

# UNIQUE VEHICLES USED FOR BATHYMETRY SURVEYS IN EXPOSED COASTAL REGIONS

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## Abstract

A portable bathymetry surveying system has been installed on several unique vehicles for solving many problems associated with surveying coastal locations such as inlets and exposed beaches. The system consists of a sounder, an inertial measurement unit, a kinematic GPS unit, and a control/recording computer. This system provides high resolution data for calculating the bathymetry directly in a geodetic datum even where the platform moves rapidly in waves and/or traverses over shoals. It has been successfully installed on a jet ski where it has obtained data in the surf zone, and also on an amphibious vehicle where it has provided data in a coastal inlet having a complex region of channels, beaches, and shoals. The system measurement errors less than 5 cms when compared with the CRAB which is a standard at the USACE Field Research Facility at Duck, NC.

## Introduction

Navigation of coastal inlets is of primary concern to the USACE and the nation. Because inlets tend to change rapidly, safe navigation often requires frequent monitoring of the channel, but this often can be difficult because of waves, currents, and large areas of shoals. In addition, when survey requirements include exposed regions having active waves and/or surf, such as along nearby beaches, the survey can be conducted only when the waves are not present. A mixture of old and new technology has been brought to bear to overcome these problems, and the results may prove to provide an economical method for monitoring natural and man-made changes at active inlets and nearby beaches.

The fundamental concept which, in itself, is not so unique, is to measure the topography directly in a geodetic datum so as to remove any dependence upon the local mean water level. The typical depth measurement relative to MLLW or some other tidal datum is replete with difficulty around inlets and along beaches because of problems associated with complex tidal heights, wave induced setup, and wave motions. These difficulties are removed by using a kinematic GPS unit. The unique aspect of this development is the application of this new technology to non-typical survey platforms, namely a jet ski and an amphibious vehicle.

The personal water craft commonly called a jet ski is attractive as a survey platform because it has large power to weight ratio which provides it with great acceleration for maneuvering to avoid the danger of breaking waves in the surf. Thus, it can be used for safely

traversing the surf even when there are moderately rough waves. In addition, the jet ski has the benefit of being light enough that it can be launched and retrieved from a light trailer on the beach, and therefore is useful for surveying beaches that are rather inaccessible and far from protected harbors. It can be used to conduct surveys in and near the surf where it would be considered dangerous to operate a typical survey launch. When the beach topography also is of interest, the survey system is easily transferred to a four wheel drive vehicle, and the height of the beach is obtained from the height of the phase center of the GPS antenna plus the distance to the bottom of the wheels.

In a similar vein, an amphibious vehicle is attractive as a survey platform because it can easily accomplish the transition from the beach to the nearshore, and it can traverse shoals that are inaccessible to all launches, even including the jet ski. When floating, the water depth is the datum adjusted height of the antenna plus the fixed distance to the fathometer transducer plus the distance to the bottom. While on its wheels, the depth is simply the datum adjusted height of the antenna plus the distance to the wheel bottoms. Thus, it is ideal where a survey requirement includes nearby beaches, shoals, and ponds in addition to the deeper channels.

To take advantage of the unique aspects of these platforms, a small instrumentation suite was designed, constructed and fielded that includes a fathometer, an inertial measurement unit (IMU), a real time kinematic GPS, and associated computers. The next section provides some details for the instrumentation, and the following summarizes the results, including comparison with a standard.

### Instrumentation

The diagram in Figure 1 provides a sketch of the critical components of the system on the jet ski, with the resulting system being called the Surf and Coastal Area Measurement Platform (SCAMP). The sounder is mounted through the bottom of the hull, and its electronics and the KGPS receiver, the computer and miscellaneous wiring are in the small box on the stern of the boat. The IMU is under the seat, and antennas are located at various positions forward and aft of the driver. They are on breakaway masts to avoid injury when the driver mounts or dismounts the boat. An EM current meter for measuring currents is mounted on a retrievable stem that is lowered over the stern. As illustrated in the figure, the bathymetry values are measured by a combination of the GPS data, the distance

