Pacific Northwest
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PNNL-38520

Characterizing Clallam Bay for Wave Energy Device Testing

Spatial Velocity Survey, May 2025

JR McVey
JH Haxel

U.S. DEPARTMENT OF ENERGY
Prepared for the U.S. Department of Energy
Under contract DE-AC05-76RL01830

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Pacific Northwest National Laboratory
Richland, Washington 99352

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1.0 Introduction

As part of phase I of the EED LDRD project #85141, Characterizing Clallam Bay for Wave Energy Device Testing, PNNL staff performed on-water survey work collecting water velocity measurements in Clallam Bay, WA in May 2025. Clallam Bay is a semi-sheltered bay on the northern coast of the Olympic Peninsula being considered for marine energy device testing primarily focused on wave energy (Figure 1). This survey work utilizes the existing PNNL programmatic permit authorizations in the area from consultation with regulatory agencies and the Makah Tribe.

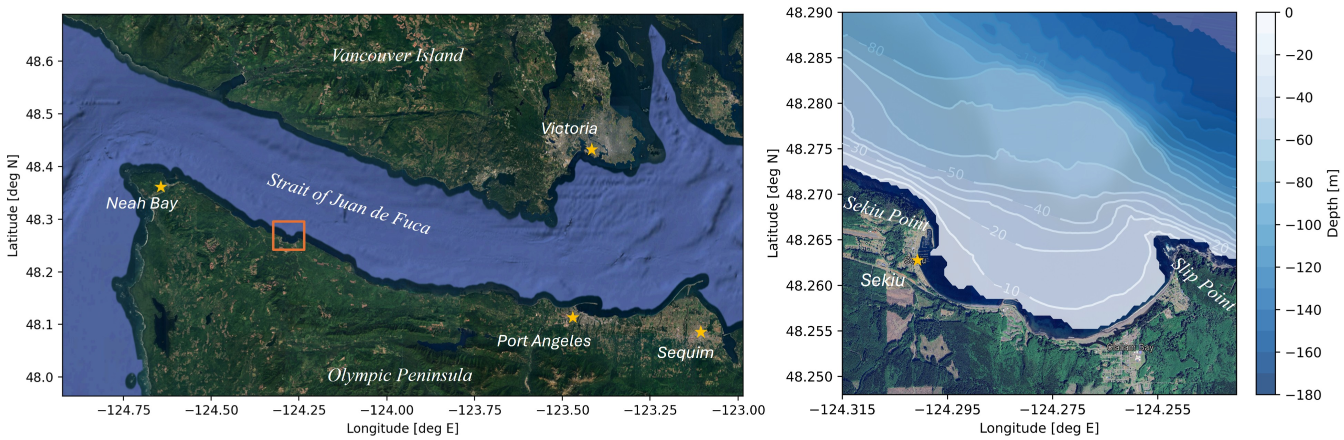

Figure 1. Maps of Clallam Bay and the surrounding Strait of Juan de Fuca region.

Many questions remain about the physical characteristics of the Clallam Bay site (e.g., bottom types, bathymetry, ambient sound levels) and the range of environmental conditions that occur there (e.g., waves, currents, winds) that are critical to understand for marine energy device testing. Currently, there is a NOAA tide gauge at the site (Station 9455760 (NOAA 1978)), and a previous 1-month wave buoy deployment by PNNL in September 2021 revealed wave heights of 1-2 m. Bathymetric and sidescan-sonar data are available for analysis from a hydrographic survey (H13414) of the north Olympic coast by the National Oceanographic and Atmospheric Administration (NOAA) in 2020 (NOAA 2020). PNNL has also developed a hindcast model for the Salish Sea based on high-resolution wind and wave hindcasts, though wave dynamics in straits, bays and estuaries are difficult to model well (Yang et al. 2019). This highlights the importance of high-resolution, long-term measurements at these kinds of sites that provide accurate characterization information for future testing. The ambient underwater soundscape in Clallam Bay has also never been studied; it is an important baseline to measure and compare with future environmental monitoring around wave energy converters (WECs).

The goal of the ADCP survey reported herein is to measure the spatial variability of water velocity across a broad swath of PNNL's permitted zone. This information is useful for understanding the hydrodynamics of the area, how it relates to the local bathymetry, and to inform the design of equipment for future studies. The secondary goal of this survey is to determine, based on the velocity distribution, the best zones to deploy an ADCP, a hydrophone, and an anchored Spotter wave buoy in phase II of this project.

2.0 Site Location

The general ADCP survey area is within the permitted zone in and outside of Clallam Bay, WA, between 20 m and 80 m water depth. The existing permitted area in Clallam Bay is quite large, roughly 6 square miles. The area lies outside of the commercial shipping lanes demarcated on NOAA navigation charts, but the region deeper than 60 m depth is marked on charts as the recommended path for ocean-going craft. NOAA performed hydrographic surveys along the north Olympic coast, including the Clallam Bay region, in 2020 using high resolution sidescan sonar and collected samples of seafloor substrate (NOAA 2020). These data provide imagery of the seafloor and a rough idea of seabed materials. Figure 2 below shows the side-scan sonar imagery as well as bathymetry contours as measured by the survey.

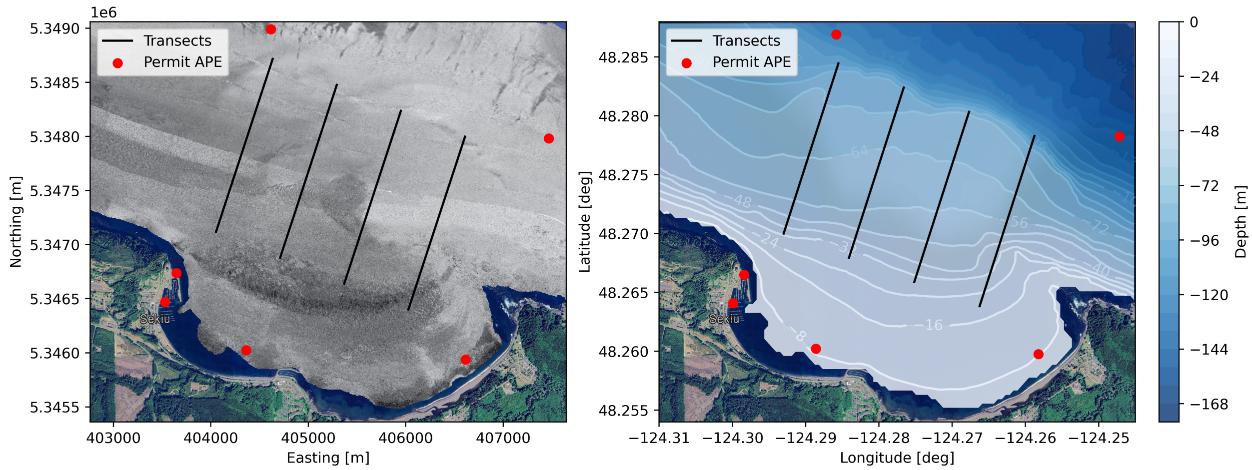

Figure 2. Maps of Clallam Bay and the boundaries of PNNL's programmatic permit area (red scatter) with planned transect lines (black). Backscatter data from sidescan sonar surveys (left). Bathymetry contours with a horizontal resolution of 40 m (right).

The bathymetry in the bay and immediately offshore can be likened to that of a two-terraced hillside (Figure 2). The inner bay has a mellow slope angle of 0-5 degrees until approximately 20 m water depth (upper terrace), where the slope steepens to around 10 degrees before returning to the 0-5 degree slope that forms a plain or rough shelf (lower terrace) above the depths of the Strait. This shelf extends off the coast north of Sekiu and Slip Points (Figure 1). Sekiu Point marks the western corner of Clallam Bay, while Slip Point is a promontory that forms the bay's eastern corner. This promontory is essentially the highest point in a series of ridge-like rocky features running WNW to ESE from the shelf and is apparent in side-scan imagery.

3.0 Site Bathymetry

NOAA collected high-resolution multibeam sonar data during the hydrographic survey H13414 (NOAA 2020). Rock formations on the seafloor were observed, particularly off Slip Point and in the western side of the bay, and bedforms on each of the terraces that form the seafloor (Figure 3). The seabed consists of gravel and sand at depth transitioning to sand and shells in the shallower bay.

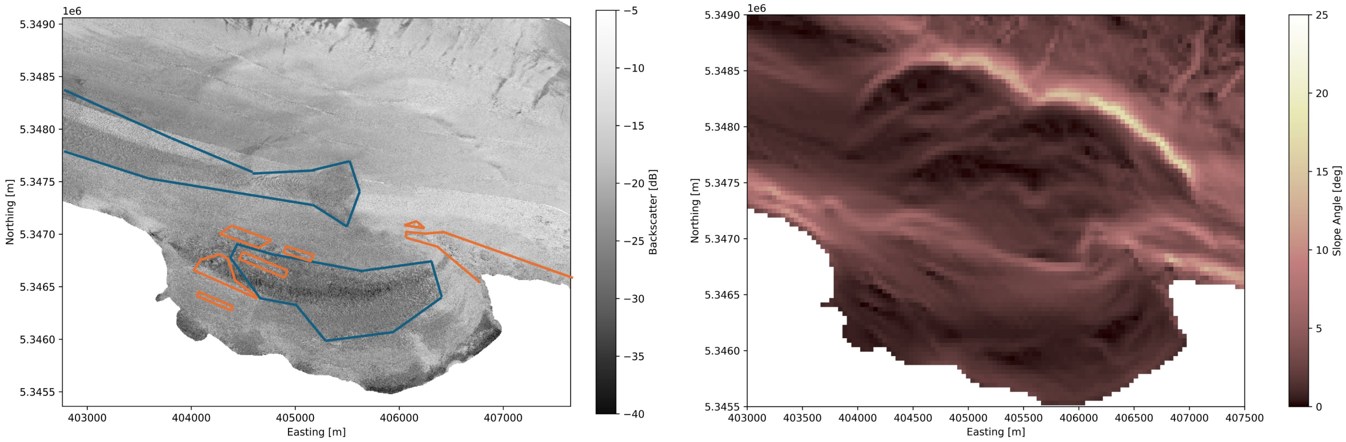

Figure 3. Maps of Clallam bay, showing side-scan backscatter on the left and slope-angle shading on the right. Approximate locations of bedforms (blue) and rock features (orange) are outlined over the backscatter imagery on the left.

