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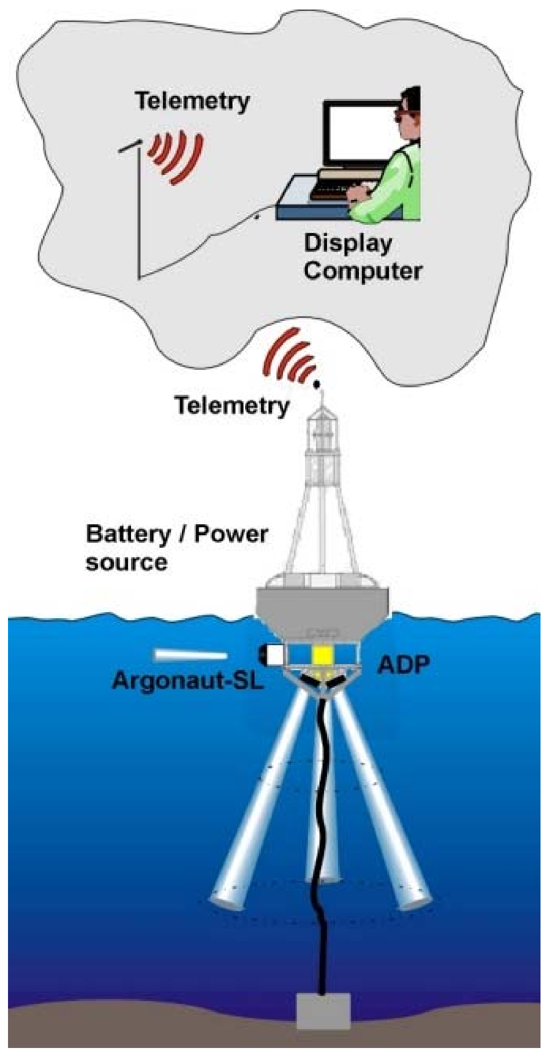
Bosphorus Straits Vessel Traffic Management Information System

July 2002 – A massive Vessel Traffic Management Information System (VTMIS) combines several SonTek and Endeco systems into real-time data collection platforms. These platforms are installed in the high-profile Bosphorus Straits, Turkey, where high current speeds prevail and operational efficiency is paramount.

Each of the 15 data collection platforms (below) integrates a down-looking 0.5-MHz Acoustic Doppler Profiler (ADP) mounted on the base, and an Argonaut-SL acoustic Doppler current meter mounted horizontally on the side of a fully self-powered EMM2000 buoy. A solar panel recharges the onboard battery pack, so the system can remain operational indefinitely. Real-time data from the buoys is transmitted in a single collected-data stream to the VTMIS by telemetry.

Based on the reported water current velocities from the buoys, the vessel traffic controller and oil tanker pilots can make informed decisions as to the safest and most efficient course of action and navigational path.



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Waste Water Study: Deep-Water Current Profiling by LACSD

July 2002 – The Los Angeles County Sanitation Districts (LACSD) began a study of water currents and vertical temperature stratification over the Palos Verdes shelf in October 2000. The purpose of the study was to gain long-term information on the normal patterns, seasonal variability, and short duration variability in currents and temperature in the vicinity of the LACSD's ocean outfalls.

LACSD continuously evaluates cost-effective and environmentally sound methods for wastewater conveyance, treatment, and reclamation/disposal. The extensive data set being produced from this study is expected to support ongoing and future efforts to optimize the discharge of treated wastewater from the LACSD's largest treatment plant, the Joint Water Pollution Control Plant.

LACSD currently has 13 sites off the Palos Verdes/San Pedro shelf, all with SonTek 0.5-MHz ADPs with a Janus, 4-transducer design. Each ADP has an external, 3-battery pack canister, and a special integrated-pinger option that outputs the operational status of the system. This feature permits the status of the system to be determined without recovery - especially when there is no immediate need to service the system.

\\hulk\market\WebSite\active\apps\deepwtr\adplacsd\lacsd-2.jpgThe inshore sites are located in 35 m of water; the offshore sites are in 65 m. All the arrays are sampling for a 3-minute average, every 15 minutes. The arrays are serviced every three months, but have gone for as long as 5+ months without any loss of data.

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RiverCat Discharge Measurements in Hell's Canyon

June 2001 – Adventurous personnel from Idaho Power Company and SonTek/YSI braved class IV rapids to make RiverCat discharge measurements using a kayak on the Snake River at the Johnson Bar gauging station. This station is about 18 miles downstream of Idaho Power Company's Hell's Canyon Hydroelectric Dam.

SonTek/YSI hydrologist John Sloat (bow) and Idaho Power Company engineer Pete Vidmar (helm) shoot Granite Rapids on the way to the measurement site at Johnson Bar on the Snake River in Hell's Canyon.

The Johnson Bar gauging station is designated by the Federal Energy Regulatory Commission (FERC) as a minimum flow and ramp rate compliance site. Idaho Power Company has recently assumed operation of this gauging station in a continued effort that began in 1996 to reduce costs. Idaho Power Company currently maintains a network of over 20 of their own gauging stations, including nine on the main stem of the Snake River. They have also been involved in the installation and maintenance of additional gauges for other organizations in a revenue generating effort since 1998.

On-shore technicians Stan Pierce and Jim Hulme observe telemetered data from the RiverCat using the RiverSurveyor data collection software program at Johnson Bar on the Snake River.

Historically, attempts to develop stage-discharge rating curves for the Johnson Bar site required massive efforts just to get metering equipment to the site and set up for data collection. Even though provisional ratings at Johnson Bar had been developed, compliance monitoring for minimum flow downstream of the dam has been reported using data from the Snake River below the Hell's Canyon Dam gauging station, which is about one-half mile downstream of the dam.

As part of a strategic effort to improve the existing stage-discharge rating at Johnson Bar, Idaho Power Company had the creative idea to use a SonTek/YSI RiverCat attached to a hard-shell kayak, which is then paddled across the river to get quick and accurate discharge measurements. This simple idea was effective, and the results of the measurements were excellent. This design also eliminated the need to navigate high-powered jet boats to the site just for the purpose of transecting a profiler across the river.

Idaho Power Company's RiverCat/kayak setup on the Snake River

Pete Vidmar (Idaho Power Company) paddles the RiverCat across Snake River

Measurements were collected over a two-day period at flow rates between 7,500 and 13,000 cfs with surface velocity often exceeding 9 ft/s. Each measurement took less than five minutes, minimizing the effect of possible flow fluctuations. The RiverCat proved itself once again as a useful tool for measuring discharge even at the most challenging and dynamic sites.

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ADP Velocity-Index Discharge Measurements in Everglades

SonTek/YSI Acoustic Doppler Profilers (ADPs) are being used to continuously measure discharge in three low-velocity tidal tributaries along the southwestern boundary of Everglades National Park (Florida, USA). The tributaries meander through red mangrove forests and swamps, and discharge freshwater into the Gulf of Mexico. The tributaries also experience variable backwater conditions and flow reversals twice per day.

Each ADP is mounted looking up from the streambed in the center of the channel. The photo below (courtesy of the U.S. Geological Survey) shows the ADP in its mount, along with the power/communication cable. Water depths at the measurement sites range from about 6 to 12 feet (2 to 4 m), and channel widths range from 250 to 450 feet (75 to 135 m). A communication cable runs along the streambed from the ADP to a datalogger housed in an equipment shelter on the nearby shoreline. A 12-volt battery and solar panel supply power to the ADP.

Discharge at each site is computed by first developing a relation between the mean velocity in the river (collected from discrete discharge measurements) to corresponding velocity measurements by the ADP; this technique is commonly known as "velocity-indexing”. Second, a relation between water level and cross-sectional area is developed. The ADP velocity data are then used with water level data to compute continuous discharge at each site.

The results of this application show that using the ADP as a velocity-indexing instrument can help provide accurate and reliable discharge data in rivers and streams that historically have been too difficult to measure because of low-velocity tidal conditions, flow reversals, bi-directional flow, or backwater conditions.

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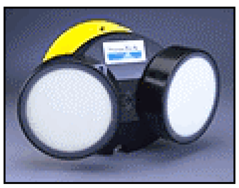
Current Monitoring at Shinnecock Inlet on Long Island, New York

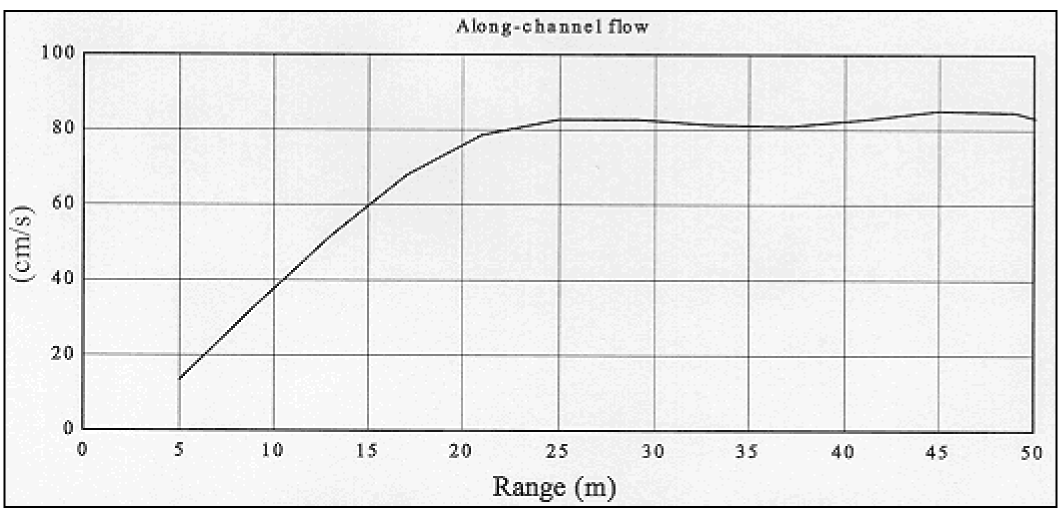
A 0.5-MHz Side-Looking Acoustic Doppler Profiler (ADP) is presently monitoring currents at Shinnecock Inlet on Long Island in New York. The project features an array of SonTek instruments, and is a cooperative partnership of the U.S. Army Corps of Engineers, the State of New York, SUNY Stony Brook, and Offshore and Coastal Technologies, Inc.

The ADP is mounted off the east jetty, and was chosen for this job to profile currents into the channel and determine the predominant flow patterns.



The large-diameter transducers in SonTek ADPs produce extremely narrow beams, offering distinct range advantages for horizontal profiling. Additionally, the use of a transducer shading technique minimizes side lobe interference, further increasing the maximum horizontal range of the system.

The graph below shows the actual performance of the side-looking ADP. Note that when the instrument was deployed 1.2 m below the surface, it was able to accurately measure currents out to 50 m. This represents a phenomenal aspect ratio of over 40 (i.e., the SL-ADP achieved a horizontal range that was at least 40 times its distance to the nearer boundary). This suggests that placing the ADP at a depth of just 2-3 m may allow a 0.5-MHz side-looking ADP to achieve its full profiling range of 70 to 110 m.



This graph shows the actual performance of the side-looking ADP at Shinnecock Inlet, New York. Note that the main along-channel flow was reached at a distance of about 20 m from the ADP. What is astonishing here is that the ADP was submerged just 1.2 m below the surface and was able to accurately measure current data out to 50 m!

