Monitoring Changes in Mean Sea Level Across the Arctic with Tide Gauges and GPS Receivers

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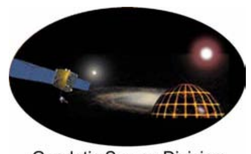

ABSTRACT

The Canadian Hydrographic Service (CHS) operates a network of five permanent tide gauge stations across the Canadian Arctic co-located with Global Positioning System (GPS) receivers operated by Natural Resources Canada (NRCan). The stations are located at Nain (Labrador), Qikiqtarjuaq and Alert (Nunavut), and Ulukhaktok and Tuktoyaktuk (Northwest Territories).

Water levels from the Arctic gauges provide a quantitative measure of mean sea level (MSL), a base level climate change indicator; the data will show changes in MSL over time. The GPS receivers provide data for monitoring vertical movement of the earth's crust. Combined, the two measurements enable the determination of absolute changes in Arctic sea level.

The data are also used to validate storm surge models and to assess the impacts of winter surge events, flooding, and erosion on coastal property. Equally important, the CHS also uses this data to establish the relationship between MSL and chart datum, the vertical reference surface for all CHS bathymetry.

INTRODUCTION

Since 2001, with funding received from the Canadian Climate Action Fund a network of tide gauges co-located with continuous GPS (CGPS) receivers was established. The stations are located at Nain (Labrador), Qikiqtarjuaq and Alert (Nunavut), and Ulukhaktok and Tuktoyaktuk (Northwest Territories) (Figure 1). All stations were constructed and equipment installed by the Canadian Hydrographic Service (CHS) and Geodetic Survey Division (GSD).

The first station was a reoccupation of a former tide gauge site at Nain in 2001, followed by new sites at Alert and Ulukhaktok (Holman) in 2002, reoccupation at Tuktoyaktuk in 2003 and new at Qikiqtarjuaq in 2004. There is planning in place to reoccupy the former site at Iqaluit to support the ship traffic at that port. The water levels recorded by the tide gauges are used to monitor the elevation of Mean Sea Level (MSL) and the continuous GPS (CGPS) data are used to monitor vertical movement of the earth's crust. By combining these two measurements absolute changes in sea level can be determined. These stations need to operate continuously for long periods of time for trends in sea level height to be determined. These trends are an indicator of climate change.

There are difficulties operating these stations in the north; servicing and maintenance can be expensive and the harsh environment can cause infrastructure breakdowns. The original funding ended in 2005 and since that time there has been no secured funding for this program.

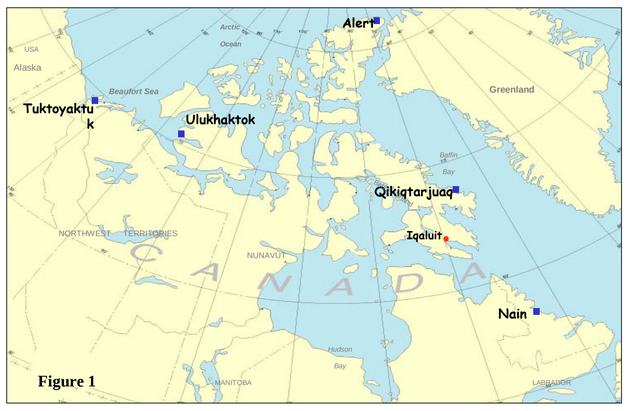

Figure 1

TIDE GAUGE EQUIPMENT

- Four of the stations employ a nitrogen gas bubbler system with a primary and a backup pressure sensor. This method was chosen because of its flexibility, the sensors can be located a long distance from the measuring point. These systems are relatively easy to install and require minimal infrastructure.
- The pressure sensors are the Paroscientific 230G which is a very stable and reliable sensor, these operate on a nitrogen gas-purge bubbler system (Figure 2). At Nain where there is a wharf structure, a stilling well (Figure 3) with a rotary shaft encoder on a float and counterweight system is the primary unit; with a Sutron Continuous Flow Bubbler and an independent pressure sensor, both used for redundancy.
- The data are recorded with Sutron 8210 data loggers instantaneous 3 minute interval, there are two at each station except at Nain where a Sutron Expert is in use.
- For all stations data retrieval is by telephone, every six hours for Tuktoyaktuk, Ulukhaktok, Qikiqtarjuaq, every 10 minutes for Nain and once daily for Alert.
- Central and Arctic Region operates and maintains the stations at Tuktoyaktuk, Ulukhaktok, Qikiqtarjuaq and Alert. Atlantic Region operates and maintains the station at Nain.
- One maintenance and calibration visit is undertaken at each site annually.

