MEEN 344, Fluids Mechanics

Mechanical Engineering Program

AQUADOPP PROFILER DATA COLLECTION

Technical Report for Fluid Mechanics Honor's Project

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Introduction and Objectives

Oceanic currents are extremely significant to the aquatic ecosystem. Currents are like wind: they are instruments for transporting nutrients and other sea material. As a result, nutrients, and food can be transported from one point to another, heat is able to be redistributed in the ocean, and oxygen reaches essential places where it wouldn't be able to if it weren't for the currents.

Figure 1 Aquadopp Profiler

This technical report describes the process of testing a 2Mhz Aquadopp Profiler, which is an Acoustic Doppler Current Profiler (ADCP) developed by Nortek.inc. This device is shown in Figure 1. The capabilities of the Aquadopp Profiler will be investigated in detail later. After testing the Aquadopp Profiler, a deployment system was designed to collect data in the Arabian sea, Northeast of Qatar. Technical specifications of this ADCP can be found in Appendix I and reference [1].

In this study, the deployment location was in the Arabian Sea. A boat was taken from Al Gharyah, Qatar, and the Aquadopp Profiler was deployed one hundred and twenty meters from the shore at a depth of approximately two meters. The Aquadopp Profiler collected data for 9 days and then was extracted for analysis. The study conducted for this paper focused on recording and later analyzing oceanic data. The data collected was current speed and direction. This data can be used to understand global water flow, as well as be stored in the huge amount of data that exists about ocean currents.

Furthermore, this data, along with old data, can be used to understand the effect of climate change on the aquatic life within the Qatari borders. According to Reuters, the Qatari fish stocks have depleted, resulting in Qatar expanding its fish farming program. Since this research was based in Qatar, the data can also be used to understand the reasons for depleting fish resources.

The objectives of this study were to:

- Learn the features of the Aquadopp Profiler,
- Carry out tests to make sure the Aquadopp Profiler is fully functional,
- Design a deployment system and carry out data collection on Qatar's waters.
- Perform basic analysis of the data collected.

Once these objectives are completed, the study can be concluded. In addition, a deployment system had to be devised that allowed us to leave an Aquadopp Profiler in the water for a long time and then retrieve it later without any problems.

Theory

The AquaDopp Profiler is a short-range Acoustic Doppler Current Profiler that can measure current velocities at multiple depths in a water body. The Aquadopp Profiler is part of the family of scientific instruments designed by Nortekgroup [2]. Nortek designs instruments that can collect water current & wave data based on the Doppler principle (discussed later). Nortek mainly develops the Aquadopp & Aquadopp Profiler, used primarily to collect current data, and the Vector & Velocimeter, which primarily collects wave data.

This specific product was used by River-Insight, which directly uses Nortek devices to 'design, develop and produce scientific measurement solutions to enable water authorities to improve and simplify the complete discharge data collection process' [3].

Principles of Operations

This Aquadopp Profiler measures current speed & direction in multiple layers either directly above the Aquadopp Profiler or below the Aquadopp Profiler. Figure 2 illustrates this. In each 'cell,' the Aquadopp Profiler averages all data collected within the cell.

The AquaDopp Profiler works on the Doppler principle.
As a source moves past an observer, the sound waves are compressed or stretched out, and the frequency of the sound wave increases or decreases respectively. This is known as the Doppler effect.

This is the change of frequency of an object moving relative to another object (the AquaDopp Profiler in this case). This frequency change can be used to calculate the speed of the first object. More information is given in reference [4].

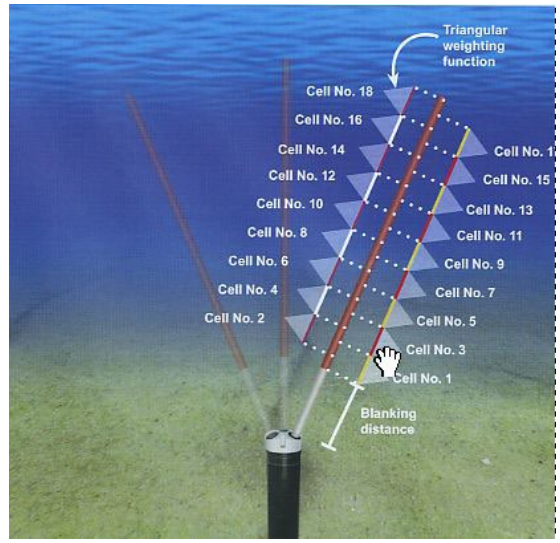

Figure 2 illustation of 'cells' for Aquadopp Profiler

The Aquadopp profiler uses an innovative way of measuring current speeds via the Doppler effect. The Acoustic Doppler transmits a short pulse of sound (ping) of constant frequency through the waters, and measures its change in frequency of the echo. More information about the technology used in Nortek's equipment can be found in the Comprehensive Manual, page 94 [5].

In addition to current profiling, the AquaDopp Profiler has the following sensors

- Pressure
- Compass
- Tilt

The AquaDopp Profiler can also measure waves. This is typically a non-trivial task since the time-period of the waves can vary very rapidly from 0.5 – 30 seconds. Nevertheless, the AquaDopp Profiler makes use of the PUV (Pressure, U and V velocity components) method to measure the characteristics of waves passing by the Aquadopp Profiler. Pressure data estimate non-directional characteristics of the wave, whilst both the combined data of the pressure & velocity time series data allows the direction of the wave to be determined. The main disadvantage of this method is its inability to be used at much greater depths (>100m).

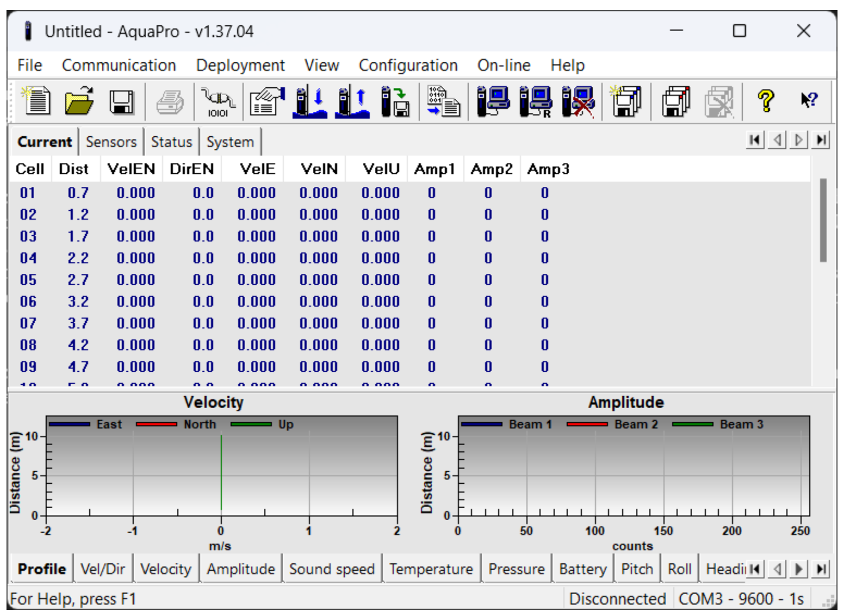

Figure 3 AquaPro interface on startup

The AquaDopp Profiler is controlled by a program called 'AquaPro'. Figure 3 shows the layout of the software. The comprehensive manual gives detailed instructions on the operations of this software [5].

Experimental Apparatus & Procedure

Testing Setup

This section describes all the features of the Aquadopp Profiler that would be tested, along with how the tests would be carried out. We would test all the components of the AquaDopp Profiler in accordance with the Comprehensive Manual. Listed below are the following components/features that would be tested:

1. Temperature
2. Tilt
3. Compass Heading
4. Ping Checks
5. Beam Amplitude
6. Velocity Checks
7. Pressure Checks

Figure 4 Testing site

We identified that the Aquadopp Profiler could be operated via AC or battery DC power. After receiving a slightly used battery from our instructor, we were able to determine the approximate capacity of the battery to be nearly full (50Wh) since the battery voltage was still operating at more than its peak voltage (13.5V). This was an improvement after working with other batteries and going as far as almost constructing a self-made battery from scratch.

After the power supply functionality was checked, we checked the recorder on the Aquadopp Profiler. There was previously data that we downloaded and stored for later use and analysis and started carrying out the necessary tests.

The simplified procedure to test each component is outlined below, along with a visual of the setup. Do note that we set up the sampling rate of all the sensors in AquaDopp Profiler to 1 sec. The testing was carried out in a swimming pool in Doha, Qatar (Figure 4).

Temperature

The Temperature read from Aquadopp Profiler should be close to room temperature. We would wait more than 10 minutes before reading via AquaPro.

