Title:

Tides under the Ice: Measuring Water Levels at Barrow, Alaska 2008-2010

Authors:

Lead Author:

Steve Gill, Senior Scientist

NOAA/NOS/CO-OPS

1305 East-West Highway, Silver Spring, MD 20910

301-713-2981 x 139

stephen.gill@noaa.gov

James Sprenke, Electronic Engineer

NOAA/NOS/CO-OPS

1305 East-West Highway, Silver Spring, MD 20910

301-713-2897 x 132

james.sprenke@noaa.gov

Jena Kent, Oceanographer

NOAA/NOS/CO-OPS

1305 East-West Highway, Silver Spring, MD 20910

301-713-2890 x 169

jena.kent@noaa.gov

Mike Zieserl, Surveyor

JOA Surveys, LLC

2000 E. Dowling Rd, #10

Anchorage, AK 99507

(907) 561-0136

mike@joasurveys.com

Abstract:

NOAA's Center for Operational Oceanographic Products and Services (CO-OPS) has developed an innovative system design to collect water level data in remote cold climate regions where winter sea ice precludes traditional tide station installations. In August 2008, two specially designed bottom-mounted water level gauges were deployed approximately 2 miles off the coast of Barrow, Alaska in 100 feet of water. The systems were equipped with a high-stability pressure sensor, conductivity sensor, an acoustic modem, a disposable ballast, and a pop-up buoy for recovery. Both systems were recovered one year later, in August 2009, and redeployed to collect a second year of water level, water temperature, and salinity data with recovery in August 2010. Data was successfully retrieved through the acoustic modem from a local skiff during the ice free season and through the sea ice during the winter. The continuous two-year water level record will help in understanding seasonal variability and climate change on the North Slope. The data show strong correlation with the water levels observed to the east at Prudhoe Bay and show very similar response to weather forcing. Correlation analysis with Prudhoe Bay data will be summarized as well as analyses of the observed versus predicted tide.

Introduction

Project Background

Based on a recent NWLON gaps analysis (Gill and Fisher, 2008), there are large spatial gaps in water level and tidal datum information for the coastal areas of Alaska for the Chukchi Sea and the North Slope. This has been largely due to the extreme environment, the remoteness, the lack of existing infrastructure on which to establish the equipment and the relatively low programmatic priority. This priority has increased in recent years spawned by trends in increased number ice-free days along the North Slope and these stations were deployed while NOAA was developing a formal arctic strategy (NOAA, 2011).

In 2006, the Center for Operational Oceanographic Products and Services (CO-OPS) obtained funding and awarded JOA Surveys the task of measuring the water level along the Alaska coast. Locations chosen for installation include the Chukchi and Beaufort Seas, with short term summer installations in Point Lay, Wainwright, and Kaktovik, and a minimum year-long deployment at Barrow. The objective was to provide tidal datum infrastructure for possible hydrographic, shoreline and remote sensing surveys as well as for tide table predictions, coastal engineering, and coastal zone management. After the locations were selected, the planning and preparation phase began in November 2006. This paper describes the Barrow tide station only and subsequent technical reports will also address the short-term deployments. The Barrow data collection ran from August 2008 through August 2010.

Project Setting

Barrow, the northernmost city in the United States, is 725 air miles and two mountain ranges from Anchorage, but despite its remoteness, it is a large city by Alaskan standards (Figure 1). The population is greater than 4,000. There are gravel roads, street signs, multi-story buildings, cell service, sewer and water, commercial chain stores, hotels, restaurants, and daily service by Alaska Air and commercial air freight companies.

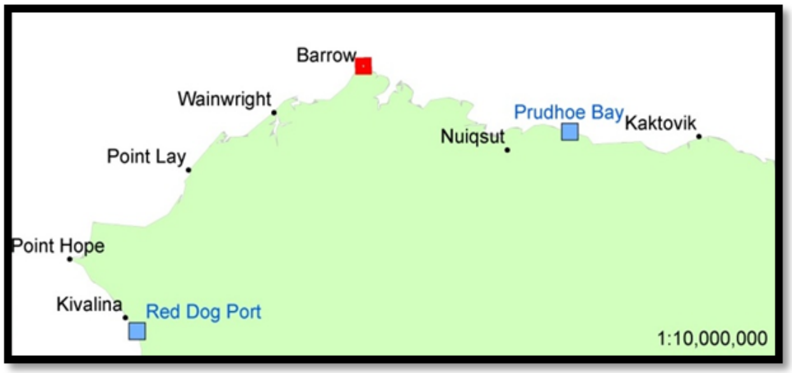


Figure 1. Location map of Barrow Alaska

There are limited marine facilities and there is no harbor, although there is a concrete boat ramp in Elson Lagoon, five miles northeast of town, and a moveable boat ramp that can be deployed on the gravel beach in front of town when there is calm weather in the Chukchi Sea. Boats are a big part of summer life in Barrow. Along with a dog, ATV, and snow machine, many homes have a boat in their front yard. Local boats are typically open skiffs with outboards. Large landing craft and fuel barges bring supplies to Barrow or pass by on their way to the oil fields near Prudhoe Bay during the summer; otherwise most boats in Barrow are launched from a trailer.

There have been U.S. scientific observatories in Barrow since the 1880's, and the former Naval Arctic Research Lab (NARL) which began in the 1940's still houses numerous government and university research programs. In addition, the NOAA Earth System Research Laboratory currently maintains a Global Monitoring facility at Barrow.

