NOAA Technical Memorandum NOS OMA 54

WATER LEVEL MEASUREMENTS IN THE POLAR REGIONS: STATUS AND TECHNOLOGY

Rockville, Maryland
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noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

NATIONAL OCEAN SERVICE

Office of Oceanography and Marine Assessment
National Ocean Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

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Water Level Measurements in the Polar Regions: Status and Technology

Eugene M. Russin
Hsing H. Shih
Richard F. Edwing

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United States Department of Commerce

Robert A. Mosbacher
Secretary

National Oceanic and Atmospheric Administration

John A. Knauss
Assistant Secretary and Administrator

National Ocean Service

Virginia K. Tippie
Assistant Administrator

Correspondence relative to this report should be addressed to the authors in care of:

Ocean Services Division
Office of Oceanography and Marine Assessment
National Oceanic and Atmospheric Administration
U.S. Department of Commerce
6001 Executive Blvd., Rm. 110
Rockville, MD 20852

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WATER LEVEL MEASUREMENTS IN THE POLAR REGIONS STATUS AND TECHNOLOGY

E. M. Russin, H. H. Shih and R. F. Edwing

National Ocean Service, NOAA

ABSTRACT

Continuous sea level measurements have been made and recorded for more than 100 years, but their importance has increased dramatically in the past few years due to the great international interest for monitoring global levels in anticipation of climate warming. Since the National Ocean Service (NOS) is the primary agency for measuring and recording water levels in the United States, it is being encouraged to increase the number of permanent sea level measuring stations especially in the polar regions where the data are extremely sparse.

Personnel from the Physical Oceanography Division (POD) and the Ocean Systems Division (OSD) of the Office of Oceanography and Marine Assessment (OOMA) have been researching the status of the technology and the requirements for water level measurements in the polar regions with special emphasis on the needs of NOAA's Climate and Global Change Program and The Global Sea Level Observing System, known as GLOSS. It is called GLOSS because it measures the global level of the sea surface, a smooth level after averaging out waves, tides and meteorological events. GLOSS, co-ordinated by the Intergovernmental Oceanographic Commission (IOC), provides high quality standarized data from which valuable sea level products are prepared for international and regional research programs as well as for practical national applications.

This report includes a survey of the work that NOS and others are or have been doing in this area and also assesses the state-of-the-art of the technology involved, the potential for future development, and provides recommendations for near and long-term projects. The report concludes that the technology and techniques exist for making sea level measurements in polar regions but that they must be site-specific; also, that stable bench mark connections and atmospheric pressure measurements are mandatory; that the field measurement system should be as automated as possible; and that near real-time transmission of data is highly desirable to ensure proper system operation and early availability of information to users. The report recommends the use of thermal bench marks in certain polar areas and the further development of acoustic and electromagnetic means of transmitting data from underwater sensors through the ice or land to nearby shore stations. It also recommends that Prudhoe Bay, AK be established as a pilot station for further investigations into the measurement requirements of other Arctic stations and that a cooperative program be initiated with the National Science Foundation for establishing stations in Antarctica.

1.0 INTRODUCTION

Continuous sea level measurements have been made and recorded for more than 100 years, but their importance has increased dramatically in the past few years due to the great international interest for monitoring global levels in anticipation of climate warming. Some scientists believe that the long term rise of sea level is due to three processes: thermal expansion of the upper layers of the ocean, the melting of glacial ice, and the addition of mass from the polar caps.

Since the National Ocean Service (NOS) in the National Oceanic and Atmospheric Administration (NOAA) is the primary agency for measuring and recording water levels in the United States, it is being encouraged to increase the number of permanent sea level measuring stations, especially in the polar regions where the data are extremely sparse.

Personnel from the Physical Oceanography Division (POD) and the Ocean Systems Division (OSD) of the Office of Oceanography and Marine Assessment (OOMA) held a meeting on March 29, 1990 to discuss the status and requirements of water level measurement in the polar regions with special emphasis on the needs of NOAA's Climate and Global Change Program and the Global Sea Level Observing System, known as GLOSS. It is called GLOSS because it measures the global level of the sea surface, a smooth level after averaging out waves, tides and meteorological events. GLOSS, co-ordinated by the Intergovernmental Oceanographic Commission (IOC), provides high quality standardized data from which valuable sea level products are prepared for international and regional research programs as well as for practical national applications.

This report is a follow-up to that March 1990 meeting and includes a survey of the work that NOS and others are or have been doing in this area and also assesses the state-of-the-art of the technology, the potential for future development, and provides recommendations for near- and long-term projects. This report can be used as a basis for planning, for future discussions within NOS and NOAA and with other U.S. agencies, and also with other nations.

2.0 PRESENT EFFORTS AND TECHNOLOGY

2.1 Background

The lack of U.S. sea level data in the polar regions is due to the lack of NOS measurement stations in those areas. Most of the Alaskan stations are sited on the southern coast of Alaska with very few on the west coast and even fewer on the north coast. The primary reason for the Alaskan station situation is funding; an Arctic station could cost up to a million dollars to establish, operate and maintain properly.

Station data problems occur mainly due to sensor failures or bench mark instability caused by either ice, icing or the freeze/thaw cycle. Sensor operability problems have been overcome in some remote areas by the use of gas-purging (bubbler) instruments connected to an onshore data collection platform. Although such instruments are not successful in areas where ice movements damage the gas-purging tubing in the ice/shore interface, at least the replacement cost is relatively low. The bench mark instability problem has been addressed in areas where no bedrock exists by what is called a thermal bench mark - a type of thermal pile filled with pressurized carbon dioxide gas used to stabilize the active layer (freeze/thaw zone) and prevent frost jacking.

The following describes the environment we are addressing and the present efforts of the United States and other countries in the technology areas related to making tidal measurements in polar regions.

2.2 The Polar Region Environment

The relatively small tides and tidal currents, and the hostile environment in the polar regions have, in the past, prevented NOS from conducting any significant long-term ocean measurements in those regions. The term polar region in this report is loosely used to include the coastal waters along the north and northwest of the state of Alaska (i.e., in the Arctic region - the Beaufort Sea in the north, Chukchi Sea, Bering Strait, and Bering Sea in the northwest), and along the United States territory in the Antarctic region. See Figures 1 and 2. Around the Arctic area, NOS maintains only one tide station along the whole northwest and north coasts of Alaska. In the Antarctica continent, NOAA currently has four measurement stations for climate research programs but no tide measuring stations.

Because of the hostile conditions, environmental data for the polar regions are scarce. A general description of the environment of the polar regions is as follows:

Air Temperature: -17^{o} C to $+5^{o}$ C along the coasts in the Arctic, colder toward the interior, and much colder in the Antarctic region.

Water Temperature: -2^{o} C to $+20^{o}$ C.

Ice: Winter is 8 to 9 months long (from mid-September through late May in the Arctic), extensive ice covers the water (from the coast to a few kilometers offshore in the Arctic, with thickness up to 3 meters); there is significant ice movement (with velocities in the order of several cm/sec) after ice break-up (including drift of large ice bergs). The extent of the ice cover varies with the seasons.

Land: Snow covered during the winter. The ground is perennially frozen to 610 meters depth (permafrost). Surface thawing causes upheaval. Glacial rebound also causes vertical land movement.

Sunlight: Weak due to low sun altitude above the horizon.

Wind: Polar winds prevail most of the time.

Tides: Low tidal amplitudes (less than 100 cm).

Waves: Non-tidal water fluctuations - storm surges and low atmospheric pressure movement-induced long period fluctuations are frequent and often overshadow the tide. Extensive ice cover may affect both the amplitude and phase of the tide.

Currents: Low speed (less than one-half meter per second) in offshore, and higher (up to several meters per second) in certain near coastal areas. An ice motion-induced boundary layer flow extending about 30 meters below the surface also exists.

Because of the above environmental conditions, the sensors or equipment one designs or selects for use in the polar areas must be capable of operation at very low temperatures with a limited power supply and have greater sensor stability and system reliability than equipment used in less hostile regions. Batteries are considered the most reliable power source. Solar power is not viable due to the low percentage on sun exposure but winds could be a possible supplemental power source in some areas. Due to the remoteness of the measurement sites, the capability of automated data collection and transmission is most desirable if only to monitor system performance as a minimum. Additional design considerations include preparing for ice cover in the long winter time and ice break-up and drifting during summer.

2.3 NOS Efforts

2.3.1 Tide Stations

NOS's experiences with water level measurements in polar regions have been only in the Arctic in Alaskan waters north of the Aleutians. There are presently 16 permanent National Water Level Observation Network (NWLON) stations operating in Alaskan coastal waters (see Figure 3). Only one of them, Prudhoe Bay, is located in Arctic waters, and it is presently operated on a seasonal basis (July - September) although there are plans to make it a year-round station starting this year. There have been approximately 1,100 short-term historical stations established in Alaska, but only 20% of them were north of the Aleutians. The majority of these stations were operated during the summer months, and most utilized bottom-mounted, pressure-type gauges whereas a typical NOS primary tide station (Figure 4) operated year-round would have an Analog to Digital Recorder (ADR) gauge with a float inside a 12-inch stilling well and a bubbler gauge as a back-up.

