Coastal Circulation and Sediment Dynamics in Hanalei Bay, Kauai

PART I:

Measurements of waves, currents, temperature, salinity and turbidity: June – August, 2005

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

Open-File Report 2006-1085

QuickBird satellite image of Hanalei Bay

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ADDITIONAL DIGITAL INFORMATION

For additional information on the instrument deployments, please see:
http://walrus.wr.usgs.gov/infobank/a/a105ka/html/a-1-05-ka.meta.html
http://walrus.wr.usgs.gov/infobank/s/s105ka/html/s-1-05-ka.meta.html

For an online PDF version of this report, please see:
http:// pubs.usgs.gov/of/2006/1085/

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 Hanalei Bay, northern Kauai, Hawaii, during the summer of 2005 to better understand coastal circulation and sediment dynamics in coral reef habitats. A series of bottom-mounted instrument packages were deployed in water depths of 10 m or less to collect long-term, high-resolution measurements of waves, currents, water levels, temperature, salinity and turbidity. These data were supplemented with a series of vertical instrument casts to characterize the vertical and spatial variability in water column properties within the bay. The purpose of these measurements was to collect hydrographic data to learn how waves, currents and water column properties vary spatially and temporally in an embayment that hosts a nearshore coral reef ecosystem adjacent to a major river 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 first part in a series, describes data acquisition, processing and analysis.

Project Objectives:

The objective of these deployments was to understand how currents, waves, tides, temperature, salinity and turbidity vary spatially and temporally in Hanalei Bay. To meet the objectives of the Coral Reef Project, flow and water column properties in Hanalei 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 instrument packages were deployed over a 3-month period during the summer of 2005. A series of vertical profiles were collected during the instruments deployments in June, 2005, to characterize the vertical and spatial variability in water column properties within the bay. Data collected during these instrument deployments provide baseline information for future watershed restoration projects proposed by the U.S. Coral Reef Task Force's (USCRTF) Hawaiian Local Action Strategy (LAS) to address Land-Based Pollution (LBP) threats to coral reefs in the Hanalei ahupua'a (linked watershed-reef system).

Study Area:

Spatial and temporal measurements were made in Hanalei Bay, on the north side of Kauai, Hawaii, USA (FIGURE 1). All instrument packages were situated on the sandy seabed in water depths less than 10 m. All vessel operations, including mobilization and demobilization, were based out of Hanalei Bay.

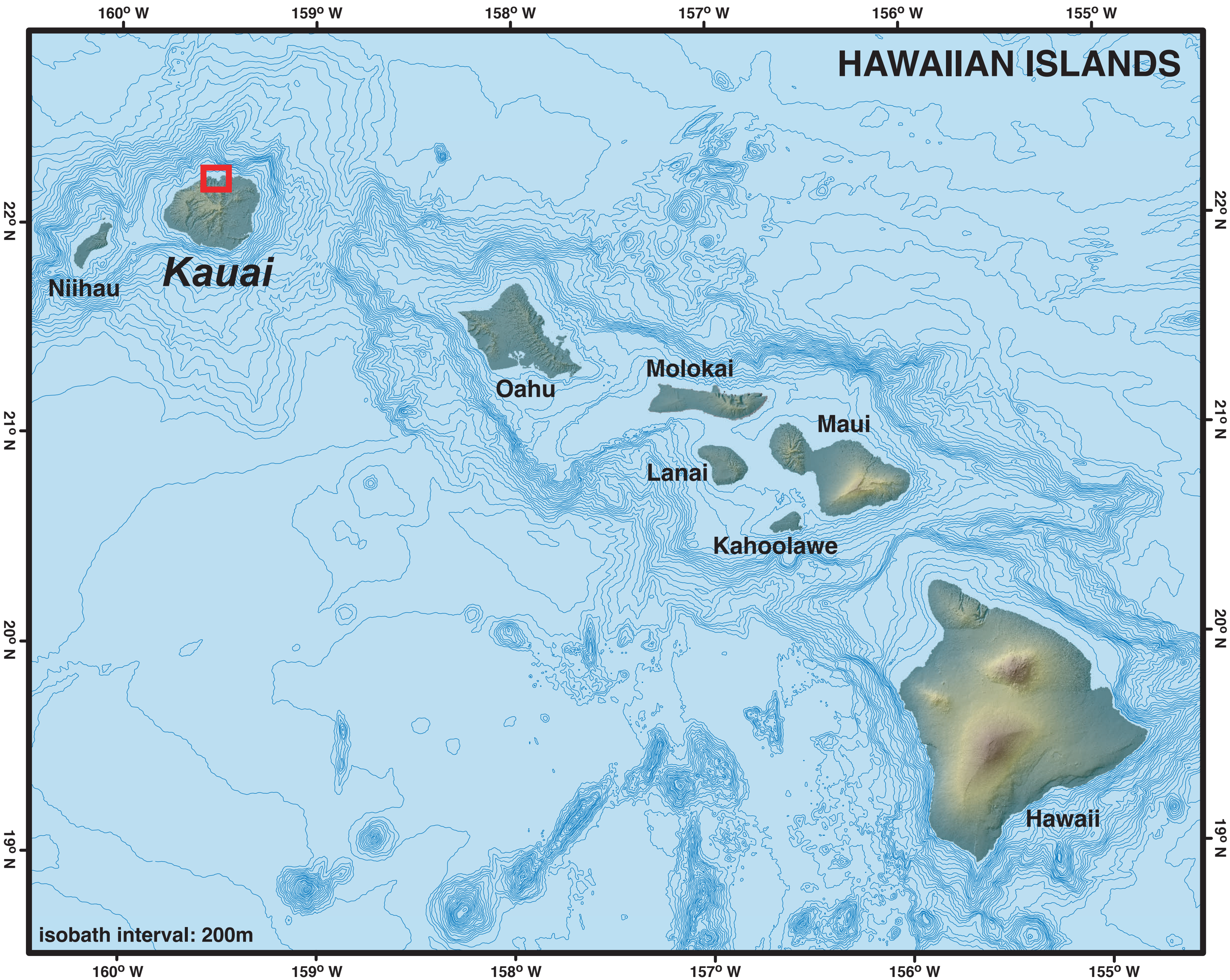

FIGURE 1. *Map of the study area location in relation to the main Hawaiian Island chain. Hanalei Bay is exposed to the large North Pacific swell during the winter but is relatively protected form the Northeast Trade winds during the summer.*

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:

Three USGS scientists deployed the bottom-mounted instrument deployments. The team for instrument deployment and recovery operations included the vessel captain as well. Vertical profiles were collected by a scientist aboard the boat concurrently with the instrument deployments.

Equipment and Data Review:

FIGURE 2 shows the location where instrument packages were deployed for extended periods (large orange circles) and where vertical profile casts were made (small white circles). Up to four different instruments, measuring waves, currents, temperature and salinity, were employed at each long-term sampling site. In some instances, more than one of the same instruments was used at a give site to measure the parameters at various depths. A summary of instrument packages and depths at which they were deployed is provided in TABLE 2. The instruments included self-contained RD Instrument 600 kHz upward-looking Acoustic Doppler Current Profilers (ADCPs), NIWA Dobie-A wave/tide gauges, Aquatec/Seapoint 200-TY and 210-TYT self-contained optical backscatter sensors (SCOBSs), and Seabird SBE-37SM Microcat conductivity-temperature sensors (FIGURE 3). The ADCPs collected vertical profiles of current speed and direction, which, in conjunction with the recorded pressure data, can be used to calculate wave height, wave period and wave direction. The Dobies, SCOBS, and Microcats collected single-point measurements of waves and tides, turbidity, and temperature and salinity, respectively.

The oceanographic instruments were deployed for a 76-day period. The sensors made measurements using three sampling schemes. The ADCP (FIGURE 3a) collected water depth and current information for 512 sec bursts at 2 Hz every 2 hours to provide directional wave and tide information. The Dobies (FIGURE 3b) collected 512 sec bursts at 2 Hz every hour to provide non-directional wave and tide information; the ADCP, SCOBS and Microcat (FIGURE 3c) recorded current profiles, turbidity, temperature and salinity data, respectively, every 5 min. Instrument specifics and sampling schemes are listed in APPENDICES 1-2.

The second type of instrument utilized was a Conductivity/Temperature/Depth (CTD) Profiler with Optical Backscatter (OBS) and Photosynthetically-Available Radiation (PAR) sensors to collect vertical profiles of water temperature, salinity, density, turbidity and PAR. The CTD/OBS/PAR data acquisition log is presented in TABLE 3. The instrument specifics and sampling schemes are listed APPENDIX 3.

The third type of instrument deployed during the study was the USGS Coral Imaging System (CIS), which consists of a Canon D60 6.3-megapixel digital camera with a 24-mm lens, an external Canon Speedlight 550EX TTL strobe, control unit and batteries on a tetrapod; this system was employed to collect a time series of sea floor images (FIGURE 3d). The CIS was deployed in a patch of sand at Site 2 (FIGURE 2)

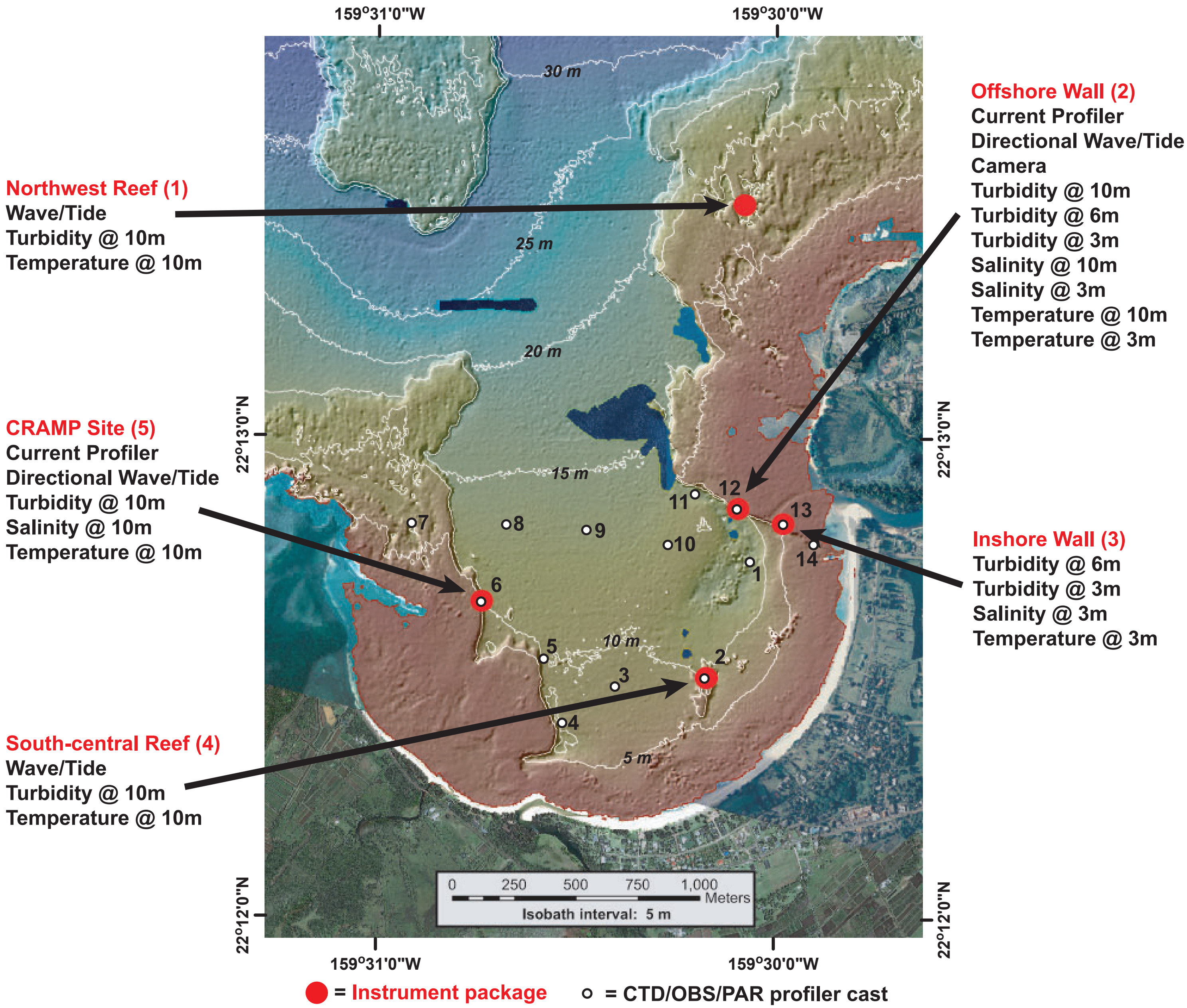

FIGURE 2. *Locations of the bottom-mounted instrument packages employed for long-term sampling and vertical profile casts used in the study. The numbers following the parameters denote the depths of the measurements below the sea surface. The CRAMP site refers to a permanent monitoring site of the Coral Reef Assessment and Monitoring Program by the University of Hawaii.*