Live data from the Shinnecock Inlet project can be viewed at
http://www.lishore.org/shinnecock/latest.htm.

In addition to the side-looking ADP, the Shinnecock Inlet Field Monitoring Project is also using the following SonTek systems for the listed purpose. The locations of these systems can be found at http://www.offshorecoastal.com/GaugeDescript.htm.

SonTek/YSI Systems at Shinnecock Inlet

System	Purpose
ADVOcean	Monitor tidal currents and incident waves
ADVOcean	Monitor longshore current and nearshore waves
Argonaut-MD	Monitor ocean water level
Argonaut-SL	Monitor horizontal (2D) inlet current
Argonaut-SL	Monitor horizontal (2D) current in channel
Argonaut-SL	Monitor horizontal (2D) current in canal

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Using an ADP from a Moving Boat

1. Introduction

When performing water-current surveys covering large areas, or when monitoring river discharge, it is often convenient to use a boat-mounted SonTek/YSI Acoustic Doppler Profiler (ADP). When operating from a moving platform, an ADP measures relative currents (Figure 1). As such, it is important to measure the speed of the platform independently so it can be subtracted from the raw current measurements. This allows you to obtain the residual water currents relative to the fixed Earth. It is generally desirable to perform these calculations in real-time.

Though there are a several ways to measure a vessel's speed and direction, the two most-practical methods commonly used with ADPs are:

- The use of GPS equipment
- The use of the SonTek ***bottom-tracking algorithm***

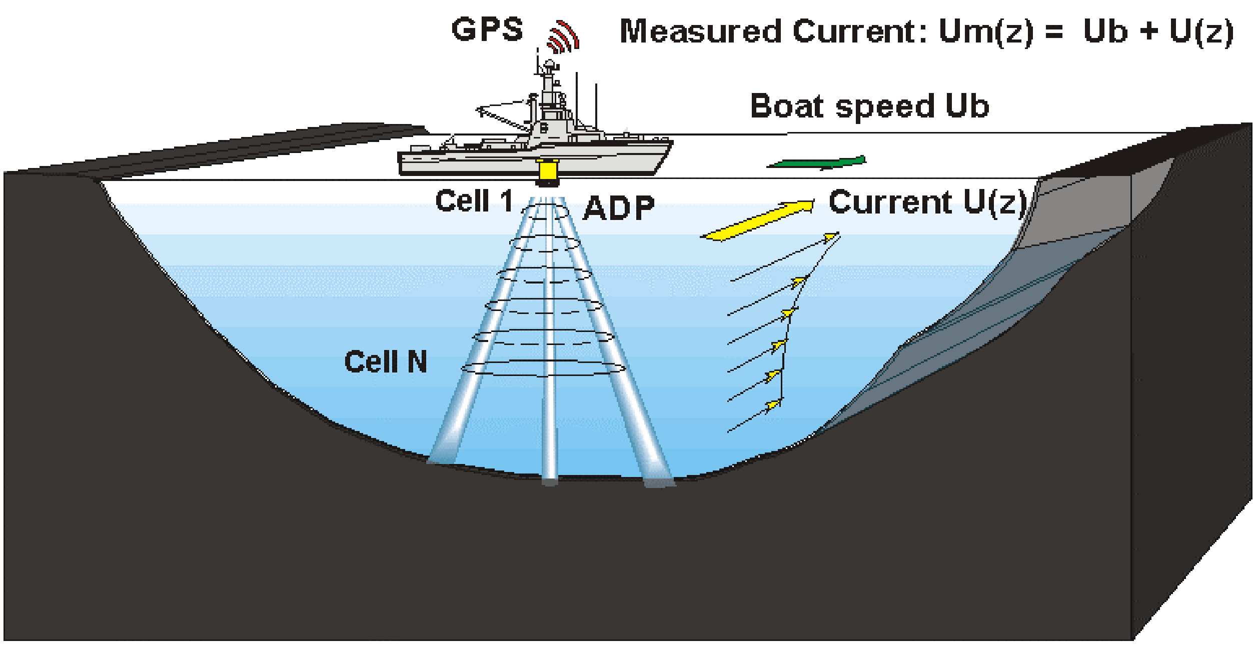


Figure 1. Measuring currents from a moving boat using an ADP

2. Using an ADP with GPS

The majority of vessels used for research have GPS systems as part of their navigation equipment. SonTek ADPs manufactured since 1996 have a built-in interface to receive GPS information, and are able to accept the NMEA 0183 data formats (GPGGA/GPGXP/GPGGK) available from most commercial GPS receivers. A good-quality GPS receiver with accurate differential corrections is recommended for robust real-time operations. The GPS-to-ADP interface requires two serial ports (one for the ADP and one for the GPS) on the PC running SonTek's real-time ADP software. The synchronization of data is done in the PC (Figure 2).

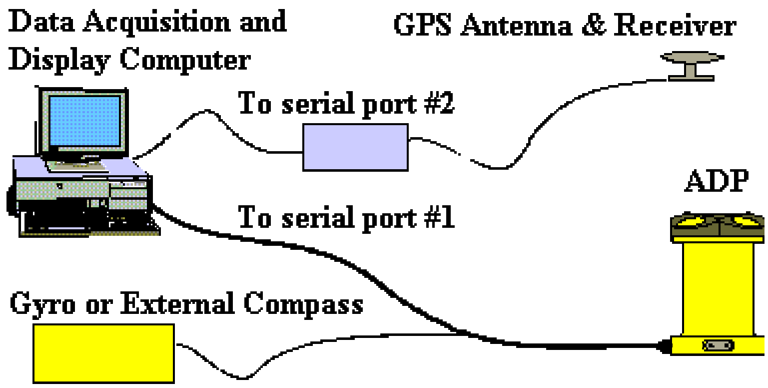


Figure 2. Operating ADP from a boat: connecting necessary equipment

To compute the vessel's velocity vector, the ADP records GPS positions at the beginning and end of a user-selected averaging interval. The resulting boat velocity is then computed from the total vessel displacement and is subtracted from the relative water currents measured by the ADP. The GPS method for removal of the boat track from ADP measurements is best suited for areas where the bottom is out of ADP tracking range or where currents change slowly in time/space so that longer averaging intervals can be used.

3. SonTek Bottom-Tracking Algorithm

Using the ADP's bottom-tracking algorithm greatly enhances the ADP's capabilities and versatility when used from a moving boat in shallow water. Bottom-tracking enables you to obtain real-time vessel-speed-over-ground data simultaneously with water current measurements without using any additional equipment. While bottom-tracking, the ADP measures the Doppler shift of reflected acoustic energy (from the bottom of a river, harbor, etc.) to infer the vessel speed. In contrast, when an ADP is current-profiling, it is measuring acoustic reflections from suspended material in the water column to determine the velocity of the water with respect to the ADP. In bottom-tracking mode, the ADP determines bottom velocity once every second. At the end of the averaging interval, all the bottom-velocity estimates are averaged and stored with the profile data. In addition to the vessel-speed-over-ground data, the bottom-tracking ADP reports an averaged depth in real-time, which is often required for surveys or river discharge applications.

The ADP can only track the bottom when it is within the acoustic range of the ADP’s transducers. Generally, it is good practice to understand the bottom characteristics of the area being surveyed, as some soft bottoms with large amounts of plant growth can imitate "moving-bottom" characteristics that might influence the ADP's bottom-track algorithm. Seabeds with strong acoustic reflections (rocky bottoms provide the best results) can typically be tracked at ranges that are 20-30% greater than the water-current profiling range.

When operating from a moving platform such as a boat, erratic course changes during the averaging interval may yield erroneous vessel velocity vectors. Therefore, when using ADP with GPS or bottom-track, you should take into consideration the vessel's proposed track-line when choosing the averaging interval. The best results will be obtained when steering a vessel in a straight line at a steady speed.

4. GPS vs. Bottom-Tracking

4.1. Performance Comparison

What are the advantages of bottom-tracking over GPS (and vice versa), and what factors affect the inherent accuracy of both approaches? The purpose of both bottom-tracking and GPS is to calculate vessel speed in order to correct the relative water currents measured by the ADP. Therefore, the accuracy of the technique used for vessel speed estimation directly determines the accuracy of the absolute current-velocity profile.

Consider the pros and cons of the GPS approach. Regular GPS is accurate to within ≈100 m, which would require extremely long averaging times (≈2.5 h) to achieve a 1 cm/s accuracy. Such measurements are useful only in the open ocean. Differential GPS (DGPS) receivers are capable of providing higher positioning accuracy -- 2-m in the open ocean or even better when in the vicinity of the reference station on land.

Even the most advanced DGPS systems determine vessel position with some uncertainty σ_R, which introduces an error σ_v into speed calculations, where Δt is the time between successive GPS fixes (averaging interval):

$$\sigma_V = \sqrt{2}\frac{\sigma_R}{\Delta t}$$

If the positioning data has an uncertainty of ±2 m, and an averaging interval of 60 seconds is chosen, the uncertainty of the vessel speed for each profile is about ±4.7 cm/s. This uncertainty puts a lower limit on the accuracy of the absolute current measurements. If a current-profiling precision of 1 cm/s is needed, the use of the GPS would require longer averaging intervals and thus limit the time resolution of profiling surveys. Although this may not pose a problem in the open ocean (where currents usually do not change over several minutes), coastal, frontal, and convergent areas require shorter averages. Sub-meter accuracy can be achieved by the latest DGPS systems, however it is usually limited to operations close to a reference station (≈100 km), and is not available for remote inland or coastal areas. Also, operating in deep canyons or in mountainous area can cause "shadow”, where the direct path to a GPS satellite is obscured.

If DGPS mode is not available during the deployment, adjustments can be done in post-processing. ADP software stores the raw GPS positions used for the vessel speed calculations, and differential corrections can be downloaded later from appropriate sources. These corrected positions can be used to obtain more accurate estimates of the vessel speed, and hence, the true water currents.

Now let us consider the performance of the bottom-tracking algorithm. As mentioned above, a bottom-tracking ADP determines the bottom velocity once each second, and then averages the raw estimates over the user-selected averaging interval. Because the bottom velocity is derived from solid-object reflections, natural variability (standard deviation) of the bottom-track velocity measurements is lower by an order of magnitude when compared to the current-profiling data. Hence, the precision of bottom-velocity measurements is always better than that of water currents. Because of this, bottom-tracking can be considered to introduce no additional errors to water current measurements.

A basic limitation of bottom-tracking is that it can operate in waters with depth no more than approximately (1.3 × Maximum ADP Profiling Range). In addition, significant plant growth, heavy wave conditions, and a moving near-bottom layer can degrade bottom-track performance.

4.2. Compass Alignment

An important consideration when operating from a moving platform is the accuracy and alignment of the compass used for obtaining vessel speed and the ADP compass. With GPS, the ship's gyro is normally provides vessel direction. If a small offset exists between the gyro and the ADP, an error proportional to the ***speed of the vessel*** is introduced. For a 5° offset, a vessel moving at 2.5 m/s will introduce a 22 cm/s velocity component into ADP measurements.

With bottom-tracking, compass offset will still produce an error in water-current measurements, but this error is proportional to the ***speed of the current***. In most applications, water-current velocities are much smaller than vessel speed, so the errors introduced are smaller. For the same 5° offset used above for GPS, and a current speed of 0.5 m/s, the error is only 4 cm/s.