Figure 2. Chris Stein, LCMF, next to historical tide gauge from 1956 at Eluitkak Pass on Beaufort Sea northeast of Barrow. Oil in this well rose and fell with the underlying sea level.

The nearest permanent NOAA National Water Level Station Observation Network (NWLON) stations to Barrow are 200 miles east at Prudhoe Bay (Figure 1), and 400 miles SW along the coastline at Red Dog Port. There have been several short-term tide gauge installations over the years at Barrow to support oceanography and hydrographic surveying, and some demonstrated innovative solutions to the challenges of recording water levels in an Arctic climate with sea ice most of the year (see Figure 2 above).

Sea ice can appear in Barrow any month of the year, but Barrow is typically ice locked from November to July. During the winter, a land fast shelf of ice forms along the coast and can extend several miles offshore. This ice shelf is constantly attacked by the offshore ice pack, buckling and creating pressure ridges that can rise more than 20ft in the air and descend 90ft below the surface. Despite the notion of a frozen arctic sea, the ice is almost never at rest (Figure 3a and 3b).

Figure 3a. Barrow in summer

Figure 3b. Barrow in winter

In addition to defining the appropriate technical and logistical approach, another significant consideration was whaling. In Alaska towns that continue subsistence whaling, by far the most important authority on maritime matters is an informal one, the whaling captains. The majority of residents in Barrow are Inupiat Eskimos and spring and fall whaling are an active part of the culture, and the community is very sensitive to any activities in the near shore waters. JOA worked around the whaling seasons, avoiding field operations during fall whaling (late September – October) and spring whaling (mid-March – early May) and consulted with the North Slope Borough Wildlife Department to make sure the proposed work and schedule would not interfere with whaling. JOA also hired local personnel in Barrow through LCMF, a local surveying and engineering firm with a field office in Barrow, who contributed crucial local knowledge and skills towards the success of this project.

Instrumentation Design

Since there are no coastal structures for mounting a water level sensor, and a normal shore based bubbler pressure tide gauge installation would likely be destroyed by the fall storms or by the sea ice, JOA recommended deploying an underwater pressure sensor in water deep enough to escape the downward extent of passing pressure ridges, but near to shore and in a small form factor so as to allow recovery and deployment with the resources available in Barrow. Available information on the Chukchi Sea indicated that the 30 m (100 ft) depth curve was a relatively safe contour to use to escape ice gouging. After reviewing the local bathymetry and scant current record, it was decided to deploy two identical platforms (for redundancy) 3.2 km (2 mi) WNW of the NARL in water 30 m (100 ft) deep.

The water level sensor chosen by CO-OPS for this task was a Seabird SBE26+, which measures water temperature and pressure and records the data internally. In addition, a Seabird SBE4M conductivity sensor was wired into the SBE26+ and all data was logged on the standard NOAA six minute interval, averaging 180 seconds of pressure measurements for each reading. Data could be downloaded through a Linkquest acoustic modem, which had an external battery pack to ensure that it would last for an entire year with sufficient capacity for multiple downloads. The anchor had no surface expression (nothing to be snagged by passing ice) so recovery was be by an ORE CART acoustic release and two floats.

Vessels with overhead lifting capability are not common in Barrow. If a larger vessel with a capstan and suitable deck was available for recovery, the underwater assembly could be dragged over the gunwale and probably flipped onto the deck. The assembly construction would have to protect all the instruments. Just general handling without overhead lifting demands a "lightweight" assembly. CO-OPS designed a fiberglass box shaped frame to house the instruments and protect them from rough handling. The frame has a square footprint a little over a meter on a side and sits about ¾ meters high. The joints on the platform were glued together and also secured with both stainless steel and fiberglass bolts. The recovery U-bolts were also part of the design. While the instrument loaded frame weighs almost two hundred pounds in air, it loses much of that in water because of the low density of the fiberglass, the recovery float, and the buoyancy of the various instruments. One hundred and fifty pounds of steel rebar is added just before deployment to help the frame stay in place in the expected one and a half knot currents. The steel was dropped as the instrumented was recovered (see Figure 4a). Severe stainless steel corrosion was reported on other deployments, however overall severe corrosion was not experienced, with only a few spots where anoxic condition might have existed. Anti-foulant was not used as it was assumed that bio-fouling would be a minimum in cold waters (see Figure 4b).

To do the periodic data recovery through the acoustic modems, commands issued through a simple terminal program allowed faster data downloads. This required more attentiveness by the observer, but avoided the troublesome "handshaking" required by the standard data recovery software. The penalty was a few errors had to be manually corrected in the binary data, and also some simple software was needed to reformat the data for standard processing.

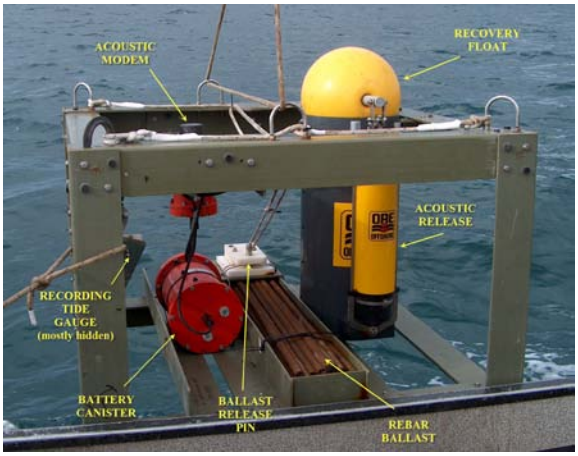


Figure 4a. Platform just before deployment

Figure 4b. Platform after recovery.

