U.S. DEPARTMENT OF COMMERCE

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION
NATIONAL OCEAN SERVICE

HORIZONTAL AND VERTICAL CONTROL REPORT

Type of Survey Navigable Area

Project No. OPR-P377-KR-18

Time Frame June – July 2018

LOCALITY

State Alaska

General Locality Aleutian Islands

2018

CHIEF OF PARTY

ANDREW ORTHMANN

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DATE

Horizontal and Vertical Control Report

OPR-P377-KR-18

Southwest Alaska Peninsula

January 11th, 2019

GPS Buoy Kayak in Dora Harbor

Project Name:	***Southwest Alaska Peninsula***
General Locality:	***Southwest Alaska Peninsula***
Sub Localities:	***H13112 – Unimak Bight Channel*** ***H13113 – Otter Cove*** ***H13114 – Northwest of Sanak Island*** ***H13115 – Main Channel Extension*** ***H13116 – Ikatan Bay (and Pankof Breaker)***
Vessel(s):	***R/V Qualifier 105 and ASV C-Worker 5***
Field Unit:	***TerraSond Limited***
Lead Hydrographer:	***Andrew Orthmann***

A. Vertical Control

Mean lower low water (MLLW) was the vertical control datum for this survey. All soundings are referenced to MLLW.

All time measurements were made in Universal Time Coordinated (UTC). The local time zone was offset from UTC by eight hours (Alaska Daylight Time = UTC – 8 hours). No measurements were made using local time.

A.1. Tide Corrector Stations

The Tides Statement of Work did not specify installation of subordinate tide stations. However, zoning stations were installed for quality control purposes.

Tide Station (AK)	Station No.	Latitude (NAD83)	Longitude (NAD83)	Julian Days of Operation (2018)	Configuration
Cape Lutke	N/A	54-34-24.878 N	164-13-22.286 W	163 - 196	2 BMPGs
Dora Harbor	N/A	54-42-19.206 N	163-15-11.365 W	168 - 202	1 BMPG + GPS buoy
Ikatan Bay	N/A	54-49-24.925 N	163-17-10.852 W	165 - 203	1 BMPG + GPS buoy

Table 1 – Zoning / QC stations

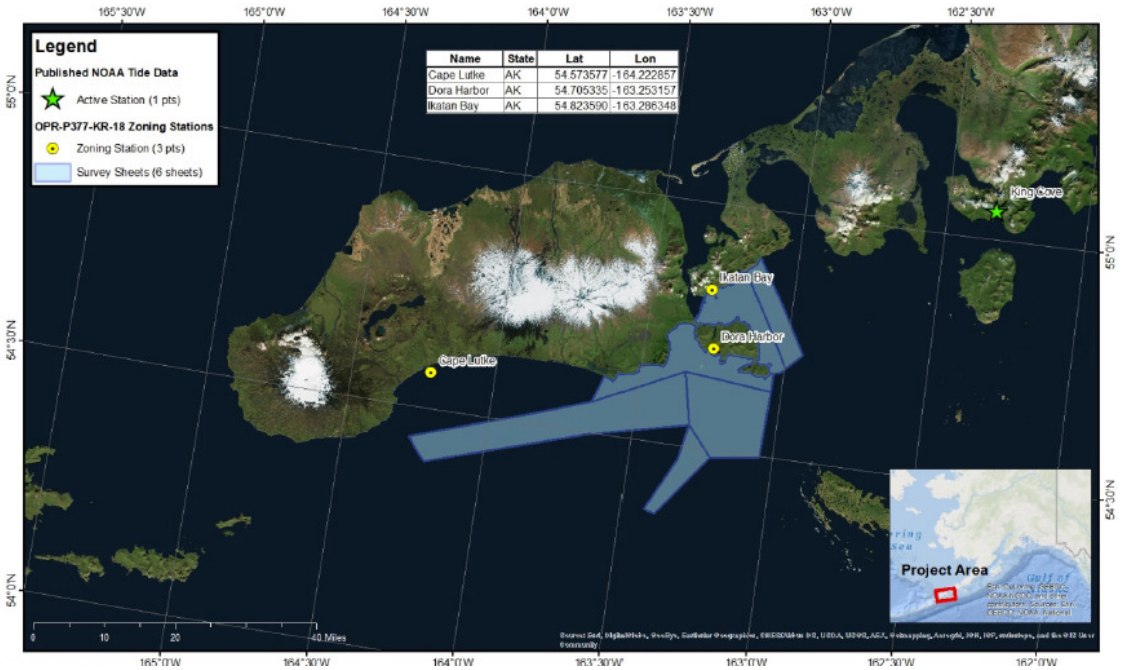


Figure 1 – Project overview including tide station locations (from JOA tide report).

TerraSond contracted JOA Surveys, LLC (JOA) for tide support. JOA's duties included processing of tide data, datum computations, providing smoothed/verified final tides, derivation of tide zones, and tide report compilation. TerraSond provided calibrated tide equipment, installed the tide station, and processed associated GPS data for QC purposes.

The NWLON stations at King Cove (9459881) served as datum control.

A.2. Tide Equipment

Dora Harbor

The Dora Harbor tide station was deployed as a single bottom mounted pressure gauge (BMPG). A custom-built GPS buoy was deployed above the mooring for QC purposes as well.

A custom-built aluminum mooring was used to house the seafloor equipment. After securing sensors in the mooring, the mooring was loaded with approximately 500 lbs of weight (sand-filled burlap bags) and gently lowered to the seafloor at the deployment site.

Seafloor equipment on the BMPG mooring consisted of a Seabird SBE26 Plus Wave & Tide Recorder and a Seabird SBE37SMP Conductivity and Temperature sensor.

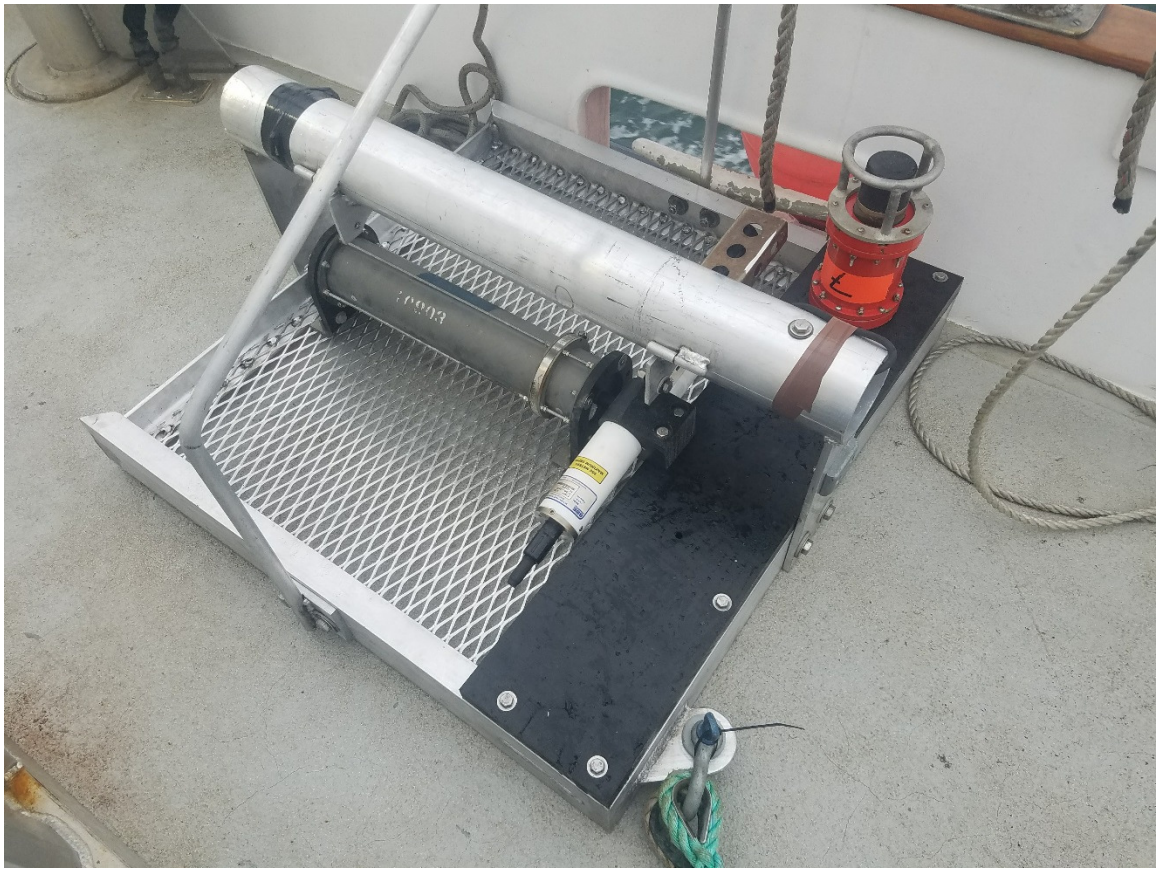


Figure 2 – BMPG mooring prior to deployment.