In general, the combination of insufficient resources and the harsh Arctic winter has prevented the establishment of any long-term, year-round NOS water level stations to-date. The specific obstacles to establishing Arctic tide stations with NOS's present water level measurement technology, whether it be the older ADR or the newer Next Generation Water Level Measurement System (NGWLMS), can be summarized as follows:

- Lack of vertical support structures for stilling and protective wells;
- Ice pack movement, shallow water depths, freezing wells;
- Bench mark instability; and
- Difficulty and cost of transportation, logistics, utilities, maintenance, etc. due to the remoteness of the sites.

Although the NGWLMS uses an air acoustic device as its primary water level sensor, and therefore also requires a support structure, it can also take inputs from pressure transducers or other underwater sensors and transmit the data via the GOES satellite communication system so that system performance can be monitored and users receive the data in near real-time (see Figure 5). A NGWLMS unit with an acoustic water level sensor has been recently installed, however, in

Prudhoe Bay, AK - only because that is a unique Arctic facility as explained in Section 3.1. A possible installation of an NGWLMS Data Collection Platform (DCP) with a bubbler system under the ice is illustrated in Figure 6.

The few existing Arctic marine facilities are typically gravel causeways extending out into the shallow waters, sometimes miles from shore. They are built with a low profile and sloping sides to minimize damage from ice pack movement. Sheet pile is used infrequently along the causeways for various purposes. However, ice scouring and the shallow water depths make it impossible to operate through the winter any system attached to the sheet pile. Even when wells are protected from destruction by ice movement, it is very difficult to prevent the water from freezing inside the wells.

There have been a few stations designed for year round operation on the gravel causeway type facilities. A sump-type design was utilized to avoid some of the problems discussed above. The installation cost of this type station is very high (several hundred thousand dollars) and none have been built.

2.3.2 Bench Marks

Bench mark stability is essential to preserving the datums established at a site. Bench mark stability has been a problem in the Arctic region due to the lack of bedrock and a large active zone. The lack of bedrock (and large concrete structures) eliminates the most stable, easily established type of bench mark. The large active zone, the layer of earth where a jacking action is produced by the freeze-thaw cycle, renders all monument and pipe marks, and a large number of Class B (unsleeved) deep rod marks, unstable. Permafrost, in itself, does not cause instability. High stability bench marks can be established in permafrost areas by anchoring the bench mark into the permafrost. In areas where permafrost does not exist, Class A (sleeved) bench marks can be established which are insulated from the active zone. Establishing permafrost-anchored and Class A bench marks is expensive and difficult to do in remote areas due to the need to augur a 1-inch diameter guide hole.

The remoteness of the arctic region has obvious impact on site accessibility, utilities service, logistics, available resources, maintenance, etc. all of which can be significant cost drivers in addition to installation costs.

Tidal datums, and the marine boundaries determined through their establishment, have been an important issue in the Arctic over the past two decades because of ownership claims. Millions of dollars have been at stake in State versus Federal ownership of oil leasing plots. The Bureau of Land Management has been surveying coastal lands for the purpose of restoration of the Federal lands to the State and native corporations; the Extended Jurisdiction Zone (200 mile boundary) has been determined; and NOAA has been conducting hydrographic surveys and mapping in the Arctic. The private sector uses tidal datums for artificial island construction, marine operations and other oil industry related activities. These projects all require tide data, to varying degrees of accuracy and for differing lengths of time, that has not been previously available in this region. These requirements, and the inability of standard technology and methods to satisfy them, has resulted in development and experimentation with new and improved procedures and instrumentation in an attempt to collect the needed tide data.

2.3.3 Dinkum Sands Project

Much of the search for new technology or procedures for making tide measurements in the polar regions has been performed in cooperation with the State of Alaska and other Federal agencies due to the common need for the data. The most ambitious, and costly, project was the Dinkum Sands project. An attempt was made to collect a full year of data off the coast of the north slope using standard technology (ADR & bubbler gauges) so that the tidal datums established would be defensible in court. Three long-term stations were established on three small, remote gravel islands for redundancy. The fully enclosed, heated, shelters (see Figure 7) were installed on specially-designed support platforms, heat tracing was used in the steel reinforced stilling wells, heated oil was dripped around the wells to prevent ice formation, bottom-mounted pressure gages supplemented the standard gages, and various other methods were employed to collect the data. Specially designed, sleeved, deep-rod bench marks were installed (and sometimes leveled to) while under ice pack cover. A full year of data was collected at one station at a cost of over $ 1 million.

Other attempts have centered around installing bottom-mounted pressure gauges but these devices have their own set of problems. Pressure gages are inherently less accurate than ADRs and must be corrected for barometric pressure and density variations; it is difficult to establish a physical reference point on them and to survey to it; and also hard to maintain their stability on the ocean bottom. If the entire instrument package is underwater, proper operation is a continual verification problem. If the data recorder is land-based, the cabling is extremely difficult to protect, particularly at the shore/sea interface. Bottom-mounted pressure gauges have been installed several times by the State of Alaska and it's contractors with limited success.

Short-term data requirements, mostly for hydrographic or photogrammetric operations, are met simply by conducting measurements during the ice-free summer months. Standard bubbler pressure gages are used as they are relatively easily transported and installed in remote and/or rugged areas. In situations where staff installations are difficult or subject to constant destruction from storms, several alternative methods are available. Sometimes a rod is driven into the ocean bottom in a shallow area. The high point of the rod is connected by survey levels to the bench mark net, and a staff is held on the high point for staff readings during an observation. The equivalent of a staff reading may also be made by leveling from a bench mark to the waters edge, if sea conditions are calm enough. These methods are dependent upon reasonably sheltered locations, however.

2.4 Canadian Efforts

With the discovery of oil and gas in the Canadian Arctic and subsequent decisions to transport these products to southern markets by sea, the Canadian Hydrographic Service (CHS) increased its involvement in collecting arctic tidal measurements. Initially, the emphasis was directed towards collecting short-term tidal records in order to obtain a general knowledge about tidal propagation through the complex archipelago in the Canadian Arctic. The method used to collect these data consisted of deploying self-recording pressure gauges on the sea bed and recovering the gauges after a specified elapsed time. The data collected from these short-term deployments were generally not corrected for atmospheric pressure variations and were not tied to bench marks.

In 1985, the CHS developed a permanent gauging system with limited application in the Arctic. This gauge used a conventional gas-purge system to measure sea levels. The system is connected to a brass orifice which is located in a protective housing attached to a wharf face. Data collected by the gauge is transmitted to satellite (ARGOS) at regular intervals and processed later in Burlington.

In 1987, the CHS commissioned the Bedford Institute of Oceanography (BIO) to design and develop an atmospheric pressure-measuring system and tide gauge capable of withstanding arctic conditions for an entire year. In August 1988, BIO successfully demonstrated such a system off the coast of Labrador using a air pressure sensor manufactured by Atmospheric Instrumentation Research, Inc.(AIR Inc.) that is accurate to ±0.7 millibar and consumes very little power. BIO is presently working on a satellite data link in order to allow the collected data to be transmitted to an operating center on an hourly or daily basis. To avoid using a physical link between the two devices, and to avoid the inherent problems of communicating through the ice/water barrier, the tide gauge will transmit ultra-low frequency electromagnetic signals to the data recording system through the intervening rock. Figure 8 is an artist's conception of the system. Electromagnetic energy has been used in mines in South Africa to communicate through rock and has proved viable for short distances. A short cable will be used to link the tide gauge to the electromagnetic communications link, located nearby on the sea bottom.

NOS is closely monitoring the progress of BIO and the Canadian Hydrographic Service with the hope that we can benefit from this important research project. Mr. George Steeves, the systems engineer in charge of the project, hopes to have a system with an electromagnetic communications link ready for testing near BIO in the winter of 1990-91.

2.5 Other Countries' Efforts

2.5.1 Japan

Japan has three observation bases in Antarctica - two of them are inland and the other is coastal. The coastal base, SYOWA STATION, was established in 1958 on the East Ongul Island which is in the face of the Indian Ocean about 5 kilometers off the Antarctic continent. In 1987, a new type of tide gauge using a quartz oscillator as a sensor was installed at the SYOWA STATION (see Figure 9). In the tide observation hut there is a junction box with a heater to protect the equipment from freezing. The heater is designed to work when the air temperature falls below -10^{o} C. The signal cable from the underwater unit to the junction box is protected with hard plastic tubing. The tide gauge has an air venting tube from the junction box to the underwater unit through the cable together with the signal lines and DC power supplying lines in order to make corrections for the effect of the atmospheric pressure automatically.

2.5.2 U.S.S.R.

Russian activities regarding sea-level measurements at Soviet Antarctic stations are performed by the Arctic and Antarctic Research Institute of the USSR. Due to severe ice conditions no permanent sea-level observations have been made at Soviet Antarctic stations. Some rough sea-level observations have been made at the Stations Bellingshausen and Russkaya and, occasionally, at the Station Molodezhnaya. There are plans to obtain regular sea-level observations at some Soviet Antarctic stations in connection with the GLOSS and WOCE programs. This will need, however, cooperation with other countries with regard to the establishment of modern tide gauges and exchange of sea-level data with other Antarctic stations.

