Sea Truth Measurements for Remote Sensing of Littoral Water

Comprehensive Sea Truth Measurements Carried Out on Oahu Island to Support Satellite Imagery of the Ocean

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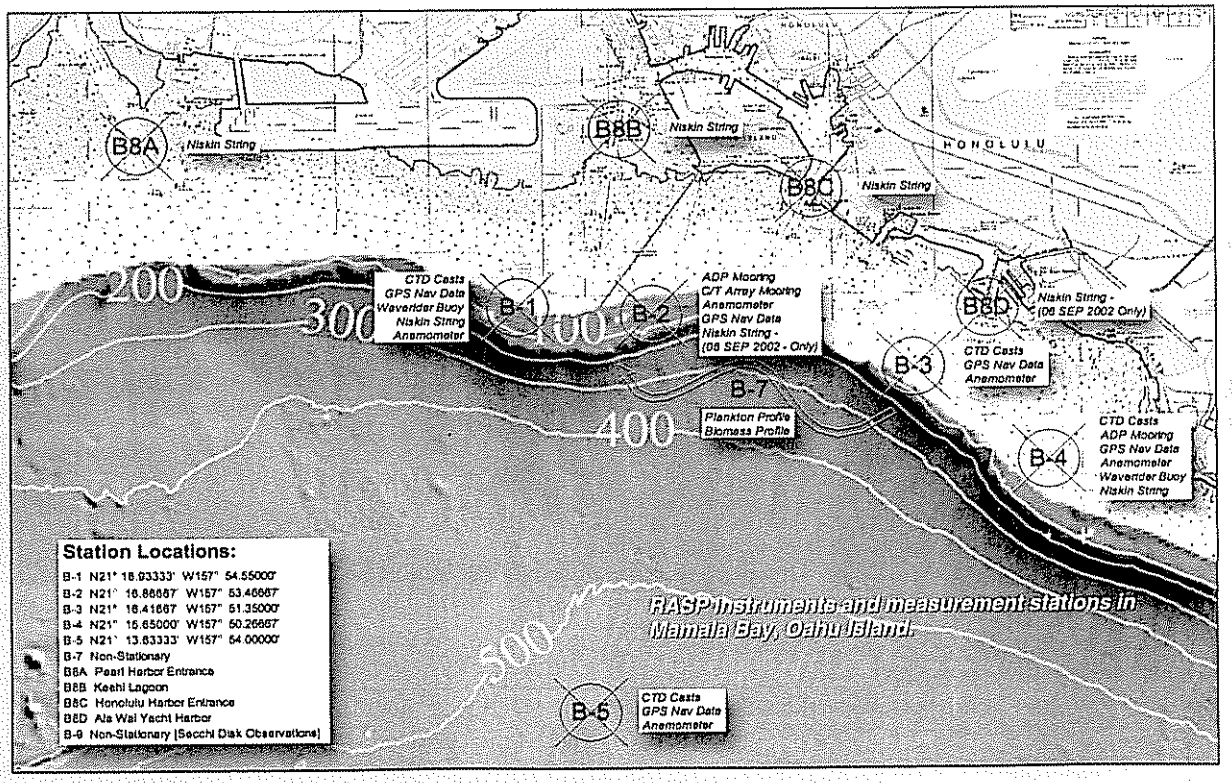
In September 2002 and 2003, experiments were carried out in Mamala Bay, Hawaii, to study the behavior of the outflow. During those experiments, the surface of the ocean was imaged by satellites and sensors carried aboard helicopters. The interpretation of the imagery was verified by sea truth measurements in the area imaged by the satellites and helicopters. Teams from the United States, Russia, Canada and Germany participated. The Russian team developed the method of the experiment, carried out the satellite and airborne data processing, and played a key role in determining the sea truth assets, which supported the interpretation of their imagery. Satellite imagery was taken of Mamala Bay by the satellites Ikonos, QuickBird, Terra, GOES and the International Space Station. On September 2, 2002, the Ikonos satellite overflew Mamala Bay and obtained 0.8-meter-resolution optical imagery of the ocean surface glint pattern from an altitude of 450 miles. Multispectral measurements were also carried out with a resolution of four meters. At the same time, a fleet of eight ships and one helicopter was deployed, taking measurements of ocean currents, temperature, salinity, wave spectra, turbulent microstructure, wind speed and various biologics. Other satellites were also deployed to obtain information on days where sea truth information was not available. Those experiments have been described in other papers.