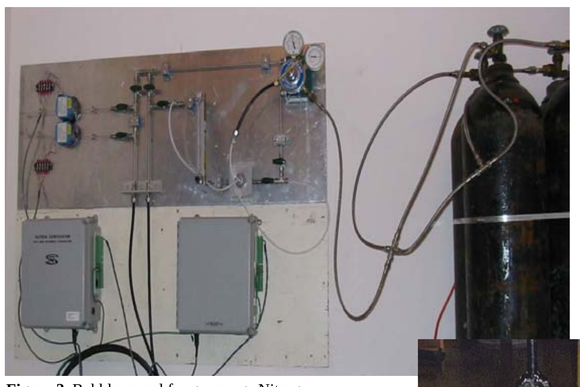

Figure 2. Bubbler panel for gas-purge Nitrogen system with two Sutron 8210 data loggers.

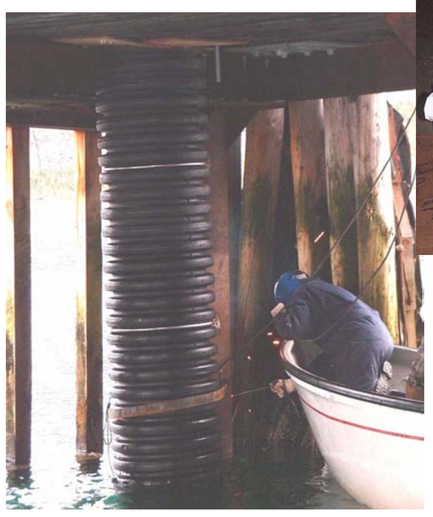

Figure 3. Stilling well under the wharf at Nain.

Figure 4. Orifice – underwater infrastructure for nitrogen gas-purge bubbler system including a bracket for a submersible gauge deployment.

GPS EQUIPMENT

- Each tide gauge is co-located with a continuous GPS (CGPS) Receiver, operated by Natural Resources Canada, Geodetic Survey Division.
- An Ashtech CGRS MicroZ 12 channel, dual frequency receiver records the GPS data at each station.
- The antenna (Figure 5) are mounted on a pillar at each station adjacent to the tide gauge shelter (Figure 6).
- At Nain the antenna and receiver are located in the Hydro Company building 800 metres away.
- Data are retrieved daily by telephone or wireless internet.

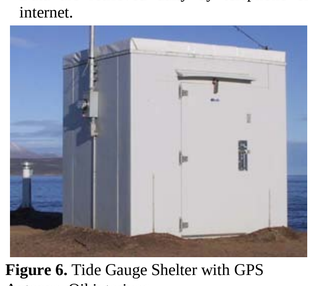

Figure 6. Tide Gauge Shelter with GPS Antenna, Qikiqtarjuaq.

Figure 5. GPS antenna.

CALIBRATION

- During the annual maintenance and calibration the tide gauge equipment is checked to ensure it is recording water level heights that are correct.
- Bench Marks are levelled (Figures 6 and 7) at each site starting from a holding bench mark, each network includes at least three bench marks. This also provides a check on bench mark network stability.
- At Nain the level loop includes the gnomen of the site gauge in the gauge shelter.
- At the other stations a series of water level checks are conducted by coming off a bench mark and establishing a gnomen within a stilling well (Figure 8) placed in the water. The water level heights obtained from the rod readings (Figure 8) are compared to the water level heights recorded in the data recorder. The offset in the recorder is adjusted by the average difference in the readings.
- The water level checks are performed at various stages of the tide and done in sets of 10 at 3 minute intervals to coincide with the Sutron data recording interval.

Figure 6. Levelling at Ulukhaktok (Holman).

Figure 7. Levelling at Tuktoyaktuk.

Figure 8. Stilling well / gnomen set-up at Alert.

Figure 9. GPS Observations on a bench mark at Alert.

- Any damage or problems at each site are repaired or noted for repair at a later date.
- Nitrogen tanks are changed over if necessary.
- The bubbler system is purged during the annual visit and when nitrogen tanks are changed.
- At each site except Nain a portable GPS antenna is set up on the Holding Bench Mark and GPS observations are recorded for 24 hours. The data file is sent to NRCan for processing.
- At Alert, Qikiqtarjuaq, Ulukhaktok and Tuktoyaktuk divers check the integrity of the underwater portion of the installation (bubbler line and orifice), every two or three years or if a problem is suspected.

