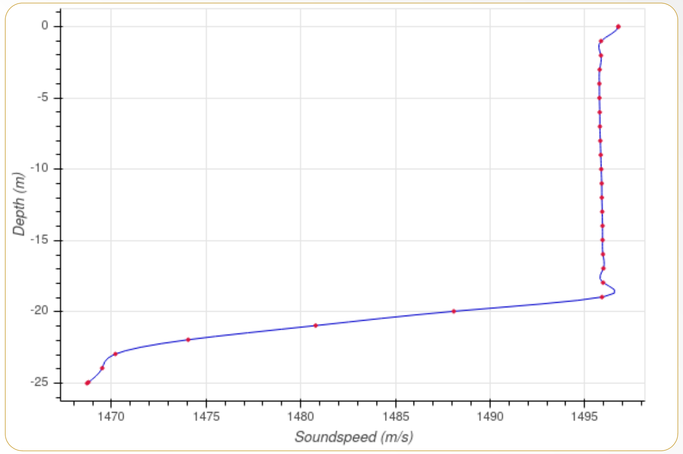
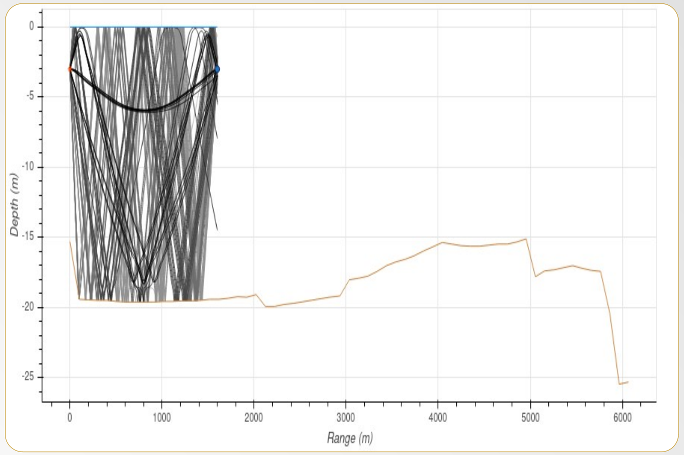


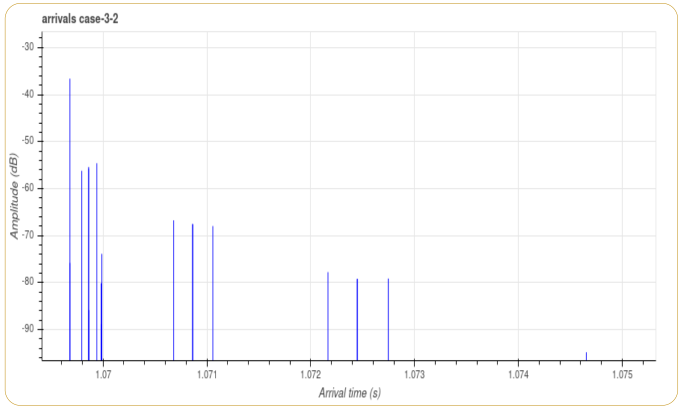
Figure 17: For water depth = 20 m; Tx=3m; Rx= 10m starting from top left corner - i) UW-env; ii) SSP; iii) Eigen rays; iv) arrivals; v) information of first 10 arrivals, and vi) incoherent TL [9]

More test cases explored using ARLPY toolbox (5 / 5)









	time_of_arrival	angle_of_arrival	surface_bounces	bottom_bounces
1	4.015582	-2.466159	7	8
2	4.015464	1.559378	6	8
3	4.015863	3.562261	9	8
4	4.015080	11.344101	9	8
5	4.015329	9.273050	9	8
6	4.015079	11.354420	9	8
7	4.015327	9.285923	9	8
8	4.015584	6.752951	9	8
9	4.015075	11.394584	9	8
10	4.015200	10.405143	9	8

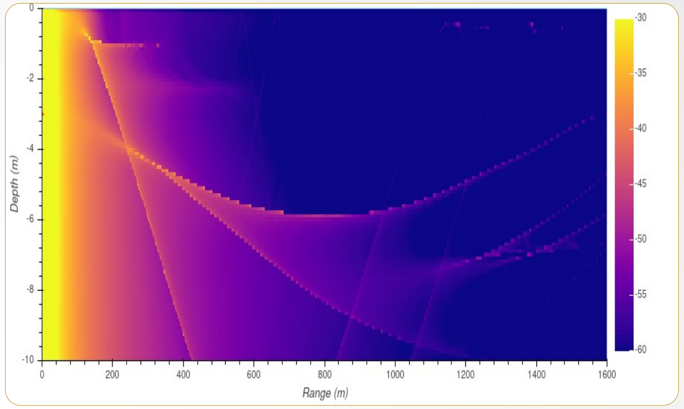


Figure 18: For water depth = 20 m; Tx=3m; Rx= 3m starting from top left corner - i) UW-env; ii) SSP; iii) Eigen rays; iv) arrivals; v) information of first 10 arrivals, and vi) incoherent TL [9]

