Coastal Circulation and Sediment Dynamics along West Maui, Hawaii

PART IV:

Measurements of waves, currents, temperature, salinity and turbidity in Honolua Bay, Northwest Maui: 2003-2004

U.S. Department of the Interior
U.S. Geological Survey

Open-File Report 2005-1068

Coastal Circulation and Sediment Dynamics along West Maui, Hawaii

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Measurements of waves, currents, temperature, salinity and turbidity in Honolua Bay, Northwest Maui: 2003-2004

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U.S. GEOLOGICAL SURVEY
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For an online PDF version of this report, please see:
http:// pubs.usgs.gov/of/2005/1068/

For more information on the U.S. Geological Survey Western Region's Coastal and Marine Geology Team, please see:
http://walrus.wr.usgs.gov/

For more information on the U.S. Geological Survey's Coral Reef Project, please see:
http://coralreefs.wr.usgs.gov/

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INTRODUCTION

High-resolution measurements of waves, currents, water levels, temperature, salinity and turbidity were made in Honolua Bay, northwest Maui, Hawaii, during 2003 and 2004 to better understand coastal dynamics in coral reef habitats. Measurements were acquired through two different collection methods. Two hydrographic survey cruises were conducted to acquire spatially-extensive, but temporally-limited, three-dimensional measurements of currents, temperature, salinity and turbidity in the winter and summer of 2003. From mid 2003 through early 2004, a bottom-mounted instrument package was deployed in a water depth of 10 m to collect long-term, single-point high-resolution measurements of waves, currents, water levels, temperature, salinity and turbidity. The purpose of these measurements was to collect hydrographic data to learn how waves, currents and water column properties such as water temperature, salinity and turbidity vary spatially and temporally in a nearshore coral reef system adjacent to a major stream drainage. These measurements support the ongoing process studies being conducted as part of the U.S. Geological Survey (USGS) Coastal and Marine Geology Program's Coral Reef Project; the ultimate goal is to better understand the transport mechanisms of sediment, larvae, pollutants and other particles in coral reef settings. This report, the final part in a series, describes data acquisition, processing and analysis. Previous reports provided data and results on: Long-term measurements of currents, temperature, salinity and turbidity off Kahana (PART I), the spatial structure of currents, temperature, salinity and suspended sediment along West Maui (PART II), and flow and coral larvae and sediment dynamics during the 2003 summer spawning season (PART III); see the REFERENCES section for these reports.

Project Objectives:

The objective of these deployments was to understand how currents, waves, tides, temperature, salinity and turbidity vary spatially and temporally in Honolua Bay. To meet the objectives of the Coral Reef Project, flow and water column properties in Honolua Bay were investigated. These data will provide insight into the impact of terrestrial sediment, nutrient or contaminant delivery and coral larval transport on nearshore coral reefs. The first cruise, A-3-03-HW, was conducted during the winter season (February, 2003) while the second set of cruises, A-4-03-HW, were conducted in late June/early July, 2003, during the spawning of the Hawaiian reef-building coral *Montipora capitata* (Storlazzi et al., 2003). The MegaDOBIE instrument package was deployed over a period spanning 9 months, starting just before the A-4-03-HW cruises in late June/early July, 2003, and extended through the winter into mid March, 2004. Data collected during these cruises and instrument deployments provide baseline information for future watershed restoration projects proposed by the Hawaiian Local Action Strategy (LAS) to address Land-Based Pollution (LBP) threats to coral reefs in the Honolua ahupua'a (linked watershed-reef system).

Study Area:

These measurements were made in Honolua Bay, Northwest Maui, Hawaii, USA, between the Hawaiian Islands of Maui and Molokai (FIGURE 1). All of the spatial

surveys were collected on the inner shelf, inshore of the 50 m isobath. These surveys extended inshore as shallow as possible, usually between the 4 m and 10 m isobaths depending on the oceanographic conditions (primarily ocean surface waves). The long-term, bottom-mounted instrument package was deployed on the inner shelf in a water depth of 10 m in a sediment-filled paleo-stream channel incised during a previous sea-level lowstand (FIGURE 2). The paleo-stream channel was more than 80 m wide and had a maximum vertical relief of 16 m. The seafloor sediment at the instrument location is a well-sorted carbonate sand. All vessel operations, including mobilization and demobilization, were based out of Lahaina Harbor, West Maui, Hawaii.

OPERATIONS

This section provides information about the personnel, equipment and vessel used during the deployments. See TABLE 1 for a list of personnel involved in the experiment.

Scientific Party:

Spatial Surveys

The scientific party for the A-3-03-HW cruise included two USGS scientists and three cooperating scientists from the University of California at Santa Cruz (UCSC). The scientific party for the A-4-03-HW cruise included two USGS scientists and two cooperating scientists from the University of California at Santa Cruz (UCSC). At any one time, however, there were only three to four scientists on board the vessel: two USGS and one or two UCSC scientists. There was one vessel captain in addition to these scientists on board.

Bottom-mounted Deployments

The scientific party for the bottom-mounted instrument deployments included at a minimum of three scientists from the USGS. During instrument deployment and recovery operations there was one vessel captain in addition to these scientists on board.

Equipment and Data Review:

Spatial Surveys

Two primary instruments were used to acquire data during the spatial surveys. The first instrument was a 600 kHz downward-looking vessel-mounted Acoustic Doppler Current Profiler (VM-ADCP), which was used to collect vertical profiles of current velocity and acoustic backscatter data. The second instrument utilized was a Conductivity/Temperature/Depth (CTD) Profiler with an Optical Backscatter Sensor (OBS) to collect vertical profiles of water temperature, salinity, density and optical backscatter (a measure of turbidity).

VM-ADCP profile data were collected continuously along a shore-normal transect while the vessel was traveling at approximately 2-3 knots. Over the 5 days of surveying, which was a small part of a more extensive data collection effort, we collected roughly 5 km of VM-ADCP data down to a maximum depth of 40 m.

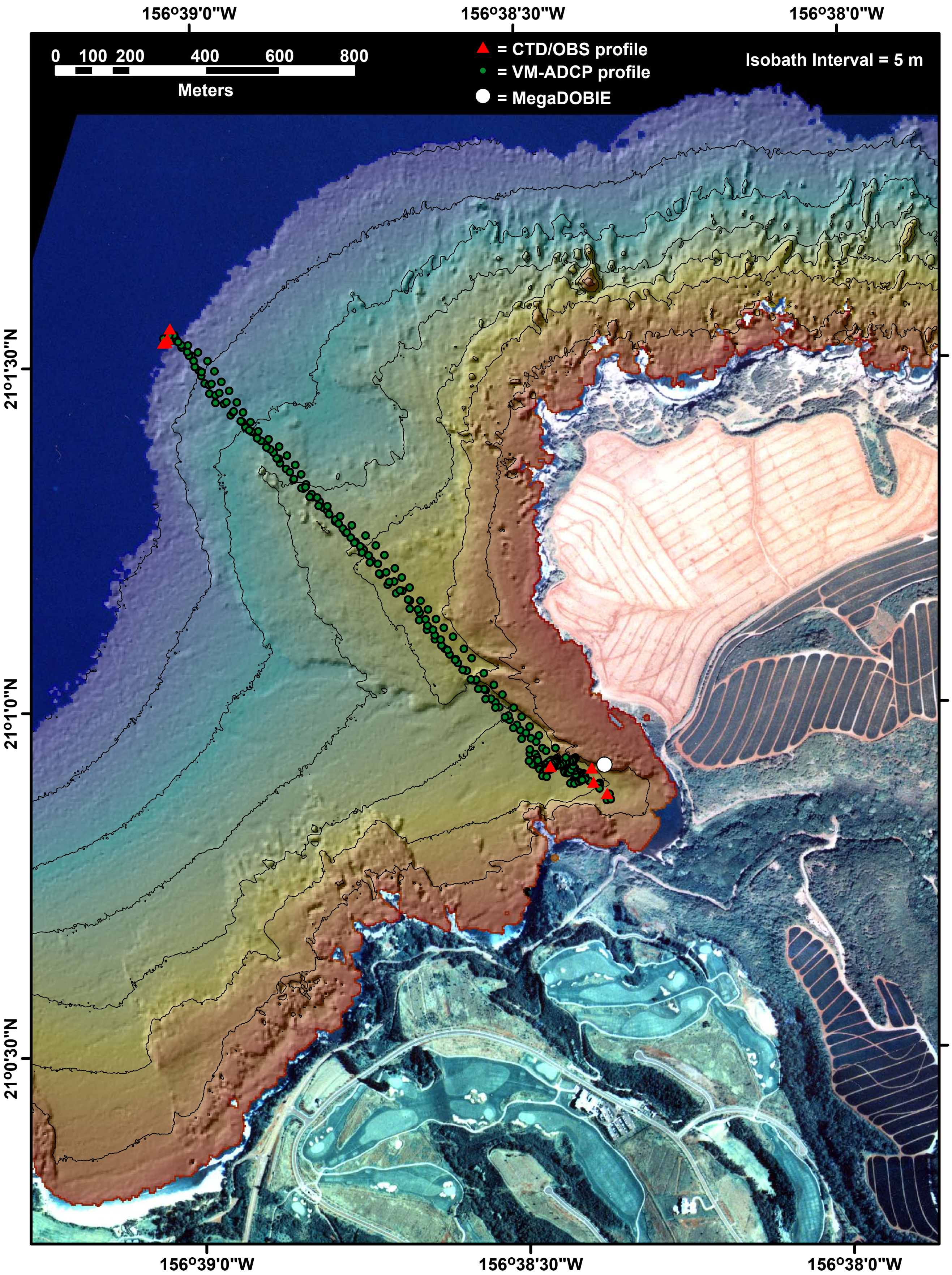

FIGURE 2. *Location of VM-ADCP measurements, CTD/OBS profiler casts, and the long-term, bottom-mounted instrument package ("MegaDOBIE") along with nearshore bathymetry from SHOALS lidar data and aerial photography of the terrestrial portion of the study area.*

CTD/OBS casts were collected at the beginning and end of each VM-ADCP profiling line (one on the inshore end of each line and one at the offshore end of each line). Thus two CTD/OBS casts were collected at each VM-ADCP profiling line in order to relate water column structure to current velocities. In all, 10 CTD/OBS casts were collected over the 5 days of surveying. The log of VM-ADCP profiler data acquisition is presented in TABLE 2, while the CTD/OBS data acquisition log is presented in TABLE 3. The instrument specifics and sampling schemes are listed in APPENDIX 1 and APPENDIX 2 for the ADCP profiler and CTD/OBS profiler, respectively.

Navigation equipment included two hand-held WAAS-equipped GPS units, a computer with positioning and mapping software and an external LCD monitor. The positioning and mapping software enabled real-time GPS position data to be combined with images of previously collected high-resolution SHOALS lidar color-coded, shaded-relief bathymetry, 5 m isobaths and aerial photographs of terrestrial portions of the maps. See FIGURE 2 for the transect location.