Deployment, Maintenance, and Recovery

Bench marks

Tidal bench marks serve as a stable reference point from which to check the stability of the water level sensor, as well as a permanent reference point from which the tidal datums can be recovered. Bench mark stability was a concern in Barrow because of the underlying permafrost. There is no exposed bedrock near Barrow and driven stainless steel rods would likely be unstable due to the freeze/thaw cycle, so non-traditional bench marks were used instead. The building support piles of the new Barrow Global Climate Change Research Facility, set in drilled holes and wrapped in plastic sleeves at depths of up to 30ft, were scribed and stamped. These marks proved stable (within 1mm) for the two year project duration (see Figures 5a and 5b).

Figure 5a. Pilings on the Barrow Global Climate Change Research Facility were used as tidal bench marks.

Figure 5b. Stamping and datum point for tidal bench mark 949 4935 D.

Sensor Deployments

Deployment of the sensor platforms required only small boats and human muscle. For the original deployment scheduled for late July 2008, JOA and CO-OPS personnel assembled and tested the platforms in Barrow. The anchor design was ideal for remote operations with limited boat selection. The anchors could be moved by hand with 2 – 3 people when unweighted. The anchor weight was simply 150 pounds of 1 inch rebar cut to length to fit in a fiberglass channel at the base of the platform. Fully weighted the platforms weighed 400lbs each.

The original deployment date at the end of July 2008 was postponed due to unusually dense sea ice, and JOA returned in early August for the second attempt. Chris Stein from LCMF towed the anchors on an inflatable 14 ft cataraft to the deployment location with his 18ft skiff. Once on site, the anchors were lowered through the open frame in between the pontoons of the cataraft (Figure 6).

Figure 6. Cataraft used for the intial deployment

In 2009, anchor deployment was accomplished with a local whaling captain's boat (Figure 7a and 7b).   Crawford Patkotak's 26ft boat added the comfort of an enclosed, heated cabin and homemade davit. Again, the light, self protecting design of the anchors made the deployment possible from a small boat with limited lifting equipment.

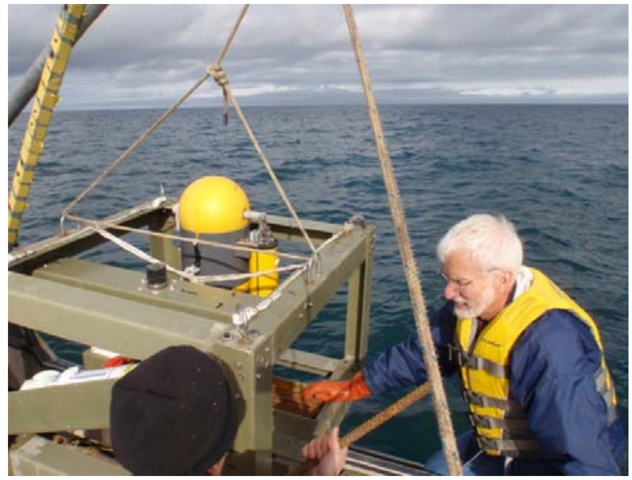


Figure 7a. Crawford Patkotak's boat with homemade davit used to deploy anchors in 2009, and recover anchors in 2010.

Figure 7b. Jim Sprenke(CO-OPS) loading rebar for weight into fiberglass anchor prior to deployment, August 2009.

Staff Observations

The water level measurements made by the underwater sensors were referenced to the onshore bench marks by a series of level runs from the bench marks to the water surface throughout the deployment period. A permanent staff was not constructed because there were no suitable structures, and storms and ice would have destroyed any temporary installation. Instead, levels were run on a monthly basis to the water's edge, and one hour of ocean heights (10 observations) were recorded by an observer with a rod standing in the water. Staff shots during the winter were made by drilling a hole through the ice. Winter staff observations were more consistent, while waves during the open water conditions made water level observations more difficult (see Figures 8a and 8b.)

Figure 8a. "Staff shots" are a method of measuring the water level relative to the bench marks. October 2008.

Figure 8b. Staff shots in March 2009, -20 Deg. F. Drilled hole 4ft through ice to reach water. Same location as picture to left.

Data Download

Both underwater platforms had an acoustic modem to allow downloading data while deployed. The acoustic modems worked very well through both years of the deployment. Download visits were scheduled as weather conditions allowed, and only 2 to 3 downloads were attempted between deployment and recovery each year. During the open water months, the download process was done from an open skiff with the receiving acoustic modem weighted and hanging several feet underwater. The download took approximately ½ hour per platform, and because of a consistent 1 – 3kts current setting to the NE, demanded an excellent skiff driver to stay within several hundred feet of the platform location.

During the winter, JOA planned to travel out onto the shore fast ice over the anchor locations, and drill a hole through the ice in order to download data with the acoustic modem. This proved to be a difficult task as the anchors were far enough offshore that they were typically near or beyond the shore fast ice edge and ice conditions could change rapidly. Through-the-ice download trips were attempted twice, with mixed success.

The first trip was attempted in late February / early March in 2009. Based on MODIS satellite imagery and sea ice radar from the UAF Snow Mass Ice Balance website, it appeared that the land fast ice shelf extended out over the anchors. Mike Zieserl (JOA) went to Barrow and traveled out on the ice with Chris Stein (LCMF) and a support crew with snowmachines and sleds only to discover that the ice shelf they had hoped to work on had broken off the night before (see Figures 9a and 9b).

