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Surf and Coastal Area Measurement Platform (SCAMP)

USACE Demonstration Survey Final Report

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Executive Summary

Areté Associates, in accordance with contract DACW43-98-D-0519[1], and in cooperation with the US Army Corps of Engineers (USACE) New York District, conducted a hydrographic survey demonstration using a unique bathymetric system based on a jet ski with RTK GPS technology. This prototype system (designated SCAMP for Surf and Coastal Area Measurement Platform) had previously been developed using Areté internal R&D and Office of Naval Research funding. Informal testing in collaboration with the USACE Field Research Facility at Duck, NC showed that SCAMP provided 5 cm rms error in surf-zone and inlet operations.

This report describes two USACE-specified modifications that were made to the SCAMP system prior to this demonstration:

(1) a left/right indicator was mounted in view of the survey driver to assist the driver in navigating the designated survey line, and
(2) the monitor-station software was modified to allow the option of re-designating the order in which survey lines are run.

Both modifications were successfully installed and shown to be valuable survey assets during the demonstration. The SCAMP hydrographic system was shown to be an easily transportable, fast-response survey tool, which is suitable for shallow water beach and harbor operation. Also during this demonstration, the system was shown to be robust, performing well in moderate seas (1.2 m H_{mo}), and adaptable to adverse circumstances. However, the HYPACK® data acquisition software developed to implement the two USACE-specified modifications produced data acquisition timing problems, the result of which was to de-correlate position and sounding measurements. After a significant post-test analysis effort, no means for correcting the data timing problems embedded in this data was identified. Thus, a comparison between the hydrographic survey data obtained by the USACE New York District and that obtained by SCAMP produced 12 to 22 cm rms error, rather than the previously experienced 5 cm rms error. This software problem is correctable. Plans are in place to work with the manufacturer and the USACE at the FRF at Duck, NC to resolve the acquisition timing problems for future use.

[1] U.S. Army Corps of Engineers contract DACW43-98-D-0519 for the Topograghic Engineering Center's work unit "Development and Modifications to SCAMP", under the direction of Dr. Robert Mann.

Background

Areté Associates, in conjunction with the Office of Naval Research, has developed the prototype Surf and Coastal Area Measurement Platform (SCAMP) to measure bathymetry and currents in the near-shore region. SCAMP was developed as a precise *in-situ* measurement tool, providing a baseline for testing algorithms that are being developed for retrieving environmental parameters from remote sensing. The fundamental concept of the SCAMP system is to measure the topography directly in a geodetic datum so as to remove any dependence upon the local waves and tide level. Standard techniques for obtaining depth measurements relative to a tidal datum have been replete with difficulty around inlets and along beaches, because of problems associated with complex tidal heights, wave-induced setup, and wave motions of the survey platform. The SCAMP system uses Real-Time Kinematic Global Positioning System (RTK GPS) technology to obtain geo-referenced, 3-D, centimeter-scale positioning to eliminate these problems. The system has demonstrated exceptional performance (yielding errors less than 5 cm rms and offset) during informal comparison tests with the US Army Corps of Engineers (USACE) bathymetry standard, the Coastal Research Amphibious Buggy (CRAB) located at Duck, NC. The ongoing development of SCAMP has led to a sufficiently mature technology to address other, more routine, survey applications. One such application is of specific interest to the USACE, namely the monitoring of coastal erosion and maintenance of shipping channels. The USACE has funded[1] this formal demonstration to show that the SCAMP system provides an expedient and economical method for monitoring natural and man-made changes at active inlets and along coastline beaches that are inaccessible to typical survey launches.

The primary components of the SCAMP survey system are: a jet-ski, RTK GPS base and rover stations, radio link and on-board receiver, a single-beam sounder, an on-board recording computer, and a monitor-station consisting of a UHF telemetry receiver and a laptop computer with real-time display. The single-beam sounder is mounted through the bottom of the jet-ski hull. The sounder electronics, along with the RTK GPS receiver, the computer and a radio transmitter, are in a small box located internal to the hull of the jet-ski. The RTK GPS antenna and the telemetry receive and transmit antennas are located on the stern. The jet-ski is the optimal platform for very-shallow-water and surf-zone operations. It has proven to be a versatile survey platform because it has a large power-to-weight ratio providing sufficient acceleration for maneuvering to avoid the danger of breaking waves in the surf. 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 is therefore useful for surveying beaches that are rather inaccessible to survey launches and far from protected harbors. When the beach topography also is of interest, the rover components of the survey system can be transferred easily to a four-wheel-drive vehicle, and the beach topography obtained from the height of the phase center of the GPS antenna plus the distance to the bottom of the wheels. On the jet-ski, the bathymetry values are derived by a combination of the RTK GPS data, the distance between the GPS receiver antenna and the sounder head, and the sounder-measured distance to the bottom. The resulting values typically

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[1] U.S. Army Corps of Engineers contract DACW43-98-D-0519 for the Topograghic Engineering Center's work unit "Development and Modifications to SCAMP", under the direction of Dr. Robert Mann.

are adjusted from the ellipsoidal reference in WGS84 coordinates to a tidal datum by accurately referencing the position of the RTK GPS base station to a local geodetic monument.

The onboard computer stores the various data streams and also telemeters the sounder and GPS data to a monitoring station on the beach via UHF radio communication. The monitor station consists of a radio receiver and a laptop computer running the commercial software package called HYPACK®, developed by Coastal Oceanographics of Middlefield, CT. HYPACK® provides the operator with a display of the SCAMP location and track made good on a local nautical chart and also a window with the time series of the measured depth values. In past applications, the monitor-station operator has used a voice radio to send steering commands to the boat operator to maintain course on the planned survey lines. The jet-ski driver has a voice-operated radio in his/her ear to avoid additional hand controls and, although this technique has worked in the past, the maintenance of good survey tracks requires constant attention of both the driver and monitoring station operator. An innovation for this demonstration was to remove this high attention level by providing a left/right indicator mounted on the steering column to assist the jet-ski operator in staying on line during each of the onshore/offshore transects.

Objectives

The primary objectives for the SCAMP demonstration were:

1) Demonstrate the usefulness of the SCAMP system for near-shore bathymetric surveying.

2) Obtain SCAMP hydrographic survey data, and compare with collocated USACE standard (sled towed via LARC) hydrographic data.

3) Verify the performance of USACE-requested survey system modifications including a left/right indicator to assist the operator in maintaining onshore/offshore transects and an automated/remote routine for changing survey lines.

Survey Summary

The demonstration survey was conducted in the vicinity of Sea Bright, NJ between September 27 and September 29, 2000. A planning meeting among participants (see attachment for list of attendees) was held in the Sunrise Suites Hotel lobby in Tinton Falls, NJ on September 26. Several issues were discussed during that meeting. Foremost, was a safety issue resulting from the USACE New York District’s on-site LARC being disabled and therefore unable to serve as the safety boat for SCAMP deployments, as had been planned. It was decided that Areté would contract for a certified Emergency Medical Technician (EMT) and experienced jet-ski driver to serve as safety person. It was also decided that the EMT would operate the second Areté jet-ski as the designated safety boat.

Other issues discussed during the meeting are summarized below.

- Since the modified safety plan that was adopted would not be in place until September 28, and several of the observers/participants were leaving on September 27, it was decided to run a preliminary demonstration of SCAMP in a benign environment prior to the surf demonstration. The preliminary demonstration was to be conducted on the sound side of Sandy Hook at the Leonardo State Marina on the morning of September 27.

- Areté participants summarized the GPS ephemeris predictions for local satellite coverage for the week. Marginal coverage could be expected for the morning operations (5 to 6 satellites) with a 20-minute down time at 11 a.m. EDT. This would be followed by improved coverage in the early afternoon (see Figure 1). Areté noted that they had successfully worked through such marginal periods in the past. In order to provide a SCAMP demonstration prior to the participants departing, it was decided the same would be attempted here. (In retrospect, this problem was underestimated. Not only was the GPS satellite coverage sparse, but several were at sufficiently low elevation angles to produce difficult operating conditions for RTK GPS positioning of the SCAMP, especially during the September 28 surf operations).

- USACE New York District representatives were skeptical about any successful use of radio links in the vicinity of the Leonardo State Marina. Their experiences in that area included interference from heavy radio traffic and apparently intentional jamming by disgruntled amateur operators. Areté noted that the SCAMP system, as configured, requires 3 radio channels to be chosen from the 16 channels for which Areté is licensed. If need be, the radios would be reprogrammed to less troublesome frequencies.

The test participants convened at the Leonardo State Marina at 8:30 a.m. September 27. The USACE New York District identified a local monument for establishing a base station and the SCAMP system was made ready for deployment. A survey plan was adopted and several survey lines were hand-entered into the HYPACK® survey software. The survey plan called for six onshore/offshore lines with one line repeated four times followed by several perpendicular transects to produce crossover points. However, while working through the pre-launch checklist, it was determined that the rover GPS on the jet-ski was not acquiring kinematic positioning, whereas kinematic positioning is essential to the SCAMP technique of geodetic-referenced topography. Several approaches were undertaken to troubleshoot the communications problem. First, the base station radio telemetry channel was changed to one that had been monitored and found to be relatively free of traffic, and then the entire suite of base station transmitting components were switched out to spares. Still, the system lock onto kinematic was not improved. The performance flag on the jet-ski GPS screen continued to shift between ‘Kinematic’ and ‘Unknown’, a status condition caused by incomplete or sporadic updates from the base station. The base station transmitting power was then increased from 2 watts to 35 watts, in an effort to overwhelm the radio interference. No immediate improvement was noted; however, the system did acquire and retain kinematic-lock a short time later.

After further analysis, it is believed that the poor RTK GPS positioning obtained on September 27 was due primarily to interference from local radio traffic rather than a result of insufficient satellite coverage as was the consensus while in the field. A summary of the recorded GPS status channels from September 27 is shown in Figure 2. The figure is a two-panel time series, with the top panel showing the GPS 'quality indicator' (a 1, 2, 3, or 4 status) and the bottom panel listing the number of satellites being used to compute the GPS positions. It can be seen that for the first 90 minutes the quality indicator was predominately locked on 4 (Unknown). At the same time, the number of satellites being used to determine the GPS position seldom dropped below five, the minimum number needed to initialize RTK GPS, and never fell below four, the minimum number needed to maintain RTK GPS, once acquired. A nearly identical satellite configuration on September 29 produced excellent kinematic performance in an area 10 miles southeast of this site. As shown in Figure 2, after 90 minutes of poor performance the system abruptly attained RTK GPS positioning and performed nearly flawlessly for the rest of the deployment.