Bottom-mounted Deployments

The MegaDOBIE package consisted of three primary instruments to acquire wave, tide, temperature, salinity and turbidity data during the long-term, bottom-mounted deployments. The instruments were a self-contained NIWA Dobie-A strain gauge pressure sensor and an Aquatec/Seapoint 200-TY self-contained optical backscatter sensor (SCOBS) approximately 0.5 m above the bed. These sensors collected single-point measurements on waves and tides, and optical backscatter, respectively. Also included in this package was a Seabird SBE-37SM Microcat conductivity-temperature sensor (~0.5 m above the bed). This sensor collected single-point measurements on water temperature and salinity.

The instrument package was typically deployed for 90-100 day periods, as constrained by the power consumption. Sensors on the MegaDOBIE package made measurements using three sampling schemes. The Dobie pressure sensor recorded a 512 sec burst at 2 Hz every hour to provide wave and tide information, while the SCOBS and Microcat recorded an 8 sample burst every 4 min. The instrument package deployment and recovery log is presented in TABLE 4. The instrument specifics and sampling schemes are listed in APPENDIX 3.

Navigation equipment consisted of a hand-held WAAS-equipped global positioning system (GPS) unit. This system made it possible to very accurately deploy the instruments in the same location and to recover them without the need for a surface float to mark the instruments' locations.

Research Platform:

Spatial Surveys

The cruises were conducted using a chartered vessel, the 28-ft-long *R/V Alyce C.*, owned and operated by Alyce C. Sport Fishing (FIGURE 3a). The *R/V Alyce C.*, which was designed as a sport-fishing boat, was modified for scientific studies. The space under the bridge was allocated for data acquisition and processing, which took place on two laptop computers. The starboard quarterdeck was allocated for the attachment of a specialized bracket used to deploy the VM-ADCP profiler (FIGURE 3b). The port beam was allocated for CTD/OBS profiler operations (FIGURE 3c), which included the use of a hydraulic winch and an overhead davit. The driver's station was

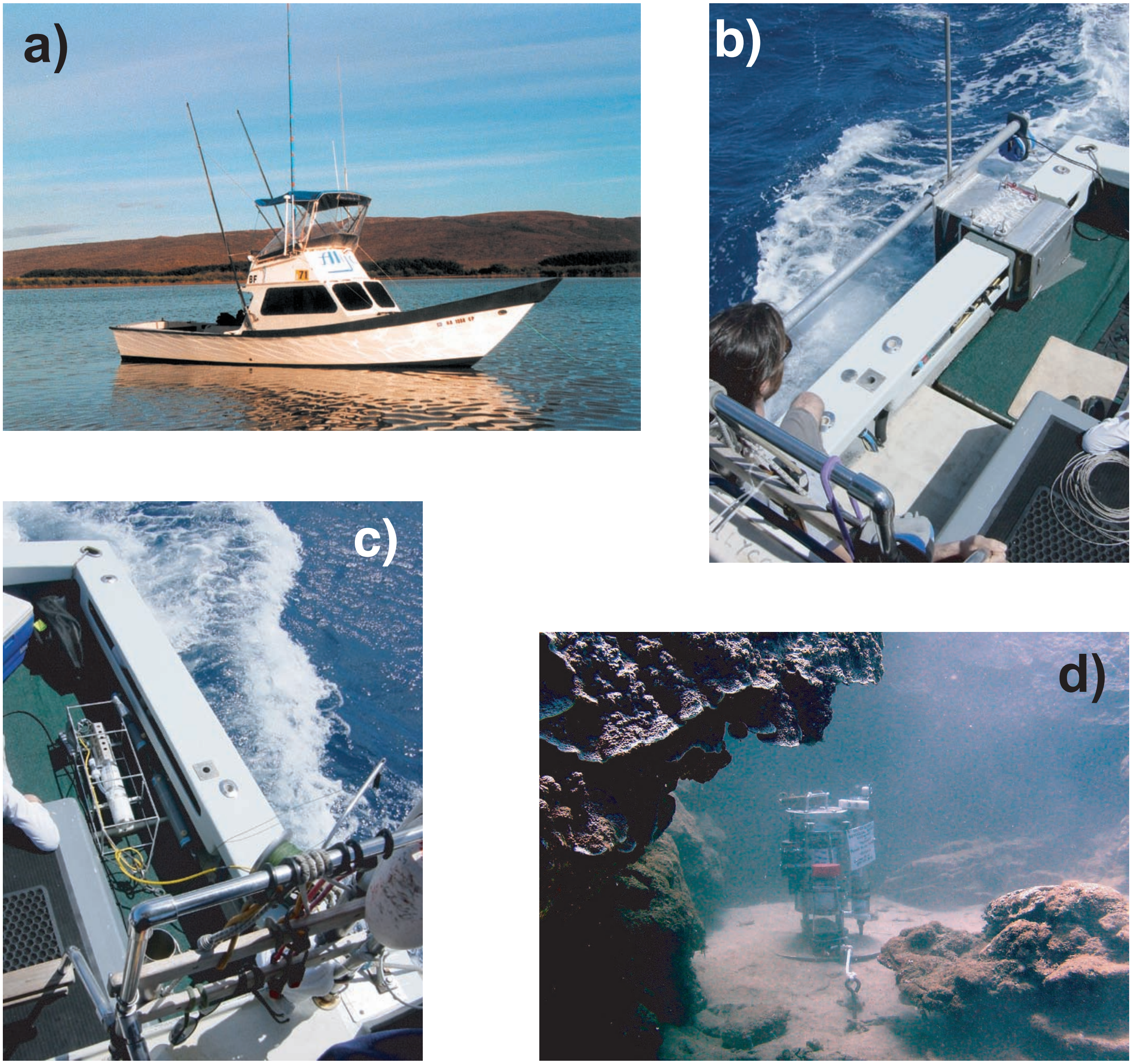

FIGURE 3. *Photographs of the equipment used in the study. (a) View of the Alyce C. (b) View of the starboard quarter showing the VM-ADCP profiler and mount up in the travel position. (c) View of the port beam showing the CTD/OBS profiler. (d) View of the MegaDOBIE instrument package deployed on the seafloor in Honolua Bay.*

outfitted with a LCD display and GPS-enabled navigation system to provide the vessel captain with a graphic display of position information, speed, heading and distance to the next transect line.

Bottom-mounted Deployments

The instrument deployments and recoveries were also conducted using the *R/V Alyce C*. The port beam and starboard quarterdeck were adapted for instrument deployment and recovery. The port beam was allocated for instrument package deployment and recovery operations, which included the use of an electric winch and an overhead davit from the same boom that was used to deploy the CTD/OBS profiler during the spatial surveys. The instruments were deployed by attaching a removable bridle to the instrument package with a connecting line through the davit and down to the winch. The instruments were lowered to within a few meters of the seafloor, where the scuba divers would attach a lift bag and detach the lifting line. The divers would then move the instrument package into place. After determining the package's location, the divers emplaced sand anchors into the seafloor and attached them to the instrument package using cables and turnbuckles (FIGURE 3d). Seafloor surficial sediment samples were collected, and the heights of the sensors above the seafloor were measured and recorded. Recovery operations employed the same techniques.

DATA ACQUISITION AND QUALITY

Spatial Surveys

Five total days of data were acquired: one day in the winter (02/26/2003) and four days in the summer (06/30/2003 – 07/03/2003). Although some of the VM-ADCP data were affected by the heave, pitch and roll of the vessel when large ocean surface waves were encountered, greater than 99% of the VM-ADCP and CTD/OBS profilers' data were of high quality. Data quality was generally very high, with some problems near the surface and near the bed. The ADCP data near the surface displayed slightly lower correlation due to surface wave-generated bubble interference with the transducers, while most of the near-bed data showed low beam correlation due to beam spreading and vessel roll. Beam spreading caused the beam footprint to be large while vessel roll caused substantial Doppler offsets from the bed that could not be post-processed out of the data. This loss of data from the bins closest to the bed is common to most mobile, downward-looking VM-ADCP surveys and was expected.

The raw VM-ADCP data were archived and copies of the data were post-processed to remove all "ghost" data from below the bed, averaged over 10 sec windows to reduce the effects of wave-induced motions. All data for which the beam correlation dropped below 70% were discarded for visualization and analysis. After post-processing, spatially heterogeneous features such as sediment plumes were identifiable in the acoustic backscatter data while an eddy was often visible in the velocity data. An example of the post-processed VM-ADCP data collected on 02/26/2003 is shown in FIGURE 4.

The CTD/OBS data near the bed often displayed spikes in the OBS data due to interaction of the optical beam with the bed. The raw CTD/OBS data were archived and copies of the data were post-processed by calculating the average over 0.5 m depth windows to reduce high-frequency system noise. These 0.5 m bin-averaged data were

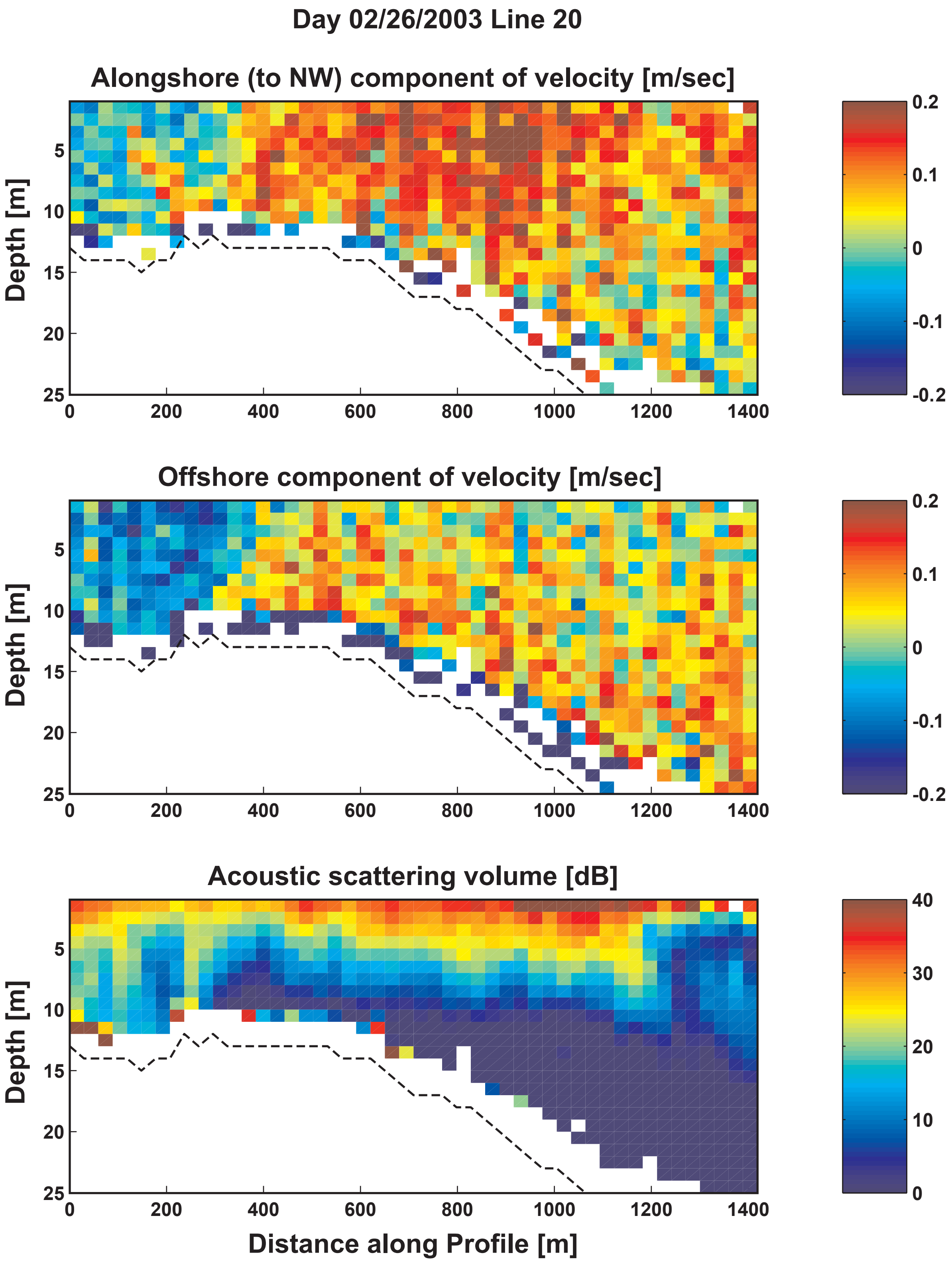

FIGURE 4. *Example of VM-ADCP profile data collected on 02/26/2003 during a flooding Neap tide. (a) Alongshore (to the northwest) component of current velocity. (b) Offshore component of current velocity. (c) Acoustic scattering volume, a proxy for turbidity in the water column. These data show that close to shore, the direction of flow is opposite of the waters further offshore, suggesting the presence of an eddy. The high acoustic scattering corresponded with visually and optically (FIGURE 5) turbid water due to discharge from Honolua Stream.*