Figure 9a. Snowmachine with sled for towing computer, acoustic modem, ice auger, gas, picks, shovels, food, blankets and guns for polar bear protection.

Figure 9b. Route finding through the ice can be a challenge. The small dots in the picture are Abe and Chris Stein on 20ft high ice blocks.

An alternative plan was formed to sledge a skiff out to the new open water lead. For this project, the resources of the Barrow Arctic Science Consortium (BASC) were used to help with a day of trail breaking through the rough ice, arranging a boat and outboard motor, thawing them out and testing the motors in the BASC heated staging facility. After waiting through another day of high winds and -35F weather, the boat, outboard motors and equipment were finally transported out to the open lead. Unfortunately, both motors had been broken by the rough transit through the ice. By the next day, ice conditions deteriorated and the download trip was cancelled.

Working with local guides was essential for these offshore ice trips. Along with excellent snowmachine skills and route finding, their years of experience reading the ice is required for safe travel offshore. During ice travel, the field crew also regularly checked in with the North Slope Borough Search and Rescue team. The ice can feel solid and appear so level as to encourage overconfidence. While it may be several feet thick in one location, it may be nothing but hardpack snow and hoarfrost covering 30 Deg. F water in another (Figure 10).

Figure 10. Smooth pan ice was the best for travel, but could also be the most unpredictable

Along with local guides, the ice download trips would not have been possible without the availability of daily MODIS satellite imagery and local sea ice radar imagery. The NASA JPL MODIS Imagery was immensely valuable for seeing the overall ice picture. The UAF Barrow Sea Ice Radar, part of the Barrow Sea Ice Mass Balance site, was also valuable for viewing near real time ice conditions and evaluating the possibility of traveling on the ice to download the tide gauges.

Fortunately, conditions were more favorable in spring 2010, and the second through-the-ice download trip was a relatively easy success. The trip took place after the spring whaling season. The whalers build camps near the open lead and break well groomed trails through ice. By chance, one of the trails traveled directly over an anchor location, and the second anchor only required a few hundred feet of trail breaking. Both tide gauges were quickly downloaded through the acoustic modem. The acoustic modem worked very well through the ice, and was even able to connect to Platform 1 from the Platform 2 ice hole, approximately 1.5km away (see Figures 11a and 11b).

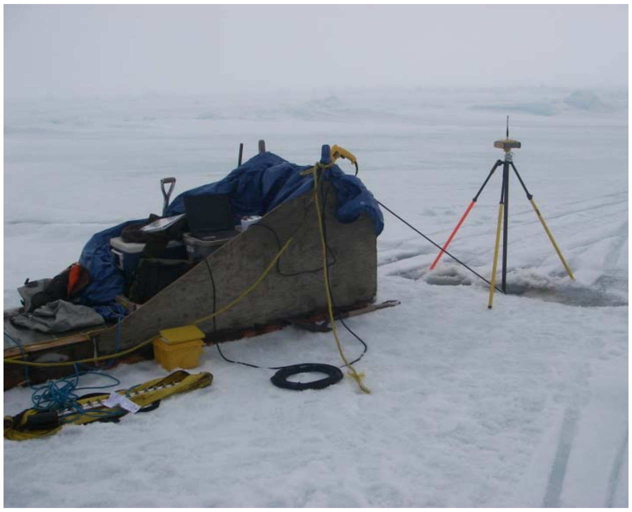


Figure 11a. Downloading tide data through the ice.

Figure 11b. This hole was drilled 4ft deep before hitting sea water.

Recovery

The sensor platforms were recovered and redeployed in August 2009, and finally recovered again in August 2010. Recovery was by an acoustically released buoy. The buoy line was attached to the four corners of the anchor frame, but also had a tag line connected to a metal pin in the fiberglass channel holding the rebar weight. When the buoy line was pulled, it pulled a release pin that dumped the rebar weight, making the anchor relatively light for retrieval. Another important design feature was the fiberglass anchor frame which enclosed all of the instruments and protected them from rough treatment.

Stormy weather prevented the field crew from using the planned small boat for recovery in August 2009, but a Bowhead Marine landing craft waiting to load equipment for Prudhoe Bay gave the field crew a 2 hour window to recover the anchors. The landing craft captain was a former crabber in the Bering Sea, and after the acoustic releases were triggered he did an amazing job of moving the landing craft onto the buoys so the deck crew could snag them with a throwing hook. Both anchors were pulled up on the stern winch, rolled onto the deck, and jostled across the landing craft deck to the bow. The landing craft returned to shore for just enough time for the field crew to toss the anchors on the beach and jump off before it sailed for Prudhoe Bay (Figure 12).

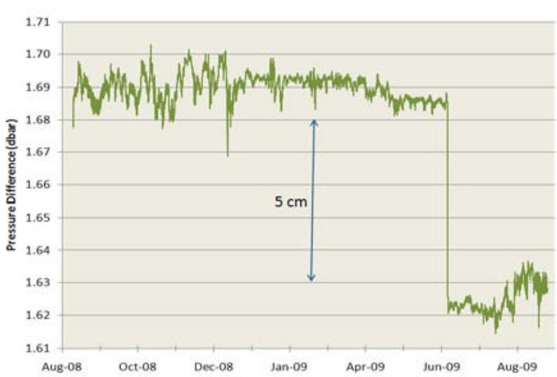
After recovery, the instruments were removed from the anchors, cleaned, batteries and desiccant packs replaced, O-rings inspected, data downloaded, clocks reset, and the conductivity sensor was remounted in a vertical position to try to prevent silt from clogging the glass cell. Although generally the fiberglass anchor and stainless steel parts held up very well, there was one point of significant corrosion on a stainless steel bale on an acoustic release which had to be replaced.