Tilt

The Aquadopp Profiler can measure how much it has rotated about two axes (roll & pitch). This sensor works with the inbuilt compass to obtain heading information. Procedure outlined below:

1. Hold in vertical position to make tilt reading close to 0
2. Find X marking and let the arrow point away from you
3. Tilt per image shown (as check to see whether you get positive & negative readings

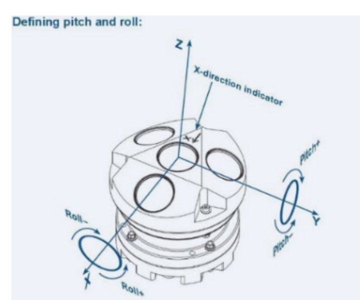

Figure 5 Principle Tilt orientations

Compass Heading

We hold the instrument away from any magnetic influence (like metal objects etc.), slowly rotate it in different directions, and verify that the heading readings are sensible.

Ping Checks

We should observe 15-30 counts for the AquaDopp Profiler. We would compare both the signal strength & velocity in the air & in water. We should observe a considerable rise in signal strength & less noisy velocity when placed in water.

Beam Amplitude

We change the AquaDopp Profiler's coordinates to beam coordinates (Beam 1, Beam 2 & Beam 3). The next step is to point each beam in turn with an angle from the horizontal (relative to the transducers) and away from any obstructions. All the beams should have similar amplitude, within 10 counts of each other.

Velocity Checks

We would change the coordinate system to XYZ and move the instrument at constant velocity in water along the X axis. +/- deflections of Vx should be seen, whilst others are 0.

Pressure Check

We set pressure offset (in AquaPro) to 0m (surface of water body), place the AquaDopp in a known distance 'y' below the water, and verify that the pressure sensor reads a depth equal to our measured length 'y', and we should observe the same value in AquaPro
Do note that the pressure sensor is not used to measure depth specifically. It's simply the fact that the pressure collates with a 1:1 ratio with depth (in meters).

Deployment system

Equipment list

- 2Mhz Aquadopp Profiler (ADCP equipment)
- AquaPro (Aquadopp Profiler controlling software)
- Cable RS422 polyurethane with 8-pin inline connector and USB converter
- A3 size buoy
- 3 x 10 m Nylon rope
- Zip ties
- Steel deployment frame
- 2 person inflatable raft

Location

The location was chosen such that valuable and relevant data would be produced for this study. In addition to this, the location had to be far from the city so that there would be no issues with the deployment and retrieval of the Aquadopp Profiler at any point during the day. Hence, the Old Ruins Beach in North-East of Qatar [6] was chosen due to the beach being exposed to the open sea and being far away from any disturbances such as marinas and boats. The issue is that if marine vehicles were to pass by the Aquadopp Profiler, there is a real possibility that the readings of the Aquadopp profiler would be anomalous. If there are many of these disturbances, the data will give inconclusive results and will not yield any useful conclusions.

Figure 6 Deployment site location on the map of Qatar [6]


Figure 7 Deployment site (Old Ruins Beach)

Deployment rig

The next step in collecting real data from the ocean was to design a deployment system that would allow for the safe deployment and retrieval of the profiler with minimal issues. One system was suggested in the comprehensive manual (page 66) [5] that was utilized for the deployment.

The deployment system consisted of a buoy attached to a frame holding the profiler in place on the seabed. The buoy was connected to the frame using a set of 10 m nylon ropes which kept the buoy from floating away under the constant pushing of the waves. There were 3 ropes banded together to increase the strength of the rope. The rope was held together using zip ties and several knots to ensure it could withstand the high forces of the seabed. The deployment of the Aquadopp Profiler is outlined below.

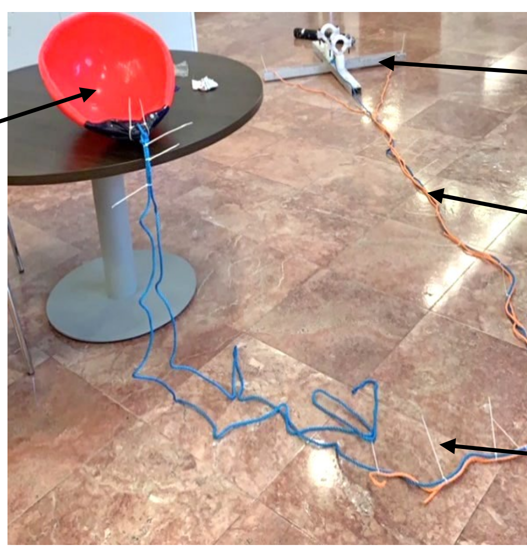

Figure 8- Deployment rig

Deployment

Figure 9 Red mark shows approximate location of Aquadopp Profiler deployment location


Figure 10 Authors of this study inflating the buoy in deployment site

After arriving at the Old Ruins beach, the raft was first inflated and then a rope was tied to the raft with a heavy sandbag tied to the other end of the rope to act as a makeshift anchor.

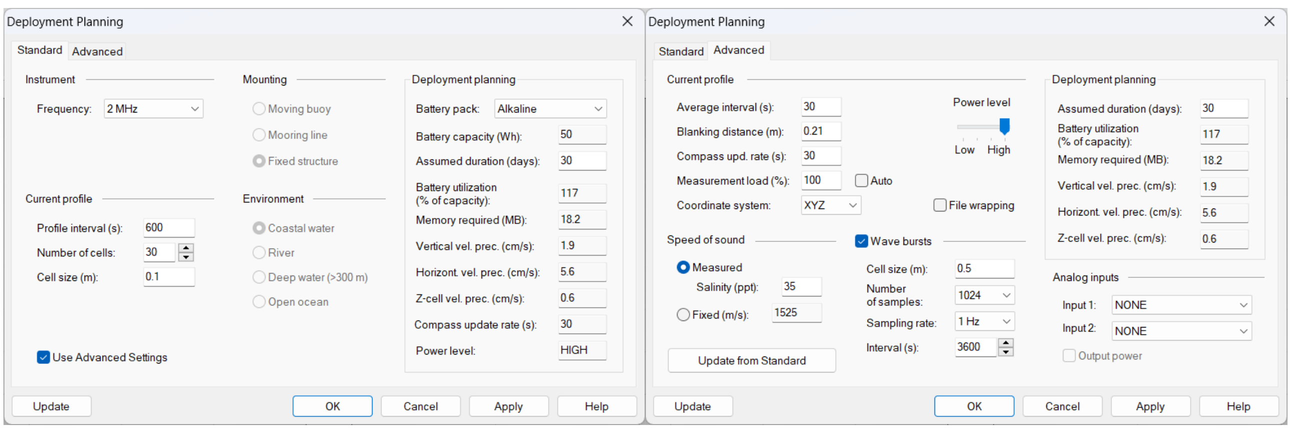

Figure 11 Deployment Planning menu (Standard & Advanced)

AquaPro was used to configure the Aquadopp Profiler via the Deployment planning menu (Figure 11). For the Current Profile, A cell size of 0.1m was used because the water level was not really deep; hence, a small cell size allows more current data to be collected. Additionally, a sampling rate of 600 seconds was chosen to avoid the risk of depleting the battery before data collection is finished. For wave data (Wave bursts prompt in Figure 11), the cell size was set to 0.5m since that was the lowest possible option available.

The raft was then taken out into the sea as it was perceived to be safe, where the deployment rig was dropped into the sea while it was recording. This was done by first dropping the anchor of the boat to stabilize it against the strong winds and keep the raft from moving. Then the metal frame with the rig in it was dropped, and the buoy was left to float on the sea surface as a marker of where the Aquadopp Profiler was. The location of the Aquadopp Profiler is approximately 26°08'13.3"N 51°18'24.0"E, as shown in Figure 9. The Aquadopp Profiler was approximately 200m from the shore.

Collecting the Aquadopp Profiler was a very similar procedure to the deployment, with the exception that when sailing out to the Aquadopp Profiler, the winds were quite strong. The raft had to be sailed about 200m to the left of the buoy so that the raft would sail with the wind and arrive at the buoy without any issues, and the Aquadopp Profiler could be collected.

Results & Discussion

This section presents and discusses the results of testing & deploying in Old Ruins Beach, respectively.