Mamala Bay was chosen because of the presence of the Sand Island wastewater treatment plant, which operates under a variance from the U.S. Environmental Protection Ag-



Summary of Satellite Pass Information for Mamala Bay, Hawaii Tests 2003

Satellite	Date of Overpass	Time (UTC)	Time (local)	Side Look (deg)	Resolution
RadarSat	9/4/2003	16:22	6:22 AM	41 43 East	8m radar
RadarSat	9/6/2003	4:40	6:40 PM	39 18 East	8m radar
RadarSat	9/11/2003	16:18	6:18 AM	46 47 East	8m radar
ENVISAT	9/13/2003	20:36	10:36 AM	~31-36 3 East	30m radar
IKONOS-II	9/13/2003	21:24	11:24 AM	1 7 East	4m multi, <1m pan
QuickBird	9/14/2003	21:02	11:02 AM	14 East	4m multi, <1m pan
EO-1	9/16/2003	20:43	12:02 PM	5 34 East	30m multi, 10m pan

ency. The hydrodynamics of this outflow are complicated and not well understood. When processing satellite optical imagery, images were obtained and spatial spectral analysis was performed with use of 2D Fourier transformation, according to methods developed by Russian scientists.

Evidence of internal wave effects originating from the 230-feet-deep outflow were found as far as 2.5 miles away from the outflow in a two lobed pattern. Internal waves were identified and localized with use of analysis of spectral harmonics of 2D spatial spectrum.[2] This was at least partially corroborated by the sea truth measurements near the outflow. The result was entirely unexpected, and is probably due to internal waves convected by the ambient ocean currents, or the persistence of internal waves which may be generated by fossil turbulence. Experiments were carried out in September 2003 to determine the mechanisms responsible for this effect, and will be mentioned briefly below.

The Sand Island Outflow

The Sand Island outfall discharges approximately 75 million gallons per day of treated effluent into Mamala Bay, 9,000 feet offshore and at a depth of 230 feet. The outflow is mixed almost immediately by factors of 200 to 600. The hydrodynamic phenomena associated with the outfall are complex and governed by wind and tides, as well as flow conditions at the outfall.

The wastewater essentially has the same density of fresh water. The ambient seawater has a higher density, so the effluent water begins to rise due to buoyancy effects. The alongshore current interacts with the rising plume and dilutes the effluent by turbulent mixing. When density stratification is high, the density of the diluted plume may not reach the density of the surface water.

In this case, the plume has an intermediate density between bottom and surface water, and it comes to horizontal equilibrium well below the surface. However, under low stratification, or fully mixed ambient conditions, the plume rises to the surface. In both cases, after reaching the equilibrium level, the plume may continue to dilute by eddy diffusion and is moved away by currents.

Satellite Deployments

In the 2002 and 2003 experiments, the principal satellites deployed were Ikonos and QuickBird. These commercial satellites are owned by Space Imaging Inc. and Digital

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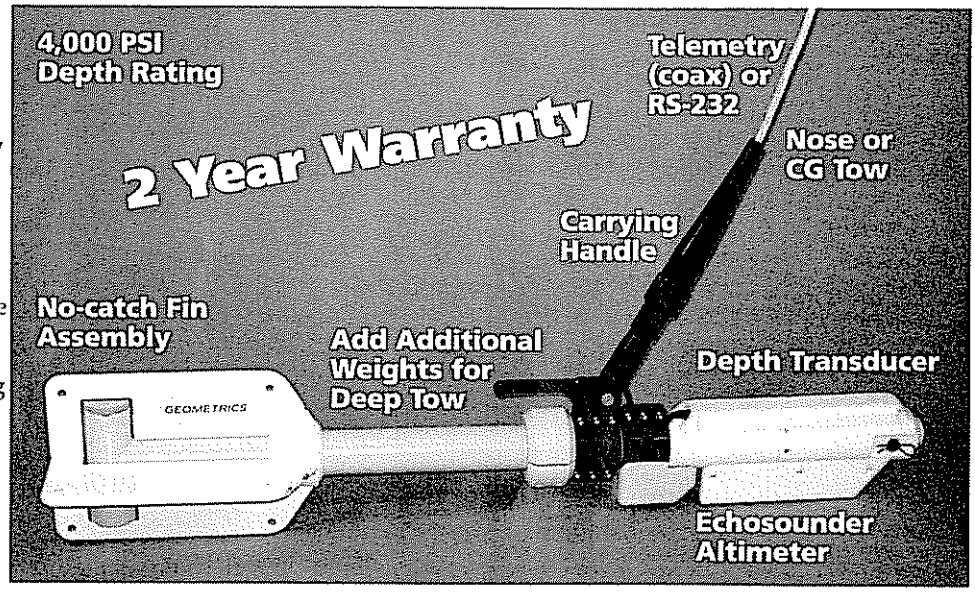

