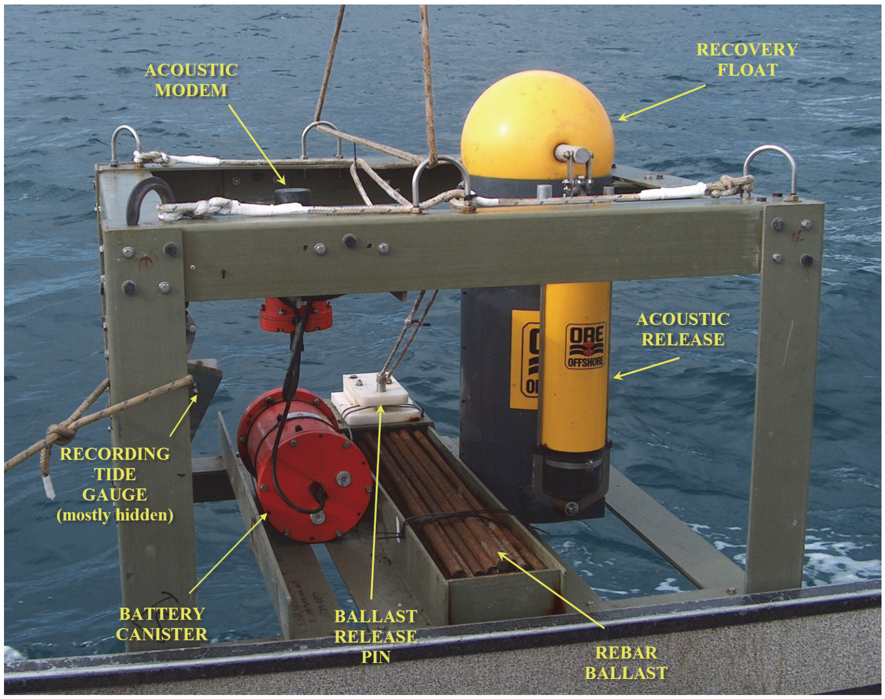
NOAA Technical Report NOS CO-OPS 062

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



Silver Spring, Maryland
September 2011

noaa National Oceanic and Atmospheric Administration

U.S.DEPARTMENT OF COMMERCE
National Ocean Service
Center for Operational Oceanographic Products and Services

Center for Operational Oceanographic Products and Services

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The National Ocean Service (NOS) Center for Operational Oceanographic Products and Services (CO-OPS) provides the National infrastructure, science, and technical expertise to collect and distribute observations and predictions of water levels and currents to ensure safe, efficient and environmentally sound maritime commerce. The Center provides the set of water level and tidal current products required to support NOS' Strategic Plan mission requirements, and to assist in providing operational oceanographic data/products required by NOAA's other Strategic Plan themes. For example, CO-OPS provides data and products required by the National Weather Service to meet its flood and tsunami warning responsibilities. The Center manages the National Water Level Observation Network (NWLON), a national network of Physical Oceanographic Real-Time Systems (PORTS®) in major U. S. harbors, and the National Current Observation Program consisting of current surveys in near shore and coastal areas utilizing bottom mounted platforms, subsurface buoys, horizontal sensors and quick response real time buoys. The Center: establishes standards for the collection and processing of water level and current data; collects and documents user requirements which serve as the foundation for all resulting program activities; designs new and/or improved oceanographic observing systems; designs software to improve CO-OPS' data processing capabilities; maintains and operates oceanographic observing systems; performs operational data analysis/quality control; and produces/disseminates oceanographic products.

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

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September 2011

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Acknowledgements

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Executive Summary

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, 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. This project represents the specific development of water level measurement technology for long-term deployment in the Arctic environment and the continuous two-year water level record has supported the understanding of 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 including very similar response to meteorological forcing. The data obtained represent one of the most unique and valuable data sets collected by NOAA on the North Slope and the results have already contributed to an improved vertical reference system for the region.

1.0 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 of increased number of 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 north slope of 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 subsequent deployment of the Barrow tide station. 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, cellular service, sewer and water, commercial chain stores, hotels, restaurants, and daily service by Alaska Air and commercial air freight companies.

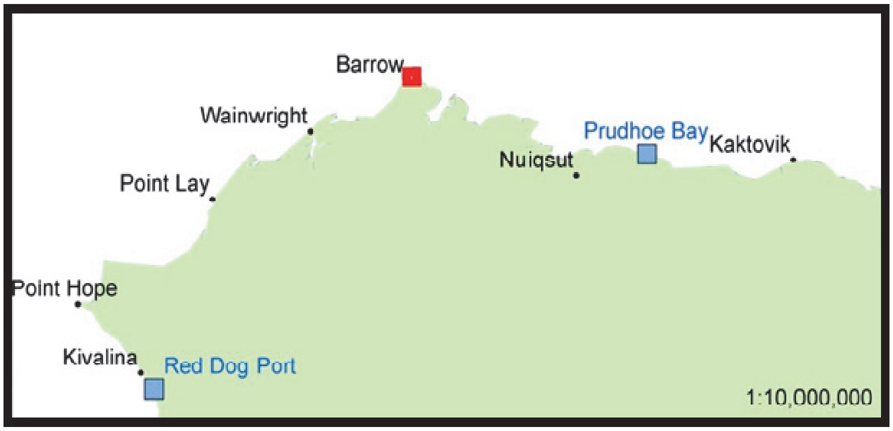

Figure 1. Location map for Barrow, Alaska

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 in Barrow.

Figure 2. Chris Stein, LCMF, next to historical tide gauge from 1956 at Eluitkak Pass on Beaufort Sea northeast of Barrow.

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. Oil in this well rose and fell with the underlying sea level).

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

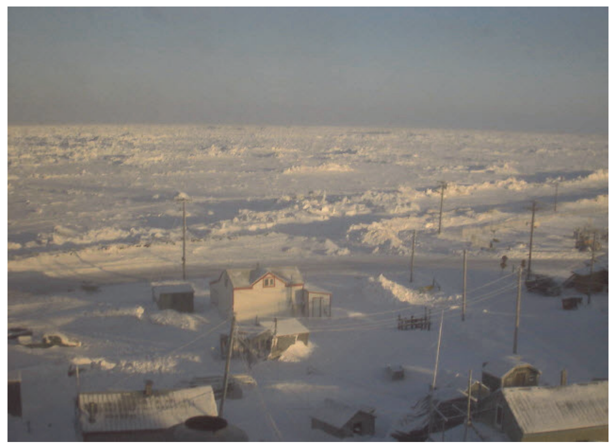

Figure 3b. Barrow in winter, same view

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 Engineering, 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.

2.0 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 contour was a relatively safe area to avoid 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+ tide gauge, 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 exposure (nothing to be snagged by passing ice) so an ORE CART acoustic release and two floats were included in the system to enable recovery

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 potentially be dragged over the gunwale and flipped onto the deck. As a result the assembly construction would have to protect all the instruments.

Also taken into account was the fact that instrumentation handling without overhead lifting demands a “lightweight” assembly. The basic requirement was for a system that could be handled by two or three people and had sensor protection in both deployment and recovery. CO-OPS designed a fiberglass box shaped frame to house the instruments and protect them from rough handling. The platform frame was assembled from 4 by 4 by ¼ inch thick angle pieces. The base was about a 40 inch square and was 30 inches tall excluding the lifting/protecting U-bolts on the top.

The joints on the platform were glued together and also secured with both stainless steel and fiberglass bolts. 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 was added just before deployment to help the frame stay in place as currents were expected to be as high as 1.5 knots in the deployment region (see Figure 4a). Severe stainless steel corrosion was reported on past oceanographic deployments using stainless steel hardware however overall severe corrosion was not experienced, with only a few spots where anoxic condition might have existed. Anti-foulant was not used for this deployment as it was assumed that bio-fouling would be a minimum in cold waters (see Figure 4b).

The tide gauge was mounted diagonally across one of the sides of the platform. The conductivity sensor was connected to the tide gauge and was attached to its body. The sensor's cell ended up in diagonal position. After the system's first recovery, this was repositioned to a vertical position prior to the second deployment to lessen the silt buildup in the cell. The battery (energy) requirement for a deployment in freezing water for a minimum of 13 months had to be carefully calculated. While the tide gauge might have been able to squeeze by with its internal battery for the year, it was decided to over-ride its battery with power from the modem external battery canister. It was estimated that it would last almost two years. The Seabird sensor was installed securely inside a specially built platform was retrieved by sending acoustic signals from the recovery boat, which released the pop-up buoy so that a lift line will be brought to the surface and the platform can be recovered. The CART acoustic release had its own battery and was estimated to last at least 18 months. The "Y" cable connection between the battery canister, tide gauge, and modem had wet mate able connectors and was supplied by the modem manufacturer, Linkquest.

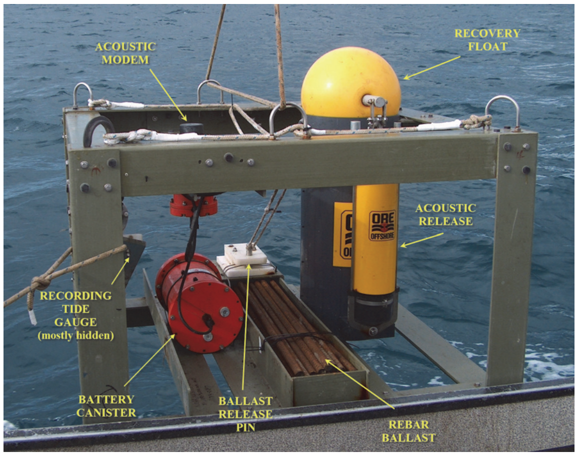

Figure 4a. Platform just before deployment

Figure 4b. Platform recovered after a 12 month long deployment.

CO-OPS chose to build and deploy two complete systems for deployment at Barrow. This redundancy was required to ensure successful measurement of continuous data without substantial breaks in data, knowing the environment was particularly harsh and this type of system had not yet been deployed in such an environment.

The Seabird pressure sensors deployed were very accurate and stable for the data collection efforts. The Seabird sensor also measures water conductivity (accuracy of +/- 0.5 ms/m) and temperature (accuracy of =/- 0.01 degree centigrade). The Linkquest acoustic modem is also very reliable (bit errors less than 1 part per billion) and uses high speed data transmission rates (1200 baud to 9600 baud, average 5000 baud) to allow a large amount of data to be downloaded to the surface equipment at convenient data collection intervals.

3.0 Deployment, Maintenance, and Recovery

A tide station consists of several major components; a water level sensor and required ancillary sensors (described previously), a data collection and transmission system; and a network of tidal bench marks.

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 6 is schematic that shows locations of all of the tidal bench marks established for the Barrow deployment.

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.

NOAA Form 76-199 (8-83) / US Department of Commerce, National Oceanic and Atmospheric Administration, National Ocean Service	FIELD UNIT	DRAWN BY: MZ	DATE: 09/18/2008
BENCHMARK SKETCH	**JOA**	REVISED BY: MZ	DATE: 08/31/2009
STATION NAME	STATION NO.	REVISED BY:	DATE:
BARROW OFFSHORE, ALASKA	**949-4934** **949-4935**	REVISED BY:	DATE:

Figure 6. Schematic showing locations of tidal benchmarks at Barrow Alaska.

Sensor Deployments

Barrow water level measurements were collected over the period of two deployments starting in August 2008. Both measurement 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 the final recovery taking place in August 2010.

Deployment of the sensor platforms required only small boats and human muscle. For the initial 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 to 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 almost 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 platforms 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 7).

Figure 7. Cataraft used for the intial deployment

In 2009, anchor deployment was accomplished with a local whaling captain's boat (Figure 8a and 8b). 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. The relative locations of the two separate deployments offshore Barrow are shown in the Chartlet in Figure 9.

Figure 8a. Crawford Patkotak's boat with homemade davit used to deploy anchors in 2009, and recover anchors in 2010.

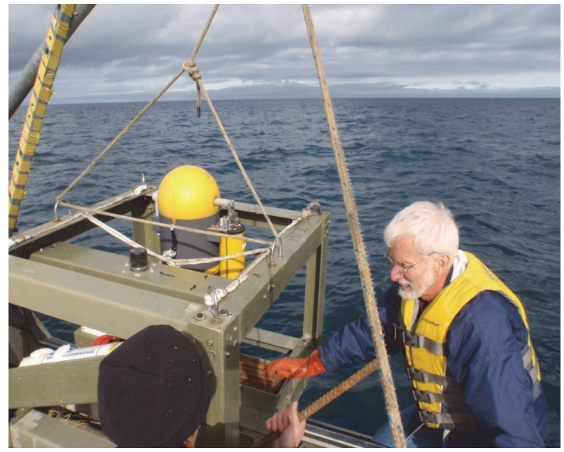

Figure 8b. Jim Sprenke (CO-OPS) loading rebar for weight into fiberglass anchor prior to deployment, August 2009.