The morning exercise of September 27 identified the first of a number of major shortcomings in the HYPACK® drivers developed specifically for SCAMP by Coastal Oceanographics. For this demonstration test, Coastal Oceanographics had been contracted to rebuild the drivers to achieve the following objectives:

1) Implement an interface to a left/right indicator for assisting the driver in maintaining track along the programmed survey lines.
2) Provide the monitor-station operator the option to switch the order in which the survey lines are prosecuted.
3) Update SCAMP sensor drivers to the latest version of HYPACK®, HYPACK®MAX. (The switch to HYPACK®MAX was required by Coastal Oceanographics to implement the remote switching option described above).

The first two of these objectives were met. The line switching option worked flawlessly and the left/right indicator produced excellent results and elicited praise from the jet-ski operator. A quantitative assessment of the improved driving performance using the left/right indicator is shown in a following section. The third objective, however, was not successful. The modifications to the SCAMP drivers for the Trimble GPS and the Datasonics sounder led to significant data drop-outs, timing uncertainties and real-time operational problems. Unlike previous versions obtained from Coastal Oceanographics, this HYPACK®MAX driver did not display the Trimble GPS status flag at the monitor-station operator's screen. This oversight has since been corrected, but for September 27 and 28, a determination as to how well the system acquired kinematic fixes was not available in the field. Only after post-processing the data was this problem quantified. One of the initial data-quality checks included in the evaluation is a track plot of the good (kinematic) positions obtained during the survey. The survey track for September 27 is shown in Figure 3. The broken line character of the survey track is a result of the system continually losing and then reacquiring kinematic-lock.

The certified EMT arrived on the evening of September 27 and, on the morning of September 28, the field operation moved to the near-shore area designated for the comparison survey. The area is located near Sea Bright, NJ and specifically defined by 10 parallel onshore/offshore survey lines extending 300 m from the shoreline with each line separated by 30 m (100 ft). The survey plan was similar to that of the previous day, namely:

1) prosecute the 10 survey lines,

2) repeat line one 4 to 6 times, and
3) run several transects perpendicular to the survey lines to obtain crossover points.

During the pre-launch checkout, the SCAMP system appeared far more stable and more like previous experiences than had been experienced the previous day. However, the inability to monitor whether the system was acquiring RTK GPS positions while surveying again proved costly. The survey was conducted between 7:45 am and 10:00 am local time (1245 and 1500 UTC). The seas were calm (H_{mo}~0.5m) with light winds, and the SCAMP launch and recovery were uneventful. The actual time in the water to complete the survey was 90 minutes. It was learned later that day that very little of the September 28 survey data were obtained while acquiring RTK GPS positions. This was a result of the number of satellites that the GPS antenna was able to lock onto being too few for kinematic positioning. Although the GPS almanac listed a sufficient number of satellites in the sky field-of-view, the GPS receiver was not using them. Three of the six available satellites were 20 degrees or less elevation and this caused the jet-ski operator, located forward of the GPS antenna on the water craft, to block out the view of low-elevation satellites during maneuvers on the water. The number of satellites actually used was generally less than five, the minimum required for initializing kinematic navigation. A smaller number of satellites is required to provide differential GPS positioning. As a result, much of the survey was obtained while in differential mode (see Figures 4 and 5). The survey did (at least) provide an excellent demonstration of the effectiveness of the left/right indicator and line switching option.

Both of the problems encountered during these surveys, namely, poor radio communications on September 27, and poor satellite coverage on September 28, have been previously encountered and overcome while in the field. The remedies have been straightforward, including:

1) switching radios, switching radio channels, and/or radio transmit power to alleviate communication problems and
2) reconfiguring GPS antenna parameters, repeating survey lines or awaiting a more favorable satellite configuration to obtain kinematic-compatible GPS positioning.

In the past, these remedies have been initiated after noting changes or discrepancies in the Trimble GPS status flag at the monitor station. The failure to include the Trimble status flag in the HYPACK® MAX driver developed for this demonstration precluded these in-the-field remedies. This has since been resolved and is no longer an operational limitation.

Once it was learned that the data from September 28 were not useable for bathymetric processing (generally not RTK GPS positions), a plan for September 29 operations was put into effect. The satellite orbits only change slightly from day to day, and the poor GPS satellite coverage (specifically the low elevations) was certain to continue into the next day. Modifications to the operating system were made. First, the monitor-station program developed by Coastal Oceanographics for this demonstration was switched in favor of an older version. The older version provides the monitor-station operator with a visual verification of the kinematic status flag during operations. The downside to the decision to use the older version was that it does not include a driver for the left/right indicator nor the ability to change the order of survey-line prosecution. Directions to the jet-ski operator for assistance in maintaining course on the survey lines was passed via voice communication. Additional modifications for the September 29 operations included lowering the acceptable elevation angle for the GPS antennas/receivers (called the elevation mask) from 13 degrees elevation to 8 degrees elevation and raising the height of the jet-ski GPS antenna. These antenna changes were known to be operationally imprudent. It is well documented that low-elevation satellites present problems for a GPS receiver. Low-elevation satellites have a lower signal-to-noise ratio and a propensity for inducing signal multipath. Also, increasing the height of the jet-ski GPS antenna (1 ft) to reduce the likelihood of the operator obstructing the antenna field-of-view to the satellites was at the same time increasing the moment arm of the unresolved pitch and roll motions of the jet-ski. According to the Trimble Reference Manual, the added noise due to multipath effects on the roving antenna is 1 to 5 cm rms. The additional unresolved roll motion of the antenna due to the increased moment arm is 0.5 cm. Nevertheless, these added noise sources were considered an acceptable compromise for obtaining useable survey data.

With these modifications accomplished, the survey was repeated on the morning of September 29. The wind had increased during the night, building the near-shore waves to a marginally operational 1.2 m H_{mo}. System set-up was begun at 7:30 a.m. EDT. The use of an older version of HYPACK® allowed the kinematic flag to be visually checked by the monitor-station operator during the survey. Whenever there was a loss of kinematic navigation noted, the jet-ski operator was instructed to repeat that section of the survey. By 10 a.m. local, the SCAMP field team had completed the survey, loaded the system for transit and was heading back to the Areté Arlington, VA office with what appeared to be a successful kinematic survey in hand. The data quality of the survey is summarized in Figures 6 and 7.

Data Quality

The survey data from September 29 produced surprisingly poor results when run through the Areté SCAMP Bathymetric Processor. Although the data were almost uniformly RTK GPS, three problems were noted.

1. An apparent gain offset in the sounder depth reading, even after adjustment to the proper sound speed.
2. An inordinate number of dropped GPS points.
3. An apparent randomness in the HYPACK®MAX time stamping that de-correlated GPS height and sounder depth measurements.

Of the three problems noted above, the third is by far the most disturbing.

An estimate of the gain adjustment to resolve the first problem listed above is straightforward. The sound speed error can be determined by normalizing spectral amplitudes between the sounder and GPS antenna height in the wave motion band. The cause for the sounder gain adjustment is a little more problematic. It may be a result of internal clock drift, or (as suspected here) an unspecified reference speed used internally in the computation of the estimated depth. Regardless of the cause, the RTK GPS antenna heights are sufficiently accurate to serve as an *in-situ* calibration of the sounder. The process is summarized in Figure 8. Power Spectral Density (PSD) curves are computed for concurrent RTK GPS antenna height and sounder depth time series, and the spectral levels are compared in the wave-induced boat motion band (in this instance 0.2-0.3 Hz). The square root of the ratio of the integrated variances over this band is the gain (relative sound speed) adjustment. This analysis in spectral space eliminates contributions from unwanted sources. The lower frequency measurements, such as from bottom topography changes, and the higher frequency variations, such as induced by boat roll or sensor digitization, are de-coupled in frequency space. Roll can be included in the de-coupling because each sensor responds to roll at two times the roll frequency and this moves that energy outside of the wave-motion band. Spectral energy peaks associated with roll can be seen in Figure 8 between 0.3 and 0.5 Hz. Normally, this process only would be used to validate the temperature/salinity-derived sound speed. In this instance the analysis is required to verify an apparent documentation error. The Datasonics sounder used in the SCAMP system has recently had a factory replacement e-prom installed. Prior to that install, the sounder-estimated depths were consistent with an assumed sound speed of 1500 m/s. This analysis, and the USACE sled data, indicates an assumed sound speed of 1450 m/s. Datasonics representatives do not yet confirm this, but it should be noted that a similar study two years ago uncovered another documentation error, when it was determined that the sounder reporting rate was 9.1 Hz and not the advertised 10 Hz.

The second problem noted above is mitigated in this test by acquiring GPS data at a 5 Hz rate. Had the same number of points (about 20%) been dropped for a data rate of 1 Hz, this problem would have been catastrophic, with two- and three-second time gaps routine. A summary of the HYPACK®MAX acquisition performance is shown in Figure 9. The missed positions are evidently a feature of the new SCAMP sensor HYPACK®MAX drivers created for this test. Though additional analysis is required for verification, there is an apparent correlation between the HYPACK®MAX handling of a sounder error flag and the subsequent skipping of GPS updates. The sounder error flag indicates either a no return from a ping (bubbles in the surf) or depth range exceeded (greater than 30 m). None of the HYPACK® drivers previously used has had difficulty dealing with this error condition.

It is unfortunate that these problems were not uncovered prior to the SCAMP demonstration test. Both of the above problems are easy to diagnose and probably have straightforward software repairs. Unfortunately, neither of these problems is apparent in a non-stressed application in the laboratory. The sounder gain error is a 5% error (not acknowledged by the manufacturer) that requires precise ground-truth to be resolved. This means either surveying a verified range or operating during high seas (when the wave motion energy is well above other noise sources). Instances of missed GPS updates, associated with the HYPACK®MAX acquisition problem, are evoked by sounder difficulties in high surf and deep water. None of these conditions was experienced during the pre-demonstration trials.