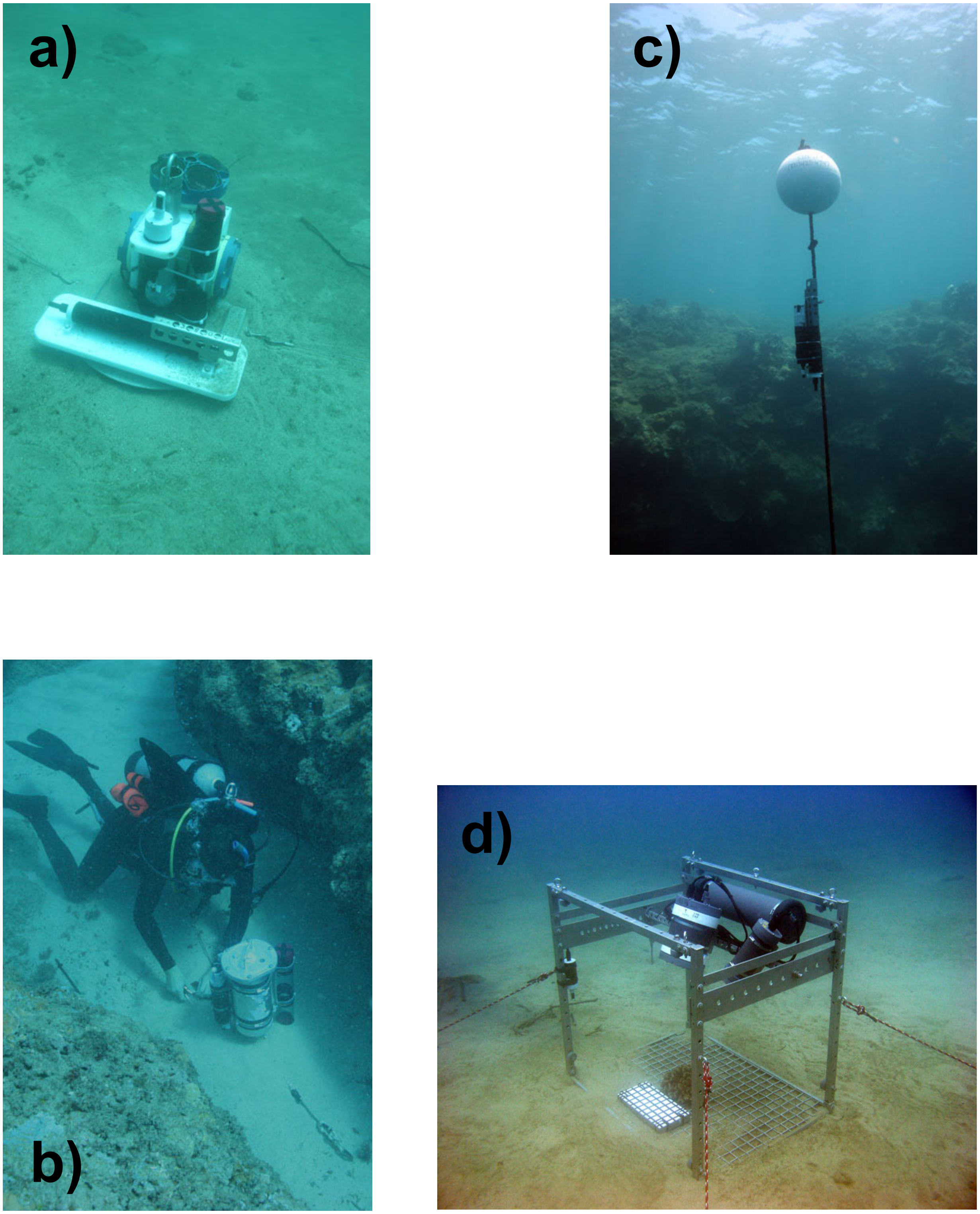

FIGURE 3. Photographs of the equipment used in the study. a) ADCP, SCOBS and Microcat along the 10m isobath at the Offshore Wall site. b) Dobie and SCOBS at the Northwest Reef site. c) Microcat and SCOBS 3m below the surface at the Offshore Wall site. d) CIS along the 10m isobath at the Offshore Wall site. All of the instrument packages and moorings were deployed in patches of sand.

and the camera and strobe were angled to not only image the seafloor and the black and white camera calibration reference block, but also a colony of the coral *Pocillapora meandrina* that had been detached from the adjacent reef, likely during a storm the previous winter. The CIS provided data on the natural frequency and duration of sediment deposition and resuspension on an actual coral surface. The CIS took images every four hours throughout the deployment (00:00, 04:00, 08:00, 12:00, 16:00 and 20:00).

Far-field oceanographic and meteorologic forcing for the study period was compiled by NOAA's National Data Buoy Center (NDBC, 2005) NW Kauai buoy. The NW Kauai Buoy, station identification #510001, is deployed in 3 km of water approximately 280 km west-northwest of Kauai. It makes hourly measurements of wind speed (m/sec), wind direction (°True), wave height (m), wave period (sec), mean wave direction (°True), sea-level barometric pressure (mBar), and air and sea-surface temperature (°C).

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

Research Platform:

The instrument deployments and recoveries were conducted using the *F/V Sea Cat*. The starboard quarterdeck was adapted for instrument deployment and recovery operations, which included the use of an electric winch and an overhead davit. 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 scuba divers attached a lift bag and detached the lifting line. The divers then moved the instrument package into position for anchoring. 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. Surficial seafloor sediment samples were collected, and the heights of the sensors above the seafloor were measured and recorded. Recovery operations employed the same techniques. The CTD/OBS/PAR profiler casts were conducted from the same vessel via hand. The driver's station was 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 cast location.

DATA ACQUISITION AND QUALITY

Data were acquired for 76 days during the period between 06/08/2005 and 08/22/2005. More than 23200 5-minute samples were recovered from each of the ADCPs, SCOBS and Microcats; less than 300 hourly data points were recovered from the Dobies due to battery failure. The ADCP and Dobie data quality was generally very high except towards the end of the deployment, when biofouling of the pressure sensor caused the data quality to decrease. The raw pressure data were archived and copies of the data were post-processed to calculate water depth, tidal height, significant wave height and dominant wave period; this data, in conjunction with the ADCP's 2 Hz current data, was used to calculate wave direction.

The Microcat data appeared to be of high quality. The SCOBS data problems were primarily due to biofouling of the optical sensor, which interrupts the SCOBS optical path and results in false elevated readings. Due to this growth, which started very shortly after the instruments' deployments, high quality concurrent data from all of the SCOBS is limited (<7 days).

The CTD/OBS/PAR profile 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/PAR 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 then used for visualization and analysis. The CTD/OBS/PAR 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.

RESULTS AND DISCUSSION

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

Oceanographic and Meteorologic Forcing

The summer study period was relatively quiescent, with relatively stable waves, and winds (FIGURE 4). The waves were small (2 m), short period (7-9 sec) and typically out of the northeast, likely driven by the Northeast Trade winds. These Trade wind waves were replaced by longer period (12-16 sec) swell out of the Northwest Pacific when the Trade Winds slackened. This generally occurs when regions of lower than average barometric pressure move through the island chain and cause the North Pacific anticyclone, which drives the Trade Winds, to weaken.

River Discharge

The US Geological Survey's Pacific Islands Water Science Center in Honolulu, Hawaii (http://hi.water.usgs.gov/), maintains a water and sediment gauging station on the Hanalei River approximately 9.2 km upstream from the river mouth. This gauge provides daily mean values of water discharge (m^3/sec), suspended sediment concentration (mg/l) and total suspended sediment load (kg/day). The study period was marked by very low water and sediment discharges compared to the entire 2004-2005 record; only one event on June 19 (Year-Day 170) had above-average suspended sediment concentrations and total sediment loads (FIGURE 5).