The BMPG mooring was deployed with a surface buoy for later retrieval. A GPS buoy was secured to the surface buoy.

The GPS buoy consisted of a repurposed river kayak, 12V deep-cycle batteries, and solar panels. A Trimble 5700 with Zephyr dual-frequency antenna was used to log kinematic GPS data at a rate of 1 Hz to a Compact Flash card. ARP height to the water level was noted at deployment, mid-project, and upon retrieval. GPS data was post-processed in Applanix POSGNSS software using the project base station on the Ikatan Peninsula.

Figure 3 – GPS buoy kayak in Dora Harbor

Both tide data and GPS data logged at the site were continuous and of good quality.

Ikatan Bay

The Ikatan Bay tide station was deployed as a single bottom mounted pressure gauge (BMPG) and Seabird C/T logger on a heavy anchor. A GPS buoy, provided by JOA Surveys, was configured as the surface buoy.

Figure 4 Ikatan Bay tide equipment prior to deployment: BMPG mooring and JOA GPS buoy

The GPS buoy was powered by 12V deep-cycle batteries. A Trimble 5700 with Zephyr dual-frequency antenna was used to log kinematic GPS data at a rate of 1 Hz to a Compact Flash card. ARP height to the water level was noted at deployment and upon retrieval. GPS data was post-processed in Applanix POSGNSS software using the nearby project base station on the Ikatan Peninsula.

Cape Lutke

Cape Lutke (not pictured) consisted of two moorings spaced approximately 1 km apart. Each had a weight of about 800 lbs. and held a Seabird SBE plus tide gauge and C/T loggers. No GPS buoy was deployed at this site due to its wide open and exposed nature.

A.3. Tide Correctors

Preliminary tidal corrections in the field were completed using discrete tide zones provided by NOAA, based off the NWLON station in King Cove. This was provided by NOAA as a Zone Definition format file (ZDF), with the filename P377KR2018_REVISED.zdf.

Final tidal corrections used the "Not So Poor Man's VDatum Grid" (NSPMVD) NAD83 to MLLW separation grid (CARIS CSAR format) provided by NOAA, OPR-P377-KR-18_NSPMVD_EPSG6332_NAD83-MLLW_Revised, issued August 6th, 2018. The provided vertical uncertainty for this model was 0.098 m. This correction file is supplied with the survey deliverables.

A.4. Tide Comparisons

For comparison purposes, an Ellipsoid Referenced Zoned Tide (ERZT) model was computed for each survey using the NOAA-provided tide zones (P377KR2018_REVISED). This separation model was created at a 100 m resolution in CARIS CSAR format. An 8 m resolution surface was made from the ERZT data set and differenced from an 8 m resolution surface created from the primary NSPMVD-corrected data set.

Similarly, for each survey, a copy of the data set was corrected to MLLW using the provided ZDF file (P377KR2018_REVISED) and King Cove verified tide data. An 8 m resolution surface was made from the tide zone-corrected data set and differenced from an 8 m resolution surface created from the primary NSPMVD-corrected data set.

NOAA's "Gridded Surface Comparison Utility" (v18.4) was used to difference the surfaces and generate statistics, which are summarized in the following table.

Survey	Surfaces (Surface 1 minus Surface 2)	Mean Difference*	StDev
H13112	NSPMVD vs ERZT	-0.02	0.10
	NSPMVD vs Tide Zones	-0.02	0.10
H13113	NSPMVD vs ERZT	-0.01	0.10
	NSPMVD vs Tide Zones	-0.01	0.11
H13114	NSPMVD vs ERZT	-0.03	0.09
	NSPMVD vs Tide Zones	-0.03	0.10
H13115	NSPMVD vs ERZT	0.01	0.09
	NSPMVD vs Tide Zones	0.01	0.08
H13116	NSPMVD vs ERZT	-0.07	0.08
	NSPMVD vs Tide Zones	-0.07	0.09
* A negative difference means that the NSPMVD-corrected set (used for final deliverables) was shoaler than the comparison data set, while a positive difference means that the NSPMVD-corrected set was deeper than the comparison data set.			

Table 2 – Tide Comparison Results

In general, the NSPMVD-corrected data sets are slightly shoaler than the data sets corrected with the alternative methods, ranging from 1 cm for H13113 to 7 cm for H13116. H13115 is the only survey with a positive bias, being 1 cm deeper.

H13116 shows the largest bias at -0.07 m. This may be due to H13116 having a more complex tidal regime than the other surveys due to its location near False Pass at the confluence of the Pacific Ocean and Bering Sea.

However, agreement is excellent between all three methods of tidal reduction. Over 99.5% of grid cells compare within allowable TVU, regardless of the method of tidal reduction.

Refer to Appendix I for JOA's analysis of the tidal data as well as the tide comparisons for each survey. The NSPMVD grid is available with the project deliverables.

B. Horizontal Control

The horizontal control datum used for this survey was NAD83 (2011). All final positions are NAD83 (2011).

Vessel positions were post-processed. Corrections for post-processing were supplied primarily by the Trimble PPRTX service in Applanix POSPac post-processing software, supplemented by Applanix Smart Base (ASB) network solutions when necessary. CORS station AB06 in False Pass, Alaska, was utilized in post-processing for ASB and occasionally SingleBase solutions.

Published positions for AB07 (as well as the other CORS stations in the ASB network) were used for CORS base station position.

Station ID	Name	Monument	Type	Position (NAD83)	Julian Days of Operation (2018)
AB06	False Pass PID=DM7469	FALSEPASS_AK 2005	PPK	ARP: 54-53-07.16838 N 163-25-24.36354 W Height: 499.746 m	Continuous

Table 3 – CORS station used for this project.

One project GPS base station, consisting of a Trimble 5700 receiver coupled with a dual-frequency Trimble Zephyr Geodetic antenna, was installed on the Ikatan Peninsula. The site was powered by two 100-watt solar panels and logged at 1 Hz to a Compact Flash memory card. The data logged at the project base station was utilized only to post-process the GPS buoy data logged on the project.

The project base station position was established by upload of the initial 24-hour data set to NOAA NGS Online Positioning User Service (OPUS). Comparisons were made at least once each week by upload of an additional 24-hour data set to OPUS. The results were entered into a base station position confidence check logsheet, included in *Appendix II*. Subsequent results were excellent with a peak difference of 0.017 m vertically and 0.011 m horizontally of the initial position.

Station ID	Name	Monument	Type	Position (NAD83)	Julian Days of Operation (2018)
5240	Ikatan Peninsula	TBM	PPK	54-45-02.73460 N 163-19-37.53937 W Height: 21.611 m	164 - 203

Table 3 – Base stations installed for this project.