Figure 12. Anchors and platforms delivered on shore with Bowhead Marine landing craft departing for Prudhoe Bay.

Final recovery of the anchors in 2010 was accomplished with Crawford Patkotak's boat with homemade davit and a battery powered anchor capstan. When the buoys were first released they popped to the surface but then were immediately pulled under by the strong current. Upon returning a couple days later, the current had lessened and both buoys were found on the surface. Hoisting the anchors with the battery powered capstan went smoothly. Back onshore the equipment was cleaned, disassembled and shipped back to the CO-OPS in Seattle.

Data Analyses

Figures 13a and 13b analyze the platform vertical stability. Comparing just the raw pressures, in the first year the two platforms stayed within a centimeter of each other until June when P1 seemed to drop 6 cm in just a few minutes. In the second year, there was no abrupt change, but two periods when P1 sunk ~3 cm over a few days and a small sinking at the end.



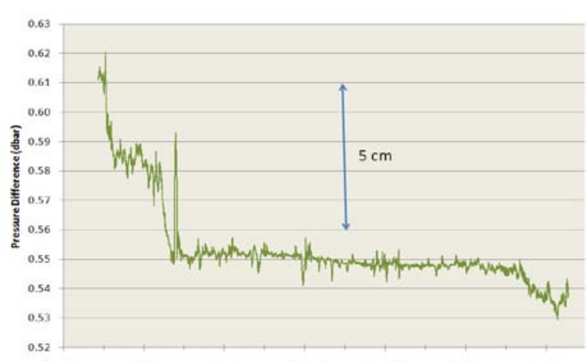


Figure 13a. Platform Stability Check 1st year **Figure 13b.** Platform Stability Check 2nd year

Each of the platforms had a conductivity sensor for computing salinity (PSS-78). The two tracked well for about a while but then differed on and off (Figure 14a and 14b). At first year recovery, sediment and some partial blockage in one sensor probably accounts for some of the difference. The first year the conductivity cells were diagonal in the platforms. They were repositioned to vertical for the second year and had a little better performance. The data from Platform 2 was ultimately used for processing and analysis.

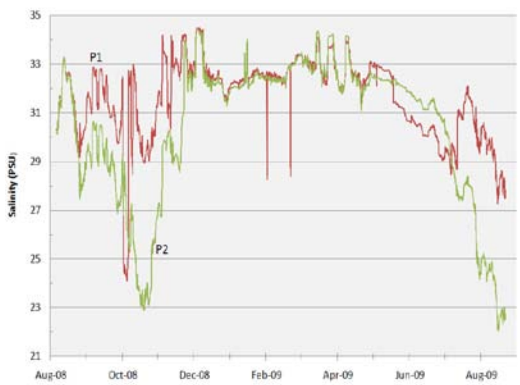


Figure 14a. Salinity time series 1st deployment

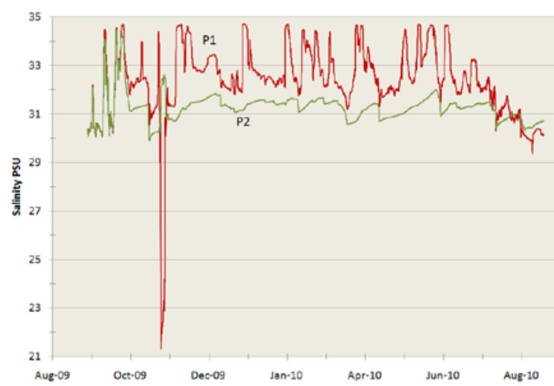


Figure 14b. Salinity time series 2 nd deployment

The absolute pressures measured by the underwater pressure gauges were corrected with hourly barometric pressures from the airport a few miles away. Gaps in this barometric pressure time series were filled in with data from the NOAA Climate Monitoring and Diagnostics Laboratory observatory. This hydrostatic pressure along with salinity, and temperature were used to compute the equivalent water height above the sensor (using EOS-80). Some of the salinity values used was a best estimate from the two sensors.

The original data from the two separate deployments were relative to the individual sensor zero elevations, and thus were offset because the re-deployment, although close to the first, was at a lower depth. Simultaneous measurements form the water level sensors and the staff shots were compared. Analyses of the staff-to-gage differences for each deployment period were used to adjust each time series to a common vertical reference. This vertical reference zero, or Station Datum at Barrow, was defined as 50.000m below the elevation of the primary bench mark "9494935F". The statistics of the overall averages of the staff shots showed consistency and low variability over the deployments periods. Once the data were referenced to a common datum, there was a small break in the time series in between the deployments. Since the break was less than three days and the simultaneous data comparison with data from Prudhoe Bay showed good comparison, the break was filled using standard procedures for gap filling. This resulted in a continuous time series for analysis from August 10, 2008 to August 18, 2010.

