

Exploring the Spatial Variation of Tides for Seafloor Mapping Data

Corrections

Hannah Delapp, B.S. Oceanography Undergraduate Thesis, UW School of

Oceanography

Science Advisor- Miles Logsdon, Senior Lecturer, UW School of Oceanography

University of Washington

School of Oceanography

1503 NE Boat Street

Seattle, WA 98105

hdelapp@uw.edu

Abstract

Acquisition of high definition hydrographic survey data has made several advancements in correcting for errors during signal acquisition. This potential error is associated with vessel position, ship motion and the changing speed of sound through the water column. However, until significant improvements occur in the vertical accuracy of GPS, the change in vertical distance of the survey vessel from the sea floor due to the constantly changing tides remains a source of error that is addressed during the post processing of hydrographic data. An accurate representation of the sea floor is critical in monitoring geomorphic processes as well as for the safety of navigation. This study used a specially designed pressure sensor array to collect tidal data near Seattle, WA in Puget Sound, and geostatistical analysis to determine the spatial scale of variability in tides. The results of this research validate the importance of collecting fine scale tide data in coastal areas with high tidal influences and offer an affordable option to collect this valuable data.

Introduction

Seafloor mapping techniques have evolved significantly since the days of lead lines and celestial navigation. Today's hydrographic surveyors use advanced multibeam acoustic sonars, global positioning systems and correct for errors caused by the ship's motion and speed of sound through water in real time. These modern methods produce comprehensive bathymetric maps that are spatially accurate and representative of the complex seafloor (figure 1). However, even with these advancements, depth error is introduced into the data as the vertical elevation from the sea floor to the survey vessel is influenced by the constantly changing tides.