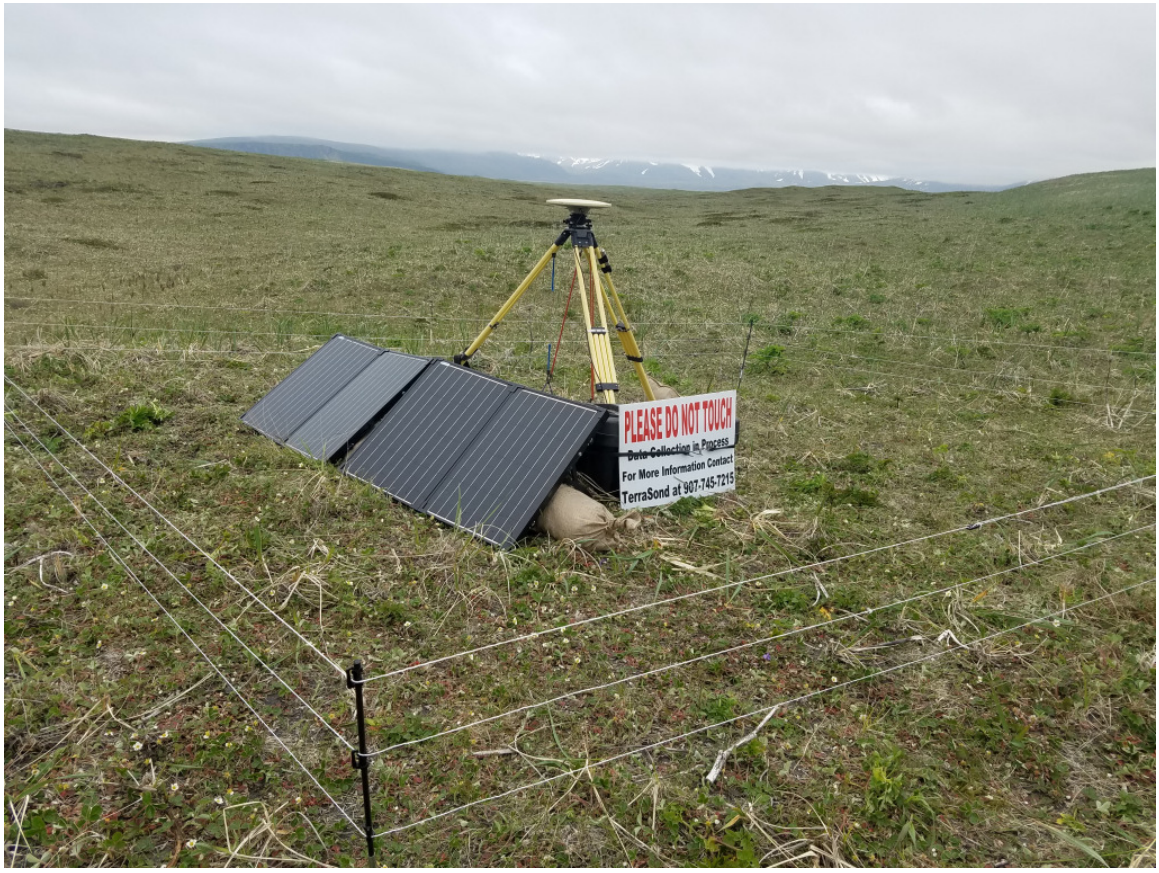


Figure 5 – Project GPS base station on the Ikatan Peninsula

The project base station performed well in general, with no major outages. However, for unknown reasons, logging was found to have ceased every day at 23:34 UTC only to resume at 00:00 UTC, resulting in no base data for the last 26 minutes of each Julian day. Since the station was used only for post-processing buoy data and QC purposes this did not have an adverse effect on survey data.

Real-time positions were FAA WAAS-based. These were replaced with PPK GPS positions in processing. Rare exceptions are noted in the applicable DR.

Refer to the DAPR for additional details on positioning results and methodology.

Base station positioning confidence checks with OPUS reports can be found in *Appendix II*. Correspondence relating to tides and confidence checks on vessel positioning are

available with the project DR's. Post-processed positioning data and error estimates are available with the survey deliverables.

APPROVAL SHEET

For

Horizontal and Vertical Control Report: H13112 through H13116

This report and the accompanying digital data are respectfully submitted.

Field operations contributing to the completion of this project were conducted under my direct supervision with frequent personal checks of progress and adequacy. This report, digital data, and accompanying records have been closely reviewed and are considered complete and adequate per the Statement of Work and Project Work Instructions. Other reports submitted with this survey include the Descriptive Report (one for each survey sheet) and the Data Acquisition and Processing Report.

This survey is complete and adequate for its intended purpose.

Andrew Orthmann

Digitally signed by Andrew Orthmann
Date: 2019.01.11 14:37:31 -09'00'

Andrew Orthmann
NSPS/THSOA Certified Hydrographer (2005), Certificate No. 225
Charting Program Manager
TerraSond Limited

APPENDIX I

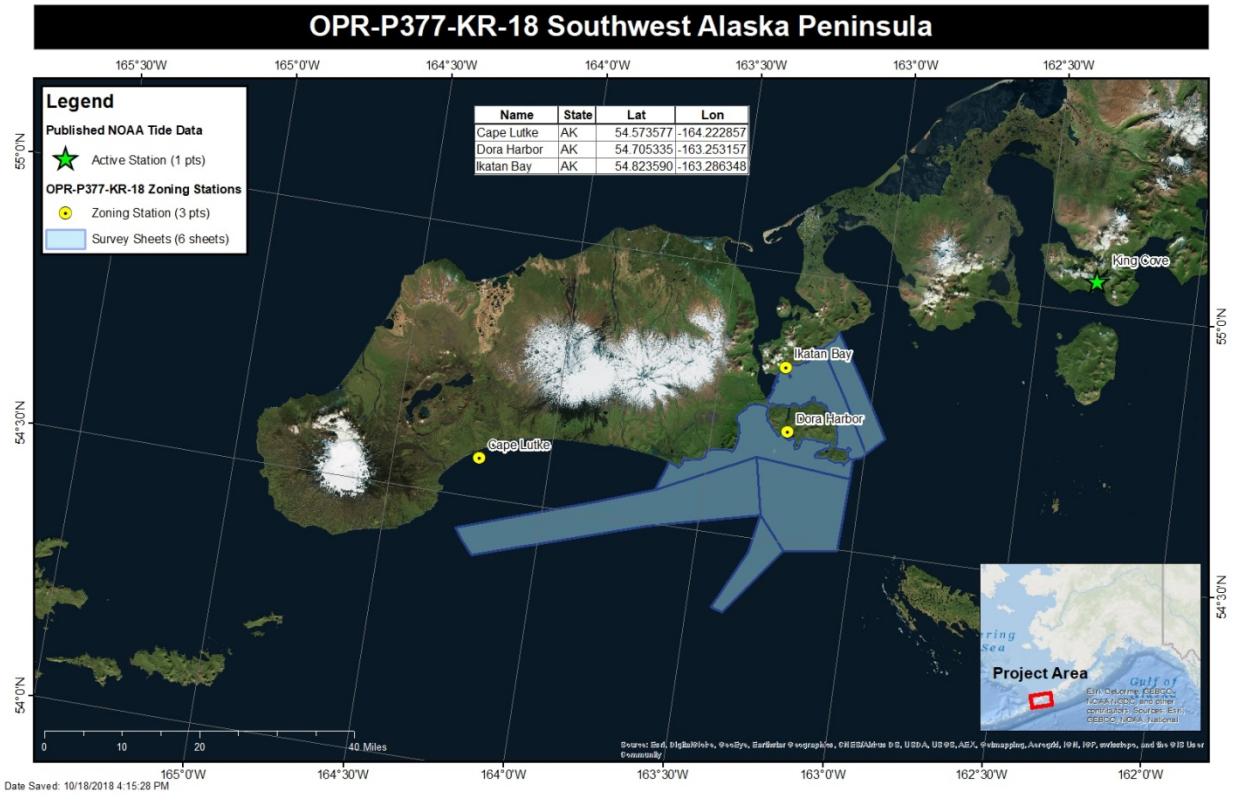
Tide Reports

This Appendix contains JOA's report "Evaluation of Vertical Control for OPR-P377-KR-18".

Note the "Appendix I Supplementary" directory included with this report includes the following data sets generated by JOA:

1. Report text
2. Zoning station data for the project zoning stations: Cape Lutke, Dora Harbor, and Ikatan Bay
3. Computed tidal datums

Evaluation of Vertical Control for OPR-P377-KR-18



To:

TerraSond Ltd.
1617 South Industrial Way Suite 3
Palmer, Alaska 99645
Attn: Andrew Orthmann

From:

JOA Surveys, LLC
2000 E. Dowling Road Suite 10
Anchorage, Alaska 99507
By: Nathan Wardwell

Project Summary

JOA Surveys, LLC was tasked with assessing vertical control for OCS contract survey OPR-P377-KR-18. The survey area is on the Pacific Ocean side of the Aleutian Island between Unimak Pass and Morzhovoi Bay. The survey was to be referenced to the ellipsoid and either a Poor Man's VDatum (PMVD) grid or Ellipsoid Referenced Zoned Tides were to be used to transfer the sounding data to Mean Lower Low Water.

The survey consisted of 5 sheets spanning more than 350 square nautical miles. The nearest NWLON station is located approximately 30 nautical miles east of the survey area in the community of King Cove. There is no published data for historic tide stations within the survey area. The nearest historic tide stations are 9462961 Isanotski Strait Entrance and 9462808 Scotch Cap. The Isanotski tide station was located just outside the survey bounds at the southern end of False Pass. The station was installed in May of 2014 and removed in September of 2014. The Scotch Cap tide station was located at the western end of Unimak Island. The station was installed in April of 2009 and removed in Sep of 2009. The tide type in this region is predominantly mixed semi-diurnal, however it is trending towards mixed diurnal near Scotch Cap. The lack of published tidal information in the survey area also means there are no locations with known vertical datum separations between the referenced ellipsoid and MLLW.

Due to the lack of tidal and vertical datum information for the area water level data was collected at three additional sites. These sites are considered zoning stations. The stations were not established to CO-OPS specifications for a tertiary station and the data is not intended to be published. The zoning stations were located at Cape Lutke, Dora Harbor and Ikatan Bay (see figure on the cover page). The data from these sites was then used to evaluate the discrete zoning model and the PMVD grid.

The remainder of this report provides details of how the water level data was acquired, processed and used in the analysis

Data Acquisition

The Cape Lutke station consisted of two Bottom Mounted Pressure Gauge (BMPG) systems. Each system consisted of a SBE26+ from Seabird Electronics with a DigiQuartz pressure sensor rated to 58 meters. Each system was secured to an 800 lb mooring with a drag anchor. The mooring and drag anchor were connected with 240' of line. One of the moorings had an YSI EXO3 conductivity and temperature (CT) sensor. The other mooring had a Minos X CT sensor.

The Dora Harbor station consisted of a BMPG system co-located with a GPS Buoy. The BMPG system consisted of a SBE26+ from Seabird Electronics with a DigiQuartz pressure sensor rated to 58 meters. The SBE26+ was secured to a 500 lb mooring. The mooring was connected to a drag anchor with 120' of line. A SBE37-SMP CT sensor was attached to the mooring with the SBE26+. The GPS Buoy consisted of a Trimble 5700 receiver and Zephyr antenna secured to a kayak.