4.3. Using GPS while Bottom-Tracking with an ADP

To avoid compass misalignment errors, the most robust solution is to use bottom-track data together with GPS data. At the start of the transect, you can simply compare the ship's direction derived from bottom-tracking with the gyro output, and then correct for possible misalignment.

The ADP can record GPS data while simultaneously bottom-tracking. This not only provides a check between the two methods, but it allows the use of GPS when the bottom is out of range. The advantages of both methods can be used, and the ADP software works with both data sets. If both the GPS and bottom-track velocities are collected, you can extract water currents relative to either bottom track or to GPS simply by using the software provided with the ADP.

5. Field Test of Bottom-Track Performance vs. GPS

Test data were collected in Mission Bay, San Diego with a 0.25-MHz ADP in January 1999 (Figure 3). Bottom depth ranged from 80 m at the beginning to less than 10 m at the end of the transect. Ocean swell was less than 0.5 m, and pitch and roll varied within 6°. Although transecting over a bottom of different composition and slope, 99% of the profiles produced percent-good pings greater than 80 (percent-good pings are that portion of the bottom-tracking pings within the averaging interval when the bottom velocity was measured successfully). This confirms the robustness of the SonTek bottom-tracking algorithms. Overall, test results demonstrate a one-percent or better agreement between the GPS and the bottom-track estimates.

The capability of using an ADP from a moving platform greatly extends the versatility of this instrument. Whether you use DGPS, bottom-tracking, or both, you can be assured that the SonTek ADP maintains high standards for quality, value, and reliability.

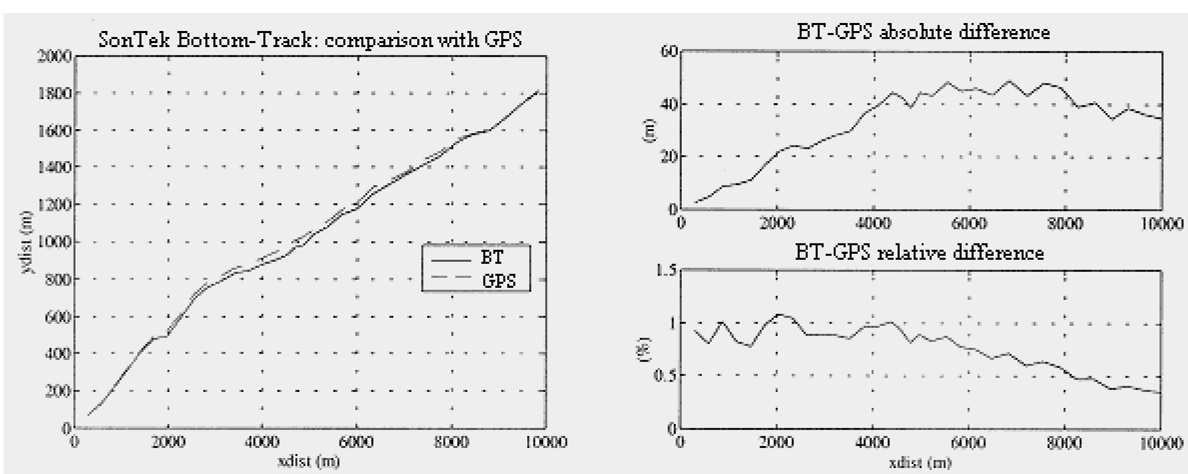


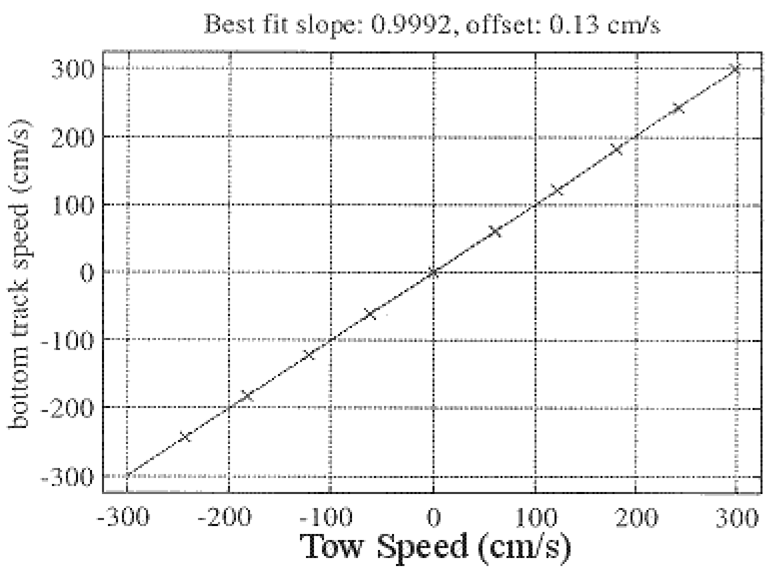
Figure 3. Field test of bottom-track vs. GPS

6. Results of Bottom-Tracking Test at Offshore Model Basin

Bottom-tracking accuracy of a SonTek Doppler system was tested at the Offshore Model Basin in Escondido, California in December 1999. This facility features a computer-controlled carriage that can move along the basin at speeds up to 5.5 m/s.

The SonTek Doppler instrument was installed in the middle of the carriage with its head submerged about 0.3 m into the water. Two independent runs were conducted at 11 speeds ranging from -3 m/s to 3 m/s. The results of the test are shown below. A least-squares linear fit of the velocity data to the carriage speed gives a slope of 0.9992 with a reported offset of 0.13 cm/s.

The results from this test indicate a bottom-tracking accuracy of 0.08 percent, which is well within our product specification of 0.2 percent.



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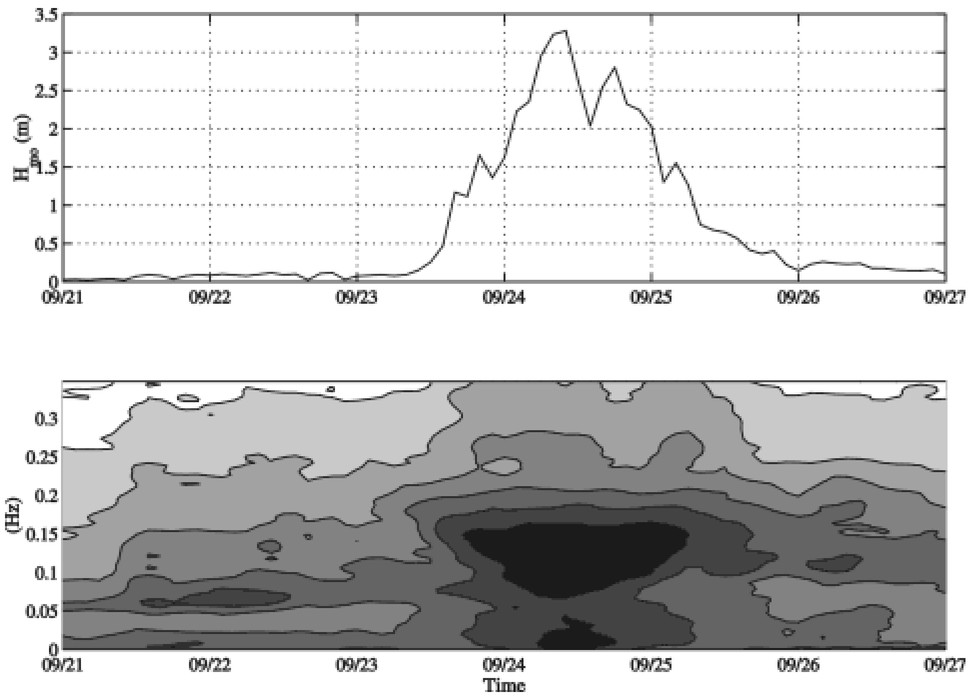
Hurricane Wave Data Collected with an ADP

September 1998 – A Florida engineering firm deployed a 1.5-MHz SonTek Acoustic Doppler Profiler (ADP), equipped with a pressure sensor and our SonWave wave spectra software package, in 25 meters of water off the Southeast Florida coast. The ADP collected ocean-current profile data and wave data during Hurricane Georges. In the graphs below, the preliminary analysis of the wave data during the passing of Georges over the experiment site shows a rapid increase in the wave energy, with significant wave height H_{mo} in excess of 3 meters.



Wave data collected during Hurricane Georges (September 1998)

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Bottom-Tracking ADP used in Poverty Bay Circulation Current Study

A SonTek bottom-tracking Acoustic Doppler Profiler (ADP) was successfully used by the Centre of Excellence in Coastal Oceanography and Marine Geology at the University of Waikato in New Zealand. The ADP was the focus of measurements of complex circulation in highly stratified Poverty Bay on the east coast of the North Island where a sewage outfall was being studied.

Researchers Scott Stephens and Kerry Black used the ADP to record a complex pattern of rotating currents in depths of 10-15 meters over several days and confirmed predictions of a numerical hydrodynamic model of the region. In particular, the ADP confirmed the model predictions of a residual anticlockwise circulation in the bay (Figures 1 and 2). A strong wind-driven influence on surface currents was also measured including an associated up-welling bottom-return-flow when winds exceeded about 4 ms^{-1} (Figure 3).

The ADP was mounted on a small vessel (5.7 m) and operated under conditions that often included small chop on the water; however, the results were very satisfactory, particularly in shallow water where a strong bottom-return signal was obtained using the 1.5-MHz ADP.

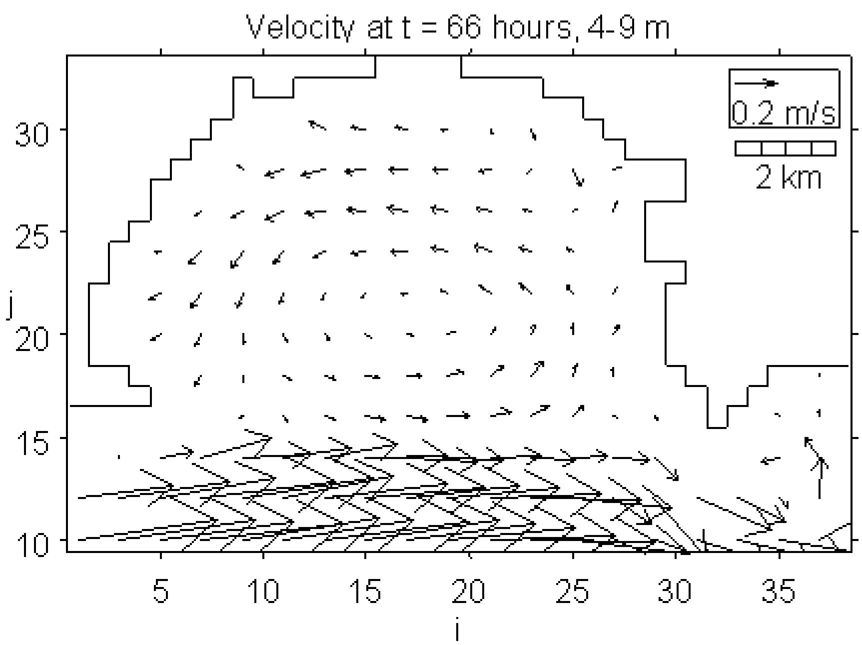

Figure 1. Numerical model velocity predictions in model layer three (4-9 m) revealing an anticlockwise circulation in response to a northeast shelf current.