Large underwater sand and gravel dunes with wavelengths between 15-30 m occur at depth of 50-65 m, which, based on their profile, are generated by flood tide currents (Figure 4). These dunes appear to be a product of flood tide flowing around the submerged bluff off Kydaka Point (not shown in Figure 2). They decrease in height from 1 m to 0.5 m along the coastline before disappearing on the lower terrace in the center of the survey area. A second series of dune bedforms occur in the center area of the bay between 12-30 m depth (Figure 5), ranging in height up to 1 m and wavelengths of 15-20 m. These are also created by flood tide sweeping into the inner bay. Other than the rocky promontories off Slip Point, there are several rocky ridgeline features extruding from the seafloor on the western side of the inner bay (Figure 3).

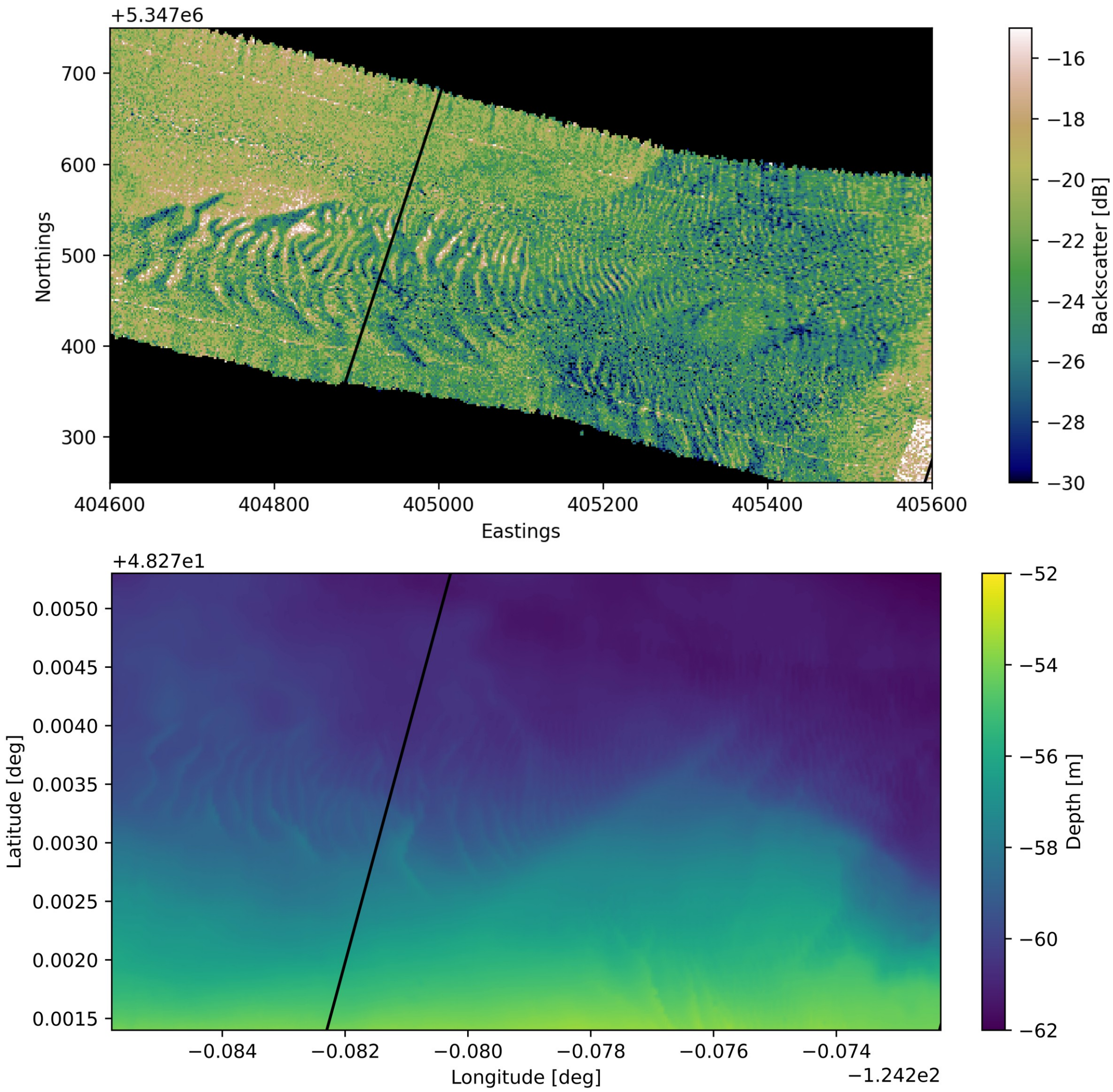

Figure 4. Maps of dune bedforms located between 50-65 m depth outside of Clallam Bay. Backscatter imagery taken by NOAA is shown in the top subplot, and high resolution (1 m) bathymetry is shown in the lower subplot. The planned course of the 2nd transect is shown as a black line in both subplots.

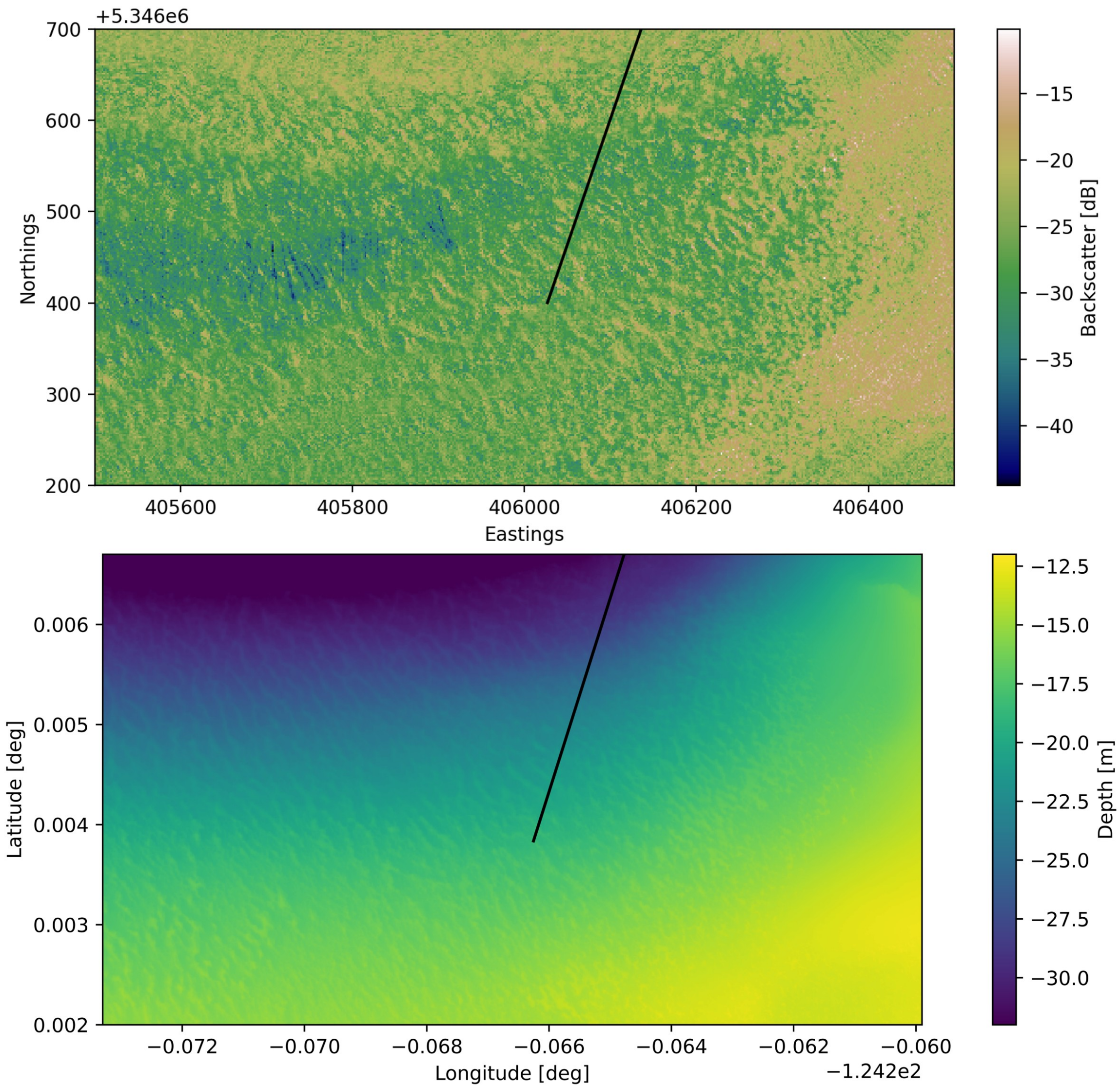

Figure 5. Maps of dune bedforms located in the southeast area of Clallam Bay between 10-30 m depth. Backscatter imagery taken by NOAA is shown in the top subplot, and high resolution (1 m) bathymetry is shown in the lower subplot. The planned course of the 2nd transect is shown as a black line in both subplots. The cause for the dark blue lines in the top subplot (weakest backscatter) may be a sonar artifact.

4.0 NOAA Water Level and Velocity Predictions

Tides in Clallam Bay are mixed semidiurnal. Unlike open water areas along the Pacific Northwest coastline, water velocity in the Strait of Juan de Fuca (SJDF) is not primarily driven by the M2 tidal constituent, which leads to differing phases for flood and ebb tide. That being said, a complete tidal velocity cycle is still approximately the same length as a lunar cycle (29 days). Forecast water level at Sekiu, WA from NOAA Station 9455760 (NOAA 1978), and modeled water speed from 16 km away in the SJDF at CMIST Station PUG1641 (NOAA 1995) are shown for 3 months in Spring 2025 in Figure 6.