The Ikatan Bay tide station consisted of BMPG system with a GPS Buoy. The BMPG system consisted of a SBE26+ from Seabird Electronics with a DigiQuartz pressure sensor rated to 58 meters. The SBE26+ was secured to an 800 lb mooring. The mooring was attached to a drag anchor with 200' of line. A SBE4m CT sensor was integrated with the SBE26+ and secured to the same mooring. The GPS Buoy consisted of a 3' diameter buoy with a fiberglass hull. Inside the hull was a bank of fourteen 18 amp hour batteries, lead weight and a Trimble 5700 receiver. A Trimble Zephyr Geodetic antenna was secured to the top of the buoy. This buoy secured to the mooring line for the SBE26+ mooring.

A GPS base station was established on the Ikatan Peninsula. This base station consisted of a Trimble 5700 GP S receiver and a Zephyr Geodetic antenna. Co-located with the base station was a HOBO U20 pressure sensor. The data from this pressure sensor was used in post processing to correct for the influence of barometer pressure.

Each SBE26+ was programmed to log every 6 minutes. Each reading was the average of 181 one second readings. The CT sensors were programmed to log at the same 6 minute interval as the SBE26+. The CT readings were instantaneous instead of an average. The receivers for the GPS Buoys and base station were programmed to log at 1 Hz. Data was logged in daily files with each daily file starting at the beginning of the UTC day. The HOBO U20 was programmed to log an instantaneous reading every 6 minutes.

All of the equipment was deployed and retrieved by TerraSond.

FIGURE 1 - PICTURE OF ONE OF THE CAPE LUTKE BMPG MOORINGS.

FIGURE 2 - PICTURE OF THE GPS BUOY AT DORA HARBOR.

FIGURE 3 - PICTURE OF THE BMPG MOORING AND GPS BUOY DEPLOYED IN IKATAN BAY.

Processing Water Level Data

The data from the SBE26+ pressure sensors were shifted in time so the reading was timestamped at the center of the averaging window. This was done by adding 1.5 minutes to each reading. The barometric pressure readings were then subtracted from the SBE26+ pressure readings to get only the pressure of the water. The resulting water pressure was converted to meters using a slope constant. The slope constant was based on predicted gravity and computed water density. Predicted gravity came from the National Geodetic Survey's API for Gravity Predictor using GRAV-D data. Water density was either computed from the CT sensor or measured onsite using a hydrometer.

Three different methods were used to process the raw observables logged by the GPS Buoys.

1. POSGNSS DGPS – This approach consisted of relative baseline processing in POSGNSS vendor software using a temporary base station on Ikatan Peninsula.
2. GAMIT DGPS – GAMIT is a scientific package developed by the Massachusetts Institute of Technology to process phase data and is designed to run on UNIX operating systems. This package does relative baseline processing so the base station on Ikatan Peninsula was used.
3. GIPSYx PPP – GIPSYx is a scientific package developed by the NASA Jet Propulsion Laboratory. It does not require a base station. Instead it provides a Precise Point Position (PPP) based on orbit and clock corrections.

The height of the GPS Buoy antenna above the waterline was corrected for during processing of the raw observables. The antenna height was based on the GPS buoy draft lines. The antenna height was recorded during deployment and retrieval.

The 1 Hz water levels from the GPS Buoys were smoothed using a 3 minute moving average and decimated to the same 6 minute interval as the data from the BMPG systems.

Water Level Data QA/QC

The quality of the water level data was based on simultaneous gauge to gauge comparisons in addition to comparisons from water levels acquired by the survey vessels (i.e. boat float) during deployment and retrieval of the tide gauges at each station.

Cape Lutke - The gauge to gauge comparison for the Cape Lutke data did not show the moorings being stable for the first few days of deployment, followed by a larger than normal amount of variation in the differences probably due to a storm, followed by a vertical shift of about 4 cm. The differences remain stable for the next week then shift 1 cm in the opposite direction (Figure 1). The differences remain stable after the last shift. A comparison of the water level data and the boat floats suggest a shift of approximately 50 cm in both moorings (Table 1). This shift is confirmed by a comparison to data from King Cove (Figure 2). The 50 cm vertical shift of the moorings is not identified in the gauge to gauge comparisons because both moorings were moving so there relative differences were not as large as the actual amount of vertical movement they underwent.

Due to the movement of the moorings at Cape Lutke, for this station only data from Jun 26, 2018 00:00 to Jul 15, 2018 22:18 UTC was used in this analysis.

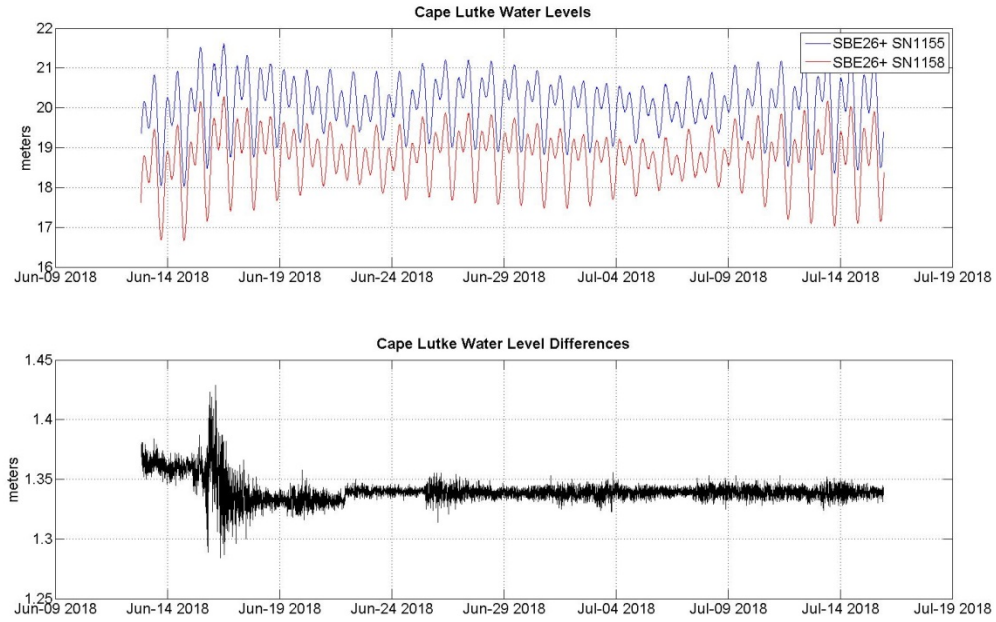


FIGURE 4 - WATER LEVEL DIFFERENCES BETWEEN THE TWO GAUGES DEPLOYED AT CAPE LUTKE.

TABLE 1 - WATER LEVEL DIFFERENCES BETWEEN THE BOAT FLOATS AND THE TIDE GAUGES AT CAPE LUTKE.

Date	SN1155 Avg	SN1155 Std	SN1158 Avg	SN1158 Std
12-Jun-2018	-1.460 m	0.201 m	-0.090 m	0.200 m
15-Jul-2018	-1.907 m	0.144 m	-0.568 m	0.144 m

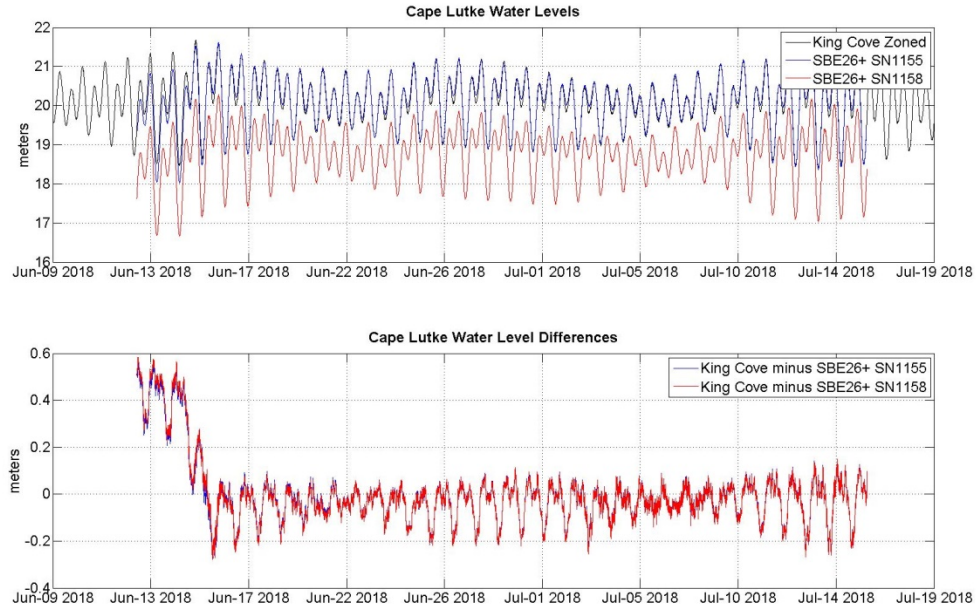


FIGURE 5 - WATER LEVEL DIFFERENCES BETWEEN THE KING COVE NWLON STATIONS AND THE TWO CAPE LUTKE GAUGES.