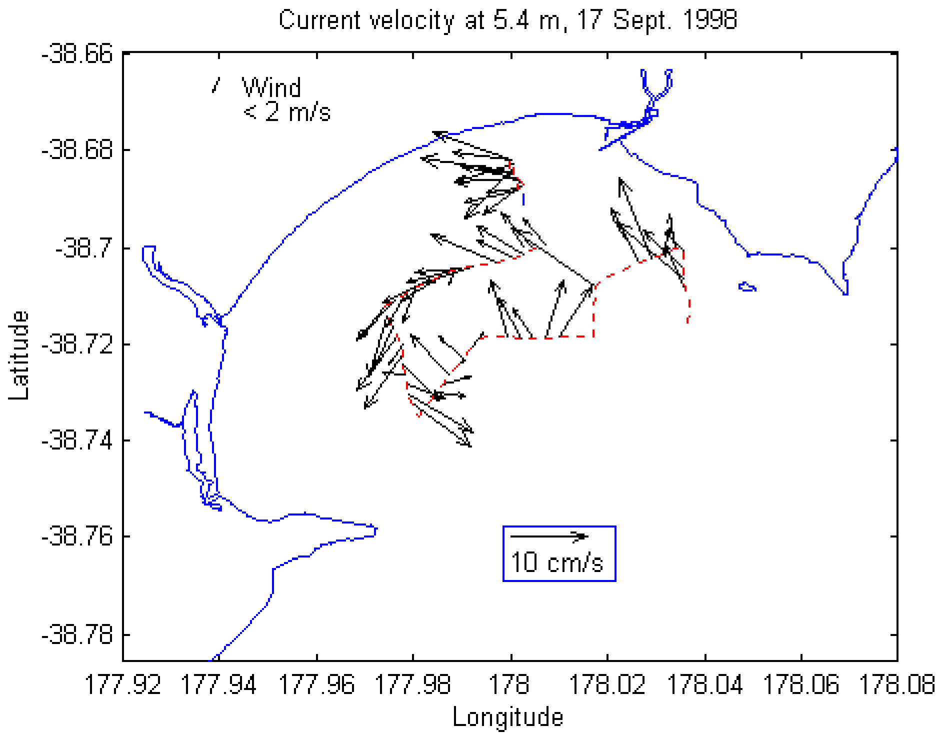

Figure 2. Currents at a depth of 5.5 m in Poverty Bay on 17 September 1998, 12:22-14:49, measured by boat-mounted, bottom-tracking ADP. Wind measured at Gisborne Aerodrome is 1 ms^{-1} from 20°.

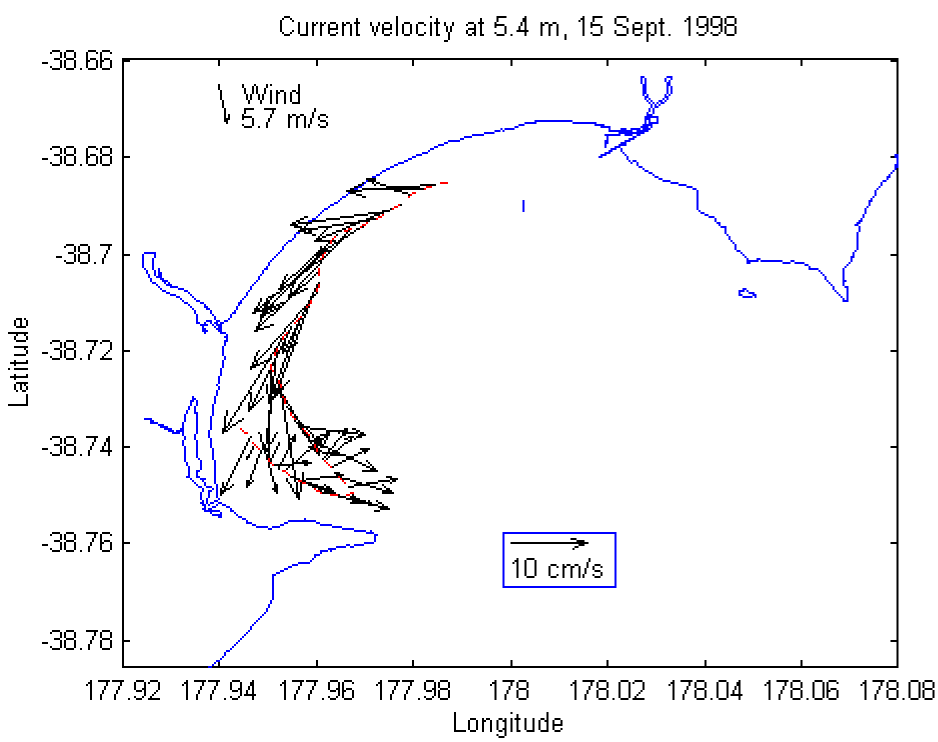

Figure 3. Currents at a depth of 5.4 m in Poverty Bay on 15 September 1998, 14:08-15:54, measured by boat-mounted ADP. A strong (6 ms^{-1}) offshore wind is including an associated bottom-return-flow.

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Sediment Transport on Columbia River

SonTek Acoustic Doppler Profiler (ADP) and Acoustic Doppler Velocimeter (ADV) integrated Hydra systems were deployed near the mouth of the Columbia River from August 18 through October 21, 1997 by researchers from the U.S. Army Corps of Engineers (USGS) Waterways Experiment Station (WES) and Oregon State University (OSU). The experiment was designed to measure movement of dredged material disposed off the mouth of the Columbia River. The data gathered are to be used for improvement of numerical model predictions of sediment transport.

Three tripods were deployed at different locations, each equipped with a Hydra and an ADP. All of the Hydras were outfitted with two optical backscatter sensors and a piezoelectric crystal pressure sensor. The ADPs incorporated a conductivity cell. WES investigators required simultaneous time stamping for the measurements made in the bottom boundary layer, and the Hydra was the SonTek solution.

Excellent data were retrieved from this deployment, and a few selected examples appear below. The velocity time series from the Hydra provide a means of estimating turbulence spectra, which are consistent with model predictions (Figure 1).

Combining measured orbital velocity with the pressure record allows calculation of a directional wave spectrum, at one point revealing dominant 11-s waves propagating from the North-East (Figure 2). Temperature and salinity show significant variability and reveal sharp fronts (Figure 3).

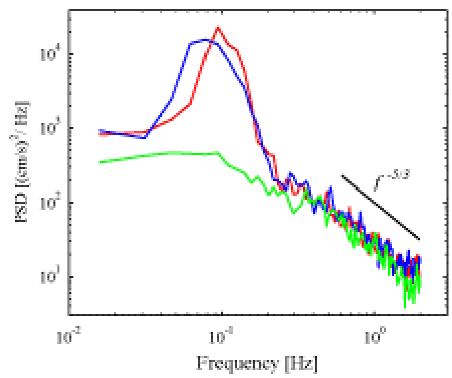

Figure 1. Turbulence Spectra

The optical backscatter sensor provides insight on the distribution of suspended sediments. Acoustical and optical methods give generally similar results (Figure 4), though with some variation due to the inherent differences between the two methods.

These examples provide a good first look at the capabilities of the Hydra package. We are certain that additional exciting data will follow as more deployments are taking place at the Columbia River and other sites. On April 5, 1998, WES and OSU deployed another four Hydra and ADP-equipped tripods off the mouth of the Columbia River to continue monitoring dredged-material disposal sites in the presence of the spring discharge plume from the river.

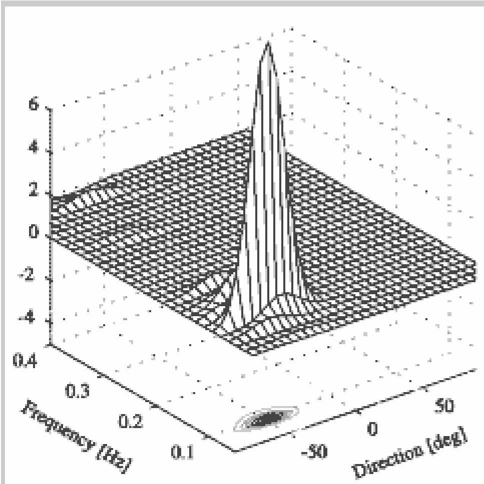

Figure 2. Directional Wave Spectrum

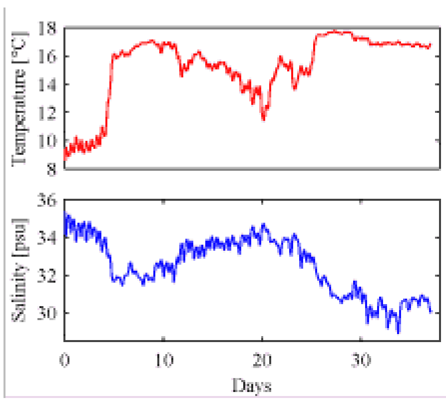

Figure 3. Temperature / Salinity

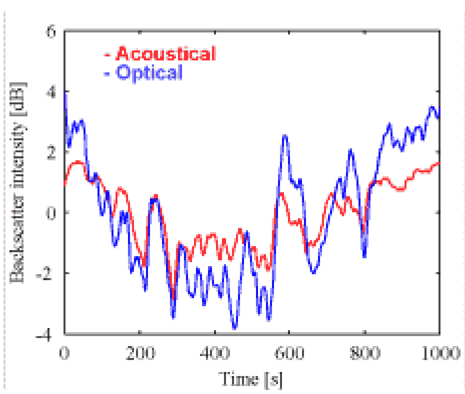

Figure 4. Sediment Distribution

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ADP Versatility in San Felipe, Mexico Deployment

Introduction

This report presents data from the deployment of a SonTek Acoustic Doppler Profiler (ADP) in the Gulf of California near San Felipe, Mexico on April 4 and 5, 1996. The instrument was deployed from a small boat working with the R/V Francisco Ulloa, operated by CICESE (Centro de Investigacion Cientifica y de Educacion Superior de Ensenada) in Ensenada, Mexico. The scientist coordinating the deployment of the ADP was Luis Gustavo Alvarez from CICESE; Craig Huhta and Matt Curry from SonTek were present to oversee instrument operation and assist in deployment and recovery. This data report is divided into the following sections.

- Deployment Location and Configuration – A description of the ADP, instrument configuration, deployment location, and data collection parameters.
- Tidal Elevation - ADP surface level measurements used to estimate tidal elevation.
- Water Currents - ADP velocity data including mean current speed and direction, contour plots showing temporal and spatial variation, and current change at slack water.
- Near Surface Velocity Measurements - A detailed look at the ability of the ADP to make measurements near the boundary.
- Signal Strength - Signal strength data from the ADP and its relation to suspended sediment.

Deployment Location and Configuration

A 1.5-MHz ADP was deployed for 16 hours starting at 2:40 p.m. (Mountain Standard Time) on April 4, 1996. The deployment site was at 31° 07.88’ N, 114° 40.96’ W, approximately 16 km northeast of San Felipe, Mexico. Water depth at high tide was about 18.5 m; tidal variation during the deployment was more than 5 m. Figure 1 is a map of the area and the deployment site.