High and low tides and hourly heights were tabulated each month, and monthly means computed using NOS/CO-OPS standard operating procedures. The type of tide at Barrow and Prudhoe is classified as mixed, mainly semidiurnal, for which two high waters and two low waters are expected each tidal day. Frequently, however, the effects of local weather on the water levels were strong enough that the tides were "masked" and could not be tabulated. This is also the case for Prudhoe Bay. Figure 15 is a plot of simultaneous observed hourly heights for the Barrow deployment period in which the similarities in water level variations between Barrow and Prudhoe Bay are quite evident. These areas have relatively shallow water and weak tidal forcing and have frequent passage of strong storms and frontal passages transiting the region. Barometric pressure changes and wind stress significantly affect daily water levels.

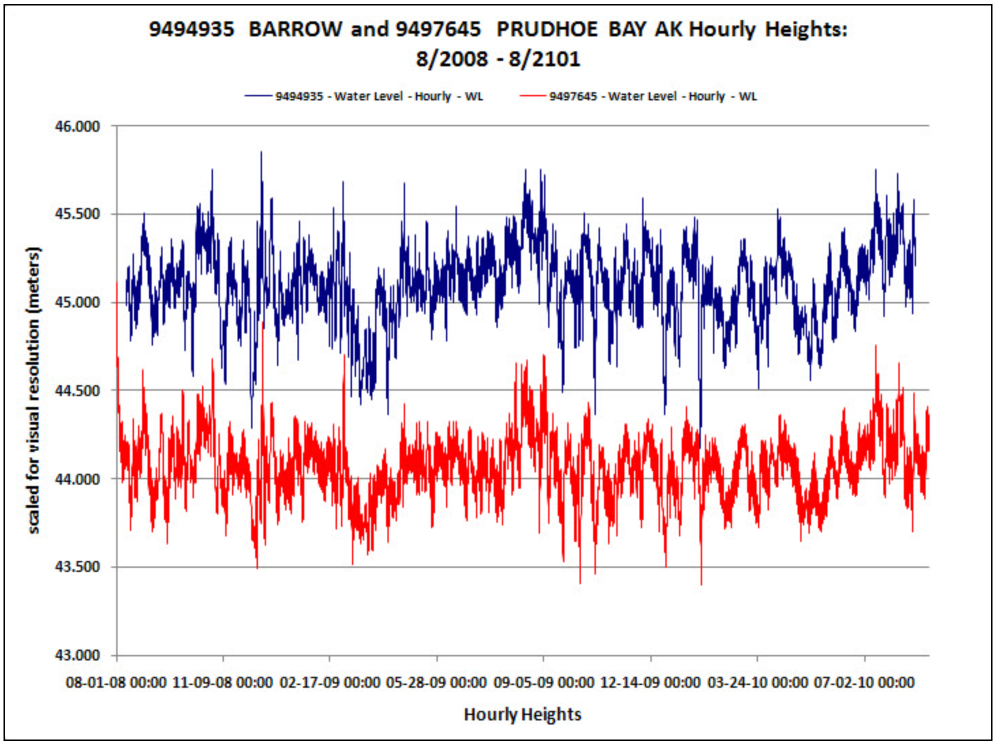


Figure 15. Observed hourly water levels at Barrow and Prudhoe Bay, AK

Monthly means and extremes were computed for each calendar month of data and are shown in Figure 16 for the two years of data. The strong seasonal effect is readily seen and is due to seasonal weather patterns and ice cover. The Highest (HWL) and Lowest (LWL) observed tides are more due to the effects of weather than the monthly variations in the astronomical tide. The other parameters plotted are monthly Mean High Water (MHW), monthly Mean Sea Level (MSL), and monthly Mean Lower Low Water (MLLW). Higher tides and sea levels are generally found in July through September of each year.

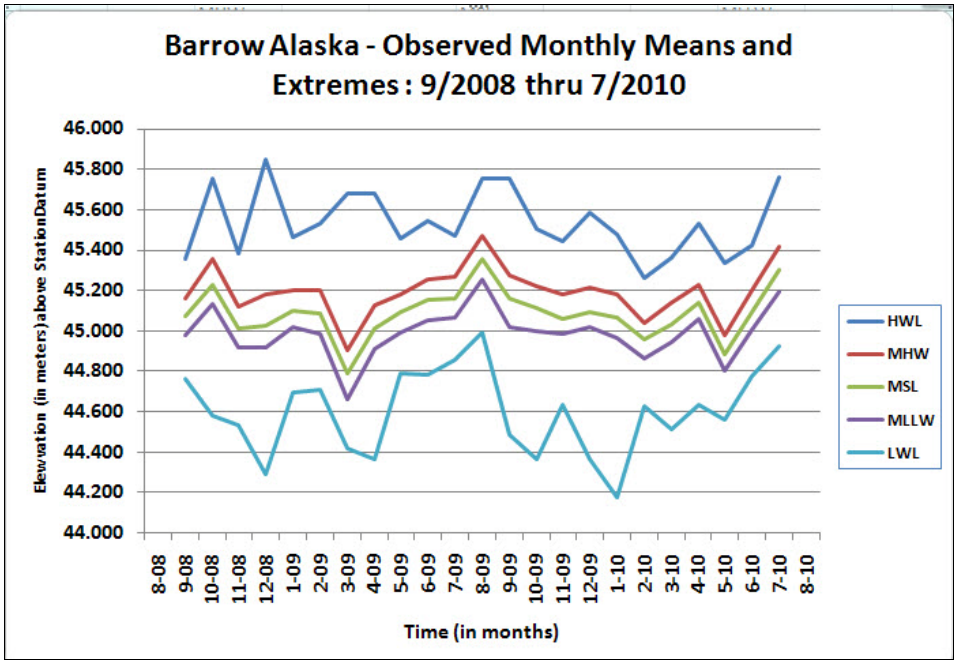


Figure 16. Observed monthly means and extremes at Barrow, AK.