Dora Harbor – The water level differences between the SBE26+ and the GPS Buoy did not show any significant movement of the moorings, nor did a comparison to the King Cove water levels. The average difference between the SBE26+ water levels and the GPS Buoy water levels was 15.704 m. This difference is expected to be large since the SBE26+ data is referenced to sensor "0" and the GPS buoy data is referenced to the ellipsoid. The standard deviation of the differences is 0.014 m. Based on this close agreement between the SBE26+ and GPS Buoy data the GPS Buoy data for this station was used in the analysis.

There were two short gaps in the GPS Buoy data that were filled with data from the SBE26+ prior to performing any further analysis. These gaps were from Jul 3, 2018 22:24 to Jul 4, 2018 00:00 and from Jul 4, 2018 21:06 to Jul 5, 2018 00:00 UTC.

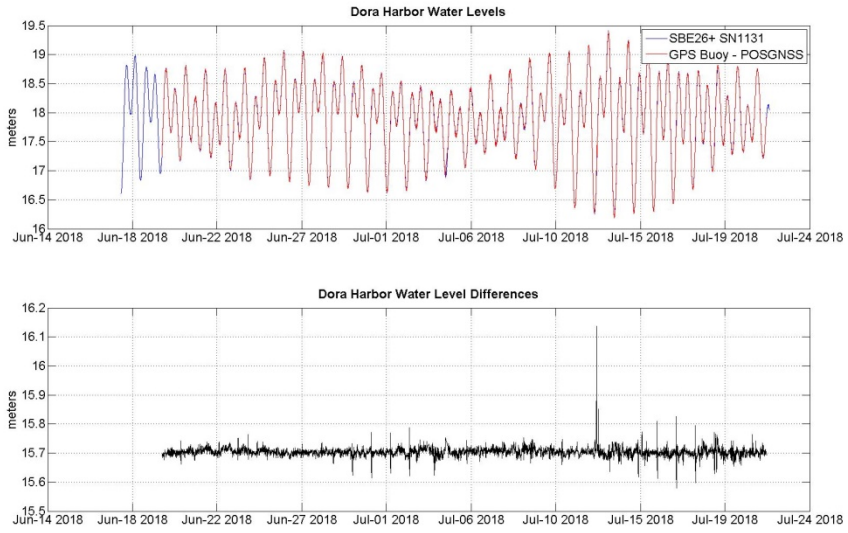


FIGURE 6 - DORA HARBOR WATER LEVELS AND DIFFERNCES BETWEEN THE SBE26+ AND THE GPS BUOY.

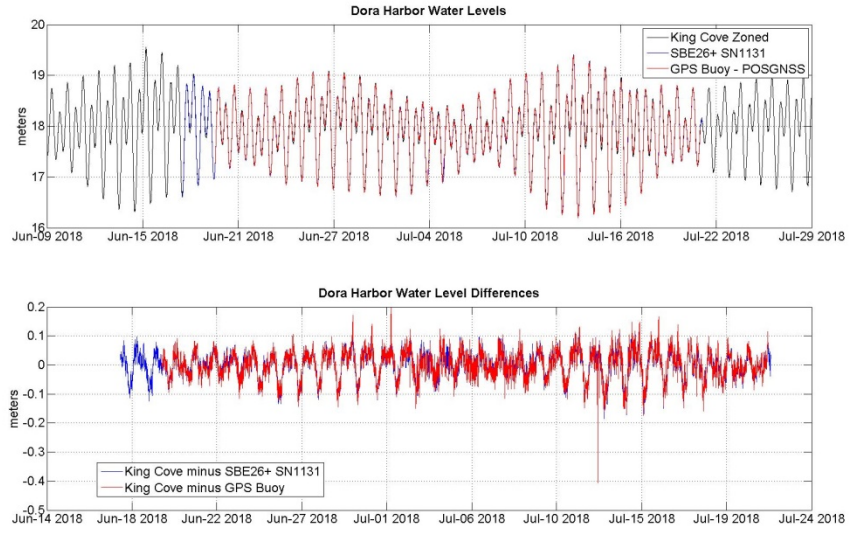


FIGURE 7 - DORA HARBOR WATER LEVELS AND DIFFERENCES BETWEEN THE KING COVE NWLON STATION AND BOTH THE SBE26+ AND GPS BUOY.

Ikatan Bay – The GPS Buoy data collected on JD175 was processed using POSGNSS, GIPSYx and GAMIT. Both GIPSYx and GAMIT provide solutions in GPS time whereas POSGNSS provides solutions in UTC time. GPS time is 18 sec ahead of UTC. Eighteen seconds were subtracted from the GIPSYx and GAMIT solutions so all three data sets were reference the same date and time. The solutions from GIPSYx and GAMIT reference IGS08. The solutions from POSGNSS reference NAD83(2011). The solutions for GIPSYx and GAMIT were shifted to NAD83(2011) by subtracting 0.679 m. This vertical offset for the location of the buoy was determined using the National Geodetic Survey's Horizontal Time Dependent Positioning tool.

There is no bias between the GAMIT and POSGNSS solutions, which are both DGPS. There is a bias of less than 2 cm between the GIPSYx data and the other two solutions. The GIPSYx data is processed using PPP. The standard deviation of differences between the three solutions is less than 5 cm. Table 2 shows the statistics for each set of differences.

TABLE 2 – INSTANTANEOUS 1 SEC WATER LEVEL DIFFERENCES FOR JD175 BASED ON THREE DIFFERENT GNSS PROCESSING PACKAGES.

	GIPSYx - POSGNSS	GIPSYx - GAMIT	GAMIT - POSGNSS
Average	**0.015 m**	**0.014 m**	**0.000 m**
Standard Deviation	**0.036 m**	**0.048 m**	**0.034 m**
Max	**0.156 m**	**1.401 m**	**0.864 m**
Min	**-0.145 m**	**-0.823 m**	**-1.356 m**

All of the GPS Buoy data was processed with both GIPSYx and POSGNSS. The 1Hz data was smoothed and decimated to the same six minute interval as the SBE26+. Because the SBE26+ data is referenced to sensor zero and the GPS buoy data is reference to NAD83(2011) the average difference between the two datasets cannot be used to show a bias between the two platforms (Figure 5). The standard deviation of the differences between the SBE26+ and the POSGNSS solutions is approximately 3 cm less than the standard deviation of the differences between the SBE26+ and the GIPSYx solutions.

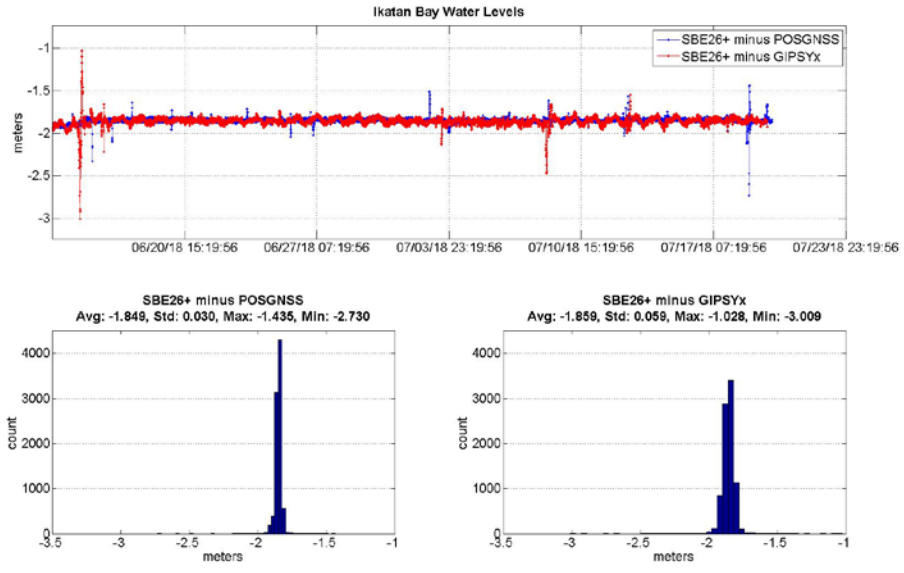


FIGURE 8 - IKATAN BAY WATER LEVEL DIFFERENCES BETWEEN THE SBE26+ AND GPS BUOY. THE GPS BUOY DATA WAS PROCESSED TWO WAYS. THE TOP PLOT SHOWS A TIMESERIES OF THE DIFFERENCES. THE BOTTOM PLOTS SHOW HISTORGRMAS OF THE DIFFERENCES.