For the third problem listed above, there is no remedy to recover these data. The procedure that was followed to obtain synchronized data from past surveys using SCAMP (all of which have employed previous versions of HYPACK® for data acquisition) has been straightforward. Data obtained asynchronously from sensors are subject to timing uncertainties associated with polling jitter and lag. Polling jitter is software driven and depends on data-port sampling rates and interrupt priority. The apparent lag is a sum of the computer time offset and drift and sensor latency, the time each sensor takes for computing and reporting its latest measurement. To alleviate problems associated with polling jitter, only the transmitted GPS time-of-fix is sacred. HYPACK® computer time stamps are treated as approximate to the known and constant reporting rate of the sensors and only used to determine where time gaps (determined via delta-t) indicate dropped or missed points. The SCAMP Bathymetric Processor then fills in the gaps with interpolated points and computes a correlation function between the two time series to establish the apparent lag. An estimate of the lag is re-computed for each data file to minimize the effect of computer clock drift. In the past, a computed time lag has been invariant over each data file. For this test, using this version of HYPACK®MAX, such was not the case.

Figure 10 is a plot showing the temporal variability in computed lag between the GPS antenna height and sounder depth. The computed lags in the figure were obtained from two consecutive 15-minute data files on September 27. The computed lags are seen to vary by more than 0.5 seconds, a huge uncertainty when attempting to synchronize the two dynamic measurements. The cause of the HYPACK®MAX timing problem is not yet known, but the impact is easily illustrated. Figures 11 and 12 are similar SCAMP system sounder time series. Each figure depicts a demeaned sounder time series in red and the processed depth, after a synchronous subtraction of the antenna height, superimposed in blue. The performance during this demonstration survey, using the new HYPACK®MAX driver, is shown in Figure 11. The residual error about the trend is about 15 cm rms in seas of 1.2 m H_{mo}, typical for the September 29 data set. Figure 12 was obtained during a 1997 informal survey demonstration at USACE facilities in Duck, NC. That demonstration was run using an older version of HYPACK® for data acquisition. The processed depth-measurement curve has a variability of 5 cm rms, approximately the combined noise level of the RTK GPS height and the sounder measurements. This is typical of past operations. In those instances when SCAMP has been deployed in heavy seas (>1.4 m H_{mo}), the rms error has been somewhat larger due to the effects of roll, but the residual noise has never exceeded 7.5 cm rms. If the increased noise of Figure 11 were assumed due to a degraded sensor performance, it would not be expected to scale with the wave-induced boat motion. But on September 27, when the waves were considerably lower in the sound, the processed depth residual noise was also considerably lower at 9 cm rms. Abnormal performance from either the RTK GPS or the sounder is not indicated. What appears to have occurred is that the use of the HYPACK®MAX delta-t has incorrectly positioned the missing sounder profiles along the time line. The net effect is to shift the sounder data series forward in time at inappropriate locations, thus misarranging the synchronous measurements between sounder depth and RTK GPS height. The timing issues related to the HYPACK®MAX software have been addressed to Coastal Oceanographics and they are investigating the problem with USACE FRF at Duck, NC and Areté assistance.

Results/Summary

A demonstration survey of the SCAMP hydrographic system was attempted on three separate days, September 27, 28, and 29, 2000. Survey operations on September 27 were plagued with radio interference. Survey operations on September 28 were limited to differential GPS by poor GPS satellite coverage. The data from all three days yield a degraded hydrographic performance due to acquisition timing errors. In spite of all this, the SCAMP Demonstration Survey was largely successful in achieving two of its three operational objectives. The following accomplishments are noted.

(1) The left/right indicator implemented for this demonstration was shown to be a valuable survey asset, as was the automated/remote survey line changing routine.

(2) The SCAMP hydrographic system was shown to be an easily transportable, fast-response survey tool, which was suitable for shallow-water beach and harbor operations, able to perform well in moderate seas (1.2 m H_{mo}), and adaptable to adverse circumstances.

A substantial improvement in the jet-ski operator's ability to follow the survey line was made possible through the use of the left/right indicator. The left/right indicator was a USACE-requested modification to the SCAMP hydrographic system that was mounted on the steering column in clear view of the operator. Figures 13, and 14 quantify the performance improvement. Figure 13 is a comparison of the (typical) line-following accuracy showing the deviation from the survey line decreasing from 7.6 ft when relying on radio communications to 2.1 ft when using the left/right indicator. The path of the USACE sled (with a deviation from the track of 10.1 ft) also is shown in the figure for comparison. A cumulative probability distribution curve for the composite of all the tracks is shown in Figure 14, which is helpful in quantifying performance. For example, as shown by the two curves, 90% of the time the operator is able to remain within 2 m of the survey line while using the left/right indicator. However, the operator is only able to remain within that range 25-30% of the time when directed by the monitor-station operator by radio communications. The SCAMP operator has attested to an additional value to the use of the indicator. Not only was the navigation improved, but also an increase in the safety was afforded by this addition. According to the operator, while using the indicator as a steering command, the driving demand was simplified, enabling a more vigilant watch for rogue waves while in the surf-zone.

The addition to the SCAMP hydrographic system to allow automated/remote survey line changing was a second USACE-requested modification. The added routine required two-way communications via radio link between the monitor-station computer and the acquisition computer aboard SCAMP. The line-changing option was exercised repeatedly during the demonstration survey without a glitch.

The SCAMP hydrographic system was ascertained to be a viable survey tool during this demonstration survey. The system was shown to be portable in that a single (minivan) vehicle was sufficient to trailer and store all SCAMP components and spares. The system showed it could quickly respond to changes in survey site. The amount of time required to make ready for deployment after arrival on the survey site was shown to be order one hour. The system was easily deployed and recovered at beach and marina sites in waves up to 1.2 m H_{mo}. Once deployed, the survey was conducted at 6 knots with total survey time approximately 90 minutes. In addition, the system was shown to be re-configured easily when stressful operating conditions were encountered. The base station transmitting radio was increased from two to 35 watts in order to overpower the radio interference and the RTK GPS antenna was re-configured to match the sub-optimal GPS satellite configuration.

The third demonstration objective, to obtain collocated bathymetric data and provide a comparative performance analysis between the SCAMP hydrographic system and the USACE standard towed sled, was not as successful as had been hoped. Excellent hydrographic profiles of the target survey lines have been obtained from the USACE New York District and compared to those obtained during the SCAMP demonstration survey. Two of the profile comparisons are shown in Figures 15 and 16. The relatively smooth blue line in each figure is a sled profile. Note in each figure that the SCAMP profiles generally follow the mean depth of the sled profiles but separate slightly at the deep end. This indicates a slight error in the sound speed adjustment of the SCAMP sounder. This is most probably caused by an underestimate of the RTK GPS height variance in the wave-motion band, a result of HYPACK®MAX‘s large number of missed GPS points. The more significant problem is that each of the SCAMP profiles is plagued with the large residual variance from the boat motion due to the HYPACK®MAX timing error discussed above. This produces the 10 to 22 cm sounder noise and that same value of rms error between the SCAMP and sled profiles. An example of an earlier (1997) informal comparison between the SCAMP hydrographic survey system and the USACE CRAB in Duck, NC is shown in Figure 17. The 1997 comparison was conducted using an older version of HYPACK® that did not exhibit the timing problem. At that time the comparison produced an rms error of 5 cm. It is most probable that the use of that older version of HYPACK® would have produced similarly acceptable results here.

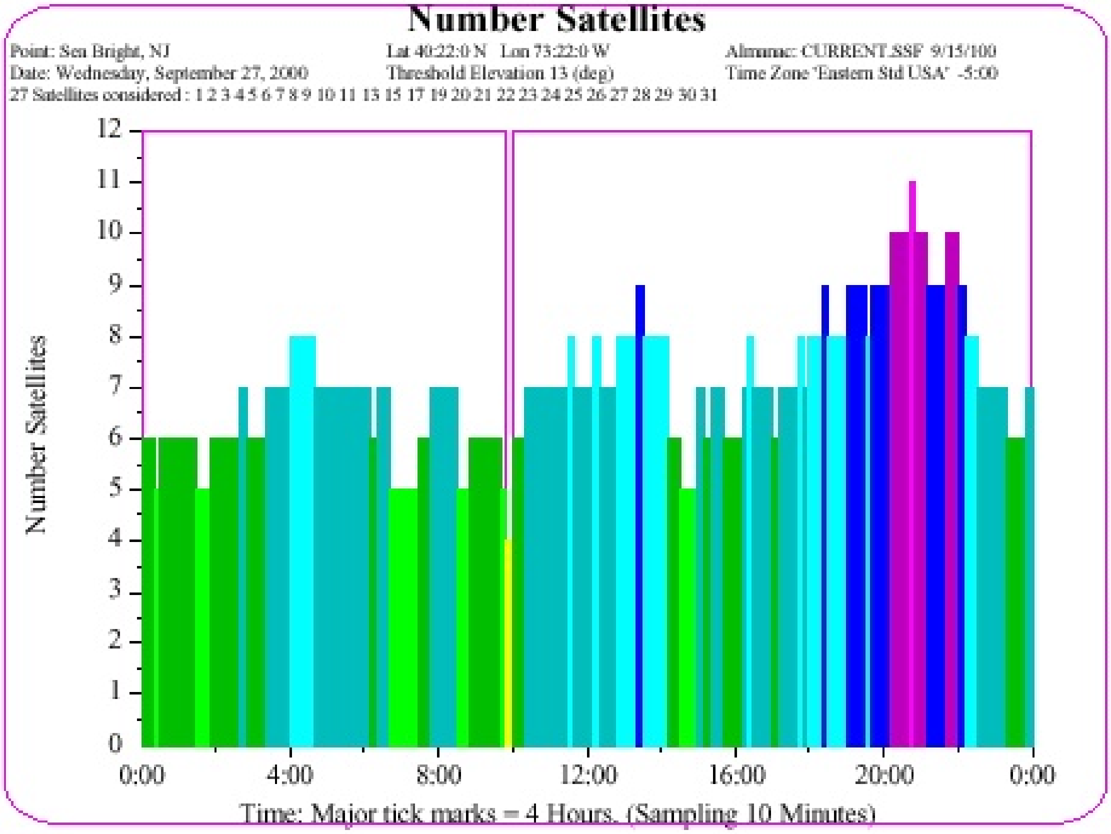

Figure 1: Number of GPS satellites in view on Sept 27, 2000 at Sea Bright NJ. The low number of satellites combined with several at low elevations proved to be a problem for KGPS positioning during early morning hours. Note time is EST.

