

Seafloor Characterization And Mapping Pods (SCAMP): Submarine-mounted Geophysical Mapping

Dale N. Chayes¹

Robert M. Anderson²

Stuart Goemmer³

Jose L. Ardai¹

Bernard J. Coakley⁴

Mark R. Rognstad⁵, Roger B. Davis⁵, Margo Edwards⁵

¹Lamont-Doherty Earth Observatory of Columbia University

²Arctic Submarine Laboratory, US Navy

³Johns Hopkins Applied Physics Laboratory

⁴Tulane University

⁵Hawaii Mapping Research Group, University of Hawaii

Abstract

In 1998 the Seafloor Characterization and Mapping Pods (SCAMP) were deployed on the US Navy nuclear attack submarine USS HAWKBILL (SSN666) for unclassified swath mapping and subbottom profiling under the Arctic ice canopy. Data was collected under the SCICEX program, which is guided by the terms of a memorandum of agreement between the Navy, the Office of Naval Research, the National Science Foundation (NSF), the U.S. Geological Survey and the National Oceanic and Atmospheric Administration. SCAMP consists of a Sidescan Swath Bathymetric Sonar (SSBS) and a High-Resolution Subbottom Profiler (HRSP), and a marine gravity meter that are integrated with a physically compact Data Acquisition and Quality Control System (DAQCS).

The transducers for each of the sonars are mounted in purpose-built hydrodynamic pods that are temporarily fastened to special purpose threaded weldments along the boat's keel. The weldments were installed in drydock but the pods, transducers and junction boxes were installed and can be serviced by divers at the pier. The inboard electronics for the system are packaged for submarine installation and mounted in the torpedo room.

The SSBS is a 12 kiloHertz SeaMARC design adapted for under-ice mapping by adding transmit and receive beam forming and shading to suppress spurious returns from the ice canopy. Transducers are housed in a keel-mounted pod with electronics mounted outside the pressure hull but above the water line when surfaced. Swath image data is produced over a 135 to 140 degree swath centered at nadir while high quality bathymetry covers a 120 degree swath.

The HRSP is a Bathy-2000P FM modulated subbottom profiler adapted for submarine installation and operation. It produces high quality subbottom data using an array of 9 DT-109 transducers driven by a 2 kilowatt transmitter. Seafloor penetration in excess of 100 meters with a resolution of tens of centimeters is common in sediment filled areas of the Arctic basins.

Initial at-sea tests on the submarine were conducted out of Pearl Harbor, Hawaii in May 1998. The first deployment in the Arctic took place during SCICEX-98 during which more than 30 days of data were collected in the data release area. Substantial improvements to the system were completed and tested in January and February 1999. The second deployment in the Arctic was completed in May of 1999.

I. Introduction

The Seafloor Characterization and Mapping Pods (SCAMP) were developed to allow modern geophysical survey techniques to be added to the SCICEX program of unclassified research from US Navy nuclear submarines operating in the Arctic. The SCICEX program is discussed by Gosset [1] and Pyle et. al. [2]. Langseth et. al.[3] describes the first unclassified research cruise using a nuclear submarine in the Arctic, which led to the creation of the SCICEX program. In many ways nuclear submarines are ideal platforms for underway geophysical and synoptic oceanography mapping because of their speed, stability, low noise and stability, and freedom to maneuver below the ice canopy.

The SCAMP development process and design issues were reported by Chayes et. al. [5] [6]. SCAMP was subsequently installed on the USS Hawkbill in the spring of 1998 in Pearl Harbor and deployed to the Arctic during SCICEX98 (August 1998) and SCICEX99 (April and May 1999). A total of approximately seventy days of underway survey has been accumulated during these cruises.

II. Subsystems

SCAMP consists of two sonar systems, a marine gravity meter and the data system that logs the data and provides on-board quality control. One sonar is a bilateral swath mapper that produces bathymetry and image data referred to as the Sidescan Swath Bathymetric Sonar after Blackinton [4]. The other SCAMP sonar is a subbottom profiler known as the High Resolutions Subbottom Profiler (HRSP.) Data from a Bell BGM-3 marine gravity meter is logged by the SCAMP Data Acquisition and Quality Control System (DAQCS). DAQCS also logs data from a sail mounted CTD and the submarines navigation system.

A. Swath Mapping Sonar

The Sidescan Swath Bathymetric Sonar (SSBS) system is based on the proven SeaMARC™ design with adaptations for submarine-mounted operation and to optimize performance while operating under an ice canopy. The SSBS was manufactured by Raytheon Systems Corporation.

Frequency	12 kHz
Pulse Length	83 μ S to 10 mS
Modulation	CW
Repetition Rate	2 to 20 seconds

Source level	230 dB re 1 μ Pascal @ 1 m
Power	115 VAC
Image Swath Width	\sim 160°
Bathymetry Swath Width	\sim 140°

Table 1: Characteristics of the SCAMP Sidescan Swath Bathymetric Sonar.