Figure 10. Diving to re-install the orifice at Tuktoyaktuk in 2007.

DATA

- At Nain the data are retrieved by Sutron XConnect software every 10 minutes, are posted to the web immediately and are also retrieved by ISDM regularly.
- Quality control is conducted by Tides, Currents and Water Levels, CHS, Atlantic Region monthly and any corrections to the preliminary data are sent to ISDM.
- At Qikiqtarjuaq, Ulukhaktok and Tuktoyaktuk the data are retrieved by Sutron PCBase 2 software every six hours, the data are quality control and posted to the CHS website daily Monday to Friday and a file is sent to ISDM daily at the same time.
- At Alert the data are retrieved daily by HyperAccess software, the file is automatically placed on an ftp site at Department of Fisheries and Oceans, Integrated Science Data Management (ISDM) and is retrieved daily Monday to Friday and quality control.
- The quality control for Alert, Qikiqtarjuaq, Ulukhaktok and Tuktoyaktuk (Figure 9) is conducted by Tides, Currents and Water Levels Section, CHS, Central and Arctic Burlington office daily Monday to Friday.
- The GPS data are retrieved every 24 hours by NRCan, Geodetic Survey Division.
- The data are processed and used to determine vertical movement of the earth's crust.

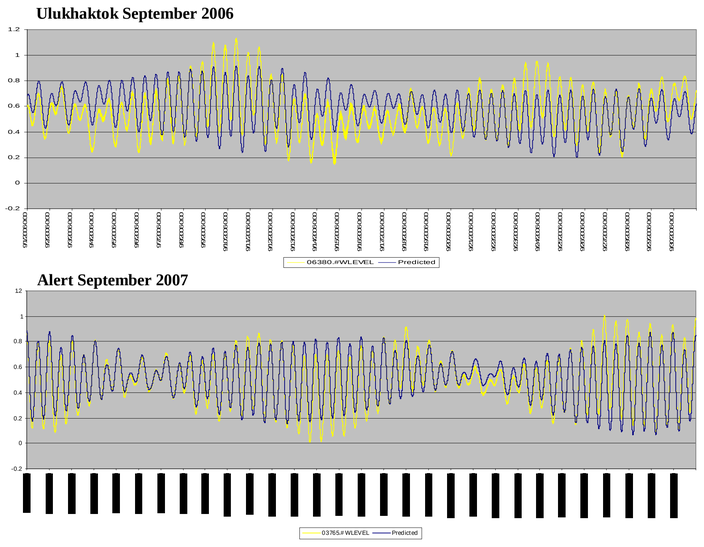

Figure 11. Data are compared with predicted tides for each station as part of the quality control process.

Challenges

The bubbler lines and measuring points (orifice) are subject to being disturbed resulting in interruptions in the continuous time series, most recently:

- Tuktoyaktuk 2006, underwater infrastructure pulled out of the water by a contractor replacing the water supply pipe to the Hamlet, first attempt at repair failed. Restored August 2007.
- Qikiqtarjuaq 2006, iceberg dragged over bubbler line and orifice destroying both, first attempt at repair has failed, bubbler line broken near shore.
- Repairs can be costly, there is a local gauge attendant employed at each site to trouble shoot, change nitrogen tanks and check on problems for both the CHS and NRCan.
- Telephone interruptions occur during storms.

VERTICAL MOTION

- The CGPS data are analyzed and the vertical movement of the earth's crust is determined (Figure 12).
- The monthly means at each tide gauge are used to determine the Relative Sea Level (RSL) Rates (Figure 13), as seen in the graphs for Alert and Ulukhaktok.
- The RSL rate is variable across the Arctic, mostly due to differences in the rates of isostatic rebound.