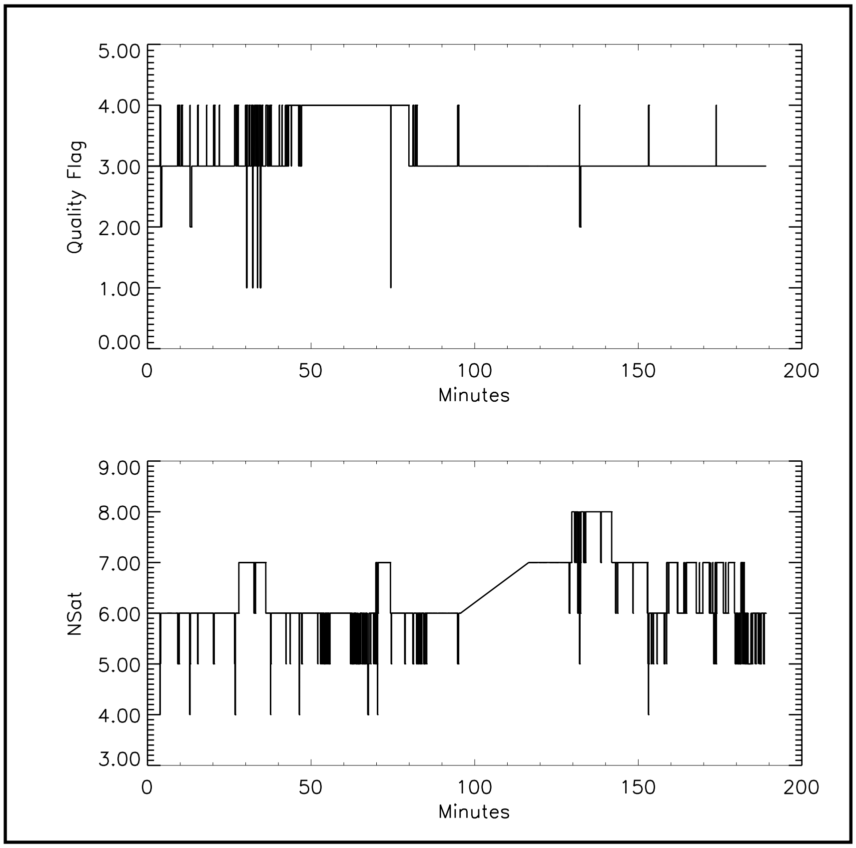

Figure 2: Time series of GPS quality flag and number of satellites used in determining each GPS position for September 27 deployment. Quality flag: 3=kinematic, 4=invalid or unavailable fix, 2=differential, 1=GPS stand-alone

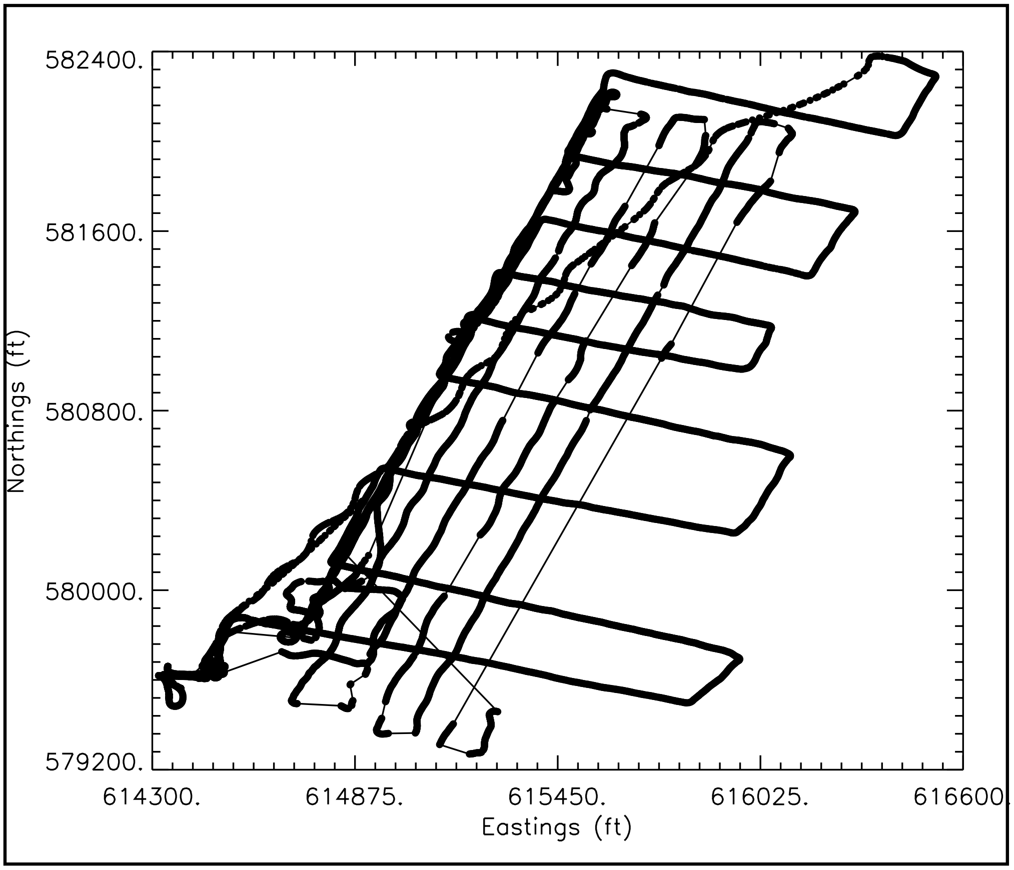

Figure 3: KGPS survey track obtained on September 27. The broken, incomplete track lines are a result of radio interference and (possibly) poor GPS satellite coverage.

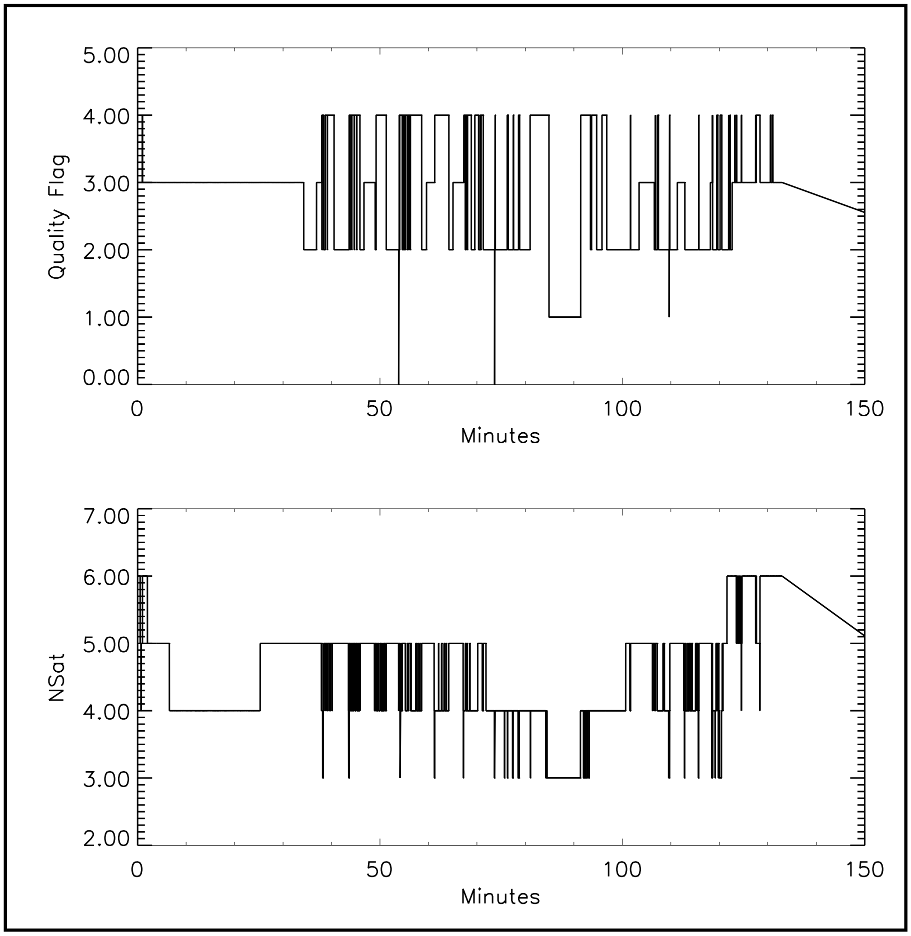

Figure 4: Time series of GPS quality flag and number of satellites used in determining each GPS position for September 28 survey. Due to the low number of available satellites the GPS system was generally in differential mode (quality flag 2).