Tidal datum elevations at Barrow were computed from simultaneous comparison of monthly mean observations (NOAA, 2003) with the control station at Prudhoe Bay. The accepted tidal datums at Prudhoe Bay are based on a 10-year time series. Figure 17 shows the elevations of the tidal datums and the reference ellipsoid relative to Station datum and the elevation of the primary bench mark "949 4935F". The mean diurnal range of tide (MHHW-MLLW) is only 0.20m.

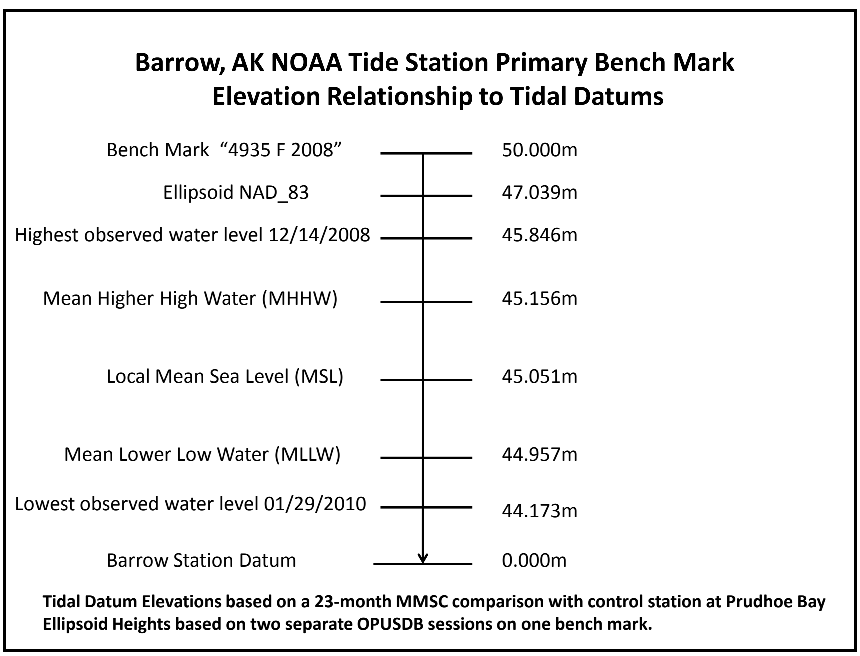


Figure 17. Elevations of the tidal datums at Barrow, AK.

Predicted time series for Barrow were developed using harmonic constants obtained from the average of two, one-year standard NOAA Least Squares Harmonic Analyses (LSQHA) for a standard set of 37 harmonic constituents (Parker, 2007). Figure 18 is a plot of the observed and predicted hourly heights for the two-year deployment. It is quickly seen that the predicted and observed tides do not agree very often with the observed tides having much more variability and having many more high and low extremes. The seasonal variation in the predicted tides is also seen to be larger than the predicted daily variation of the tides.

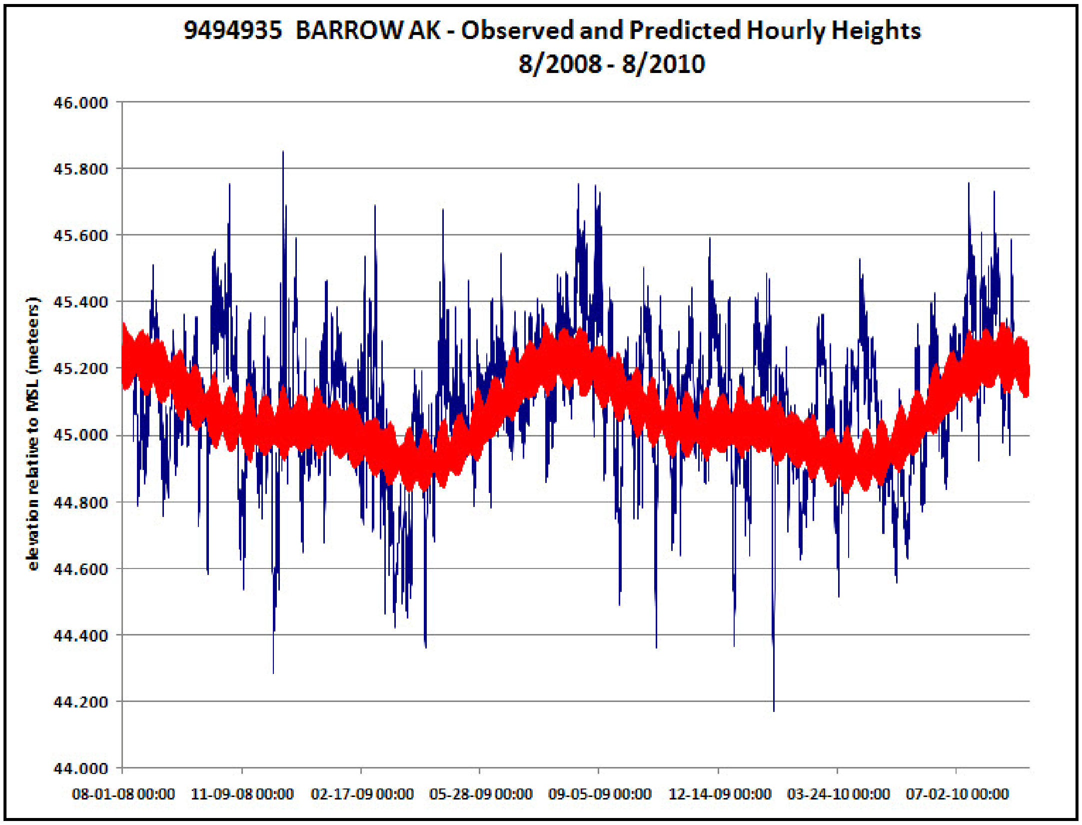


Figure 18. Observed and predicted hourly heights at Barrow, AK.