then used for visualization and analysis. The CTD/OBS data were very high in quality, with features such as low-salinity (freshwater) surface plumes visible in the salinity data, multi-layered structures (water masses) identified by density contrasts, and turbid layers identifiable in the OBS data. Co-located laser in-situ scattering and transmissometry (LISST) data showed wide spatial and temporal variability in the size of the material that was imaged by the OBS (J.Harney, USGS, personal communication). Due to this variability, we were unable to calculate valid regression that would allow us to accurately determine suspended sediment concentrations by mass (i.e- mg/l) and thus only raw OBS voltages are presented. An example of data from a single CTD/OBS cast collected on 02/26/2003 is shown in FIGURE 5.

Bottom-mounted Deployments

Data were acquired on 260 days during the 9 month period between 06/29/2003 and 02/27/2004; this was more than 97% coverage over the entire experiment. The instruments were out of the water for only 7 days during these 9 months for data recovery and instrument refurbishment.

More than 4880 hours of data were recovered from Dobie wave/tide gauge; data loss was confined to the end of the third deployment (01/2004-03/2004) due to battery failure. Data quality was generally very high except towards the end of the 6/2003-10/2003 deployment, when biofouling of the pressure sensor caused the data quality to decrease. The raw Dobie pressure data were archived and copies of the data were post-processed to calculate water depth, tidal height (*h*), significant wave height (*Hsig*) and dominant wave period (*Tdom*).

The SCOBS and Microcat data appeared to be of high quality. Data problems were primarily due to something interrupting the SCOBS optical path (likely fish and/or scuba divers). Overall, 93303 samples of high-resolution turbidity data were recovered over the 9 month study period. The Microcat's sensors started to fail shortly after the second deployment (10/2003-01/2004) and completely failed during the last deployment (01/2004-03/2004); thus only 39567 samples of high-resolution temperature and salinity data are available from the first instrument deployment (06/2003-10/2003).

RESULTS AND DISCUSSION

This section reviews the data collected by both systems during the deployments and addresses the significance of the findings to better understand the local oceanographic conditions in the study area.

Tides

The tides in Honolua bay are mixed, semi-diurnal with two uneven high tides and two uneven low tides per day; thus the tides change just over every 6 hours. The mean daily tidal range is roughly 0.6 m, while the minimum and maximum daily tidal ranges are 0.4 m and 1.0 m, respectively.

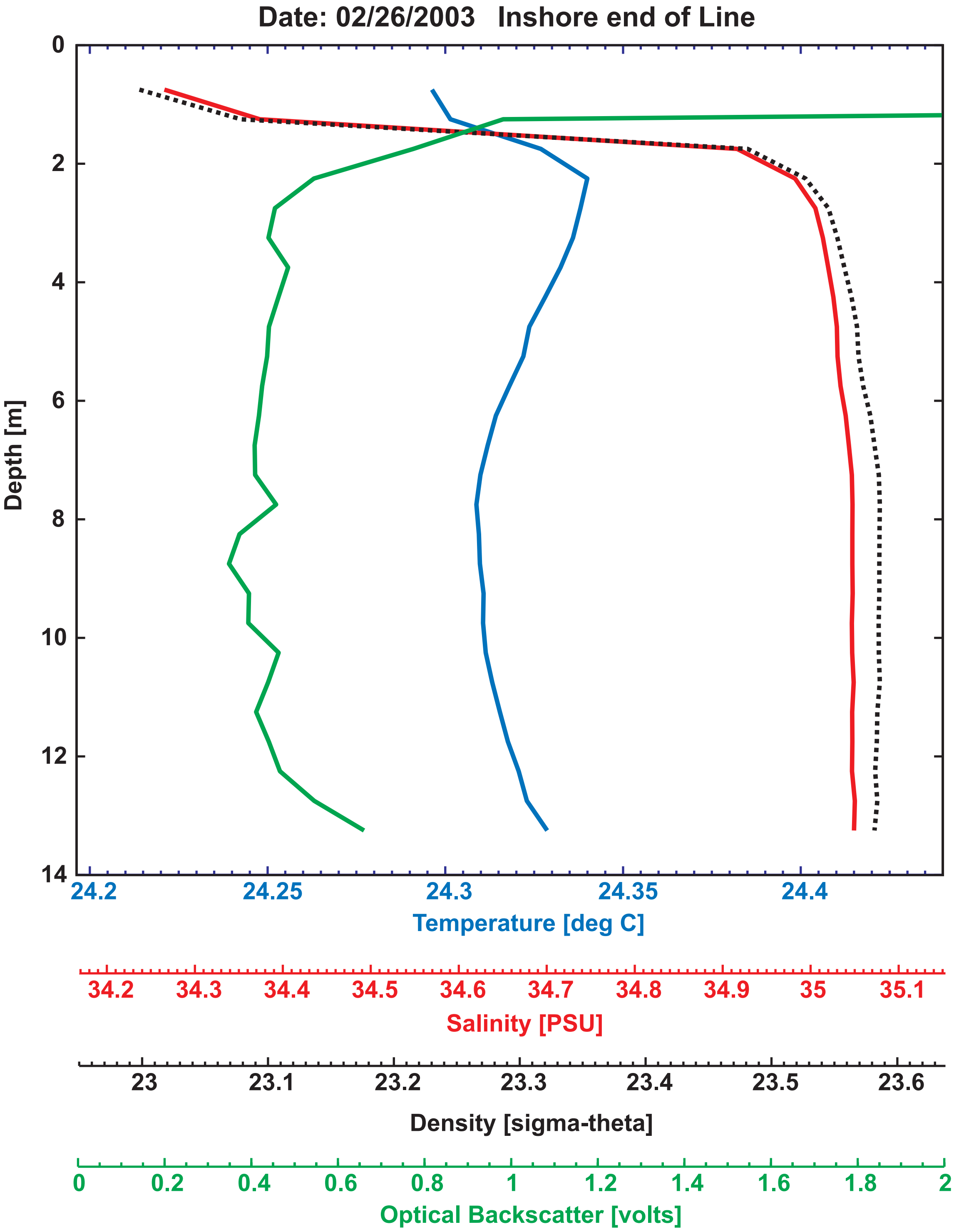

FIGURE 5. *Example of CTD/OBS profiler data collected on the inshore end of the survey line collected on 02/26/2003. Although this cast was taken four days after rainfall, a turbid, low-salinity and low-temperature freshwater surface plume is identifiable in the data due to continued stream discharge. This plume was visible to the naked eye and was also identifiable in the VM-ADCP's acoustic scattering data (FIGURE 4).*

Waves

The waves that impacted Honolua Bay during the course of the experiment are shown in FIGURES 6-8. Significant wave heights (*Hsig*) ranged from between 0.01 m and 1.16 m, with a mean significant height ± one standard deviation of 0.17 ± 0.18 m. Dominant wave periods (*Tdom*) varied from between 2.36 sec and 17.91 sec, with a mean dominant period ± one standard deviation of 8.33 ± 3.16 sec. Peak wave-induced near-bed shear stresses (*taub*) ranged from between 0.001 N/m^2 and 1.749 N/m^2, with a mean shear stress ± one standard deviation of 0.100 ± 0.178 N/m^2. Apparent in the data is the impact of the large, long-period swells generated in the North Pacific during the winter months. Not evident in the data is the very high wave energy gradient in Honolua Bay, with the maximum *Hsig* measured by the Dobie along the 10 m isobath only 1.16 m, while roughly 400-500 further out into the mouth of the bay, *Hsig* during one event were visually estimated to exceed 7 m.

Currents

Current speeds in the study area ranged between < 0.01 m/sec to 1.84 m/sec, with a mean ± one standard deviation of 0.51 ± 0.54 m/sec (~2 km/hr or 1 knots). Maps of depth-averaged currents measured during the VM-ADCP transects are shown in FIGURES 9-11. Flow at the survey lines is primarily alongshore (northeast-southwest). The interaction of this alongshore flow with the headland that borders the eastern side of Honolua Bay appears to result in strong topographic steering. This topographic steering causes the currents to be rotated, up to 180 degrees from their orientation further offshore, in the inner portion of the bay. This rotation of the currents generates what is assumed to be a semi-permanent eddy in the inner portion of the bay during low wave energy conditions. The plot displaying the orientations of net flow and its variability (FIGURE 11b) show that mean flow is primarily to the north and northeast around the headland that borders the east side of Honolua Bay; the mean flow in the innermost portion of the bay, however, is to the southwest, towards Honokahua Bay and DT Fleming State Beach.

Assuming flow remained constant alongshore, which is generally not the case, the range in alongshore current speeds of 0.01 m/sec to 1.84 m/sec, with a mean ± one standard deviation of 0.51 ± 0.54, would result in a total replacement of water along the 1 km width of Honolua Bay in as little time as 17 minutes to as long as 27 hours, with an average replenishment time of 33 minutes. Seeing that a recirculating eddy was observed in the innermost portion of the bay 60% of the time during the surveys, the replenishment rates presented above are likely an order of a magnitude too large during low wave conditions, as the eddies would help to retain water within the innermost portion of the bay. When large waves impact the bay, however, the high wave energy gradient discussed earlier would cause these eddies to break down and would likely drive strong cross-shore flows, flushing out the bay over very short time scales (order of 1-10's of minutes).