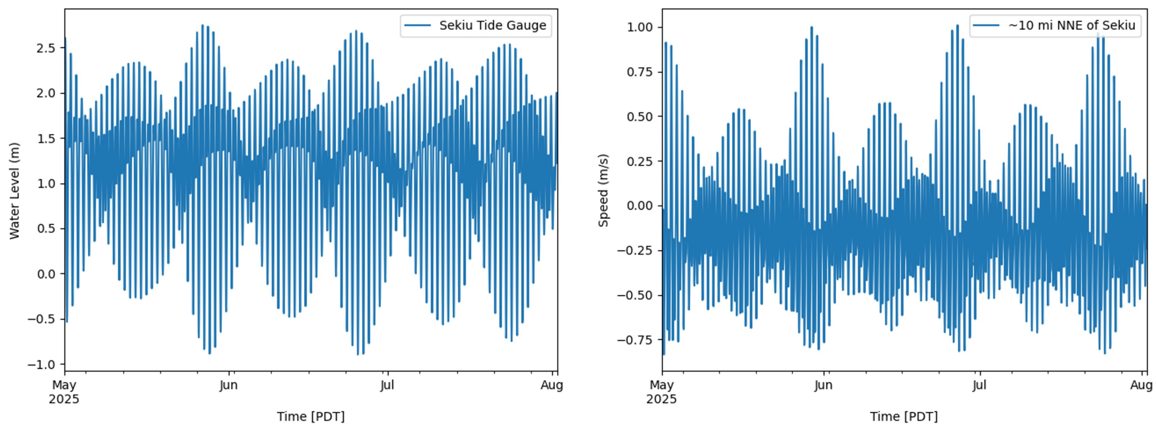

Figure 6. Predicted water level at Sekiu, WA (left) from NOAA Station 6455760 and water speed at CMIST Station PUG1641, located 16 km NNE of Sekiu in the Strait of Juan de Fuca (right), from May to July, 2025.

5.0 Vessel Surveys

The PNNL ADCP survey focused on the region where currents were expected to be strongest, the area viewed as the most viable for wave energy converter deployments, and where data would help create an understanding of the dunes seen in sonar imagery: a roughly 3.2 km x 1.6 km area where water depths range from 30 to 70 m depth. Figure 2 shows the planned transect lines, which are 1700 m long, 700 m apart and at an angle of 20 degrees from true North. Table 1 lists the lat/lon of each transect.

Table 1. GPS points of each survey transect

Transect	Start (Lat, Lon)	End (Lat, Lon)
1	(48.2700, -124.2930)	(48.2845, -124.2855)
2	(48.2679, -124.2840)	(48.2824, -124.2766)
3	(48.2659, -124.2752)	(48.2803, -124.2677)
4	(48.2638, -124.2663)	(48.2783, -124.2588)

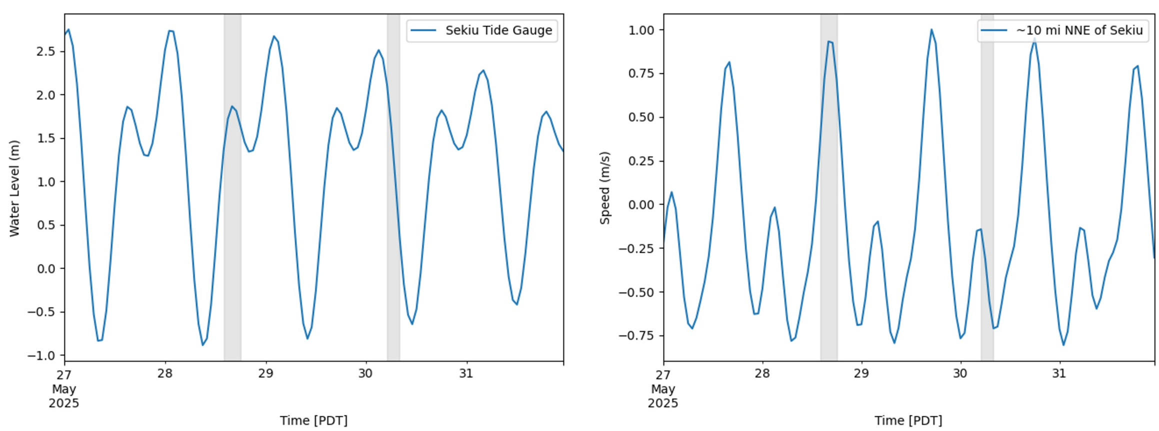

Figure 7. Predicted water level at Sekiu, WA (left) from NOAA Station 6455760 and water speed at CMIST Station PUG1641, located 10 miles NNE of Sekiu in the Strait of Juan de Fuca (right), during the week of the survey. Survey times are shaded.

A single survey set consisted of running 4 transects perpendicular to shore. Each 1.7 km transect took between 15-20 minutes to run at speeds of 3 - 5 kt and were conducted for a full ebb and flood tide. The flood tide survey was conducted on May 28, 2025 between 2 PM and 6 PM PDT, and the ebb tide survey was run on May 30, 2025 between 5:30 – 8 AM PDT. Winds averaged 15 kt from the WNW during the flood tide survey, with approximately 0.5 m wind seas with shorter, underlying gravity waves from the same direction. A squall on May 29th caused low visibility and strong waves during the next daytime tidal cycle, so the survey was called off that day. Weather on the 30th was better for surveying ebb tide: no wind with a westerly < 0.25 m, 10-second swell crossing the deeper region of the bay. Two sets of transects were completed during the strong flood tide, and a single set was completed for the weaker ebb tide. Transects were run west to east along the north-south transects shown in Figure 2, over the peak of each tidal cycle shown by the gray boxes in Figure 7.

6.0 Instrument Configuration and Mounting

One vessel-mounted ADCP was used during the survey, an RDI Workhorse Sentinel 300 kHz (WH300), with an Advanced Navigation Compass GNSS mounted above it. The ADCP and GPS were connected to a deck box running RDI vessel-mounted data acquisition software (VMDAS) to collect and stream GPS and water velocity data.

The ADCP was set to collect data at 0.5 Hz, a blanking distance of 2 m, and with a bin size of 3 m to reduce single-ping uncertainty. The maximum range was set to 30 bins, or 90 m below the transducers. The manufacturer-specified single-ping uncertainty was 5.4 cm. Configuration specifications for the ADCP are listed in Table 2.

Table 2. ADCP Specifications and Configuration

Location	**Manufacturer**	**Model**	**Sampling Rate [Hz]**	**Bin Size [m]**	**Blank Dist. [m]**	**Number of Bins**	**Ping Uncertainty [m/s]**
Vessel	Teledyne RDI	Workhorse 300 kHz	0.5	3	2	30	0.054

The ADCP was deployed below the surface via a mounting frame attached to R/V Desdemona's handrail near the stern of the vessel, where it is most stable. When fully submerged, the ADCP transducers were located 1 m below waterline, setting the center of the first depth bin at 6 m. The GPS mounted directly above the ADCP on the same pole and aligned with the long axis of the vessel. The frame as mounted to R/V Desdemona is shown in Figure 8. The GPS was configured to output GGA (position), VTG (speed), and HDT (heading) NMEA-0183 sentences at 2 Hz. A hotspot was set up to supply WiFi connection to the deck box, which allowed the GPS to connect to the satellite-based augmentation system (SBAS) network to get real-time satellite corrections. This manifested in a horizontal dilution of precision (HDOP) of 0.6. For UTC time synchronization, VMDAS records both UTC timestamps from the GPS and local timestamps from the computer. It records the difference in seconds between those timestamps for every ADCP ping.

Figure 8. ADCP and GPS mounted on the survey vessel, R/V Desdemona. Left: active surveying, Center: pole-mount in raised position at dock, Right: pole-mount rotated 90 degrees in transit position

7.0 Data Processing

Water velocity and GPS measurements recorded by the RDI software were processed, analyzed, and quality-controlled using MHKiT (Klise et al. 2024) and Tsdat (Levin et al. 2025). The ADCP timestamps were first synchronized to UTC time, as recorded by VMDAS, and then corrected using GPS-measured velocity and heading. To do the latter, the ADCP's coordinate frame must be rotated by a heading offset until it is aligned with the GPS heading. Upon setup, the GPS heading was manually aligned to the vessel's longitudinal axis, while the ADCP's heading was rotated to ideally 45 degrees, with two beams pointing forward and two aft. To verify and/or correct the ADCP heading offset, the recorded ADCP-to-GPS heading offset was manually adjusted until the measured water current direction was agnostic to the vessel's heading. If the heading offset is not corrected accurately, the resulting water direction will change depending on what direction the vessel is pointing.

Once the heading alignment and velocity correction was completed, the measured water velocity was filtered using a 1st order butterworth low-pass filter to remove excess motion caused by wave action and then bin-averaged into 15 second bins. This averaging resulted in bins that have a horizontal resolution of 50 m and a vertical resolution of 3 m. Water depth was found using the along-beam backscatter measurements, where the seafloor was apparent as the single strongest backscatter return. Any depth bins below water depth and those affected by sidelobe interference were removed. As a result, the depth bins representing the seafloor up to 6 – 9 m above the seafloor were removed.

8.0 Results

After averaging, the depth-averaged water velocity was used to compare the tidal current velocity and phase to the predictions from CMIST Station PUG1641 (NOAA 1995) located about 16 km to the NE. While the velocity magnitudes do not align, shifting the tide phase by about 40 minutes aligns the forecast peak currents with what was observed during the surveys. This method is not perfect, as it is known that the magnitude and phase of the harmonic constituents change along the length of the SJDF. Nonetheless, while velocity magnitude is not comparable, this phase-shifted tidal forecast could be used to generate an estimate of the peak tidal flow across the entire Bay. To do this, the predicted flood and ebb tide currents were normalized, with 0 corresponding to the previous and future slack and 1 corresponding to the local maxima/minima. The depth-averaged velocity was then multiplied by this normalized magnitude.