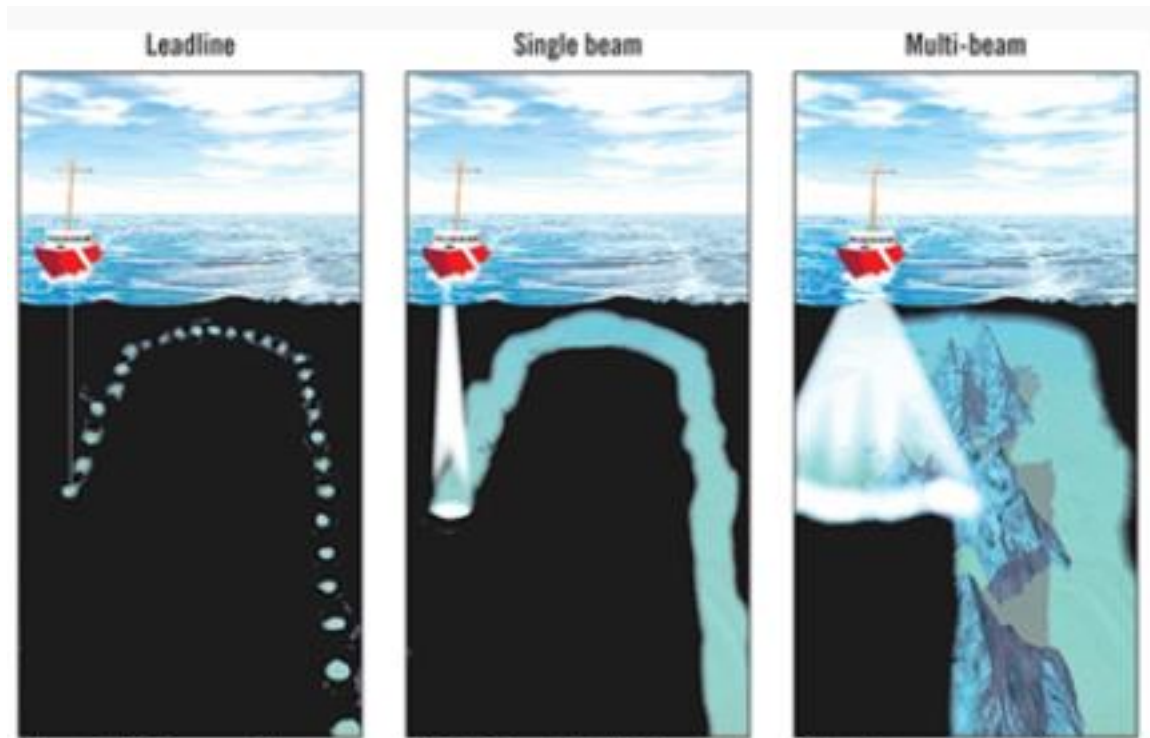


Figure 1. Multibeam survey data (right), has advanced from single lead line data points (left). These advances have increased the accuracy and detail in hydrographic surveying.
http://www.nauticalcharts.noaa.gov/hsd/hydro_history.html

Tides are shallow water waves with long periods created by the gravitational influences of celestial bodies. As a tide propagates into an enclosed body of water the vertical amplitude of the wave increases. Tidal phase and amplitude can be estimated at specific locations by modeling these constituents (Scherneck, 1990) and the model's accuracy is increased when paired with local tidal data (Blair, 1983). The National Ocean Service requires at least 30 days of observed tidal data to be collected to supplement computerized models used for tide corrections during post processing of hydrographic survey data (NOS Hydrographic Survey Specification and Deliverables, May 2015). The National Oceanic and Atmospheric Administration, which is responsible for the nation's nautical charts and

environmental monitoring, exceeds this standard by collecting up to 18 months of tidal data for a new survey location.

Tide corrections are referenced to a standard vertical datum and can be made from a single tide station or from multiple tide stations. When there is a single tide station, the correction is based on the time in which the survey was conducted, with no regard to position. When multiple tide stations are available, the survey area is broken up into zones. For a survey line that crosses between tide zones, the correction is based on both time and location of the survey (CARIS, 2013). Vessels equipped with differential GPS's, which fix the vessel's vertical position via antenna phase corrections often do not need to correct for tides during post processing (Keiland et al., 1995).

It is important to accurately map the seafloor to monitor changes in geomorphic processes of the benthic layer, as well as to monitor long-term trends for safety of maritime navigation. Most potential sources of error can either be addressed before or during acquisition of hydrographic survey data. Tides on the other hand can only be corrected for during post processing. The purpose of this investigation is to design a low cost pressure sensor array to collect tidal data near Seattle, WA in Puget Sound and to use the geostatistical analysis method of semivariance to better understand the spatial and temporal variability of tides in order to decrease error.

Methods

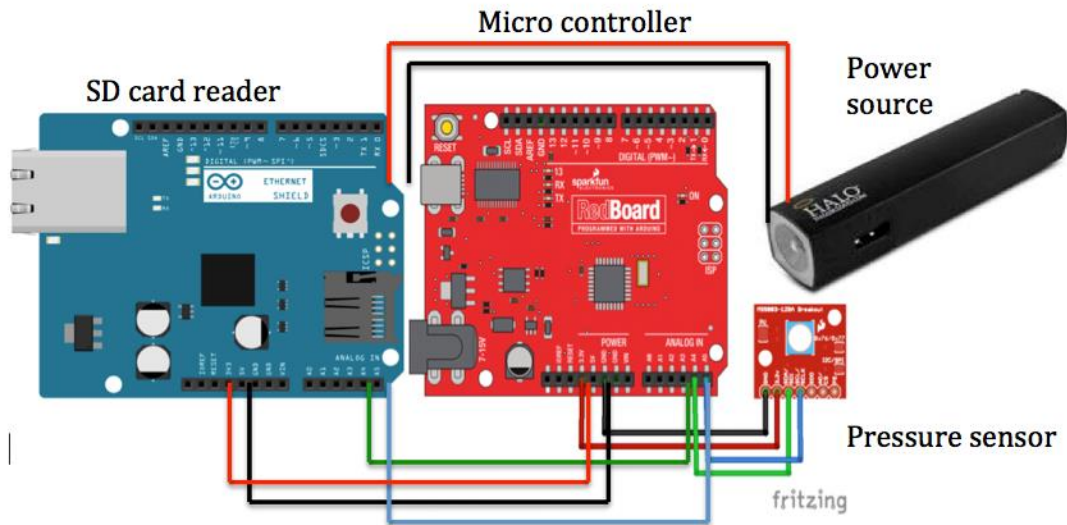
This project investigates the spatial variation in the rate of change of tide height near Carkeek Park in Puget Sound. Using a custom designed pressure sensor