Water Column Properties

The water column properties that were collected by the CTD/OBS profiler included measurements of variations in temperature (ºC), salinity (PSU) and raw optical backscatter (volts) with depth; from these data we were able to compute the density of

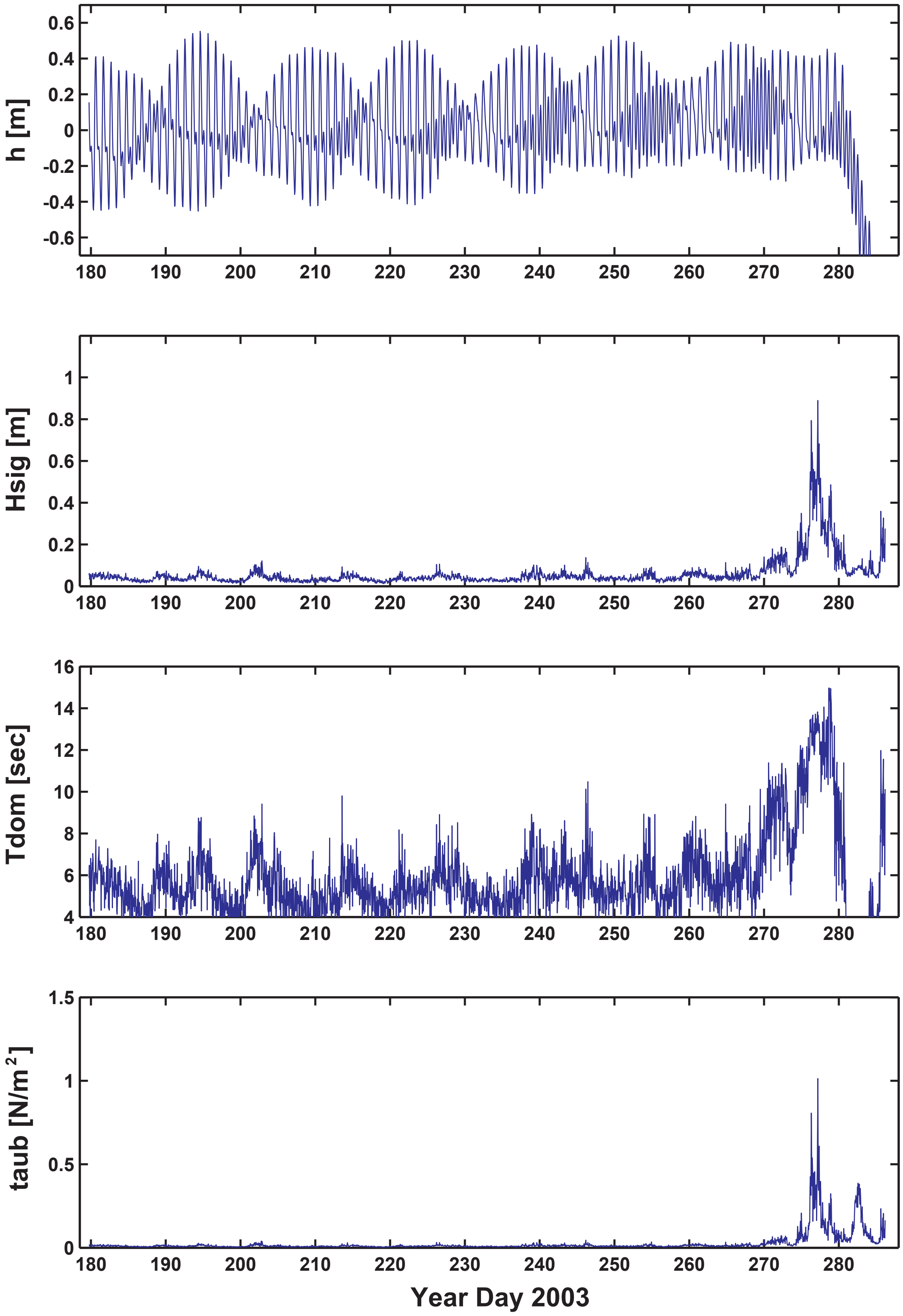

FIGURE 6. *Tide and wave data during the 06/2003-10/2003 deployment from the MegaDOBIE instrument package at a depth of 10 m. From top to bottom: Tidal height (h), significant wave height (Hsig), dominant wave period (Tdom) and peak wave-induced near-bed shear stress (taub). The wave heights, wave periods and shear stresses were all quite low during most of the deployment and were indicative of Trade wind waves. The large, long-period waves that generated high shear stresses near the end of the deployment display the influence of North Pacific winter swell on the study area.*

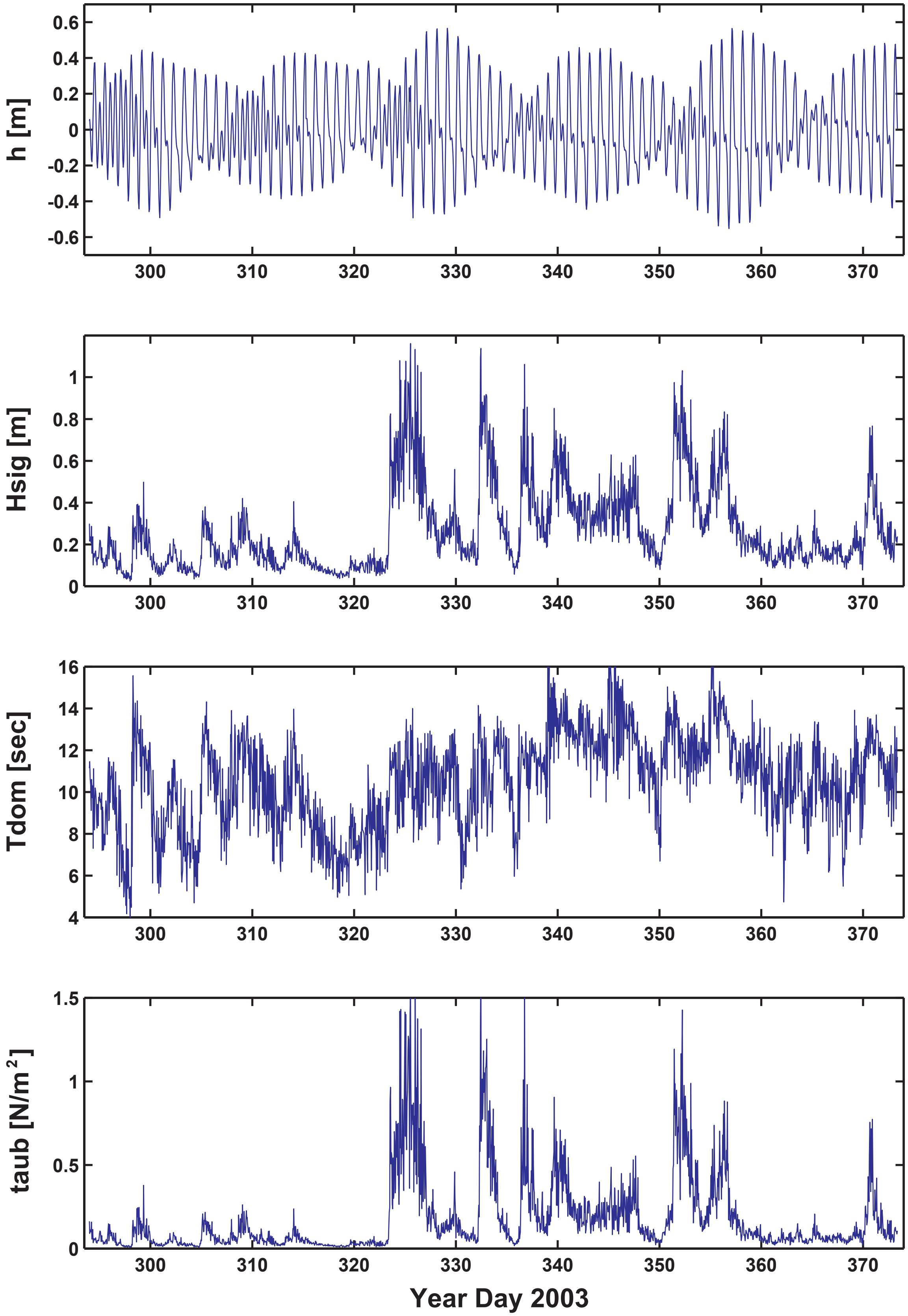

FIGURE 7. *Tide and wave data during the 10/2003-01/2004 deployment from the MegaDOBIE instrument package at a depth of 10 m. From top to bottom: Tidal height (h), significant wave height (Hsig), dominant wave period (Tdom) and peak wave-induced near-bed shear stress (taub). The wave heights, wave periods and shear stresses were all high during the deployment as North Pacific winter swell impacted the study area.*

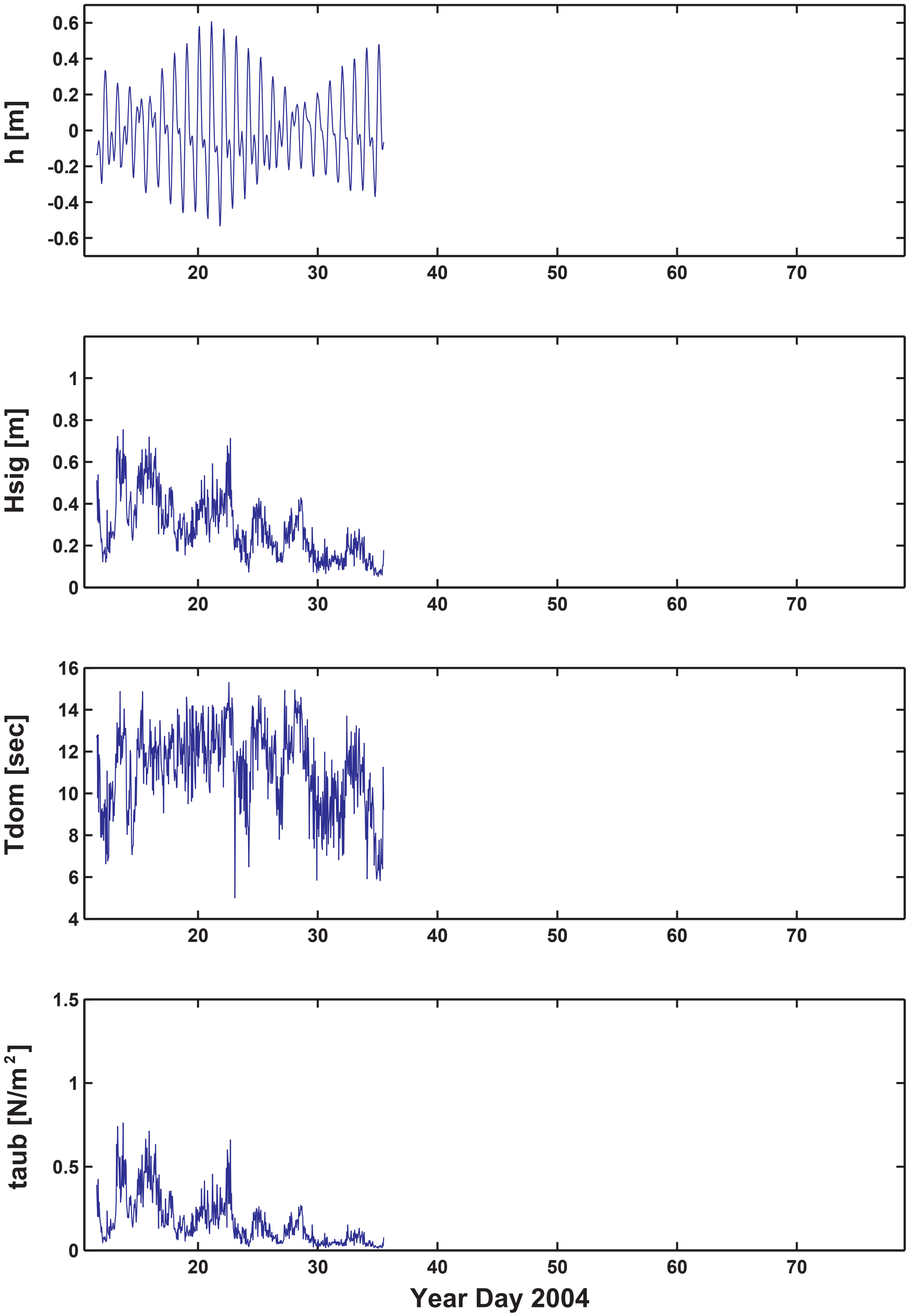

FIGURE 8. *Tide and wave data during the 01/2004-03/2004 deployment from the MegaDOBIE instrument package along the 10 m isobath. From top to bottom: Tidal height (h), significant wave height (Hsig), dominant wave period (Tdom) and peak wave-induced near-bed shear stress (taub). The wave heights, wave periods and shear stresses all decreased from the previous deployment (FIGURE 7), as the frequency of North Pacific winter swell declined and Trade wind waves again became the dominant wave climate in the study area.*