Testing Results

Temperature

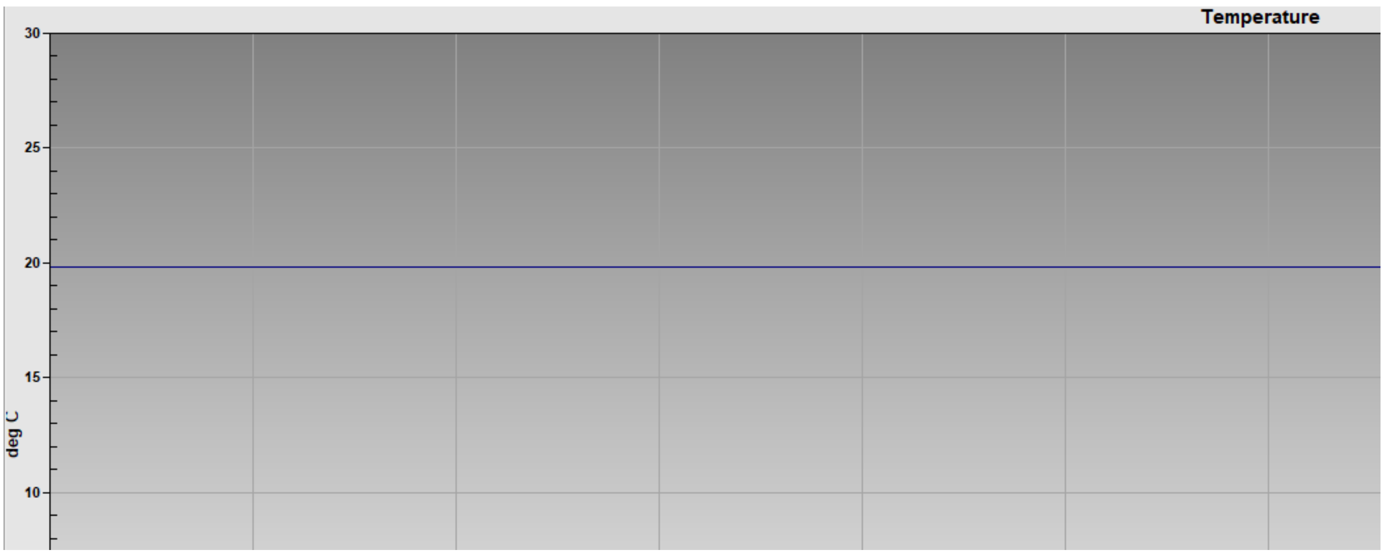

Figure 12 Temperature Results

The Temperature shown in Figure 12 was close to what was measured in the lab (room temperature).

Tilt

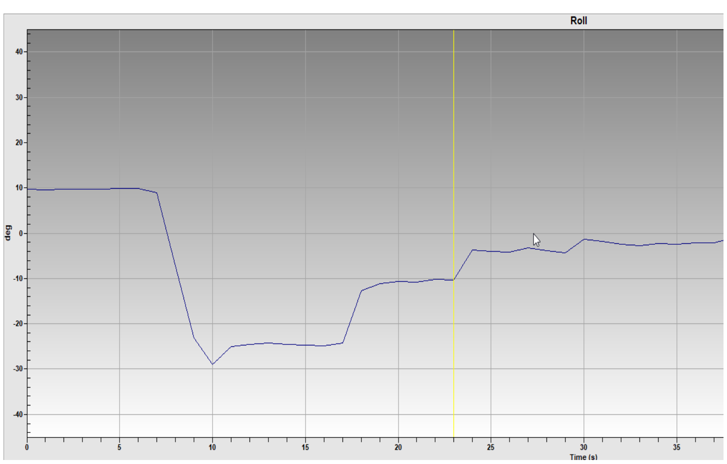

Figure 13 Tilt Roll Results

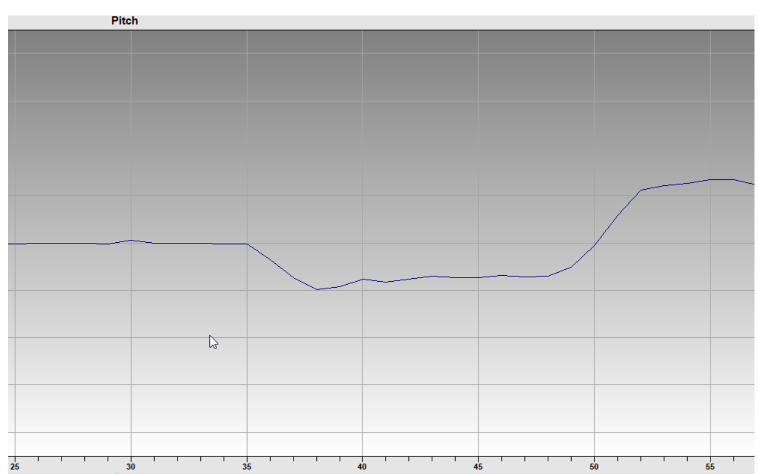

Figure 14 Tilt Pitch Results

Figure 13 and Figure 14 shows that the tilt sensors work since the signs shown in the figures are coherent with the manual.

Compass Heading

Figure 15

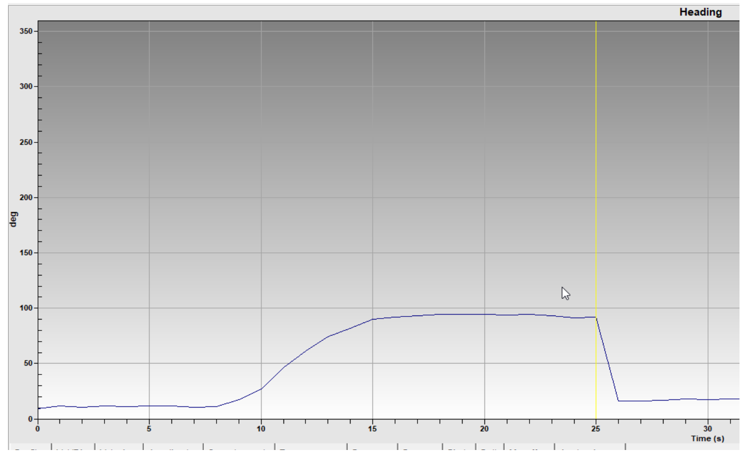

Figure 16 Compass Heading

The compass headings shown in are the same as shown in the iPhone in Figure 15. Figure 16 shows the Compass heading readings from AquaPro.

Ping Changes

Cell	Dist	VelEN	DirEN	VelE	VelN	VelU	Am	Am	Am
01	0.7	3.206	42.7	2.175	2.355	0.427	19	19	19
02	1.2	3.393	16.6	0.971	3.251	0.181	19	19	19
03	1.7	0.931	133.3	0.677	-0.639	0.299	19	19	19
04	2.2	1.657	238.3	-1.410	-0.870	0.010	19	19	19
05	2.7	0.513	88.8	0.513	0.011	-0.300	19	19	19
06	3.2	1.098	132.5	0.810	-0.741	0.306	19	19	19
07	3.7	1.960	307.1	-1.563	1.182	-0.432	19	19	19
08	4.2	2.907	32.6	1.568	2.448	0.409	19	19	19
09	4.7	1.218	244.3	-1.098	-0.528	-0.317	19	19	19

Figure 17 Signal strengths in air

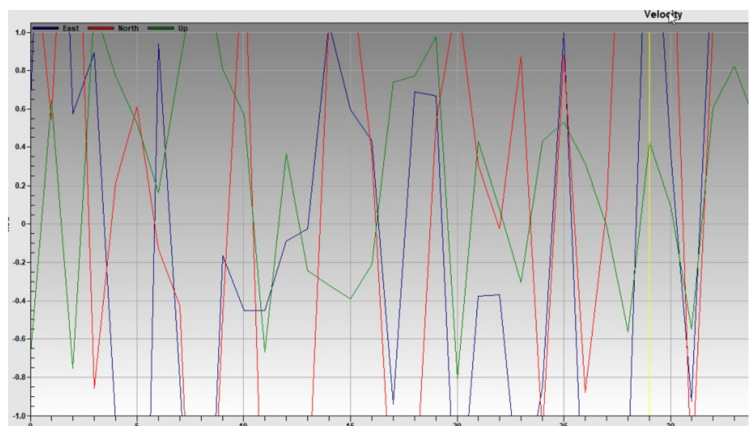

Figure 18 Current Profiling (Velocity Measurements) in air

Figure 17 and Figure 18 clearly shows that the counts are between 19 & 30, and the velocity measurements are just noise as expected since the profiler was in the air not under water.

Cell	Dist	VelXY	DirXY	VelX	VelY	VelZ1	Am...	Am...	Am...
01	0.7	0.228	271.0	-0.228	0.004	-0.014	157	152	157
02	1.2	0.216	296.9	-0.193	0.098	-0.038	126	135	133
03	1.7	0.166	278.3	-0.164	0.024	-0.029	147	165	136
04	2.2	0.347	275.1	-0.346	0.031	-0.025	196	174	205
05	2.7	0.184	245.7	-0.168	-0.076	-0.020	79	112	106
06	3.2	0.218	261.3	-0.215	-0.033	-0.013	106	151	113
07	3.7	0.315	286.8	-0.302	0.091	-0.041	98	106	120
08	4.2	0.366	271.6	-0.366	0.010	-0.018	92	145	96
09	4.7	0.160	267.9	-0.160	-0.006	-0.053	125	147	118

Figure 19 Signal strengths in water

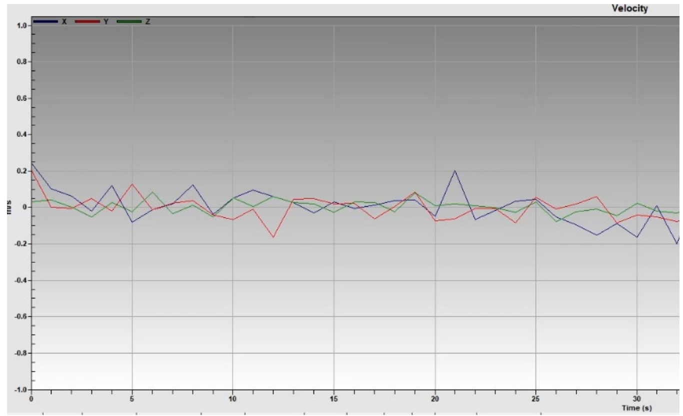

Figure 20 Current Profiling (Velocity Measurements) in water

Figure 19 shows an increase in the signal strengths of the AquaDopp Profiler in water. The velocity graph shown in Figure 20 is visually cleaner as compared to Figure 18, hence a clear indication of noise reduction.