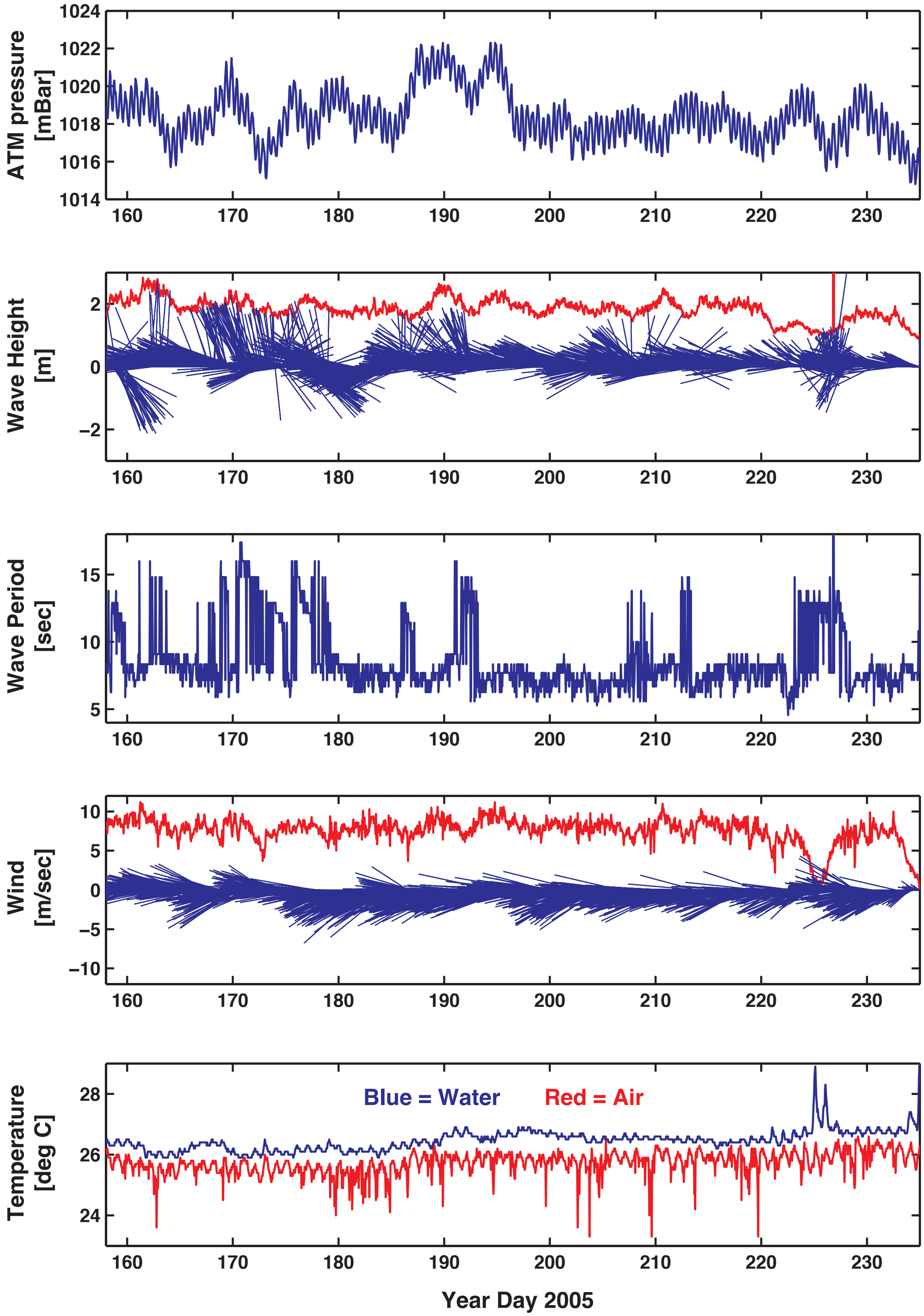

FIGURE 4. Oceanographic and meteorologic forcing during the study period. The waves were predominantly due to the Northeast Trade winds throughout most of the study. The study area was not impacted by any substantial storms during the course of the experi-

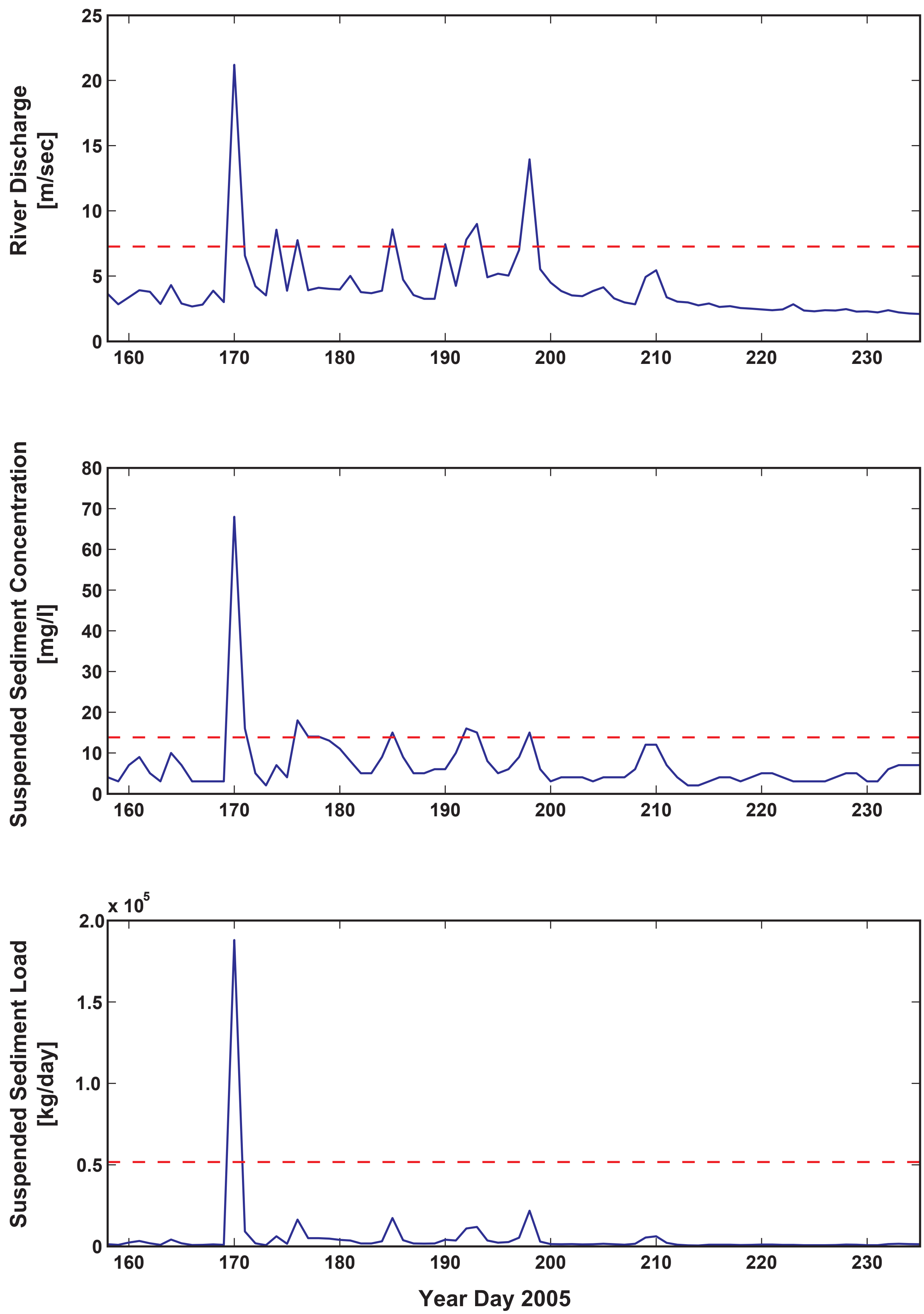

FIGURE 5. *Water and suspended sediment discharged from the Hanalei River during the study period from the USGS Pacific Islands Water Science Center. The daily mean data are in blue; the mean values for the entire 2004-2005 period are shown in red. The study period was marked by very low water and sediment discharges compared to the entire 2004-2005*

Tides

The study period encompassed more than five complete spring-neap tidal cycles. The tides in Hanalei 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 (FIGURES 6-7). The mean daily tidal range is roughly 0.6 m, while the minimum and maximum daily tidal ranges are 0.4 m and 0.9 m, respectively.

Waves

The waves that impacted Hanalei Bay during the course of the experiment are shown in FIGURES 6-7 and, while substantially smaller and shorter period than those observed further offshore (FIGURE 4), their temporal variations are in general agreement with the deep-water NDBC data. In the eastern side of the bay at the Offshore Wall site (Site 2, FIGURE 6), significant wave heights (*Hsig*) ranged from 0.12 m to 0.30 m, with a mean significant height ± one standard deviation of 0.19 ± 0.03 m. Dominant wave periods (*Tdom*) varied from 2.5 sec to 4.3 sec, with a mean dominant period ± one standard deviation of 3.2 ± 0.3 sec. Mean wave direction ± one standard deviation was 235.1° ± 70.3°. The mean wave direction out of the southwest is likely the result of two processes: wave refraction and wave energy dissipation. As the waves propagate into the bay, they refract around the large reef in the eastern half of the bay; the instrument package at Site 2 was situated along the south side of this reef and thus the waves had to refract around the west side of the reef and propagate onshore, which, at this location, would correspond to a direction out of the southwest, as the edge of the reef is oriented northwest-southeast. Second, the shorter period waves, which refract less and can propagate over the reef from the northwest, dissipate much of their energy by breaking over the top of the reef. Thus, by the time they make it over the reef and to the instrument site on the sheltered south side of the reef, they are quite small. It is very difficult for the ADCPs to resolve wave direction for very small, short-period waves, and thus much of the variability in direction may be due to poor analytical solutions in the wave direction calculations, especially for the smaller, shorter-period waves.

In the eastern side of the bay at the CRAMP site (Site 5, FIGURE 7), significant wave heights (*Hsig*) ranged from 0.22 m to 0.82 m, with a mean significant height ± one standard deviation of 0.54 ± 0.10 m. Dominant wave periods (*Tdom*) varied from between 3.1 sec and 5.9 sec, with a mean dominant period ± one standard deviation of 4.4 ± 0.1 sec. Mean wave direction ± one standard deviation was 26.3° ± 39.8°. The waves were primarily out of the north-northeast and appear to be due to the Trade winds. The wave heights are greater and their directions are more consistent at the CRAMP site than the Offshore Wall, as the CRAMP site is directly exposed to the northeast Trade wind waves while the Offshore Wall site is shadowed by the reef, as discussed above. Because of this greater exposure, the wave data from the CRAMP site provides a much better picture of the general wave parameters in the bay during these summer months.

Currents

Mean current speeds ± one standard deviation at the Offshore Wall site (Site 2) were 0.02 ± 0.02 m/sec close to the surface and 0.01 ± 0.01 m/sec close to the sea floor (FIGURE 8). At the CRAMP site (Site 5), mean current speeds ± one standard