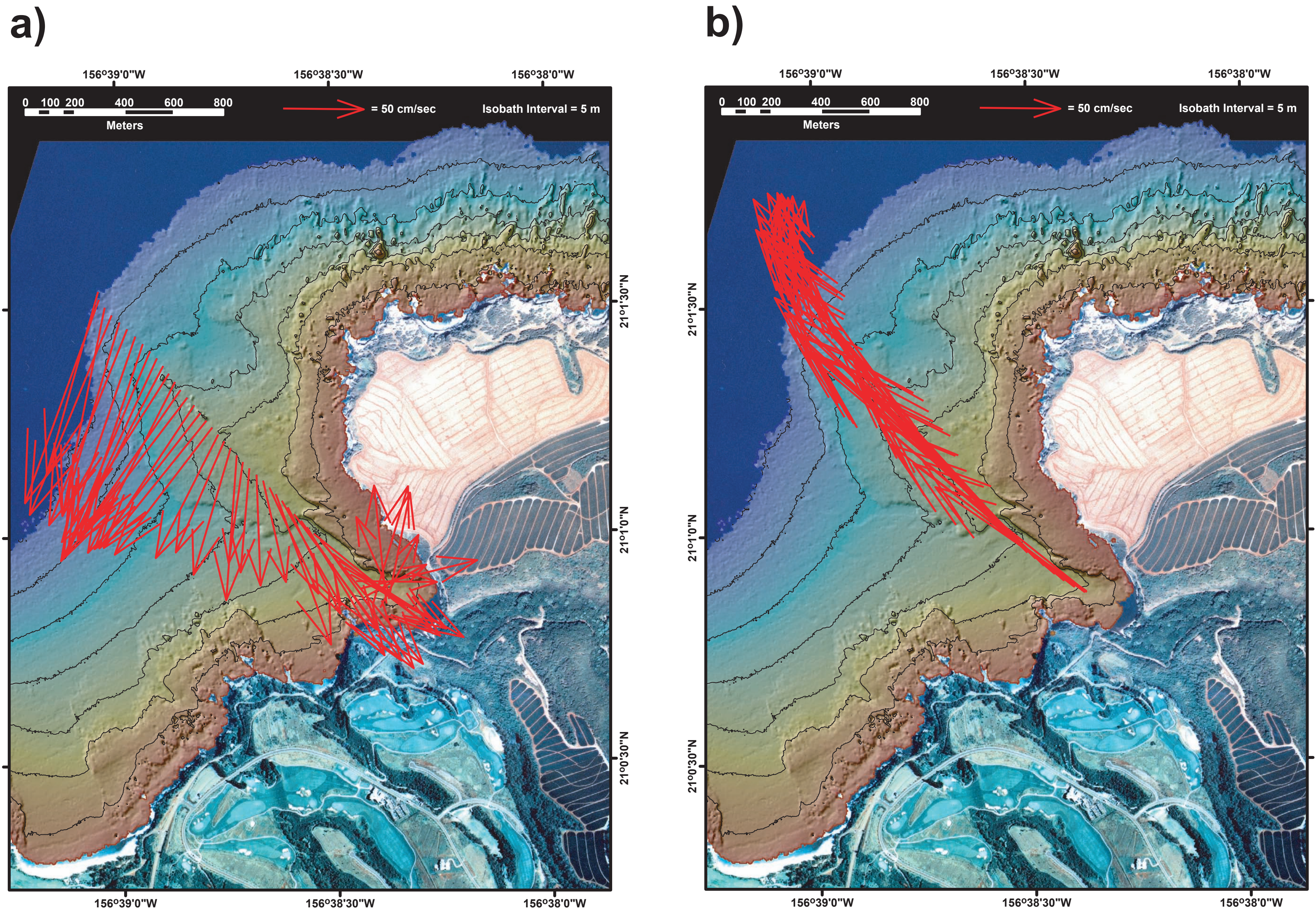

FIGURE 9. *Flow patterns in Honolua Bay measured by the VM-ADCP. (a) On 02/28/2003. (b) On 06/30/2003. Note the stronger flow offshore and the change in orientation of the flow inshore on the map in Part "a", suggesting the presence of an eddy in the inner portion of the bay. The map in Part "b" shows a strong flushing event of the bay, the cause of which is unknown.*

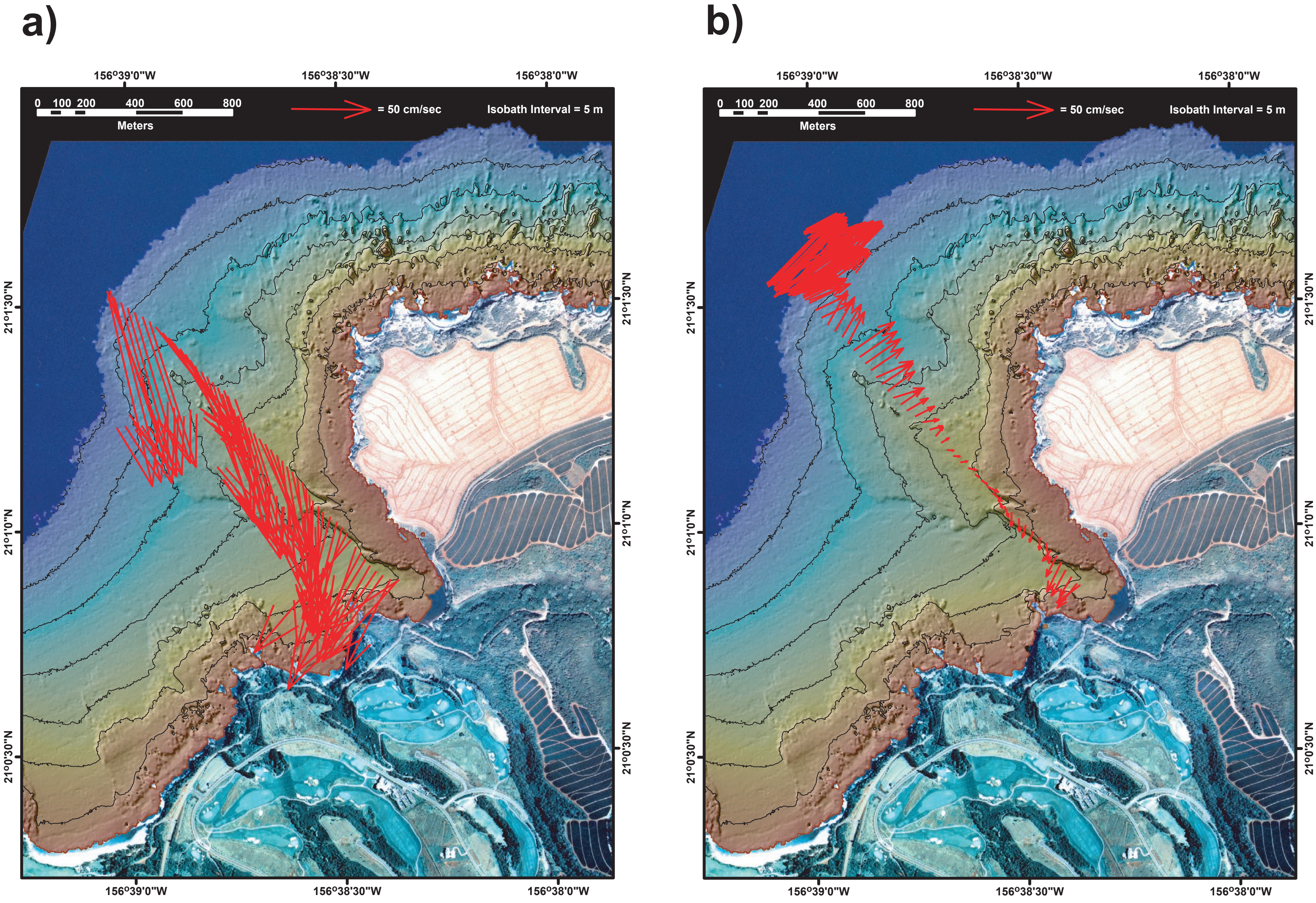

FIGURE 10. Flow patterns in Honolua Bay measured by the VM-ADCP. (a) On 07/01/2003. (b) On 07/02/2003. Note the stronger flow offshore and the change in orientation of the flow in the inner portion of the bay, suggesting the presence of an eddy on both days.