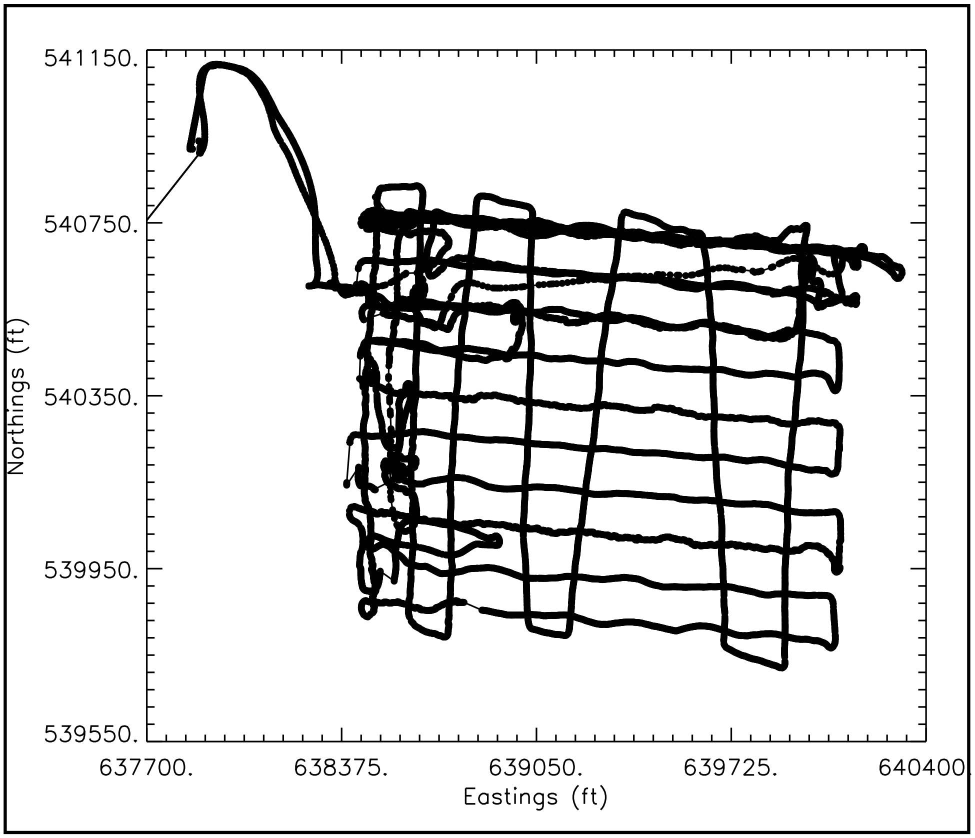

Figure 5: A plot of the full track (kinematic and differential) obtained on September 28. Although the GPS data were not sufficient for bathymetry processing, they did allow a performance analysis of the left/right indicator as an aid to navigating the programmed survey lines, one of the test objectives.

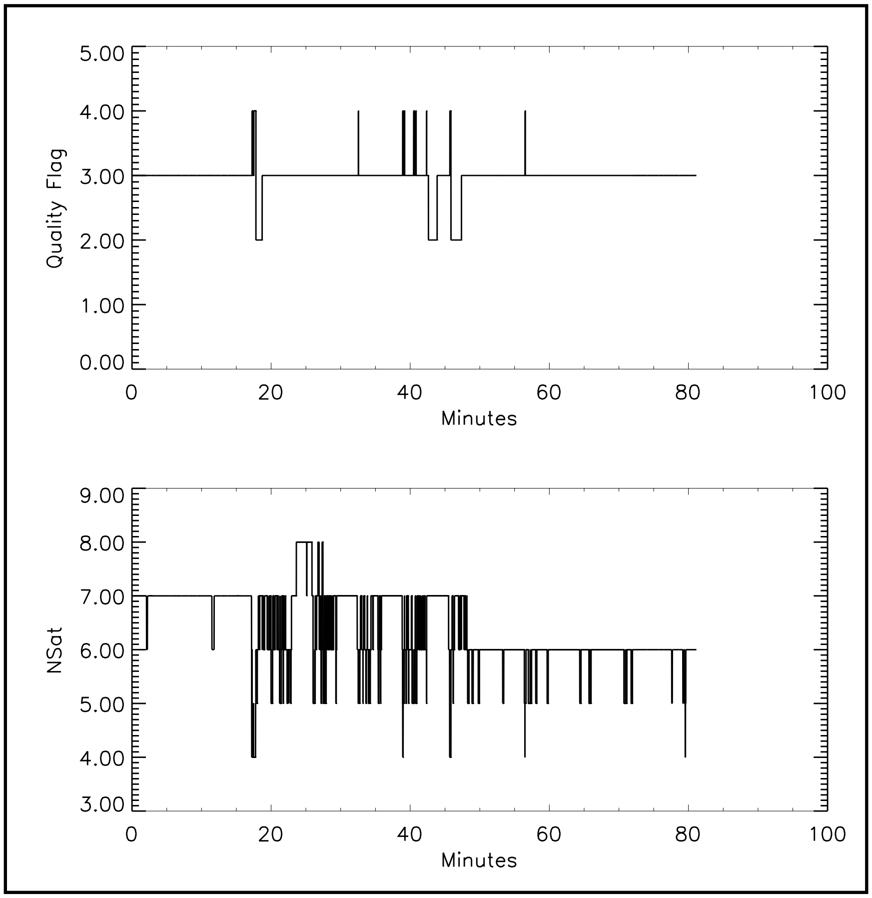

Figure 6: Time series of GPS quality flag and number of satellites used in determining each GPS position for September 29. The nearly constant lock onto quality flag of 3 reflects nearly constant kinematic positioning during the survey.

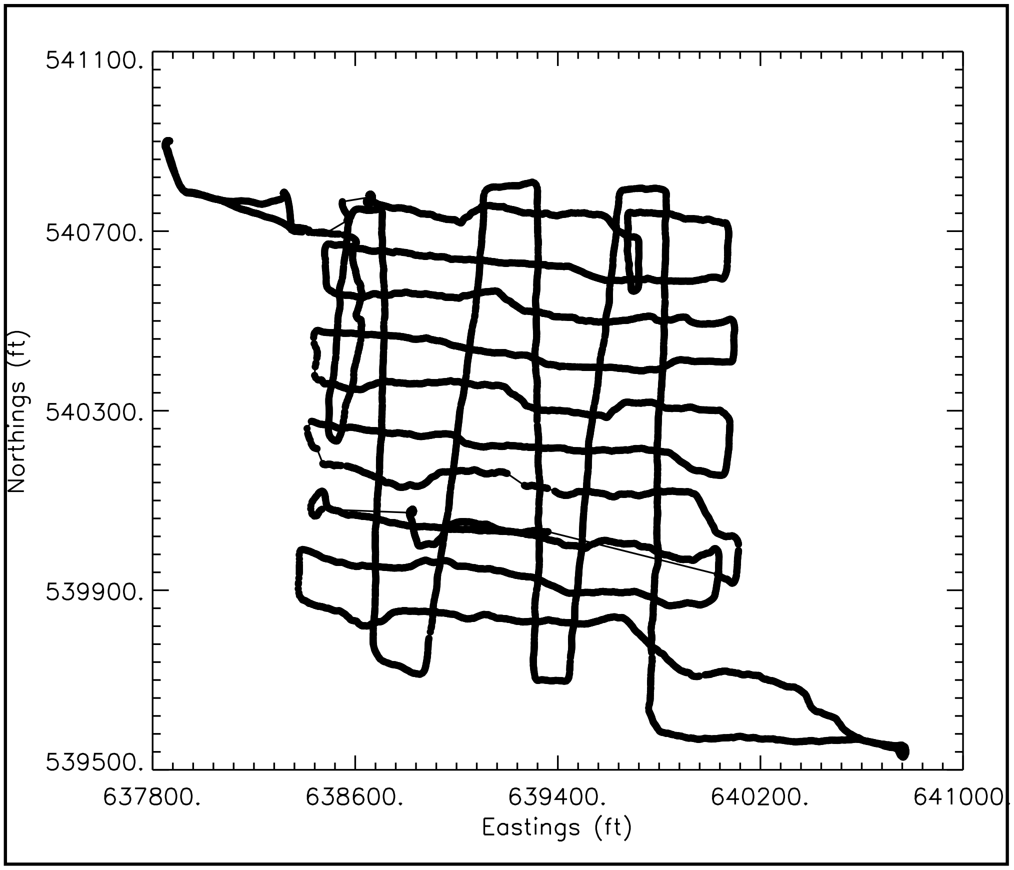

Figure 7: KGPS survey track obtained on September 29.

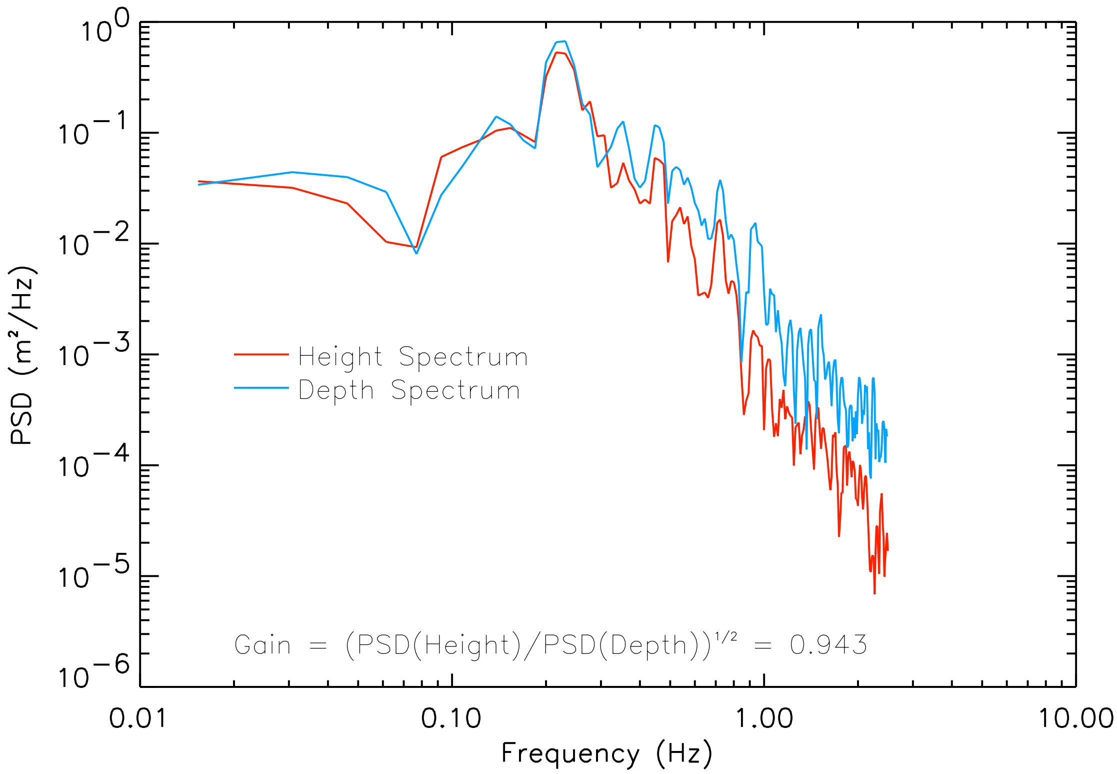

Figure 8: PSDs from GPS antenna height and sounder time series. Relative energy in wave motion band is used to normalize sounder output to local sound speed.