2.5.3 New Zealand

New Zealand has, at infrequent intervals, collected sea level data in the Ross Sea region of Antarctica since 1957. The best continuous sea level data sets are 15 months of data from Scott Base in 1988 to 1990. The Scott Base gauge, an absolute pressure transducer type, was lost in a storm in February 1990. The gauge is to be re-established as a permanent site in 1990 with a second gauge to be established as a permanent site at Cape Roberts in 1991.

2.6 Recent and Applicable Meetings and Workshops

2.6.1 Workshop on Sea-Level Measurements in Hostile Conditions

This meeting was held at the Proudman Oceanographic Laboratory, Bidston Observatory in Bidston, U.K. on March 28-31, 1988. The workshop ended with the participants agreeing on the following general conclusions:

- The technology needed to make sea level measurements in hostile regions exists and is affordable;
- the technology and techniques used must be site specific;
- bench mark connections are mandatory using the applicable state-of-the-art technology;
- atmospheric pressure measurements are mandatory using the applicable state-of-the-art technology;
- real-time data transmission is required to ensure proper operation and early availability of data to the user community;
- since the availability of global reference systems (Very Long Baseline Interferometry [VLBI] and Global Positioning System [GPS]) has increased, the local reference system can be connected to them and subsequently the sea level data measured in relation to the latter will become extremely valuable;
- bench marks themselves have to meet the technical requirements for the site in view of permafrost disturbances and other local hazards.

2.6.2 First Session of IOC Group of Experts on the Global Sea-Level Observing System (GLOSS)

This meeting was also held at the Proudman Oceanographic Laboratory, Bidston Observatory in Bidston, U.K. in June 19-23, 1989. The Group discussed the draft report of the Committee on Geodetic Fixing of Tide Gauge Bench Marks (TGBMs) set up by the IAPSO Commission on Mean Sea-Level and Tides. The Group supported the recommendations, technical conclusions and strategy in the report. In particular, it was agreed that the primary strategy of connecting GLOSS (and other) tide gauges with differential GPS measurements to the fundamental VLBI/ Satellite Laser Ranging (SLR) stations of the conventional terrestrial reference frame (of the International Earth Rotation Service [IERS]) was very important for the various oceanographic and geophysical requirements listed in the report. Wherever possible, the vertical movements of the TGBMs should be verified by absolute gravity measurements.

The Group discussed the five technical conclusions of the Committee's draft report and made the following recommendations:

- "It is recommended that all gauges used to monitor mean sea-level must have a local network of bench marks (6 to 10) that are resurveyed by accurate levelling or GPS at least once per year and that information on this local bench mark control should be collected by the Permanent Service for Mean Sea Level (PSMSL).
- Using the accuracy of differential GPS stated in the report (1 cm in 1000 km) and the positions of the IERS (VLBI/SLR), it is possible to identify those GLOSS gauges that can be fixed to within 1 cm radially with respect to the IERS stations. It is recommended that the GLOSS gauges within this range and with, for example, (a) 20 years mean sea-level data and (b) 60 years mean sea-level data be identified and priority be given to geocentric location of these gauges.
- It is recommended that GLOSS gauges that have 60 years mean sea-level data, and where no IERS station is within 1000 km, should be identified as priority locations for either permanent VLBI/SLR stations or for mobile VLBI/SLR measurements.
- It is recommended that present IERS stations with no suitable GLOSS gauges within 1000 km should be identified and consideration should be given to installing suitable tide gauges within this range.
- It is recommended that the PSMSL would be a suitable center to collect, archive and distribute the geodetic information for each TGBM and that the PSMSL should consult the IERS Directing Board with regard to the information defining the geodetic reference frame that needs to be stored."

2.6.3 Workshop on Sea Level Measurements in Antarctica

This meeting was held in Leningrad, USSR in May 28-31, 1990. The participants at this workshop reported the following specific problems facing installers of reliable tide gauges in the Antarctic region:

- Ice scouring on the near-shore sea bed;
- the destruction of support structures by sea ice;
- the logistics of gauge maintenance;
- the lack of ice free locations and/or the unknown spurious effects encountered when using a gauge with a heated stilling well;

- the power requirements necessitated by any mechanism including automated data uplink to a satellite.

The Group's review of the gauges currently in operation revealed that one was a conventional float gauge (using a heated stilling well), one was a bubbler gauge and four were absolute pressure gauges.

The consensus of the participants was that the most appropriate type of gauge for Antarctic conditions was a bottom-mounted absolute pressure gauge, both recessed into the sea floor and with cabling either recessed into the local rock or well protected by some other means from ice action. The Group also agreed that gauges must be calibrated on an annual basis at ice free periods.

2.6.4 Second Session of the IOC Group of Experts on the Global Sea-Level Observing System (GLOSS)

This meeting will be held in Miami, FL, USA in October, 1990.

2.7 Organizations Interested in the Polar Regions

Organization	Country	Contact Person
NOAA/NOS	USA	L.Baer 301-443-8938
National Science Foundation Div. of Polar Programs	USA	T. Delaca 202-357-7894
IOC Ocean Services Unit	France	V. Jivago 33-1-45-68-40-44
Canadian Hydrographic Service Tides,Currents,Water Levels	Canada	G.M. Yeaton
Flinders University School of Earth Sciences	Australia	G.W. Lennon 08-275.2298
Inst. of Oceanographic Sciences	U.K.	D.T. Pugh 042879-4141

U. of Hawaii Dept. of Oceanography	USA	K. Wyrtki 808-948-7633
Arctic/Antarctic Res. Inst. Comm. for Hydrometeorology	USSR	V. Ivchenko 352-03-19
Dept. of Survey/Land Info New Zealand	N.Z.	J. Hannah 64-4-710-380
Hydrographic Dept. Maritime Safety Agency	Japan	M. Odamaki 81-3-541-3811
Army Corps of Engineers Cold Regions Res.& Eng. Lab	USA	J. Brown
Off. of Naval Research Arctic R & D	USA	T. Curtin 703-696-4118
U. of Alaska Modelling	USA	D. Kowalik 907-474-7753

3.0 WHAT NOAA/NOS COULD DO IN THE NEAR-TERM

NOS is presently performing two projects to improve measurements in the Arctic region. The first is the establishment of a year-round tide station on the north slope of Alaska. The second is the testing and evaluation of a new type bench mark resistant to frost heave.

3.1 Prudhoe Bay Saltwater Treatment Plant

The establishment of a long-term, year-round, tide station, using NGWLMS technology, at the ARCO Saltwater Treatment Plant (STP) in Prudhoe Bay was accomplished in July 1990. This station will replace the seasonal Prudhoe Bay station located about 1.6 Km away on the same gravel causeway known as West Dock. A year-round station at the STP is possible only through the unique circumstances associated with the STP design. The ARCO STP is a massive barge sunk in-place at the end of West Dock. It is surrounded on three sides by gravel, with the fourth side fronting onto a small, sheltered, bay. The STP is used to process seawater before it is pumped underground to facilitate oil removal. Two bubbler gages were installed at the STP in August of 1988. The instruments were located inside the reservoir room at the southern end of the barge, which is where the large water intakes are located. One orifice was installed outside the barge (on a pile), and the other was installed inside the barge, just inside one of the large intakes to the western reservoir. See Figure 10.

The purpose of two gages was to determine whether or not the water level in the western reservoir truly reflected the outside water level, so that it might provide a protected environment for the establishment of a permanent station using standard equipment. It was initially thought that the outside orifice would not survive the severe winter conditions.

After a year of operation, tidal analysts of the Physical Oceanography Division determined that the inside water level does accurately reflect the true outside water level. In addition the outside orifice survived the winter conditions so well that it is now believed that an outside orifice can be permanently maintained. In July, 1990, a full NGWLMS was installed inside the STP. In addition, the outside orifice is being used, and a digital bubbler gauge, using a high precision Paroscientific pressure sensor, is measuring the pressure variation in the gas-purged tubing. This station is the United States' first permanent year-round tide station north of the Aleutians!

Future projects in this area could be the establishment of other stations, on facilities like the Arco STP if they exist at other oil fields, or on some of the oil companies' artificial islands. Investigations should be conducted to determine the number and locations of these types of facilities and analyses made of their suitability as strategic GLOSS stations.

3.2 Thermal Bench Marks

A new type of bench mark was developed inhouse through the application of existing technology. It is being tested for use in remote areas where no bedrock or permafrost exists, and Class A type bench marks are too difficult or expensive to install. The new type bench mark, called a thermopile or "thermo" bench mark, is a type of bench mark specifically designed to resist the frost heave (vertical) forces generated by seasonal freeze/thaw cycles, specifically in Arctic regions. The thermo bench mark operates on a heat transfer mechanism and is generically known as a two-phase closed thermosyphon. Ten foot of a 1-inch diameter iron pipe is sealed and pressurized to 600 psi with carbon dioxide gas. The process is activated only when the air temperature is colder than the ground temperature. The temperature differential can be as small as one degree. The temperature differential starts an evaporation /condensation cycle within the pipe. The material within the pipe is in both a liquid and gas state due to being charged with a refrigerant. Heat is absorbed from the ground through evaporation of the liquid which rises to the top of the pipe. The rising gas meets the colder air temperature and condenses, radiating heat out from the upper half foot of pipe. Gravity pulls the condensate back down the pipe to the bottom and starts the cycle over again. This cycle tends to keep the thermopile at a uniform temperature over its entire length. This will reduce the thermal expansion /contraction effects and result in freezing occurring radially about the thermopile. Ice lenses and other associated pressures will develop radially and therefore not in the vertical direction necessary to cause heaving. See Figure 11.