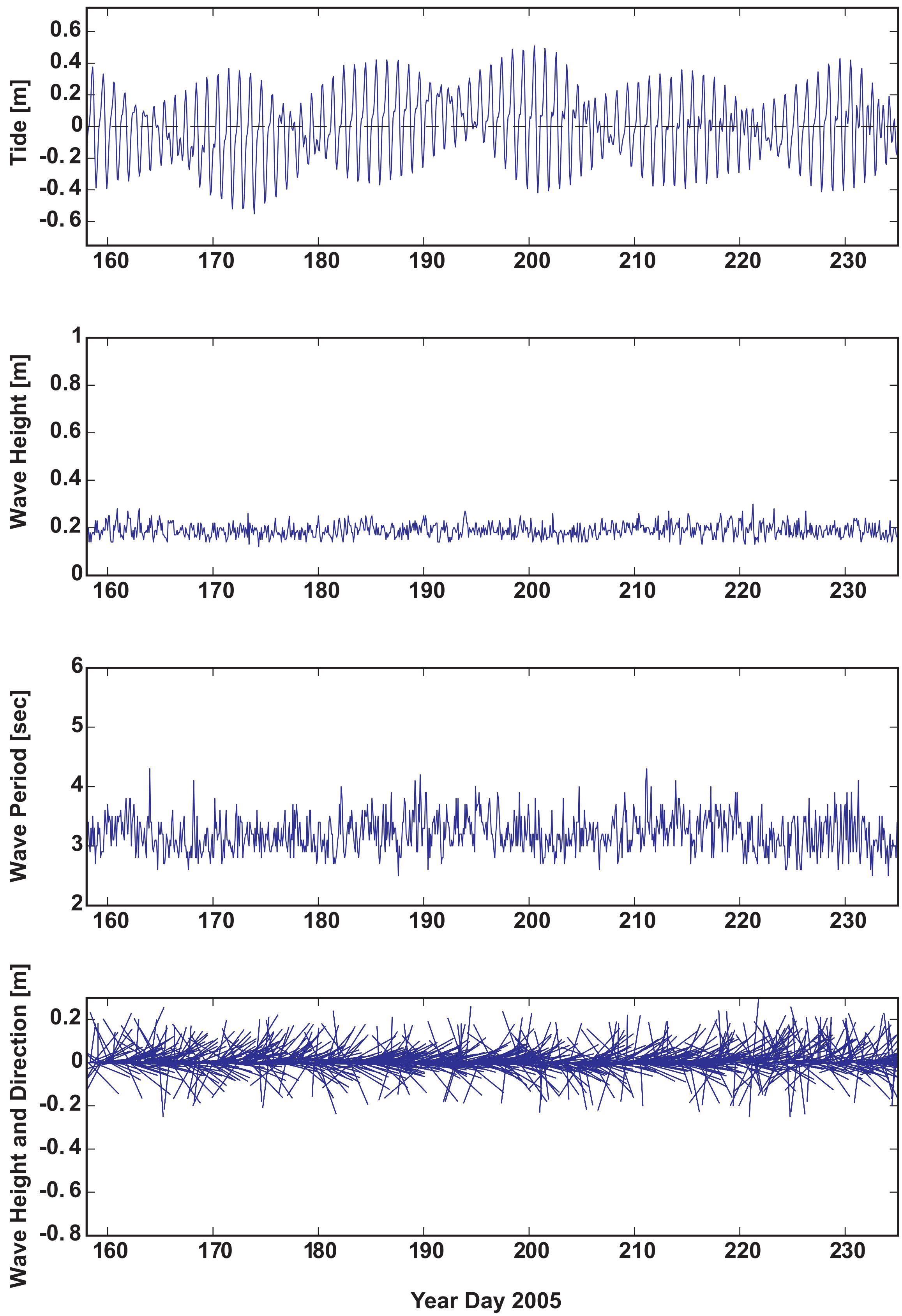

FIGURE 6. *Tide and wave data from the Offshore Wall Site. The vectors denote the height and direction of the waves. The wave heights and periods were very small here, as the Trade wind waves underwent substantial breaking and refraction over the adjacent reef to the north that sheltered this area from direct wave impact.*

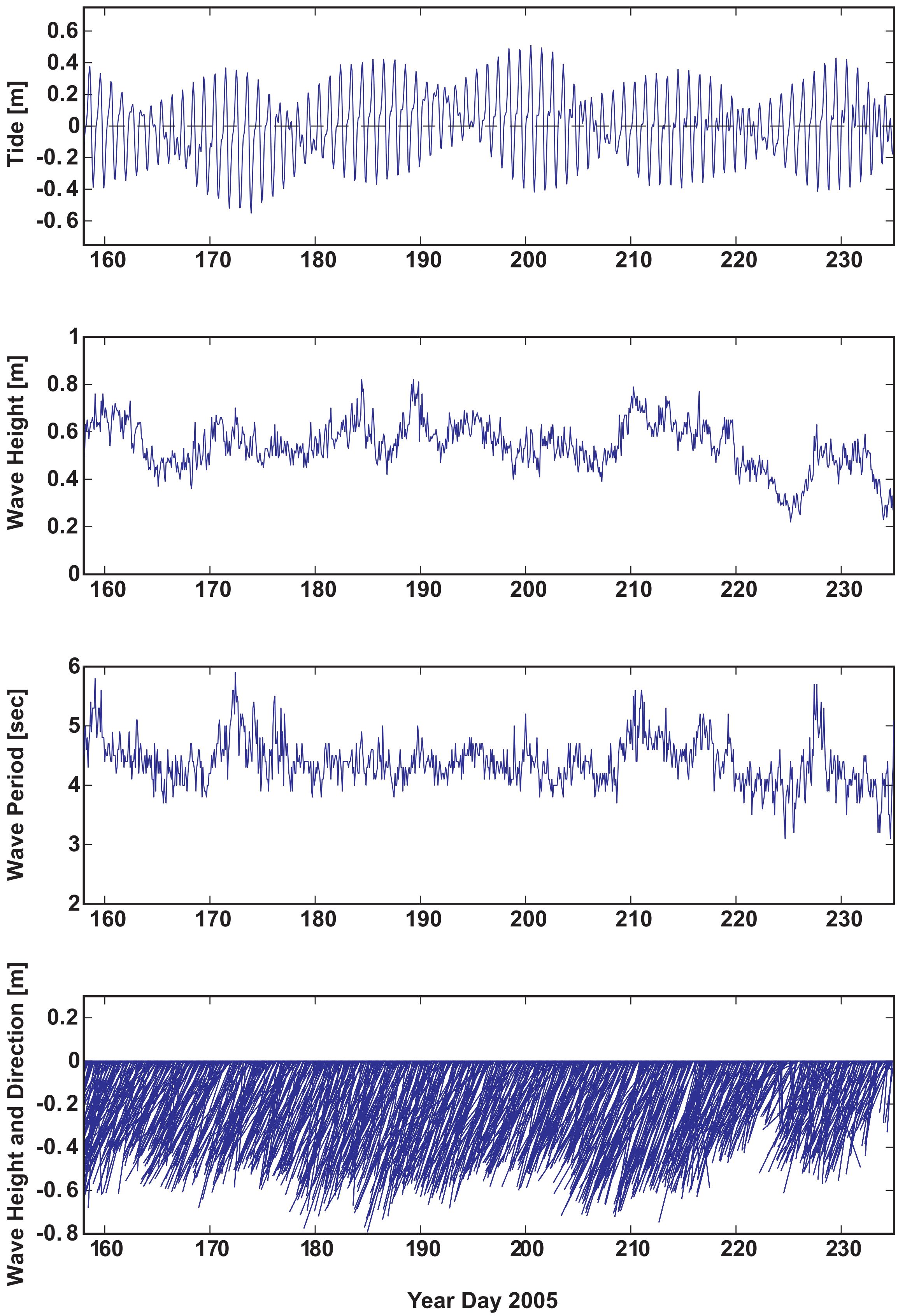

FIGURE 7. *Tide and wave data from the CRAMP Site. The vectors denote the height and direction of the waves. The wave heights and periods were much larger at this site, as it is directly exposed to the Northeast Trade wind waves.*

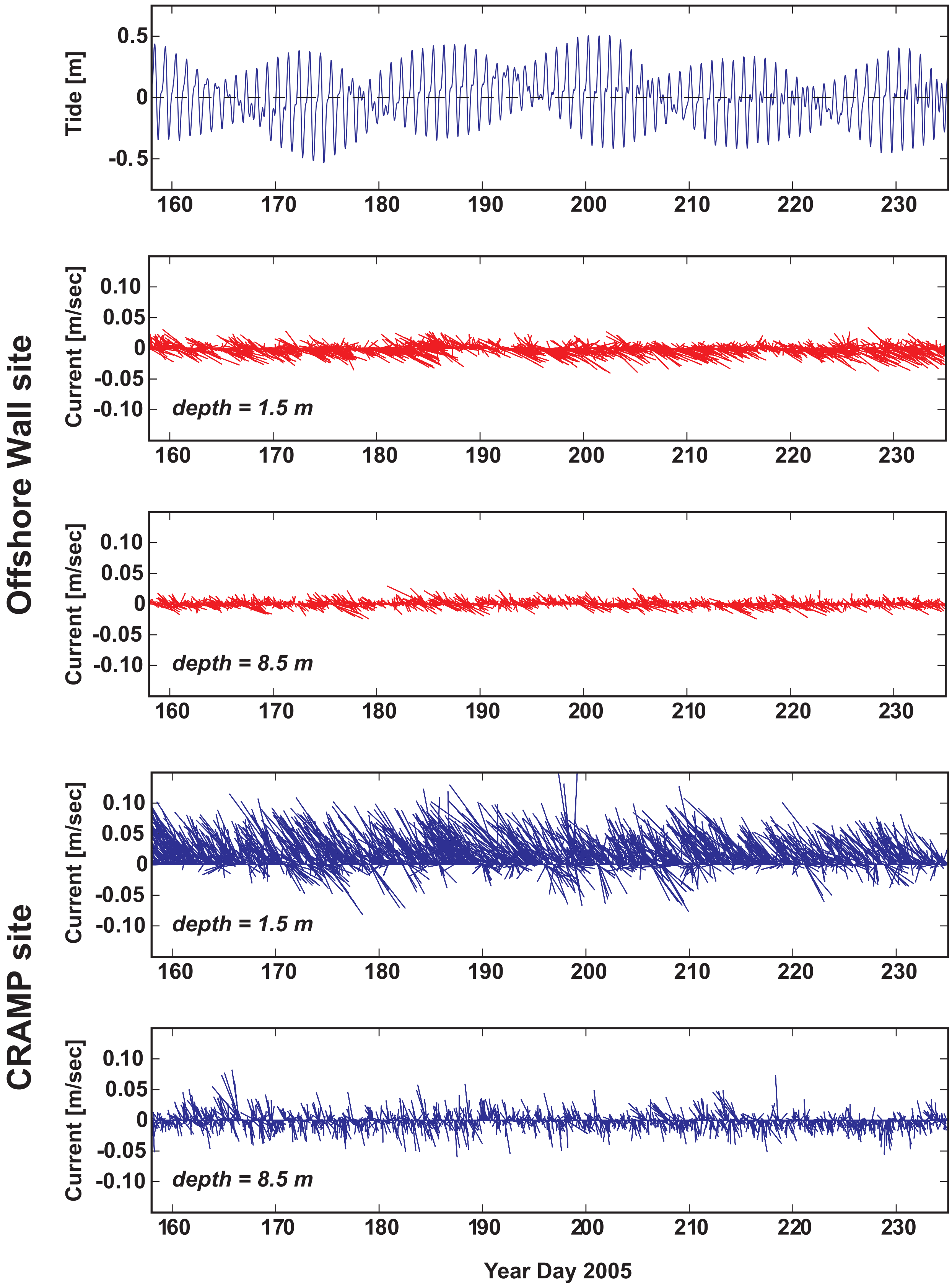

FIGURE 8. *Tide and current data from the CRAMP and Offshore Wall Sites. The vectors denote the speed and direction of the currents at the different depths. In general the currents were stronger near the surface and in the western part of the bay, likely due to its greater exposure to the open ocean.*

deviation were more than 50% higher both close to the surface (0.05 ± 0.03 m/sec) and close to the sea floor (0.02 ± 0.01 m/sec) than along the Offshore Wall site. Overall, net flow near the surface at the Offshore Wall site was to the southeast into the bay and to the northwest out of the bay at the CRAMP site (FIGURE 9). Close to the bed, however, the net flow at both sites were in the opposite directions- to the northwest out of the bay at the Offshore Wall site and to the southeast into the bay at the CRAMP site. The orientation of maximum flow variability varied vertically at each site, implying bathymetric steering. At the Offshore Wall site, the flow close to the surface oriented west-northwest by east-southeast, along the general trend of the top of the adjacent wall, while close to the seafloor the flows are oriented more northwest by southeast, along the general trend of the 10 m isobath (see FIGURE 2). Similar vertical variation in the orientation of maximum flow variability is seen at the CRAMP site, with the flow close to the surface oriented northwest by southeast, along the general trend of the top of the adjacent reef, while close to the seafloor the flows are oriented more north-northwest by south-southeast, along the general trend of the 10 m isobath (see FIGURE 2). These vertical variations in flow speed and direction at each site result not only in different magnitudes and directions of net transport at different depths, but also vertical velocity shear, which, in turn, likely increases turbulence and vertical mixing.