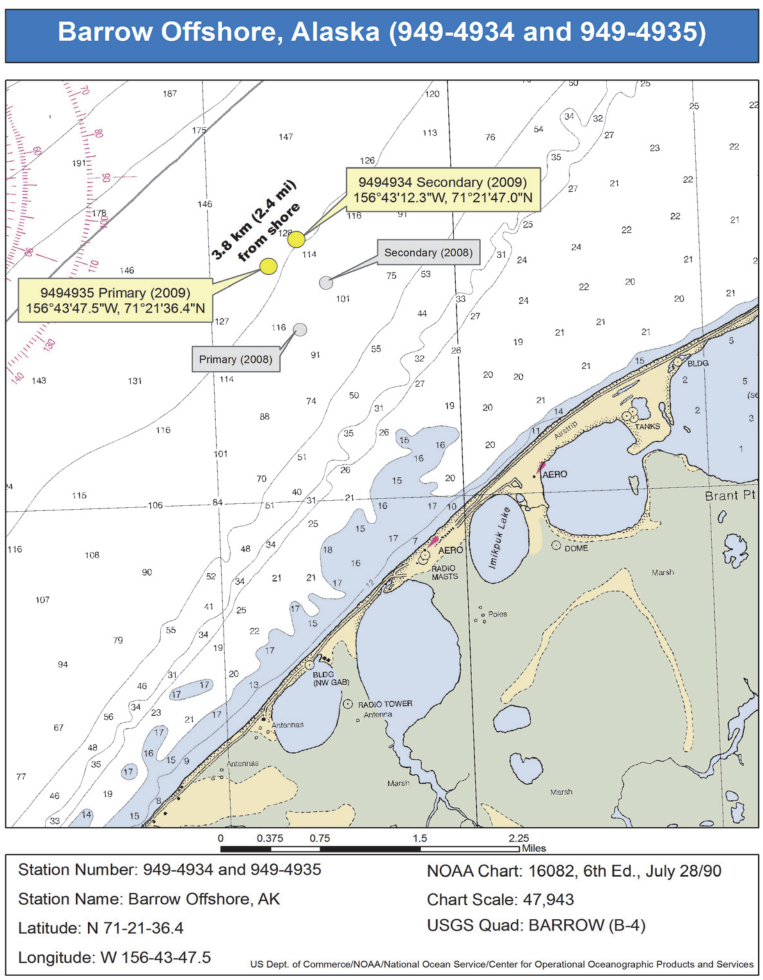

Figure 9. Chartlet from a NOAA nautical Chart showing the bathymetry and the location of the redundant sensors in each deployment period.

Staff Observations

Water level sensors such as the pressure sensors deployed for this project cannot be directly surveyed to local bench marks. Thus, the water level data cannot be directly related to land elevations without a transfer process. Traditionally, this transfer process is accomplished by installing a tide staff that is surveyed into the primary bench mark (NOAA, 1965). A series of tide staff readings are manually observed and compared to the simultaneous water level sensor elevations. By taking numerous readings throughout the deployment period, a statistical average staff-to-gage difference is computed and that average is applied to all sensor data to refer them to the tide staff and the bench marks.

The water level measurements made by the underwater sensors at Barrow 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 (this is often referred to as a "virtual" tide staff). 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 10a and 10b.) The backsight of the level run was made to a Temporary Bench mark (TBM) that was, in turn, leveled to the bench marks. The level run foresight was the actual elevation of the water level on the survey rod. By repeating this process periodically, a statistically valid relationship of the water level relative to the bench marks and the water level measured by the sensor was derived.

Figure 10a. "Staff shots" are a method of measuring the water level relative to the bench marks. October 2008.

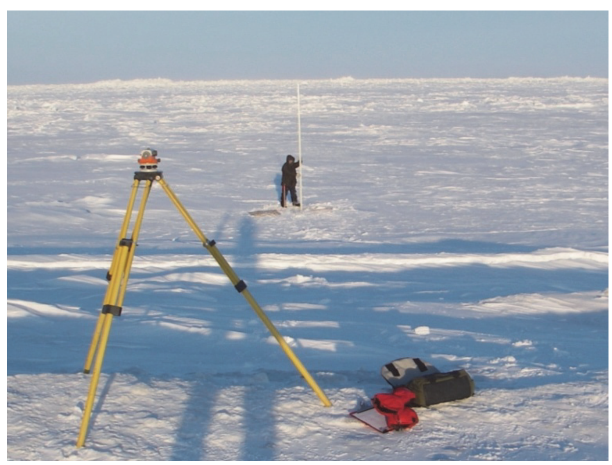

Figure 10b. Staff shots in March 2009, -20 Deg. F. Drilled hole 4ft through ice to reach water. Same location as picture to left.

It was necessary to establish the staff-to-gage difference separately for each yearly deployment, as the sensors were not deployed back at the same exact location or the same exact sensor depth. Staff shot sessions were made over 9 separate sessions throughout the 2008-2009 deployment period, with each session containing 6-minute staff shots over one-hour in length. Similarly, staff shot sessions were made over 10 separate sessions throughout the 2009-2010 deployment period. After rejection of outlier values, the standard deviation of the staff-to-gauge differences was approximately 0.03m. The consistency of the staff-to-gage differences over time also indicated that there was neither vertical drift of the sensor platforms nor drift in the pressure sensors themselves over the deployment periods.

An arbitrary Station datum for Barrow was established as 50.000m below the elevation of the PBM (4935F). The analysis of the staff-to-gage differences gave good datum elevation recovery for each deployment such that the two data series were reliably connected and referred to the same Station Datum. This enabled an accurate simultaneous comparison with observations at Prudhoe Bay and an accurate tidal datum computation.

Data Download

In order to periodically recover data via acoustic modems, commands issued through a simple terminal program were used to allow 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. The original acoustic communication design required the capability to communicate to both platforms, which were separated up to a kilometer from a single location. Some of the original testing showed this might be difficult. Better communication results could possibly be achieved with a directional surface modem. And both were made available for use. The modem wakes up every two minutes for about a half second to "see" if anything is trying to talk to it.

The surface acoustic modem is powered by a small 12 volt battery. A laptop computer running a terminal communication program is also required. 'BBtalk' software which can record without modification or length limit was used to record the data from the tide gauge. A single character is sent through the modems to get the tide gauge to respond. After some status information is acquired, the tide gauge data collection is stopped: it can't collect and output recorded data at the same time. The data is downloaded using non-handshaking commands. This results in a few errors in the data but results in a much faster download over the acoustic modems. The data collection is restarted, and status (data collection mode) information acquired. This is repeated for the second platform a few hundred meters away. Back "home" the acquired data is checked for errors and corrected post download. Since the data is a repeating 12 byte format, by setting the editor to a 12 byte wide data display, the screen view can be easily used to detect what's out of line. An editor is required that can handle binary (hex) data and VEDIT was used on these data. The corrected data was now reformatted with some custom software, then it is changed to ASCII-HEX and a header is added.

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 ice free 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 station keep 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 11a and 11b).

Figure 11a. Snowmachine with sled for towing computer, acoustic modem, ice auger, gas, picks, shovels, food, blankets and guns for polar bear protection.

Figure 11b. 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 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 12).

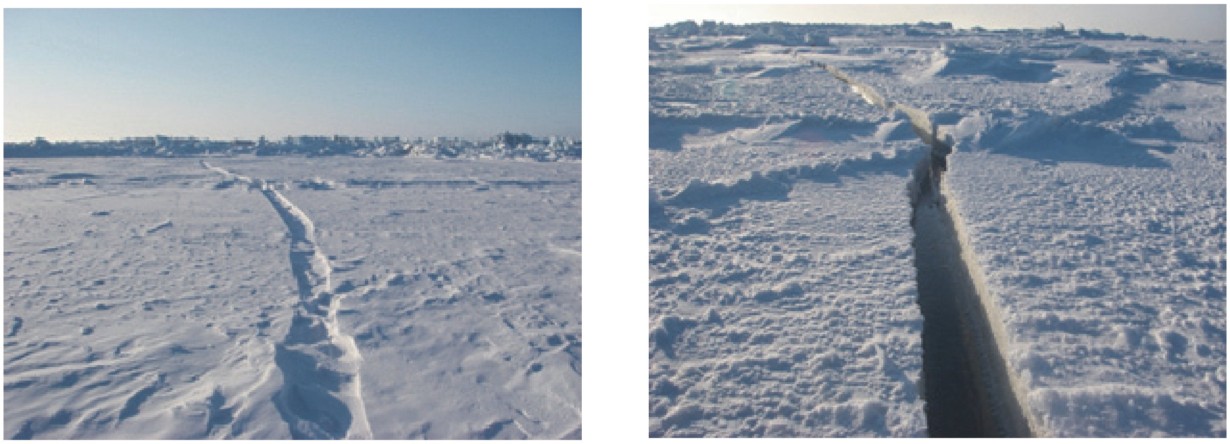

Figure 12. Smooth pan ice was the best for travel, but could also be the most unpredictable

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. Data from both tide gauges were quickly downloaded via acoustic modem on this particular trip. 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 13a and 13b). While the data collected via acoustic modem was processed to look at viability and acceptability, the direct download after recovery of the whole deployment was the data extensively analyzed. It’s the same data without the need for error correction and reformatting.

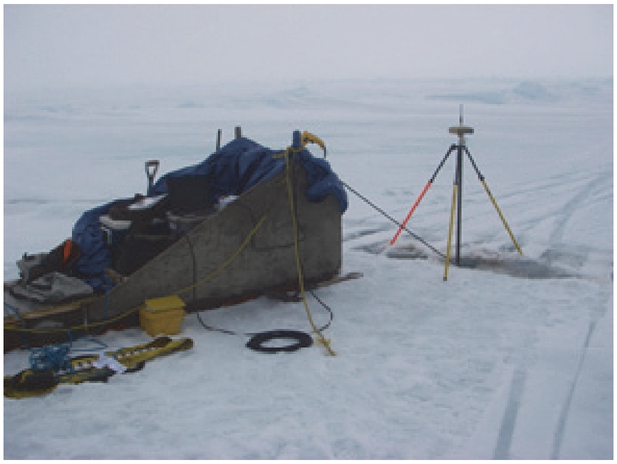

Figure 13a. Downloading tide data through the ice.

Figure 13b. 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 accomplished using 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 14).

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 14. 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.

4.0 Data Processing and Analyses

The reformatted data from the modems or data recovered directly was fed into the standard Seasoft data processor. Seasoft is software provided by Seabird for processing raw data from their SBE26+ tidegage. An external Seabird program, ExtractTide.exe, was sometimes needed to separate the data starts. Barometric pressure information was collected from BRW airport located a few miles away. It needed to be reformatted to be accepted by Seasoft. This can be tediously done with EXCEL or more easily with some simple user written code. The simple format is given in the SBE26+ manual. Gaps in the barometric pressure time series were filled in with data from the NOAA Climate Monitoring and Diagnostics Laboratory observatory. One of the options in Seasoft is to apply the density (from the measured conductivity and temperature) to the pressure data. That option was not used and data for conversion used from Seasoft was baro-corrected pressure (psi), temperature (degC), and Seabird computed salinity (PSU). 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 were a best estimate from the two sensors. No correction was applied for the height of the airport's barometer above sea level as it would have been a constant of a couple millimeters and would have no consequence on the water level elevation data given all of the error sources. In Excel developer, Visual Basic (VB) code was written to enable initial plotting and QC. (Appendix 3). A year's worth of six minute data is about 90000 data points per parameter per platform. Bringing this much data into the cells of a spreadsheet and trying to work with it is extremely challenging and slow. Keeping the data in arrays in VB and outputting to the spreadsheet as necessary for visual comprehension is very fast and much less frustrating with this much data.

Figures 15a and 15b 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.

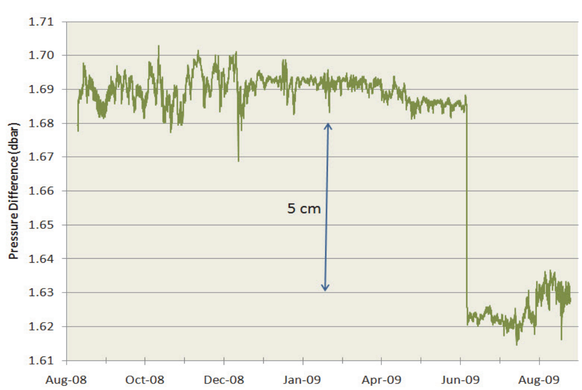

Figure 15a. Platform Stability Check 1st year

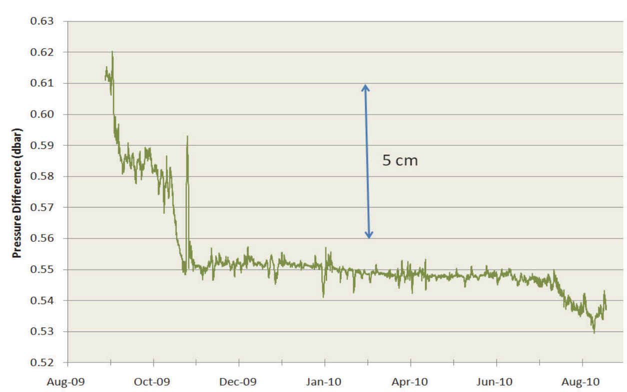

Figure 15b. Platform Stability Check 2nd year

Each of the platforms had a conductivity sensor for computing salinity (PSS-78). Ideally the salinity data should be the same from both platforms. For both yearly deployments they were located only a couple hundred meters apart, a couple kilometers from the shore and only 1.6 and 0.5 meters respectively different in depth. The plots however, showed more significant differences. This was assumed to be caused by silt deposits or minor biofouling in the conductivity cell. Best estimates of salinity were made usually using the higher reading. For both deployment periods, a table was created to determine which platform salinity to use and for what time period. The table (see Appendix 4) contains some offsets and salinity time slopes for a few periods.

Measurements from the two systems tracked well for about 20 days but then began to differ on and off (Figure 16a and 16b) in September 2008. After the first year recovery, sediment and some partial blockage found in one sensor probably accounted 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 time drift between the two platforms only differed by a few seconds for each deployment, so this drift was not applied for the initial platform comparisons. The time drift was corrected in the final data. The two sensors also compared well the first month of the second deployment but then deviated for the duration of the deployment.