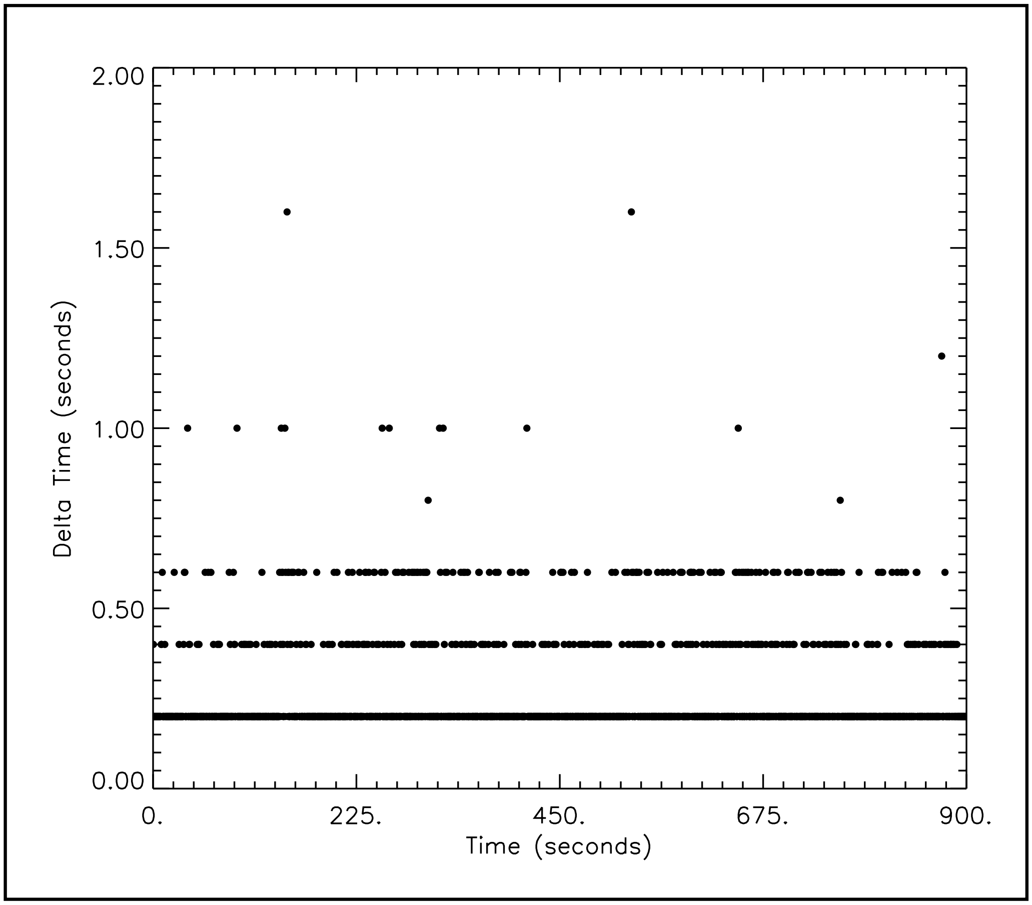

Figure 9: HYPACK delta-t between sequential data points. Reporting rate is 0.2 s. delta-t of 0.4=1 missed GPS update, 0.6=2 missed GPS updates.

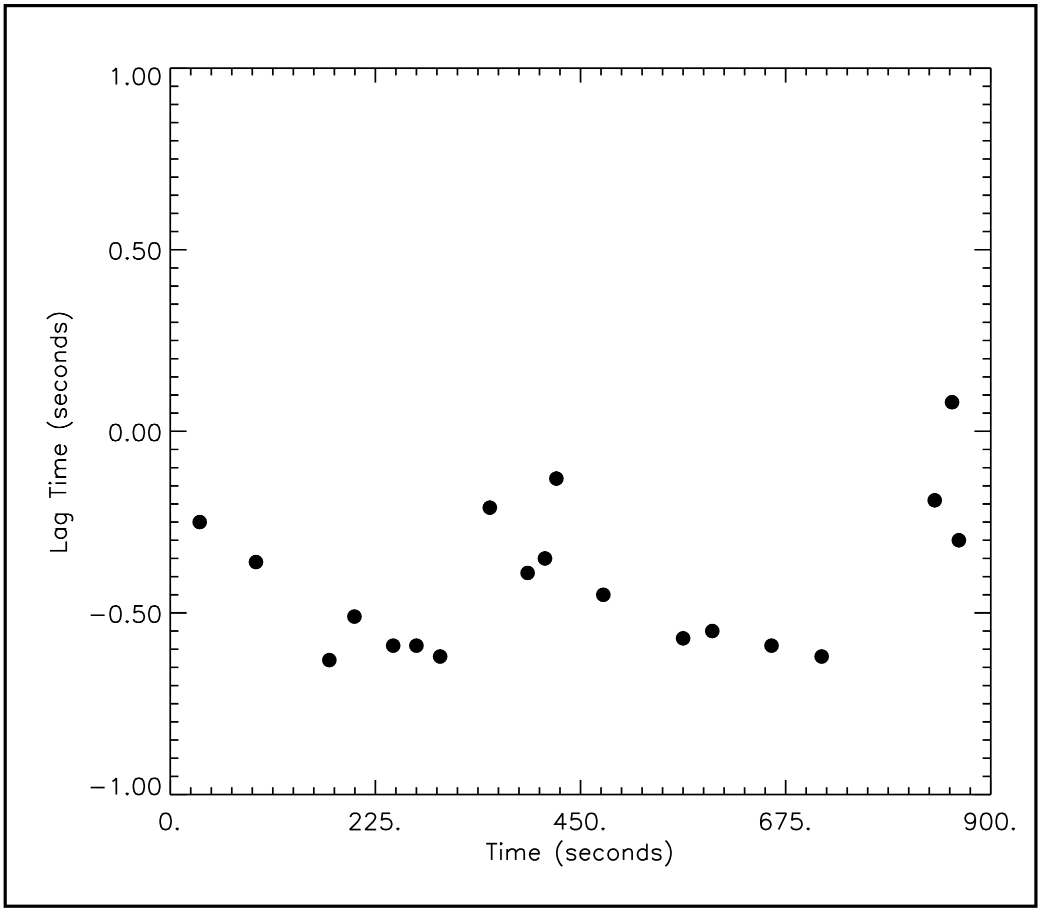

Figure 10: A plot showing the variability in computed lag between GPS height and sounder.

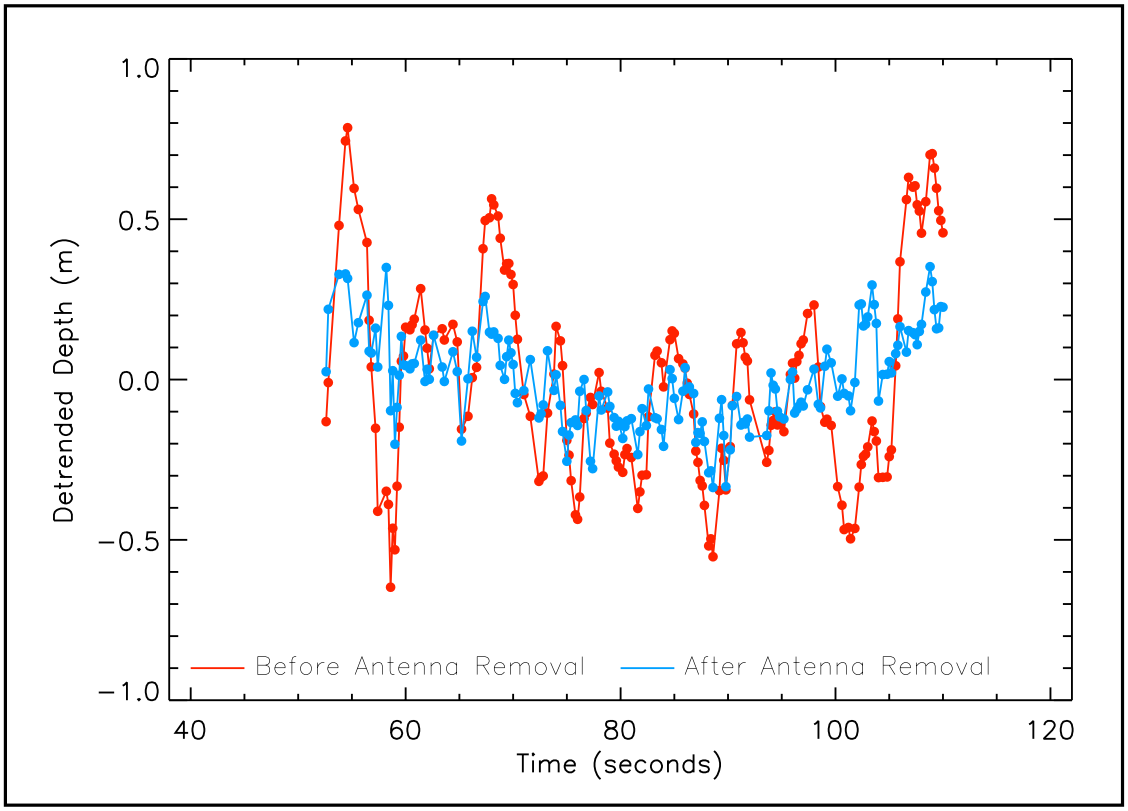

Figure 11: Raw sounder data from September 29 (red) and processed sounder data (blue). Unexpectedly large residual is due to HYPACK®MAX acquisition timing errors.