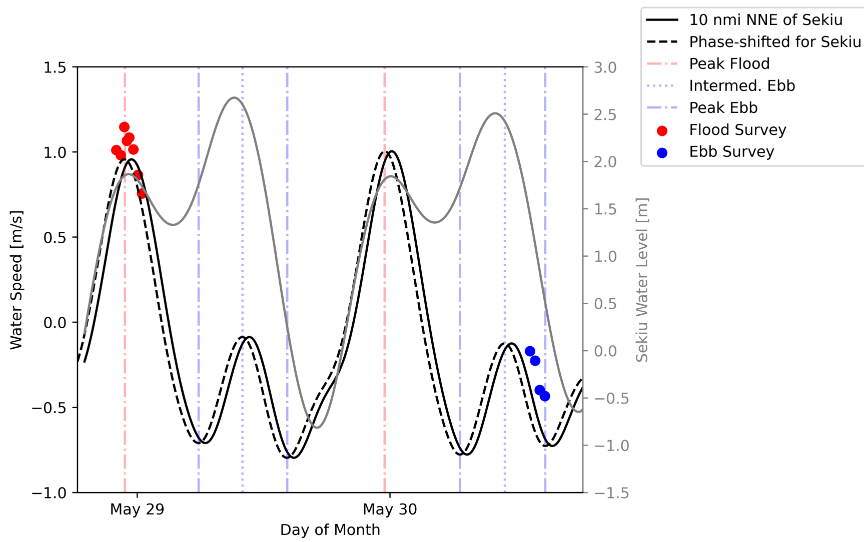

Figure 9. Water level and water speed forecasts compared to the depth- and time-averaged water speed measured from each survey transect. Predicted water levels from NOAA Station 6455760 are shown in gray, predicted water speed at CMIST Station PUG1641 is shown as a solid black line. The depth- and horizontal-averaged velocity for each survey are shown as a scatter. Flood tide is shaded red and ebb tide shaded blue. The dashed black line is the predicted water speed shifted to match the phase of the survey datapoints.

The forecast water level from the tide gauge in Sekiu, forecast water speed for the SJDF, and the phase-shifted water speed forecast are shown in Figure 9. Notice in Figure 9 that the peak water velocity does not align in time with the highest and lowest water levels. Flood tide currents are short and swift, while ebb tides are slower and longer lasting. Slack water is nearly nonexistent; rather, ebb tide currents increase and decrease in speed in a single cycle. This results in a flood tide that is a progressive wave and a double ebb tide that is approximately a standing wave.

Spatially, as can be seen in Figure 10, depth-averaged flood tide currents peak at 1.3 m/s and are nearly continuous across the survey area. The fastest currents occur at the western and eastern sides of the survey area, though it appears they slow 0.1-0.2 m/s across the center of it. This could be caused by the 1.3 m/s current from the west decelerating as it approaches the 50-70 m deep shelf. Momentum carried over the shallower shelf then spills across the eastern side of the bay into deeper water, accelerating back again to 1.3 m/s. While surveying the eastern side of the bay, measurements registered a 1.5 m/s gust in the upper 15 m of the water column, possibly due to turbulence and/or waves. Current direction ranged between 100-130 degrees from true north across the area during the survey period. It should also be noted that in estimating the peak tidal speed via the tidal phase correction, there is some discrepancy between the corrected depth-averaged water speed measured by the first and last survey transect conducted (the westernmost one in Figure 10). This may be due to water current shifting away from shore as flood tide slows down.

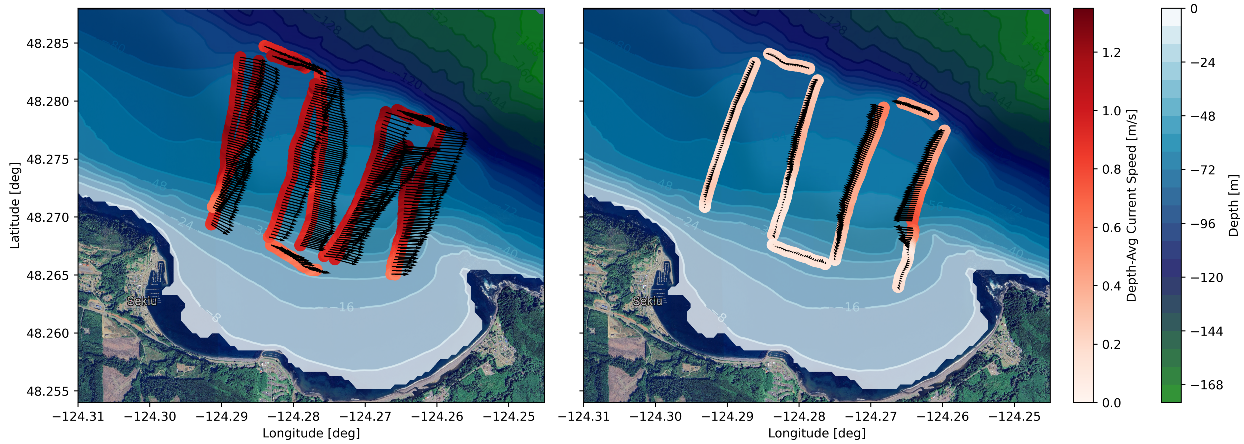

Figure 10. Depth-averaged water velocity during the flood tide survey (left) and the ebb tide survey (right).

Ebb tide is calm as compared to flood tidal currents, except around the eastern corner of Clallam Bay. The bathymetric promontory offshore of Slip Point generates a 0.9 m/s jet that dissipates across the bay, slowing to 0.3 m/s at the western side of the survey region. This jet generates lateral instabilities that circulate into the bay's shallower waters. Unlike flood, which exhibits a textbook bottom boundary layer profile, ebb current does not show a strong bottom shear and flows primarily in the upper 30-40 m of water, with recirculation zones at depth and near shore. From these observations, it can be deduced that the weak ebb current is likely what allows the dunes to grow to such large sizes in the western region of the survey area. The jet created by the promontory erodes away any dunes that would be created on the eastern side.

Profiles from each of the survey transects are shown in the Appendix, depicting velocity in East-North coordinates and as magnitude and direction. These profiles provide a snapshot of the water current at a particular point in time and have not been corrected for tidal phase.

9.0 Discussion and Conclusions

The presence of a strong flood current (up to 1.3 m/s during this survey) complicates the design of floating platforms in Clallam Bay, as these platforms must have enough buoyancy to counter the drag exerted on mooring systems, while the mooring system itself must be designed with enough compliance to not compromise platform stability in rough seas. Though measurements were not conducted at depths shallower than 25 m (to focus on spatially characterizing the strongest currents), the area within the bay itself (that shallower than 30 m) is sheltered from ebb tide currents but not from flood currents, judging by the 1 m tall dunes that exist in the inner bay. The size, and thereby buoyancy, of a platform will dictate the depth at which it can be moored. Smaller platforms will likely need to be deployed in the region between 15 and 30 m water depth. This area is out of the general traffic area, deep enough to be beyond the kelp beds that hug the coastline, and still exposed to waves traveling down the SJDF. The dune bedforms apparent in this region could be an issue for bottom-deployed instrumentation, and platforms should be designed to mitigate scour. The area around Slip Point, marked with an aid to navigation USGC hazard buoy, should be avoided for boating safety. Dune bedforms on the shelf occur between 50 and 60 m depths but are not seen east of the 3rd transect line. Bedforms do not appear to exist in water deeper than 60 m, though the sidescan-sonar loses resolution with depth. Given the available space, it should be possible to avoid deploying on or near these dunes. Bottom-deployed instrumentation here will also need to account for high current drag and sediment transport.

The SJDF has a complicated tidal regime that results in strong flood tides and a double ebb near the Pacific. While more challenging than an area that lacks a tidal current altogether (e.g. PacWave), Clallam Bay could prove to be a rigorous testing ground for wave energy converters - or even offshore wind - mooring systems. Water currents that reach 1.0 m/s are not uncommon around U.S. coastlines, and research into mooring systems has not been a priority in the marine energy industry.

Spatially characterizing the water currents in and outside of Clallam Bay is critically important from an engineering perspective for future deployments of marine energy converters and informed by this LDRD project. The ADCP data collected by PNNL, combined with the side-scan imagery and bathymetric data, provide insights into the best locations to deploy equipment and an upper limit to how much current drag systems will need to be designed for.

10.0 Future Work

The next steps involve planning deployments to characterize the long-term environmental trends in Clallam Bay. This includes choosing locations to deploy an upward looking bottom mounted ADCP, hydrophone, and a surface wave measurement buoy. The ADCP will have an ideal deployment length of two months, while the hydrophone and wave buoy will have ideal deployment lengths of 1 year. The preferred location for the ADCP is the location with the strongest current during both tides, which based on the vessel survey is somewhere between the 3rd and 4th transects. The best location for the hydrophone is somewhere with the slowest flow speeds and deeper water to avoid flow noise and increase low-frequency capture, as well as near to where WEC devices are most likely to be deployed. Given the strength of flood tide, we'll need to rely on the bottom boundary layer for the slowest flow speeds. In this way, we'll want to avoid steep slopes, where the boundary layer will be the thinnest, and avoid swift currents during ebb tide. The wave buoy, a Sofar Spotter, has minimal buoyancy, so it will benefit from a shallower water depth (a physically shorter mooring line has less drag than a longer line) and avoiding fast current speeds. At the same time, it still needs to be exposed to wave action. Figure 11 displays the potential planned locations for each of these instrument deployments in Clallam Bay.

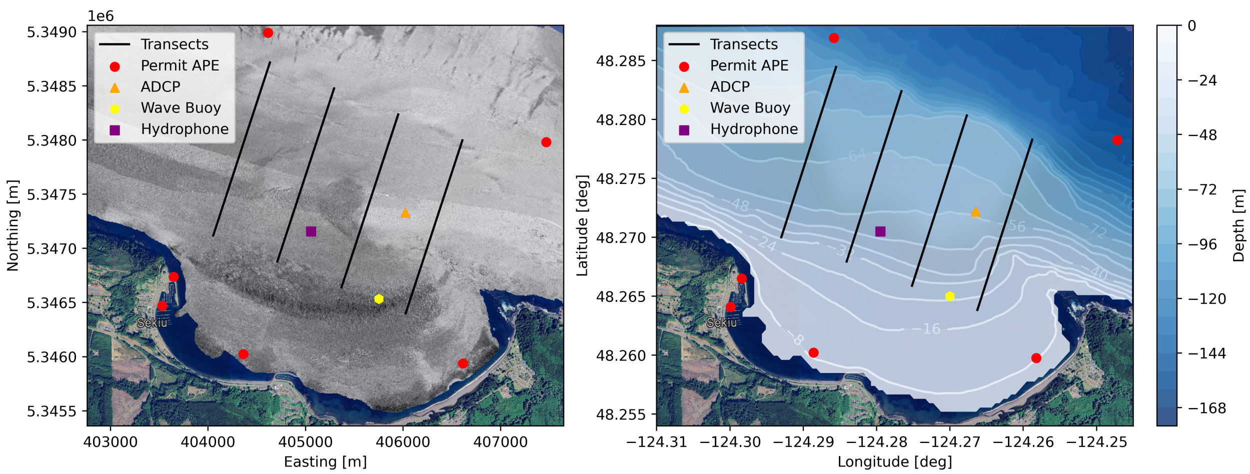

Figure 11. Updated survey map with possible locations of long-term instrumentation. Backscatter is shown on the left and water depth is shown on the right. Black lines are the planned survey transects, and red scatter outlines the proposed PNNL permitted area. The proposed locations for the ADCP, wave buoy, and hydrophone are shown by the orange, yellow and purple points on each subplot.