Beam Amplitude

Cell	Dist	VelXY	DirXY	VelX	VelY	VelZ1	Am...	Am...	Am...
01	0.7	0.133	120.8	0.114	-0.068	-0.001	147	151	195
02	1.2	0.137	5.9	0.014	0.136	0.039	138	131	174
03	1.7	0.087	114.5	0.079	-0.036	-0.006	122	121	123
04	2.2	0.091	153.2	0.041	-0.081	-0.004	205	202	124
05	2.7	0.059	113.1	0.054	-0.023	0.021	125	93	116
06	3.2	0.063	167.1	0.014	-0.061	-0.020	96	127	93
07	3.7	0.048	180.0	0.000	-0.048	0.061	117	112	101
08	4.2	0.135	116.0	0.121	-0.059	0.048	93	116	95
09	4.7	0.065	156.6	0.026	-0.060	0.020	100	161	98

Figure 21 Beam Amplitudes (same as signal strength) in water

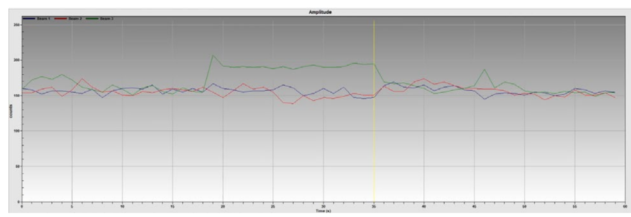

Figure 22 Beam Amplitudes (same as signal strength) in water graph

It can be seen in Figure 21 and Figure 22 that the beam amplitudes seem to vary from within 10 counts and more. This could be due to changing beam directions & angles whilst testing. Nevertheless, the beam amplitudes show areas where they are close to each other. Do note that the beam amplitudes are shown in terms of counts. Hence we used the beam amplitudes to check for ping changes previously.

Velocity Checks

Cell	Dist	VelXY	DirXY	VelX	VelY	VelZ1
01	0.7	0.410	81.3	0.405	0.062	0.097
02	1.2	1.238	89.4	1.238	0.012	0.179
03	1.7	0.988	128.0	0.779	-0.608	-0.125
04	2.2	1.092	121.2	0.934	-0.566	-0.161
05	2.7	1.111	104.2	1.077	-0.272	-0.080
06	3.2	1.236	108.6	1.171	-0.395	-0.057
07	3.7	1.016	123.0	0.852	-0.554	-0.124
08	4.2	1.014	111.4	0.944	-0.369	-0.048
09	4.7	0.970	113.1	0.892	-0.380	-0.043

Figure 23 Current Profiling (Velocity Measurements) in water with movement in x direction

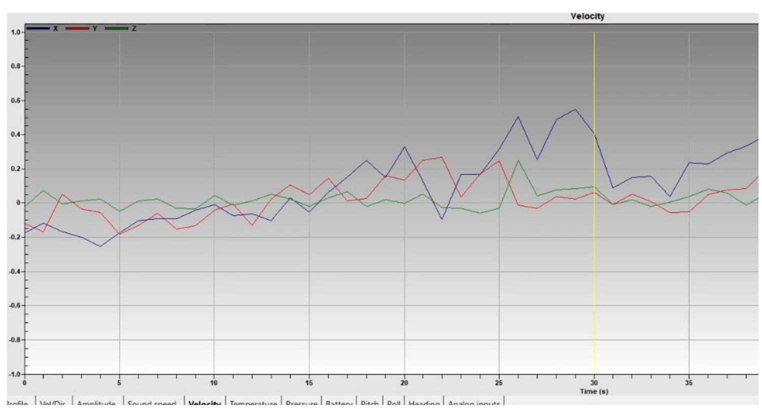

Figure 24 Current Profiling (Velocity Measurements) in water with movement in x direction graph

Figure 23 and Figure 24 show how there is a major change in the Vx value compared to the other directional velocities.

Pressure Check

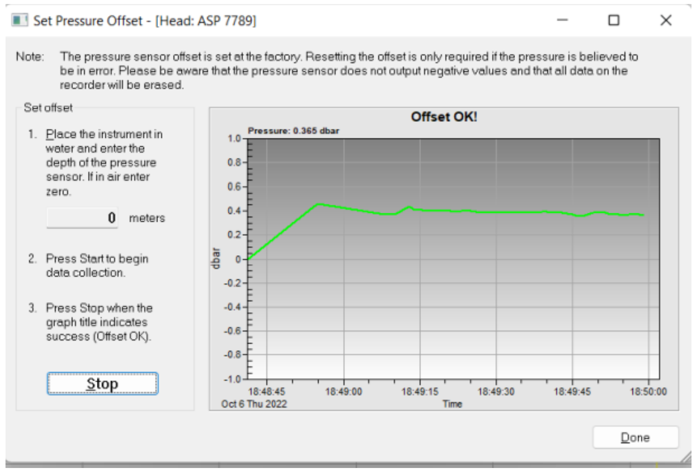

Figure 25 Pressure check test

It can be seen in Figure 25 that by setting an offset of 0dbar (surface of the pool), we observed a dbar in the range of 0.3dbar to 0.5dbar, which was what we expected since we dropped the Aquadopp Profiler to a depth of around 0.4m. The variation of pressure is due to not being able to hold the Aquadopp Profiler steady.