array, field measurements of an outgoing ebb tide were collected on February 13th, 2016 from the R/V Clifford A. Barnes (figure 3). Analysis of the tidal data uses semivariance to determine the variation in the rate of change.

Sensor Design

Sensor design, prototyping and assembly were performed in the Ocean Technology Center at the University of Washington during winter quarter 2016. Design considerations of the pressure sensors addressed variable data collection rates, data storage, power source, remaining watertight under pressure, ability to link many spatial observations over a synchronized time interval, to be low cost, and easy to deploy and recover.

The 5 sensors in the array consisted of a Sparkfun MS5803-14BS pressure sensor, a RedBoard Arduino compatible micro controller, an SD data storage card reader, a rechargeable 5 volt 1 amp lithium ion power source, and a watertight PVC housing. The pressure sensor produced data in millibars of pressure, which was recorded once a minute by the embedded code on the microprocessor and stored on an SD card, requiring minimal data storage space (figure 2). The pressure sensor was potted in two-part epoxy, exposing the sensor head to the salt water while protecting the micro processor, data recorder and battery. The PVC housing was watertight to 3 atmospheres of pressure and each sensor was fixed to an anchor, which was connected to 30 meters of line and a buoy with a flag at the surface for deployment and recovery.



<p style="text-align: center;">Function Libraries</p> <pre>#include <Wire.h> #include <SPI.h> #include <SD.h></pre>	<p style="text-align: center;">Read Sensor</p> <pre>void loop() { temperature_c = sensor.getTemperature(CELSIUS, ADC_512); temperature_f = sensor.getTemperature(FAHRENHEIT, ADC_512); pressure_abs = sensor.getPressure(ADC_4096); pressure_relative = scalevel(pressure_abs, base.altitude); altitude_delta = altitude(pressure_abs., pressure.baseline);</pre>
<p style="text-align: center;">Variable Declaration</p> <pre>File myFile; MS5803 sensor(ADDRESS_HIGH); float temperature_c, temperature_f; double pressure_abs, pressure_relative, altitude_delta; double baseline; double base_altitude = 0</pre>	<p style="text-align: center;">Write Sensor</p> <pre>Serial.print("Temperature C = "); Serial.println(temperature_c); Serial.print("Temperature F = "); Serial.println(temperature_f); Serial.print("Pressure abs (mbar) = "); Serial.println(pressure_abs); Serial.print("Pressure relative (mbar) = "); Serial.println(pressure_relative); Serial.print("Altitude change (m) = "); Serial.println(altitude_delta);</pre>
<p style="text-align: center;">Initiation of Sensor Component</p> <pre>void setup() { Serial.begin(9600); sensor.reset(); sensor.begin(); pressure_baseline = sensor.getPressure(ADC_4096); while (!Serial) { ; } Serial.print("Initializing SD card..."); if (!SD.begin(4)) { Serial.println("initialization failed!"); return; } Serial.println("initialization done."); myFile = SD.open("FileName.txt", FILE_WRITE);</pre>	<p style="text-align: center;">Record Data</p> <pre>myFile = SD.open("FileName.txt", FILE_WRITE); if (myFile) { myFile.print(temperature_c); myFile.print(","); myFile.print(temperature_f); myFile.print(","); myFile.print(pressure_abs); myFile.print(","); myFile.print(pressure_relative); myFile.print(","); myFile.println(altitude_delta); } Serial.println(" done."); } else { Serial.println("error opening test.txt"); myFile.close(); myFile = SD.open("testend code example delay(60000);</pre> <p style="text-align: center;">Continuous Read/Write/Record Loop with 1-Minute Delay</p>