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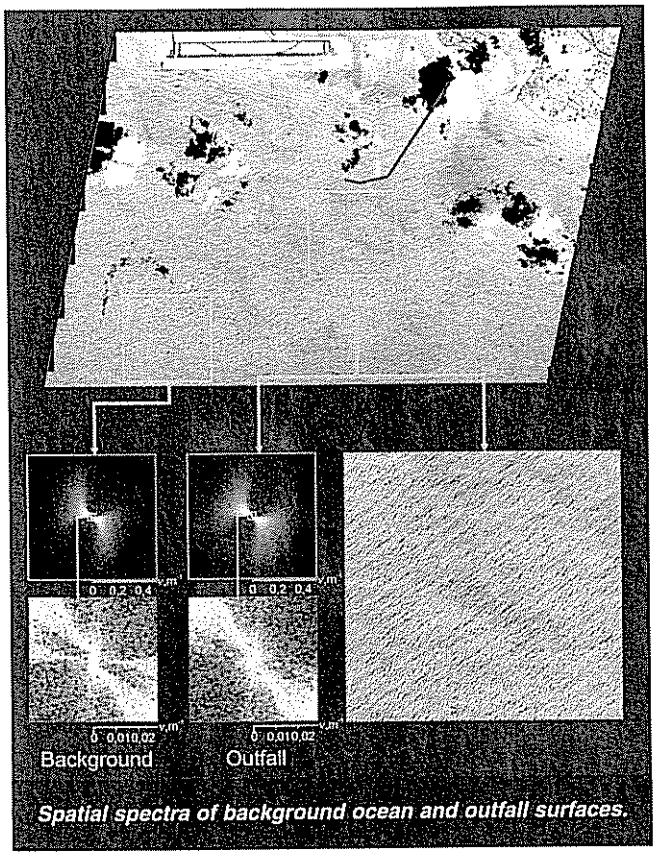

Spatial spectra of background ocean and outfall surfaces.

Globe, respectively. The Ikonos satellite was deployed September 2, 2002, during an 11:25 a.m. overpass. Fourier analysis was applied to the Ikonos satellite imagery of Mamala Bay, effectively analyzing the ocean surface. The method of analysis was applied across all images of ocean collected by the satellite. Areas with anomalous patterns were discovered that correspond to the region of water affected by the sewage outfall.

These favorable results led to expanded tests in 2003. Difficulty was experienced with QuickBird in the September 6, 2002, experiments, when a planned overflight was not properly tasked; but an excellent set of imagery was obtained from this satellite on September 14, 2003, during its 11:02 a.m. overpass, during the more recent series. QuickBird has a 0.61-meter resolution in the panchromatic mode, and four meters-multispectral resolution. The pattern observed was similar to, and reconfirmed, the long-range propagation of hydrodynamically driven surface effects observed the previous year. The Ikonos image taken September 13, 2003, had to be processed using the same procedure.

The resolution of Ikonos is 0.81 meters in the panchromatic modes, and approximately four meters in multispectral imaging. Processing results confirmed effects detected earlier.

Supporting Sea Truth

Extensive sea truth was taken in both the 2002 and 2003 experiments. Like in 2002, in 2003, wind velocity was measured, as were ocean wave spectra, ocean currents, biological and water-quality profiling, and conductivity, temperature and depth (CTD) from various arrays. In addition, microstructure dropsondes and a towed sled were also deployed to measure turbulent microstructure.

The objective of the field measurements was to provide data on the following parameters in Mamala Bay, Oahu, in

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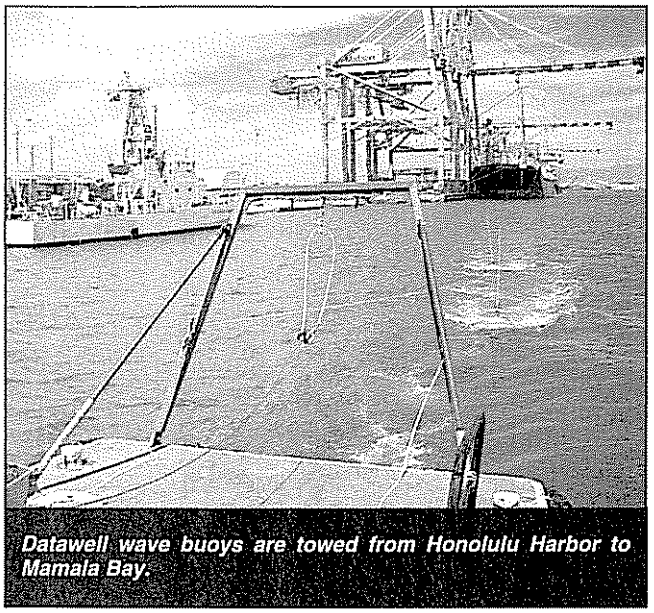
the proximity of the Sand Island outfall, adjacent areas and in deepwater offshore.