Three thermo bench marks were installed in Port Moller in 1987 to supplement five standard Class B deep-rod bench marks installed in 1984. Three of the Class B deep-rod marks are steadily being jacked out of the ground by frost heave. To date, after three years of seasonal freeze and thaw, the three thermo bench marks have not shown any movement.

It is recommended that thermo bench marks be incorporated into NOS' accepted bench mark types and be used at remote sites with suitable conditions, where appropriate.

4.0 CONCLUSIONS AND RECOMMENDATIONS

4.1 Conclusions

The conclusions of this report are essentially the same conclusions reached by the various workshops held on making water level measurements in polar regions. The problems are associated with ice scouring on the near-shore sea bed, the destruction of support structures by sea ice, the logistics of gauge installation and maintenance, the lack of ice free locations, and the necessary power requirements of the site. But, on the other hand, it appears that these problems are not insurmountable and, with proper planning and resources, are definitely solvable. The consensus of the experts is that the technology needed to make sea level measurements in polar regions exists today and is considered affordable. However, the technology needed and the techniques used for installation and maintenance are quite site specific and therefore no standard "manual" can be written at this time. Bench mark connections and atmospheric measurements made in conjunction with underwater pressure sensors are considered mandatory using the applicable state-of-the-art technology for the site. Near real-time data transmission is highly desirable to ensure proper operation of the station equipment and early availability of the data to the user community. Also desirable is to make the field measurement system as automated as possible and to connect the local measurement and reference system to the VLBI and GPS global reference systems, if available.

4.2 Recommendations for Future Study and Work

The United States (and therefore NOAA/NOS) appears to have fallen behind the other countries of the world in making water level measurements in hostile environments and in particular the polar regions. The following general and specific recommendations are made relating to future efforts that NOS should continue or commence to ensure its world leadership in the area of water level measurements.

4.2.1 General Recommendations

- Continue to actively support NOAA's Climate and Global Change Program and the Intergovernmental Oceanographic Commission (IOC) GLOSS Program. These two programs provide the network of international experts and hopefully resources to obtain world-wide high quality standardized data from which valuable sea level products will be obtained.

- Establish near and long-term objectives and goals for NOS for making measurements in polar regions. A committee consisting of a subset of the managers involved in the Climate and Global Change Program should prepare such a list of goals and objectives for NOS over the next ten years initially and then beyond.

- Foster development of advanced technology through the DOC Small Business Innovation Research (SBIR) Program and others means such as grants, contracts and visiting research scientists/engineers.

- Establish cooperative programs with other agencies (NSF, COE, NASA, etc.), universities and foreign governments. The National Science Foundation is very interested in polar research and funds many projects in Antarctica but its mission prevents it from funding monitoring programs. It appears feasible that a cooperative program could exist between NSF and NOAA whereby NSF funds the initial research portion of a water level measurement project in the Antarctic and then NOAA would continue the funding when the project becomes more routine. A similar type of arrangement could be made with the U.S. Army's Cold Regions Research and Engineering Laboratory or with NASA. We already have cooperative projects in progress with the Canadians, British, Australians, and Russians and should expand them to include field measurements in polar regions. NOS should also develop projects with Japan and New Zealand.

4.2.2 Specific Recommendations

- Investigate and find additional suitable sites for polar tide stations such as the one established at the Prudhoe Bay, AK Saltwater Treatment Plant. After suitable sites are found, they should be prioritized and an installation schedule generated. The Prudhoe Bay site should be established as a pilot station for continued R&D activities.

- Continue to refine techniques for the installation of thermal bench marks at appropriate cold region sites. These types of bench marks have been proven very successful in areas where an active zone exists on top of the permafrost layer.

- Continue and foster the development of acoustic and electromagnetic links for the transmission of information through the water/ice interface. A few American companies have developed prototype underwater acoustic modems with much improved reliability and data rates. A Canadian company has developed a prototype electromagnetic device for transmitting data from sensors under the water to a land-based receiver. Both of these developments show great promise as the communication links of the future.