The pressure data from Platform 2 was ultimately used for processing and analysis. For both years it was decided that P2, the lower platform, was the more stable. A sequential time series centered on the six minute marks was created. The SBE26+ clock gained about 70 seconds for the year and was assumed to be linear for the deployment period. Based on the instrument start time, a time gain was computed for the time in the series. The time stamp in the Seasoft processed data is the data start time of the 180 second sampling period. The time gain was added and 90 seconds subtracted from the series time. This was the pseudo time for the data. The two lines of Seasoft processed data that surrounded this time were used to interpolate the pressure at the pseudo time. Based on the time, the salinity table indicated what platform salinity and corrections to use. The water density was computed from the salinity and temperature. That along with pressure and local gravity produced a water height above the platform. This is the procedure used to create the file used for tidal processing and tidal datum determination.

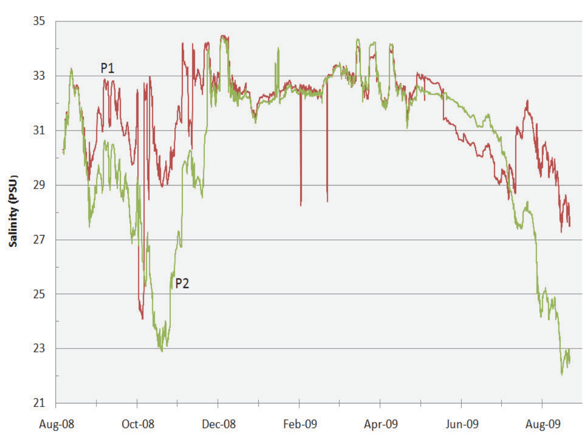

Figure 16a. Salinity time series 1st deployment

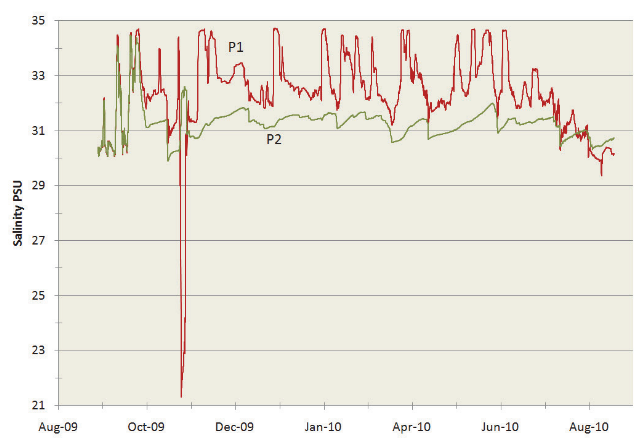

Figure 16b. Salinity time series 2nd deployment

As mentioned earlier, 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. 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 "949 4935F". From the staff-to-gage differences, a constant of 14.553m was applied to the data from the first deployment, and a constant of 7.460m was applied to the sensor data from the second deployment to put them both on Station Datum.

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 6-minute interval 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 tides a both Barrow and Prudhoe bay are classified as mixed, mainly semi-diurnal, with generally two highs and two lows per tidal day, but with the two high tides being unequal in height and the two low tides being unequal in height as well. 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 17 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.

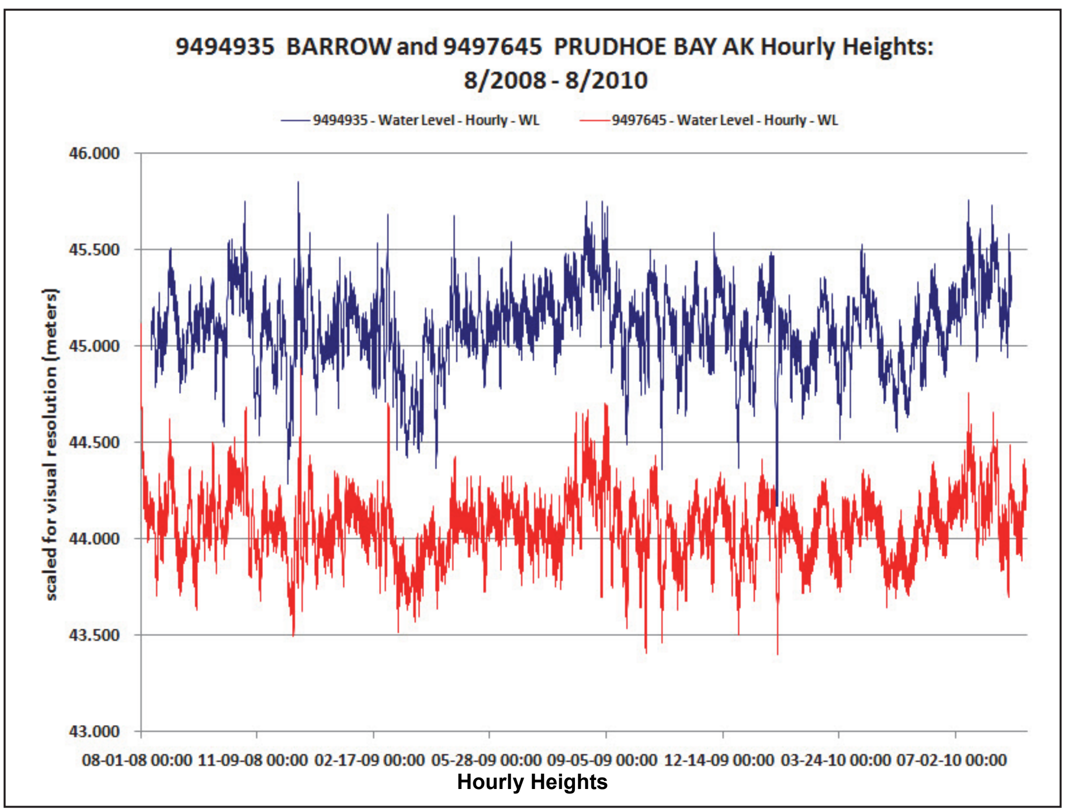

Figure 17. Observed hourly water levels at Barrow and Prudhoe Bay, AK

Monthly means and extremes were computed for each calendar month of data and are shown in Figure 18 for the two years of data. The strong seasonal effect is readily seen and is due to seasonal weather patterns and ice cover. The monthly Highest (HWL) and Lowest (LWL) observed tides are due to more 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.

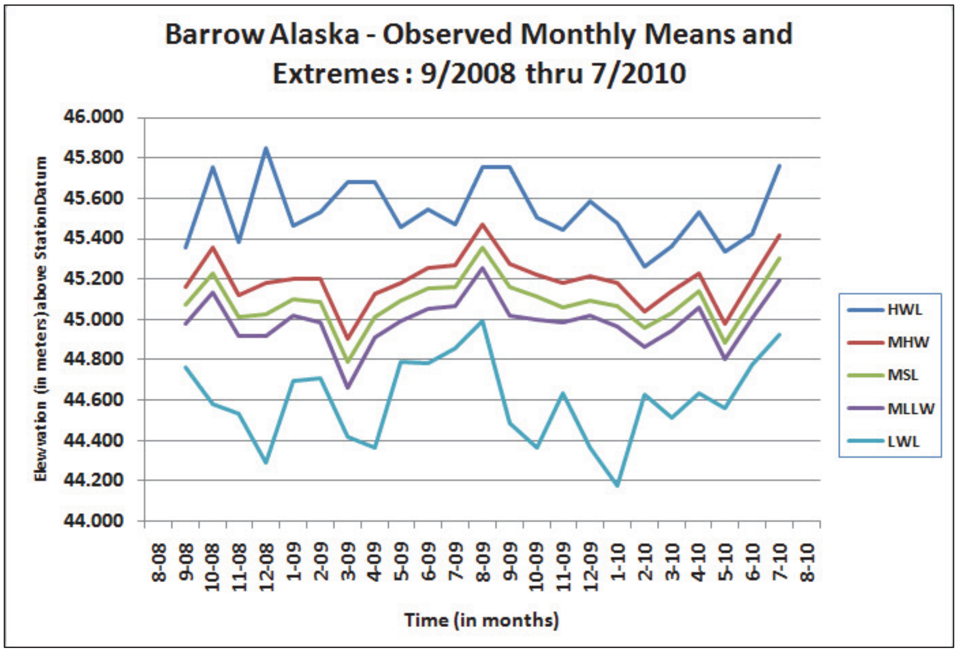

Figure 18. Observed monthly means and extremes at Barrow, AK.

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 19 shows the elevations of the tidal datums Barrow and the reference ellipsoid relative to Station datum and the elevation of the primary bench mark “949 4935F”. The mean diurnal range of tide (elevation difference between MHHW and MLLW) at Barrow is 0.20m. The mean diurnal range of tide at Prudhoe Bay is 0.21m. On average the time of high tide at Barrow is approximately 0.4 hours before the time of high water at Prudhoe Bay. Similarly, the average time of low tide at Barrow is about 0.6 hours before low tide at Prudhoe Bay.

Appendix 1 contains the accepted datums for all of the tidal datums and the NOAA Published Bench Mark Sheet containing the published descriptions and elevations of each tidal bench mark.

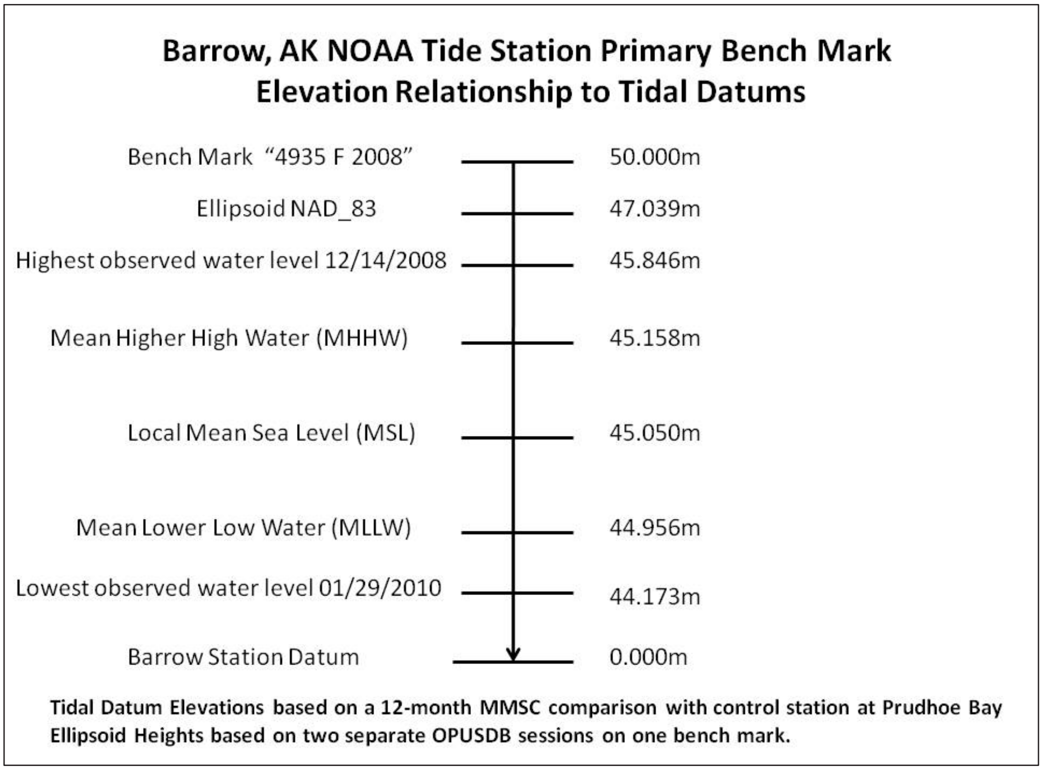

Figure 19. Elevations of the tidal datums at Barrow, AK.

The estimated uncertainty of the tidal datum elevations at Barrow are estimated to be 0.04m at the 95% Confidence Interval, after taking into account the two year simultaneous comparison with Prudhoe Bay as the control and the fact that datum at Prudhoe Bay itself is not based on a full NTDE 19 year –period (Stoney et al, 1983).