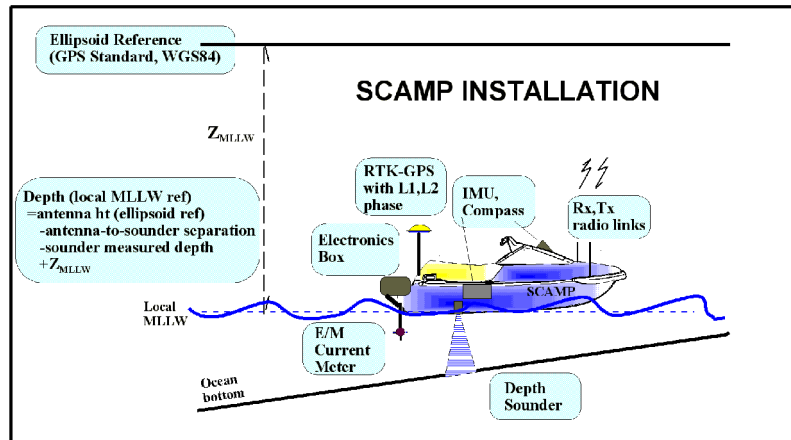


Figure 1. Diagram for jet ski installation

between the GPS antenna and the sounder head, and the sounder measured distance to the bottom. The resulting values typically are adjusted from the ellipsoidal reference in WGS84

coordinates to a tidal datum by accurately surveying in the base station relative to a known

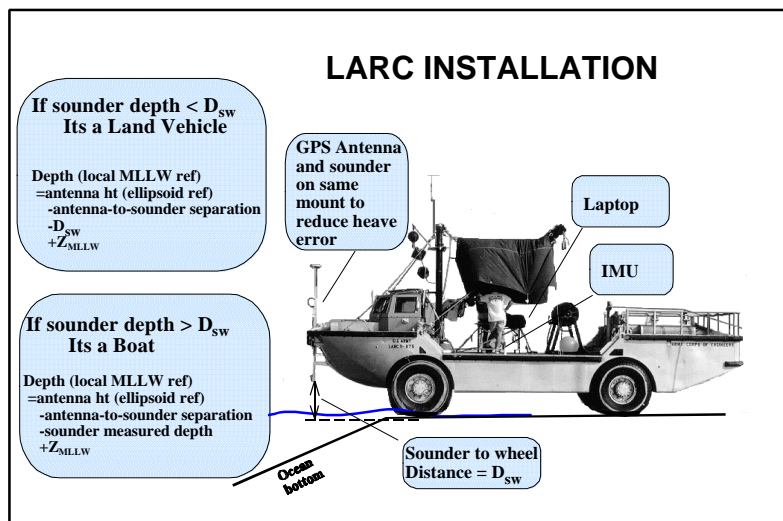


**Figure 2.** Photo of SCAMP in action

geodetic monument on the beach and using the appropriate offsets for the monument. The base station provides the correction signal in real time to the rover unit on the boat via a digital UHF radio signal labeled Rx in the figure. The onboard computer stores the various data streams and also telemeters the sounder and GPS data to a monitoring station on the beach via the antenna labeled Tx. This station consists of a UHF receiver and a laptop computer running a common software package (Hypack™) so that the operator has a display of the SCAMP location on the local nautical chart and also a window with the time series of the measured depth values. The monitoring station

operator has a voice radio that is used to send steering commands to the boat driver to keep him on the planned survey lines. The boat driver has an earphone voice activated radio so that he is not distracted from his driving chores by having to manually key the transmitter. We have utilized a flat panel display for the driver in the past, but he often is too busy avoiding waves to use it effectively. Figure 2 is a photograph showing the SCAMP in action; and the electronics box and multiple antennas can be easily seen.

This instrumentation suite is easily installed on other vehicles. For example, the GPS receiver and recording computer is used on a four wheel drive all-terrain vehicle to conduct subaerial surveys of nearby beaches. When combined with nearshore surveys by the SCAMP, this provides a continuous topographic map from the base of the dunes across the shoreline to depths offshore. Also, the system has been installed on an amphibious vehicle to enable surveys across the shoreline with a single vehicle and also enable complete coverage of shoals.