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Appendix A – Velocity Profiles (East and North)

This section displays water velocity (East and North vectors) and speed/direction profiles for each transect. Each row of the following Figures displays Transect #1 (westernmost) to #4 (easternmost) from top to bottom. The leftmost column shows bathymetry contours, the planned transects in gray and black, and the actual vessel track in a black dash-dotted line. The center-left column displays the water level as forecast by the Sekiu tide gauge station, with a gray line showing the point in the tidal cycle that the transect was taken. The right column displays the transects using water depth vs Latitude. The seafloor is shown in the right column as a gray line.

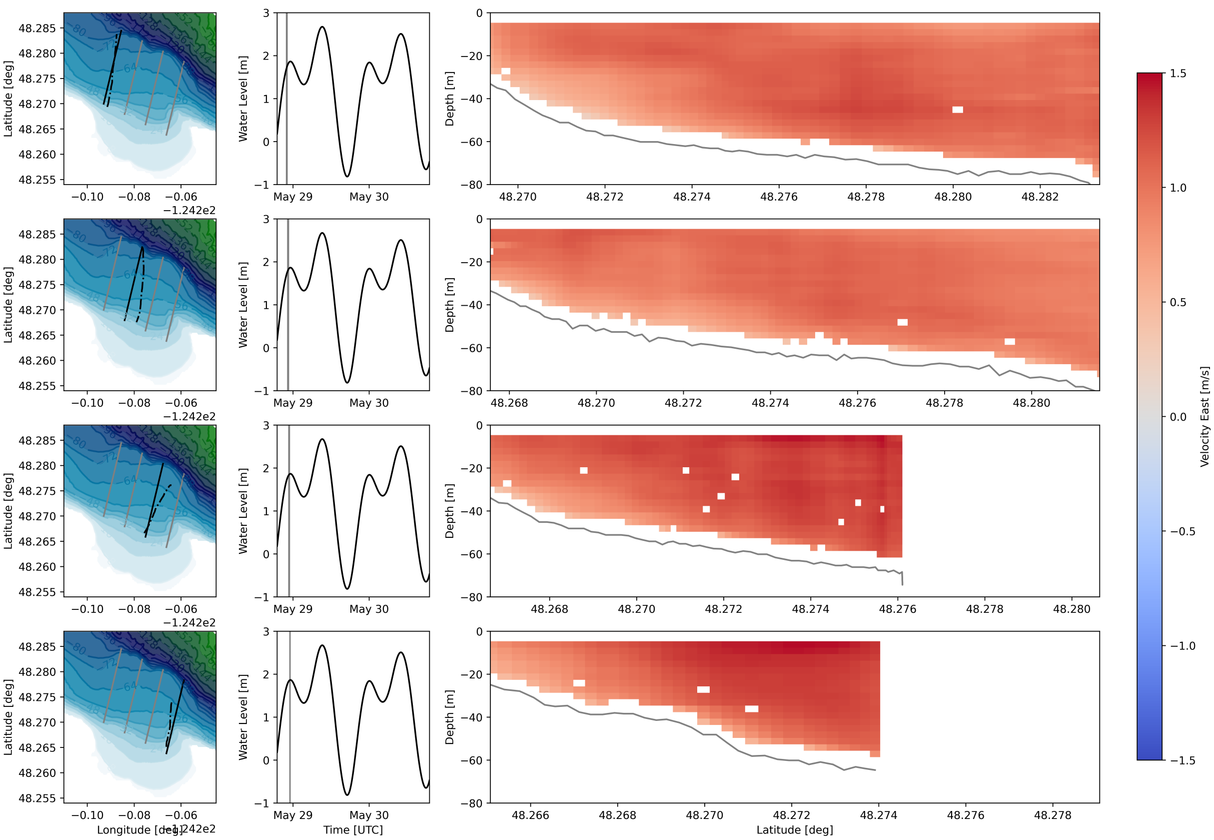

Figure A.1. Velocity East, Flood Tide Survey

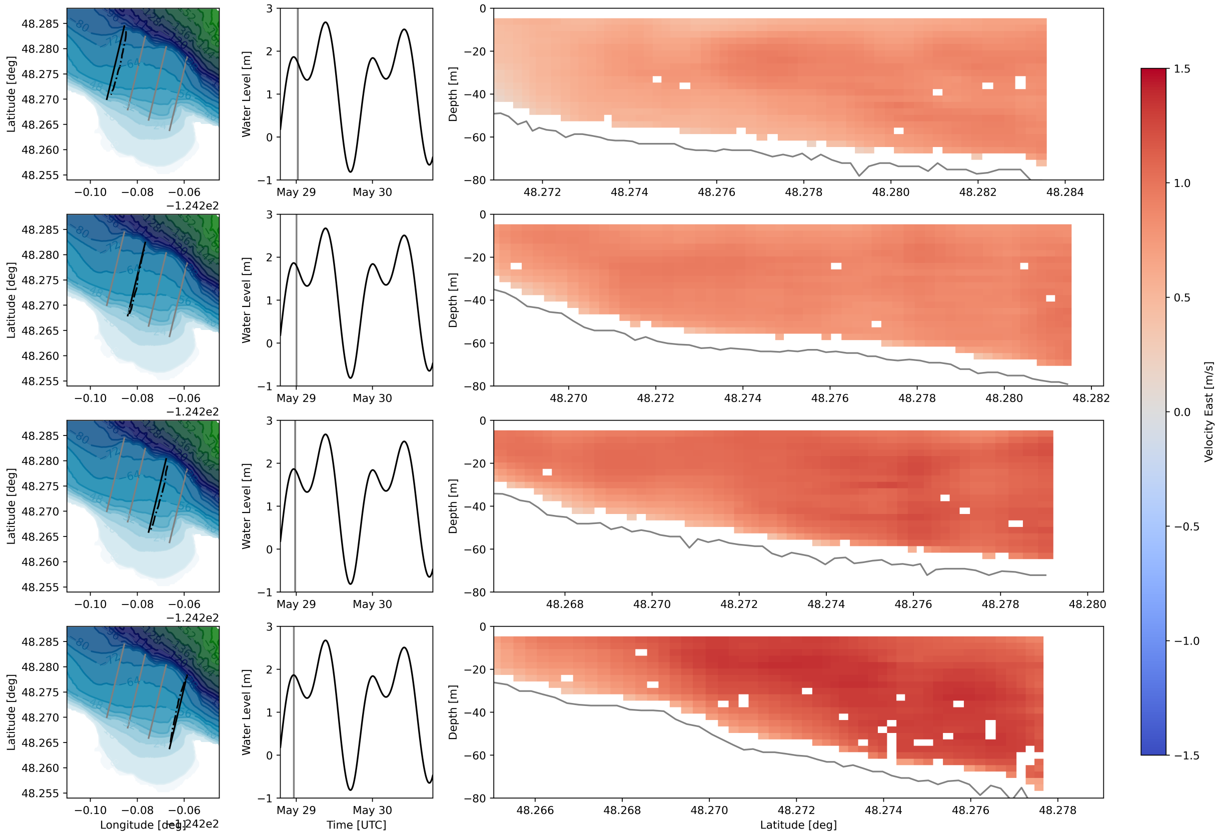

Figure A.2. Velocity East, Flood Tide Survey

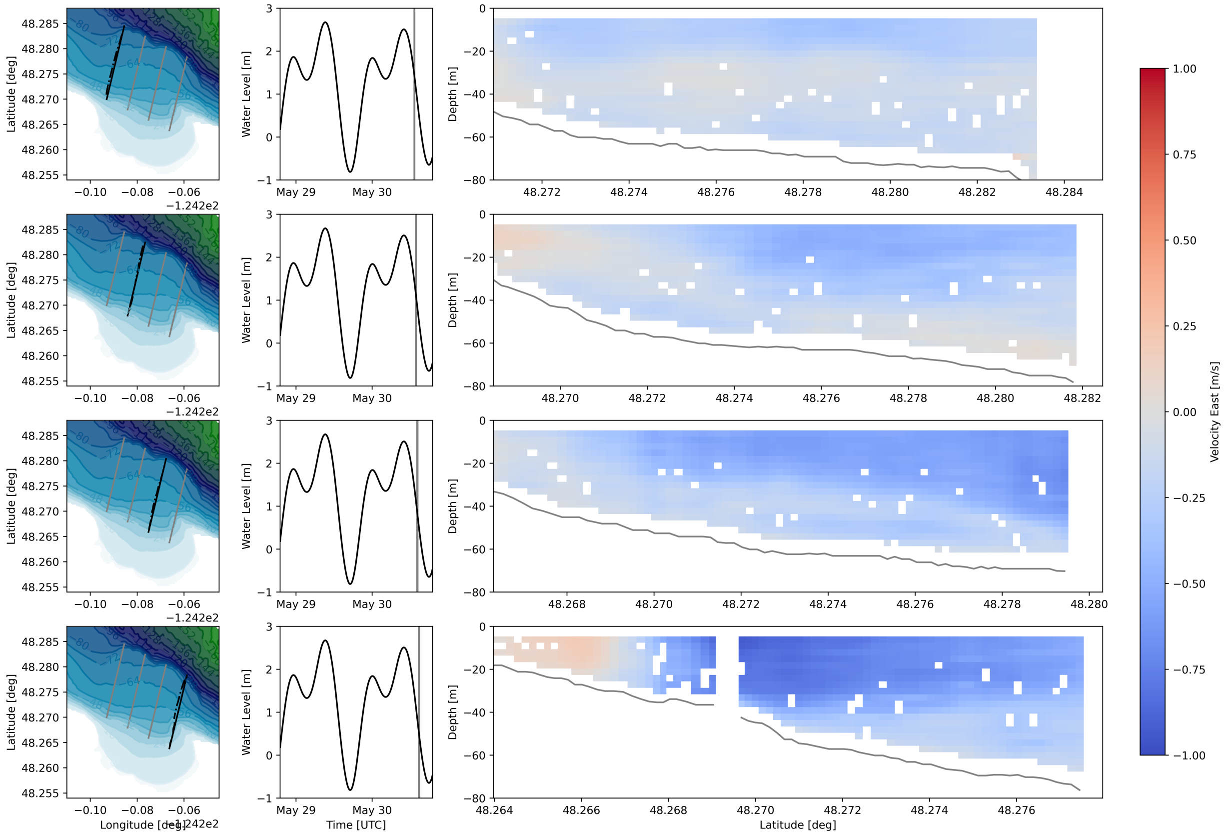

Figure A.3. Velocity East, Ebb Tide Survey

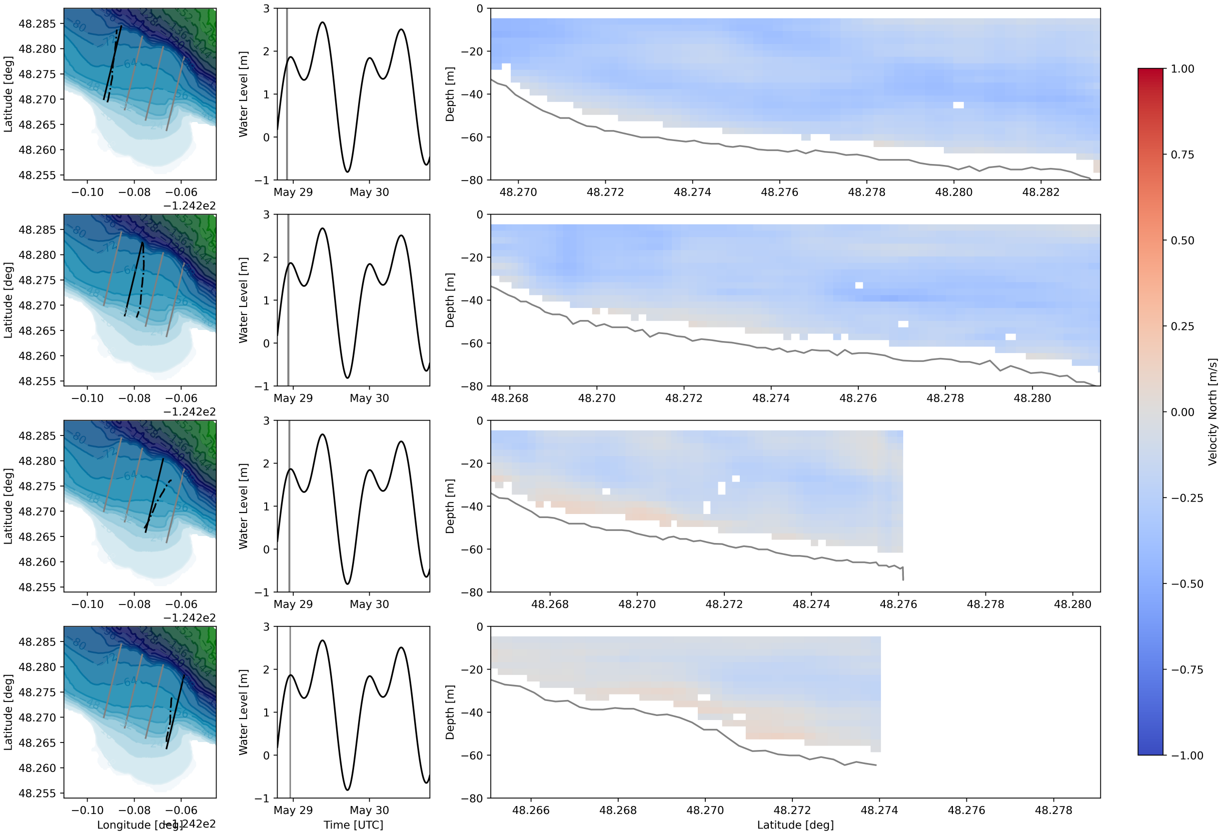

Figure A.4. Velocity North, Flood Tide Survey

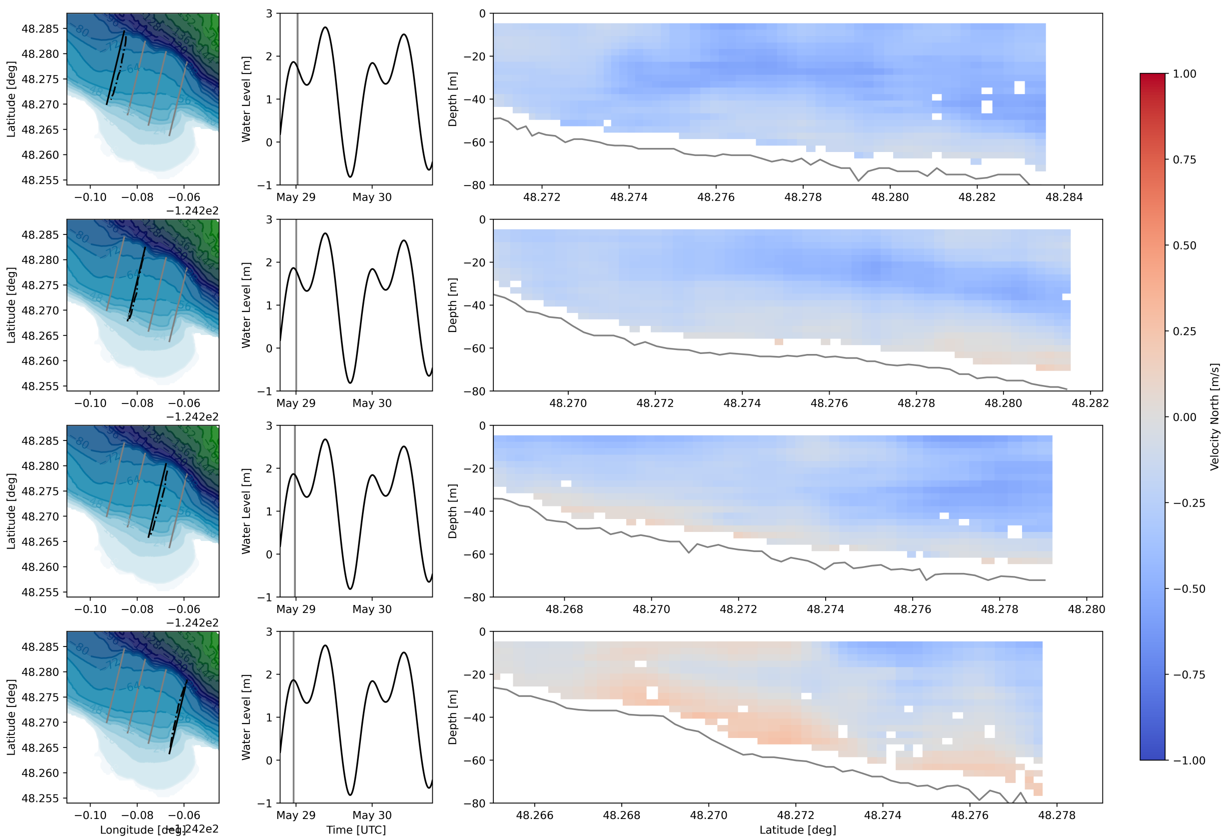

Figure A.5. Velocity North, Flood Tide Survey

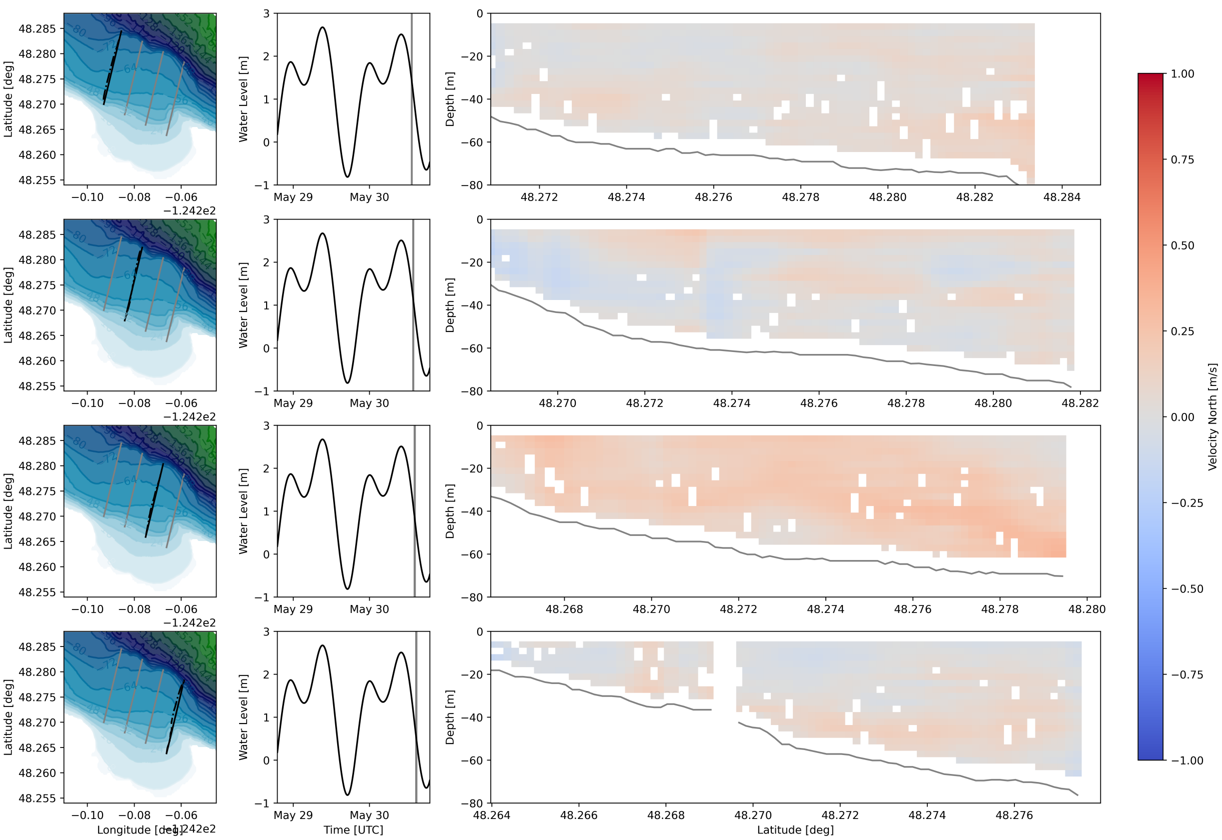

Figure A.6. Velocity North, Ebb Tide Survey

Appendix B – Velocity Profiles (Speed and Direction)