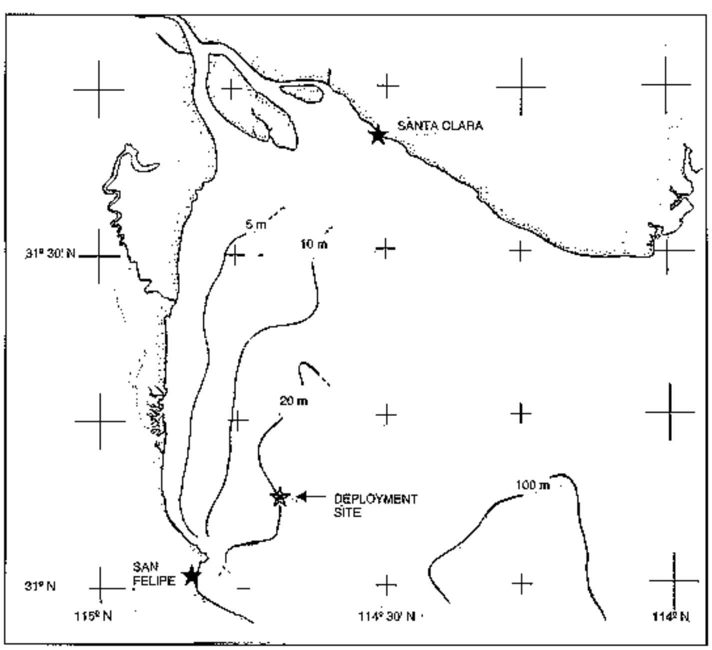

Figure 1. San Felipe ADP Deployment Location

The ADP included a 20-MB internal recorder, compass/2-axis tilt sensor, temperature sensor, and pressure sensor. The recorder was used as a memory buffer; data were collected on a portable computer using the ADP real-time data acquisition software. The compass/tilt sensor allowed the ADP to report velocity data in earth coordinates (East-North-Up) regardless of ADP orientation. The temperature sensor was used for sound speed corrections (handled automatically by the ADP); the pressure sensor was used to estimate deployment depth and tidal variations.

Figure 2 shows the deployment configuration. The ADP was mounted on a small platform using lead shot as ballast. The frame was deployed on the bottom with the instrument looking upwards. A small vessel was secured nearby using a 3-point anchor; a multi-conductor cable from the vessel to the instrument supplied power to the ADP and real-time communication. The primary deployment and recovery cable was attached to a surface float located 30-40 m away; a secondary (safety) recovery line was run to the monitoring vessel.

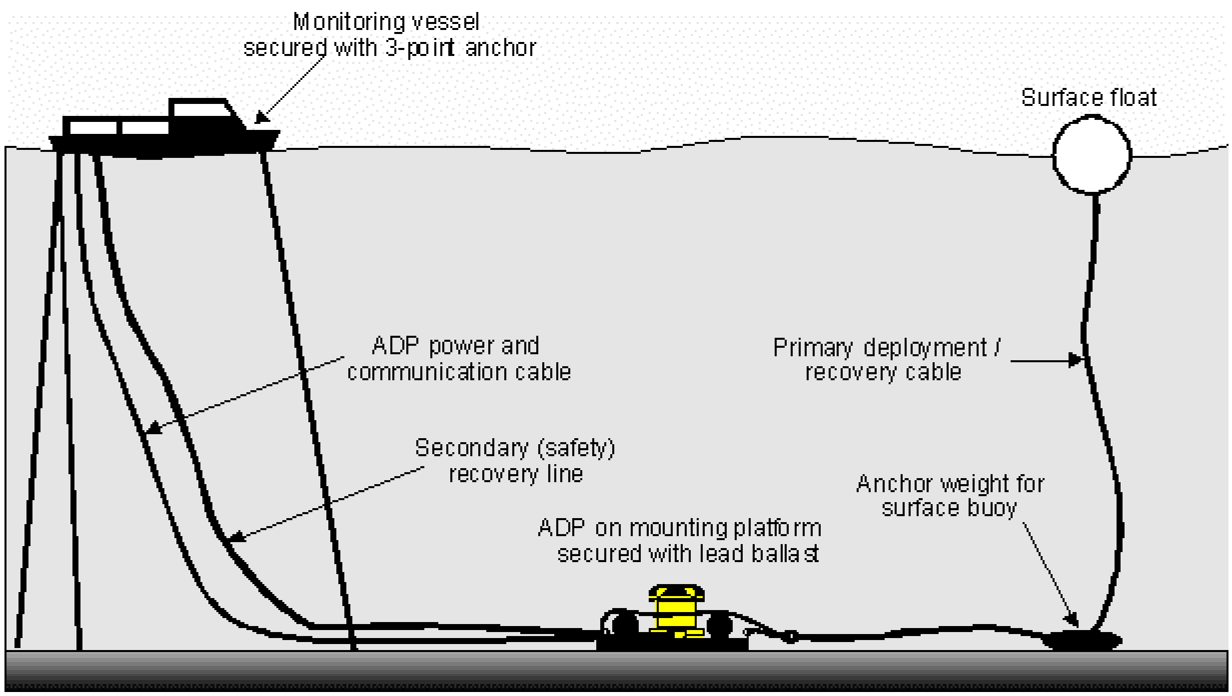

Figure 2. ADP Deployment Configuration

Power came from a marine battery with an inverter that supplied 110 VAC. The battery was changed after 15 hours; a data gap of about 4 minutes occurred during the change. The deployment site was chosen to match previous measurements in this area and to provide a water depth maximizing the effectiveness of the ADP. With a maximum water depth about 18 m, the ADP measured the entire velocity profile with a vertical resolution of 0.5 m. The ADP recorded 50 cells per profile, using a 0.5-m cell size, ensuring that the recorded profile included the entire water column and surface reflection. The ADP recorded the mean velocity profile every 5 minutes. Velocity data were recorded in earth coordinates (East-North-Up, relative to magnetic north); at this location, magnetic north is 11° 46’ east of true north.

Tidal Elevation

The ADP used for this deployment has two ways to estimate distance to the surface, and hence total water depth. The first method is the optional pressure sensor installed in the ADP. While not intended for precise tidal measurements, the pressure sensor provided excellent resolution of the large tidal variations in this deployment. The second method to estimate surface elevation uses the profile of return signal strength. Figure 3 shows sample plots of ADP signal strength versus range. In this plot, the x-axis gives range from the transducers (in m) and the y-axis gives return signal strength (in internal units called counts).

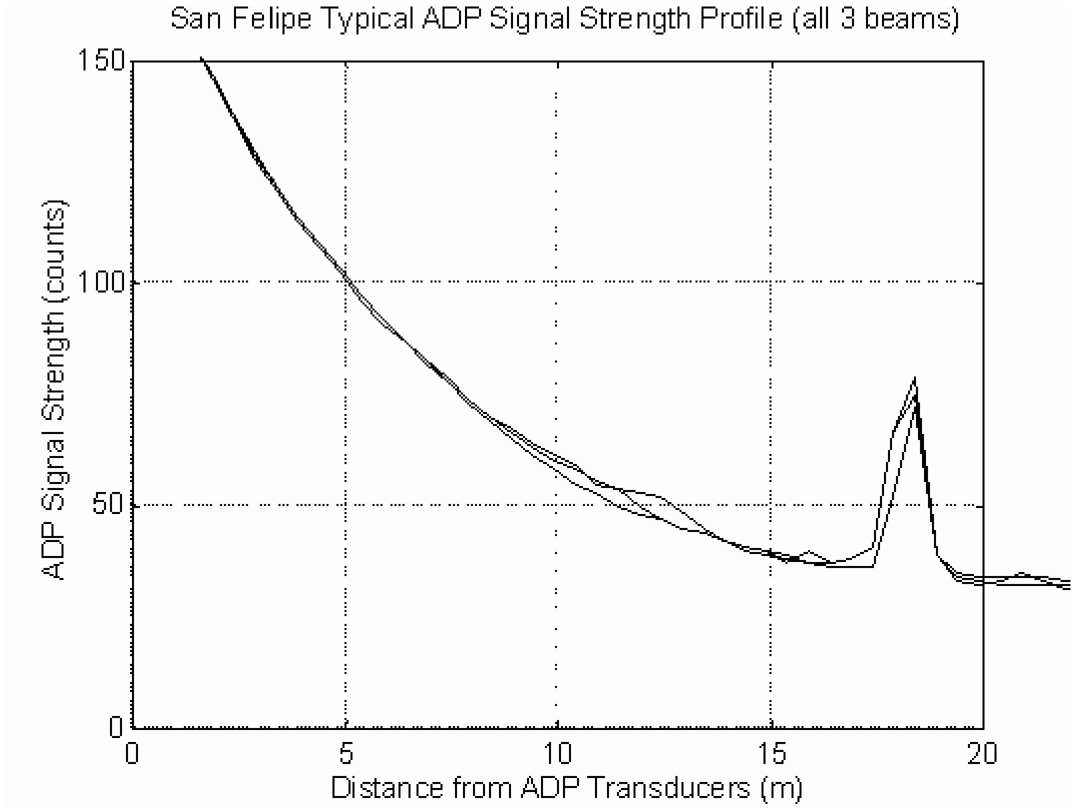

Figure 3. Measuring Surface Range using the ADP Signal Strength Profile

Range to the surface is estimated from the location of the spike in signal strength data associated with the reflection of the acoustic pulse from the surface. For the profile shown in Figure 3, this peak occurs in a cell whose center is located 18.4 m from the ADP transducers. Since the transducers are 0.3 m off the bottom, this gives an estimated water depth for this profile of 18.7 m; the corresponding estimate from the pressure sensor was 18.2 m.

Figure 4 compares estimates of surface elevation from the pressure sensor and signal strength over the entire deployment. Data collection began just after high tide, continued through the next low and high tides, and ended just before the following low tide. The minimum water depth is estimated at 13 m; maximum depth is about 18.5 m. Data from the pressure sensor and signal strength showed very consistent results, with a mean offset of about 0.2 m (the pressure data consistently estimate lower water depth than signal strength). The expected accuracy of the pressure sensor is ±0.5 dBar (equals ±0.5 m), while the accuracy of the signal strength is equal to the cell size (0.5 m).

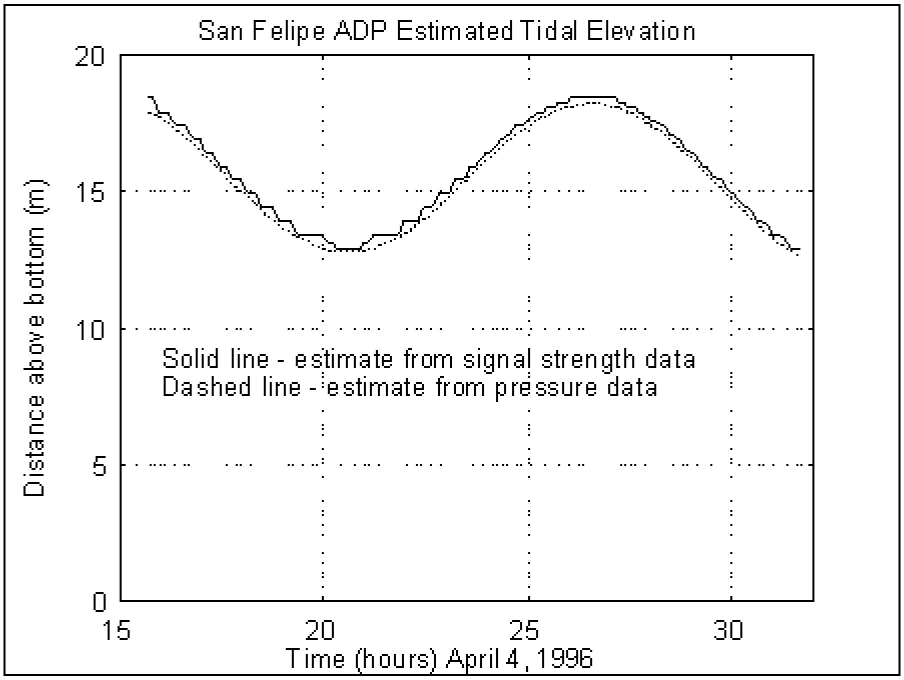

Figure 4. Estimated Tidal Elevation

Water Currents

The primary interest in ADP data is the measurement of water velocity. This section shows several different presentations of velocity data to illustrate the information contained in the ADP data and to highlight interesting features in this data set.