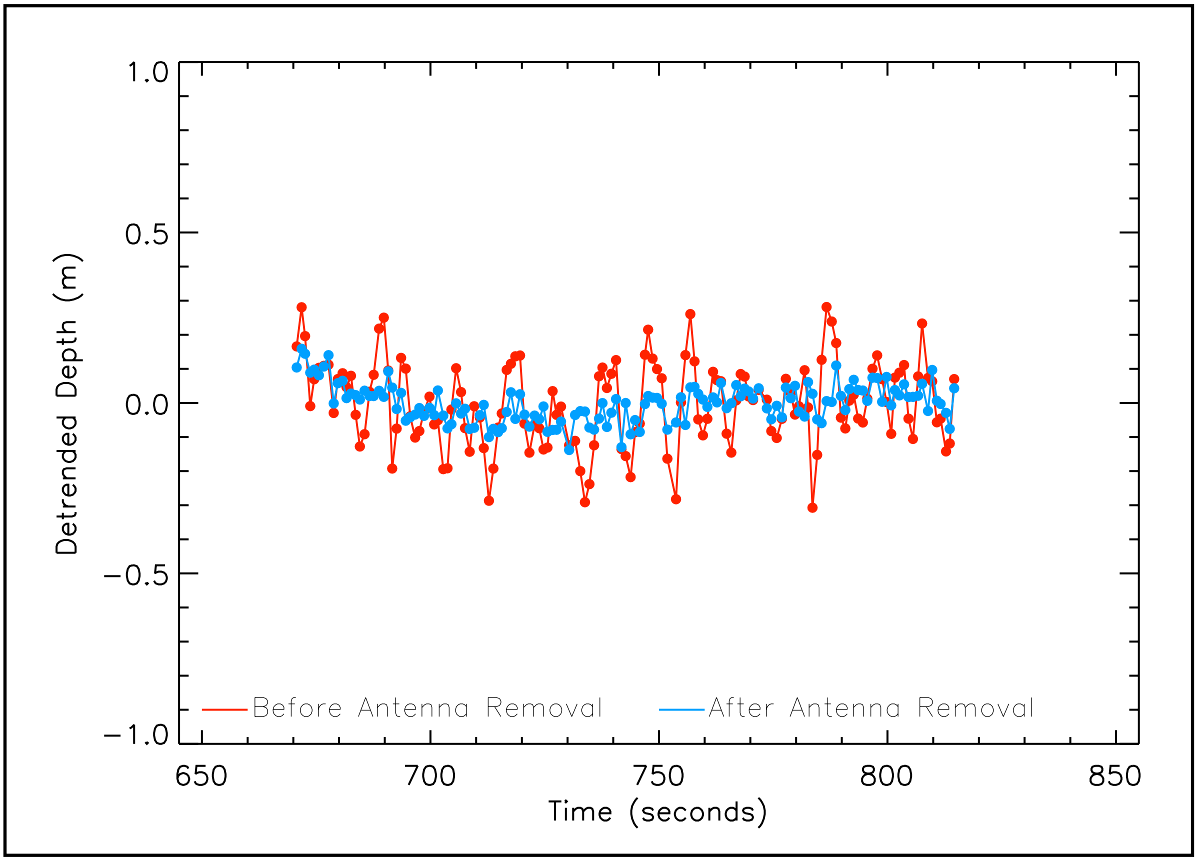

Figure 12: Similar to Figure 11, but obtained in 1997 using older version of HYPACK® acquisition.

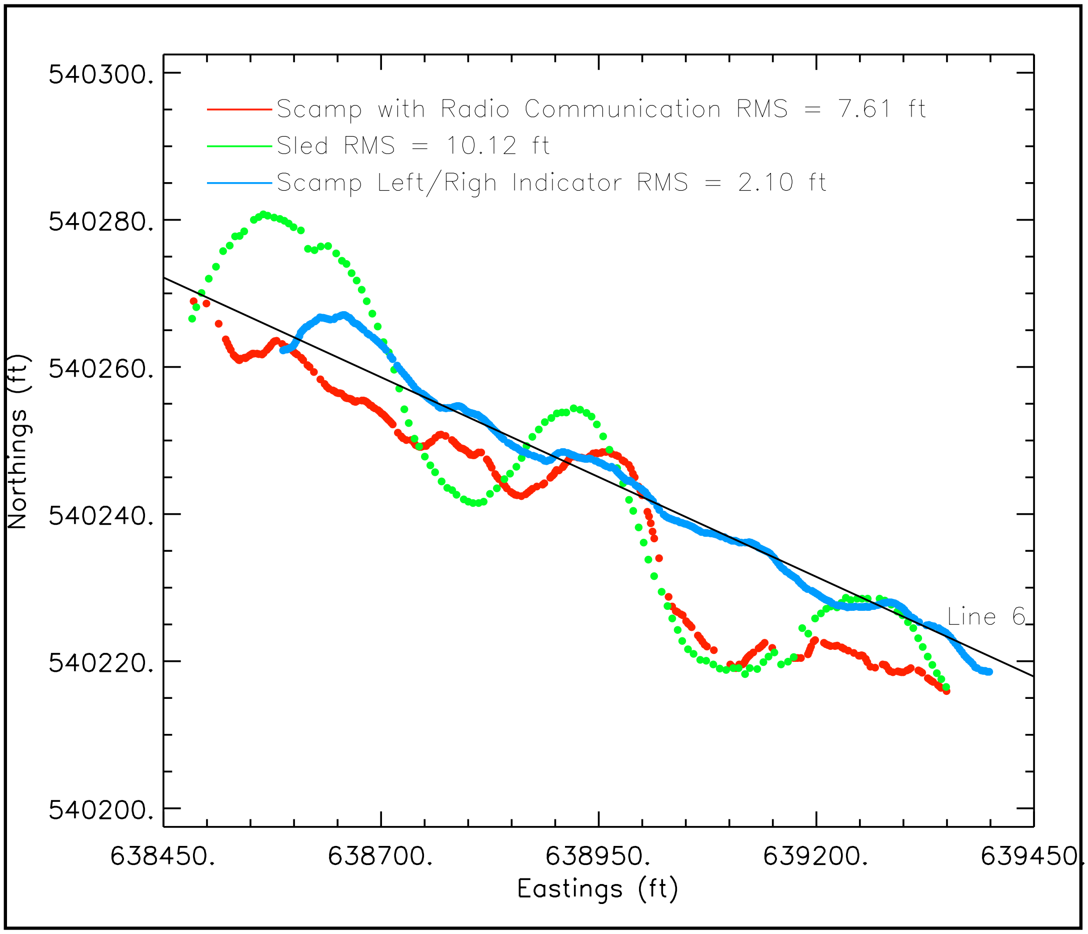

Figure 13: Comparison of line-following accuracy using SCAMP with left/right indicator (blue), SCAMP with voice coms (red), and USACE sled (green). Tracks are plotted in NJ State coordinates.

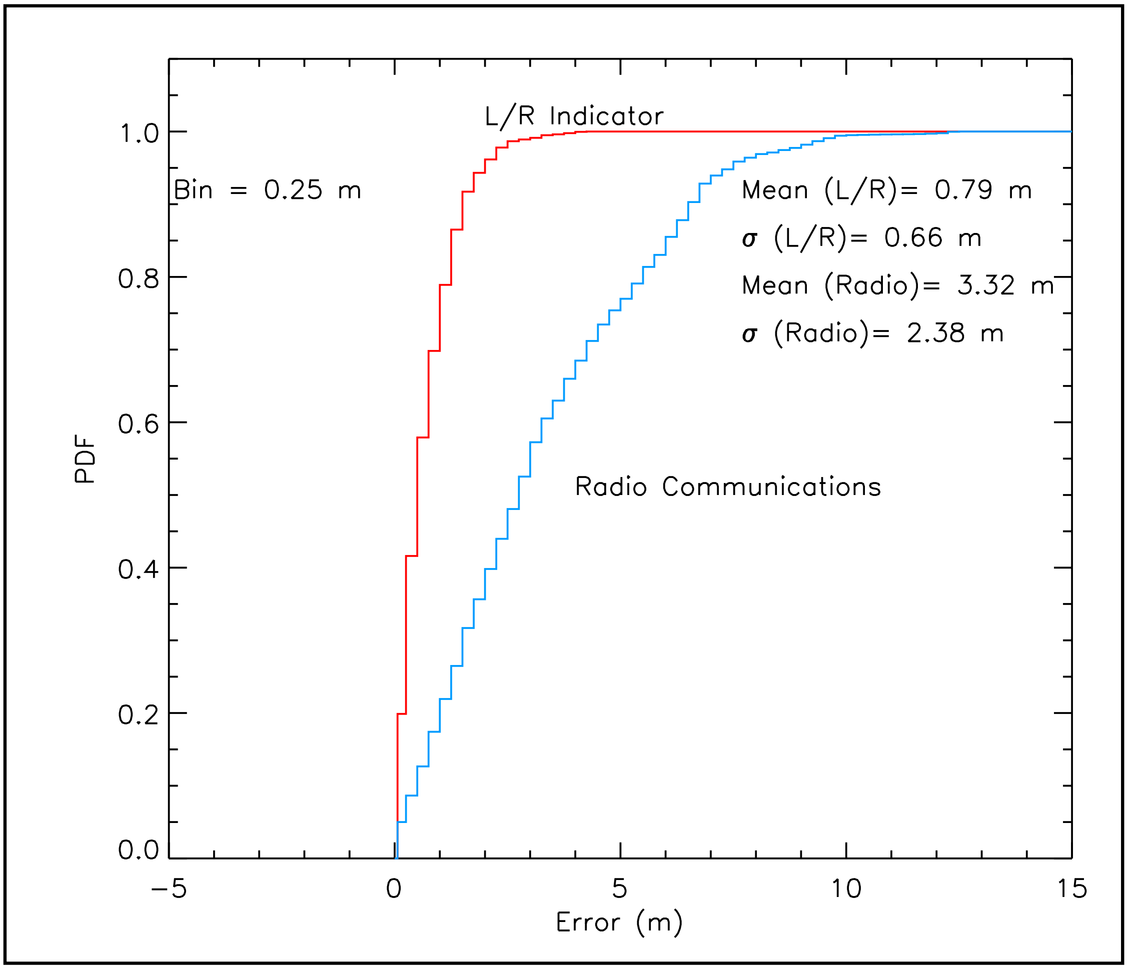

Figure 14: Cumulative distribution curves of distance from track line for two SCAMP driving techniques: using Left/Right indicator (red), and using voice radio communications (blue).