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). The accepted sets of harmonic constants for both Barrow and Prudhoe Bay are found in Appendix 2. Most of the phases of the harmonic constituents are earlier than those at Prudhoe Bay, which is consistent with the earlier time of tide derived from the tabulations of the simultaneous high and low tides. Figure 20 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 amplitude of seasonal variation in the predicted tides is also seen to be larger than the predicted daily variation of the tides, thus underscoring the need for more observational data

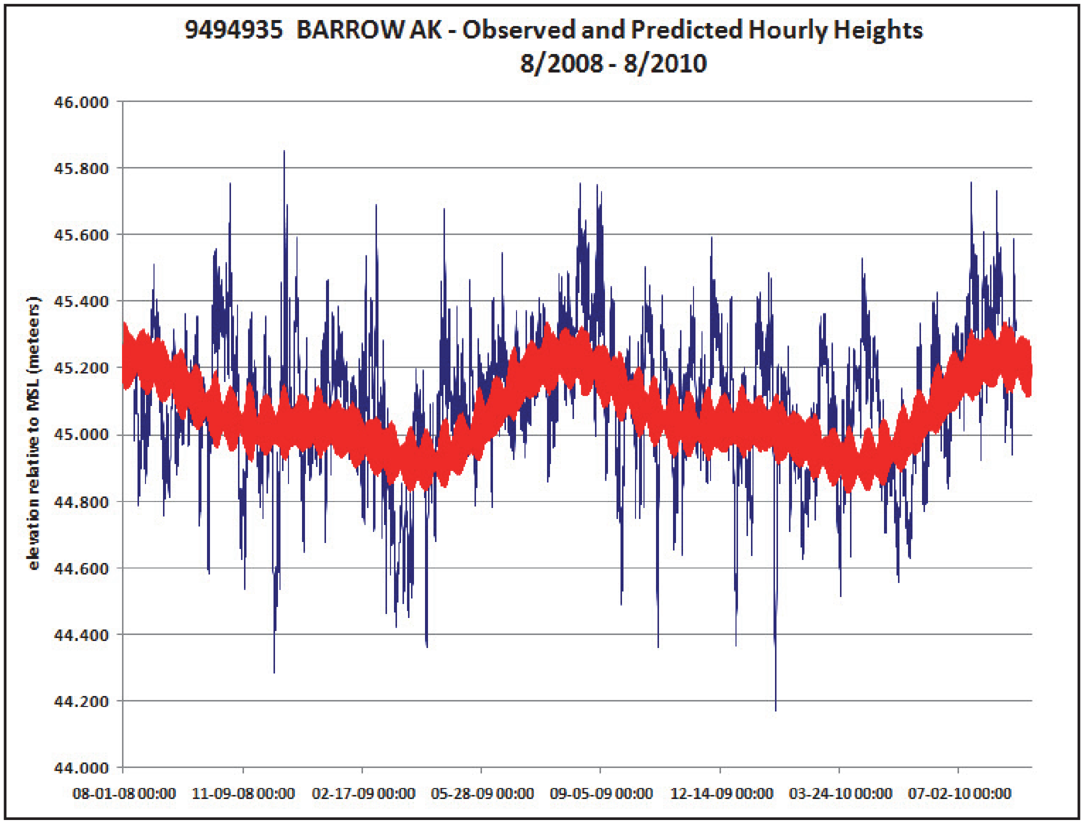

Figure 20. Observed (blue curve) and predicted (red curve) hourly heights at Barrow, AK.

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.

Residuals between observed and predicted tides at Barrow and Prudhoe Bay are very similar, as shown in Figure 21, because the non-tidal meteorological forcing is similar at the two locations. Barrow residuals appear to have slightly more variability; however the lower frequency oscillations track each other well.

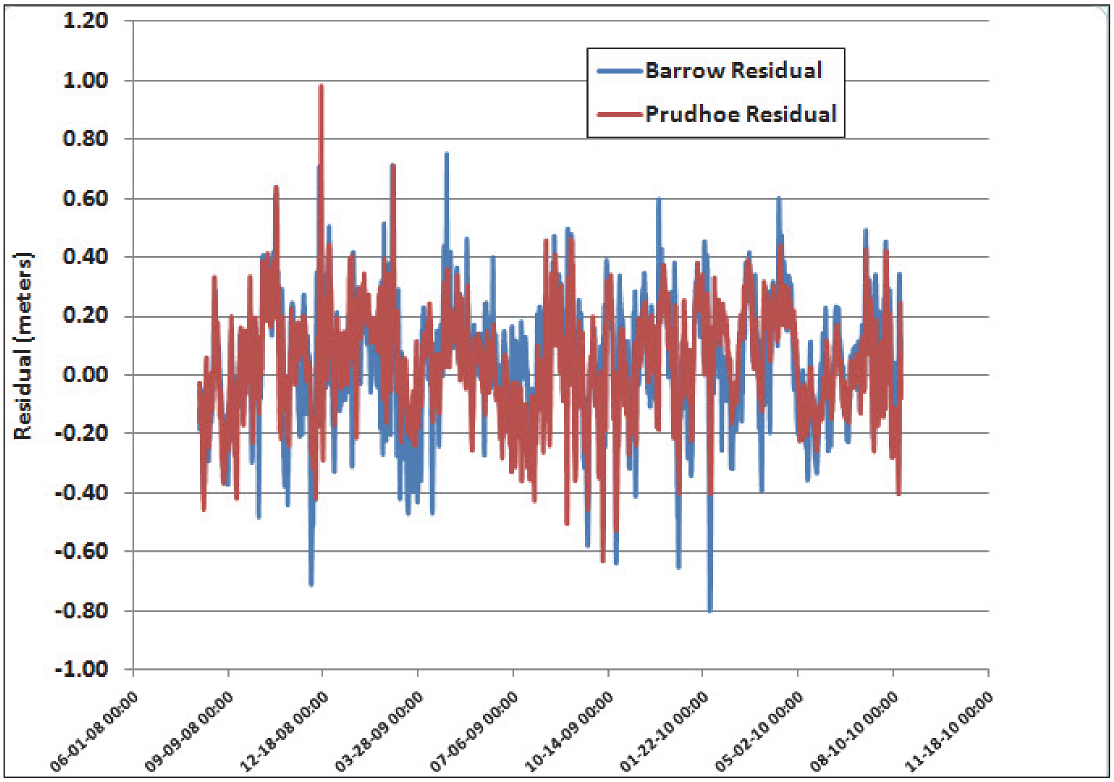

Figure 21 . Comparison of hourly observed vs. predicted tide residuals for period of record

The effects of strong weather systems on the water levels at Barrow are illustrated in Figures 22a and 22b. The plots show a comparison of the observed and predicted tides for two separate monthly time periods. The depression of the water level due to pronounced offshore winds is seen earlier in the month in Figure 22a, while the storm surge effects of frontal passages and storm centers is seen in Figure 22b.

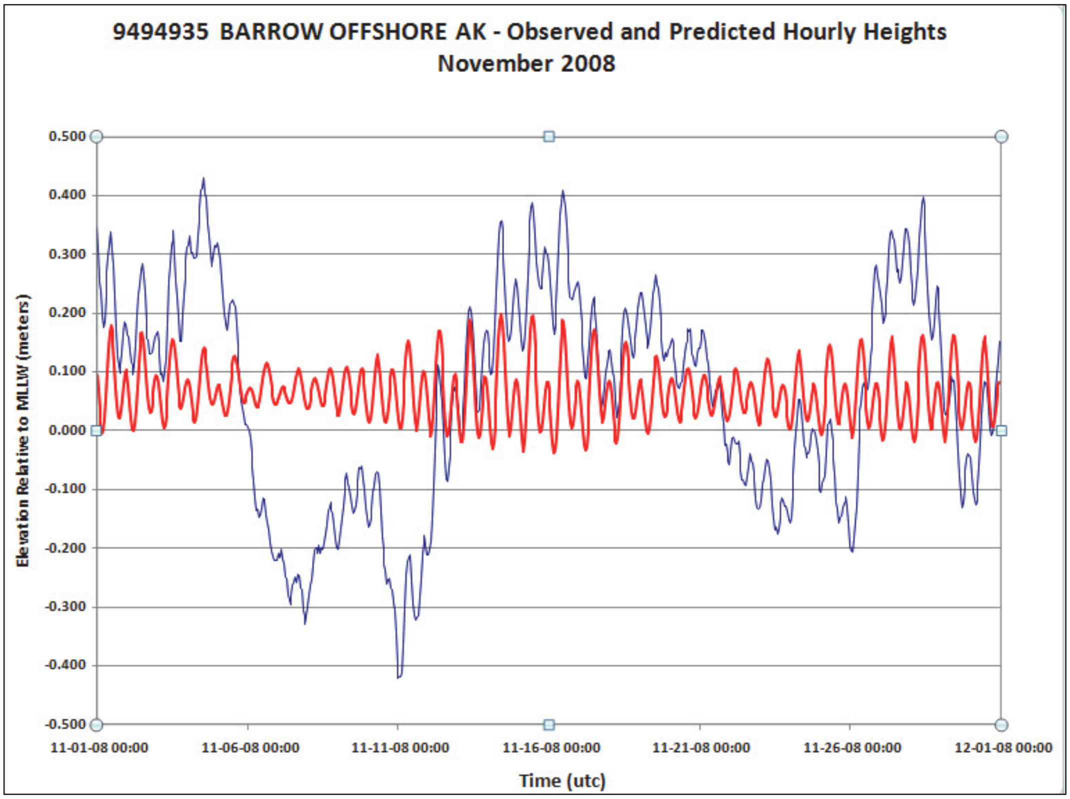

Figure 22a. Observed (blue curve) vs. predicted (red curve) water levels for November 2008.

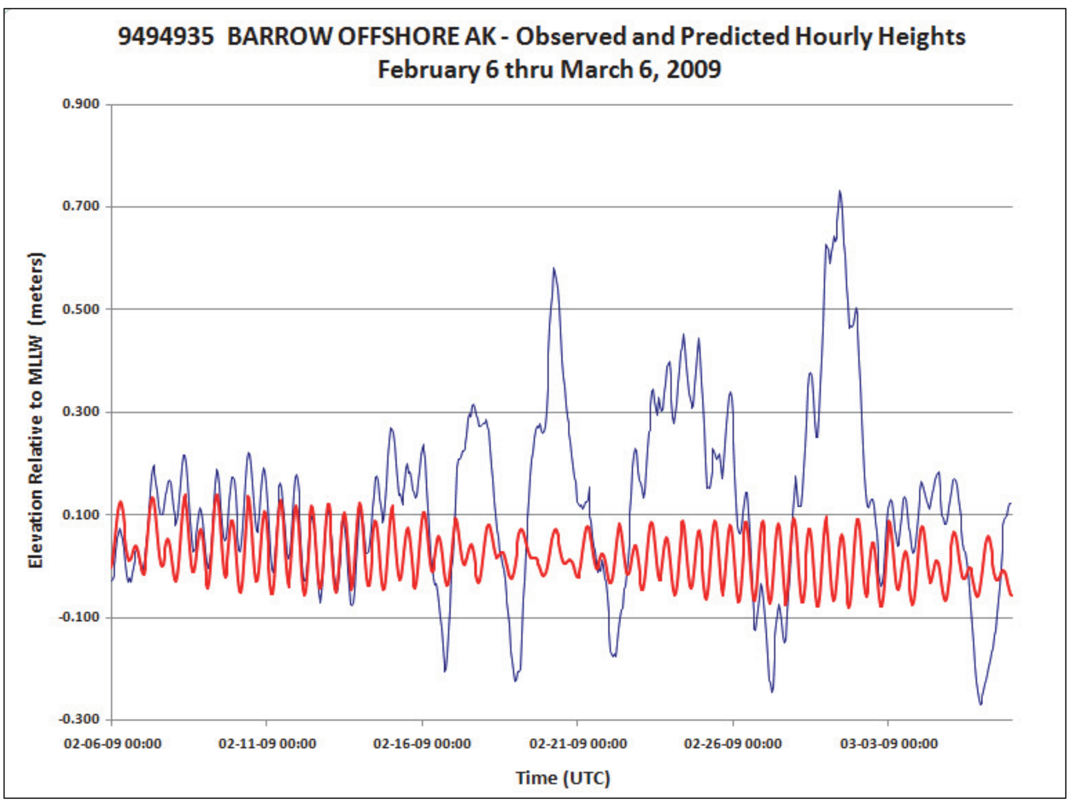

Figure 22b. Observed (blue curve) vs. predicted (red curve) water levels for Feburary 6 – March 6 2008.

For context with longer term mean sea level variations, Figures 23a and 23b show that Barrow monthly mean sea levels plotted with Prudhoe Bay, which goes back to 1993. Figure 23b shows only the common time period of observation. Using procedures and formula for computing relative sea level trends found in Zervas (2009), the estimated relative trend in sea level for Prudhoe Bay is -0.26mm/yr +/- 2.47mm/yr. Due to the very large uncertainty for this trend, the -0.26 mm/yr trend is not statistically significant. The standard error of the trend is very large due to the relative short length of record (approximately 20 years) and the high "noise" content to the monthly mean sea levels. Fifty (50) to 60 years of record are typically required for climate research and NOAA only published trends if they have 30 years or longer. Since Barrow and Prudhoe Bay are in similar geomorphologic settings on the North Slope, the relative sea level trend is likely to be similar to that at Prudhoe Bay; however this can only be confirmed with long term water level and geodetic observations.