Conclusion (1 / 2)

- simulating several underwater networks test case, it was observed that for the given environmental conditions, feasible range between UUV and USV as less than or equal to 1.3 km.

- this tools were important part of any project in-which a real time uw-network operational range are critical parameter of the mission.

Video 1: Gazebo simulations experimental validation of all 3 marine robots in the.

Conclusion (2 / 2)

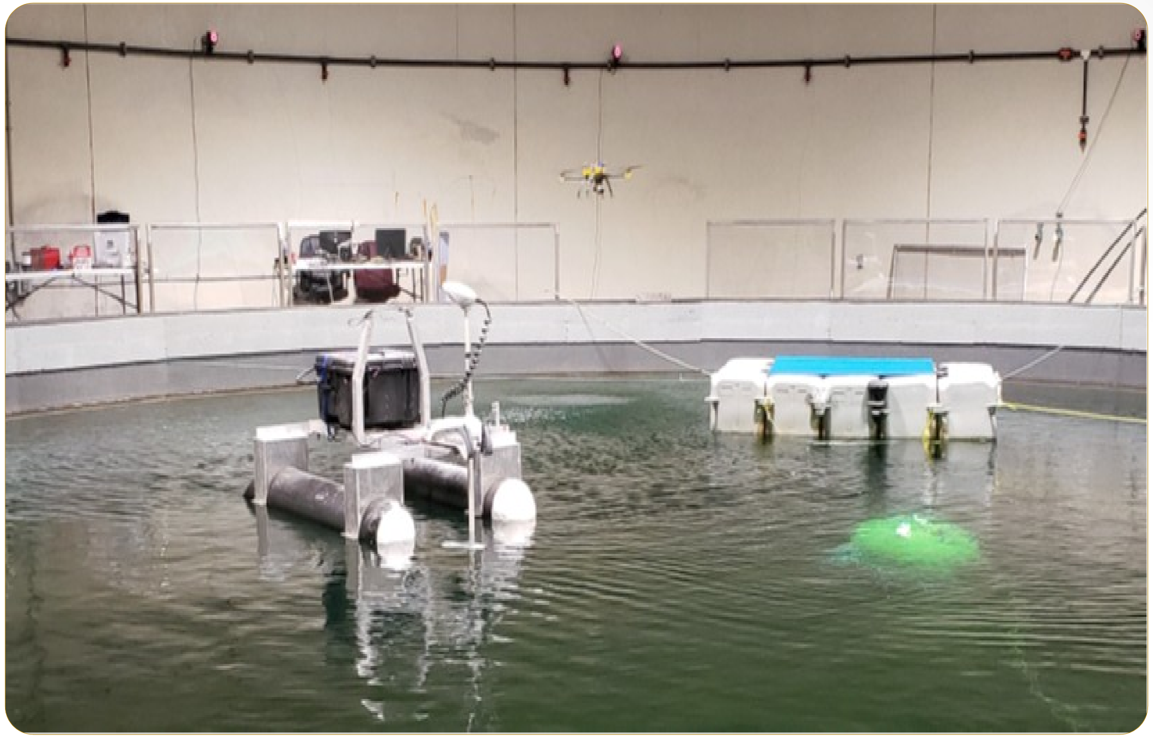


Figure 18: All 3 marine robots in the experimental validation. The USV is left in the foreground. The surfaced UUV is right in the foreground. The barge is behind both. The UAV is left of the barge. On the wall, the red LED rings are 3 of the 8 motion capture cameras installed in the Aquatron Pool tank. [6]

- Integration of hardware-in-loop simulator for multi-domain marine robots may increase the complexity.