Tidal Datum Computation

The tidal datums for Cape Lutke, Ikatan Bay and Dora Harbor were computed using the Tide-by-Tide Simultaneous Comparison method and King Cove as the control station. The final datums are based on the Standard Method for datum computations. All of the computations follow the guidance in NOAA Special Publication NOS CO-OPS 2 – Computational Techniques for Tidal Datums Handbook. All of the computations were performed using JOA Surveys' Online Tidal Datum Computation Tool (www.tidaldatumtool.com).

The tidal datums resulting from both the SBE26+ and GPS Buoy platforms agree very well at Dora Harbor and Ikatan Bay. At both Ikatan Bay and Dora Harbor the RMS of the tidal datum differences between the SBE26+ data and the GPS Buoy data processed with POSGNSS was 2 mm. At Ikatan Bay the RMS increased to 16 mm when compared to the GPS Buoy data processed with GIPSYx. The SBE26+ to GIPSYx tidal datum comparison was not performed using the data at Dora Harbor. Before drawing conclusions from the GIPSYx results showing a larger RMS the following must be considered. First, the POSGNSS data was used put the SBE26+ data on NAD83 at both locations so there should be no bias, whereas the GIPSYx data is completely independent of the SBE26+ data. Second, due to some noise in the GIPSYx data a few of the TBYT pairings are incorrect for the month of July. These incorrect pairings biased the datums. This pairing issue could be resolved with some manual cleaning of the 6 minute GIPSYx water level data.

TABLE 3 - IKATAN BAY TIDAL DATUM DIFFERENCES WHEN COMPUTED USING DATA FROM THE SBE26+ AND GPS BUOY. THE GPS BUOY DATA WAS PROCESSED USING POSGNSS AND GIPSYX. ALL VALUES ARE IN METERS.

	SBE26+	GPS Buoy (POSGNSS)	GPS Buoy (GIPSYx)	SBE26+ minus GPS Buoy (POSGNSS)	SBE26+ minus GPS Buoy (GIPSYx)
MHHW	18.651	18.653	18.672	-0.002	-0.021
MHW	18.448	18.448	18.470	0.000	-0.022
DTL	17.622	17.623	17.630	-0.001	-0.008
MTL	17.732	17.731	17.740	0.001	-0.008
MSL	17.717	17.715	17.726	0.002	-0.009
MLW	17.015	17.013	17.009	0.002	0.006
MLLW	16.594	16.592	16.589	0.002	0.005
GT	2.057	2.061	2.083	-0.004	-0.026
MN	1.433	1.435	1.461	-0.002	-0.028
DHQ	0.203	0.205	0.201	-0.002	0.002
DLQ	0.421	0.421	0.420	0.000	0.001
			RMS	0.002	0.016
			STD	0.002	0.013

TABLE 4 - DORA HARBOR TIDAL DATUM DIFFERENCES WHEN COMPUTED USING DATA FROM THE SBE26+ AND GPS BUOY. THE GPS BUOY DATA WAS PROCESSED USING POSGNSS ONLY. ALL VALUES ARE IN METERS.

	SBE26+	GPS Buoy (POSGNSS)	SBE26+ minus GPS Buoy (POSGNSS)
MHHW	18.910	18.913	-0.003
MHW	18.715	18.714	0.001
DTL	17.916	17.917	-0.001
MTL	18.032	18.032	0.000
MSL	18.016	18.015	0.001
MLW	17.349	17.350	-0.001
MLLW	16.922	16.921	0.001
GT	1.989	1.991	-0.002
MN	1.366	1.364	0.002
DHQ	0.195	0.199	-0.004
DLQ	0.427	0.428	-0.001
		RMS	0.002
		STD	0.002

Analysis of PMVD Grids

The Ikatan Bay and Dora Harbor tide stations were located within the coverage area for the PMVD grids. The Cape Lutke tide station was not so the data from this station was not used to evaluate the PMVD grid. For this project two separate grids were provided, one for Mean High Water (MHW) and the other for Mean Lower Low Water (MLLW). Of these two grids the MHW grid agreed better with the computed tidal datums than the MLLW grid. The RMS for MHW is 0.050 m. The RMS for MLLW is 0.137 m. Both PMVD grids performed better in Dora Harbor than Ikatan Bay. This is notable because Ikatan Bay is much closer to a known SEP than Dora Harbor is.

TABLE 5 - THIS TABLE SHOWS THE DIFFERENCES BETWEEN PMVD AND THE COMPUTED TIDAL DATUMS FOR MHW AND MLLW.

	Ikatan Bay		Dora Harbor	
	MHW	MLLW	MHW	MLLW
GPS Buoy (POSGNSS)	18.448	16.592	18.714	16.921
PMVD	18.513	16.754	18.740	17.028
Difference	-0.065	-0.162	-0.026	-0.107

The vessel altitude from the survey vessels were used to evaluate the PMVD grid offshore. This evaluation was performed using the following procedure. The vessel data was parsed into 5km grid cells. Each grid cell represented a unique tide zone. The vessel data in the zone represented the unique tide curve for that zone. Verified MLLW water levels for the King Cove NWLON station were then fit, in a least squares sense, to the vessel data in each tide zone. Since the vessel data is referenced to NAD83(2011) and the King Cove data is referenced to MLLW the offset resulting from the least squares fit is the MLLW SEP. Figure 6 shows the PMVD MLLW grid and

the differences from the MLLW SEP derived using the vessel data. These differences are shown as dots with their size showing the magnitude of the difference. There were two tide zones at the southern edge of the PMVD grid where the vessel derived MLLW SEP was more than a meter different than the PMVD MLLW SEP. After excluding these two values the mean difference is -0.08m (+/- 0.08m at 1 sigma). There is a slight east/west trend in the differences with the vessel MLLW SEP values in the west tending to be about equal with the PMVD MLLW SEP, whereas in the northeastern region the vessel MLLW SEP tended to be lower than the PMVD MLLW SEP. The MLLW SEP value derived from the vessel data is within 2cm of MLLW computed from the GPS buoy data collected at Dora Harbor and 7cm at Ikatan Bay (Table 6). In general the MLLW SEP derived from the vessel data tends to agree with the MLLW SEP computed from the GPS Buoy better than the PMVD grid.

TABLE 6 - THIS TABLE SHOWS THE DIFFERENCES BETWEEN THE MLLW SEP DERIVED USING THE VESSEL ALTITUDE DATA AND THE GPS BUOY DATA.

	MLLW at Ikatan Bay	MLLW at Dora Harbor
GPS Buoy (POSGNSS)	16.592	16.921
VESSEL Altitude Data	16.613	16.850
Difference	-0.021	0.071

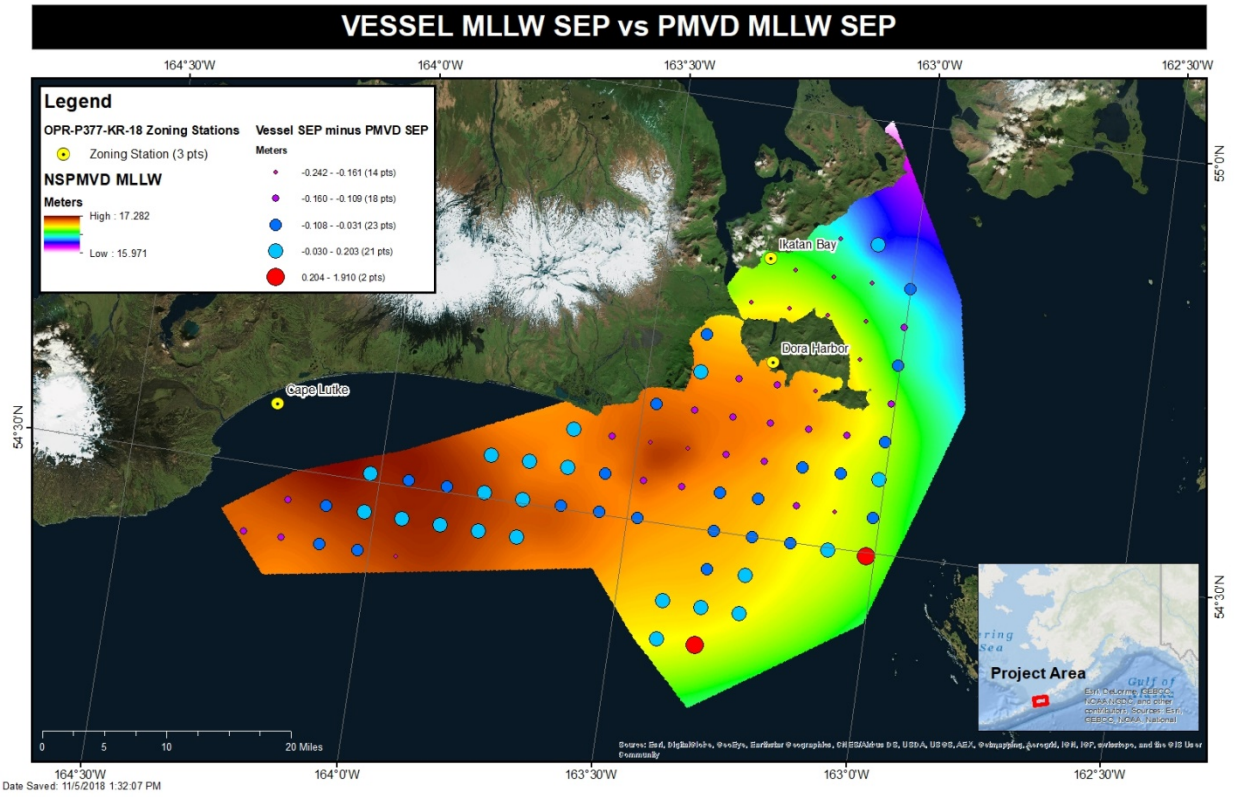


FIGURE 9 - COMPARISON OF PMVD MLLW SEP TO MLLW SEP DERIVED FROM THE SURVEY VESSELS' ELLIPSOID REFERENCED WATER LEVELS.