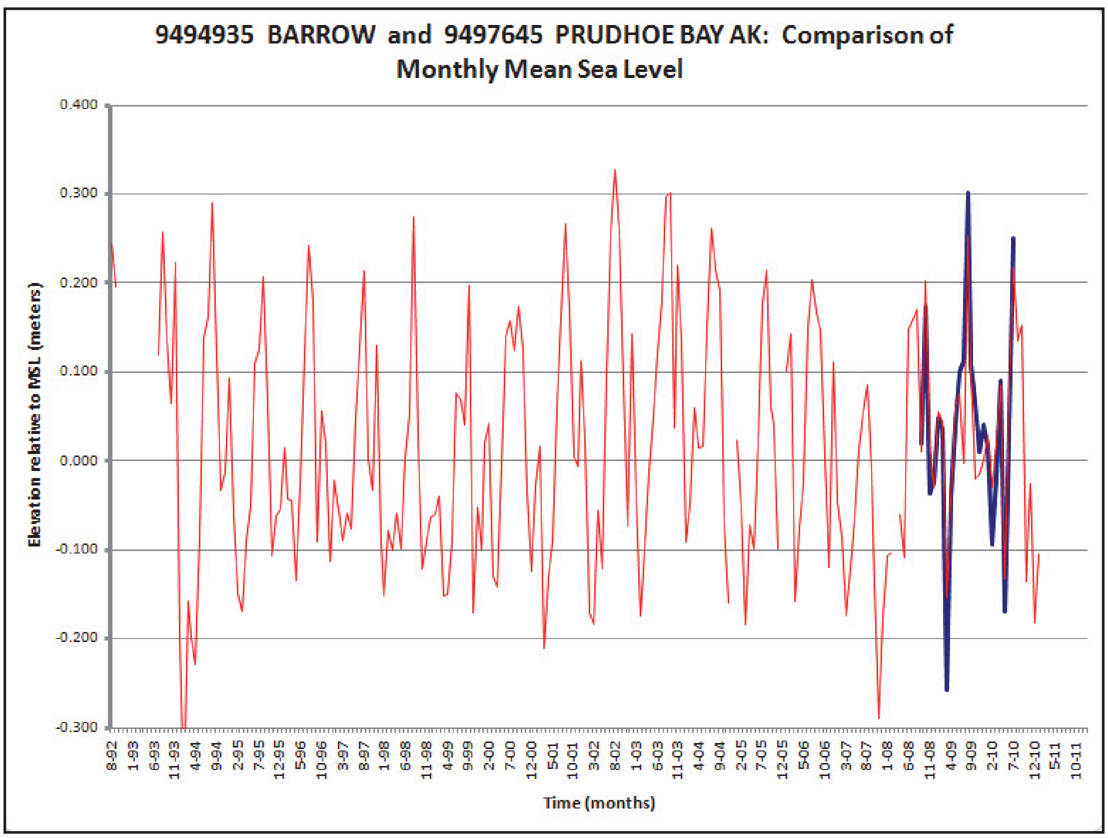

Figure 23a. Comparison of monthly mean sea level at Prudhoe Bay and Barrow, AK.

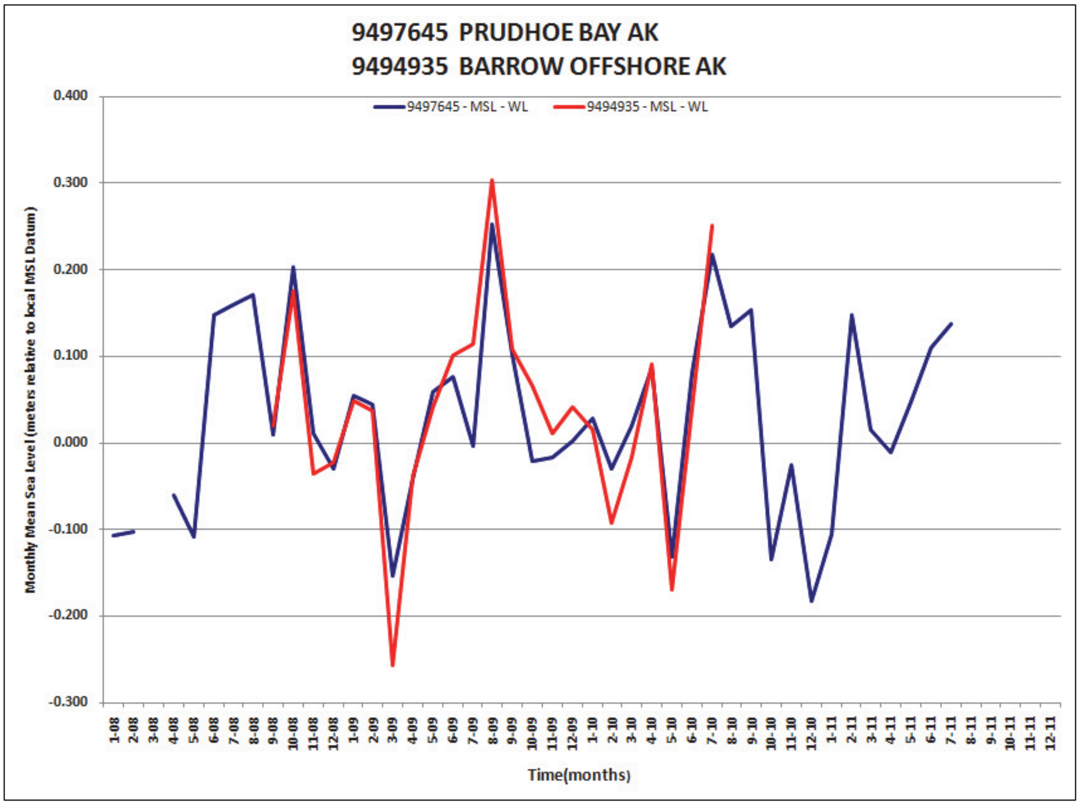

Figure 23b. Comparison of monthly mean sea level at Prudhoe Bay and Barrow, AK for common period.

5.0 Summary and Recommendations

This project's main objective to collect year-around water level data from Barrow, Alaska was successfully achieved. 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.

This project was successful in two levels: First, it represented the specific development of water level measurement technology for long-term deployment in the Arctic environment. It is recommended that the water level sensor configuration used for this project become part of the operational CO-OPS inventory for future deployments in this region. Secondly, the project delivered much needed new information of the water level variations along the North Slope. 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.

It is recommended that this station be added to Table 2, Tidal Differences and other Constants, of the NOS Tide Tables. This height and time differences would use Prudhoe Bay as the Reference Station. This new station would be named "Barrow Offshore" and would not replace the existing Table 2. #2535, Point Barrow. The historical station at Point Barrow was located inside Elson lagoon where the there is a much diminished tidal range and the station should be treated separately.

Verified data, including 6-minute elevations, hourly heights and monthly means; along with the bench mark sheet, accepted datums and accepted harmonic constants can all be found on the CO-OPS home page at:

http://tidesandcurrents.noaa.gov/geo.shtml?location=9494935

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

NOAA, 1965. Manual of Tide Observations, Publication No. 30-1, Coast and Geodetic Survey, 1965.

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.

Stoney, W.M., D.M. Martin, and D.A. Calderone, 1983. Error Analysis Procedures Used by the National Ocean Service to Compute Estimated Error Bounds for Tidal Datums in the Beaufort Sea, Arctic Ocean, Internal Report, NOS, September 1983 18pp

Appendix 1. Barrow Offshore Accepted Tidal Datums and Published Bench Mark Sheet

ACCEPTED DATUMS — Station ID - 9494935

EPOCH: 1983-2001

HWL	45.846
MHHW	45.158
MHW	45.122
MTL	45.048
DTL	45.057
NAVD88	
MSL	45.050
MLW	44.974
MLLW	44.956
LWL	44.173

DHQ	0.036
DLQ	0.018
GT	0.202
MN	0.148

Meters

HWI	
LWI	

Stage	Date	ID
Complete:	5-17-11	280
Verified:	5-18-11	390
Accepted:	5-18-11	211

Source	Control Station
MMSC_MR	9497645

Staff	PBM
8-10-2008	4935 F 2008

Segments:

Begin	End
09/01/08 00:00	08/31/09 23:54

Balance?

DHQ	DLQ	MN	GT	MTL	DTL
YES	YES	YES	YES	YES	YES

Extreme	Date	Time
HWL	12-14-2008	09:48
LWL	01-29-2010	15:18

Published Bench Mark Sheet for 9494935 BARROW OFFSHORE ALASKA
U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Ocean Service

Station ID: 9494935 PUBLICATION DATE: 05/20/2011
Name: BARROW OFFSHORE, ALASKA
NOAA Chart: 16082 Latitude: 71° 21.6' N
USGS Quad: BARROW (B-4) Longitude: 156° 43.8' W

To reach the bench marks from the Wiley Post-Will Rogers Memorial Airport in Barrow, proceed 0.3 km (0.2 mi) west on Ahkovak Street in front of the airport, turn right on Kiogak Street and proceed 0.5 km (0.3 mi) north to the intersection with Eben Hopson Street, turn slightly right and proceed 0.6 km (0.4 mi) NE on Eben Hopson Street around the NW side of a lagoon, turn left on Brower Street and proceed north 0.3 km (0.2 mi) to the intersection with Stevenson Street, turn right and follow Stevenson Street 4.5 km (2.8 mi) NE along the beach to the Naval Arctic Research Lab (NARL) complex, turn right at a large sign for Ilisagvik College and meander east 0.3 km (0.2 mi) through the many old NARL buildings keeping the blue Ilisagvik College building on the right, continue under the utilidor on the NE side of the Ilisagvik College building and continue east 0.4 km (0.2 mi) on the gravel access road to the Barrow Global Climate Change Research Facility (BGCCRF). The bench marks are chisel marks on the building pilings of the BGCCRF and one bench mark SE of the facility in the tundra. The tide gauges are underwater pressure sensors located on anchors 3.5 km (2.2 mi) NW offshore from this facility.

T I D A L   B E N C H   M A R K S

PRIMARY BENCH MARK STAMPING: 4935 F 2008
DESIGNATION: 949 4935 F

MONUMENTATION: Not specified (see descriptive text) VM#: 18932
AGENCY: PID:
SETTING CLASSIFICATION: Chiseled horizontal line in a steel pile

The bench mark is a chiseled horizontal line on the side of a pile at the SW corner of the Barrow Global Climate Change Research Facility building, 36.47 m (119.6 ft) north of the most northerly power pole at the SW corner of the gravel pad, 19.66 m (64.5 ft) SE of bench mark 9494935 E, 12.95 m (42.5 ft) SE of the center of the entrance door, and 11.98 m (39.3 ft) SE of the center of red post supporting the roof over the entryway. The bench mark is 0.72 m (2.4 ft) above the level of the gravel pad, and 0.17 m (0.6 ft) below the bottom of the siding on the building, chiseled into a 0.19 m (0.6 ft) diameter steel pile 8.5 m (28 ft) long set in an augured hole backfilled with slurry.

BENCH MARK STAMPING: 4935 A 2008
DESIGNATION: 949 4935 A

MONUMENTATION: Not specified (see descriptive text) VM#: 18927
AGENCY: National Ocean Service (NOS) PID:
SETTING CLASSIFICATION: Chiseled arrow in metal pile cap

The bench mark is a chiseled arrow in the center of the outside edge of a metal pile cap on the NE side of the Barrow Global Climate Change Research Facility building, 16.61 m (54.5 ft) NW of the southernmost corner of the power plant, 14.81 m (48.6 ft) SE of bench mark 9494935 B and the north corner of the expanded metal deck, 4.78 m (15.7 ft) NE of the center a double wide door, 4.33 m (14.2 ft) SE of the center of the utilidor beneath the deck, and 3.16 m (10.4 ft) NW of the SE corner of the expanded metal deck. The bench mark is 1.20 m (4.3 ft) above the level of the gravel pad, and 0.29 m (1.0 ft) below the top of the expanded metal deck, chiseled into a metal plate welded to the top of a 0.17 m (0.6 ft) diameter steel pile 7.3 m (24 ft) long set in an augured hole backfilled with slurry.

BENCH MARK STAMPING: 4935 B 2008
DESIGNATION: 949 4935 B

MONUMENTATION: Not specified (see descriptive text) VM#: 18928
AGENCY: National Ocean Service (NOS) PID:
SETTING CLASSIFICATION: Chiseled square in metal pile cap

The bench mark is a chiseled square on top of the north corner of a metal pile cap on the NE side of the Barrow Global Climate Change Research Facility building, 14.81 m (48.6 ft) NW of bench mark 9494935 A, 13.94 m (45.7 ft) WNW of the NW corner of the power plant, 11.45 m (37.6 ft) SE of bench mark 9494935 C, 10.52 m (34.5 m) NNW of the center of the utilidor below the deck, 4.17 m (13.7 ft) north of the center of a double wide door, and 1.71 m (3.8 ft) ENE of the face of the building. The bench mark is 1.00 m (3.3 ft) above the level of the gravel pad, and 0.30 m (1.0 ft) below the top of the expanded metal deck, chiseled into a metal plate welded to the top of a 0.17 m (0.6 ft) diameter steel pile 7.3 m (24 ft) long set in an augured hole backfilled with slurry.

BENCH MARK STAMPING: 4935 C 2008
DESIGNATION: 949 4935 C

MONUMENTATION: Not specified (see descriptive text) VM#: 18929
AGENCY: National Ocean Service (NOS) PID:
SETTING CLASSIFICATION: Chiseled square in metal pile cap

The bench mark is a chiseled square on top of the SE corner of a metal pile cap on the NE side of the Barrow Global Climate Change Research Facility building, 23.94 m (78.5 ft) NW of the NW corner of the power plant, 11.45 m (37.6 ft) NW of bench mark 9494935 B, 8.78 m (28.8 ft) NNW of the center of the door at the SSE end of the deck, and 2.23 m (7.3 ft) ENE of the face of the building. The bench mark is 0.85 m (2.8 ft) above the level of the gravel pad, and 0.30 m (1.0 ft) below the top of the expanded metal deck, chiseled into a metal plate welded to the top of a 0.17 m (0.6 ft) diameter steel pile 7.3 m (24 ft) long set in an augured hole backfilled with slurry.

BENCH MARK STAMPING: 4935 D 2008
DESIGNATION: 949 4935 D

MONUMENTATION: Not specified (see descriptive text) VM#: 18930
AGENCY: National Ocean Service (NOS) PID:
SETTING CLASSIFICATION: Chiseled horizontal line in a steel pile

The bench mark is a chiseled horizontal line on the side of a pile at the NW corner of the Barrow Global Climate Change Research Facility building, 27.96 m (91.7 ft) SSW of a wooden light pole on the north edge of the gravel pad, 24.02 m (78.8 ft) NNW of bench mark 9494935 E, and 15.64 m (51.3 ft) ENE of a wooden power pole along the west edge of the gravel pad. The bench mark is 0.66 m (2.2 ft) above the level of the gravel pad, and 0.13 m (0.4 ft) below the bottom of the siding on the building, chiseled into a 0.19 m (0.6 ft) diameter steel pile 8.5 m (28 ft) long set in an augured hole backfilled with slurry.