The deployment covered two periods of maximum ebb and one of maximum flood current. Current speeds near the surface reached a maximum of 75 cm/s; mean currents over the entire water column reached 60 cm/s at maximum flow. Figures 5 and 6 show plots of the mean current speed and direction over the course of the deployment. The mean velocity values are taken as all cells in the profile to within about 1 m of the surface (see next section for a discussion of near surface data). The center of the first cell is located 1.2 m above the bottom; the last good cell is specified such that its center is at least 1 m below the surface level estimated by the ADP pressure sensor.

Flood current is positive; ebb is negative. Ebb current showed a direction estimated as 133°, while flood current showed a direction of 315°. There was no variation of current direction over the entire water column, nor was there any significant variation in flow direction during ebb or flood. See the vector plots later in this section for details about the current change at slack water.

Figure 7 is a color contour plot of current speed versus time and depth. This presents the temporal and spatial variations in water speed over the entire deployment. The color shown at each depth cell and each time indicates current speed by the scale on the right side of the plot. No editing was done to the current data for this plot; the values were filtered using a 1-cell, 4-point linear interpolation to improve the color presentation. (The value shown at each cell is an average including data from the same profile in adjacent cells, and the same cell in adjacent profiles.) The variation in the height of the contour plot is based upon the surface elevation with changing tide. In addition to the mean tidal fluctuations, we see significant variations in velocity shear during the deployment. These variations in shear may be related to changes in wind speed, and the relative direction of wind and current.

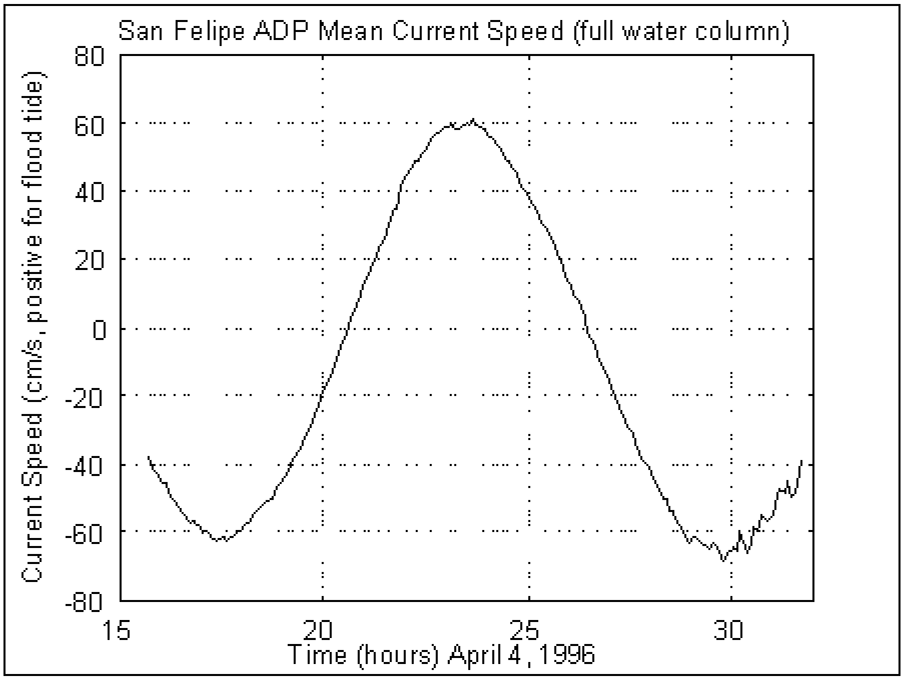

Figure 5. Mean Tidal Current Speed

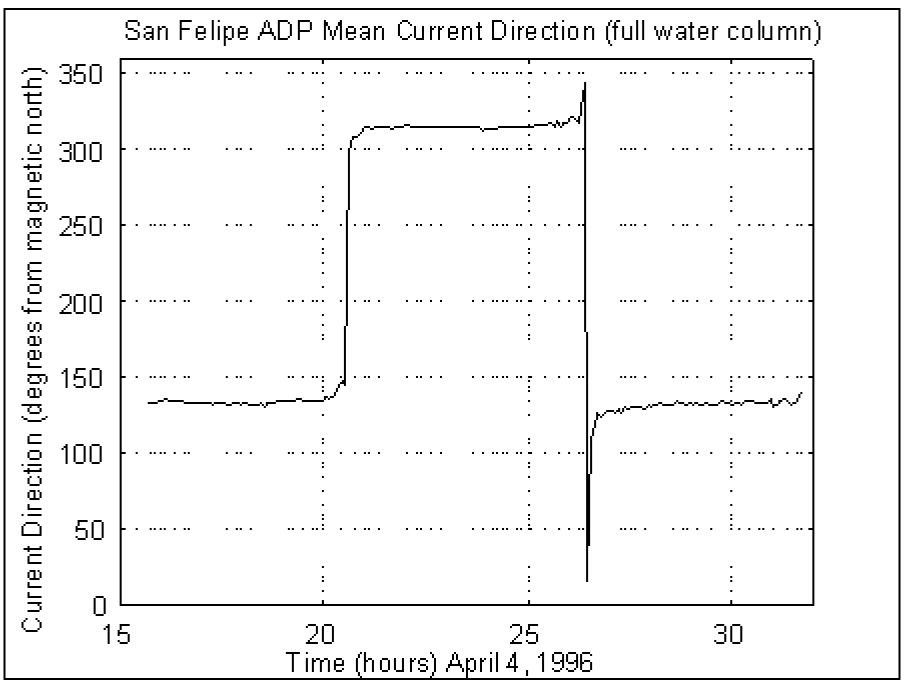

Figure 6. Mean Tidal Current Direction

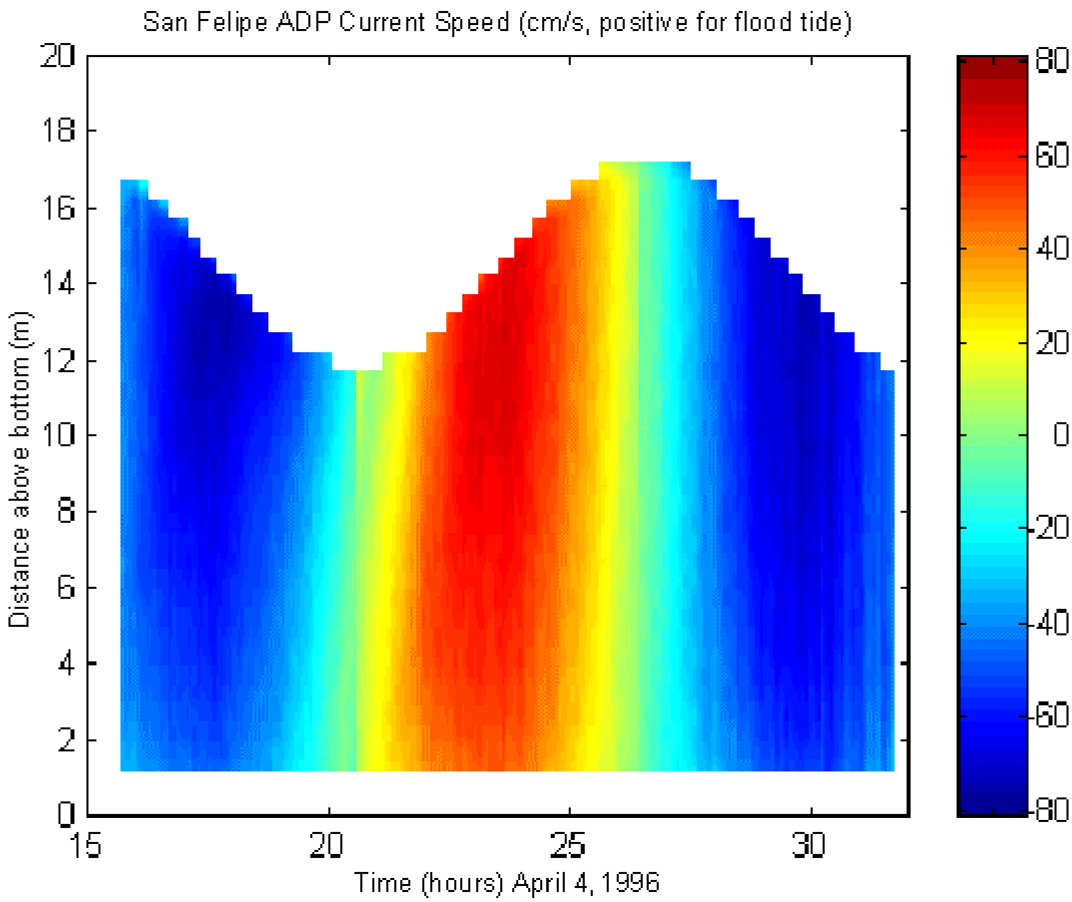

Figure 7. ADP Tidal Current Speed Contour

One interesting feature in the current data is the behavior during slack tide. Figure 8 and Figure 9 show vector plots of the water current at each period of slack tide. These plots show an arrow for each data point, with the length and orientation of the arrow determined by current speed and direction. For clarity, these plots were generated using every other profile and every other range cell (no averaging or filtering done). Particularly in the first plot (at low tide), we see that the bottom water changes direction considerably sooner than the water at the top of the profile. A similar effect, although less pronounced, is seen in the current change at high tide.