Data Collection Results

Current Profile

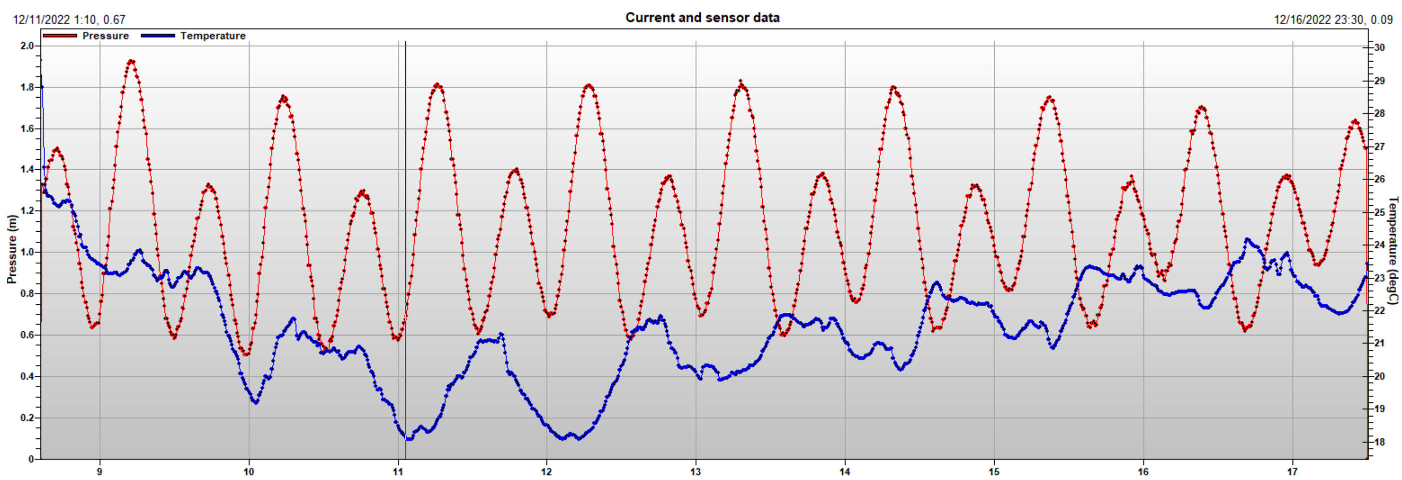

Figure 26 Pressure (m) & Temperature (℃) measured during data collection period

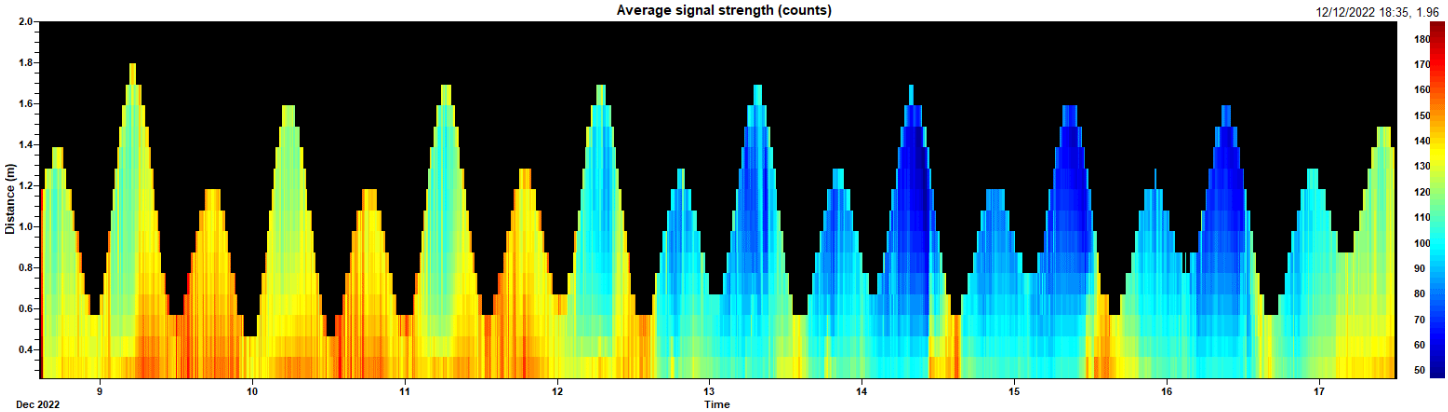

Figure 27 Signal Ping strength profile during data collection period (black- no signal, dark red-strongest signal)

Figure 26 shows how the Pressure & Temperature measured by the Aquadopp Profiler varied. The pressure experienced by the Aquadopp Profiler seems to vary sinusoidally over the days, and there seems to be distinct periods of high pressure & low pressure each day. This could be explained by tides. Figure 26 shows the average signal strength in terms of the distance from the Aquadopp Profiler to the water surface. Figure 26 gives information on the depth of water over the course of the experiment, as the black background represents the Aquadopp Profiler's inability to collect data. It can be seen that the depth of the water varied sinusoidally over the days, with 2 crests, & 2 troughs. Thus, it makes sense to state that tidal variations led to a changing pressure experienced by the Aquadopp Profiler. Additionally, the accuracy of this data is verified by the high strength of the signals as shown in Figure 27 (black signifies no signal, & dark red signifies highest signal strength).

Across each day, the Temperature shows an increase and then a decrease, which repeats each day. On December 9th & 10th, it can be seen that the temperatures peaked in the early mornings (around 5-6am), whilst the temperatures hit its lowest points around midnight. However, this trend seems to change for the next couple of days as it can be observed that the temperatures peaked around the afternoon time and reaches its lowest points during the daytime (9am to 12pm). This would not make a lot of sense since it would be expected that the coldest temperatures should be reached during the nighttime. Therefore, this observation can be attributed to local weather fluctuations. Collecting data for a longer period of time during winter would allow us to detect any further patterns.

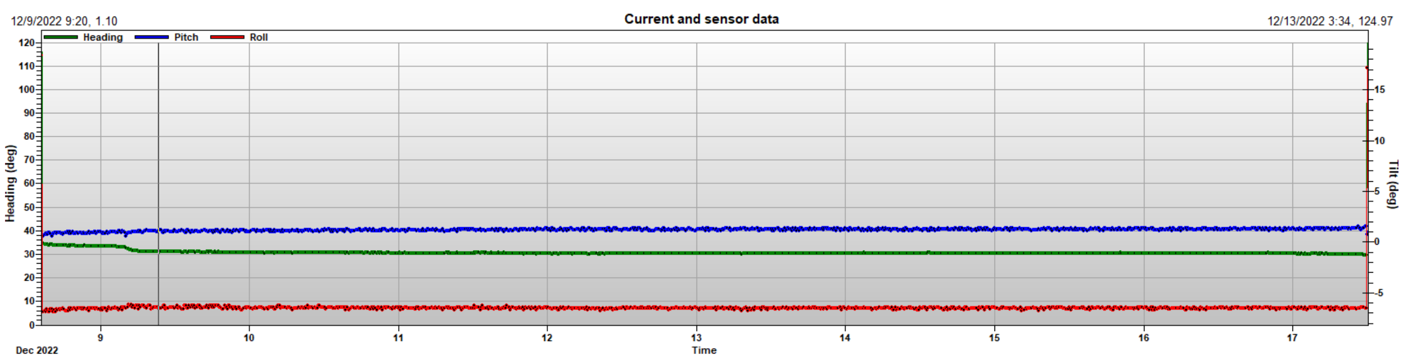

Figure 28 Heading & Tilt (Pitch & Roll) during data collection period

Figure 28 shows the orientation of the Aquadopp Profiler when it was placed. It can be seen that there was a substantial pitch, as the Aquadopp Profiler was dropped from the surface, since the team did not have the adequate equipment to dive into the water and place the Aquadopp Profiler.

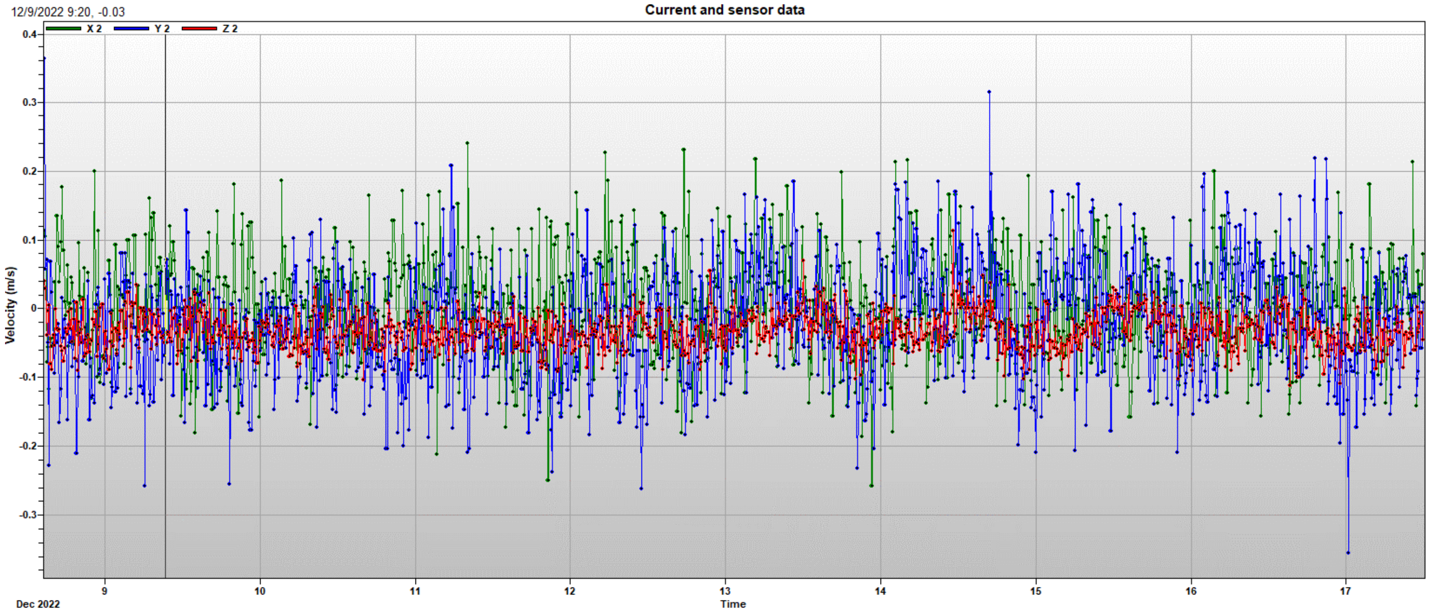

Figure 29 XYZ velocity of current at approximately 0.41m from sea bed

Figure 29 shows the XYZ velocity of the water currents for cell 2 (≈0.41m from the surface). The data makes sense since the z-component of current velocity (marked in red) is relatively small, whilst the x-component & y-components have larger magnitudes. Additionally, the magnitudes themselves are in the range of 0 – 0.2m, which is expected, since this measurement is near the surface. As we increase the cell size, hence increasing the distance from the seabed, we observe some areas of the velocity is not available, this is because of the tides. These data are shown in Appendix II.