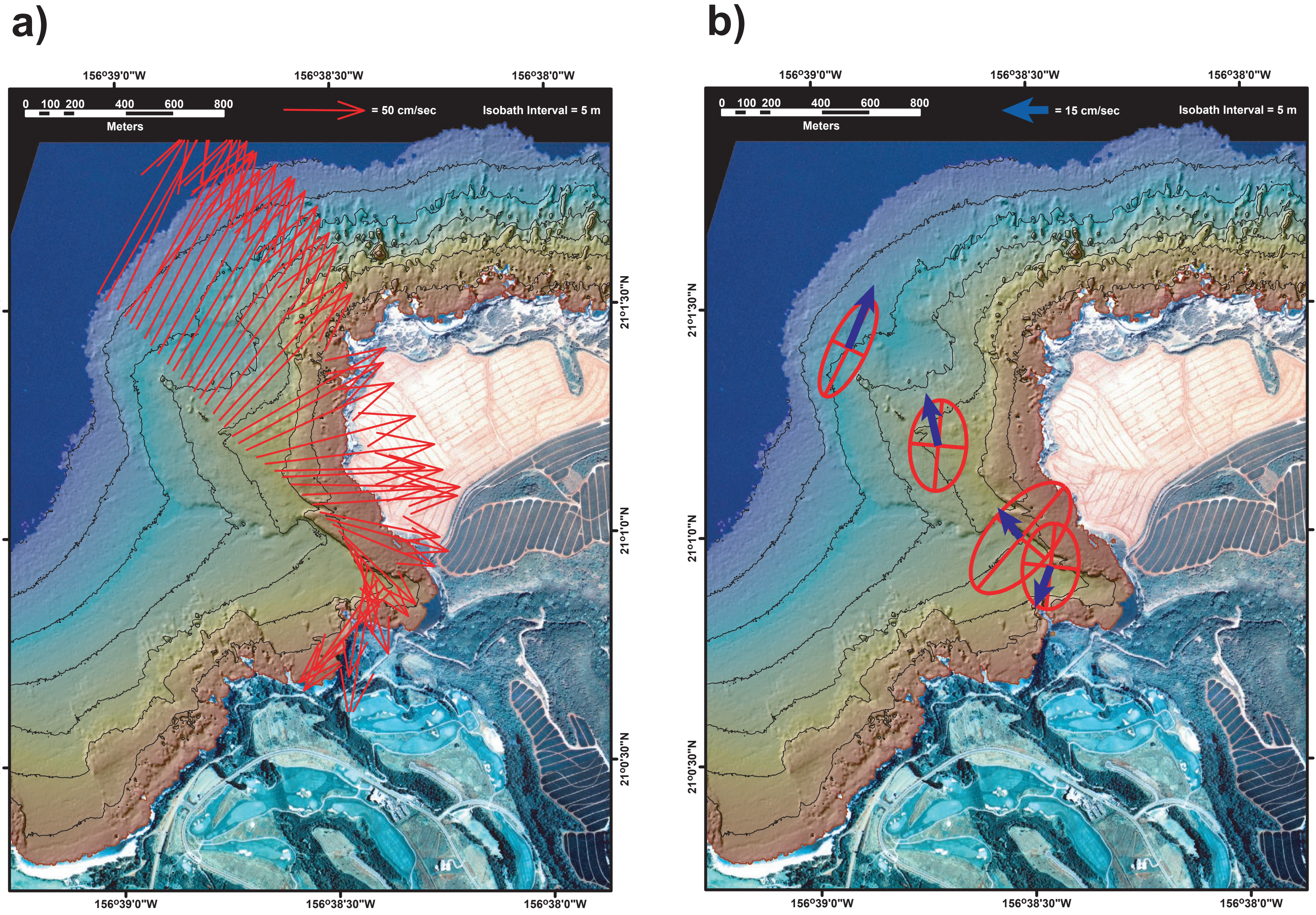

FIGURE 11. *Flow patterns in Honolua Bay measured by the VM-ADCP. (a) On 07/04/2003. Note the stronger flow offshore and the change in orientation of the flow inshore of part "a", suggesting the presence of an eddy in the inner portion of the bay. (b) Principal axes of flow at different distances along the VM-ADCP survey lines calculated from all of the VM-ADCP survey data. The red ellipses denote the major (longer) and minor (shorter) axes of flow, with the major axis of flow being oriented roughly parallel to shore. The blue arrows denote the direction and magnitude of mean flow at each of the locations. Note the different orientations in the principal axes of flow and the different orientations in mean flow closer to shore than those measured further offshore, suggesting bathymetric steering of currents by the headland along the eastern side of Honolua Bay.*

seawater (sigma-theta). Only vertical profiles of temperature, salinity and raw optical backscatter will be addressed in this report. The water column properties that were collected by the long-term, bottom-mounted instruments included variations in temperature (ºC), salinity (PSU) and optical backscatter (NTU).

Variability in Temperature, Salinity, Turbidity and Density with Depth:

The overall trends for the variation in water column properties with depth over both survey periods display two dominant modes: turbid buoyant freshwater surface plumes inshore and two-layer structure offshore (FIGURE 12). Overall, optical backscatter decreased with depth while salinity and density increased with depth. At the shallow ends of the survey lines, the higher backscatter but lower temperature, salinity and density at the surface are indicative of the influence of a turbid buoyant freshwater surface plume, likely due to runoff from Honolua Stream. The temperature typically rose to its maximum just below the surface, below which it decreased slowly towards the bed. Optical backscatter generally decreased logarithmically towards the bed, typically reaching base levels 2 m below the water's surface; this suggests the slow settling of material (likely fine-grained terrestrial sediment and/or organics) from the surface plume. The low salinity and density near the surface also support the presence of a buoyant freshwater surface plume.

The waters further offshore are generally less turbid, cooler, more saline and denser than those measured closer to shore. The effects of the turbid buoyant freshwater surface plumes can still be identified at the offshore ends of the survey lines by their lower temperature and higher optical backscatter; the low salinity and densities observed in the inner portion of the bay, however, were not observed at the offshore ends of the survey lines. More important, however, were the presence of two-layer structures in the water column that were clearly identified in the individual casts but are manifested in the mean profiles as a general decrease in temperature and increase in salinity and density with depth. The differences between the overlying warmer water mass and the deeper cooler water mass were often on the order of 0.25 ºC.

***Temporal Variability in Temperature*:**

Over the first deployment when high-quality data were available (06/2003-10/2003), water temperatures roughly 0.5 m above the bed at the site along the 10 m isobath ranged between 24.85 °C and 27.59 °C, with a mean temperature ± one standard deviation of 26.20 ± 0.55 °C (FIGURE 13). The water typically warmed 0.2-0.6 °C during the day, likely due to insolation. Over time scales longer than tidal periods (>24 hours), temperature increased throughout the summer due to insolation. Cyclic variations in temperature over a roughly 14-day period were observed and were likely due to the propagation of cooler, deeper water from father offshore being advected into the 10 m isobath, possibly due to the same internal tides that were observed by Storlazzi and Jaffe (2003) a few kilometers south off Kahana from 2001-2003.

***Temporal Variability in Salinity*:**

Over the first deployment when high-quality data were available (06/2003-10/2003), water salinities roughly 0.5 m above the bed ranged between 33.15 PSU and 35.12 PSU, with a mean salinity ± one standard deviation of 34.82 ± 0.22 PSU

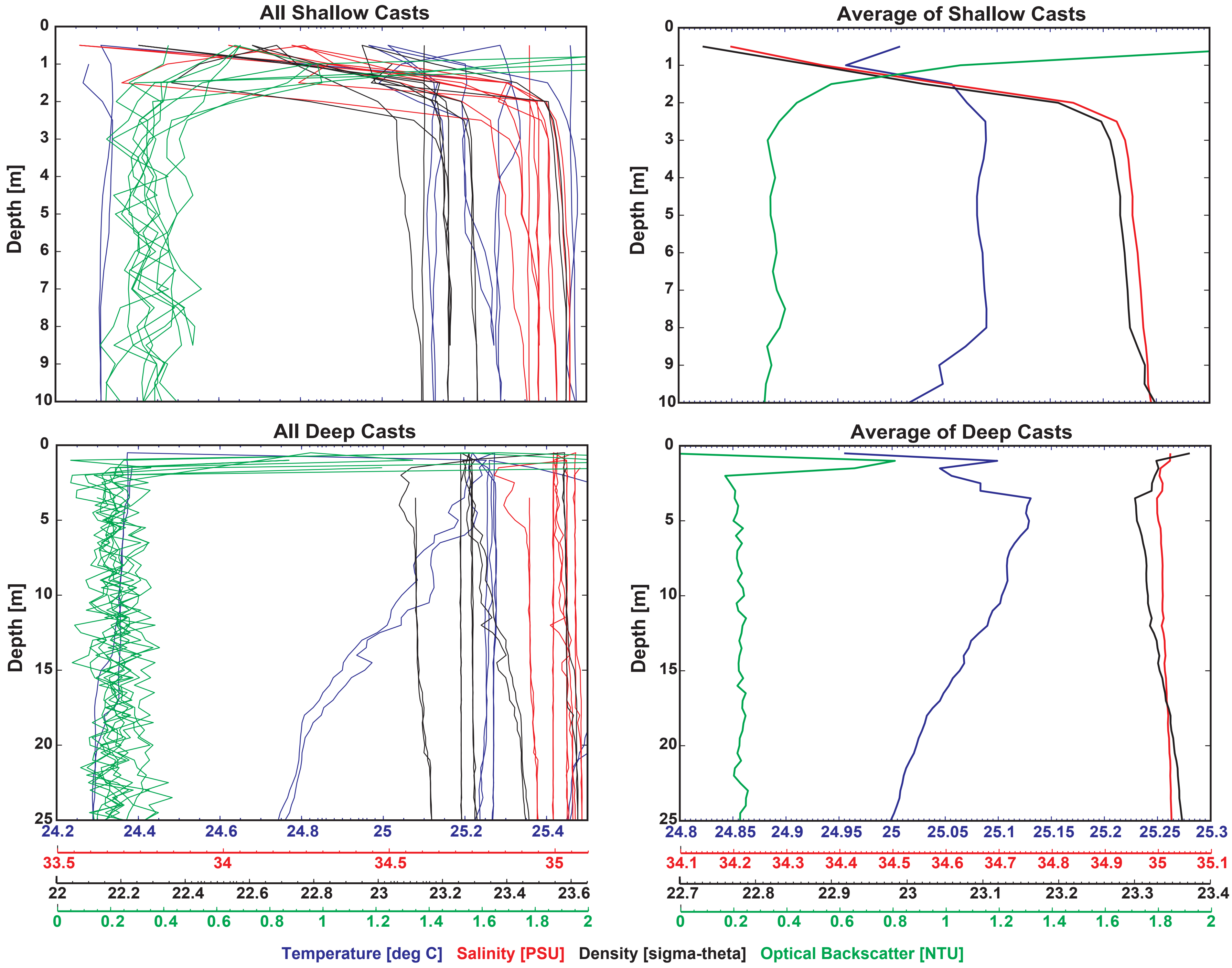

FIGURE 12. *Plots of mean variation in CTD/OBS profiler data with depth during the cruises. Turbidity is typically higher and salinity and temperature are lower right at the surface due to freshwater runoff close to shore. Turbidity and temperature then decrease with depth as salinity increases closer to the bed.*