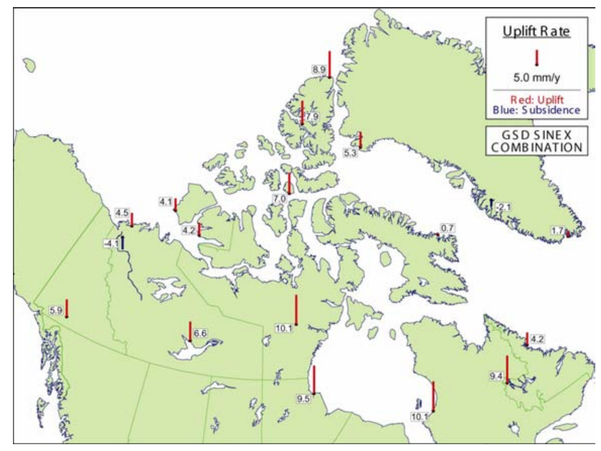

Figure 12. Observed CGPS vertical rates. Preliminary results from the SINEX combination of weekly GPS solutions in Canada exhibit a pattern of uplift largely consistent with post-glacial rebound (Craymer et al 2006).

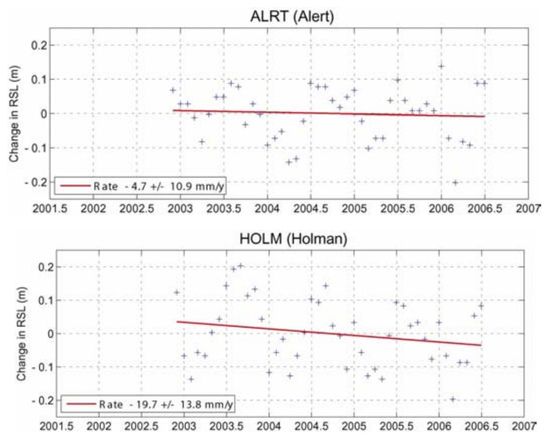

Figure 13. Monthly Relative Sea Level (RSL) Time Series for Alert and Ulukhaktok, (Craymer et al 2006)

- The two measurements, vertical movement of the earth's crust and RSL, are combined and the result is the Absolute Sea Level (ASL) Rate for each site where a tide gauge is co-located with a CGPS receiver (Figure 14).
- An anomaly at NAIN is being investigated and could be due to instability in the tide gauge installation.
- RSL and therefore ASL values are not available for Qikiqtarjuaq, the gauge has not been operational for a long enough time period.

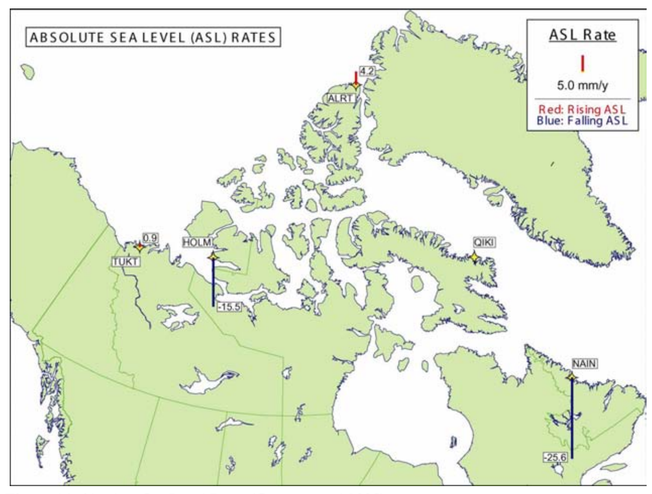

Figure 14. Absolute Sea Level Rates (Craymer et al 2006)

CONCLUSIONS

- The data collected is of a short time series, to determine the rate of sea level rise and noticeable long term trends at least 10 years of data are needed.
- The long term trends will be an indicator of climate change.
- The water level data also show immediate effects of climate (Figure 11), storm surges and seiche activity are seen when the water level heights and predicted tides are plotted together.
- Alert and Nain are GLOSS (Global Sea Level Observing System) stations and the data are submitted to the University of Hawaii Sea Level Centre as part of the Canadian contribution for long-term climate change and oceanographic sea level monitoring.
- The five stations are part of Permanent Service for Mean Sea Level and they are sent the water level data annually.
- At Tuktoyaktuk where there is an active oil and gas industry as well as marine navigation interest and coastal zone erosion is a concern the water level data are utilized on a continuing basis.
- For the Canadian Hydrographic Service the continued operation of the Arctic Network is vital for ensuring the Charts and tidal information are up to date to ensure safe and efficient navigation. This is especially important as the navigation season lengthens due to climate change.
- The CGPS data in conjunction with the GPS observations at Holding Bench Marks provides a relationship between the geiod, ellipsoid and chart datum.

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Author Biographies

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