Most of the daily variability in current speed and direction at the study sites are due to the tides. As the tide rises (floods), tidal currents close to the surface at the Offshore Wall site flow to the southeast (~110º); these tidal current speeds are greater than those observed when the tide falls (ebbs) and tidal currents are to the northwest (~290º). The flow close to the seafloor at this location appears to be in the opposite direction (FIGURE 10). The flood tidal currents close to the surface at the CRAMP site flow to the southeast (~150º); these tidal current speeds are slower than those observed when the tide falls (ebbs) and tidal currents are to the northwest (~330º). The flow close to the seafloor at this location appears to be in the opposite direction. This pattern is set by the local tidal node (amphidrome) to the west of the Hawaiian Island chain and the counter-clockwise sweep of the tidal bulge around the amphidromic point. The magnitude of the tidal currents is driven by the lunar tidal cycle, with the highest tidal current speeds occurring during the spring tides (new and full moons) and the weakest during the neap tides (quarter moons). Overall, the tidal currents are faster but less consistent in the alongshore direction at the CRAMP site (Site 5) than along the Offshore Wall site (Site 2).

Due to the lack of co-located wind measurements and the high topographic complexity of the north shore of Kauai, it is unwise to try to interpret the local wind field from the offshore NDBC buoy's anemometer data. At this time we are unable to resolve the magnitude of the influence of local winds on driving currents in the bay.

Water Column Properties

The water column properties that were measured by the bottom-mounted Microcats and SCOBS included variations in temperature (ºC), salinity (PSU) and optical backscatter (NTU). The water column properties that were measured by the CTD/OBS/PAR profiler included variations in temperature (ºC), salinity (PSU), optical backscatter (NTU) and PAR (mE) with depth; from these data we were able to compute the density of seawater (sigma-theta).

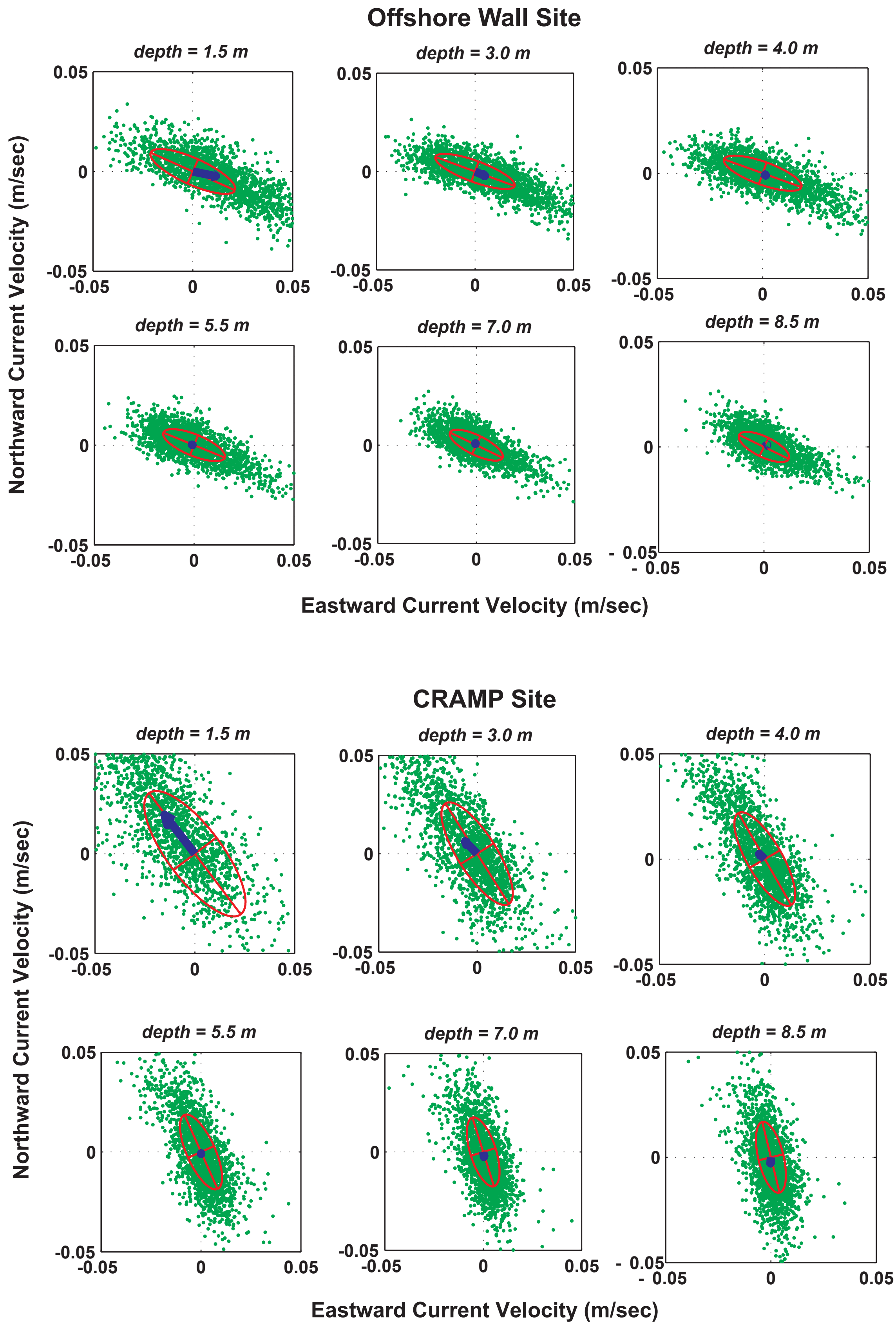

FIGURE 9. *Mean and principal axes of flow at the CRAMP and Offshore Wall Sites at different water depths. Blue vectors show the orientation and magnitude of net flow; red ellipses show the variability of flow. Mean flow is primarily along-isobath at all depths; net flow is onshore at the Offshore Wall site and offshore at the CRAMP site.*

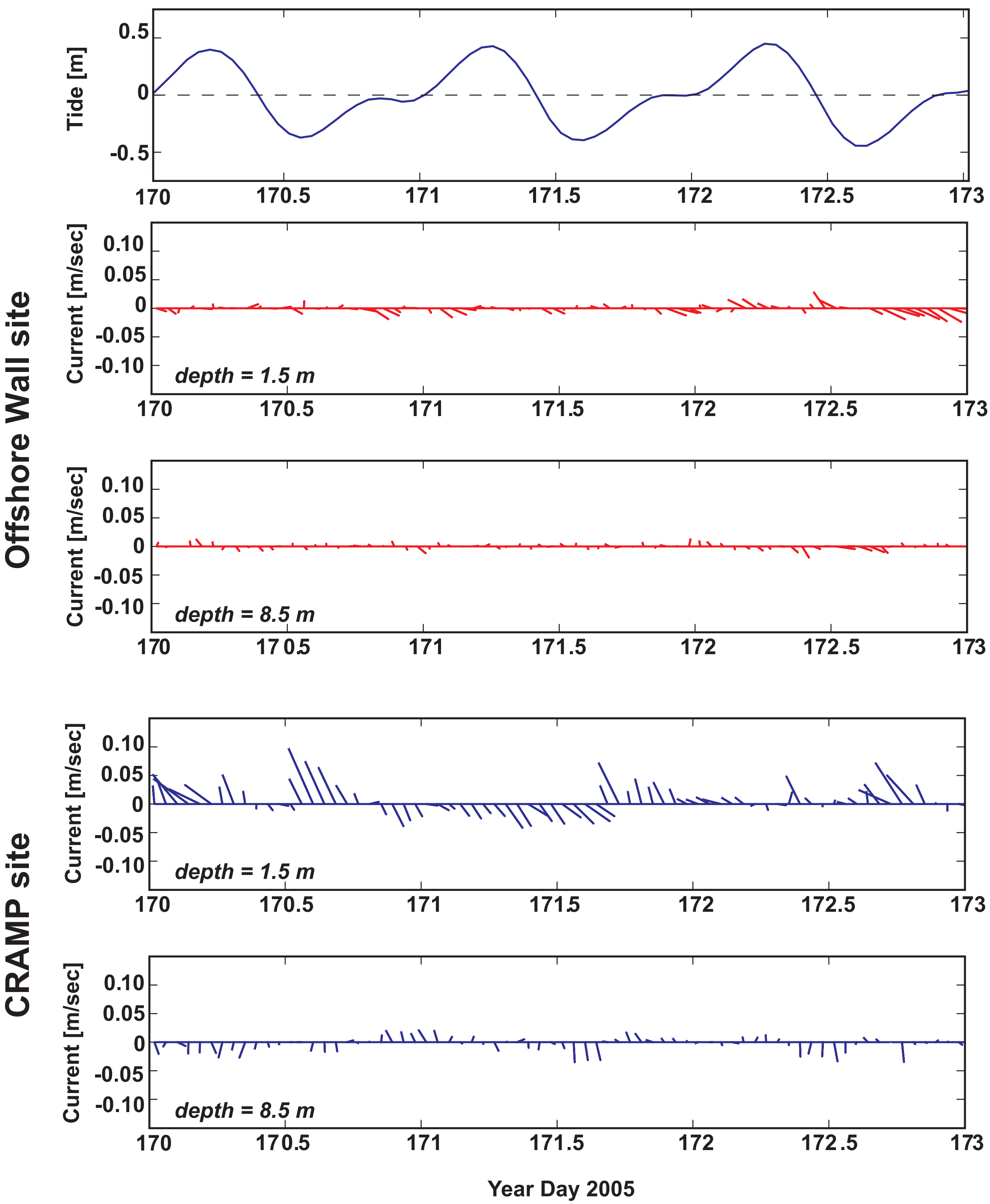

FIGURE 10. *Phasing between tides and flow at the CRAMP and Offshore Wall Sites. The vectors denote the speed and direction of the currents at the different depths. As the tide rises (floods), tidal currents at the Offshore Wall and CRAMP sites flow to the southeast; as the tide falls (ebbs), the tidal currents are to the northwest.*

Spatial and Temporal Variability in Temperature:

Water temperatures ranged between 24.22 °C and 27.03 °C, with a mean temperature ± one standard deviation of 25.97 ± 0.45 °C (TABLE 4). The water typically warmed 0.1°C during the day, likely due to insolation (FIGURE 11). In general, temperatures at the sites along the wall in the eastern part of the bay (Sites 2-3) were less variable than that at the CRAMP site (Site 5). Water temperatures increased slightly as the tide fell, likely because of water warmed by the air and/or sun in the shallows was being advected out past the sensors (FIGURE 12). Without co-located meteorologic data we are not sure what the cause was for the low frequency variations in water temperature (see next section for further detail).

Spatial and Temporal Variability in Salinity:

Salinity in the bay ranged between 33.78 PSU and 35.24 PSU, with a mean temperature ± one standard deviation of 34.80 ± 0.17 PSU (TABLE 4). The salinities generally varied on the order of 0.01 PSU (FIGURE 11) and mirrored the tides, increasing slightly during flood tides and decreasing slightly during ebb tides (FIGURE 12). The increases are likely due to the advection of more saline waters onshore during the rising tide and the advection of fresh submarine groundwater or fluvial discharge offshore during the falling tide. In general, salinities at the Offshore Wall site (Site 2) were higher and less variable than at the Inshore Wall site (Site 3) and at the CRAMP site (Site 5). The higher variability and lower salinities at the Inshore Wall and CRAMP sites is likely due to the greater proximity to freshwater being discharged by the Hanalei River and Waipa and Waioli Streams. The low frequency variations in salinity mirror those in water temperature (see above), suggesting some large-scale variations in water mass composition in the bay, with possibly a slow introduction of a more oceanic (cooler, more saline) water mass in the bay starting around June 29 (Year-Day 180) and it slowly being mixed out starting around July 14 (Year-Day 195).