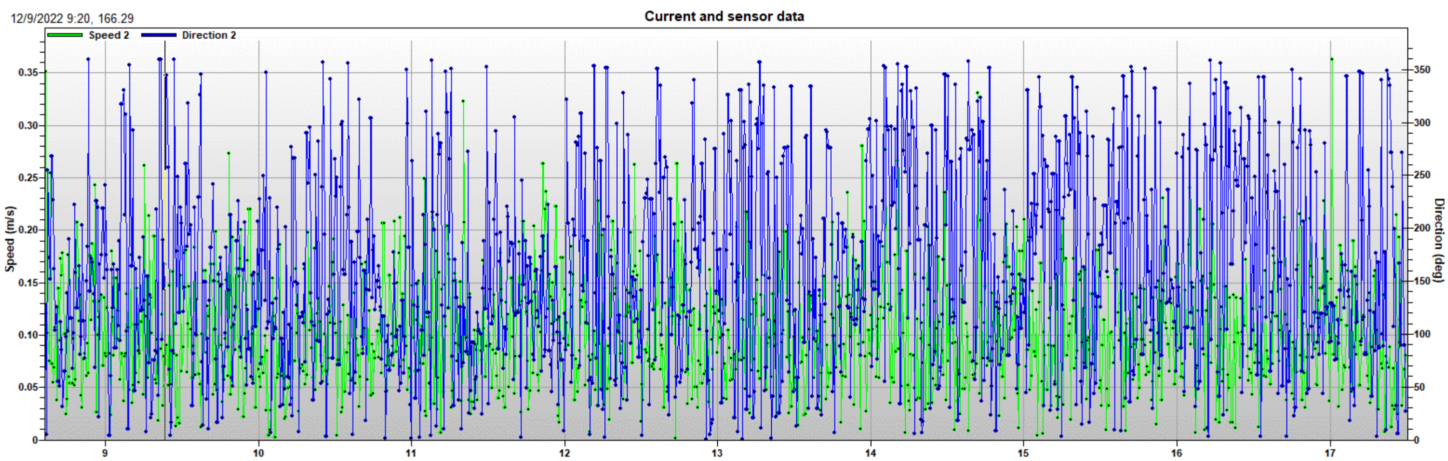

Figure 30 Speed & direction of current at approximately 0.41m from sea bed

Figure 30 shows the magnitude of the current at 0.41m from the ocean floor. It can be seen that the direction fluctuates substantially. A better trend could be observed if the sampling rate was increased from 10 minutes to 1 second, to observe how the direction of the current changes. Needless to say, it can be seen that the current velocity magnitude peaks mainly around 0.20m/s (20cm/s). A publication involved in investigating bottom currents by G. Shanmugam has stated that measured current velocities range from 1 – 20cm/s [7].

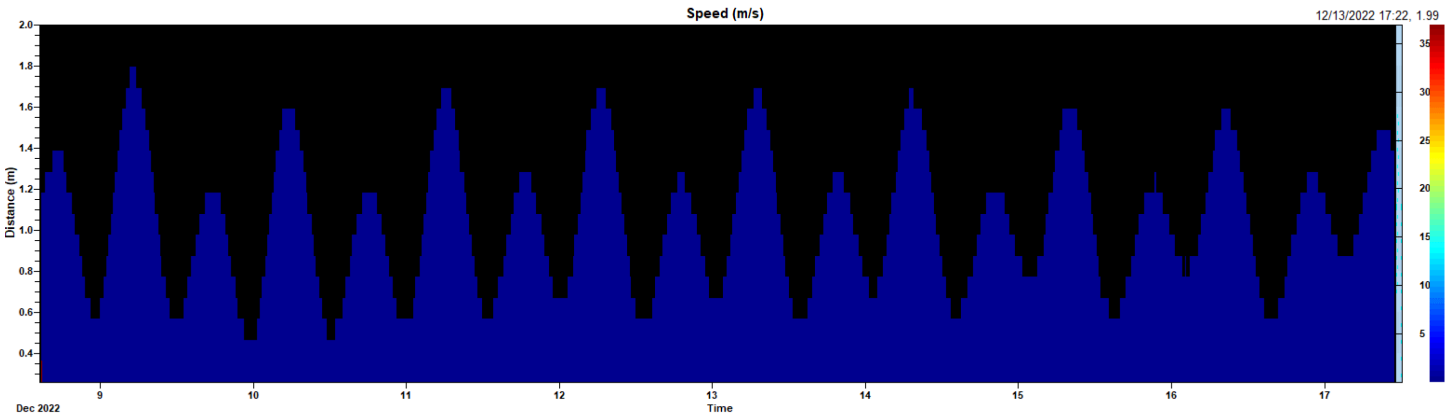

Figure 31 Current speed profile during data collection period (black- no signal, dark red-strongest signal)

Figure 31 shows a complete view of the current speed profile plotted vs distance & time. It can be clearly seen that there are 2 peaks & 2 troughs in each day, which verifies the tidal presence in the waters in the north of Qatar.

Wave Data

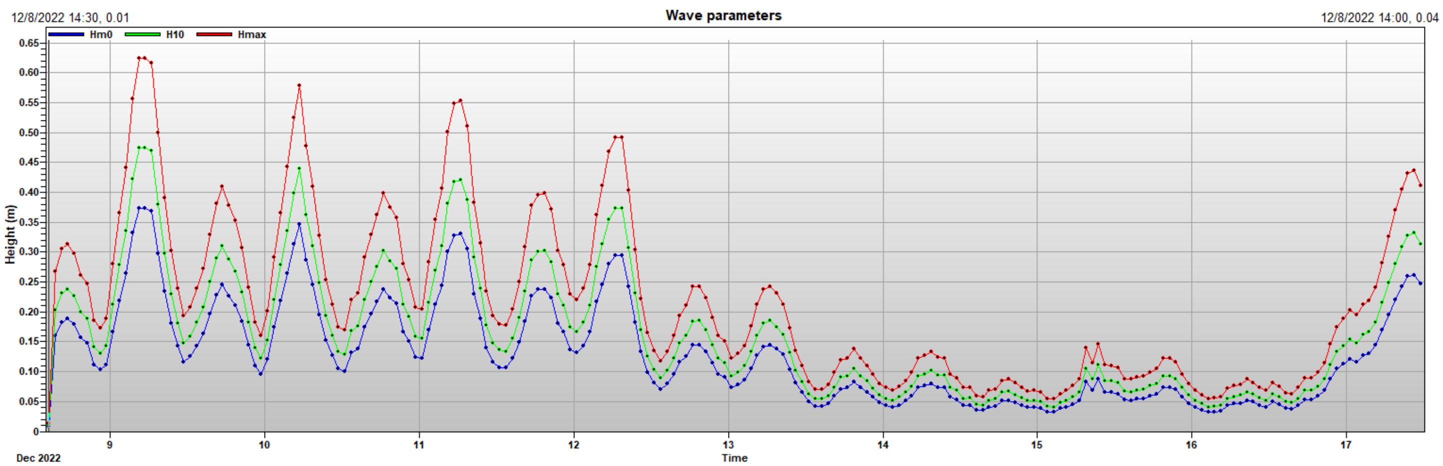

Figure 32 Measured height of waves during data collection period

Figure 32 shows that the waves were substantially higher from December 9th to 13th. The high wave heights could have led to lower temperatures in Figure 26, data should be collected over a longer period to determine if any trend exists.

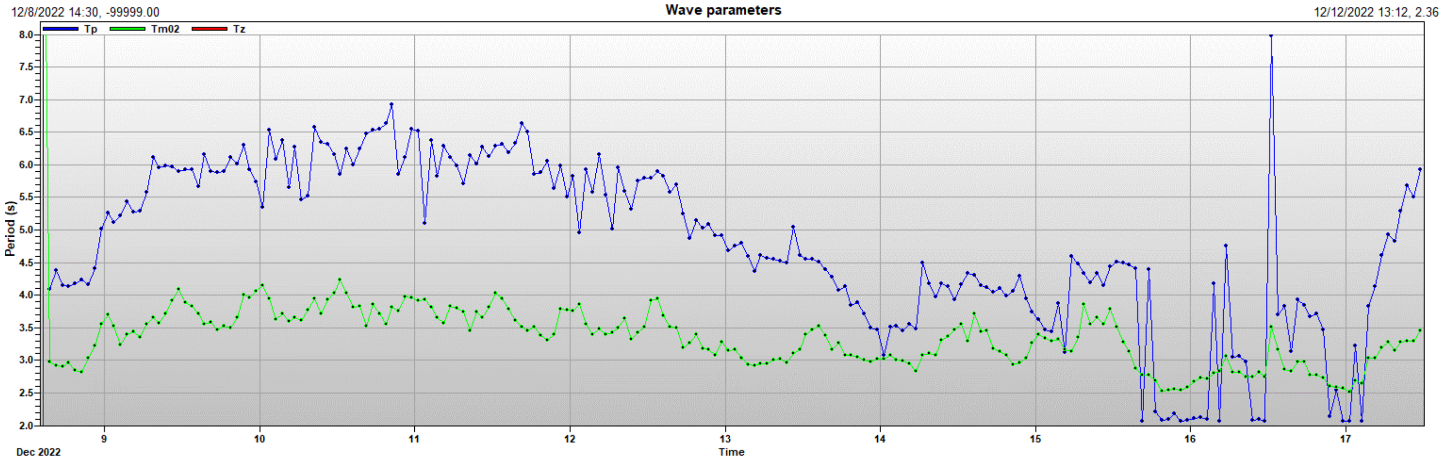

Figure 33 Wave time-period during data collection period

Figure 33 shows the time period as a spectra vs time of the waves.