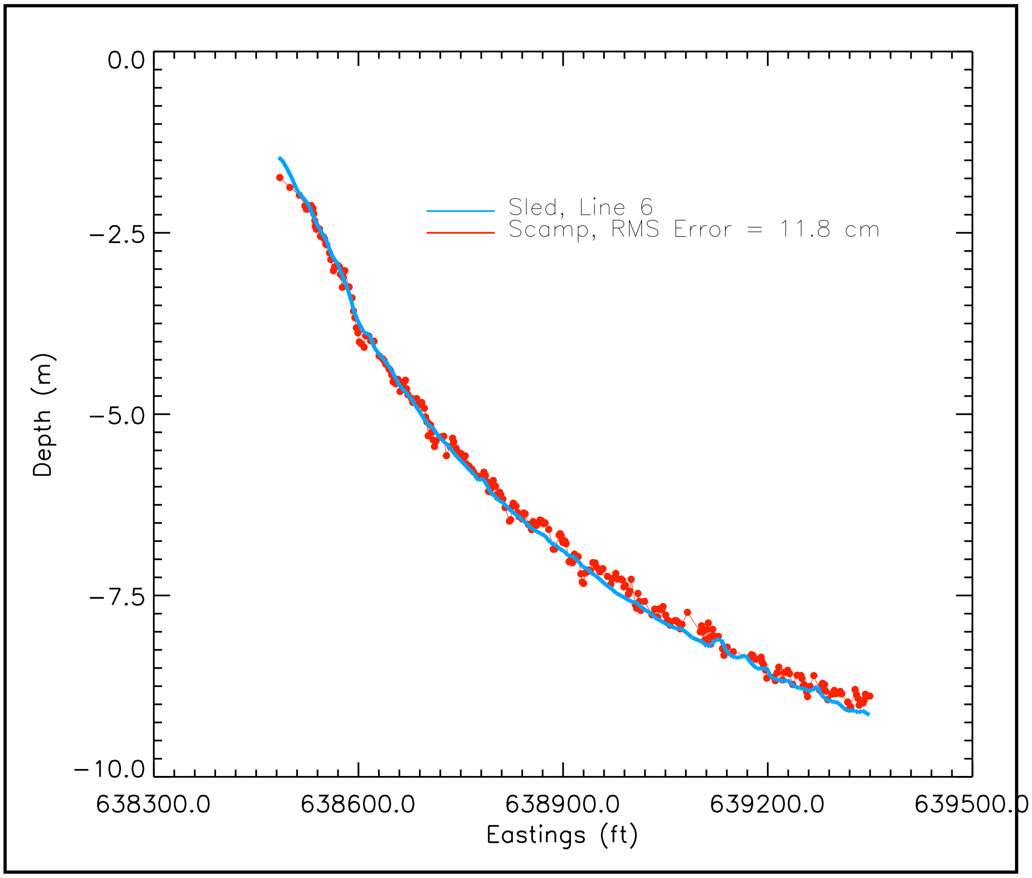

Figure 15: Comparison between USACE sled (blue) and SCAMP hydrographic system profiles obtained from line 6 of survey grid. Large rms error is largely due to the HYPACK®MAX timing problem.

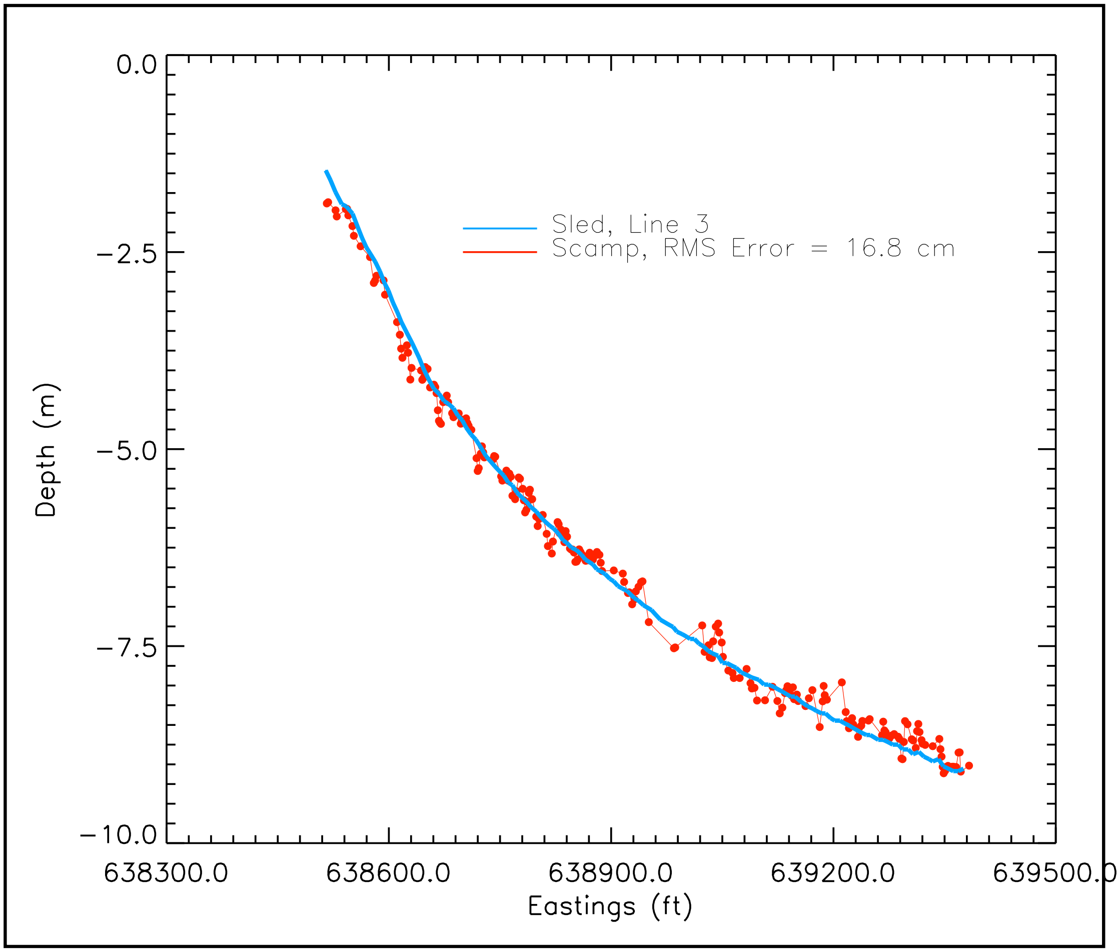

Figure 16: Similar to Figure 15. Residual noise from the HYPACK® timing problem varies with the number of incorrectly positioned time gaps. Here the rms error is near the largest observed, 16.8 cm.

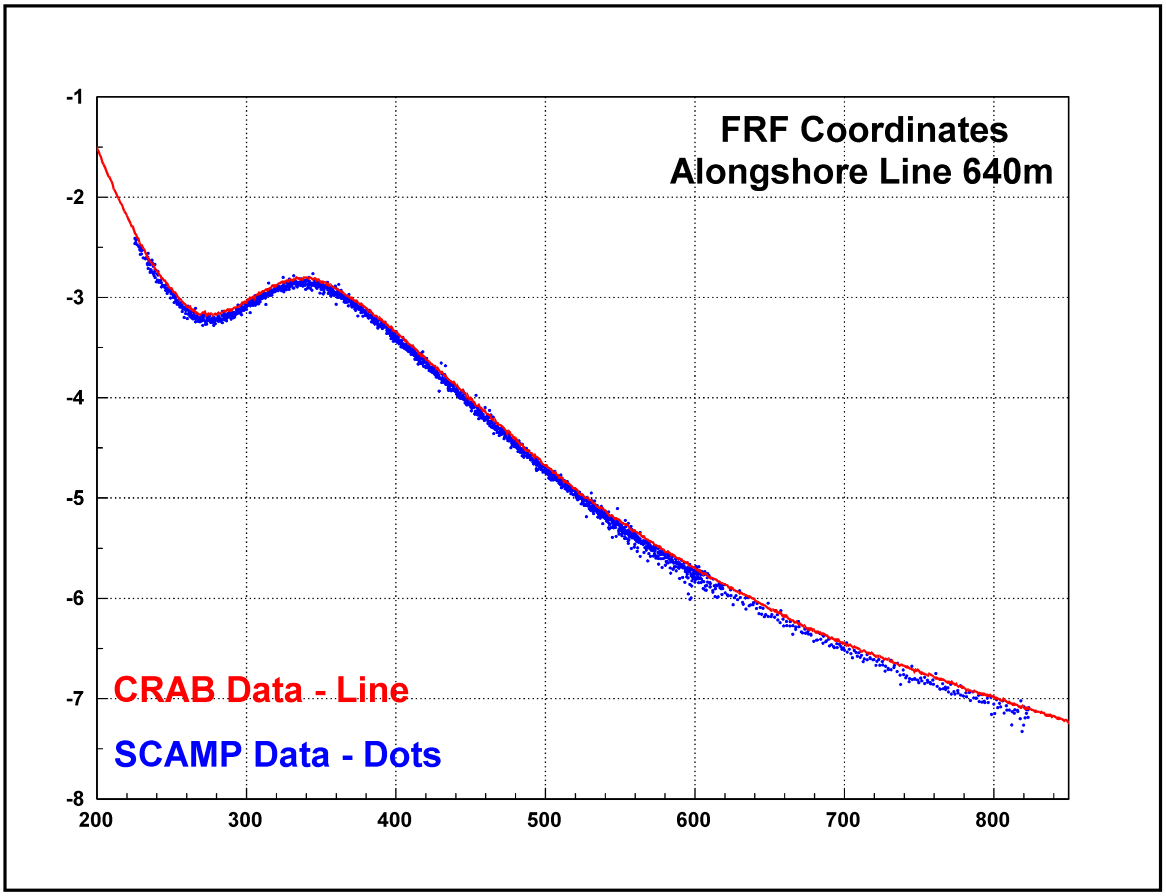

Figure 17: Profiles from an informal survey comparison between SCAMP (blue) and USACE CRAB in 1997. The comparison showed 5 cm rms error. SCAMP system included older version of HYPACK® acquisition software that did not exhibit the timing problems noted in this demonstration.