Figure 2. The components of each pressure sensor in the array consist of a Redboard micro controller, an SD card data recorder, a 5V 1amp power source and a SparkFun MS5803 pressure sensor break out board. The pressure sensors were potted in epoxy, exposing just the sensor head to the water, and each sensor was bench tested overnight to analyze data storage and battery life (top). Micro controller code reads the sensor and records the data on the SD card (bottom).

Data Collection

Since most of the tide variation occurs along the axis the tide travels (Chang, 2002), it was important to deploy the 5 sensors in the pressure array along the longest north/south oriented 30-meter bathymetric contour line that was reasonably accessible. During the ebb tide on February 13, 2016 off Carkeek Park in Puget Sound, high slack tide occurred at 0816 and low slack at 1448. The tide traveled from south to north as the wave propagated out to sea. Observational measurements were collected in the form of pressure changes at 5 stations, spaced 500 meters apart (figure 3).

Each pressure sensor in the array collected data in millibars of pressure and stored it to an SD card once per minute. This method of time stamping the data was verified by referencing it against the time each sensor was deployed and retrieved, where there was a large pressure change at a known time. There was no measurable time drift. Once each sensor was adjusted for time, a 6-minute running average of bottom pressure was used to remove surface wave noise and a 6-minute average was then taken (figure 4), as per NOAA standards.

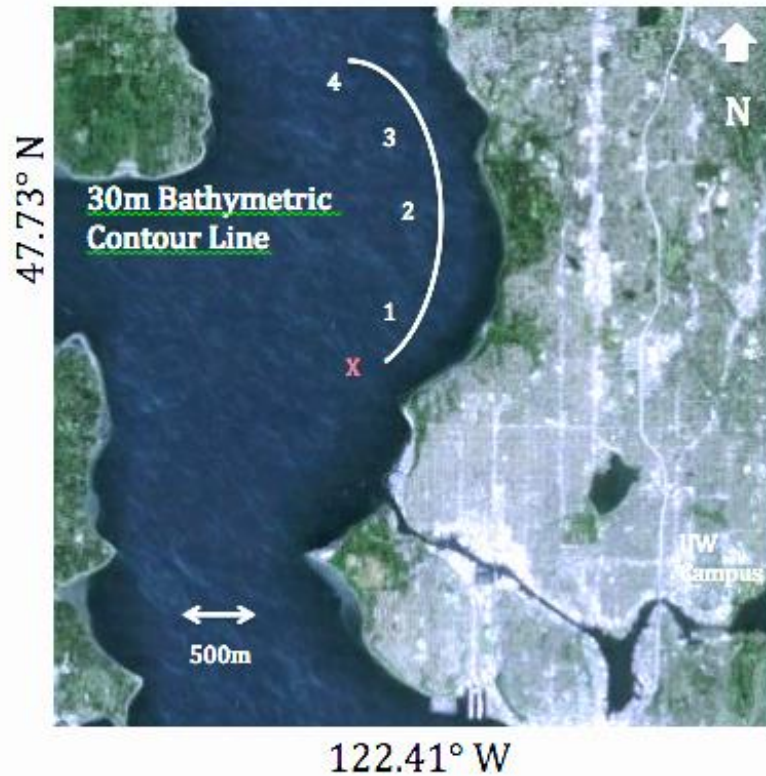


Figure 3. The array was deployed in the direction of tide propagation (North/South) following a 30m contour line (above) on Feb. 13th, 2016 during an ebb tide.