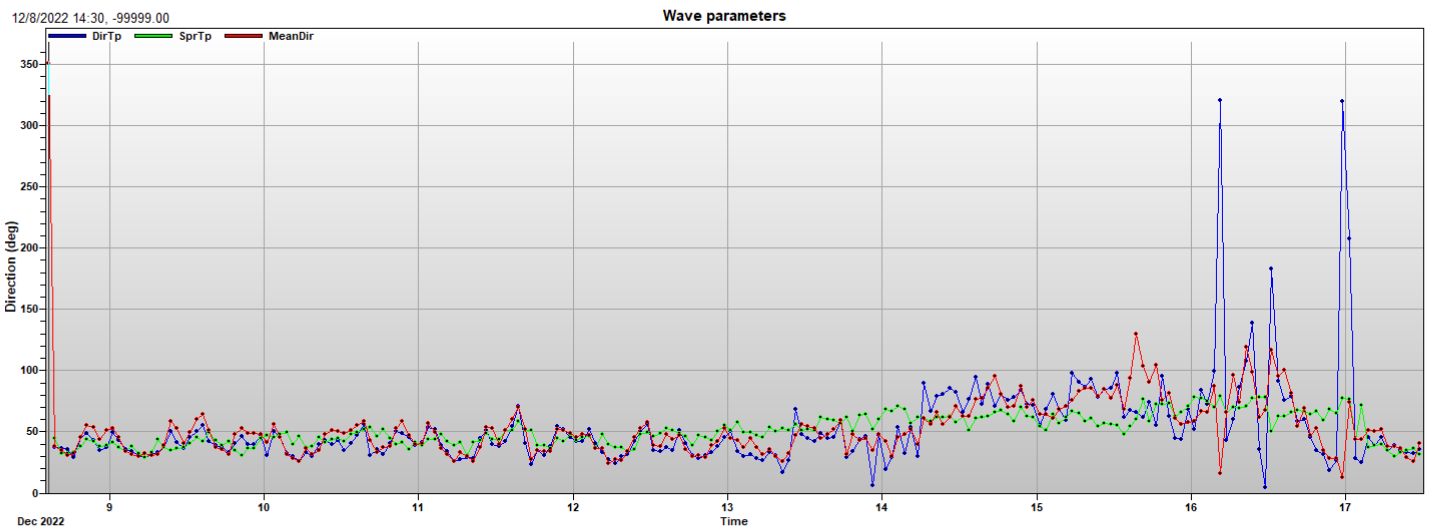

Figure 34 Direction of waves vs time during data collection period

Figure 34 shows the direction of the waves vs time across the days. There seemed to be a large fluctuation on December 16th & 17th, which could be attributed to man-made influences. The rest of the days remained fairly consistent.

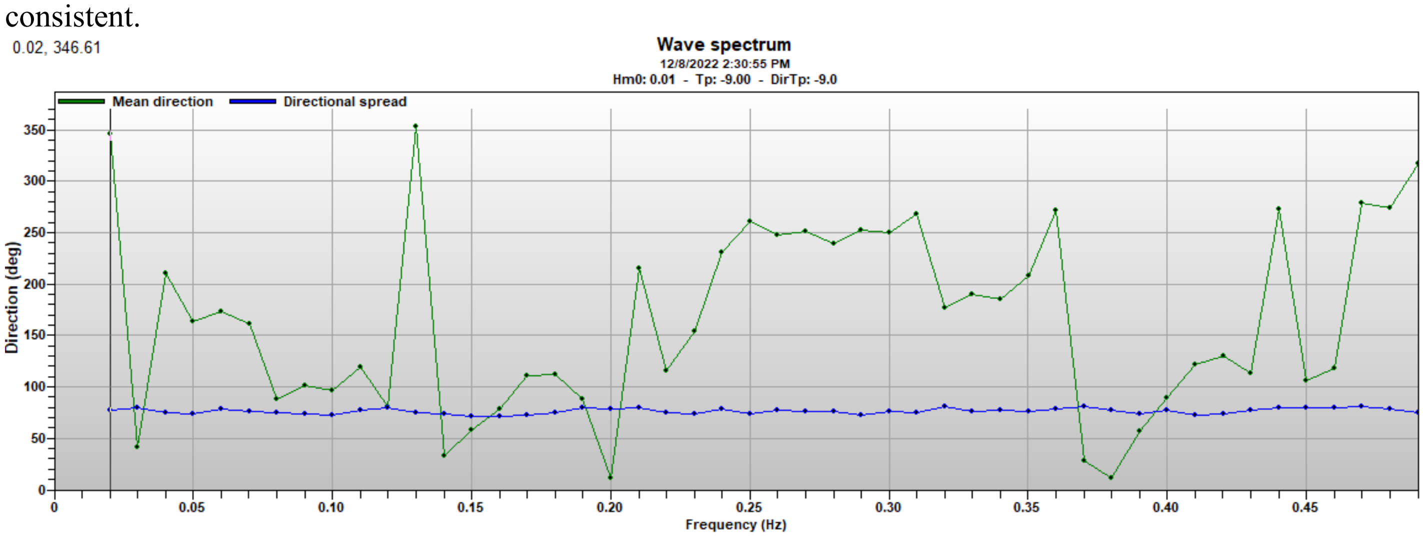

Figure 35 Direction of waves vs frequency during data collection period

Figure 34 shows the range of wave frequencies detected throughout the days, and its mean direction & directional spread.

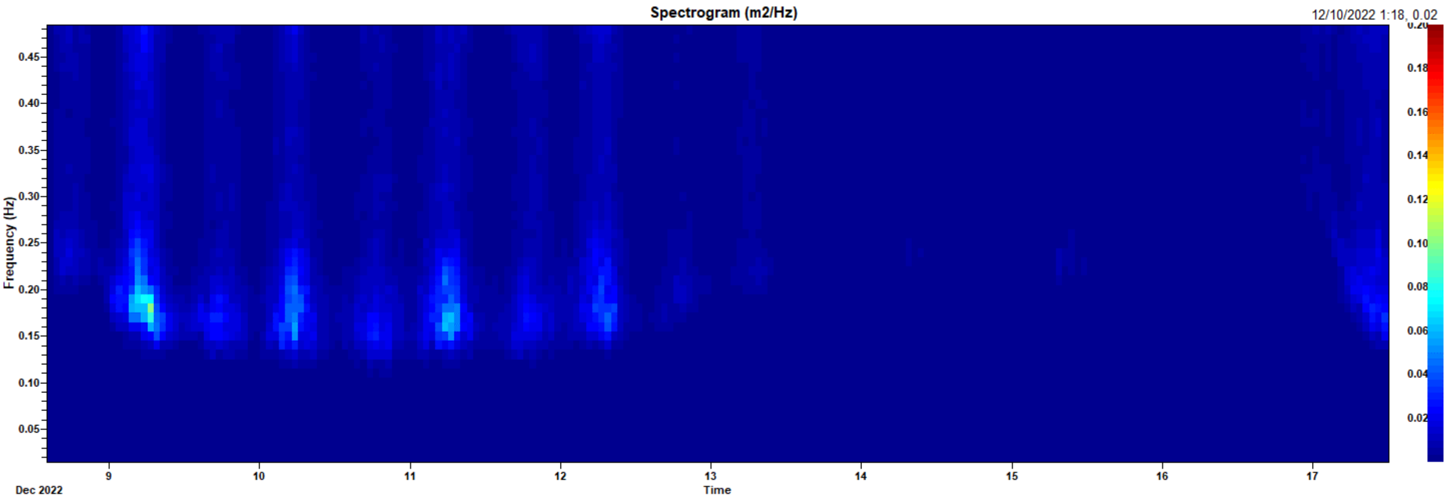

Figure 36 Spectrogram of waves during the data collection period

Figure 36 shows the Spectrogram of the waves (spectrum of frequencies) during the data collection period. It can be seen that the highest frequency waves can be observed from December 9th to December 12th. Considering the increased height of the waves, as shown in Figure 32, it can be stated that local weather factors such as a cold front could've led to the data shown in Figure 36.

Conclusion

The data is conclusive with what would be expected from the shallow sea with a regular 24-hour tide in a coastal region. Furthermore, the pressure and temperature fluctuate in accordance with what would be expected from a natural tide, as the pressure varied sinusoidally. The data collected was verified to be accurate by the high signal strengths. Temperature showed low and high points every day from December 9^{th} to 16^{th}. If more data was collected, a helpful trend for the Temperature could be observed. However, due to time & equipment constraints, that was not possible.