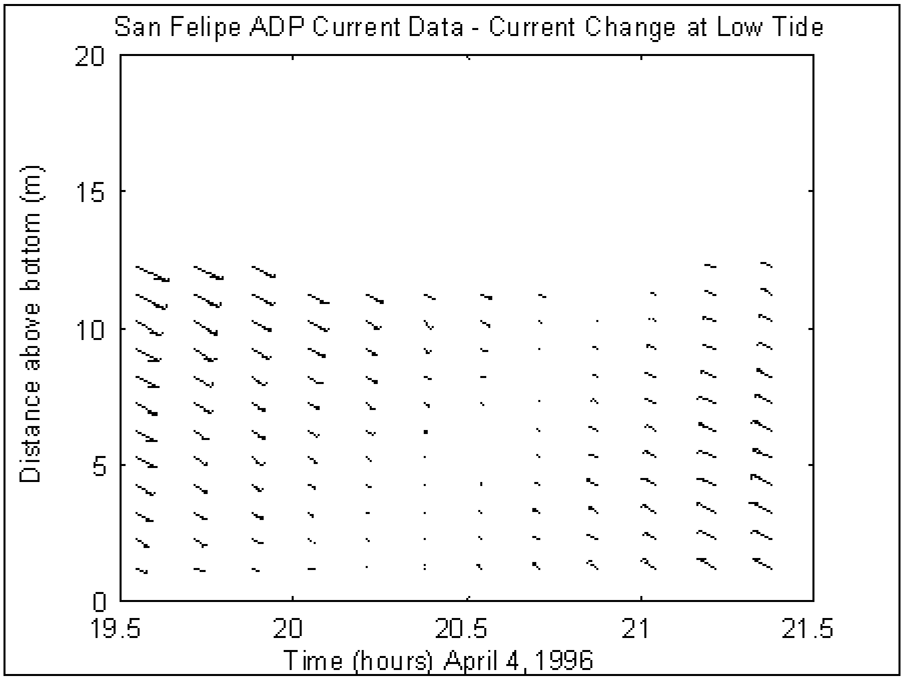

Figure 8. Current Change at Low Tide

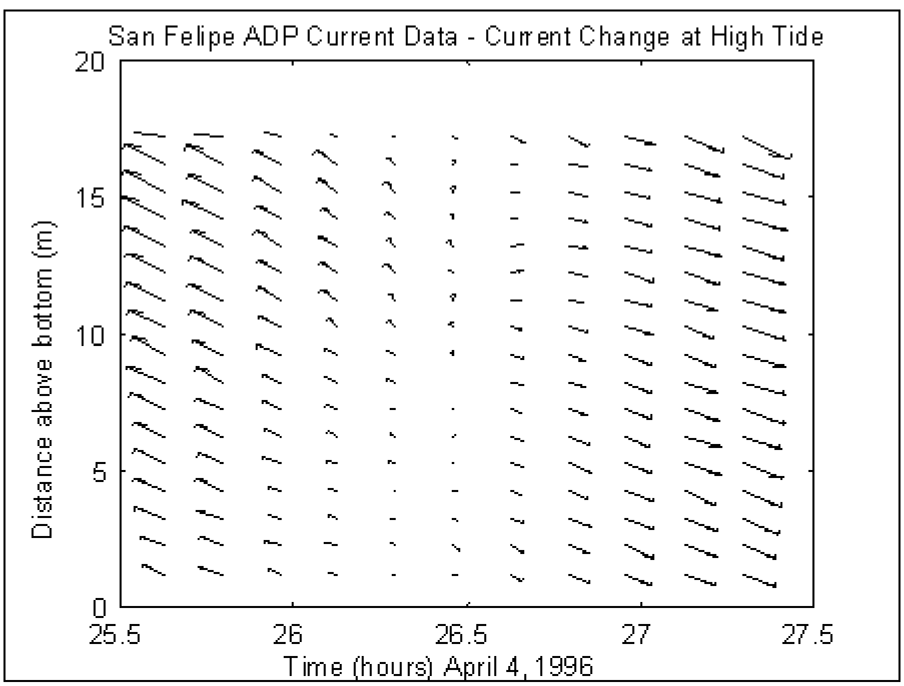

Figure 9. Current Change at High Tide

Near Surface Velocity Measurements

One consideration when using a current profiler in shallow water is the validity of near boundary data. How close to the surface (or bottom) can the ADP make accurate measurements? There are two sources of interference: the reflection of the acoustic pulse (along the axis of the beam) from the boundary and side lobe interference. The first occurs when the center of the acoustic beam hits the boundary. The region affected by this interference is a function of the length of the acoustic pulse. The ADP uses an acoustic pulse size equal to the depth cell size. For a stationary boundary, direct pulse reflection will affect the last two cells immediately before the boundary; the center of the last good cell is located two cell sizes from the boundary. For this deployment, using 0.5-m cells, we expect the center of the last good cell to be located 1.0 m from the surface. When waves are present, this distance will be measured from the lowest water level.

While ADP transducers are built to concentrate the majority of the acoustic energy in a narrow cone, some energy is transmitted in all directions. Some portion of this energy will travel a direct path to the boundary; the reflection of this "side lobe" energy can contaminate velocity data while the axis of the beam is still some distance from the boundary. The region potentially affected by side lobe interference is determined by the beam-mounting angle. ADP transducers are mounted 25° off vertical, so side lobe interference may affect the last 10% of the velocity profile (this is 10% of the profile below the cells affected by the direct reflection of the pulse). The ADP transducers have been designed to minimize side lobe levels, so interference may not be a significant factor depending on the acoustic conditions. Without an external reference for velocity measurements, there is no absolute means to determine the presence of side lobe interference.

Figures 10 and 11 show the mean current speed and signal strength profiles from two different periods during this deployment. Current speed in cm/s is plotted using "*"; signal strength is plotted as signal-to-noise ratio in dB using "o". Figure 10 is an average of 15 minutes of data during ebb flow shortly after high tide. Figure 11 shows the average of 15 minutes of data during ebb flow just before low tide.

The profile of SNR decays with distance from the transducers, with a large spike corresponding to the reflection from the surface. The location of the peak of this spike corresponds to the range to the mean surface level. The current profiles show the measured current speed at each cell; these estimates show large variations starting just before the surface reflection.

The SNR profiles in Figures 10 and 11 show increased signal strength in the two cells below the surface peak caused by the direct reflection of the acoustic pulse from the surface. We suspect the velocity data from these cells are contaminated. There is a potential for side lobe interference to affect 10% of the profile before these cells, so the previous 2-3 cells may also see interference.

In the high tide data, the third cell from the peak shows significant interference with a velocity of ≈22 cm/s compared with 48 cm/s in the main portion of the profile. Contamination in this cell may be caused by a lower effective water level (due to waves), or by side lobe interference. The next 2 cells in the profile show a decrease of 5-10% (44-45 cm/s vs. 48 cm/s) from the rest of the profile. This decrease in velocity may reflect the true motion of the water (decrease in surface velocity caused by the effect of wind and waves) or may indicate limited side lobe interference. Without an external reference, it is not possible to determine whether these cells reflect the true water motion. Based on data parameters from the ADP, we would discard the data from the 3 cells prior to the surface peak, and would mark the next 2 cells as suspect for minor interference.

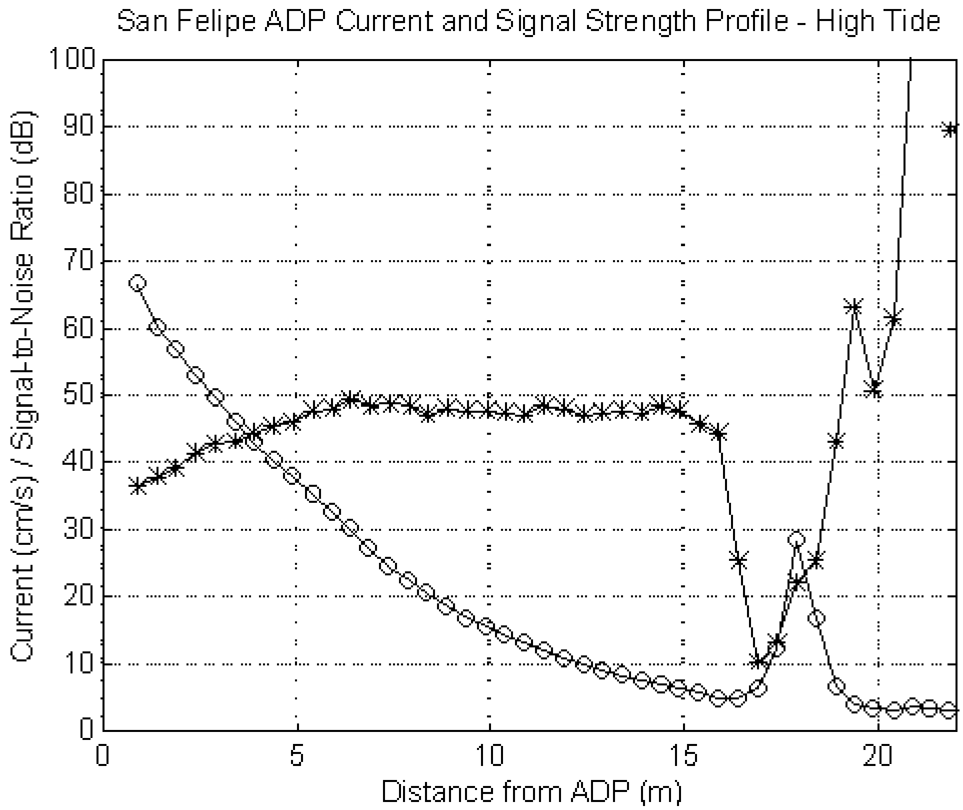

Figure 10. Current and Signal Strength (High Tide)

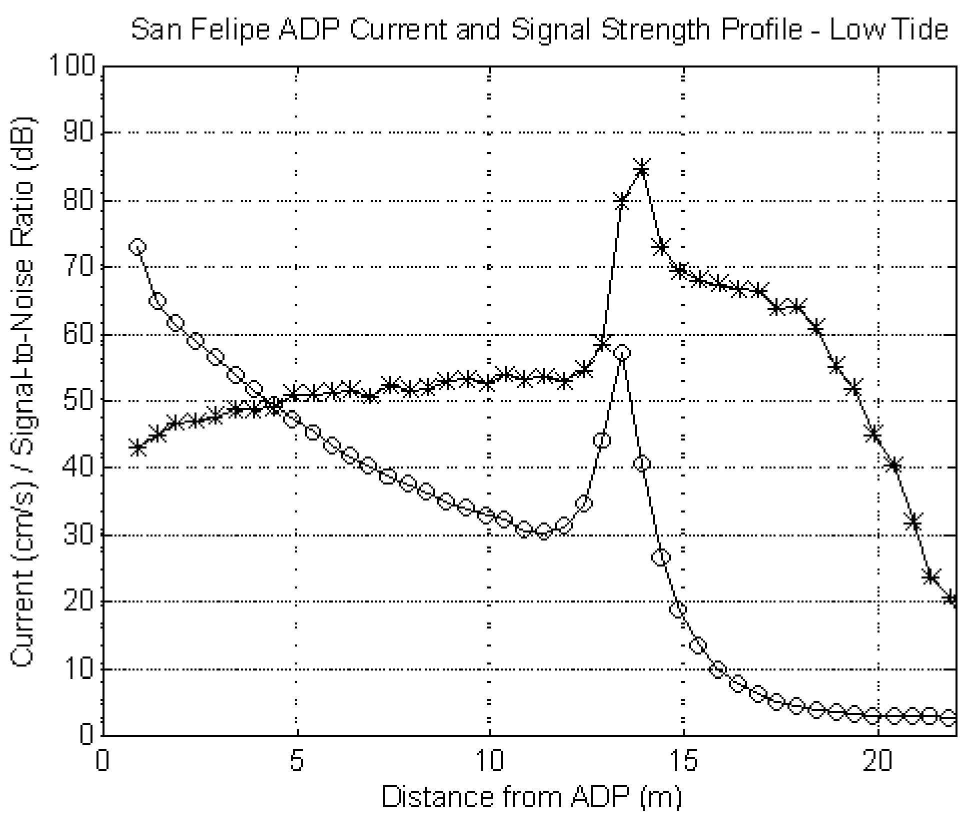

Figure 11. Current and Signal Strength (Low Tide)

In the low tide data, there is similar, although far less pronounced, bias in velocity data in two cells prior to the surface peak. These cells show an increase of 5-10% over the main portion of the profile. There is nothing in the data for cells below these to indicate any surface reflection or side lobe interference. We would discard the two cells prior to the surface as contaminated by direct reflection, and would consider the remainder of the profile to reflect true water motion.