The parameters measured were temperature profiles, salinity profiles, current velocity profiles, nutrient profiles (nitrogen and phosphorus), biomass profiles (plankton and chlorophyll), surfactant concentrations, optical characteristics, directional wave information, wind information, effluent discharge rate from Sand Island outfall, effluent quality and tide data

Four data collection stations along the 200-foot contour (the approximate depth of the effluent diffuser), one offshore station approximately four miles from the shoreline and three mobile platforms were used during the data collection. The measurements were conducted whenever the optical satellites transited over the study area.

The 2003 locations of measuring assets were similar to those of the 2002 experiments, but microstructure sensing system runs were held farther out in the later experiment to verify the long-range propagation of the hydrodynamic anomalies.



Datawell wave buoys are towed from Honolulu Harbor to Mamala Bay.

Data Collection Methods

Directional wave spectra were measured at three locations in the study area using two Datawell buoys and a Trident wave buoy. Datawell directional wave buoys were deployed at stations B1 and B4. The data collected consisted of significant wave heights values, wave periods, wave statistics and directional spectra. The Trident wave buoy was deployed at a third point to supplement the data from the other buoys. All three buoys were deployed in a free floating configuration and retrieved at the end of the measurement period.

Current profiles were measured at one-minute intervals at stations B2 and B4 from August 31 to September 8, 2002. Two Sontek acoustic Doppler current profilers (ADCP) were deployed at the stations B2 and B4 on August 31, 2002. Each ADCP was mounted on a fiberglass spider with the transducers facing up. The ADCPs were recovered to download data from the memory.

Salinity and temperature profiles were measured continuously at stations B1, B3, B4 and B5 during the transit of the satellites. Ten SeaBird instruments and 10 YSI instruments were leased for the measurements. Four instrument strings

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were fabricated by attaching five recording meters that measured CTD to a polypropylene rope. The instruments were spaced at 40 feet on the rope. The meters were programmed to sample and record CTD data at intervals of 10 seconds. The string was lowered and raised from the boat to measure profiles. Seabird instruments were used at B1 and B4 and YSI 600XLM sonde instruments were used at stations B3 and B5, respectively. Only the top 200 feet of the water column were monitored at B5.

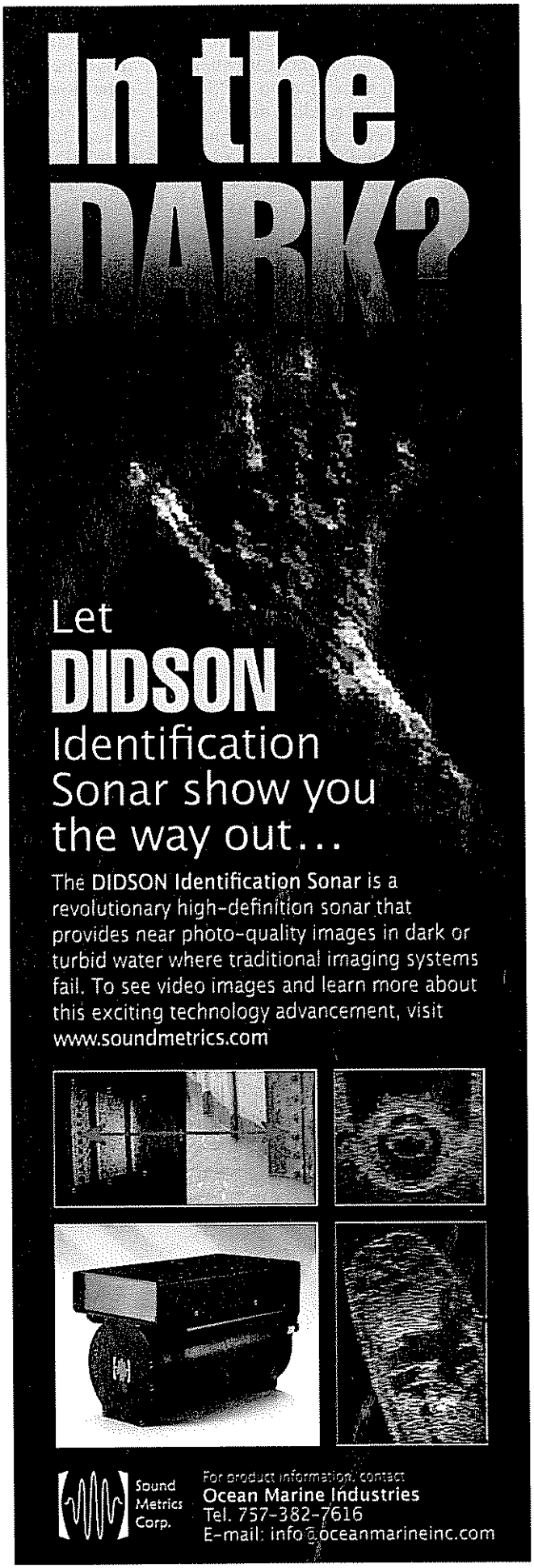
A CTD string, the CTR-7, designed by Aanderaa, was deployed for eight days at station B2, from August 31 to September 8, 2002. The instrument string consisted of 15 temperature and conductivity sensors mounted at intervals of 10 feet with a data logger at one end. The CTD string was deployed to sample temperature and conductivity from the bottom to 50 feet below the surface at intervals of 10 minutes. The string terminated at a depth of 50 feet to avoid damage from passing boats. The instrument string at the bottom end was connected to an anchor through acoustic releases connected in parallel. The string was kept in a vertical position by a submerged buoy with sufficient buoyancy to lift the instruments and the acoustic release system to the surface. The acoustic releases were triggered by a coded message during retrieval.