Analysis of Discrete Zoning

The survey area spans nine zones in the preliminary tidal zoning scheme. The King Cove NWLON station is the reference station for all of the zones in the scheme. The time offset ranges from 0 minutes at the eastern end of the survey area to +24min at the western end. The range correctors vary from 0.96 in the eastern end to 0.83 in the western end (Figure 7).

The Ikatan Bay and Dora Harbor tide stations are located in the same tide zone. The Cape Lutke tide station was located just west of the northwestern most tide zone provided in the scheme. The tidal datums for the reference and zoning stations are shown in Table 7. Table 8 shows statistics on the differences between the water levels observed at the three tide stations, the zoned water levels and reference station water levels fit to the observed water levels in a least squares sense. In general the preliminary tidal zoning scheme underestimates the tide range throughout the survey area primarily in the eastern region. The time offset in the preliminary scheme is within several minutes of the offset determined from the tidal datums.

The preliminary scheme was revised based on the datums computed for the three zoning stations (Figure 8). The error for each zone is based on the published datum uncertainty for King Cove and the Tier A uncertainties outlined in CO-OPS Policy for Management and Dissemination of External Source Water Level Data.

TABLE 7 - TIDAL DATUM FOR THE REFERENCE STATION (KING COVE) AND THE THREE ZONING STAITONS.

	King Cove	Ikatan Bay	Dora Harbor	Cape Lutke
GT	2.082 m	2.061 m	1.991 m	1.949 m
HWI	11.40 hr	11.56 hr	11.57 hr	11.77 hr
LWI	4.960 hr	5.11 hr	5.18 hr	5.38 hr

TABLE 8 - TIME OFFSETS, RANGE CORRECTORS AND STATISTICS ON DIFFERENCES BETWEEN ZONED AND OBSERVED WATER LEVELS AT EACH ZONING TIDE STATION.

	Ikatan Bay			Dora Harbor			Cape Lutke		
	Datums	LSQ Fit	Prelim Zones	Datums	LSQ Fit	Prelim Zones	Datums	LSQ Fit	Prelim Zones
Time Offset	9.3	-6	6	11.7	-6	6	23.7	-12	24
Range Ratio	0.990	0.99	0.89	0.956	0.95	0.89	0.936	0.94	0.86
Avg	0.008	0.000	0.069	0.015	0.000	0.083	0.022	0.000	0.100
Std Dev	0.033	0.034	0.087	0.052	0.046	0.061	0.080	0.071	0.097
RMS	0.034	0.034	0.111	0.055	0.046	0.103	0.082	0.071	0.139
Max	0.140	0.148	0.329	0.221	0.185	0.261	0.293	0.253	0.375
Min	-0.123	-0.122	-0.165	-0.172	-0.134	-0.121	-0.226	-0.197	-0.169

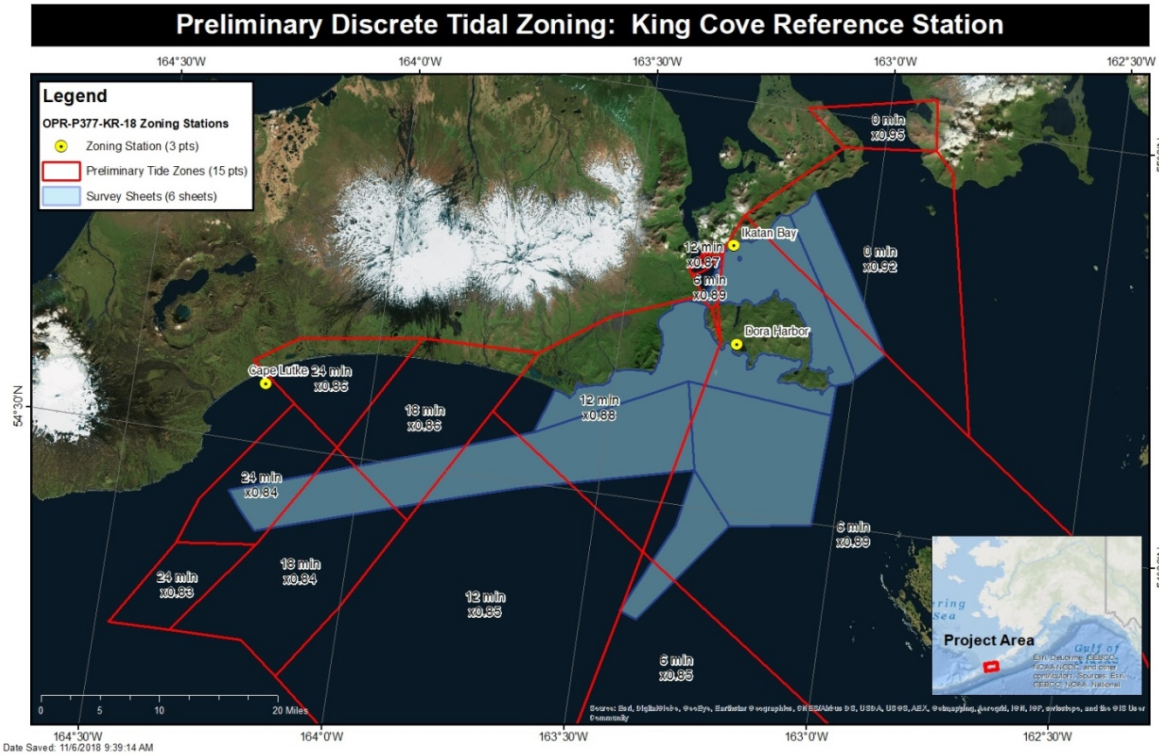


FIGURE 10 - MAP OF THE PRELIMINARY DISCRETE TIDAL ZONING SCHEME FOR THE SURVEY AREA.

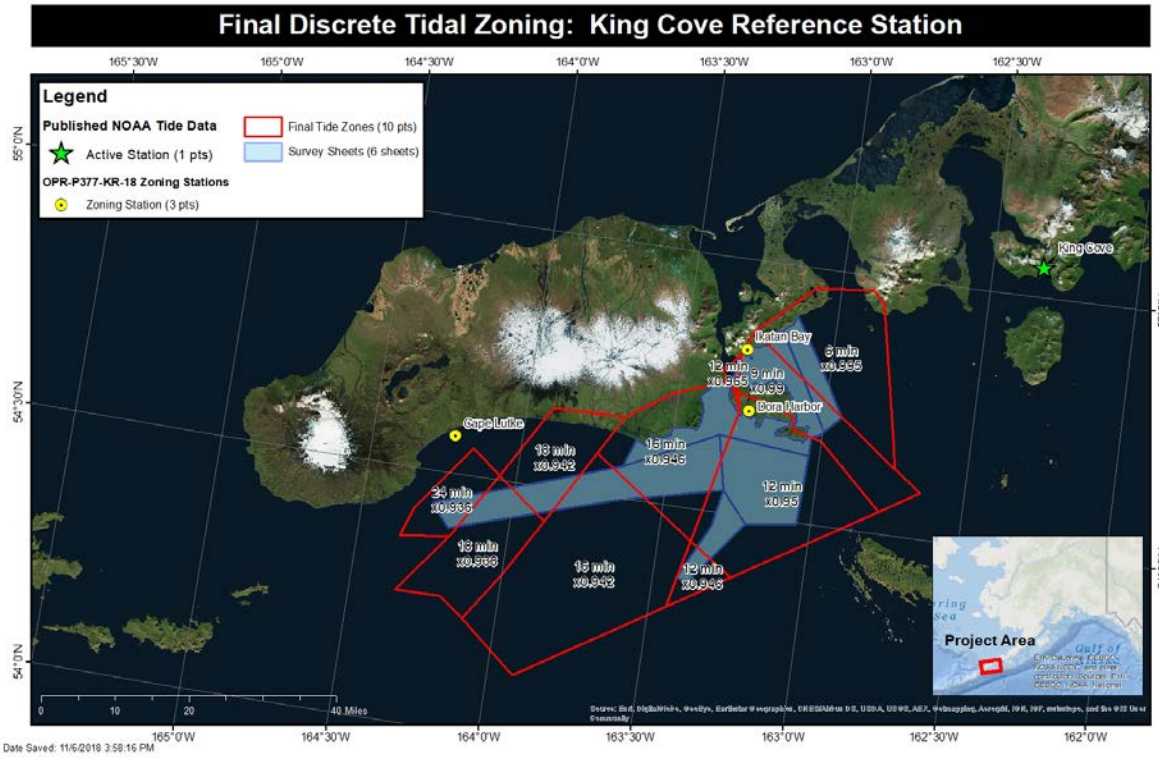


FIGURE 11 - MAP OF THE FINAL DISCRETE TIDA ZONING SCHEME FOR THE SURVEY AREA.