The variability in salinity as a function of temperature is shown in FIGURE 13. The near-surface and near-bed measurements at the Offshore Wall site (Site 2) show increasing salinity with decreasing temperature that are indicative of oceanic water being transported into the eastern part of the bay at this location. Data from the Inshore Wall site (Site 3) show a pattern similar to the Offshore Wall site; in addition, they show the influence of fresh water being discharged from the Hanalei River that is not concurrently seen at the Offshore Wall site. This freshwater is identifiable as a vertical trend in the temperature-salinity plot of a variation in more than 1.5 PSU in salinity around 25.5°C. The pattern at the CRAMP site (Site 5) shows the inverse temperature-salinity relationship seen along the wall overprinted by a decrease in temperature with a decrease in salinity that indicates freshwater being transported into the area, likely from the Waipa and Waioli Streams that discharge into the west side of Hanalei Bay.

Spatial Variability in Turbidity:

Due to the very short length of concurrent, high-quality data from all of the SCOBS, we cannot at this time present an accurate picture of the temporal variability of turbidity in the study area. Concurrent, reliable data were recorded only during the first 5 days (June 8-13). During that time period, the turbidity in the study area ranged

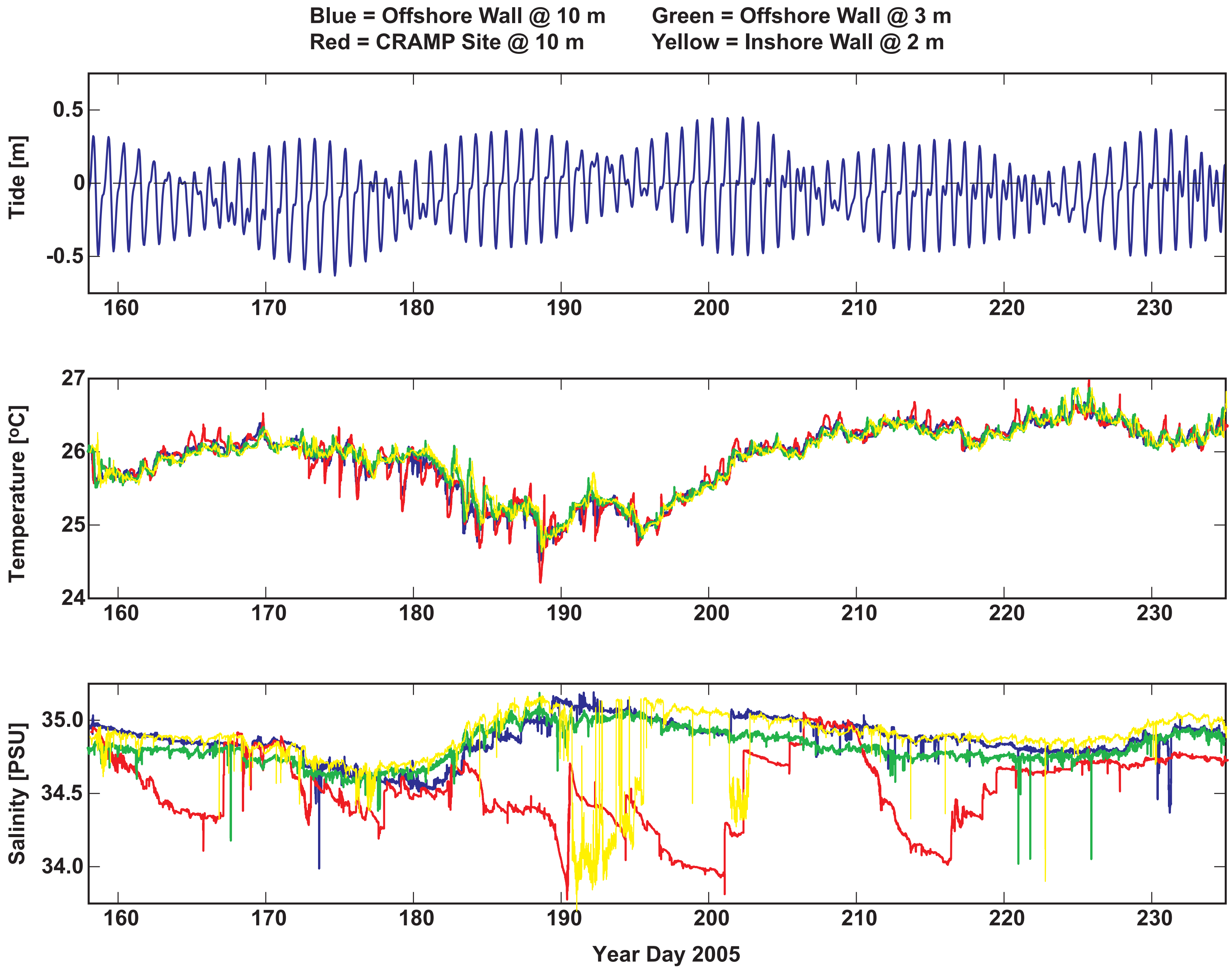

FIGURE 11. *Water temperature and salinity at the CRAMP and Wall Sites. The higher variability and lower salinities at the Inshore Wall and CRAMP sites is likely due to the greater proximity to terrestrial freshwater discharge. The low frequency variations in salinity mirror those in water temperature, suggesting some large-scale variations in water mass composition in the bay.*

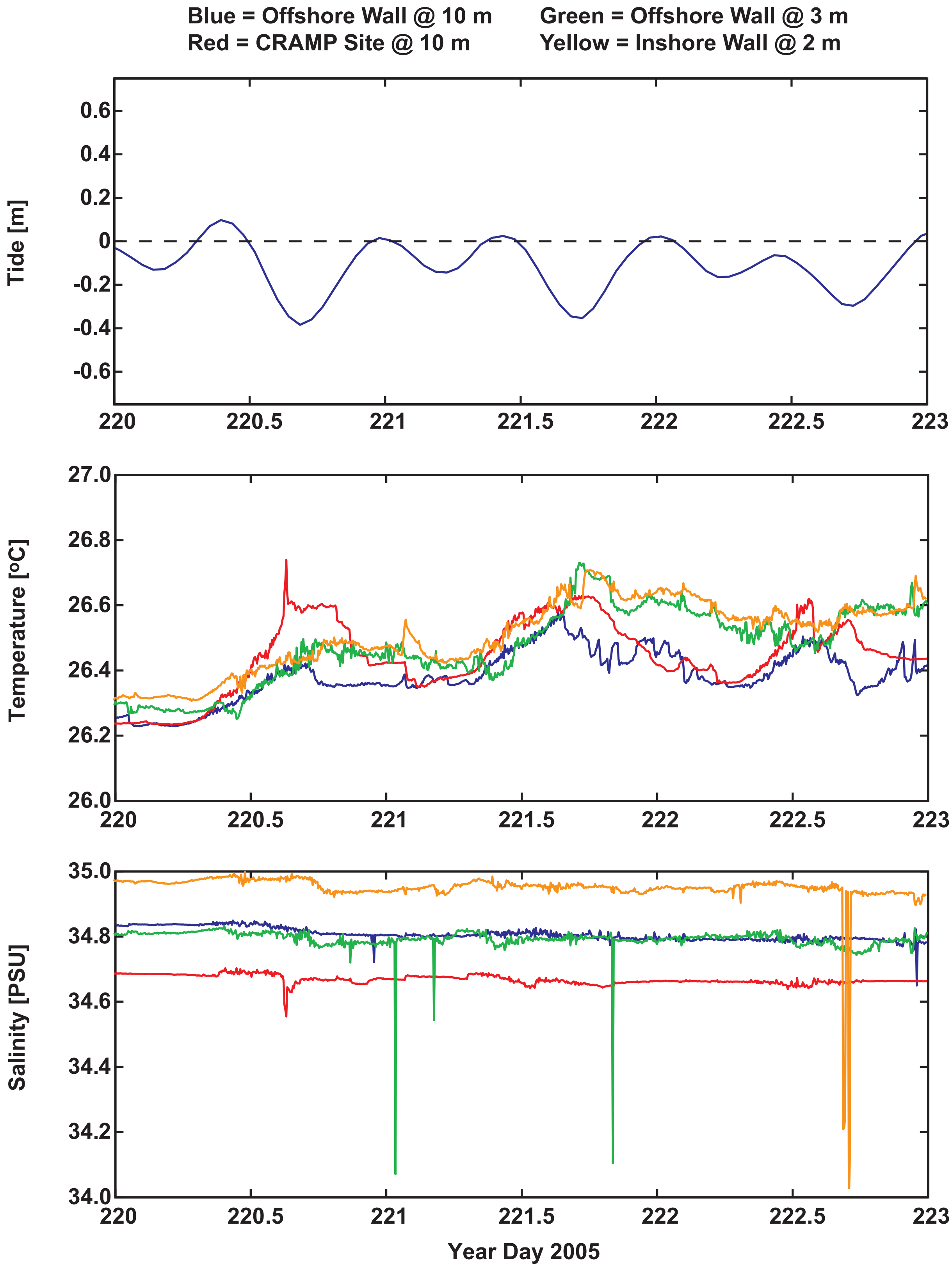

FIGURE 12. *Phasing between tides, temperature and salinity at the CRAMP and Wall Sites. The temperatures decrease and the salinities increase slightly during flood tides; temperatures increase and the salinities decrease slightly during ebb tides. These variations are likely due to the advection of cooler, more saline waters onshore during the rising tide and the advection of fresh submarine groundwater or fluvial discharge offshore during the falling tide.*