**Figure 3.** Diagram for LARC installation

The USACE LARC-5 (Lighter Amphibious Resupply Cargo-5) amphibious vehicle that is operated at the WES CHL Field Research Facility (FRF) at Duck, NC is an excellent vehicle for this application. Figure 3 illustrates the installation. The GPS antenna and fathometer have both been mounted on a temporary mast on the bow to minimize the magnitude of necessary offset corrections. The recording computer and IMU are on the working deck. The illustration was made from a



**Figure 4.** Photo of LARC in action

photograph of the actual setup during a hot summer day, and a canvas cover was used to shield the operator from the sun. Figure 4 is the photograph of the LARC while surveying in Oregon Inlet nearby the FRF.

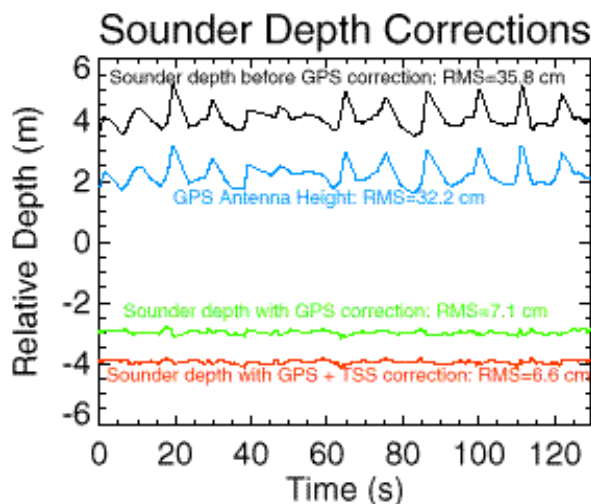
### Data Processing

In both cases that are illustrated in this article, the data are processed in a reasonably straightforward manner. As noted above, the GPS derived antenna heights are recorded in real time and subsequently transferred to topographical

heights by simple algorithms that coherently compute and combine the height differences between the phase center of the antenna, the antenna-sounder distance, and the sounder measured distance to the bottom. The single most vexing problem that required a significant level of analysis to resolve during the development of the algorithm was an accurate estimation of latency of the different sensors. The resulting height can be transferred to a tidal datum by using appropriate information on the height of the monument (thereby typically requiring use of an NOS rather than a USGS monument.) The algorithm includes changes of attitude of the platform as measured by the IMU, though we have found this to be a small improvement in general. For the case of the LARC, the topographic surface value is chosen in a simple logical software decision to be either the depth as indicated above or the distance to the bottom of the wheels depending on whether the vehicle is floating or is supported on its wheels.

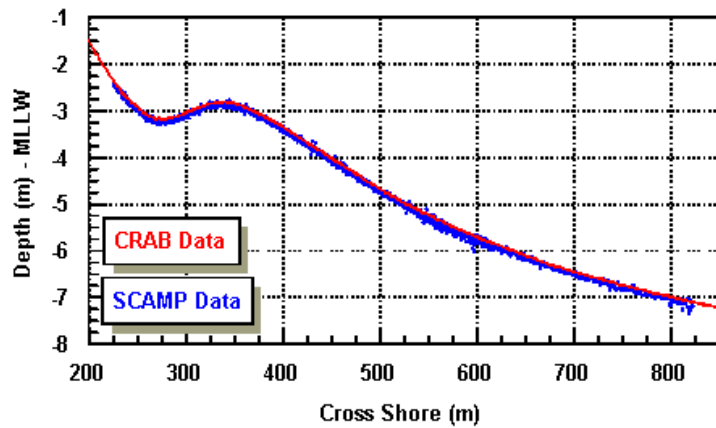
### Results and Error Sources

Figure 5 is an example time series of data collected by the SCAMP when not underway over a flat bottom at 10 m depth in waves having  $H_{mo}$  of about 1.3 m. The time series for the fathometer and GPS antenna height data are shown along the top. These data channels obviously are highly correlated as would be expected, and their difference is the third time series. Finally, the bottom plot includes a further correction in which the IMU data are used to account for heave motions for frequencies above 1 Hz and the attitude of the boat for all frequencies. Clearly, the GPS antenna height accounts for most of the motion, with the IMU accounting for a much smaller percentage. In this example, the motion compensation system reduces the contamination of the sounder data by 15 db.