BENCH MARK STAMPING: 4935 E 2008
DESIGNATION: 949 4935 E

MONUMENTATION: Not specified (see descriptive text) VM#: 18931
AGENCY: National Ocean Service (NOS) PID:
SETTING CLASSIFICATION: Chiseled horizontal line in steel pile

The bench mark is a chiseled horizontal line on the side of a pile on the SW side of the Barrow Global Climate Change Research Facility building, 24.02 m (78.8 ft) SSE of bench mark 9494935 D, 19.66 m (64.5 ft) NW of bench mark 9494935 F, 6.88 m (22.6 ft) NW of the center of the main entrance door, and 1.69 m (5.5 ft) west of a brass fire hose fitting. The bench mark is 0.77 m (2.5 ft) above the level of the gravel pad, and 0.21 m (0.7 ft) below the bottom of the siding on the building, chiseled into a 0.19 m (0.6 ft) diameter steel pile 8.5 m (28 ft) long set in an augured hole backfilled with slurry.

BENCH MARK STAMPING: S5253 WCMC L9C3 L8C7 2005
DESIGNATION: 9494935 BLM S5253

MONUMENTATION: Tidal Station disk VM#: 18933
AGENCY: US Bureau of Land Management PID:
SETTING CLASSIFICATION: Stainless steel post

The bench mark is a disk set in the tundra SSE of the Barrow Global Climate Change Research Facility building and west of a Imikpuk Lake, 156.8 m (514.4 ft) SSE of bench mark 9494935 F, 92.30 m (302.8 ft) WSW of Imikpuk Lake, 67.94 (222.9 ft) ENE of wooden power pole #19, 43.04 m (141.2 ft) NNE of a 1.5 m (5.0 ft) tall 6-inch by 6-inch wooden post, 34.83 m (114.3 ft) WNW of an aluminum survey marker stamped "TR100 S5048 2005" set flush in the tundra, and 0.06 m (0.2 ft) above grade.

Station ID: 9494935 PUBLICATION DATE: 05/20/2011
Name: BARROW OFFSHORW, ALASKA
NOAA Chart: 16082 Latitude: 71° 21.6' N
USGS Quad: BARROW (B-4) Longitude: 156° 43.8' W

T I D A L D A T U M S

Tidal datums at BARROW OFFSHORE based on:

LENGTH OF SERIES: 1 YEAR
TIME PERIOD: September 2008 - August 2009
TIDAL EPOCH: 1983-2001
CONTROL TIDE STATION: 9497645 PRUDHOE BAY

Elevations of tidal datums referred to Mean Lower Low Water (MLLW), in METERS:

HIGHEST OBSERVED WATER LEVEL (12/14/2008)	= 0.890
MEAN HIGHER HIGH WATER (MHHW)	= 0.202
MEAN HIGH WATER (MHW)	= 0.166
MEAN SEA LEVEL (MSL)	= 0.094
MEAN TIDE LEVEL (MTL)	= 0.092
MEAN LOW WATER (MLW)	= 0.018
MEAN LOWER LOW WATER (MLLW)	= 0.000
LOWEST OBSERVED WATER LEVEL (01/29/2010)	= -0.783

Bench Mark Elevation Information In METERS above:

Stamping or Designation	MLLW	MHW
4935 F 2008	5.044	4.878
4935 A 2008	5.930	5.764
4935 B 2008	5.928	5.762
4935 C 2008	5.926	5.760
4935 D 2008	5.070	4.904
4935 E 2008	5.011	4.845
S5253 WCMC L9C3 L8C7 2005	1.760	1.594

Appendix 2. Barrow Offshore and Prudhoe Bay Accepted Harmonic Constants

CONSTANT		Barrow H	Barrow K-PRIME	Prudhoe Bay H	Prudhoe Bay K-PRIME
1	M2	0.054	270.0	0.061	273.0
2	S2	0.024	320.0	0.028	315.9
3	N2	0.007	248.3	0.010	255.4
4	K1	0.021	150.3	0.022	161.2
5	M4	0.000	0.0	0.000	161.7
6	O1	0.018	153.2	0.032	187.5
7	M6	0.000	0.0	0.000	62.5
8	MK3	0.000	0.0	0.000	36.2
9	S4	0.000	0.0	0.000	180.0
10	MN4	0.000	0.0	0.000	156.8
11	NU2	0.000	0.0	0.002	257.8
12	S6	0.000	0.0	0.000	90.0
13	MU2	0.000	271.6	0.000	251.7
14	2N2	0.000	0.0	0.001	237.8
15	OO1	0.000	0.0	0.002	134.8
16	LAM2	0.000	0.0	0.000	293.0
17	S1	0.004	91.8	0.000	135.0
18	M1	0.000	0.0	0.002	174.4
19	J1	0.002	141.3	0.002	148.1
20	MM	0.000	0.0	0.012	258.8
21	SSA	0.067	252.4	0.055	240.7
22	SA	0.118	155.5	0.155	142.8
23	MSF	0.000	0.0	0.006	157.7
24	MF	0.000	0.0	0.018	215.4
25	RHO	0.002	109.6	0.001	198.9
26	Q1	0.004	130.9	0.009	175.3
27	T2	0.002	7.3	0.002	314.1
28	R2	0.003	353.6	0.000	317.5
29	2Q1	0.002	127.1	0.001	213.7
30	P1	0.008	147.0	0.009	177.0
31	2SM2	0.000	0.0	0.000	279.1
32	M3	0.000	0.0	0.000	31.2
33	L2	0.000	0.0	0.002	290.6
34	2MK3	0.000	0.0	0.000	26.3
35	K2	0.006	306.0	0.008	306.2
36	M8	0.000	0.0	0.000	323.4
37	MS4	0.000	0.0	0.000	170.8

Amplitudes in meters, Phases in degrees (referenced to UTC)
Barrow - Average of two LSQHA analyses 2008 2010
PrudhoeBay - Average of 4 LSQHA analyses 1989-1995

APPENDIX 3. Software Code

A) HEX transformation code using VisualBasic delveloped to convert raw binary data from the acoustic modem to ASCII Hex format.

```
Public Class Form1
    Inherits System.Windows.Forms.Form
    Dim dataFileLen As Long
    Dim dataDir = "c:\barrowRaw\"
    Dim dataFile As String = dataDir & "modem.dat"
    Dim keyParm As String = "FFFFFFFFFFFFFFBFFFFFFFF"
    Dim KeyParmEnd As String = "FFFFFFFFFFFFFFCFFFFFFFF"
    Dim keyWave As String = "00000000000000000000000"
    Dim keyWaveEnd As String = "FFFFFFFFFFFFFFFFFFFFFFF"
    Dim waveFlag As Boolean = False
    Dim waveLines As Integer  ', thisKey As Integer
    Dim cntW, cntWe, cntP, cntPe, cntTheRest As Integer
#Region " Windows Form Designer generated code "

    Public Sub New()
        MyBase.New()

        'This call is required by the Windows Form Designer.
        InitializeComponent()

        'Add any initialization after the InitializeComponent() call

    End Sub

    'Form overrides dispose to clean up the component list.
    Protected Overloads Overrides Sub Dispose(ByVal disposing As Boolean)
        If disposing Then
            If Not (components Is Nothing) Then
                components.Dispose()
            End If
        End If
        MyBase.Dispose(disposing)
    End Sub

    'Required by the Windows Form Designer
    Private components As System.ComponentModel.IContainer

    'NOTE: The following procedure is required by the Windows Form
Designer
    'It can be modified using the Windows Form Designer.
    'Do not modify it using the code editor.
    Friend WithEvents btnAll As System.Windows.Forms.Button
    Friend WithEvents lblPtr As System.Windows.Forms.Label
    Friend WithEvents TextBox1 As System.Windows.Forms.TextBox
    <System.Diagnostics.DebuggerStepThrough()> Private Sub
InitializeComponent()
        Me.btnAll = New System.Windows.Forms.Button
        Me.lblPtr = New System.Windows.Forms.Label
```

```
        Me.TextBox1 = New System.Windows.Forms.TextBox
        Me.SuspendLayout()
        '
        'btnAll
        '
        Me.btnAll.Location = New System.Drawing.Point(24, 64)
        Me.btnAll.Name = "btnAll"
        Me.btnAll.Size = New System.Drawing.Size(88, 32)
        Me.btnAll.TabIndex = 4
        Me.btnAll.Text = "transform"
        '
        'lblPtr
        '
        Me.lblPtr.Location = New System.Drawing.Point(176, 72)
        Me.lblPtr.Name = "lblPtr"
        Me.lblPtr.Size = New System.Drawing.Size(88, 16)
        Me.lblPtr.TabIndex = 3
        '
        'TextBox1
        '
        Me.TextBox1.AcceptsReturn = True
        Me.TextBox1.AutoSize = False
        Me.TextBox1.Font = New System.Drawing.Font("Microsoft Sans Serif",
10.0!, System.Drawing.FontStyle.Regular,
System.Drawing.GraphicsUnit.Point, CType(0, Byte))
        Me.TextBox1.Location = New System.Drawing.Point(40, 152)
        Me.TextBox1.Multiline = True
        Me.TextBox1.Name = "TextBox1"
        Me.TextBox1.Size = New System.Drawing.Size(256, 112)
        Me.TextBox1.TabIndex = 6
        Me.TextBox1.Text = "TextBox1"
        '
        'Form1
        '
        Me.AutoScaleBaseSize = New System.Drawing.Size(5, 13)
        Me.ClientSize = New System.Drawing.Size(576, 382)
        Me.Controls.Add(Me.TextBox1)
        Me.Controls.Add(Me.btnAll)
        Me.Controls.Add(Me.lblPtr)
        Me.Name = "Form1"
        Me.Text = "Form1"
        Me.ResumeLayout(False)

    End Sub

#End Region

    Private Sub OpenOutFile()

        Dim outFile As String
        outFile = dataDir & "test.hex"
        dataFileLen = FileLen(dataFile)
        Try
            FileOpen(2, outFile, OpenMode.Output)
```

```
        Catch ex As Exception
            MsgBox("output file !?")

        End Try
    End Sub

    Private Sub btnAll_Click(ByVal sender As System.Object, ByVal e As
System.EventArgs) Handles btnAll.Click
        OpenOutFile()
        writeHeader()
        writeHeaderData()

        transformData()
    End Sub
    Private Sub writeHeader()
        Dim s As String = "1"
        Dim headFile As String = "seabirdHeader.txt"
        Dim headFileLen, ptr As Long
        FileOpen(4, headFile, OpenMode.Input)
        headFileLen = 3
        For ptr = 1 To headFileLen
            s = LineInput(4) & Chr(13) & Chr(10)
            Print(2, s)
        Next

        FileClose(4)

    End Sub
    Private Sub writeHeaderData()

        Dim s, s1 As String, lineCount, linePtr, ptr As Integer
        Dim foundDB As Boolean = False
        Dim sa(300) As String

        FileOpen(4, dataFile, OpenMode.Input)
        'input all the lines upto db9600,
        While Not foundDB
            s = LineInput(4)
            foundDB = (InStr(UCase(s), "S>DB9600") > 0)
            lineCount += 1
            sa(lineCount) = s
        End While

        'find last DS ... a couple could be there
        For linePtr = lineCount To 1 Step -1
            If InStr(UCase(sa(linePtr)), "S>DS") > 0 Then Exit For
        Next
        ptr = linePtr
        'copy the DS data
        sa(ptr) = UCase(sa(ptr))  'just to make it consistant with Seabird
upload
        Do
            s1 = "*" & sa(ptr) & Chr(13) & Chr(10)
```

```
            Print(2, s1)
            ptr += 1
        Loop Until InStr(UCase(sa(ptr)), "S>") = 1 Or ptr > lineCount

        'find DC
        For linePtr = 1 To lineCount
            If InStr(UCase(sa(linePtr)), "S>DC") > 0 Then Exit For
        Next

        ptr = linePtr
        'copy the DC data
        sa(ptr) = UCase(sa(ptr))
        Do
            s1 = "*" & sa(ptr) & Chr(13) & Chr(10)
            Print(2, s1)
            ptr += 1
        Loop Until InStr(UCase(sa(ptr)), "S>") = 1 Or ptr > lineCount

        s1 = "*" & "S>DD" & Chr(13) & Chr(10)
        Print(2, s1)

        FileClose(4)

    End Sub
    Private Sub transformData()
        Dim b As Byte, bHex As String, ptr As Long, crlf As String =
Chr(13) & Chr(10)
        Dim strDum As String = "123456789012345678901234"
        Dim strDum2 As String, locParm As Integer
        Dim strx As String
        FileOpen(1, dataFile, OpenMode.Binary)

        ' find beginning of a recording session ...look for parameters
        Do While Loc(1) < dataFileLen And strDum <> keyParm
            FileGet(1, b)
            bHex = Hex(b).PadLeft(2, "0")
            strDum = strDum.Substring(2, 22) & bHex
        Loop
        If Loc(1) >= dataFileLen Then
            MsgBox("can't find parm start")
            Stop
        Else
            Print(2, strDum, crlf)
            'Print(2, crlf)
        End If
        locParm = 100 * Loc(1) / dataFileLen
        Do While Loc(1) < dataFileLen - 12
            For ptr = 1 To 12
                FileGet(1, b)
                bHex = Hex(b).PadLeft(2, "0")
                strDum = strDum.Substring(2, 22) & bHex
            Next
            findKey(strDum)
            If Not waveFlag Or waveLines > 0 Then
```

```
                Print(2, strDum, crlf)
                waveLines -= 1
            Else
                Print(2, strDum.Substring(0, 12), crlf)
                Print(2, strDum.Substring(12, 12))
                Print(2, crlf)
            End If
        Loop
        lblPtr.Text = "DONE"

        FileClose(1)
        FileClose(2)

        strx = " Start Key " & locParm.ToString & "% into FILE"
        strx &= crlf & " dataStarts = " & cntP.ToString
        strx &= crlf & " dataEnds = " & cntPe.ToString
        strx &= crlf & " waveStarts = " & cntW.ToString
        strx &= crlf & " waveEnds = " & cntWe.ToString
        strx &= crlf & " the rest = " & cntTheRest.ToString
        TextBox1.Text = strx

    End Sub
    Private Sub findKey(ByVal strdum As String)

        Select Case strdum
            Case keyParm
                cntP += 1
            Case KeyParmEnd
                cntPe += 1
            Case keyWave
                waveLines = 3
                waveFlag = True
                cntW += 1
            Case keyWaveEnd
                cntWe += 1
                waveFlag = False
            Case Else
                cntTheRest += 1
        End Select

    End Sub


End Class
```