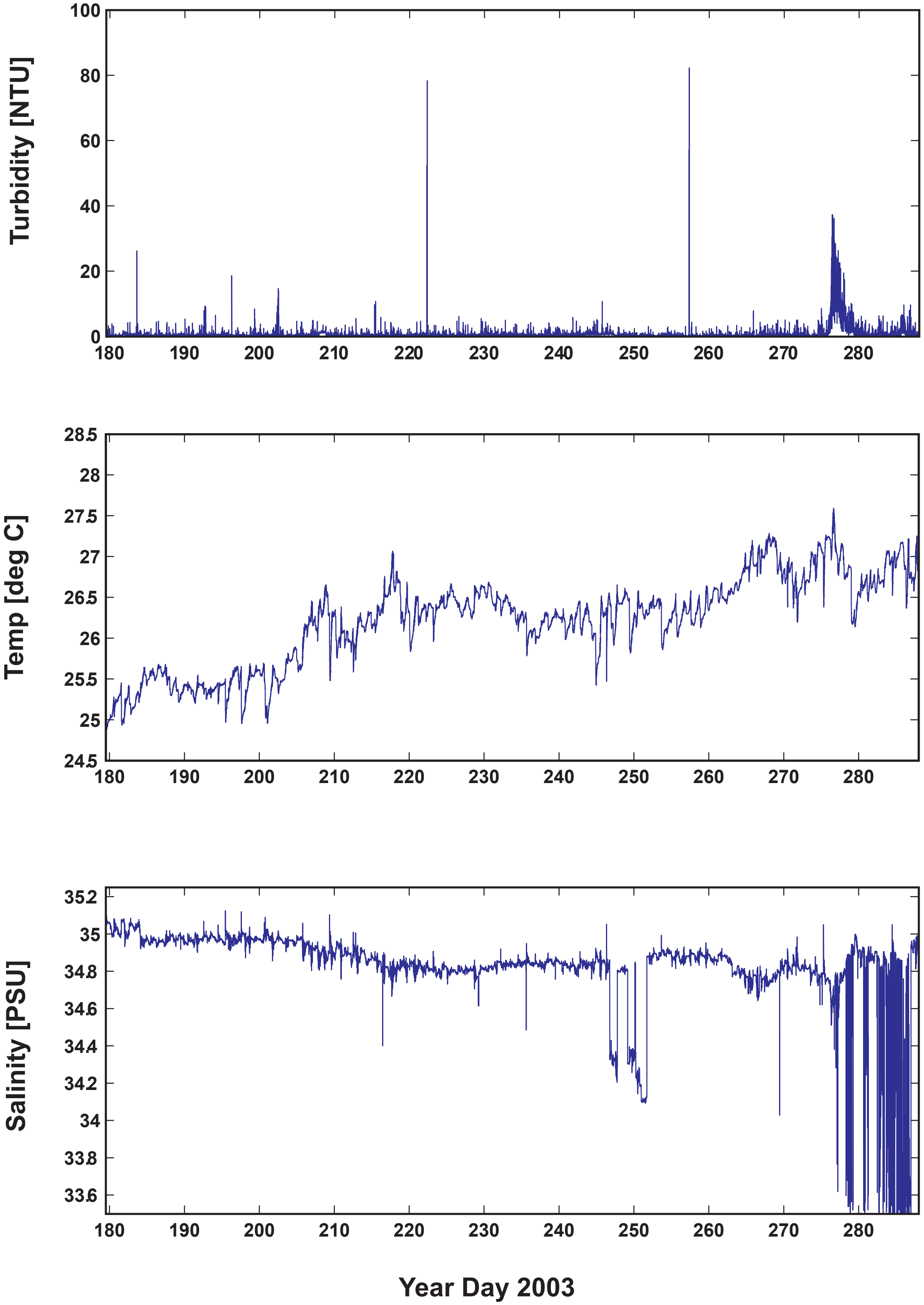

FIGURE 13. *Variability in water column properties during the 06/2003-10/2003 deployment from the MegaDOBIE instrument package at a depth of 10 m. Top panels: turbidity from the SCOBS. Middle panel: temperature from the Microcat. Bottom panel: salinity from the Microcat. The large, sustained increase in turbidity at the end of the deployment are due to the large waves that impacted the site, as shown in FIGURE 6. Temperature increased throughout the summer due to insolation. The sustained decreases in the salinity are likely due to rainfall and stream flow or submarine groundwater discharge.*

(FIGURE 13). Similar to temperature, the variability in salinity had a roughly 14-day cyclicity, which is also likely due to the propagation of cooler, deeper water from father offshore being advected into shallower water past the 10 m isobath due to the internal tides. The large, sustained decreases in salinity are likely either due to freshwater discharge from Honolua Stream or due to submarine groundwater discharge through the reef, which was often observed in the field during instrument deployment or recovery operations.

The variability in salinity as a function of temperature is shown in FIGURE 14. Most of the data display the typical decrease in temperature with increasing salinity. This trend is indicative of colder, more saline waters (generally deeper offshore water) being advected in under lower salinity, warmer surface waters that form a stable water column. The cooler, more saline values are likely due to either weak wind-driven upwelling or tidal pumping. The greater scatter of some of the data is due to different water masses, likely due to the influence of freshwater effluence through the reef or direct runoff from Honolua Stream. The higher variability in salinity with temperature occurred during the later part of the deployment when more precipitation fell (Storlazzi et al., 2004), causing more freshwater to be in the system.

***Temporal Variability in Turbidity*:**

Over the period of study, the burst-averaged turbidity roughly 0.2 m above the bed at the site along the 10 m isobath ranged between 0.0 NTU and 1418.5 NTU, with a mean turbidity ± one standard deviation of 3.0 ± 15.3 NTU (FIGURES 13 and 15); the 10% exceedence and 2% exceedence levels are 5.8 NTU and 20.2 NTU, respectively. These values exceed, by more than 5-10 times, the State of Hawaii Department of Health's Administrative Rules, Title 11, Chapter 54, Water Quality Standards for "open ocean out to 600 foot depth" (defined on page 54-30 of that report), which define wet season turbidity levels (which are roughly twice those of dry season levels) of 0.50 NTU, 1.25 NTU and 2.00 NTU for the mean, 10% exceedence and 2% exceedence levels, respectively. The highest turbidity values were related to large wave events (FIGURES 6-8), periods following high rainfall, or both. It is not clear whether the high turbidity during large wave events was caused by the surface waves resuspending the predominantly calcareous sand-sized seafloor sediment at the site, or silt- and/or clay-sized sediment inshore of the sites, which would be advected seaward by wave-induced downwelling flows and imaged by the optical backscatter sensors.

CONCLUSIONS

In all, 5 km of high-resolution VM-ADCP profile data and 10 CTD/OBS casts were collected in Honolua Bay off northwestern Maui, Hawaii, USA during the winter and summer of 2003. These data were collected along shore-normal transects between the 4 m and 50 m isobaths and included CTD/OBS casts at the offshore and inshore ends of each transect line. More than 4800 hourly observations of waves and tides were collected at a fixed location on the 10 m isobath over the course of 9 months between June 2003 and March 2004; more than 93300 observations of turbidity were collected every 4 minutes over this time period. Just over 39500 observations of temperature and salinity at a depth of 10 m were collected over the course of 4 months between June

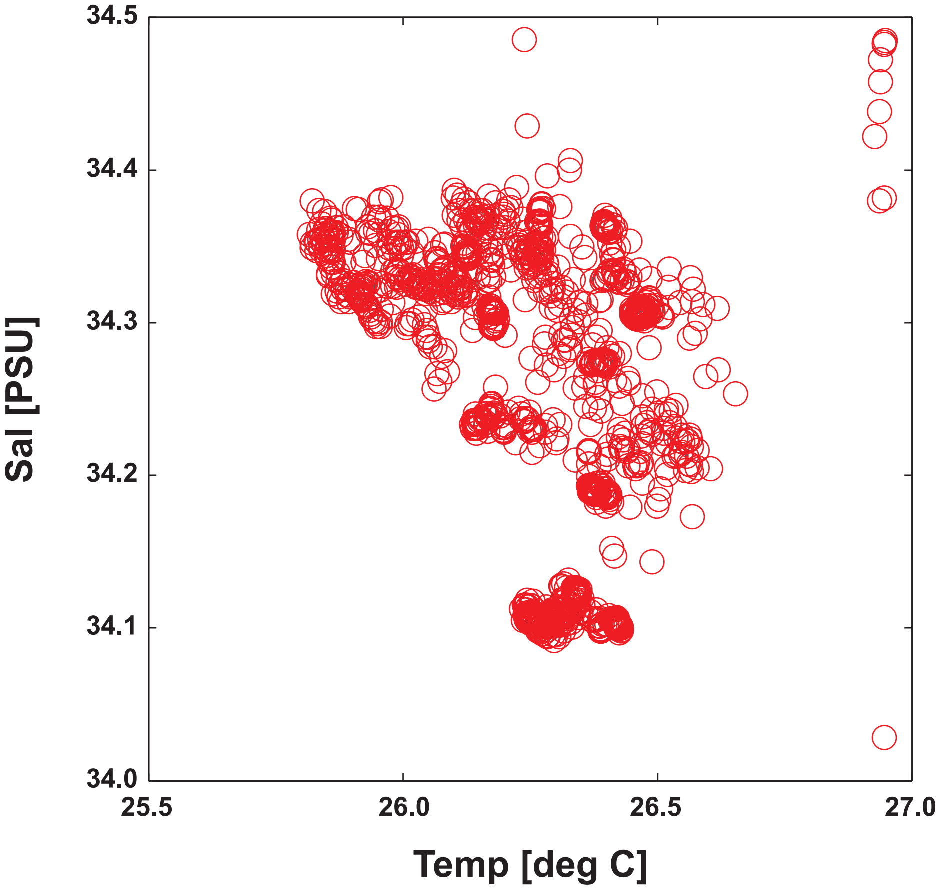

FIGURE 14. *Variation in salinity as a function of temperature from the MegaDOBIE instrument package at a depth of 10 m during the 06/2003-10/2003 deployment. The data display more than one distinct water mass in the study area: one with high salinity and a wide range of temperatures, and another with a small temperature range but with a wide range in salinity. These distinct signatures are likely heavily influenced by freshwater runoff from streams or groundwater effluence through the reef.*