Conclusion

The tight agreement between the tidal datums derived from the SBE26+ and the GPS Buoy show that GPS Buoys are suitable for tidal datum determination. They may even be better at providing ellipsoid referenced datums than Bottom Mounted Pressure Gauges with Boat Floats due to the uncertainty of resolving the waterline of the vessel below the GNSS antenna.

There is a potential vertical bias between DGPS and PPP GNSS solutions. The small spatial sample size in this project is not enough to estimate the bias and its spatial variability. Even though this bias exists it is most likely within the acceptable error budget for Tier B[1] water level data.

The comparison of the ellipsoid referenced tidal datums and vessel altitude data suggest the MLLW PMVD grid has a slight east/west tilt with the MLLW SEP in the northeastern region being approximately 10cm larger than the observed MLLW SEP. The PMVD MHW grid approximates MHW better than the PMVD MLLW grid.

The preliminary discrete zoning model under estimated the tide range in the survey area and was revised based on the datums computed for the zoning stations. The revised zoning scheme still uses the King Cove NWLON station as the reference station. The geometry of the preliminary scheme was left the same except for the zone spanning Ikatan Peninsula was divided into two. The maximum estimated uncertainty for the revised zoning scheme is 18.4 cm at the 95% confidence level. As expected this zone is located farthest from the reference station.

[1] The CO-OPS Policy for Management and Dissemination of External Source Water Level Data outlines three data tiers. These Tiers are A, B and C. The minimum accuracy for Tier A is 10 cm. The minimum accuracy for Tier B is between 10 and 30 cm. Tier C is for any data with accuracy greater than 30 cm or unknown. This policy groups water level data for hydrographic surveys in Tier B.

APPENDIX II

Base Stations

This appendix contains the following documentation regarding the project base station(s):

Base Station Position Checks (Confidence Checks) logsheet, summarizing the weekly confidence check results accomplished via OPUS

Refer to the Appendix II subdirectory included with the HVCR for:

- All OPUS solutions, including weekly check results
- CORS station data sheet
- POSPac Processing Reports
- Tide Comparisons

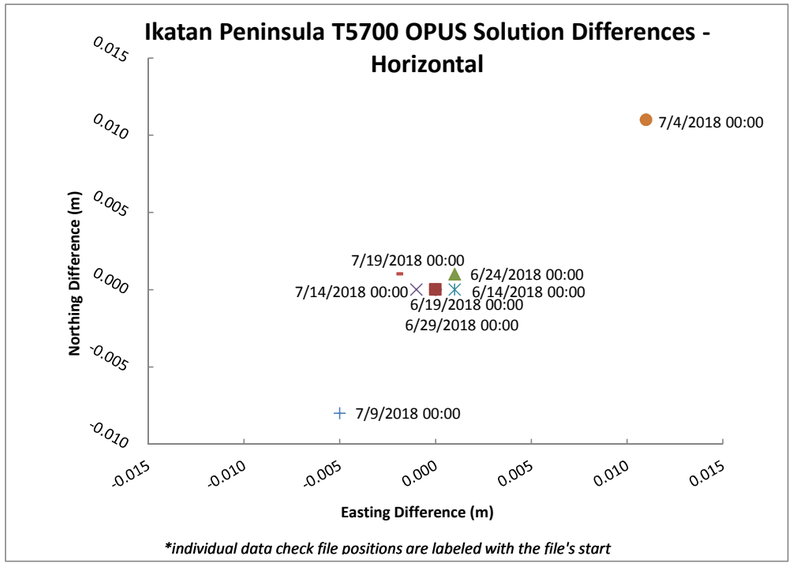
Base Station Position Checks

Base Name: TerraSond Ikatan Peninsula Base **ID: 5240**
Site Description: Located over TBM on Ikatan Peninsula
Receiver Type: Trimble 5700
Antenna Type: Trimble Zephyr Geodetic (TRM41249.00)
Project number: OPR-P377-KR-18
Horizontal Datum: NAD83 (2011)
Projection: UTM Zone 3N
Ellipsoid: GRS80

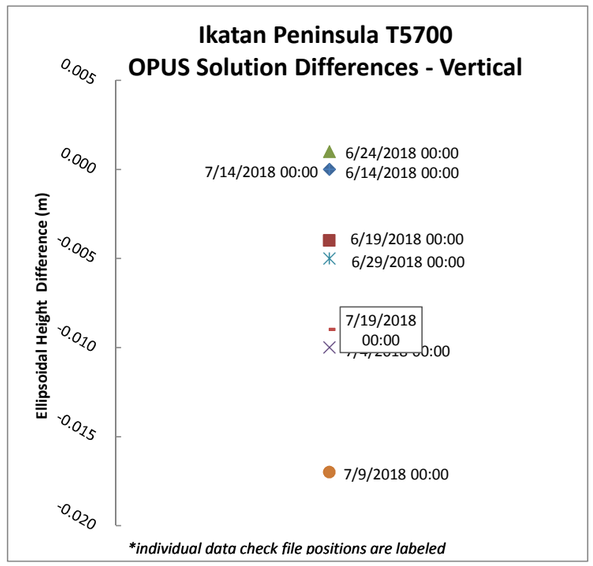
Receiver Serial: 220275240
Antenna Serial: 60078756

Notes:
** Surveyed position is from 24-hour OPUS solution filename "52401650.18o", logged JD165 (6/14/18), with ARP height of 1.118 m*

PPK Site Coordinate:		Latitude(dms)	Longitude(dms)	Northing(m)	Easting (m)	Ellipsoidal Height(m)
Surveyed*	24-hr OPUS (6/14/18)	54 45 2.73460	163 19 37.53937	6068340.588	607670.553	21.611



**individual data check file positions are labeled with the file's start*



**individual data check file positions are labeled*

Ikatan Peninsula T5700 Location

Base Station Position Uncertainty Check:

Times of OPUS solution			File Information		Antenna Height		OPUS Solution Results (NAD83)					RESULTS (DIFFERENCE) Delta (m) =OPUS solution check - Surveyed Coord.		
Deployment #	Start	End	Hours	OPUS Rinex File name	Measure Point	ARP(m)-Enter in OPUS	Latitude(dms)	Longitude(dms)	Northing(m)	Easting(m)	Ellipsoidal Height (m)	Northing (m)	Easting (m)	Ellipsoidal Height (m)
1	6/14/2018 00:00	6/14/2018 23:34	24.0	52401650.18o	ARP	1.1180	54 45 2.73460	163 19 37.53937	6068340.588	607670.553	21.611	0.000	0.000	0.000
1	6/19/2018 00:00	6/19/2018 23:34	24.0	52401700.18o	ARP	1.1180	54 45 2.73460	163 19 37.53934	6068340.588	607670.553	21.607	0.000	0.000	-0.004
1	6/24/2018 00:00	6/24/2018 23:34	24.0	52401750.18o	ARP	1.1180	54 45 2.73463	163 19 37.53930	6068340.589	607670.554	21.612	0.001	0.001	0.001
1	6/29/2018 00:00	6/29/2018 23:34	24.0	52401800.18o	ARP	1.1180	54 45 2.73460	163 19 37.53930	6068340.588	607670.554	21.606	0.000	0.001	-0.005
1	7/4/2018 00:00	7/4/2018 23:34	24.0	52401850.18o	ARP	1.1180	54 45 2.73496	163 19 37.53872	6068340.599	607670.564	21.601	0.011	0.011	-0.010
1	7/9/2018 00:00	7/9/2018 23:34	24.0	52401900.18o	ARP	1.1180	54 45 2.73434	163 19 37.53966	6068340.580	607670.548	21.594	-0.008	-0.005	-0.017
1	7/14/2018 00:00	7/14/2018 23:34	24.0	52401950.18o	ARP	1.1180	54 45 2.73460	163 19 37.53941	6068340.588	607670.552	21.611	0.000	-0.001	0.000
1	7/19/2018 00:00	7/19/2018 00:00	24.0	52402000.18o	ARP	1.1180	54 45 2.73463	163 19 37.53944	6068340.589	607670.551	21.602	0.001	-0.002	-0.009

Comments: Good agreement between all subsequent data points

Max Delta:	**0.011**	**0.011**	**0.001**
Min Delta:	**-0.008**	**-0.005**	**-0.017**
Std Dev:	**0.005**	**0.005**	**0.006**