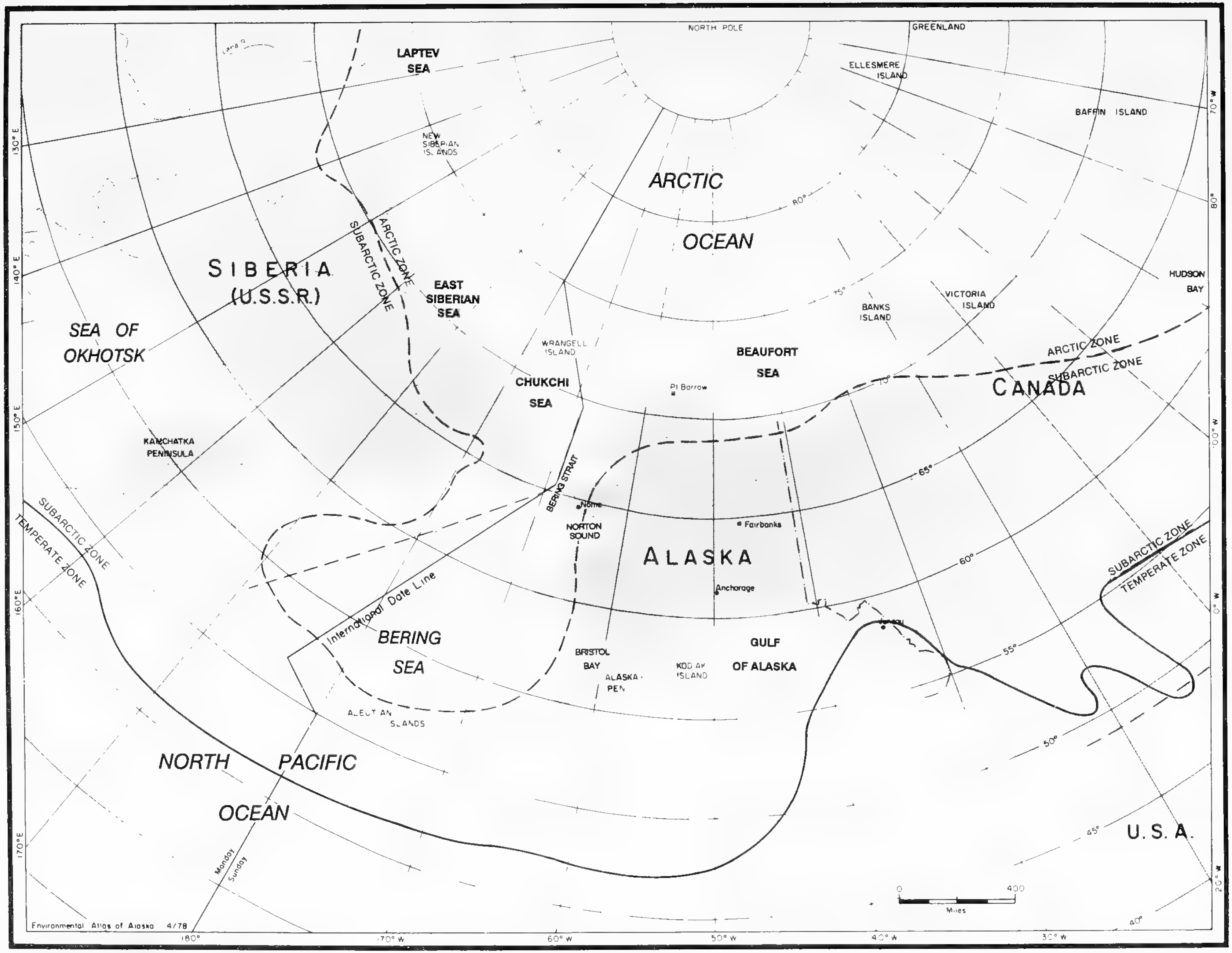


Figure 1. The Arctic Region

Figure 2. The Antarctic Region

NOS TIDE STATIONS

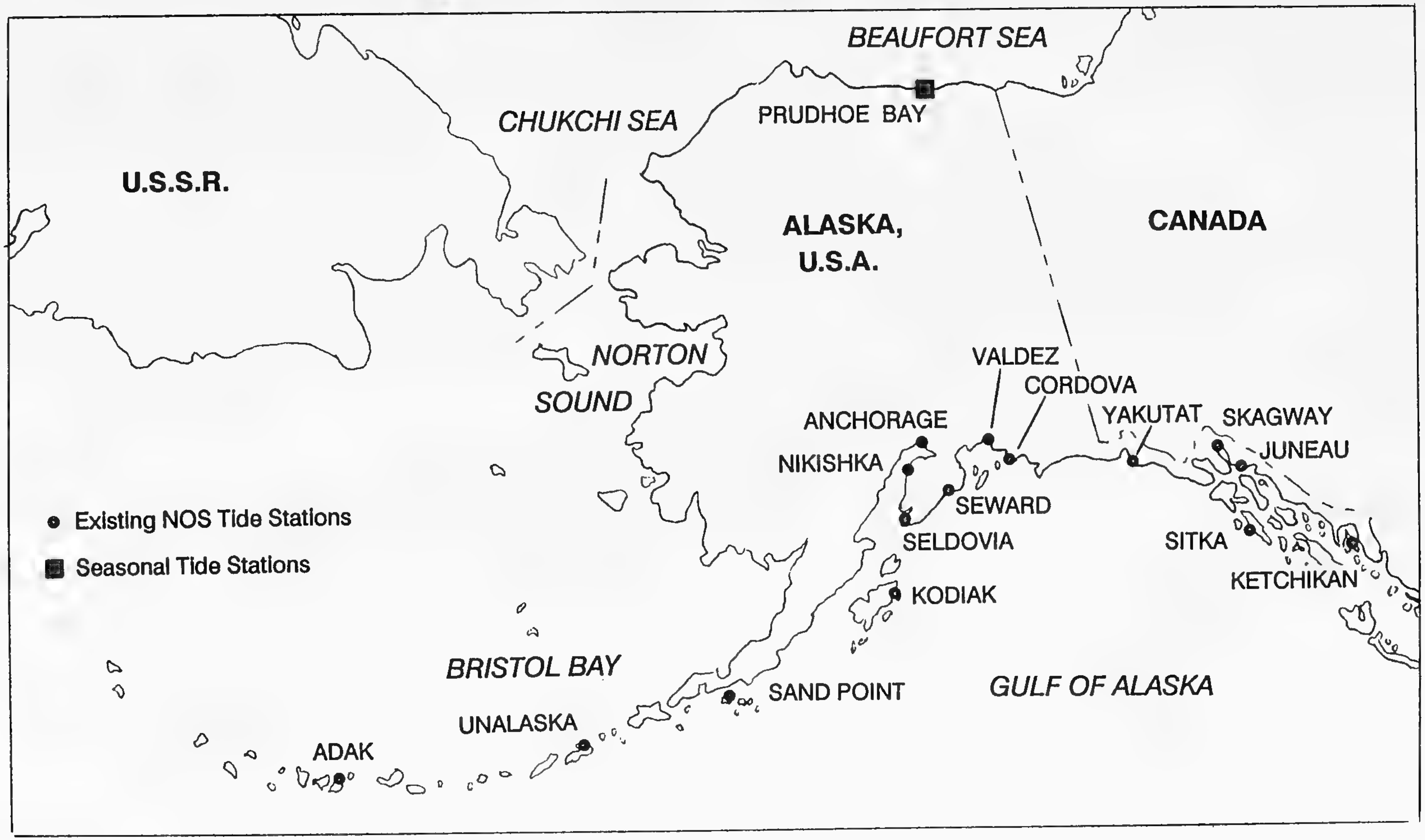


Figure 3. NOS Tide Stations in Alaska