Data Analysis

The relationship of spatial stationarity in the rate of change in tide height when modeled by the semivariance equation (equation 1) (Isaaks, 1989) quantitatively represents Toblers Law of geographic pattern, which states, “everything is related to everything else, but near things are more related than distant things.” (Tobler, 1970). From this perspective semivariance compares the variation of paired observations at known distances apart to identify the spatial scale, or more explicitly the maximum spatial lag of stationarity. In the equation, $(\Delta T_6 X_i)$ is the average rate of change in tide height over 6 minutes at one location and $(\Delta T_6 X_i + h)$ is the spatial lag of observed pairs. Paired observations close to each

other typically have lower variance than paired observations farther apart. The spatial lag, at which the assumption of stationarity is not true, is the distance between paired observations where there is so much variance between the data points that you can no longer make accurate predictions of one location based on only knowing the distance from a measured point. The Kriging interpolation technique makes use of empirical observations of semivariance allowing observations at one location to be used to draw conclusions about another location, as long as the second location is within the spatial distance of the maximum spatial lag of stationarity.

$$\text{Equation 1: } \eta = \Sigma((\Delta T_6 X_i) - (\Delta T_6 X_i + h)^2) \div 2N$$

Results-

Raw Tide Data

There was a vertical offset due to slight differences in deployment depths, but since change in pressure is a linear relationship at 30 meters, this offset was corrected for by applying the rate of change at each sensor to the mean starting pressure at slack water (figure 5). Slack tide, where there is no change in pressure, occurred at 08:16 and 14:48 PST with a max rate of change at 11:02 PST. The northern most station experience the change from slack to ebb before the other stations, and from ebb back to slack before the other stations. The total pressure change during the ebb tide was 300 mbar, a total depth change of -2.15 meters.