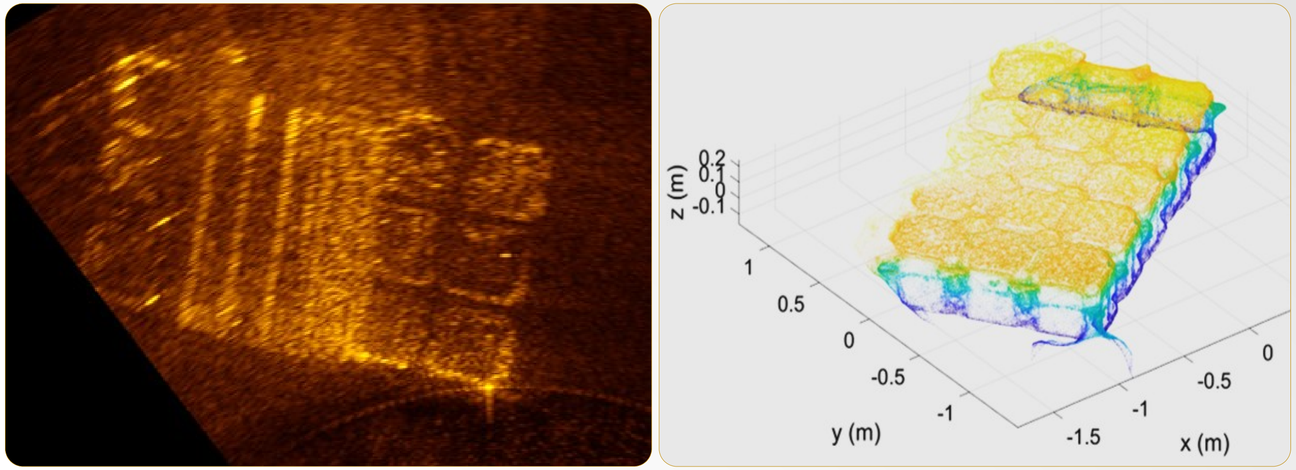


Figure 19: starting from left (a) Flexview sonar imaging of the barge underside from the IMOTUS UUV, (b) Optical camera photogrammetry reconstruction of the barge topside with the Pelican UAV on top of the bottom-side sonar (isometric view).[6]

Questions ?

patel.jay@dal.ca

Intelligent Systems Laboratory,

Dalhousie University.

References

1. Hanjiang Luo, KaishunWu, Rukhsana Ruby, Feng Hong, Zhongwen Guo, and Lionel M. Ni. 2017, “Simulation and experimentation platforms for underwater acoustic sensor networks: Advancements and challenges”, ACM Comput. Surv. 50, 2, Article 28 (May 2017), 44 pages.
2. Nayyar A., Balas V.E. (2019), “Analysis of Simulation Tools for Underwater Sensor Networks (UWSNs)”, Bhattacharyya S., Hassanien A., Gupta D., Khanna A., Pan I. (eds) International Conference on Innovative Computing and Communications. Lecture Notes in Networks and Systems, vol 55. Springer, Singapore, March 2019 .
3. D. Pompili, T. Melodia and I. F. Akyildiz, "A CDMA-based Medium Access Control for UnderWater Acoustic Sensor Networks," in IEEE Transactions on Wireless Communications, vol. 8, no. 4, pp. 1899-1909, April 2009.
4. Hala Jodeh, Aisha Mikkawi, Ahmed Awad, and Othman Othman. 2018, “Comparative analysis of routing protocols for under-water wireless sensor networks”, in Proceedings of the 2nd International Conference on Future Networks and Distributed Systems (ICFNDS '18). ACM, New York, NY, USA, Article 33, 7 pages.
5. I. Calabrese, R. Masiero, P. Casari, L. Vangelista and M. Zorzi, "Embedded systems for prototyping underwater acoustic networks: The DESERT Underwater libraries on board the PandaBoard and NetDCU," 2012 Oceans, Hampton Roads, VA, 2012, pp. 1-8.

References

6. J. Ross, J. Lindsay, E. Gregson, A. Moore, J. Patel, and M. Seto. 2019 “Collaboration of multi-domain marine robots towards above and below-water characterization of floating targets”. in IEEE International Symposium on Robotic and Sensors Environments (ROSE), pages 1–7, June 2019.
7. J. Patel and M. Seto. 2019. “CDMA-based multi-domain communications network for marine robots”, in WUWNET’19: International Conference on Underwater Networks Systems (WUWNET’19), October 23–25, 2019, Atlanta, GA, USA. ACM, New York, NY, USA, 2 pages.
8. https://www.canada.ca/en/defence-research-development/news/articles/exercise-unmanned-warrior-an-international-exercise-using-autonomous-tech-to-detect-underwater-mines.html
9. M. Chitre 2020, “ARLPY python toolbox” , https://github.com/org-arl/arlpy