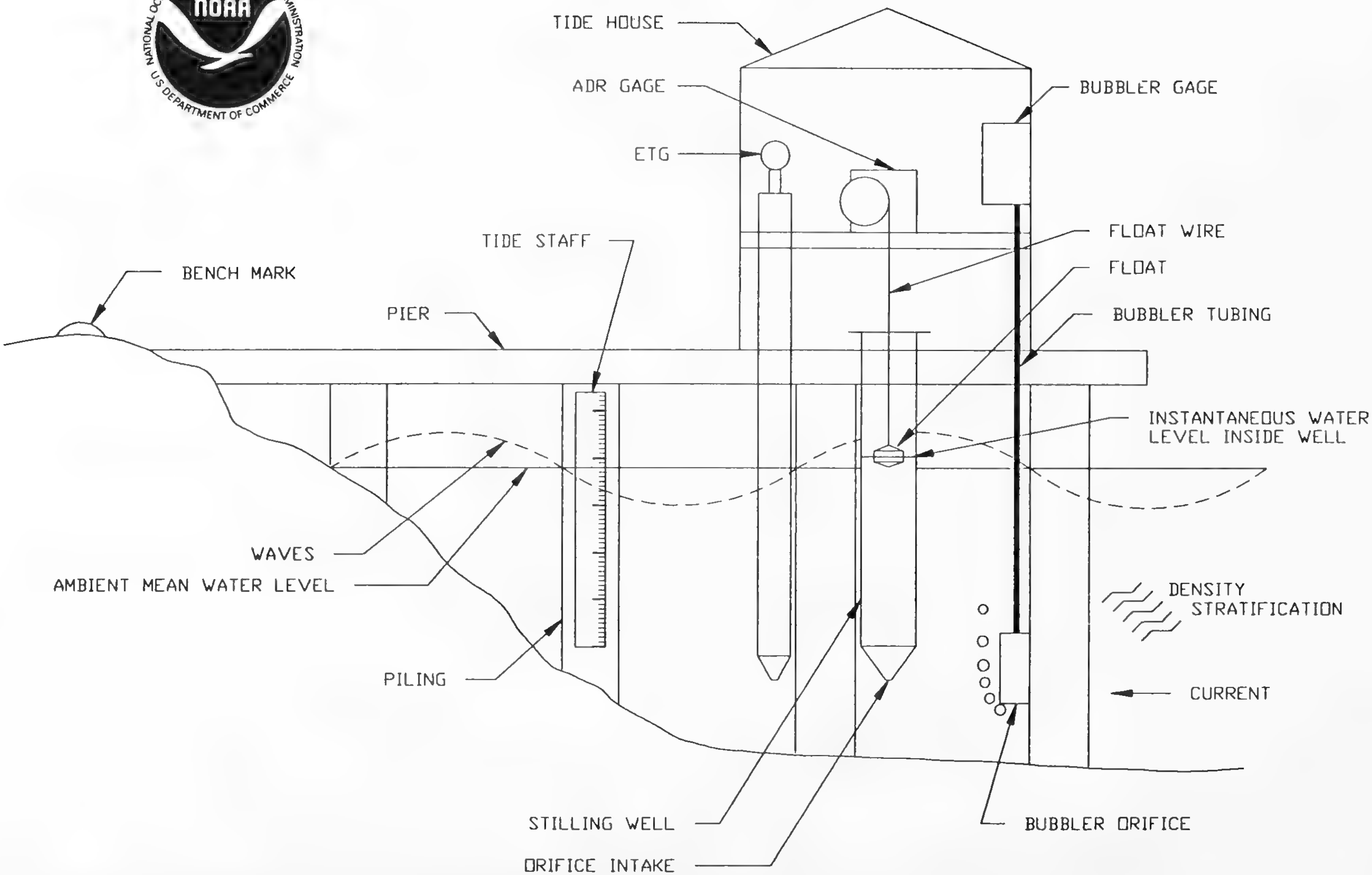


Figure 4. Present Data Acquisition System

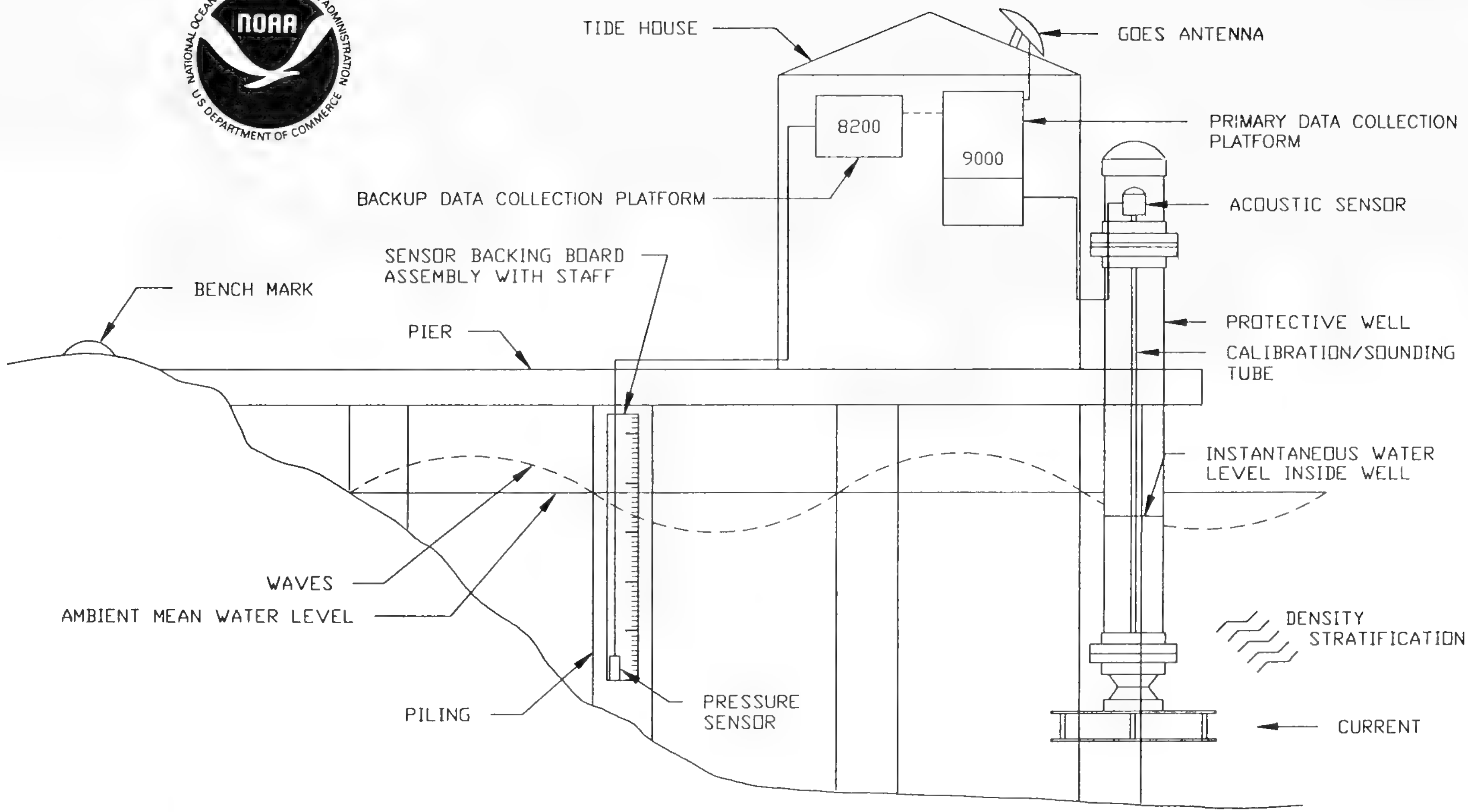


Figure 5. Next Generation Water Level Measurement System