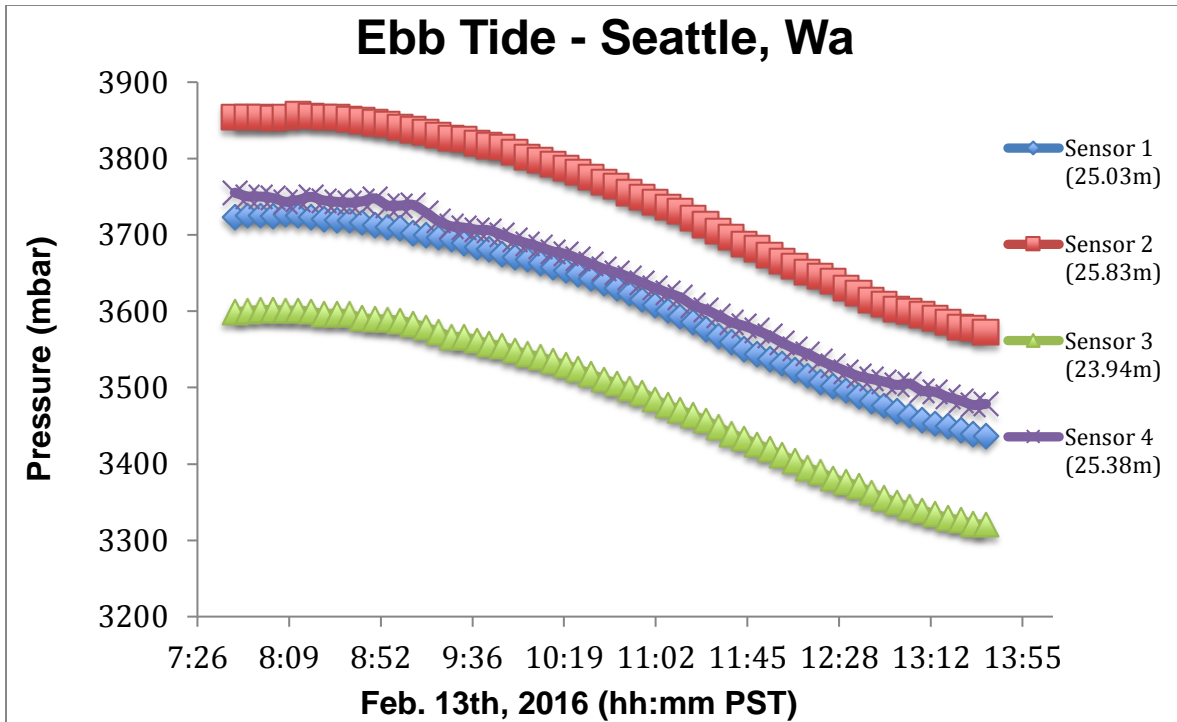


Figure 4. Pressure array data showing the 6 minute running average of bottom pressure during an ebb tide from four sensors. The vertical offset is due to the difference in deployment depth (see legend).

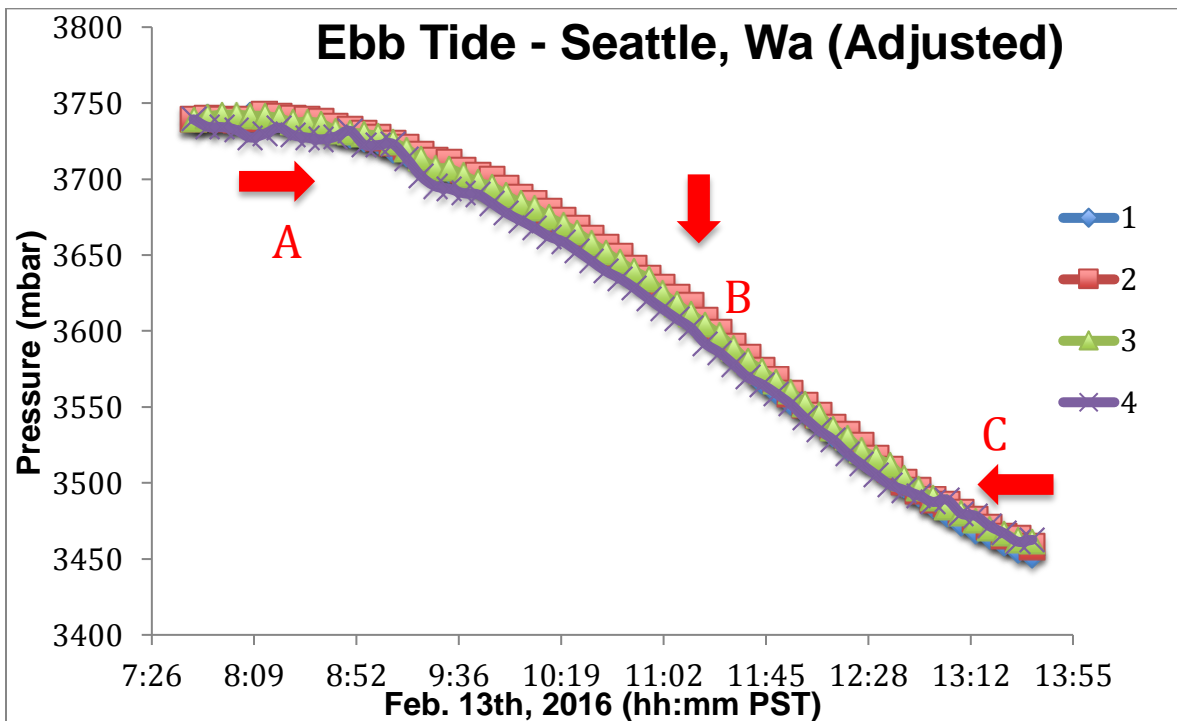


Figure 5. Tide data adjusted for difference in deployment depth. (A) The northern most sensor experiences change from high slack tide to ebb earlier than the sensors to the south. (B) The rate of change during the middle of the ebb tide does not propagate from north (#4) to south (#1). (C) The northern most sensor experiences change from ebb to low slack earlier then the sensors to the south.