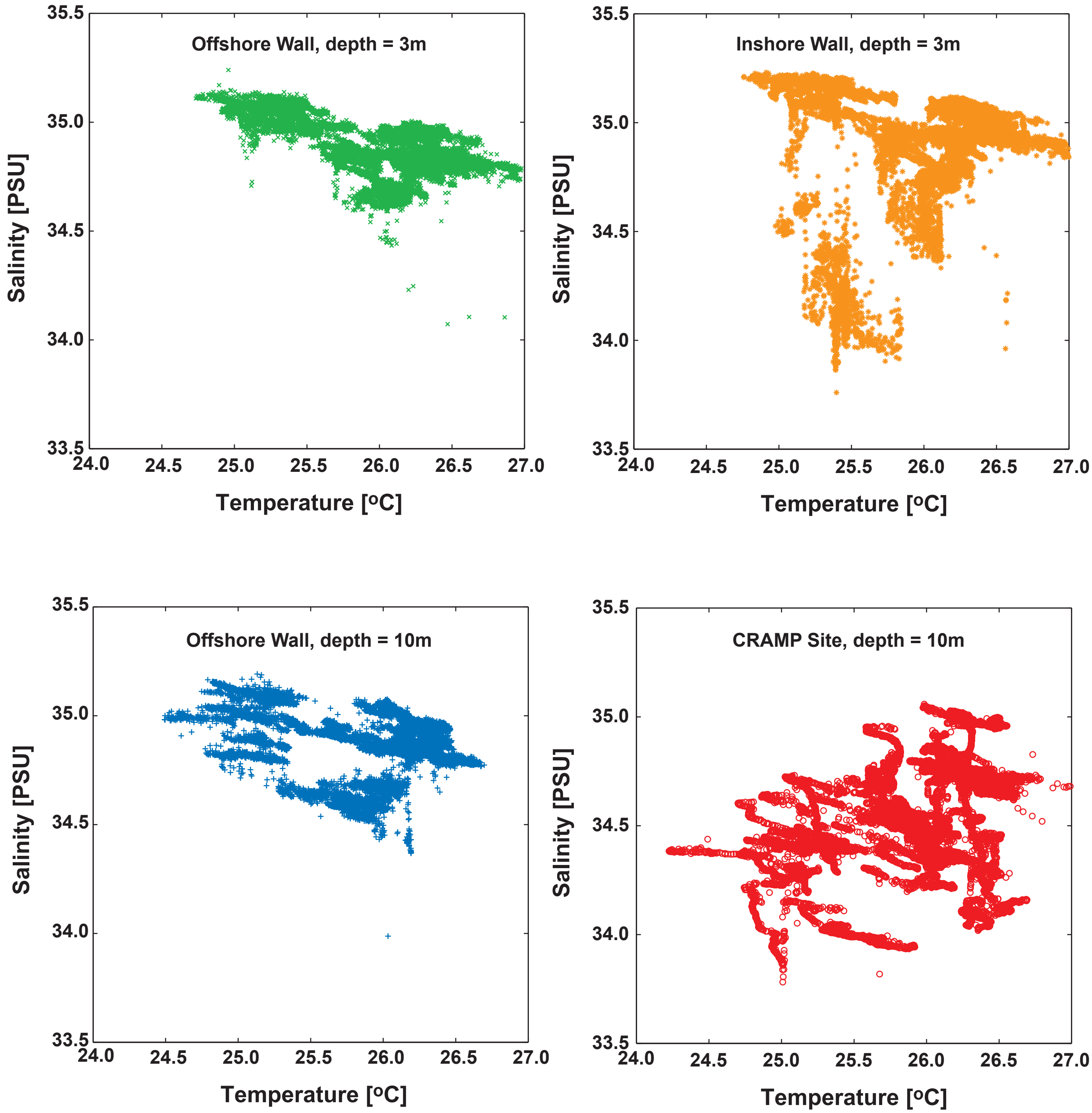

FIGURE 13. *Variation in salinity as a function of temperature at the CRAMP and Wall Sites. The general trend of increasing salinity with decreasing temperature are indicative of oceanic waters. This inverse temperature-salinity relationship seen throughout most of the bay is overprinted by a decrease in temperature with a decrease in salinity that indicates freshwater being transported into the area, likely from the adjacent river and streams.*

between 0.0 NTU and 12.2 NTU, with a mean turbidity ± one standard deviation of 1.2 ± 0.7 NTU (TABLE 5). In general the waters were more turbid inside the bay, especially close to shore and close to the seafloor. The highest turbidity levels were close to the bed at the Inshore Wall site (Site 3), closest to the Hanalei River mouth. The turbidity was slightly higher in the western part of the bay at the CRAMP site (Site 5) than in the middle of the bay (Site 4), likely due to discharge from the Waipa and Waioli Streams.

All of the mean turbidity values recorded during this dry summer period exceed 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). The maximum allowable wet season mean turbidity level (which are roughly twice those of dry season levels) is 0.50 NTU; the mean turbidity near the seafloor at the Inshore Wall site exceeds the maximum acceptable mean level by 7 times (TABLE 5).

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

The overall trends for the variation in water column properties with depth during the June survey displays a very thin turbid buoyant freshwater surface plume overlying a stable water column (FIGURE 14); these data reflect the influence of rainfall that started ~12 hours before the start of the survey and continued through the survey. In general, temperature and PAR decreased with depth while salinity and density increased with depth. The higher turbidity but lower temperature, salinity and density at the surface are indicative of the influence of a turbid, buoyant lower-salinity surface plume, likely due to runoff from Hanalei River and the streams that drain into Hanalei Bay. The temperature typically rose to its maximum just below the surface, below which it decreased slowly towards the bed. Turbidity generally decreased towards the bed, typically reaching base levels 3 m below the water's surface; this suggests the slow settling of material (likely fine-grained terrestrial sediment and/or biogenic material) from the surface plume. The turbidity then increased towards the bed, likely due to resuspension of the fine sediment and organics that typically cover the sea floor. Spatially, the water in Hanalei Bay is generally more saline and cooler further offshore and with increasing depth.

Short-term Sediment Deposition and Resuspension

The CIS was placed roughly 5 m south of the Offshore Wall site (Site 2) to provide visual documentation of sedimentation on coral surfaces that will be correlated with measurements of waves, currents, rainfall, and stream discharge (FIGURE 15). The CIS's images show whether the particles actually settled on the bottom or were transported through the region. The gridded concrete block is used as a proxy for an irregular coral surface so that estimates of levels of sediment accumulation - and erosion - can be correlated with other measurements and improve understanding of the conditions that affect sedimentation on corals. A small coral, broken off from a previous storm, was also placed under the camera as a reference. Images from the CIS show a relatively rapid initial accumulation (estimated to be up to 0.5 cm thick) of fine-grained sediment on the gridded block over the first 3 weeks of the deployment, followed by low levels of gradual removal and re-accumulation of fine-grained sediment over the rest of the deployment. The small piece of coral that was placed adjacent to the concrete

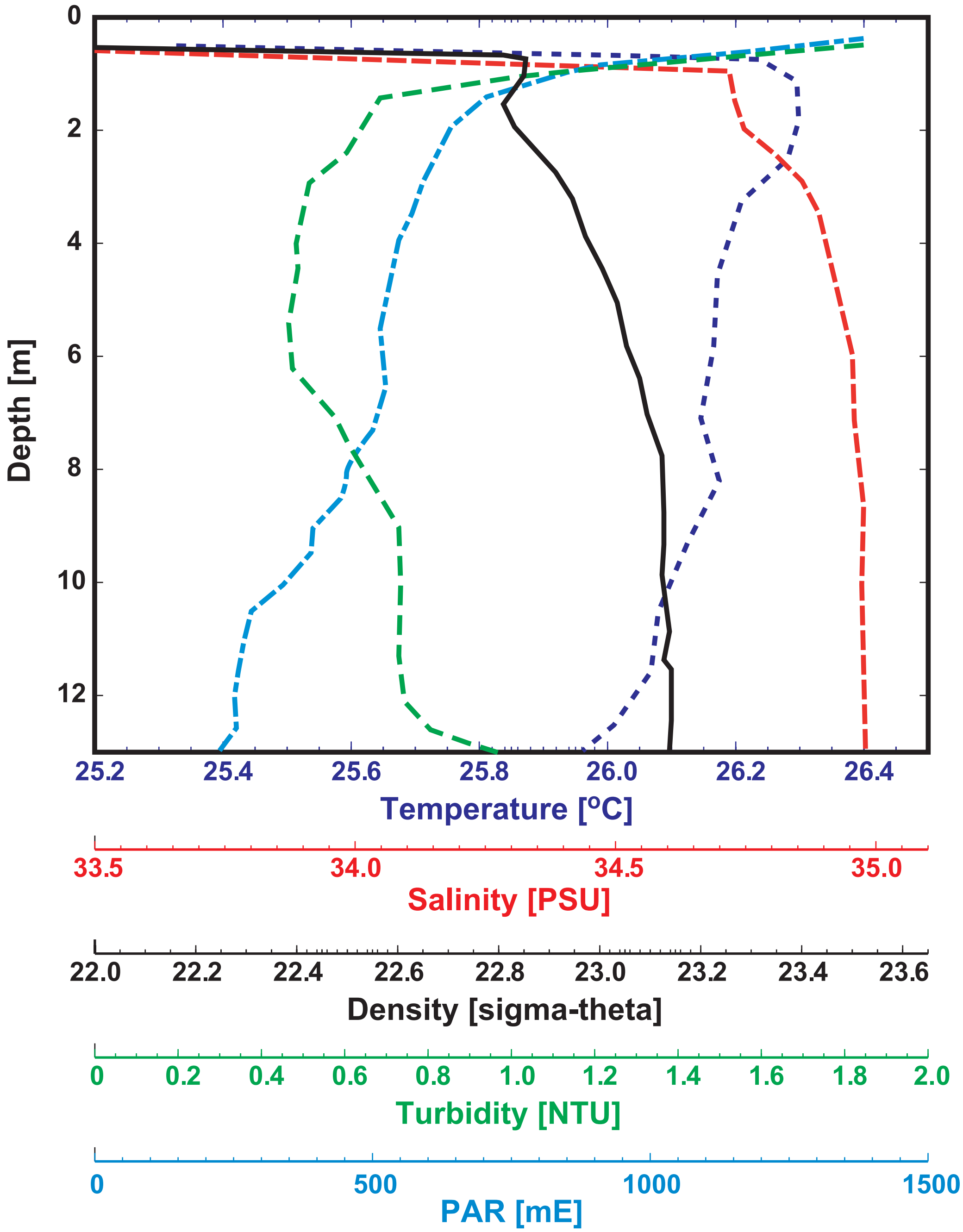

FIGURE 14. *Mean variation in water temperature, salinity, density, turbidity and PAR with depth complied from 14 casts made throughout the bay in June, 2005. The overall trends for the variation in water column properties with depth during the June survey displays a turbid buoyant freshwater surface plume overlying a stable water column. Spatially, the water in Hanalei Bay is generally more saline and cooler further offshore and with increasing depth.*