**Figure 5.** Time series when SCAMP not moving

To provide an assessment of the overall accuracy of the system, the SCAMP surveyed several lines that the FRF Coastal Research Amphibious Buggy (CRAB) surveyed at the same time.



**Figure 6.** Comparison between SCAMP and CRAB profiles

source of the difference is not known at this time. This magnitude of error is within realistic expectations (see the error sources in the next paragraph.)

Figure 6 shows the resulting comparison, with the solid line being the CRAB profile and the dots the SCAMP data points.  $H_{mo}$  was less than 1 m.. There is an offset between the two of <4 cm and an rms noise of 5 cm.. The source of this offset is unknown, but the actual CRAB height is expected to change due to additional buoyancy when the wheels are submerged, and this has not been accounted for. Nevertheless, the CRAB is the recognized standard, so we conclude that our data are too low by this offset, though the precise

Also, Figure 7 provides a comparison between a bathymetry profile collected with this survey system installed on the LARC and the CRAB. The profile includes the transition across the shoreline (the zero is relative to the MLLW datum), and the largest differences are at locations of rapid changes. The mean offset again is about 4 cm, but the noise is slightly higher at 6 cm rms. In this case, it was not possible to maneuver the LARC on precisely the same straight line as the CRAB, so that the survey lines were not coincident. This may have contributed to the slightly higher noise level. It is interesting to find

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**Figure 7.** Comparison between LARC and CRAB profiles

the offset very close to the result for the SCAMP comparison with the CRAB.

As to specific sources of errors in the data collected by this system, the sounder has a precision of 1 cm, but has errors as large as 3-10 cm in the nearshore water depths where we typically operate, the value depending upon the water depth (since the sounder only measures time of flight) and the level of knowledge of the sound velocity in the water column. The KGPS accuracy is 3-4 cm and noise level is 1-2 cm for the vertical value when operating at 1 Hz rate and at distances less than 10 km from the base station. These levels are increased to about 5 cm each when the unit is operated at a higher sampling rate (either the KGPS operating at a higher rate or

the IMU being required to fill in the higher frequency motions.) The roll and pitch of the boat contributes an uncertainty error of magnitude 5-10 cm for the SCAMP and 10-20 cm for the LARC for depths nearshore, and this attitude error is reduced to about 5 cm when using the IMU. The rms sum of all of these errors typically is less than 10 cm, and this compares very well with the errors we have found in our comparisons with standards as indicated above. They are significantly smaller than the errors we have experienced when surveying without this system in the nearshore. When not using a system of this type, the largest single source of error is directly due to the waves, as shown above. Unfortunately, averaging the data to reduce these wave motions is not always helpful when surveying in locations where the topography is changing rapidly over rather small spatial scales, such as the nearshore. Also, without this system, smaller but significant errors (that is, larger than those we have experienced with this system) are caused by uncertainty in the mean water level. This uncertainty is due to a number of factors including tides in complex inlets (when the tide station is not close to the survey site), set up in the surf, infra-gravity waves in and near the surf, non-sinusoidal wave profiles in and near the surf, and boat squat.

## **Conclusions**

A very capable bathymetry survey system has been designed, constructed and tested using unique platforms -- a jet ski and an amphibious vehicle -- for surveying relatively inaccessible locations such as exposed coasts having moderately high waves and surf, and inlets having a region of complex shorelines, ponds and shoals. The accuracy has been evaluated positively in realistic environments against USACE FRF standard tools.

## **Acknowledgments**

These comparative data for evaluating the accuracy of this system were collected with the full cooperation of the very capable personnel at the U.S. Army Corps of Engineers (USACE) Waterways Experiment Station (WES) Coastal and Hydraulics Laboratory (CHL) Field Research Facility (FRF) on the Outer Banks at Duck NC. We much appreciate having access to their capabilities and facilities, and being the recipients of their able assistance and support. In addition, we benefitted from an early discussion of using jet skis for nearshore research with Dr. Reginald Beach of Oregon State University and now with the Office of Naval Research. Dr. Dugan is located at the Washington office of Areté Associates, 1725 Jefferson Davis Hwy, Suite 703, Arlington VA, 22202, and he can be reached at 703 413 0290 or [dugan@arete-dc.com](mailto:dugan@arete-dc.com).