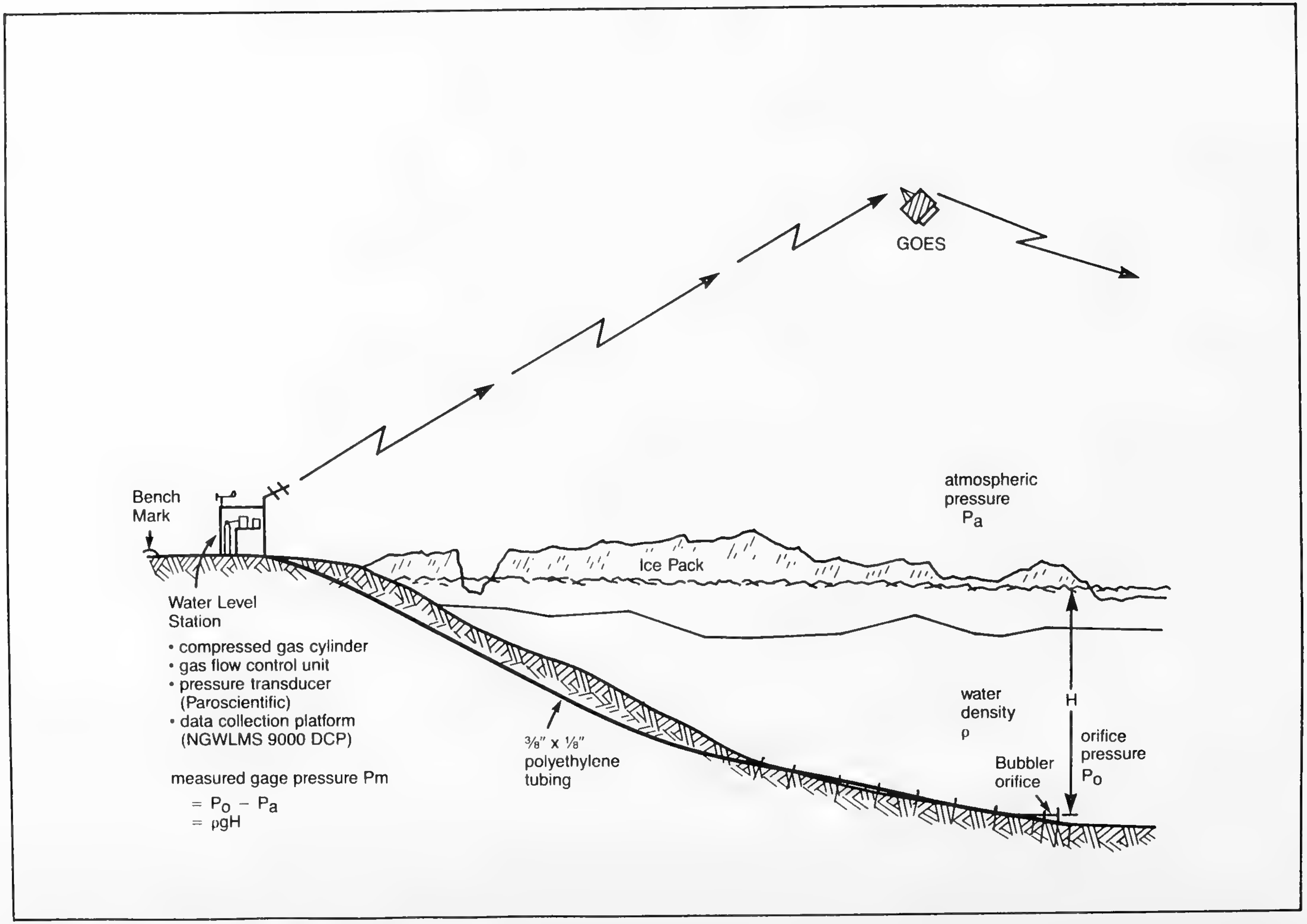


Figure 6. Possible Polar Region Installation

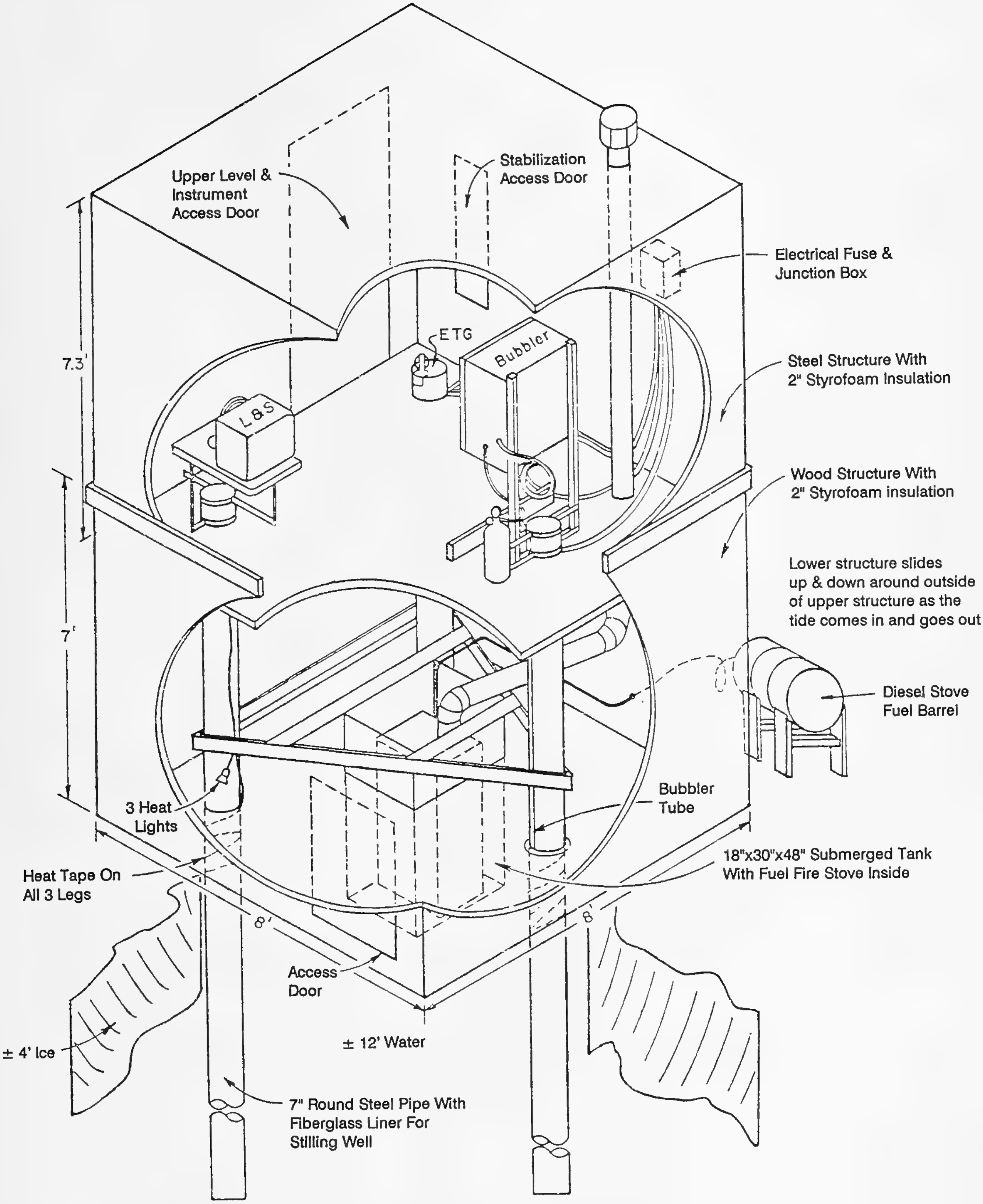
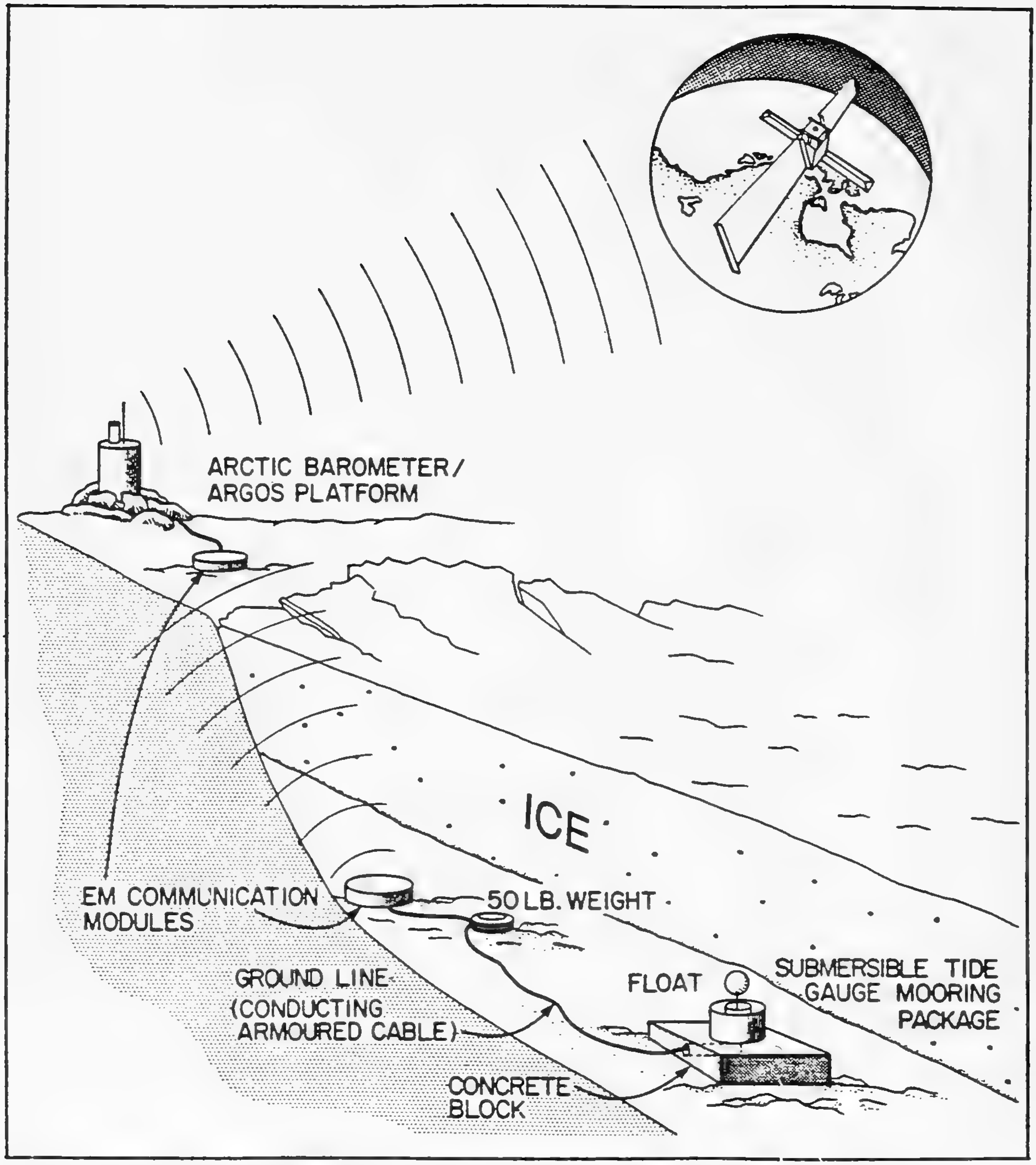