Based on these observations, we have set a standard editing criteria for determining the last good cell within each profile. For all profiles, we would discard the two cells prior to the surface as contaminated; in some cases, we have also observed contamination in the third cell. For this report, we have discarded any cell whose center is within 1 m of the surface as estimated by the pressure sensor. While this criterion leaves a small amount of potentially contaminated data, we feel this is best for preliminary analysis; additional editing, if necessary, can be done later.

Signal Strength

ADP signal strength is a measure of the strength of the acoustic reflection from the water. In shallow water applications (using high acoustic frequencies), this return is normally dominated by reflection from suspended sediment. The relationship between signal strength and sediment concentration is a function of sediment size, type, and concentration. When comparison measurements of sediment concentration are available, signal strength can be converted to concentration with a reasonably high degree of accuracy and excellent spatial and temporal resolution.

Several processing steps are required when analyzing ADP signal strength data: converting internal units, correcting for range losses, and setting a relative scale value. The first step involves multiplying the ADP signal amplitude data (in internal units called "counts") by 0.43 to convert to dB. Next, the data must be corrected for the effects of geometric spreading and absorption to allow comparison of data from different portions of the profile. Spreading and absorption cause a decay in signal strength with increasing range from the transducers. This decay can be predicted by the following formula.

$$DECAY = -20 * \log_{10}(R_{beam}) - 2 * \alpha * R_{beam}$$

where:

DECAY = decrease in signal strength as a function of range (in dB)
R_{beam} = along beam range (equals the vertical range divided cos(25°))
α = sound absorption (for 1.5 MHz at salinity 35 ppt = 0.68 dB/m).

To make signal strength data independent of range, we subtract the range correction for each depth cell from the signal strength (after converting signal amplitude to dB). The final step is to choose a reference level; for this report, we have set the lowest values of range corrected signal strength to 0 dB, with all other values shifted relative to this. The choice of a reference level is arbitrary, as the relative scale is most interesting for analysis.

With precise measurements of transducer output power and receive sensitivity, it is possible to provide an absolute measure of the return signal strength. This absolute measure is referred to as volume scattering strength; it is measured as the strength of the return reflection relative to the strength of the incident signal. Calibration allows the comparison of acoustic from multiple instruments. This type of calibration is difficult and typically results in an overall accuracy of no better ±3 dB; it is useful only in situations utilizing multiple acoustic instruments and precise calibration of the acoustic signal.

Figure 12 shows a contour plot of signal strength from the ADP over the entire deployment. As with the velocity contour, the scale on the right shows the signal strength as plotted for each depth cell. The ADP data have been corrected for range losses and converted to an arbitrary reference as described above. As with the velocity contour plot, data were filtered using a linear interpolation from each adjacent point.

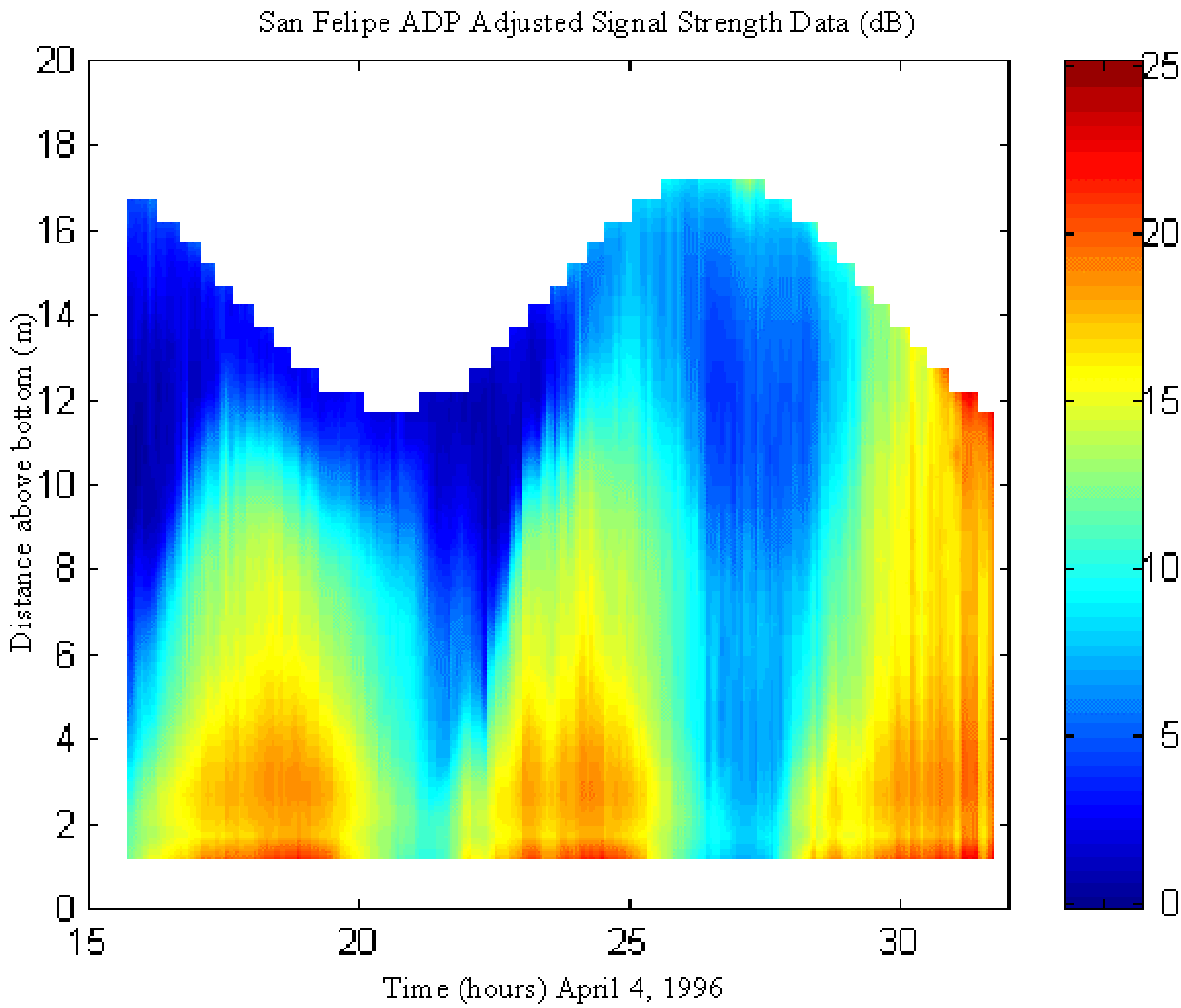

Figure 12. ADP Signal Strength Data Corrected for Range Loss

Figure 12 shows more than 20-dB variation in corrected signal strength during the deployment. Increased signal strength reflects greater sediment concentrations towards the bottom at all times during in the deployment, and increased sediment concentrations through most of the water column during periods of high current. We also see increased signal strength throughout the water column towards the end of the deployment (during a period of high wind and waves). The increased signal strength at the top of the water column may reflect sediment suspension or bubbles caused by wind and breaking waves.

ADP signal strength can be theoretically related to sediment concentration only in certain situations. Sediment must be the only significant source of acoustic scattering, and the size distribution of sediment must be assumed to be constant. Under these conditions, signal strength is directly proportional to sediment concentration; an increase in signal strength of 3 dB will correspond to an increase in sediment concentration by a factor of 2 (10*log10(2) = 3 dB). When analyzing signal strength data, remember there may be other sources of scattering, particularly biological creatures or suspended air bubbles. If comparison measurements of sediment concentration are available, signal strength can often be related to sediment concentration even with non-uniform particle sizes and types.

During this project, hourly profiles of suspended sediment concentrations were taken using an optical backscattering sensor (OBS). Figure 13 shows OBS-measured sediment concentration vs. ADP signal strength data. The comparison is made by matching a single ADP profile (closest in time to the suspended sediment profile) and depth cell (closest in depth to the estimated location of the OBS measurement) to the suspended sediment data. Figure 13 shows a scatter plot of all comparisons available over the entire deployment. We see excellent correlation between the data at higher concentrations, with large variations at lower levels. The large variations at lower levels have many potential sources including the presence of non-sediment scattering material (biological matter, bubbles, etc.), and different sensitivities of the different measurement techniques.

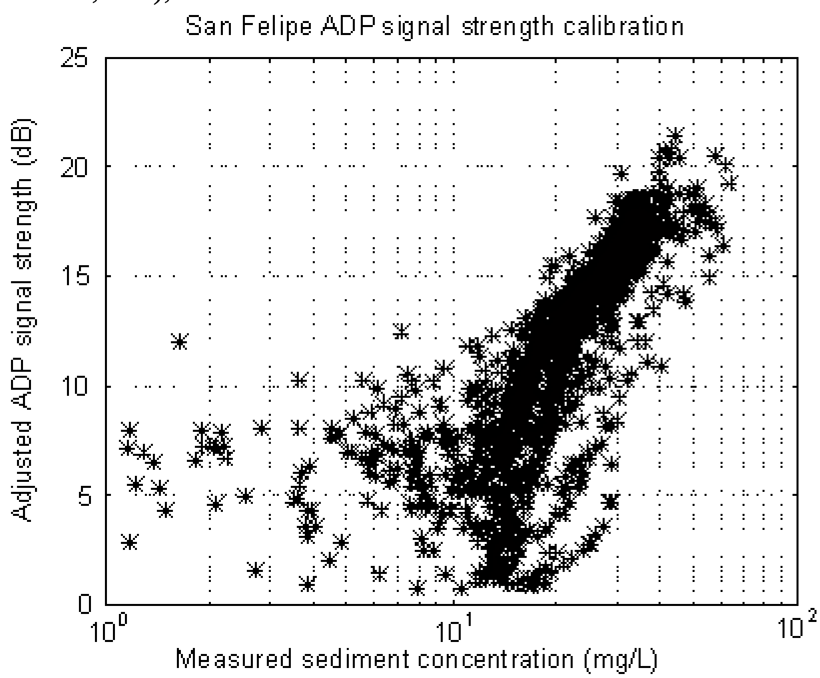

Figure 13. ADP Signal Strength Calibration using Preliminary Concentration Data

The mean slope of the correlation is considerably steeper than expected based on the theoretical relation discussed above (i.e., a change in concentration by a factor of 10 should give a change in scattering strength of 10 dB). This is caused by changes is the particle size distribution with depth; higher concentrations are typically towards the bottom of the water column, where particle sizes will be larger. For sediment sizes smaller than about 200 mm, the 1.5-MHz ADP has significantly greater sensitivity (signal strength for a given concentration) to larger particles.

Using the comparison data in Figure 13, we can make a best-fit relation between ADP signal strength and suspended sediment concentration. This would allow the contour plot in Figure 12 to be converted to absolute concentration units. In this instance, the ADP provides an estimate of sediment concentration with each profile (every 5 minutes) and at each depth cell (every 0.5 m). Based on the scatter in Figure 13, these estimates of suspended sediment concentration should be accurate to about a factor of two.