B. Processing Software for creating water level from water pressure using VisualBasic 6.5 in Excel Delveloper

```
Attribute VB_Name = "Module2"
Option Explicit
Dim taskDir As String, gravity As Double, dbarPerPsi As Double
Dim tym(100000, 1 To 2) As Date, pres(100000, 1 To 2) As Single,
therm(100000, 1 To 2) As Single, cond(100000, 1 To 2) As Single
Dim sal(100000, 1 To 2) As Single, dataCnt(2)
```

```
Dim tymHour(10000) As Date, AvgSal(10000) As Single, AvgTherm(10000) As
Single, AvgWL(10000) As Single, avgPres(10000) As Single
Dim AvgSalP(10000, 1 To 2) As Single, AvgThermP(10000, 1 To 2) As Single,
avgPresP(10000, 1 To 2) As Single, avgCondP(10000, 1 To 2) As Single
'SAT  is Salinity Adjustment Table
Dim tymSAT(50) As Date, platSAT(50) As Integer, offsetSAT(50) As Single,
slopeSAT(50) As Single, cntSAT As Integer
Dim avgPresPx(10000, 1 To 2) As Single ' old way of hour average
Dim thermPtr As Long, pOut As Single, tOut As Single, cOut As Single, sOut
As Single

Sub readTID2010()
'this reads the the barrow P1 and P2 platform data and puts it into arrays
'for EXCEL ploting and some analysis it averages the six minute data to
hourly averages
'it has subroutines to apply the salinity corections to the pressure data
'variables starting with "tym" are time

Dim fileName(2) As String, fileDir As String, fileSAT As String
Dim xd As String, cnt As Long, plat As Integer, hourPtr As Long
taskDir = "C:\data\Barrow2010\"
gravity = 9.8268345  ' from equation
dbarPerPsi = 1 / 1.45037744 ' ~ 0.6894757

fileName(1) = "p1\tid\p1_2010bp.tid"
fileName(2) = "p2\tid\p2_2010bp.tid"
'READ IN P1 AND P2 DATA FROM .TID FILE
'THIS DATA HAS BEEN CORRECTED FOR ATMOSPHERIC PRESSURE...pressure still
psi
For plat = 1 To 2
    Open taskDir & fileName(plat) For Input As #2
    cnt = 0
    Do While Not EOF(2)
        Line Input #2, xd
        If Len(xd) = 72 Then
            cnt = cnt + 1
            tym(cnt, plat) = DateValue(Mid(xd, 10, 10)) +
TimeValue(Mid(xd, 21, 8))
            pres(cnt, plat) = Val(Mid(xd, 32, 8))
            therm(cnt, plat) = Val(Mid(xd, 44, 7))
            cond(cnt, plat) = Val(Mid(xd, 54, 8))
            sal(cnt, plat) = Val(Mid(xd, 66, 7))
        End If
    Loop
    Close (2)
    dataCnt(plat) = cnt  'save the data length
    'HOW MUCH IS THERE
    Debug.Print cnt, tym(1, plat), tym(cnt, plat)
Next plat

'create adjusted sal array
'read in salinity map fromspreadsheet
getSalMapFromSheet
Debug.Print cntSAT   ' number of correction areas
```

```
'create a hour time array and corrected salinity averages
' this is really only a tool for coming up with the SAT (salinity
adjustment table
Dim tymStart As Date, tymStop As Date, hr As Date, SAT As Integer, ptr As
Long
tymStart = DateValue("8/28/2009") + TimeValue("00:00:00") + 0.000001
tymStop = DateValue("8/19/2010") + TimeValue("00:25:00")
hr = tymStart
hourPtr = 0
Do While hr < tymStop
    hourPtr = hourPtr + 1
    tymHour(hourPtr) = hr
    For plat = 1 To 2
        getSalHrAvgP hourPtr, plat  'also does temp and cond
        getBetterWLevHrAvgP hourPtr, plat
        getWLevHrAvgP hourPtr, plat ' just for demo
    Next plat
    hr = DateAdd("h", 1, hr)
    'Debug.Print SAT, tymSAT(SAT), hr
Loop

Debug.Print hourPtr, "timeStop", hr

If MsgBox("write data to spread sheat?", vbYesNo, "spread sheet") =
VBA.vbYes Then

 'write salinity temperature and conductivity to spread sheet
    Worksheets("sal").Activate
    Range("a4").Activate
 For ptr = 1 To hourPtr
    ActiveCell.Offset(ptr, 1).Value = tymHour(ptr)
    plat = 1
    ActiveCell.Offset(ptr, 2).Value = AvgThermP(ptr, plat)
    ActiveCell.Offset(ptr, 3).Value = avgCondP(ptr, plat)
    ActiveCell.Offset(ptr, 4).Value = AvgSalP(ptr, plat)
    plat = 2
    ActiveCell.Offset(ptr, 5).Value = AvgThermP(ptr, plat)
    ActiveCell.Offset(ptr, 6).Value = avgCondP(ptr, plat)
    ActiveCell.Offset(ptr, 7).Value = AvgSalP(ptr, plat)
 Next ptr

    'column headers
    ActiveCell.Offset(0, 1).Value = "time"
    ActiveCell.Offset(0, 2).Value = "p1Th"
    ActiveCell.Offset(0, 3).Value = "p1Con"
    ActiveCell.Offset(0, 4).Value = "p1Sal"
    ActiveCell.Offset(0, 5).Value = "p2Th"
    ActiveCell.Offset(0, 6).Value = "p2Con"
    ActiveCell.Offset(0, 7).Value = "p2Sal"

    'write water level averages to spreadsheet
    Worksheets("WL").Activate
    Range("a4").Activate
```

```
 Dim rho As Single
    ActiveCell.Offset(-1, 2).Value = "wl_p1" 'xx
    ActiveCell.Offset(-1, 3).Value = "wl_p2" 'xx
    ActiveCell.Offset(-1, 4).Value = "wl_dif" 'xx
    ActiveCell.Offset(-1, 5).Value = "wl_dif old" 'xx
    ActiveCell.Offset(-2, 5).Value = "25 mm off" 'xx
 For ptr = 1 To hourPtr
    ActiveCell.Offset(ptr, 1).Value = tymHour(ptr)
    ActiveCell.Offset(ptr, 2).Value = avgPresP(ptr, 1) 'xx
    ActiveCell.Offset(ptr, 3).Value = avgPresP(ptr, 2) 'xx
    ActiveCell.Offset(ptr, 4).Value = avgPresP(ptr, 2) - avgPresP(ptr, 1)
'xx
    ActiveCell.Offset(ptr, 5).Value = avgPresPx(ptr, 2) - avgPresPx(ptr,
1) - 0.025 'xx offset for graph
 Next ptr

 matchStaff
 write29MayData
End If

If MsgBox("write WL file?", vbYesNo, "File for DataBase") = VBA.vbYes Then
    write6minuteWaterLevelFile
End If

Debug.Print "DONE with readTID2010"
If MsgBox("readTID2010 completed", vbOKOnly, "done") = vbOK Then
End If

End Sub

Sub write29MayData()
'used to verify that phase shift in pressure difference wasn't true
    Dim tymStart As Date, tymStop As Date, ptr As Long, rowPtr As Long,
plat As Integer
    Dim newTym As Date, oldTym As Date
    tymStart = DateValue("5/27/2010") + TimeValue("00:00:00") + 0.000001
    tymStop = DateValue("6/4/2010") + TimeValue("00:00:00")
    oldTym = tymStart
    Worksheets("wl(6min)May29").Activate
    Range("a6").Activate
    For plat = 1 To 2
        If plat = 2 Then Range("d6").Activate  'move it across a couple
col
        ptr = 0  'find starting point
        Do
            ptr = ptr + 1
        Loop Until tym(ptr, plat) > tymStart
        rowPtr = 0
        While tym(ptr, plat) < tymStop  'put data on sheet
            rowPtr = rowPtr + 1
            newTym = tym(ptr, plat)
            If DateDiff("n", oldTym, newTym) > 10 Then rowPtr = rowPtr + 1
' skip a line
            oldTym = newTym
```

```
            ActiveCell.Offset(rowPtr, 0).Value = newTym
            ActiveCell.Offset(rowPtr, 1).Value = pres(ptr, plat) *
dbarPerPsi
            ptr = ptr + 1
        Wend
    Next plat
End Sub

Sub getSalHrAvgP(tymPtr As Long, plat As Integer)
    Dim ptr As Long, salSum As Single, thermSum As Single, condSum As
Single
    Dim stopTime As Date, cnt As Integer, tm As Date, SATptr As Single
    tm = DateAdd("n", -30, tymHour(tymPtr)) ' 30 minutes before hour
    salSum = 0: thermSum = 0: condSum = 0: cnt = 0

    ptr = findLow(tm, plat) + 1
    stopTime = DateAdd("n", 60, tm)
    While tym(ptr, plat) < stopTime And ptr < dataCnt(plat)
        salSum = salSum + sal(ptr, plat)
        thermSum = thermSum + therm(ptr, plat)
        condSum = condSum + cond(ptr, plat)
        cnt = cnt + 1
        ptr = ptr + 1
    Wend
    'in case there is a blank spot
    If salSum < 1 Or cnt = 0 Then
        salSum = sal(ptr, plat)
        thermSum = therm(ptr, plat)
        cnt = 1
    End If
    AvgSalP(tymPtr, plat) = salSum / cnt
    AvgThermP(tymPtr, plat) = thermSum / cnt
    avgCondP(tymPtr, plat) = condSum / cnt
End Sub

Function findLowSAT(d1 As Date) As Integer
'this finds the time in a assending list just before the argument time
'this is for the Salinity Adjust Table
'uses sequential search
    Dim i As Integer
    i = 1
    Do While d1 > tymSAT(i) And d1 > tymSAT(i + 1) And i < cntSAT
        i = i + 1
    Loop
    findLowSAT = i
    'findLowSAT = 1 'no sal adjust
    'iSum(i) = iSum(i) + 1
End Function
Function findLow(d1 As Date, plat As Integer) As Long
'this finds the pointer to the time in a assending list just before the
argument time
'uses a binary search since list is about 100000 long
' this is for the P1 and P2 data
```

```
    Dim iMax As Long, iMin As Long, gap As Long, ptr As Long, iter As
Integer
    iMax = dataCnt(plat): iMin = 2: gap = (iMax - iMin) \ 2
    ptr = gap
    While gap > 1
        gap = (gap + 1) \ 2
        If tym(ptr, plat) > d1 Then
            ptr = ptr - gap
        Else
            ptr = ptr + gap
        End If
        If ptr > iMax Then ptr = iMax  'these are unnecessary unless close
to edges
        If ptr < iMin Then ptr = iMin
    Wend
    'it is always just above or just below d1
    If tym(ptr, plat) > d1 Then ptr = ptr - 1

    findLow = ptr

End Function

Sub getSalMapFromSheet()
'this makes anaylsis a little easier...not as many steps to change SAT
Dim cnt As Integer
Worksheets("salMap").Activate: Range("a3").Activate
cnt = 0
Do While ActiveCell.Offset(cnt + 1, 0).Value > DateValue("08/01/2008")
    cnt = cnt + 1
    tymSAT(cnt) = ActiveCell.Offset(cnt, 0).Value
    platSAT(cnt) = ActiveCell.Offset(cnt, 2).Value
    offsetSAT(cnt) = ActiveCell.Offset(cnt, 3).Value
    slopeSAT(cnt) = ActiveCell.Offset(cnt, 4).Value
    Debug.Print cnt; tymSAT(cnt); platSAT(cnt); offsetSAT(cnt);
slopeSAT(cnt)
Loop
cntSAT = cnt

End Sub


Sub getWLevHrAvgP(tymPtr As Long, plat As Integer)
'this has been replaced with a better averaging method
...getBetterWLevHrAvgP()
'this averages the 6 minute wlev to hour averages centered on the time
pointer
'and stores it in an array
    Dim ptr As Long, sum As Single
    Dim stopTime As Date, cnt As Integer, tm As Date, SATptr As Single
    tm = DateAdd("n", -30, tymHour(tymPtr)) ' 30 minutes before hour
    sum = 0:  cnt = 0

    ptr = findLow(tm, plat) + 1
    stopTime = DateAdd("n", 60, tm)
```

```
    While tym(ptr, plat) < stopTime And ptr < dataCnt(plat)
        sum = sum + pres(ptr, plat)
        cnt = cnt + 1
        ptr = ptr + 1
    Wend
    'in case there is a blank spot
    If sum < 1 Or cnt = 0 Then
        sum = pres(ptr, plat)
        cnt = 1
    End If
    'avgPres(tymPtr) = (sum / cnt) * dbarPerPsi
    avgPresPx(tymPtr, plat) = (sum / cnt) * dbarPerPsi

End Sub

Sub getBetterWLevHrAvgP(tymPtr As Long, plat As Integer)
'this better one does not introduce a phase shift
'this averages the 6 minute wlev to hour averages centered on the time
pointer
'and stores it in an array
    Dim ptr As Long, sum As Single
    Dim cnt As Integer, tm As Date, maxCnt As Integer
    Dim t1 As Date, t2 As Date, p1 As Single, p2 As Single, avgP As Single
    maxCnt = 10
    tm = DateAdd("n", -33, tymHour(tymPtr)) ' 33 minutes before hour..sets
up centering data on hour mark
    ptr = findLow(tm, plat)
    sum = 0
    For cnt = 1 To maxCnt
        tm = DateAdd("n", 6, tm) ' add 6 minutes
        While tym(ptr + 1, plat) < tm
            ptr = ptr + 1
        Wend
        t1 = tym(ptr, plat)
        t2 = tym(ptr + 1, plat)
        p1 = pres(ptr, plat)
        p2 = pres(ptr + 1, plat)
        sum = sum + p1 + (p2 - p1) * (tm - t1) / (t2 - t1)
    Next cnt
    avgP = sum * dbarPerPsi / maxCnt
    avgPres(tymPtr) = avgP
    avgPresP(tymPtr, plat) = avgP

End Sub

Sub write6minuteWaterLevelFile()
Dim tymPtr As Long, tymStart As Date, tymStop As Date, tm As Date, days As
Integer, coefTimeDrift As Single
Dim tmP2 As Date, offset90 As Double, ptr As Long, SATptr As Integer
Dim p1 As Double, p2 As Double, d1 As Date, d2 As Date, pt As Double
Dim outFile As String, stationID As String, plat As Integer, out As String
Dim ptrSal As Long, thePlat As Integer, theSal As Double, rho As Double,
wl As Double, th10 As Single
Dim wlStr As String, th10Str As String
```

```
stationID = "9494935"
outFile = stationID & "P2_2009_2010a.txt"
plat = 2

tymStart = DateValue("8/28/2009") + TimeValue("00:00:00") + 0.000001
tymStop = DateValue("8/19/2010") + TimeValue("00:00:00")
Open taskDir & outFile For Output As #2
tm = tymStart

While tm < tymStop
    wl = waterLevel(tm, plat) * 1000 ' millimetrs
    wlStr = Right("      " & Str(Round(wl)), 7)
    'thermPtr added in 2010 since wl was done in waterLevel function and
not here
    th10 = therm(thermPtr, plat) * 10
    th10Str = Right("    " & Str(Round(th10)), 6)
    out = stationID & "1" & Format(tm, "mmm dd yyyy") & " " & Format(tm,
"Hh:Nn")
    out = out & wlStr & Space(12) & th10Str & "Z1 D"
    Print #2, out
    tm = DateAdd("n", 6, tm)
Wend

Close 2
Debug.Print "finished" & taskDir & outFile
End Sub

Sub matchStaff()
Dim plat As Integer, tm As Date, wl As Double, cellOffset As Integer,
aDate As Date
aDate = DateValue("8,1,2008")
Worksheets("staffShots").Activate: Range("a19").Activate
For cellOffset = 1 To 300
    If IsDate(ActiveCell.Offset(cellOffset, 0).Value) Then
        tm = ActiveCell.Offset(cellOffset, 0).Value
        If tm > aDate Then
            For plat = 1 To 2
                wl = waterLevel(tm, plat)
                ActiveCell.Offset(cellOffset, 12 + plat).Value = wl
            Next plat
        End If
    End If
Next cellOffset

End Sub

Function waterLevel(tm As Date, plat As Integer) As Double
Dim tymStart As Date, tymStop As Date, days As Integer, coefTimeDrift As
Double
Dim tmP2 As Date, offset90 As Double, ptr As Long, SATptr As Integer
Dim p1 As Double, p2 As Double, d1 As Date, d2 As Date, pt As Double
Dim ptrSal As Long, thePlat As Integer, theSal As Double, rho As Double,
tDrift(2) As Double
tymStart = DateValue("8/28/2009")
```

```
tymStop = DateValue("8/19/2010")
tDrift(1) = 75  ' seconds fast
tDrift(2) = 67  ' seconds fast
'below tmP2 moves into the psudo time of the raw data
days = DateDiff("d", tymStart, tymStop)
coefTimeDrift = tDrift(plat) / (days * 86400)
offset90 = -90# / 86400  'date function is actually days... 180 second
sample
tmP2 = tm + DateDiff("d", tymStart, tm) * coefTimeDrift + offset90
ptr = findLow(tmP2, plat)
p1 = pres(ptr, plat)   '1st pressure
p2 = pres(ptr + 1, plat)   '2nd pressure
d1 = tym(ptr, plat)  '1st time
d2 = tym(ptr + 1, plat)   'second time
'interpolate
pt = p1 + (p2 - p1) * (tmP2 - d1) / (d2 - d1)
pt = pt * dbarPerPsi   ' change to dbar
SATptr = findLowSAT(tmP2)
thePlat = platSAT(SATptr)
ptrSal = findLow(tmP2, thePlat)
theSal = sal(ptrSal, thePlat) + offsetSAT(SATptr) + slopeSAT(SATptr) *
DateDiff("d", tymSAT(SATptr), tm)
rho = rhoSTP(theSal, therm(ptr, plat), p1)
thermPtr = ptr ' this is a pass back to write6mindata
'p(Pa) = rho(kg/m^3) g(m/s^2) h(m)   <<<< equation and proper units
waterLevel = pt * 10000 / (gravity * rho)  ' pt in dbar and wl in mm
(10000 Pa/dbar)

End Function

Sub allData(tm As Date, plat As Integer)
'corrects time and intepolates the data for a requested time
Dim tymStart As Date, tymStop As Date, days As Integer, coefTimeDrift As
Double
Dim tmP2 As Date, offset90 As Double, ptr As Long
Dim p1 As Double, p2 As Double, d1 As Date, d2 As Date, pt As Double
Dim t1 As Double, t2 As Double, c1 As Double, c2 As Double, s1 As Double,
s2 As Double
Dim tDrift(2) As Double
Dim interPortion As Double
tymStart = DateValue("8/28/2009")
tymStop = DateValue("8/19/2010")
tDrift(1) = 75  ' seconds fast
tDrift(2) = 67  ' seconds fast
'below tmP2 moves into the psudo time of the raw data
days = DateDiff("d", tymStart, tymStop)
coefTimeDrift = tDrift(plat) / (days * 86400)
offset90 = -90# / 86400  'date function is actually days... 180 second
sample
tmP2 = tm + DateDiff("d", tymStart, tm) * coefTimeDrift + offset90
ptr = findLow(tmP2, plat)
d1 = tym(ptr, plat)  '1st time
d2 = tym(ptr + 1, plat)   'second time
interPortion = (tmP2 - d1) / (d2 - d1)
```

```
p1 = pres(ptr, plat)   'lst pressure
p2 = pres(ptr + 1, plat)   '2nd pressure
'interpolate
pOut = p1 + (p2 - p1) * interPortion
pOut = pOut * dbarPerPsi   ' change to dbar


t1 = therm(ptr, plat)   'lst temperature
t2 = therm(ptr + 1, plat)   '2nd temperature
'interpolate
tOut = t1 + (t2 - t1) * interPortion

c1 = cond(ptr, plat)   'lst conductivity
c2 = cond(ptr + 1, plat)   '2nd conductivity
'interpolate
cOut = c1 + (c2 - c1) * interPortion

s1 = sal(ptr, plat)   'lst salinity
s2 = sal(ptr + 1, plat)   '2nd salinity
'interpolate
sOut = s1 + (s2 - s1) * interPortion

End Sub

Sub write6minuteAlldata()
Dim tymStart As Date, tymStop As Date, tm As Date
Dim outFile As String, plat As Integer
Dim outStr As String
outFile = "BarrowAllData2010.txt"

tymStart = DateValue("8/28/2009") + TimeValue("00:00:00") + 0.000001
tymStop = DateValue("8/19/2010") + TimeValue("00:00:00")
Open taskDir & outFile For Output As #2
tm = tymStart

While tm < tymStop
    plat = 1
    Call allData(tm, plat)
    outStr = Format(tm, "yyyy mm dd") & " " & Format(tm, "Hh:Nn ")
    outStr = outStr & Format(pOut, " 00.0000 ") & Format(tOut, " 0.000 ;-
0.000 ")
    outStr = outStr & Format(cOut, "0.0000 ") & Format(sOut, "00.000 ")
    plat = 2
    Call allData(tm, plat)
    outStr = outStr & Format(pOut, " 00.0000 ") & Format(tOut, " 0.000 ;-
0.000 ")
    outStr = outStr & Format(cOut, "0.0000 ") & Format(sOut, "00.000")
    Print #2, outStr
    tm = DateAdd("n", 6, tm)
WendClose 2
Debug.Print "finished" & taskDir & outFile & Time
End Sub
```

```
Function rhoSTP(s, t, p) As Double
'UNESCO equation of state 1980
'(density(kg/m^3) in terms of Salinity(PSU), Temperature(C) and
Pressure(dbar).
'equation uses bars ..function input is dbar
'function checked against "fofonoff_millard_1983"
Dim aa As Double, bb As Double, ee As Double
Dim a As Double, b As Double, c As Double, d As Double, e As Double, f As
Double
Dim g As Double, h As Double, i As Double, j As Double, k As Double, m As
Double
Dim Ap As Double, Bp As Double, Aw As Double, Bw As Double, Kw As Double
Dim pbar As Double, S12 As Double, rho_0t0 As Double, rho_st0 As Double
Dim Ksto As Double, Kstp As Double

'this vb can't handle more than 3 )))  therefore the aa bb and ee
  aa = -0.00909529 + t * (0.0001001685 + t * (-0.000001120083 + t *
0.000000006536332))
  a = 999.842594 + t * (0.06793952 + t * aa)
  bb = 0.000076438 + t * (-0.00000082467 + t * 0.0000000053875)
  b = 0.824493 + t * (-0.0040899 + t * bb)
  c = -0.00572466 + t * (0.00010227 + t * (-0.0000016546))
  d = 0.00048314

  ee = -2.327105 + t * (0.01360477 + t * (-0.00005155288))

  e = 19652.21 + t * (148.4206 + t * ee)
  f = 54.6746 + t * (-0.603459 + t * (0.0109987 + t * (-0.00006167)))
  g = 0.07944 + t * (0.016483 + t * (-0.00053009))
  h = 3.239908 + t * (0.00143713 + t * (0.000116092 + t * (-
0.000000577905)))

  i = 0.0022838 + t * (-0.000010981 + t * (-0.0000016078))
  j = 0.000191075
  k = 0.0000850935 + t * (-0.00000612293 + t * 0.000000052787)
  m = -0.00000099348 + t * (0.000000020816 + t * 0.00000000091697)

pbar = 0.1 * p
S12 = Sqr(s)
rho_0t0 = a  'rhow
rho_st0 = rho_0t0 + (b + c * S12 + d * s) * s

Kw = e
Aw = h
Bw = k
aa = Aw + (i + j * S12) * s
bb = Bw + m * s
Kst0 = Kw + (f + g * S12) * s
Kstp = Kst0 + (aa + bb * pbar) * pbarrhoSTP = rho_st0 / (1 - pbar / Kstp)

End Function
```