Figure 7. Dinkum Sands Project Tide Station Installation



The atmospheric pressure-measuring system operating in situ with the satellite uplink, the electromagnetic (EM) link, and the submerged tide gauge.

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Figure 8. Canadian Developments

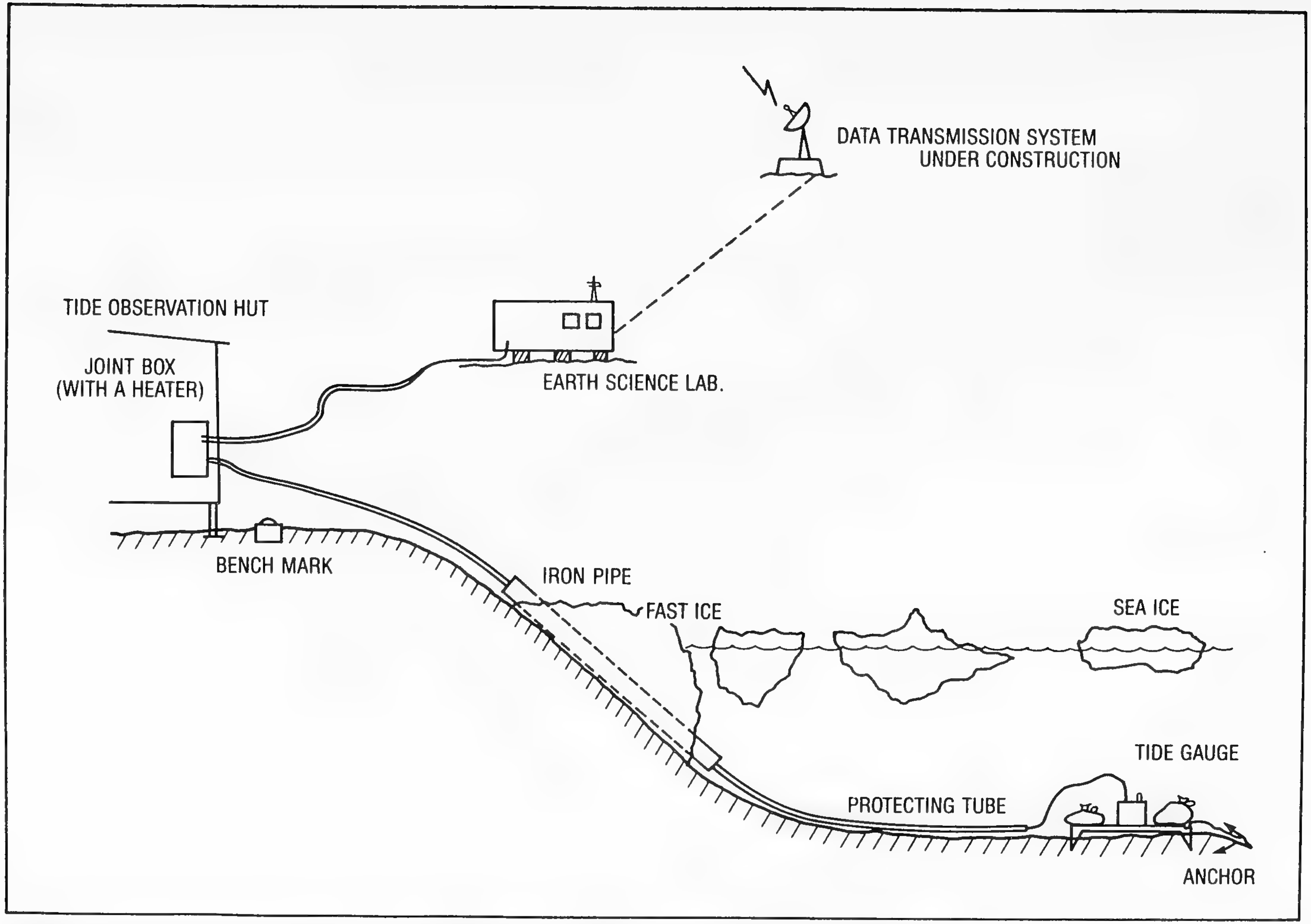


Figure 9. The present system of tidal observation at the Japanese SYOWA Station

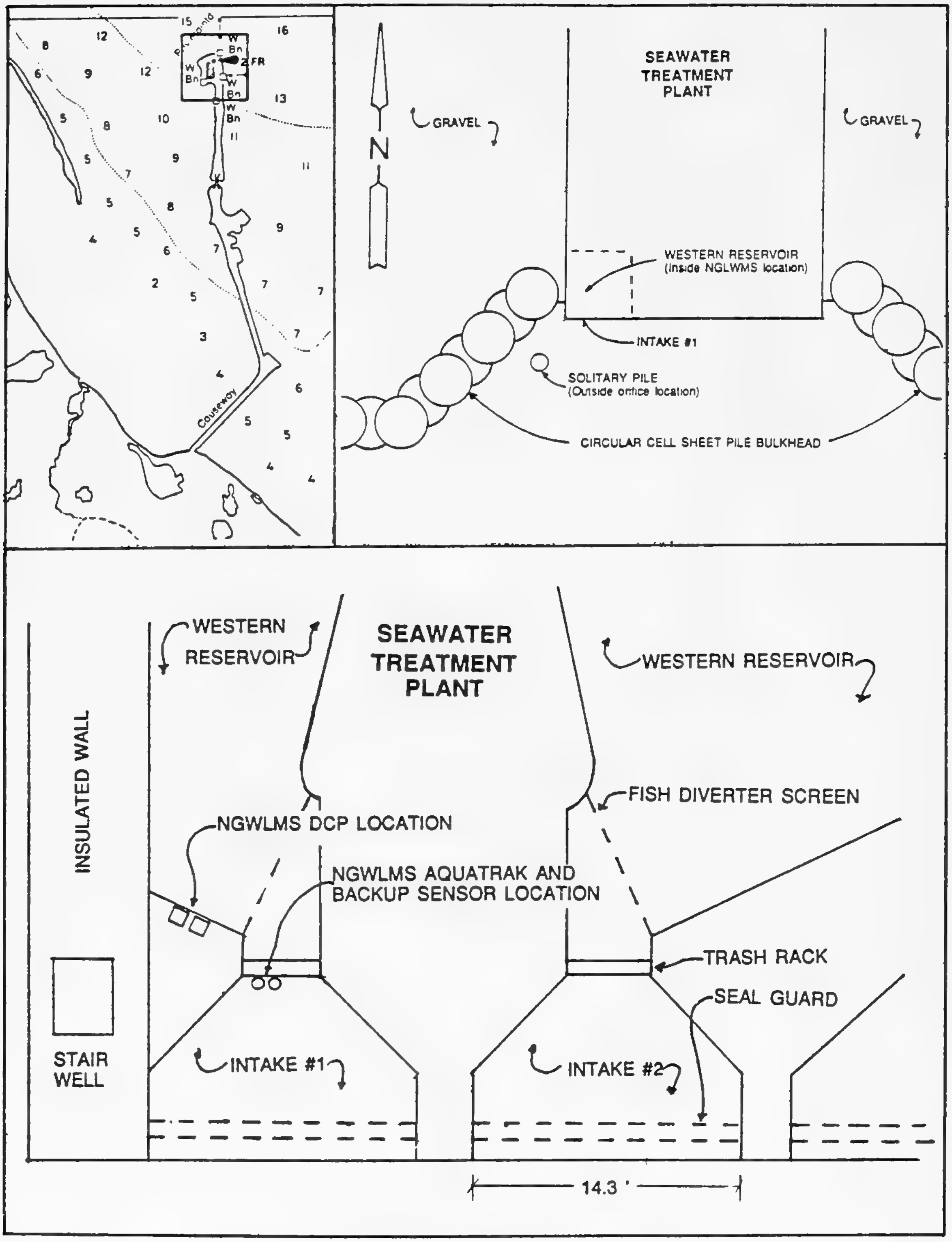
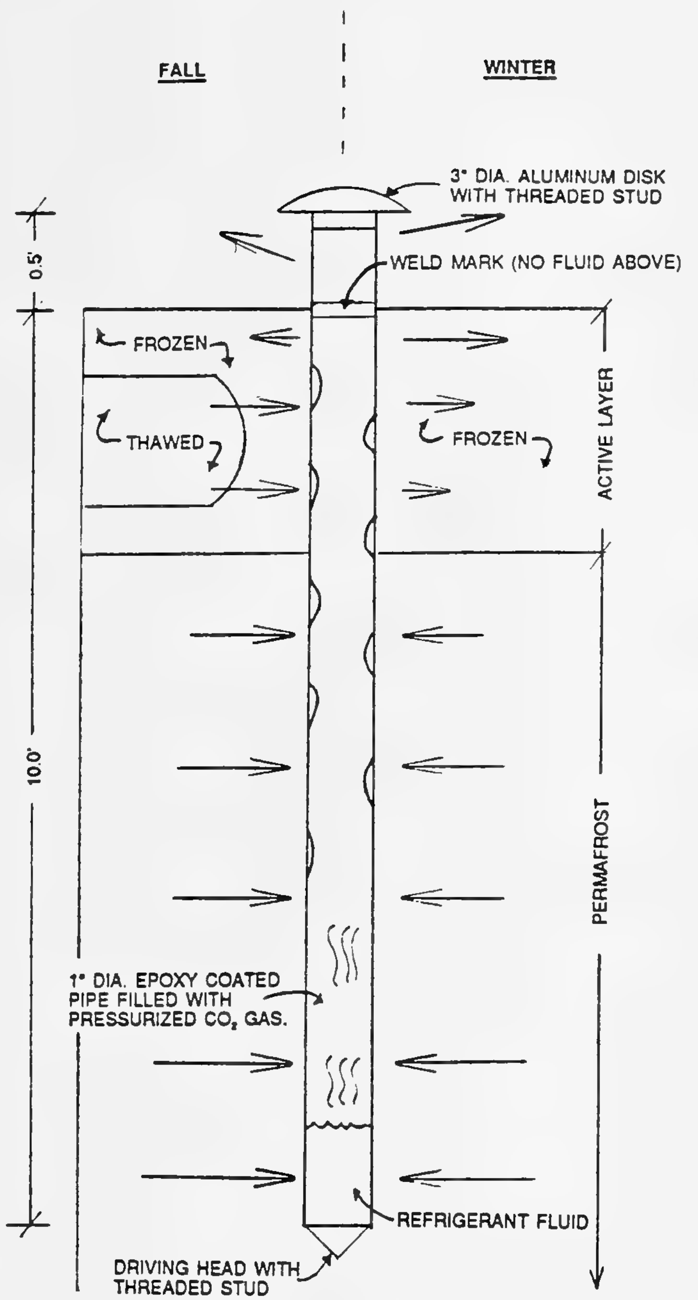


Figure 10. Prudhoe Bay, Alaska, NGWLMS Site Sketch



FALL: The active layer starts freezing from the top and proceeds down. Ice lenses form creating heave forces in upward direction. The thermo bench mark is activated by the air temperature dropping below ground temperature. The refrigerant is heated to the boiling point by the higher ground temperature along the bottom of the mark, and evaporates to the top, where it condenses. The condensate then returns to the bottom of the mark through gravity. This thermal cycling draws heat out of the ground radially around the thermo bench mark. The radial freezing prevents ice lense formation adjacent to the mark and therefore upward heaving forces. Higher temperatures near the top of the mark also cause the frozen soil to sublimate and relax its grip on the mark.

WINTER: The active layer is completely frozen and the potential for frost heave is past. The thermo bench mark continues to cycle and reduce the grip of the frozen soil near the surface.

SPRING/SUMMER: Air temperature is greater than ground temperature and the thermo bench marks thermal cycling stops. No heave forces are present during these seasons.

Figure 11. Thermo Bench Mark

APPENDIX A

REFERENCES

Aagaard, K. et al. Outer Continental Shelf Environmental Assessment Program (OCSEAP) Final Reports of Principal Investigators. NOAA/NOS/OMA. Vol. 65. January, 1990.

Brochure of Artic Foundations, Inc., Anchorage, AK. Frozen Assets. Erwin L.Long, President. 1983.

Global Sea-Level Observing System (GLOSS) Implementation Plan. Fifteenth Session of the IOC Assembly. (IOC-XV/8 Annex 4) Paris, 4-19 July 1989.

Hartman,C.W., and P.R. Johnson. Environmental Atlas of Alaska. University of Alaska. Revised 1984.

Report of First Session of IOC Group of Experts on the Global Sea-Level Observing System (GLOSS). Proudman Oceanographic Laboratory, Bidston, U.K., 19-23 June 1989.

Russin, E.M., T.N. Mero, and S.K. Gill. NOAA's Water Level Measurement System for the Nineties and Beyond. Conference Proceedings. Marine Instrumentation '90 Exposition and Conference. pp 52-56. February, 1990.

Schwerdtfeger, W. Weather and Climate of the Antarctic. Elsevier, NY, 1984.

Shih, H.H. Pneumatic Tide Gauge Upgrade. NOAA Technical Memorandum, NOS OMA46. 1989.

Smith, T.E. Atmospheric Barometer Measures Sea Surface Height. Sea Technology. February, 1990.

Steeves, G., Bedford Institute of Oceanography, Nova Scotia, Canada, personal communication, May 31, 1990.

Weller, G. and S.A. Bowling, Editors. Climate of the Artic. 24th Alaska Science Conference. University of Alaska. 1973.

Workshop on Sea-Level Measurements in Antarctica. IOC Workshop, Draft Report, Leningrad, USSR, 28-31 May 1990.

Workshop on Sea-Level Measurements in Hostile Conditions. IOC Workshop Report No. 54. Bidston, U.K., 28-31 March 1988.

Wrathall, P., Correpro Atlantic, Ltd., Nova Scotia, Canada, personal communication, August 13, 1990.

APPENDIX B

SELECTED BIBLIOGRAPHY

Antarctic Oceanography. Proceedings of Symposium. Santiago, Chile. SCAR/SCOR/IAPO/IUBS. 1966.

Barnes, P.W.,D.M. Schell, and E. Reimnitz. Editors. The Alaska Beaufort Sea Ecosystems and Environments. 1984.

Coachman, L.K., K. Aagaard, and R.B. Tripp. Editors. Bering Strait, The Regional Physical Oceanography. 1975.

Murphy, T.K.S., J.J. Connor, and C.A. Brebbia. Editors. Ice Technology. Springer-Verlag, New York. 1986.

Rey, L. Editor. The Arctic Ocean. John Wiley and Sons. New York. 1982.

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