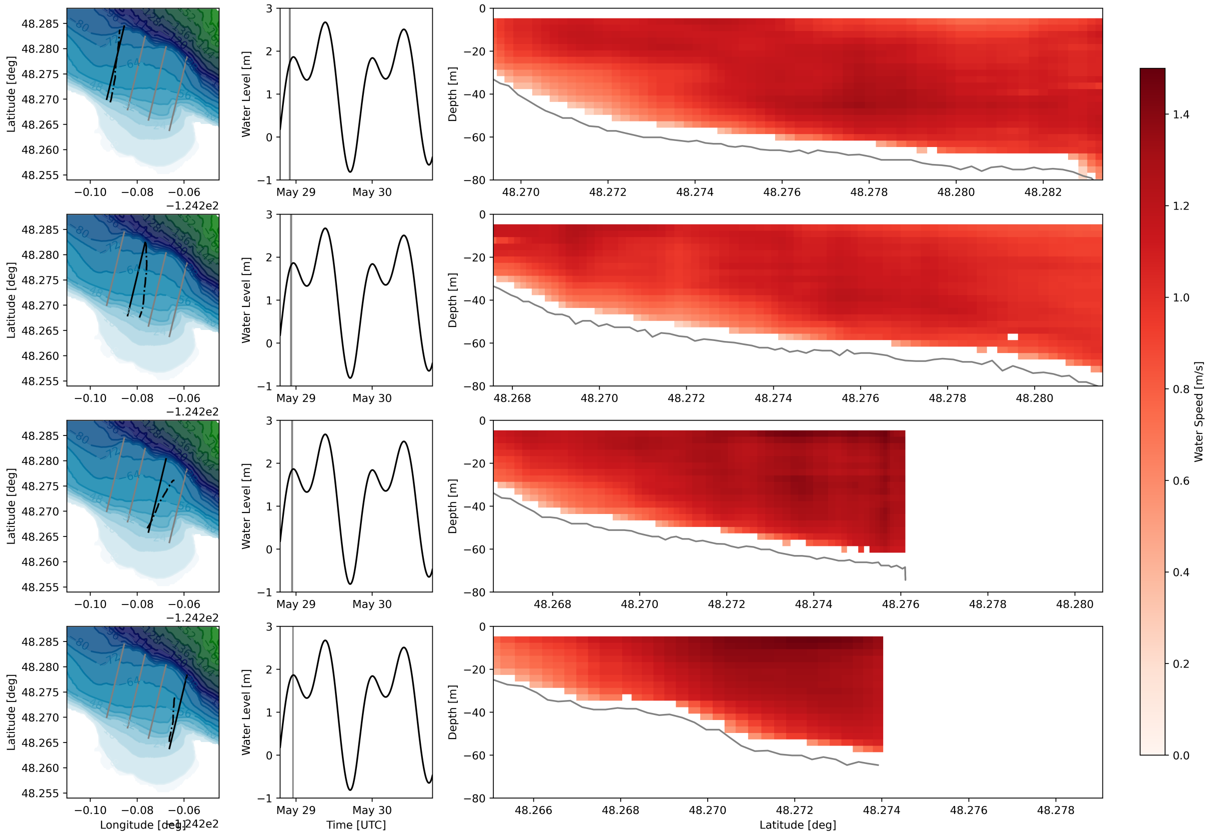

Figure B.7. Water Speed, Flood Tide Survey

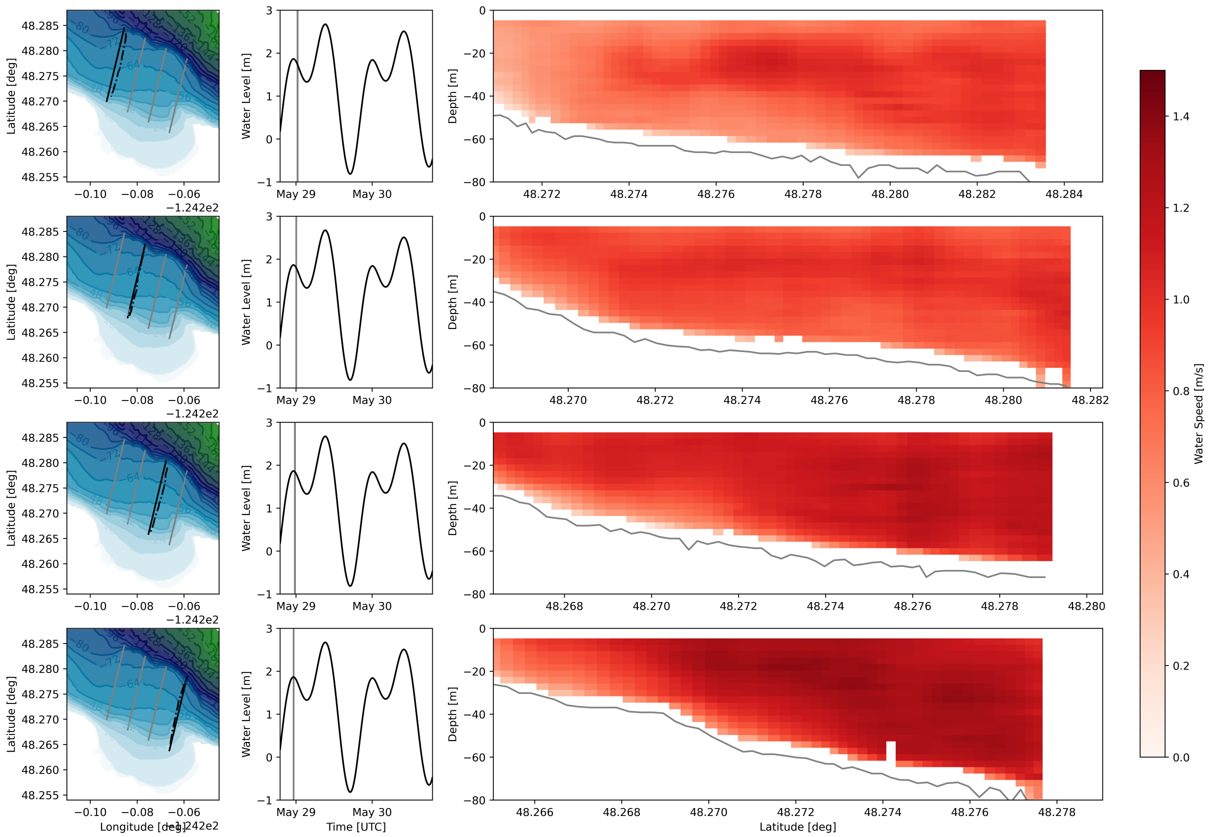

Figure B.8. Water Speed, Flood Tide Survey

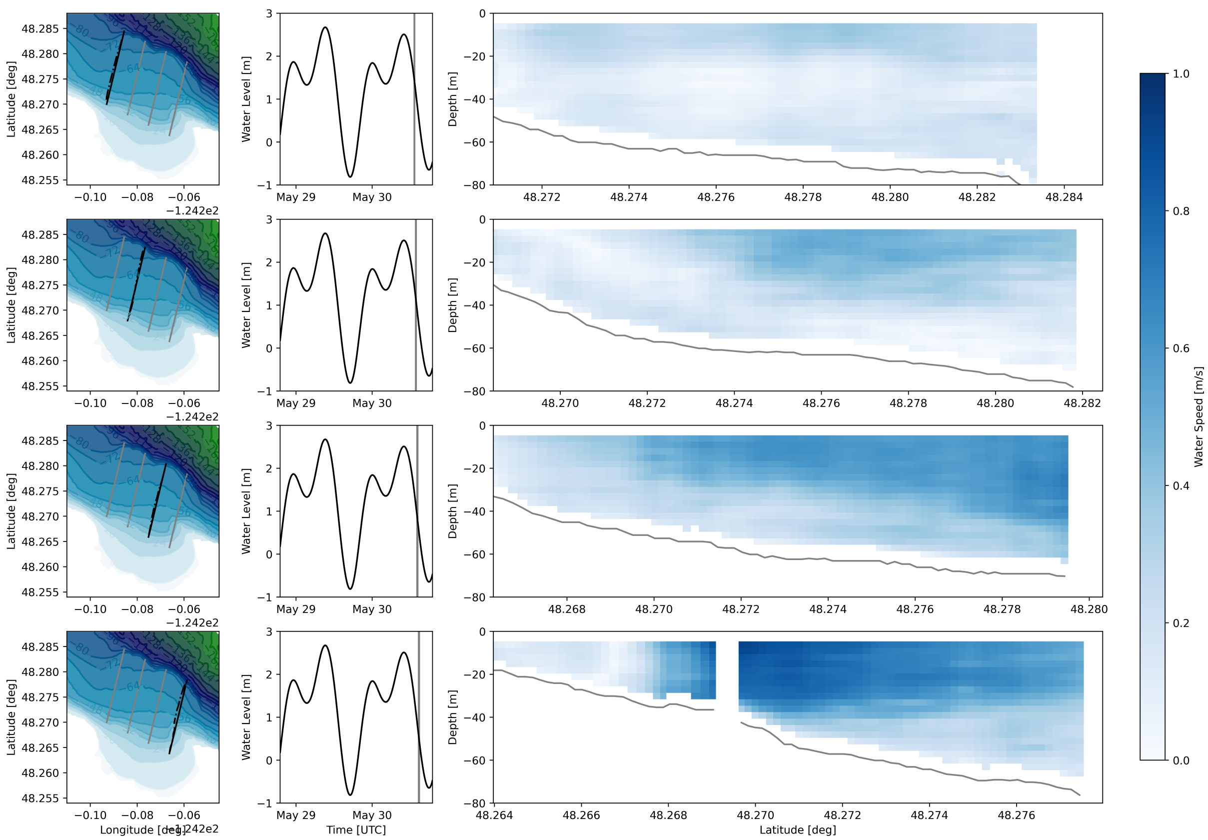

Figure B.9. Water Speed, Ebb Tide Survey

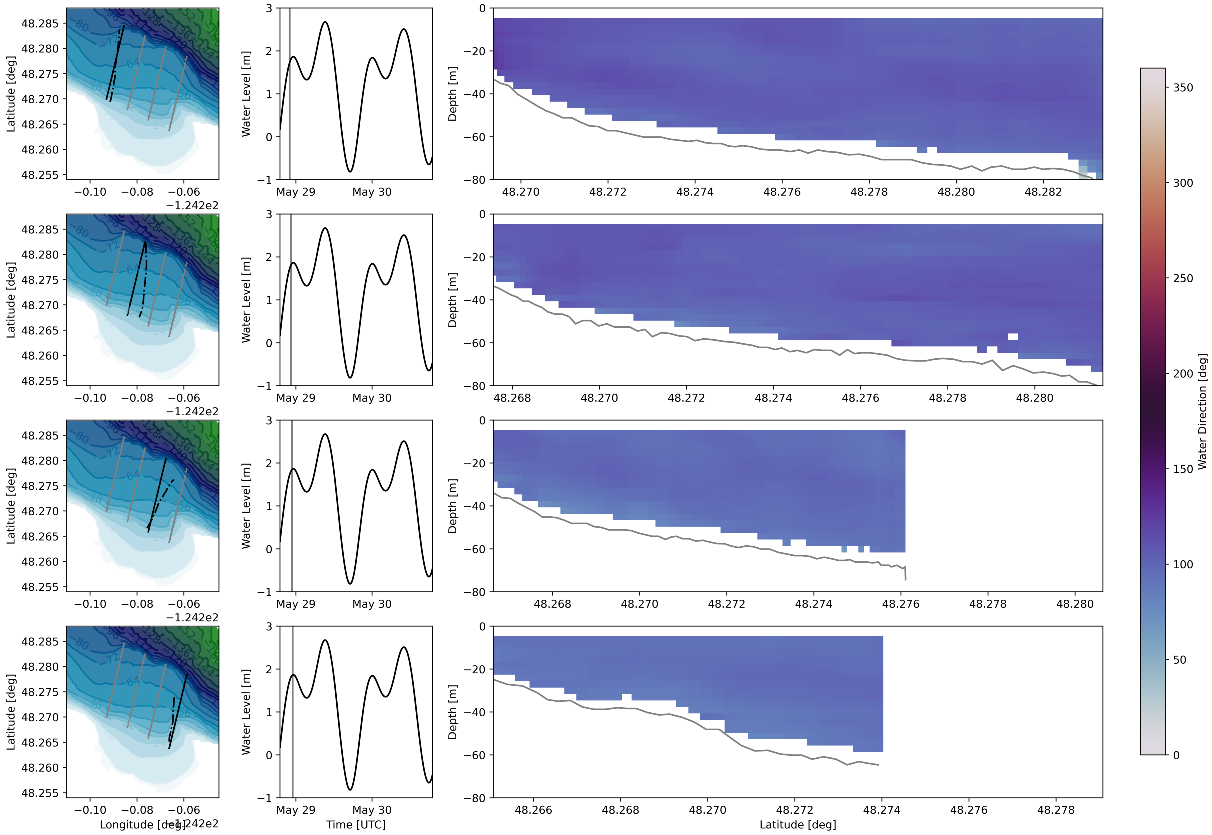