Water quality parameters monitored included total nitrogen, nitrate plus nitrite, total phosphorus, ortho-phosphates, biochemical oxygen demand, total suspended solids, turbidity, chlorophyll and surfactants. Water samples were collected at the surface and at intervals of 15 feet over the water column down to the bottom using Niskin samplers. Water samples were collected from different depths as planned at B1 and B4 on September 2, 2002. One surface sample was collected at B5. Surface, mid-depth and bottom samples were collected by boat at the Honolulu Harbor entrance, the Pearl Harbor entrance and at the Keehi Lagoon entrance to the harbor. Wind speed and direction were measured at stations using NK Kestrel 1000 pocket wind meter anemometers. Measurements were taken every five minutes and manually recorded. Hourly wind data from the Honolulu airport were obtained for the period of August 2001 to September 2002 to supplement *in-situ* measurements.

Water level data measured at Honolulu Harbor in 2002 were obtained from the Oceanography Department of the University of Hawaii. The tide gage was operated by the University of Hawaii.

Data on discharge rate of wastewater effluent from the Sand Island wastewater treatment plant were obtained to cover the duration of the two tests. In addition, effluent samples were collected and analyzed for biochemical oxygen demand, concentration of total suspended solids, nitrates phosphates and surfactants.

Services from the University of Hawaii were obtained to conduct these measurements. Samples to quantify the plankton biomass and composition were collected using Niskin bottles. In addition, vertical net-tows were performed for zooplankton in three depth strata (bottom to 50 meters, 50 to 25 meters and 25 to zero meters) with an opening-closing net (.75 meters mouth diameter and 150 micron mesh). Samples were analyzed for heterotrophic bacteria, prochlorococcus spp, synechococcus spp, total bacteria, total phytoplankton cells, HPLC chlorophyll a, total suspended carbon and nitrogen, nano-plankton, micro-plankton, total phytoplankton biomass, mesozooplankton and total plankton biomass.



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The sampling and measurement positions of all boats were continuously monitored with Garmin GPS 76 global positioning satellite units.

In 2002, Secchi disk measurements were made with disks of two different diameters. These results have been reported elsewhere. In 2003, Secchi disk operations were shifted to deeper ocean water with casts taken farther out. Here, an entirely new set of operational procedures was developed. The Star-Oddi sensor was used to determine Secchi disk depth as a function of time. In this way, a diver afloat above the disk could be used to determine time of disappearance, and this was correlated with distances determined from shipboard deployed lines to the diver and the disks. To verify performance of the ADCP units, Compact-EM sensors were deployed in the 2003 tests measuring current velocity and direction, and conductivity-temperature. These new units are made by Alec Electronic, Japan, and were distributed by Rockland Scientific, Canada.

We anticipate carrying out further work utilizing radar satellites and airborne lidar systems.

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References

For a full list of references please contact the author Norris Keeler at Norris_Keeler@DirectedTechnologies.com. /st/

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