Statistical Analysis

Variance in the rate of change based on distance between paired observations was evaluated using the semivariance equation. The semivariance in rate of change in pressure had a smaller range and magnitude at sensors in the array that were closer together than sensors that were farther apart (figure 6). The range of semivariance between stations 500 meters apart was 0 to 0.3 $\text{mbar}^2/6$ mins, the range of semivariance at 1000 meters was from 0.18 to 0.7 $\text{mbar}^2/6$ mins and the only data point at 1500 meters had a variance of 0.9 $\text{mbar}^2/6$ mins. The Sparkfun pressure sensor had a high-resolution module with accuracy of ± 0.2 mbar. Based on the data collected, 0.2 mbar equates to an error of 0.16 cm.

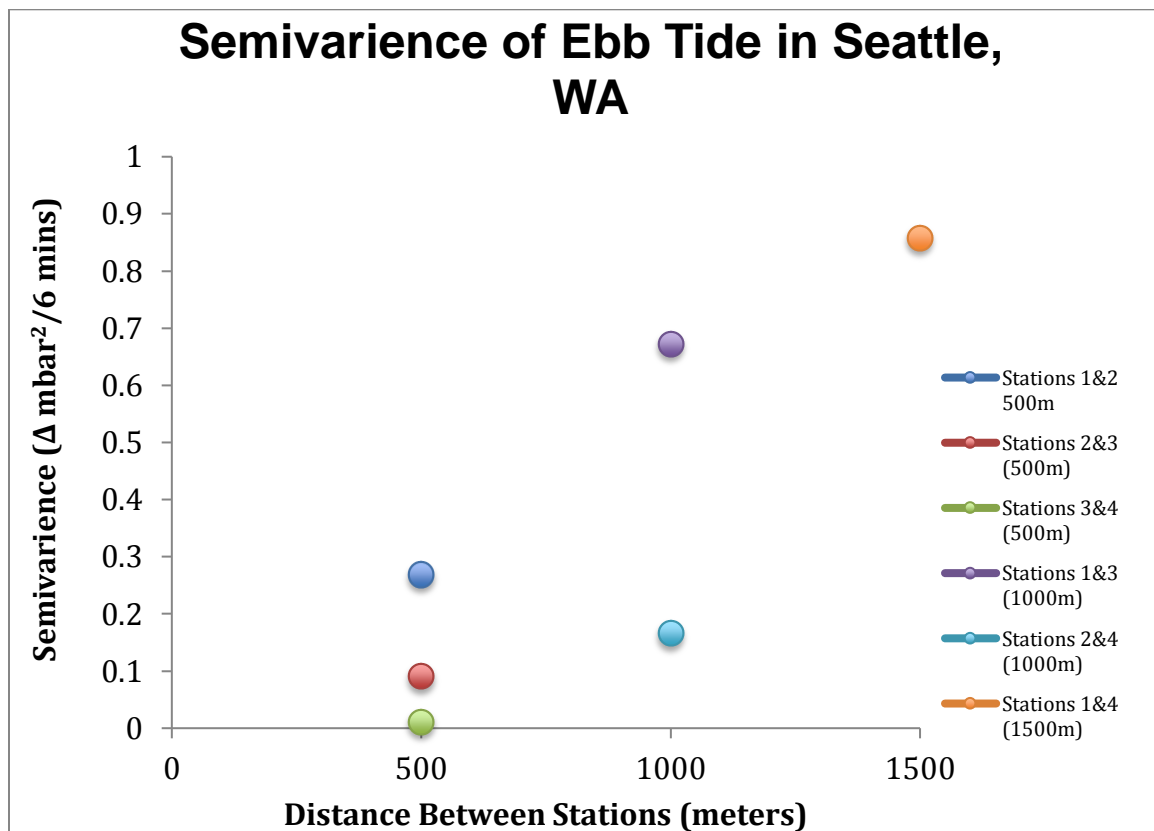


Figure 6. Semivariance demonstrates the variation in the rate of change. Sensors close together (500m) have a lower range and magnitude of variation in rate of change than the stations farther apart (1000m). The sensors that were farthest apart (1500m) experienced a higher magnitude of variation.