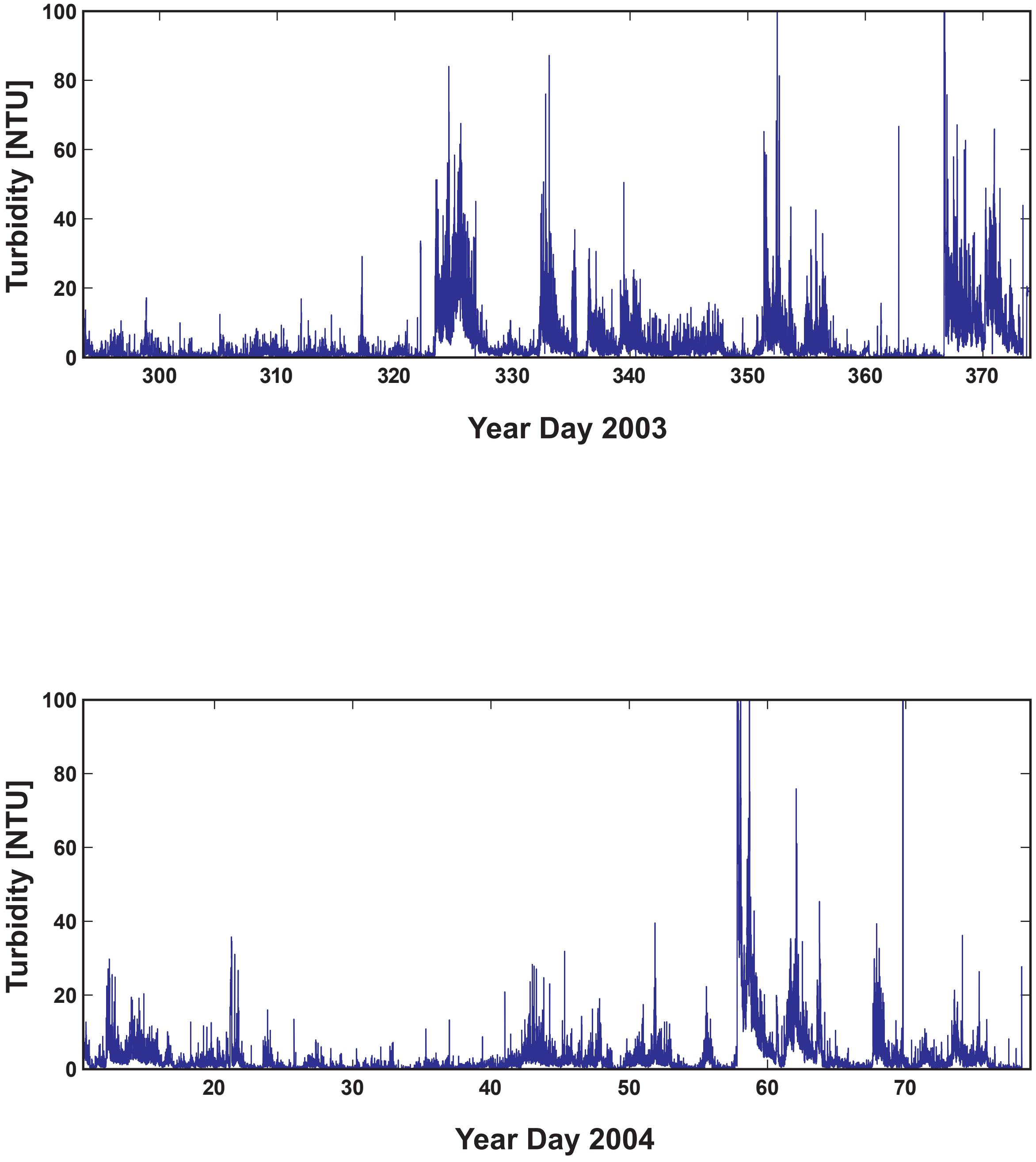

FIGURE 15. *Variability in turbidity during the 10/2003-01/2004 and 10/2003-01/2004 deployments from the MegaDOBIE instrument package at a depth of 10 m. Top panel: during the 10/2003-01/2004 deployment. Bottom panel: during the 10/2003-01/2004 deployment. The large, sustained increases in turbidity during the deployments are due to the large waves that impacting the study area, as shown in FIGURES 7-8*

2003 and November 2003 in Honolua Bay. Key findings from these measurements and analyses include:

(1) There is a persistent eddy in Honolua Bay during low wave energy conditions. Current speeds are greater further offshore and the direction of flow is primarily alongshore. Mean flow offshore is primarily to the north and northeast around the headland that borders the east side of Honolua Bay; the mean flow in the innermost portion of the bay, however, is to the southwest. This suggests significant steering by the coastline.

(2) High turbidity was generally correlated with one of two processes: large wave events that resuspended fine-grained bed sediment and turbid freshwater runoff from the Honolua Stream.

(3) The water in Honolua Bay is generally more saline and cooler further offshore and with increasing depth. These general trends, however, are greatly influenced by the presence of freshwater either from stream discharge or groundwater effluence through the reef.

These data provide us with a much clearer picture of the nature of, and controls on, flow and water column properties in the study area. A number of interesting phenomena were observed that indicate the complexity of coastal circulation in Honolua Bay and may help to better understand the implications of the processes on coral reef health.

ACKNOWLEDGEMENTS

This work was carried out as part of the USGS's Coral Reef Project as part of an effort in the U.S. and its trust territories to better understand the affect of geologic processes on coral reef systems. Project Chief Michael Field deserves thanks for providing us with the opportunity and support to carry out these deployments. Rebecca Stamski contributed as part of the ongoing USGS/University of California at Santa Cruz's Cooperative Studies Program. We would like to thank Joe Reich, the captain of the *R/V Alyce C.*, who piloted and navigated during during our numerous instrument deployments. As always, Eric Brown (University of Hawaii's Institute for Marine Biology) overextended himself by helping us pick a site, cleaning and checking the instrument packages. Joshua Logan (USGS) helped during most of the boat operations, produced the maps we used in the field and in this report, and collected most of our geospatial information, and for that we owe him much thanks. We would also like to thank Ann Gibbs (USGS), who contributed numerous excellent suggestions and a timely review of our work.

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TABLE 1. Experiment personnel

Person	Affiliation	Responsibilities
Curt Storlazzi	USGS	Chief scientist, led scuba diving operations, led CTD/OBS profiler data acquisition
Joshua Logan	USGS	Led navigation acquisition, scuba diver
Margaret McManus	UCSC	Scientist, oversaw VM-ADCP operations
Brian McLaughlin	UCSC	Led VM-ADCP data acquisition
Olivia Cheriton	UCSC	Helped VM-ADCP data acquisition
Kathy Presto	UW/USGS	Instrument support
David Gonzales	USGS	Instrument support
Scot Lucas	CADFG	Instrument support, scuba diver
Rebecca Stamski	UCSC	Instrument support, scuba diver
Dana Wingfield	UCSC	Instrument support
Eric Brown	UH	scuba diver
Joe Reich		Captain, *R/V Alyce C.*

TABLE 2. VM-ADCP profiler log: 02/2003 and 06/2003 - 07/2003

Cruise ID	Island ID	Local Date	Local Time	Line ID
A-3-03-HW	MA	2/26/2003	12:10	030226_20
A-4-03-HW	MA	6/30/2003	10:55	030630_20
A-4-03-HW	MA	7/1/2003	9:20	030701_20
A-4-03-HW	MA	7/2/2003	10:20	030702_20
A-4-03-HW	MA	7/3/2003	9:05	030703_20

TABLE 3. CTD/OBS profiler log: 02/2003 and 06/2003 - 07/2003

Cruise ID	Island ID	Local Date	Local Time	Site/Line ID	Latitude [dd]	Longitude [dd]
A-3-03-HW	MA	02/26/2003	11:59	030226_20N	21.0154780	-156.6412026
A-3-03-HW	MA	02/26/2003	12:18	030226_20F	21.0255229	-156.6510495
A-4-03-HW	MA	06/30/2003	10:40	030630_20N	21.0148203	-156.6398803
A-4-03-HW	MA	06/30/2003	11:16	030630_20F	21.0259276	-156.6506077
A-4-03-HW	MA	07/01/2003	9:10	030701_20N	21.0145430	-156.6395307
A-4-03-HW	MA	07/01/2003	9:30	030701_20F	21.0255856	-156.6507807
A-4-03-HW	MA	07/02/2003	10:11	030702_20N	21.0152151	-156.6409875
A-4-03-HW	MA	07/02/2003	10:28	030702_20F	21.0256831	-156.6506794
A-4-03-HW	MA	07/03/2003	8:53	030703_20N	21.0151628	-156.6399215
A-4-03-HW	MA	07/03/2003	9:12	030703_20F	21.0256001	-156.6507058

TABLE 4. MegaDOBIE deployment log: 06/2003 - 03/2004

Instrument	Island ID	Depth (m)	Deployment Date	Recovery Date	Latitude (dd)	Longitude (dd)
MegaDOBIE	MA	10	06/27/03	10/15/03	21.01523	-156.63997
MegaDOBIE	MA	10	10/20/03	01/09/03	21.01523	-156.63997
MegaDOBIE	MA	10	01/11/04	03/20/04	21.01523	-156.63997

APPENDIX 1

Vessel-Mounted Acoustic Doppler Current Profiler (VM-ADCP) Information

Instrument:

RD Instruments 600 kHz Workhorse Monitor; s/n: 3098

Transmitting Frequency:	614 kHz
Depth of Transducer:	1 m
Blanking Distance:	0.5 m
Depth of First Bin:	1.5 m
Bin size / number of bins:	1.0 m / 40
Operating Mode:	High-resolution, broad bandwidth
Bottom-track:	enabled
Sampling Frequency:	4 Hz
Beam Angle:	20 deg
Time per Ping:	00:00:00.30
Pings per Ensemble:	1
Time per Ensemble:	00:00:02.00
Sound Speed Calculation:	Set salinity, updating temperature via sensor

Position Information:

Garmin GPS-76 GPS; s/n: 80207465; USGS/CRP unit#1
RDI internal compass/gyroscope, set to –10 deg magnetic offset

Data Log File Name: “0302_CRP_ADCPprofiler_log.xls”

Total Profiles: 110

Profile Lengths:	Minimum:	253 m
	Maximum:	1897 m
	Mean:	997 m

ADCP Profile Naming Convention: “YYMMDD_LL”, with:

YY = year (03)
MM = month (02)
DD = day (18-26)
LL = line number (1-22)

Thus, “030218_02” was taken on 02/18/2003 on line #2

Navigation File Name: Navigation data are embedded in the ADCP data files.

Data Processing:

The data were averaged over 10-bin (10 sec) ensembles, all of the spurious data below the seafloor were removed and all of the data in bins where the beam correlation dropped below 70% were removed for visualization and analysis.

APPENDIX 2

Conductivity/Temperature/Depth (CTD) Profiler with Optical Backscatter Sensor (OBS) Information

Instruments:
Seabird 19plus CTD; s/n: 4299; calibrated 10/08/2002
D&A Instruments OBS-3; s/n: 1983; calibrated 10/24/2002
Sampling Frequency: 4 Hz

Position Information:
Garmin GPS-76 GPS; s/n: 80207465; USGS/CRP unit#1

Data Log File Name: “0302_CRP_CTDprofiler_log.xls”

Total Casts: 211

Cast Depths: Minimum: 4 m
Maximum: 43 m
Mean: 15 m

CTD Cast Naming Convention: “YYMMDD_LLP”, with:
YY = year (03)
MM = month (02)
DD = day (18-26)
LL = line number (1-22)
PP = position on line (“F” for offshore end of line, “N” for onshore end of line)

Thus, “030630_02F” was taken on 06/30/2003 at the offshore end line #2

Navigation File Names: embedded in Data Log File

Data Processing:

The data were averaged into 0.5 m vertical bins and all of the spurious data marked by a flag in the raw data were removed for visualization and analysis. Stratification were measured as the difference between the mean of the top three bins (0.5-1.5 m below the surface) and the bottom three bins (0.5-1.5 m above the bed).

APPENDIX 3

MegaDOBIE Sensor Information

Instruments:

NIWA Dobie-A Pressure Sensor
- Depth of Transducer: 10 m
- Operating Mode: Time series
- Sampling Frequency: 2 Hz
- Measurements per Burst: 1024
- Time Between Bursts: 01:00:00.00

Aqautec/Seapoint 200-TY optical-backscatter sensor
- Sampling Frequency: 2 Hz
- Measurements per Burst: 30
- Time Between Bursts: 00:04:00.00

Seabird Microcat SBE-37SM temperature and salinity sensor
- Sampling Frequency: 2 Hz
- Measurements per Burst: 30
- Time Between Bursts: 00:04:00.00

Data Processing:

The Dobie water level data were averaged over the entire 20 min burst to compute tidal height while hourly significant wave height and dominant wave period data were computed spectrally using the USACE SUPERDUCK method. The SCOBS and CT data were post-processed for visualization and analysis by removing all instantaneous (only one data point in time) data spikes that exceeded the deployment mean + 3 standard deviations.

Position Information:

Garmin GPS-76 GPS