Figure 1 and Figure 2 show preliminary results from the SSBS during SCICEX99. Figure 1 shows iceberg scours from the top of the Lomonosov Ridge in 675 meters of water. Figure 2 shows a color coded contour plot of gridded, processed SSBS bathymetry across the Northwind Escarpment.

B. Subbottom Profiler

The SCAMP High Resolution Subbottom Profiler (HRSP) is a modified version of Ocean Data Equipment Corporation's Bathy-2000P. Significant re-packaging of the inboard electronics was required to meet the space requirements and the transducers were designed to operate at depth.

Frequency:	3.75-6.75 kHz
Pulse Length:	1 - 50 mS
Modulation:	CW or FM
Source level:	218 dB re 1 μ PI @ 1 m
Athwartships beam width:	\sim 30°
Fore/Aft beam width	\sim 30°
Repetition Rate:	1-10S
Penetration	up to 200m
Resolution	\sim 10s of cm

Table 2: Operational characteristics of the SCAMP HRSP. Under optimum sediment conditions penetration in excess of 200 meters has been observed.

Figure 3 shows HRSP data collected in the Barents Basin along the transit from the Gakkel Ridge to the Yermak Plateau. Well laminated sediments, with some evidence of diapiric disruption, characterize the abyssal plain.

C. DAQCS

The DAQCS provides the computer infrastructure to support the data acquisition, logging and validation necessary for successful data collection at sea. The version implemented for SCAMP is evolved from a sequence of systems that originated on the R/V Conrad in

1985 running on single processor 68010 based Masscomp computers under a real-time Unix variant called RTU. Over time the core system has been expanded and adapted to run on Sparc-based single and multi-processors under a succession of Sun Operating systems from Sun-OS 3.1 through Solaris 5.3, under X86-based Linux systems, and on several generations of MIPS-based single and multi-processors from Silicon Graphics.

In the SCAMP implementation there are two Sun Ultra2 servers rack mounted in Artecon Sphinx enclosures, which also contain additional peripherals. One server acts as the real-time system while the other is used for offline data archiving and quality control. To save space in the submarine environment, interaction with DAQCS is provided through laptop computers. Three NEC 6050MX laptops running a RedHat Linux distribution provide the principal displays by way of X11 servers. In addition to being fully networked through a switching hub, one laptop is connected to the first serial interface of each Ultra2 (/dev/ttya) to provide single user and boot time control through a terminal emulator (kermit) running on the laptop.

The real-time system interfaces with the SSBS through an S-Bus interface card that implements a high speed digital interface known as a TI 'C40 comport. Software provided by Raytheon provides the real-time displays necessary to operate the SSBS and to capture its data to disk. Additional software collects the SSBS data from disk, applies a narrow band decimation filter and translates the SSBS data from "atk" format provide by the Raytheon code into "tts" format that is used in subsequent data processing. The tts-format files are decimated by a factor of five as part of the narrow band filtering.

The interface between DAQCS and the HRSP has several data channels. Time, position and depth data are provided to the HRSP from DAQCS via a serial interface. Two status message streams (one for routine messages and another for errors) are transferred from the HRSP to DAQCS via serial interfaces. The HRSP sonar data is written across a 10BT network connection to one of the DAQCS disks using the Network File System protocol.

Digital data from the Submarine Data Recording System (providing ship's own position, depth, speed and attitude), the second sail mounted CTD (to derive sound speed), and from the Gravimeter come to DAQCS for real-time

display on unidirectional asynchronous serial interfaces.

The SSBS data is internally time-tagged with DAQCS CPU time by the Raytheon supplied software. The HRSP is time-synchronized with DAQCS via serial interface and applies this time stamp to the data files it creates. The SDRS data stream has two times imbedded in it: one from the ship's precision frequency reference and a second that is simply the CPU time of the SDRS computer. All other data streams have DAQCS CPU time prepended to the data message.

III. Installation

Installation, removal and maintenance issues are a crucial part of the success of SCAMP. Johns Hopkins Applied Physics Lab provided invaluable assistance with this aspect of SCAMP, based on their substantial experience with a large number of other submarine based programs.

A. Background

Submarine installations must be designed to assure optimum system performance, maintain ship performance and assure personnel safety. Identification of external equipment locations is critical because hull attachment, cabling, serviceability pose the biggest challenges. System performance is optimized by selecting the best operating position on the hull, maintaining appropriate separation from ship's systems, and properly orienting sensors. For bottom-mapping systems, keel mounted sensors are recommended to minimize hull interference and maximize sensor performance. Sensor orientation would be symmetrical. Also, attachment is simplified because roll is zero and pitch is small, and no anechoic tiling has to be removed.