The current velocities made sense, mainly since it was observed that the z-component of velocity was small compared to the other velocity components.

The wave data collected showed that the wave heights were substantially higher, along with a higher frequency. In addition to this, it can be seen that the waves were around 2 meters at peak high tide and around 0.5 meters at the lowest point in the tide (figure 22). This is a significant change in height of water above the Aquadopp Profiler may have caused the sharp increases and decreases in the Temperature.

It can be concluded that the deployment system worked as intended. However, in the future the deployment setup should be improved, by using topological data to ensure that the Aquadopp Profiler remained flat. Additionally, topological data from the deployment site would give us insight into what type of equipment we would need to bring. For example, in the Northern Arabian sea, we would have to sail around 1km before we could get any substantial decrease in depth. In the future, we could use more upgraded equipment & better planning to collect oceanic-related data for an extended period of time.

Acknowledgments

Thank you, Dr. Reza Sadr and Mr. Yuan Li, for your continued support and guidance throughout this project. It has been a very challenging experience, and we have gained invaluable experience from it and learned many real-life skills that we may not have had a chance to do until now.

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Appendix

Appendix I

Table 1 Technical Specifications of AquaDopp Profiler

Temp. range	-4 to +40 °C
Temperature Accuracy/resolution	0.1 °C/0.01 °C
Compass accuracy	2°/0.1° for tilt < 20°
Maximum Tilt & Accuracy/Precision	30° & 0.2°/0.1°
Range	0-100 m
Range Accuracy/precision	0.5% FS / 0.005% of full scale

I/O	RS-232 or RS-422
Communication baud rate	300-115200 Bd
Recorder download baud rate	600/1200 kBd for both RS-232 and RS-422
DC input	9-15 V DC
Maximum peak current	3 A
Avg. power consumption	0.03 W
Battery capacity	50 Wh (alkaline or Li-ion),
New battery voltage	13.5 V DC (alkaline)

Link to Technical Data sheet for AquaDopp Profiler: https://www.nortekgroup.com/products/aquadopp-profiler-2-mhz/pdf
Link to Comprehensive Manual: https://www.nortekgroup.com/assets/software/N3015-031-ComprehensiveManual_ADCP_1118.pdf

Appendix II

Additional velocity vs time graphs for depths 0.51m, 0.71m & 1.41m.

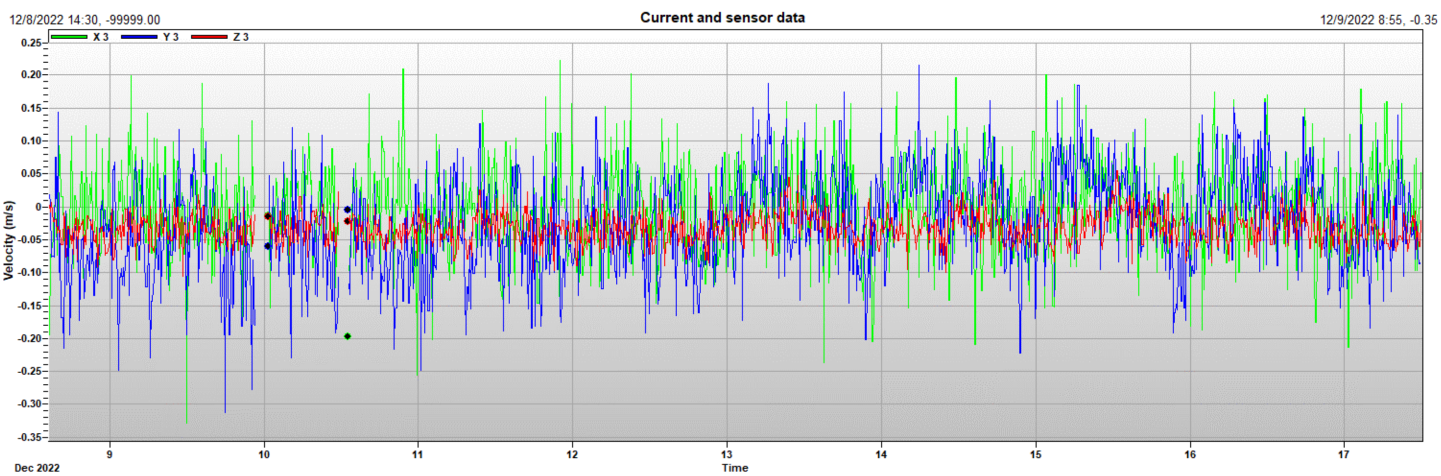

Figure 37

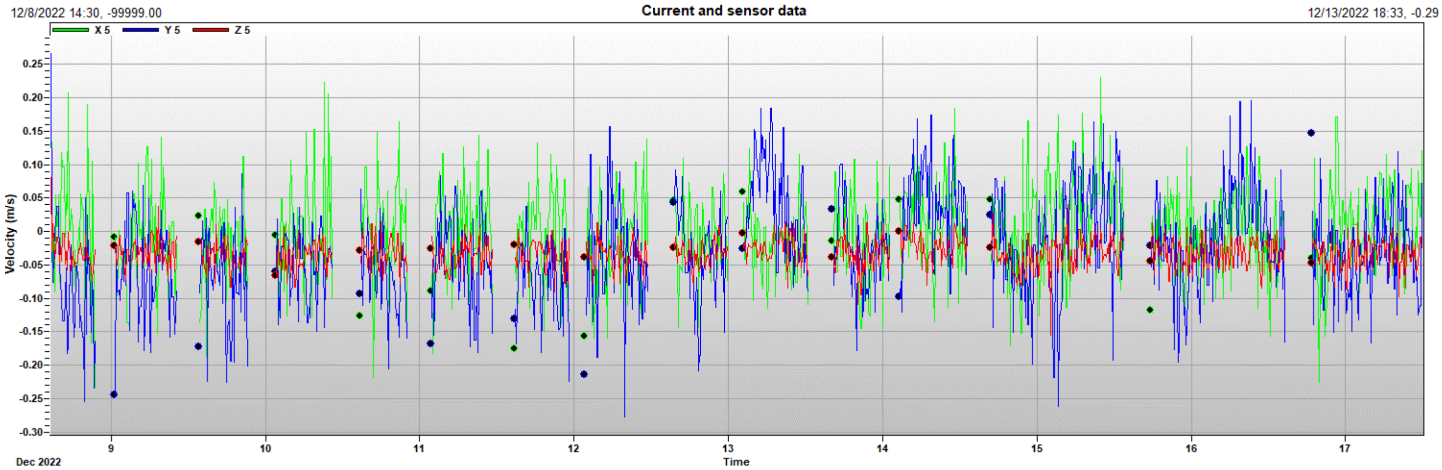

Figure 38

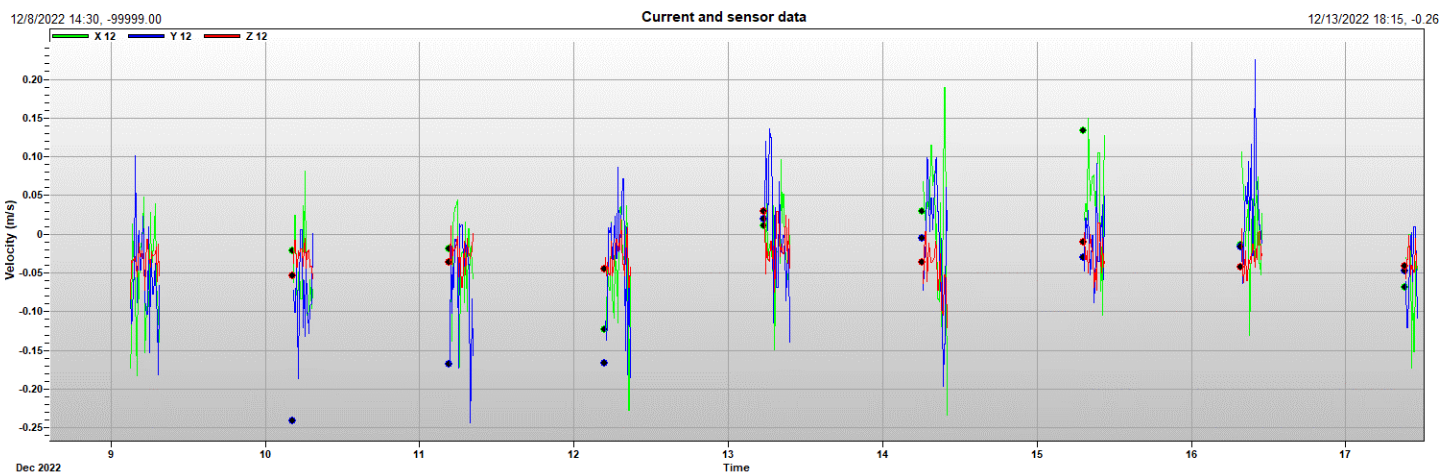

Figure 39