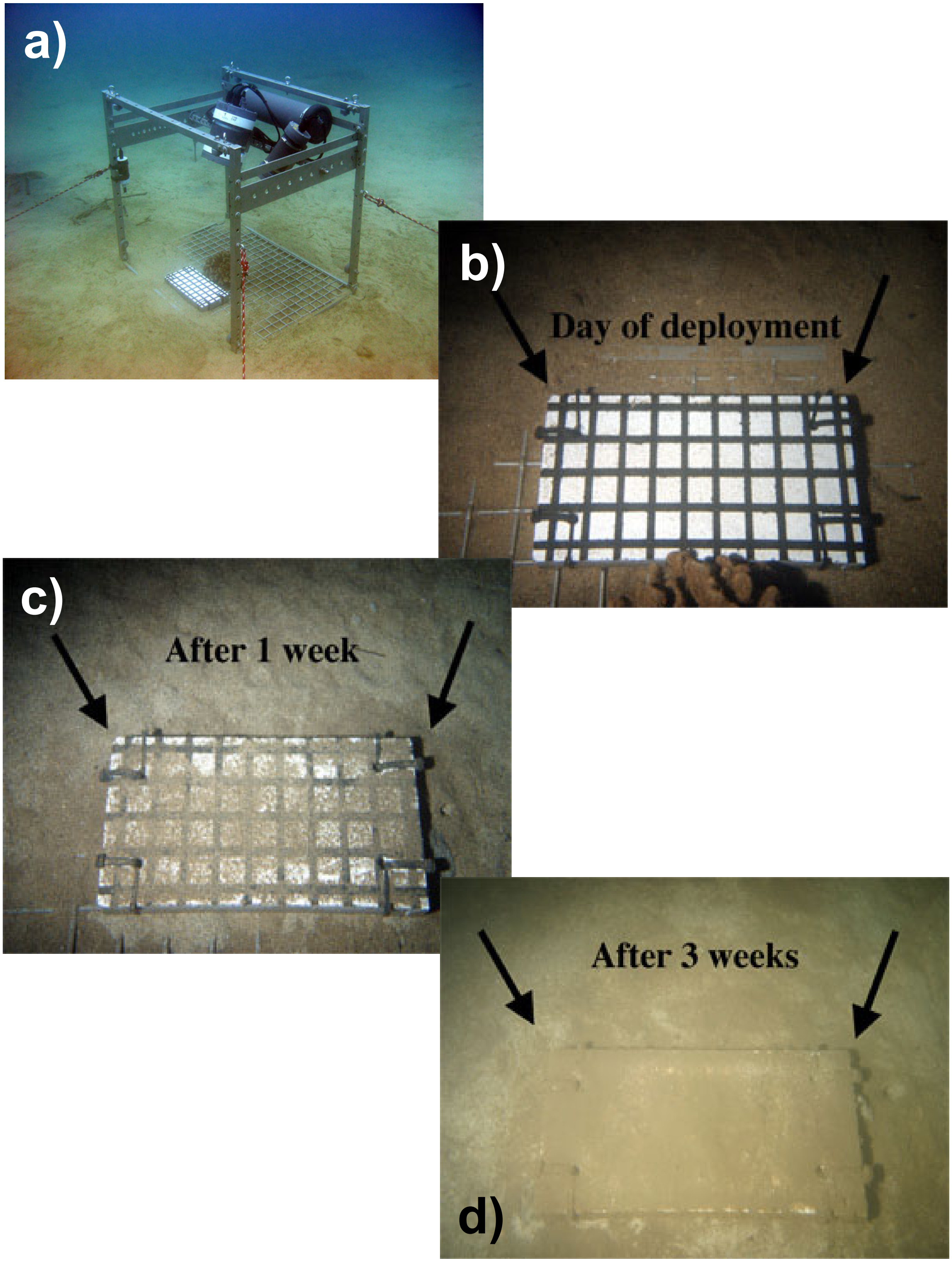

FIGURE 15. *Images of the seafloor at different times from the Coral Imaging System. a) Photograph of the CIS, block and coral head at the time of deployment. b) CIS image 8 hours after deployment. c) CIS image 1 week after deployment. d) CIS image 3 weeks after deployment. The CIS imagery revealed a relatively rapid initial accumulation of fine-grained sediment that occurred over the first 3 weeks of the deployment, followed by low levels of gradual removal and re-accumulation of sediment over the rest of the*

block during deployment and is visible in the first images was moved out of the camera's view by unknown forces during the first week of the experiment. Further analysis of the CIS data and its comparison to oceanographic forcing will be discussed in further detail in a subsequent report.

CONCLUSIONS

In all, more than 24000 measurements of currents, waves, tides, temperature, salinity, turbidity and PAR were made in Hanalei Bay, Kauai, during the 3-month period between 06/08/2005 and 08/22/2005. Key findings from these measurements and analyses include:

1) Flow was relatively weak and circulation was sluggish in Hanalei Bay during the 2005 summer study period. Flows were generally oriented parallel to shore but varied vertically, with the near-surface flows often heading in the opposite direction of the near-bed flows, causing vertical velocity shear. Net near-surface flow was into the eastern portion of the bay and out of the western portion of the bay, net near-bed flows had an opposite pattern. The waves were relatively small during the deployments and primarily driven by the Northeast Trade Winds. Both waves and currents were more energetic in the western portion of the bay that was more directly exposed to the Trade Winds.

2) Lower salinities and higher turbidities were observed closer to shore, especially near the mouths of the Hanalei River and the Waipa and Waioli Streams.

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

4) A relatively rapid initial accumulation of fine-grained sediment occurred at the Offshore Wall site over the first 3 weeks of the deployment, followed by low levels of gradual removal and re-accumulation of fine-grained sediment over the rest of the deployment.

These data provide information on the nature and controls on flow and water column properties in Hanalei Bay during the summer months. A number of interesting phenomena were observed that indicate the complexity of coastal circulation in Hanalei 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. We would like to thank Hanalei residents Charlie

Bass and Garret Santos of the *F/V Sea Cat*, who graciously donated their time, effort and aloha during our numerous instrument deployment and recovery operations. Carl Berg (Hanalei Watershed Hui) overextended himself by helping us with every aspect of the fieldwork and coordinating our efforts with the numerous other institutions working in the Hanalei watershed-reef system, and for that we owe him much thanks. We would also like to thank Li Erikson and Katie Farnsworth (USGS), who contributed numerous excellent suggestions and a timely review of our work.

REFERENCES

National Data Buoy Center, NW Kauai Buoy, 2005. Online digital data. http://www.ndbc.noaa.gov/station_page.php?station=51001

TABLE 1. Experiment personnel

Person	Affiliation	Responsibilities
Mike Field	USGS	Chief scientist, diver
Curt Storlazzi	USGS	Co-chief scientist, diver
Joshua Logan	USGS	Information specialist, diver
Kathy Presto	USGS	Instrument specialist
Amy Draut	USGS	Geologist, diver
Tom Reiss	USGS	Dive safety officer
Dave Gonzales	USGS	Instrument specialist
Hank Chezar	USGS	Instrument specialist
Carl Berg	HWH	Hanalei Watershed Hui science coordinator
Charlie Bass	*F/V Sea Cat*	Vessel captain
Garret Santos	*F/V Sea Cat*	First mate

TABLE 2. Instrument package sensors

Site Name	Depth [m]	Sensors
Northwest Reef [1]	10	NIWA Dobie-A wave/tide gauge
	10	Aquatec/Seapoint 200-TYT optical backscatter sensor with temperature sensor
Offshore Wall [2]	10	RD Instruments 600 kHz Workhorse Monitor acoustic Doppler current profiler
	10	Aquatec/Seapoint 200-TY optical backscatter sensor
	10	Seabird SBE-37SI Microcat conductivity-temperature sensor
	10	Coral Imaging System time-series camera
	6	Aquatec/Seapoint 200-TY optical backscatter sensor
	3	Seabird SBE-37SI Microcat conductivity-temperature sensor
	3	Aquatec/Seapoint 200-TY optical backscatter sensor
Inshore Wall [3]	5	Aquatec/Seapoint 200-TY optical backscatter sensor
	3	Seabird SBE-37SI Microcat conductivity-temperature sensor
	3	Aquatec/Seapoint 200-TY optical backscatter sensor
South-central Reef [4]	10	NIWA Dobie-A wave/tide gauge
	10	Aquatec/Seapoint 200-TYT optical backscatter sensor with temperature sensor
CRAMP Site [5]	10	RD Instruments 600 kHz Workhorse Monitor acoustic Doppler current profiler
	10	Aquatec/Seapoint 200-TY optical backscatter sensor
	10	Seabird SBE-37SI Microcat conductivity-temperature sensor

Numbers in brackets refer to locations on FIGURE 2.

TABLE 3: CTD/OBS/PAR profiler log.

Cast Number	Time [HST]	Latitude [decimal degrees]	Longitude [decimal degrees]	Depth [m]
1	10:21	22.212117	-159.501450	14.5
2	11:36	22.207917	-159.503800	8.5
3	11:43	22.206800	-159.508900	10.0
4	11:52	22.208183	-159.507117	10.0
5	12:05	22.208967	-159.509850	4.5
6	13:23	22.210983	-159.511483	11.5
7	13:28	22.214467	-159.513633	7.5
8	13:35	22.214150	-159.510200	13.5
9	13:39	22.213733	-159.507300	13.0
10	13:45	22.212967	-159.504383	12.5
11	13:59	22.214917	-159.503117	13.5
12	14:38	22.214067	-159.501717	13.5
13	14:42	22.213400	-159.500267	7.5
14	14:45	22.212717	-159.499333	7.5

Cast numbers refer to locations on FIGURE 2.

TABLE 4: Salinity and temperature statistics.

Site Name	Depth [m]	Salinity [P.S.U.]	Temperature [^oC]
Northwest Reef [1]	10	N.D.	25.91 ± 0.47
Offshore Wall [2]	3	34.87 ± 0.12	26.02 ± 0.44
Offshore Wall [2]	6	N.D.	N.D.
Offshore Wall [2]	10	34.87 ± 0.13	25.90 ± 0.46
Inshore Wall [3]	3	34.91 ± 0.21	26.04 ± 0.43
Inshore Wall [3]	5	N.D.	N.D.
South-central Reef [4]	10	N.D.	25.98 ± 0.45
CRAMP Site [5]	10	34.54 ± 0.25	25.91 ± 0.48

All values are mean ± one standard deviation.
N.D. = No data.
Numbers in brackets refer to locations on FIGURE 2.

TABLE 5: Turbidity statistics.

Site Name	Depth [m]	Turbidity [N.T.U.]
Northwest Reef [1]	10	0.67 ± 0.18
Offshore Wall [2]	3	1.06 ± 0.43
Offshore Wall [2]	6	0.78 ± 0.77
Offshore Wall [2]	10	1.74 ± 0.82
Inshore Wall [3]	3	1.16 ± 0.69
Inshore Wall [3]	5	3.40 ± 2.92
South-central Reef [4]	10	1.01 ± 0.73
CRAMP Site [5]	10	1.47 ± 1.05

All values are mean ± one standard deviation.
Numbers in brackets refer to locations on FIGURE 2.
These data are from the time period from June 8-13 when concurrent, reliable data were recorded.

APPENDIX 1

ADCP Information

RD Instruments 600 kHz Workhorse Monitor; s/n: 2074 and 2432

Transmitting Frequency:	614 kHz
Depth of Transducer:	10 m
Blanking Distance:	0.25 m
Height of First Bin above Bed:	0.73 m
Bin Size:	0.5 m
Number of Bins:	24
Operating Mode:	High-resolution, broad bandwidth
Sampling Frequency:	2 Hz
Beam Angle:	20 deg
Time per Ping:	00:00:00.30
Pings per Ensemble:	120
Profile Ensemble Interval:	0:05:00.00
Wave Ensemble Interval:	2:00:00.00
Sound Speed Calculation:	Set salinity, updating temperature via sensor

Data Processing:

The data were averaged over 36-bin (1 hour) ensembles, all of the spurious data above the water surface were removed and all of the data in bins where the beam correlation dropped below 70% were removed for visualization and analysis.

Position Information:

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

APPENDIX 2

Dobie, Microcat and SCOBS Sensor Information

NIWA Dobie-A Wave/tide Gauge; s/n: 2000-18 and 2000-21

Depth of Transducer:	10 m
Operating Mode:	Water level time series
Sampling Frequency:	2 Hz
Measurements per Burst:	1024
Time Between Bursts:	01:00:00.00

Seabird Microcat SBE-39SM CT; s/n: 1161, 2792, 3800 and 3801

Sampling Frequency:	2 Hz
Measurements per Burst:	8
Time Between Bursts:	00:05:00.00

Aquatec/Seapoint 200-TY SCOBS; s/n: 371-013, 371-014, 371-015, 371-025 and 371-026
Aquatec/Seapoint 210-TYT SCOBS; s/n: 024-002, 024-005, 024-006 and 024-007

Sampling Frequency:	2 Hz
Measurements per Burst:	30
Time Between Bursts:	00:05:00.00

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; s/n: 80207465; USGS/CRP unit#1

APPENDIX 3

Conductivity/Temperature/Depth (CTD) Profiler with Optical Backscatter (OBS) and Photosynthetically-Available Radiation (PAR) Sensor Information

Instruments:

Seabird 19plus CTD; s/n: 4299
D&A Instruments OBS-3; s/n: 1983
Li-Cor SPQA-3562; s/n: 825
Sampling Frequency: 4 Hz

Position Information:

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

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).