APPENDIX 4. Salinity table of Barrow water level processing showing use of either Platform 1 sensor or the Platform 2 sensor.

Salinity Table

			use platform	plus
starting at this time	starting at this time	Normalization Conversion	sal data	PSU
8/9/08 21:00	8/9/08 21:00	p1	1	
9/1/08 23:00	9/1/08 23:00	p2 +1.9	2	1.9
9/4/08 3:00	9/4/08 3:00	p1	1	
9/21/08 15:00	9/21/08 15:00	p2+2.8	2	2.8
10/1/08 20:00	10/1/08 20:00	p1	1	
10/4/08 12:00	10/4/08 12:00	p2+3.3+.66D	2	3.4
10/9/08 12:00	10/9/08 12:00	p1	1	
10/11/08 2:00	10/11/08 2:00	p2+6.8	2	6.8
10/14/08 0:00	10/14/08 0:00	p1	1	
11/6/08 12:00	11/6/08 12:00	p2+4.5	2	4.5
11/15/08 4:00	11/15/08 4:00	p1	1	
2/4/09 0:00	2/4/09 0:00	p2	2	
2/4/09 16:00	2/4/09 16:00	p1	1	
2/23/09 18:00	2/23/09 18:00	p2	2	
4/15/09 16:00	4/15/09 16:00	p1	1	
5/8/09 10:00	5/8/09 10:00	p2	2	0.5
5/8/09 20:00	5/8/09 20:00	p1	1	
5/21/09 8:00	5/21/09 8:00	p2+.4	2	0.4
7/5/09 5:00	7/5/09 5:00	p2+.8+.22D	2	0.8
7/16/09 20:00	7/16/09 20:00	p1+.0+.067D	1	0
8/26/09 12:00	8/26/09 12:00	p1	1	