Figure B.10. Water Direction, Flood Tide Survey

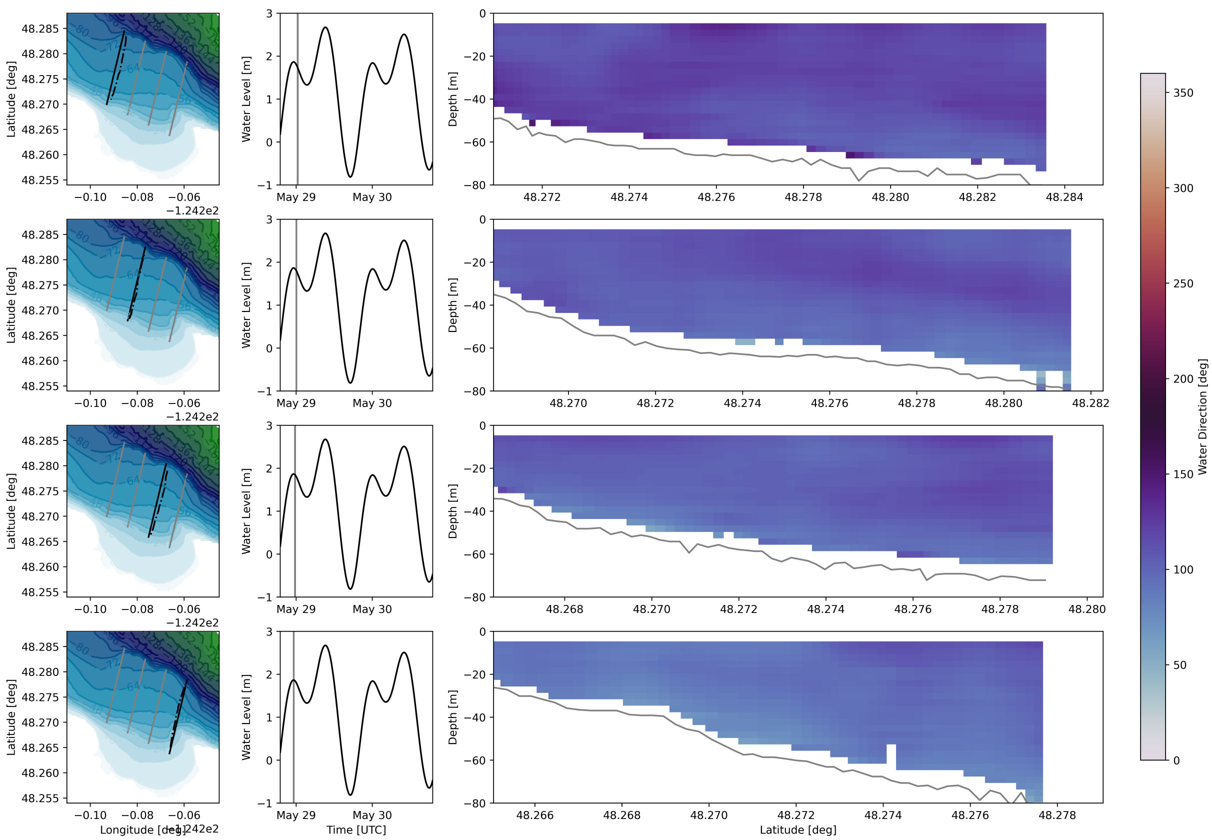

Figure B.11. Water Direction, Flood Tide Survey

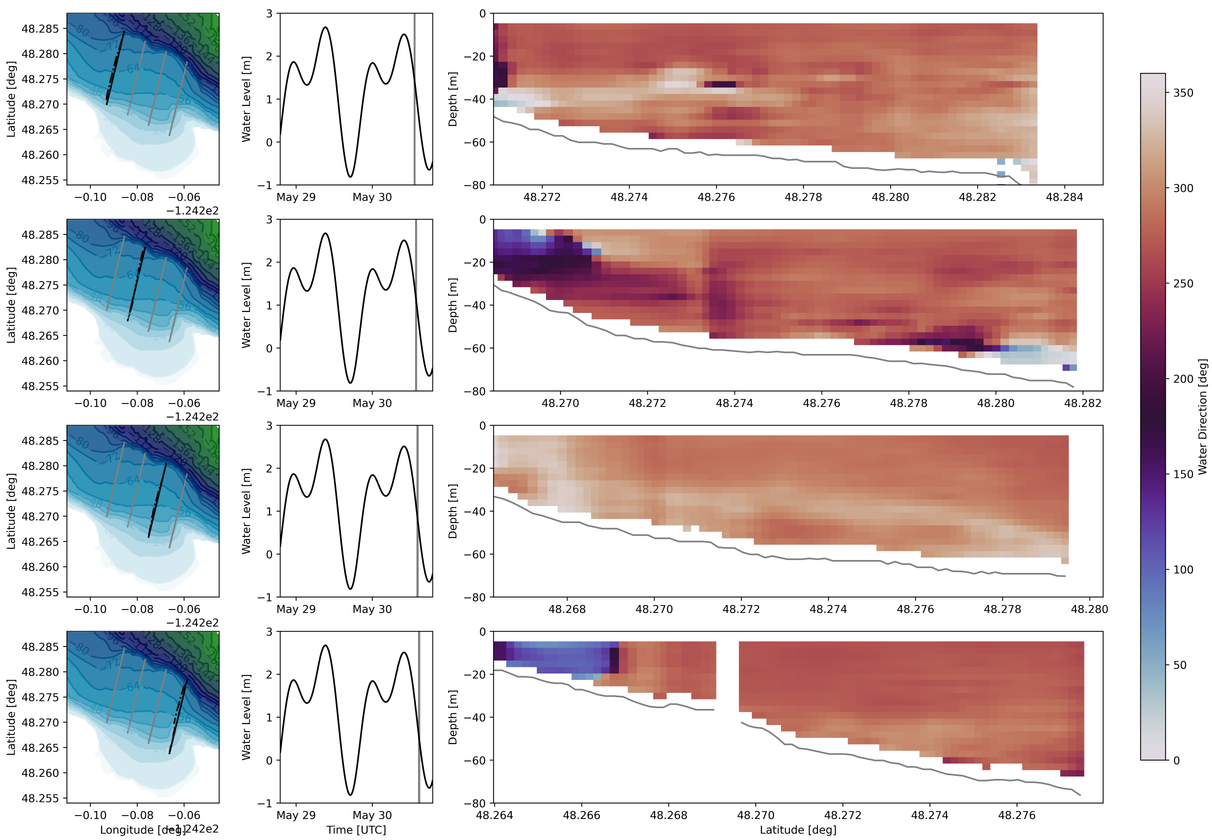

Figure B.12. Water Direction, Ebb Tide Survey

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