Typical hull-mounted structures consist of a foundation and pod. The foundation provides a flat surface to attach the pod while accounting for hull curvature and ship frame locations. Attachment points must be located at frame locations to avoid possible hull distortion. The typical attachment technique involves welding cylindrical mounting pads to the hull. Each pad has a tapped hole which results in a hull attachment point significantly stronger than simply welding a stud to the hull. The number of pads and size of hardware depend upon the size of the pod and number of frames in the pod location. Below-the-waterline welding and anechoic tile removal requires dry-docking the submarine because of the precision required. A skirt, which is fitted during the installation, is attached to the foundation to ensure

no gaps between the foundation and hull exist. These gaps could cause hydrodynamic noise. Criteria for attaching hull-mounted structures are defined by the Naval Sea Systems Command.

The pod houses the sensor(s) in a hydrodynamic shape that is readily removed from the foundation. Typically pods are designed to have NACA or "tear drop" shape where the length is at least 4 to 5 times the pod's width to minimize hydrodynamic noise. An example of a NACA shape is the submarine's sail. The top of the pod is typically domed.

Cable routing is simplified if the pod is located near the submarine's forward main ballast tanks (MBTs). MBTs and free flood areas typically have wireways, electrical hull penetrators, and tank penetrators located within them for servicing various ship systems. Electrical penetrators are electrical connections that penetrate the pressure hull of a submarine, and tank fittings. Penetrators are conduits that pass cables between ballast tanks and between ballast tanks and free flood areas such as the sail and torpedo tube launchways. Cables can be routed into MBTs either through MBT grates or by cutting holes in the nonpressure hull near the grates as long as the hole is not above the grate resulting in a rise in the MBT residual waterline. Identifying and utilizing available space in existing electrical hull penetrators and tank penetrators is preferred. Replacing existing electrical hull penetrators and/or tank penetrators with new penetrators that accommodate both existing cables and new cables is very complex and expensive. Replacement of a penetrator could add a fiber conductor in addition to or in lieu of an existing electrical conductor, but at great expense.

B. USS Hawkbill Installation

The SCAMP installation on the USS Hawkbill consists of a Sidescan Swath Bathymetric Sonar (SSBS) and a High Resolution Subbottom Profiler (HRSP). The pod containing the SSBS is mounted on the underside of the keel below the sail, and the pod containing the HRSP is also mounted to the underside of the keel approximately 17 feet forward of the SSBS pod. Both pods are located such that the forward end of the pod overlaps a Main Ballast Tank (MBT). The SSBS and HRSP inboard electronics are mounted in shallow depth 19" relay racks on a torpedo skid plate in the Torpedo Room. A Remote Display and blanking switch are mounted in the Control Room.

Both the SSBS and HRSP pods are attached to the hull via foundations and cylindrical

mounting pads. A hole was cut in the non-pressure hull above each pod to allow cables to be routed into the ballast tanks. Each pod has forward and aft composite fairings attached to the stainless steel skeletal structural members.

The HRSP pod contains nine ITC-5465 transducers in a 3 by 3 matrix. These transducers are mounted in a plane parallel to the pod/hull tangent point at 0 and 4.6 pitch. They are connected to a junction box mounted in the ballast tank immediately above the forward end of the pod with underwater mateable connections. The junction box has a single cable output that is routed through an existing cable pipe to a free flood cavity topside where it connects to an existing ship's electrical penetrator.

The SSBS pod carries ten ITC-5485 subarrays, five port looking and five starboard looking. These transducers are mounted a 0 pitch and tilted such that the bore sight is 25 down from horizontal. Independent port and starboard junction boxes are mounted in the MBT above the forward end of the pod. Each subarray has a single multi-conductor cable routed to its junction box with an underwater mateable connector. Each junction box has a single multi-conductor cable, which is routed through the ballast tank into a topside free flood space (the ESM Void under the forward edge of the sail) by way of an existing tank penetrator. The cable from, each side's junction box is mated to that side's transceiver electronics, which is mounted in the void.

The SSBS outboard power, telemetry and control electronics are contained in a third pressure case also mounted in the ESM void. Power and telemetry are carried through the hull via an existing seven conductor electrical hull fitting from the ESM Void into the Control Room.

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References:

- [1] Gossett, J. (1996.). "Arctic Research Using Nuclear Submarines." *Sea Tech* March.
- [2] Pyle, T. E., M. Ledbetter, et al. (1997). "Arctic Ocean Science." *Sea Technology* 38 No. 10(October 1997): 10-15.
- [3] Langseth, M., Theodore Delaca, et al. "SCICEX-93: Arctic Cruise of the US Navy Nuclear Powered Submarine USS PARGO." *MTS Journal* 27(4).
- [4] Blackinton, J. G. (1991). Bathymetric Resolution, Precision and Accuracy Considerations for Swath Bathymetry Mapping Sonar Systems. *IEEE Oceans '91*, Honolulu Hawaii, IEEE.
- [5] Chayes, D. N., B.J. Coakley, et al. (1996). "SCAMP: An Enhanced Geophysical Mapping System for Arctic Submarine Cruises." *EOS* 77 (315.).
- [6] Chayes, D. N., B. J. Coakley, et al. (1997). SCAMP: A submarine-mounted geophysical survey system for use under the Arctic ice. *Oceans' 97*, Halifax, NS, IEEE.