Discussion-

The pressure array performed in the field as expected. Each individual sensor was easy to deploy and recover. The sensors were inexpensive and each one successfully collected high-resolution tide data. In agreement with Chang (2002) the array demonstrated variation in the ebb tide along the axis of propagation. The rate of change observed between stations demonstrates the small-scale variation that Blair (1983) illustrated. Small-scale variability data is important to increase the accuracy of tide models in localized areas for high definition hydrographic surveying. At a maximum distance of 1500 meters apart, the empirical spacing of the paired observations was below the maximum spatial lag of stationarity of the semivariogram. This spatial lag represents the point where the semivariogram becomes asymptotic from high variance between paired observations and are therefore unrelated as a stationary process.

Conclusion

Hydrographic surveys in coastal areas that are subject to tides require accurate tidal corrections to ensure that the data used for maritime navigation and scientific research is precise. High-resolution surveys are important to monitor changes in geomorphic processes of the benthic layer, as well as for safety of maritime navigation. This research illustrates the importance of obtaining fine scale tide data in order to design and conduct high-resolution hydrographic surveys in coastal areas that have large tidal influences. Commercially built pressure sensors cost around \$650. At less than \$100 each, these pressure sensors make accurately monitoring tides during or before a hydrographic survey convenient and affordable.

The data is also useful for planning hydrographic surveys. Since most of the variation occurs along the axis of propagation, survey lines that run perpendicular to the tides would result in the least amount of error from changing tides. Since the maximum spatial lag of stationarity in rate of change of tidal propagation in the shallow waters of north Puget Sound is greater than 1500 meters, future studies focused on including longer length scales between paired observations would be beneficial to increase the certainty of this statistical relationship and identifying the actual scale of stationarity of the tidal process.

Acknowledgements

I would like to give a very special thank you to my advisor Miles Logsdon for the countless hours of guidance over the past year. Thank you for helping me materialize my ideas, for creating a well-appointed makers space to work in, organizing ship time and for not getting mad at me when I lost one of your HOBO sensor at sea. I would also like to thank Arthur Nowell for all the support over the past year. You were the metronome that kept order and sanity to this process.

References

- Carvel Blair, M. ASCE. 1983. Tidal Correction in Hydrographic Surveying. *J. Waterway, Port, Coastal, Ocean Eng.*, 109(1): 31-40.
- Chang, C.C., H.W. Lee, J.T. Lee, I.F. Tsui. 2002. Multi-applications of GPS for Hydrographic Surveys. *Department of Surveying and Mapping Engineering, Chung Chang Institute of Technology*, Vol. 125 p. 353-358.
- Isaaks, E.H., R.M. Srivastava. 1989. An Intro to Applied Geostatistics. *Oxford University Press*.
- Kieland, P., H. John. 1995. Using DGPS to measure the heave motion of Hydrographic Survey Vessels. *International Hydrographic Review*, Monaco, LXXII (1), March 1995.
- Scherneck, H.G. 1990. A parametrized solid earth tide model and ocean tide loading effects for global geodetic baseline measurements. *Geophys. J. Int.* 106, 677-694.
- Tobler, W.R. 1970. A computer movie simulating urban growth in the Detroit region. *Economic Geography* 46:234-240.
- U.S. Department of Commerce/ National Oceanic and Atmospheric Administration. May 2015. *NOS Hydrographic Surveys Specifications and Deliverables*.
- CARIS HIPS and SIPS 8.1 *User Guide*. 2013