The statistical reduction of variance analysis from the LSQHA shows that only approximately 27% of the variability in the hourly heights is potentially due to tidal forcing. And of this 27%, 19% of that is due to the long-period Sa (annual) and Ssa (semi-annual) constituents. Both of these constituents are forced not by the astronomical tides, but by the seasonal variations in mean sea level. Thus, the true tidal forcing from the rest of the 35 tidal constituents is only approximately 8%. This is consistent with what is found from the tabulations, from the hourly height plots and noting the low range of tide obtained from the datum computation. Traditional NOAA tide prediction methodology will not predict the tides well at Barrow, AK.

For context with longer term mean sea level variations, Figure 19 shows that Barrow monthly mean sea levels plotted with the longer record from Prudhoe Bay, which goes back to 1993.

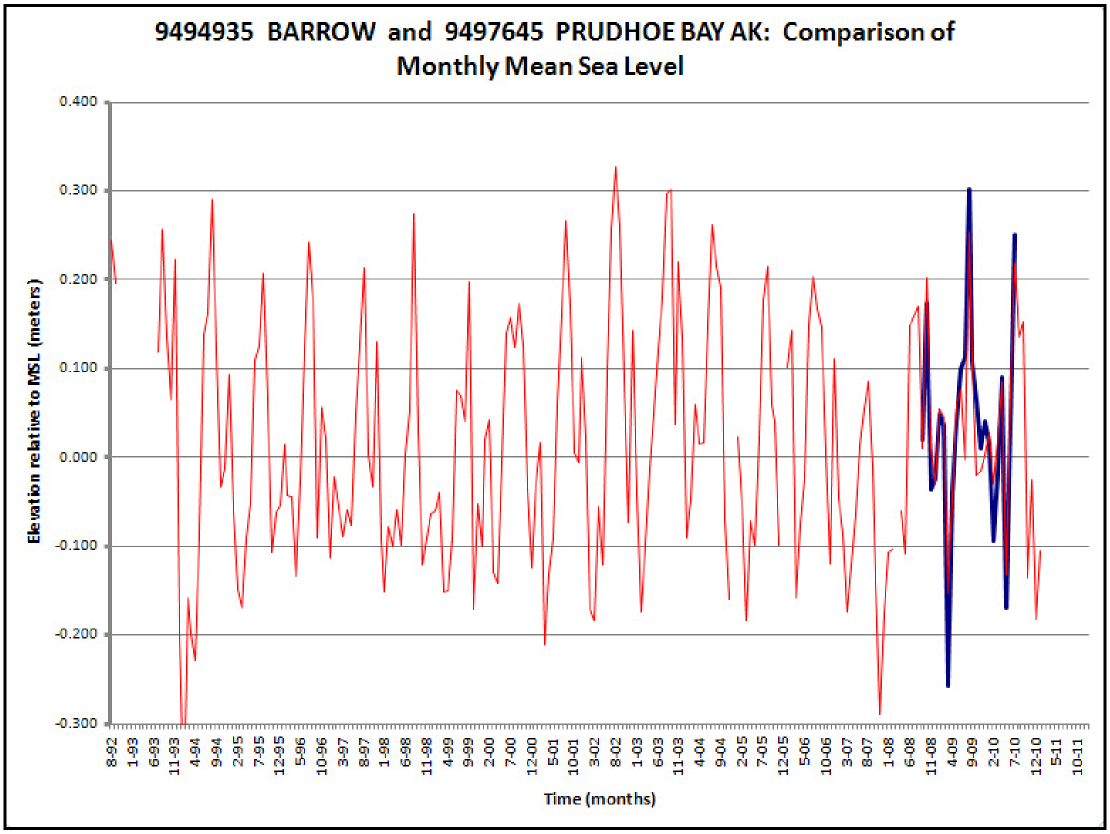


Figure 19. Comparison of monthly mean sea level at Prudhoe Bay and Barrow, AK.

Conclusion

This project attempting to collect year-around water level data from Barrow, Alaska was highly successful. The partnership between NOAA CO-OPS and JOA resulted in a strong team that was required for completing a difficult project in an extreme environment. The data obtained represent one of the most unique and valuable data sets collected by NOAA on the North Slope and the results are already contributing to improving the vertical reference system for the region.

References

Gill, S.K. and K.M. Fisher, 2008. A network gaps analysis for the national Water Level Observation Network, NOAA Technical Memorandum NOS CO-OPS 0048, NOAA/NOS Center for Operational Oceanographic Products and Services, Silver Spring, MD, 50 pp.

NOAA, 2011. NOAA's Arctic Vision and Strategy, February 2001. Available at: http://www.arctic.noaa.gov/docs/NOAAArctic_V_S_2011.pdf

Parker, B.B., 2006. Tidal Analysis and Prediction, NOAA Special Publication NOS CO-OPS 3, NOAA/NOS Center for Operational Products and Services, Silver Spring, MD 378pp.