Coastal Circulation and Sediment Dynamics Along West Maui, Hawaii

PART I:

Long-term measurements of currents, temperature, salinity and turbidity off Kahana, West Maui: 2001-2003

U.S. Department of the Interior
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Long-term measurements of currents, temperature, salinity and turbidity off Kahana, West Maui: 2001-2003

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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

Long-term (15 months), high-resolution measurements of currents, water levels, temperature, salinity and turbidity were made off West Maui, Hawaii, in 2001-2003 to better understand coastal dynamics in coral reef habitats. Measurements were made through the emplacement of a series of bottom-mounted instruments deployed in water depths less than 10 m. The studies were conducted in support of the U.S. Geological Survey (USGS) Coastal and Marine Geology Program's Coral Reef Project. The purpose of these measurements was to collect hydrographic data to learn how currents and water column properties such as water temperature, salinity and turbidity in the vicinity of nearshore coral reef systems vary over the course of a year. These measurements support the ongoing process studies being conducted under the 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 in a series of three, describes data acquisition, processing and analysis. Subsequent reports will provide data and results on 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)

Project Objectives:

The objective of these deployments was to understand how currents, waves, tides, temperature, salinity and turbidity vary temporally along West Maui over the course of a year. These data were collected to support the ongoing studies being conducted off northwest Maui as part of the USGS's multi-disciplinary Coral Reef Project that focuses on the geologic processes that affect coral reef systems. To meet these objectives, flow and water column properties off West Maui 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 REEFPROBE instrument package was deployed over a period spanning 15 months and encompassed two winter seasons (2001-2002 and 2002-2003) and the intervening spring, summer and fall (2002). Towards the end of the experiment, another smaller instrument packages (MiniPROBE) was deployed inshore of the long-term station to look at the cross-shore variability in flow, tides, waves and suspended sediment flux. Data collected during these deployments provided a long-term baseline for short-term but more spatially-extensive measurements in the future (see PART II and PART III of this report).

Study Area:

These measurements were made offshore Kahana, Northwest Maui, Hawaii, USA, between the Hawaiian Islands of Maui and Molokai (FIGURE 1). All of the measurements were on the inner shelf in water depths less than 11 m (FIGURE 2). The long-term station was at the 10 m isobath in a sediment-filled paleo-stream channel incised during a previous sea-level lowstand. The paleo-stream channel was more than 20 m wide and had a maximum vertical relief of 2 m. The second, shallower station was deployed inshore of the long-term station along the 2 m isobath in a large sand patch

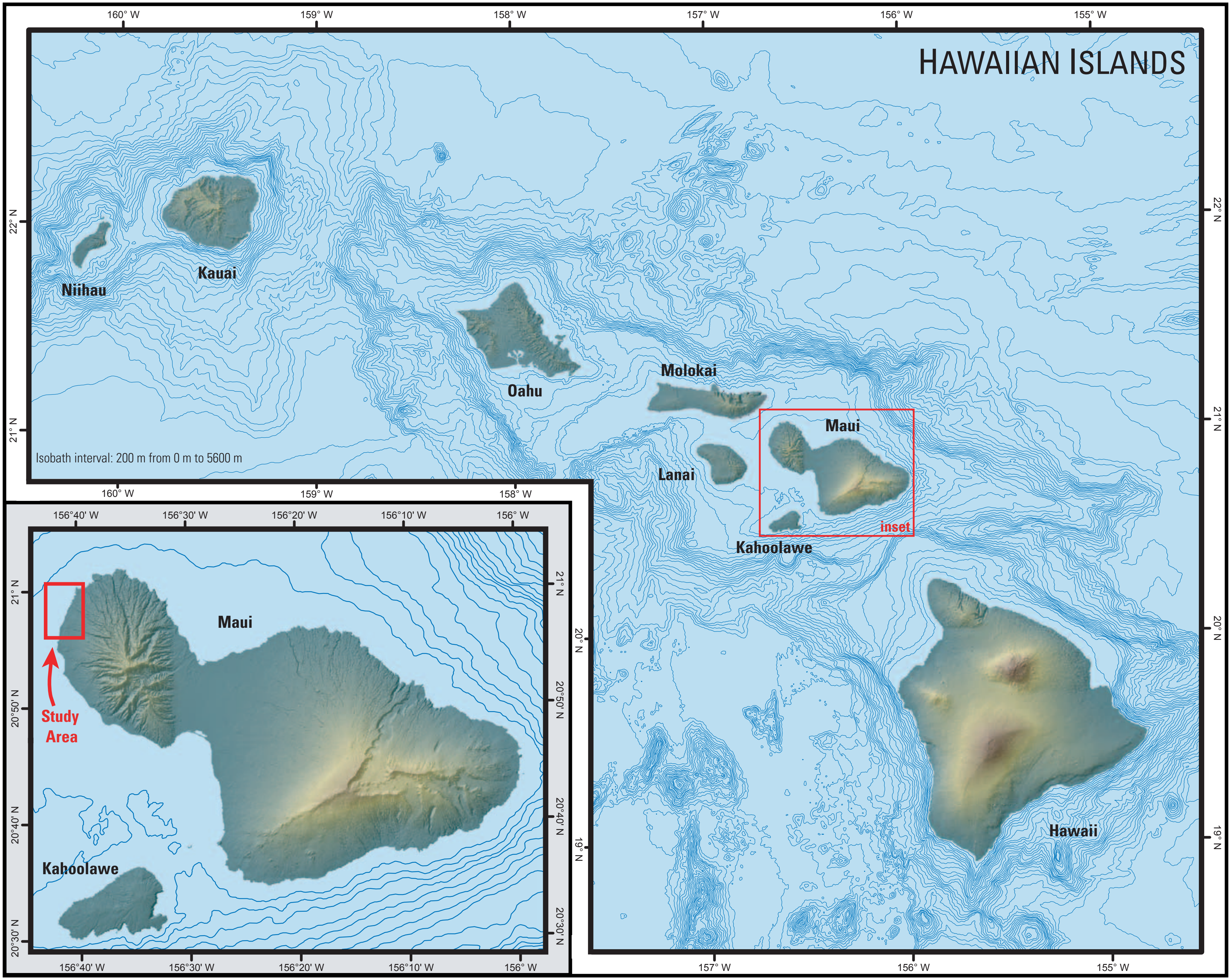

FIGURE 1. *Map of the study area location in the main Hawaiian Island chain. Red box in inset shows the location of FIGURE 2.*

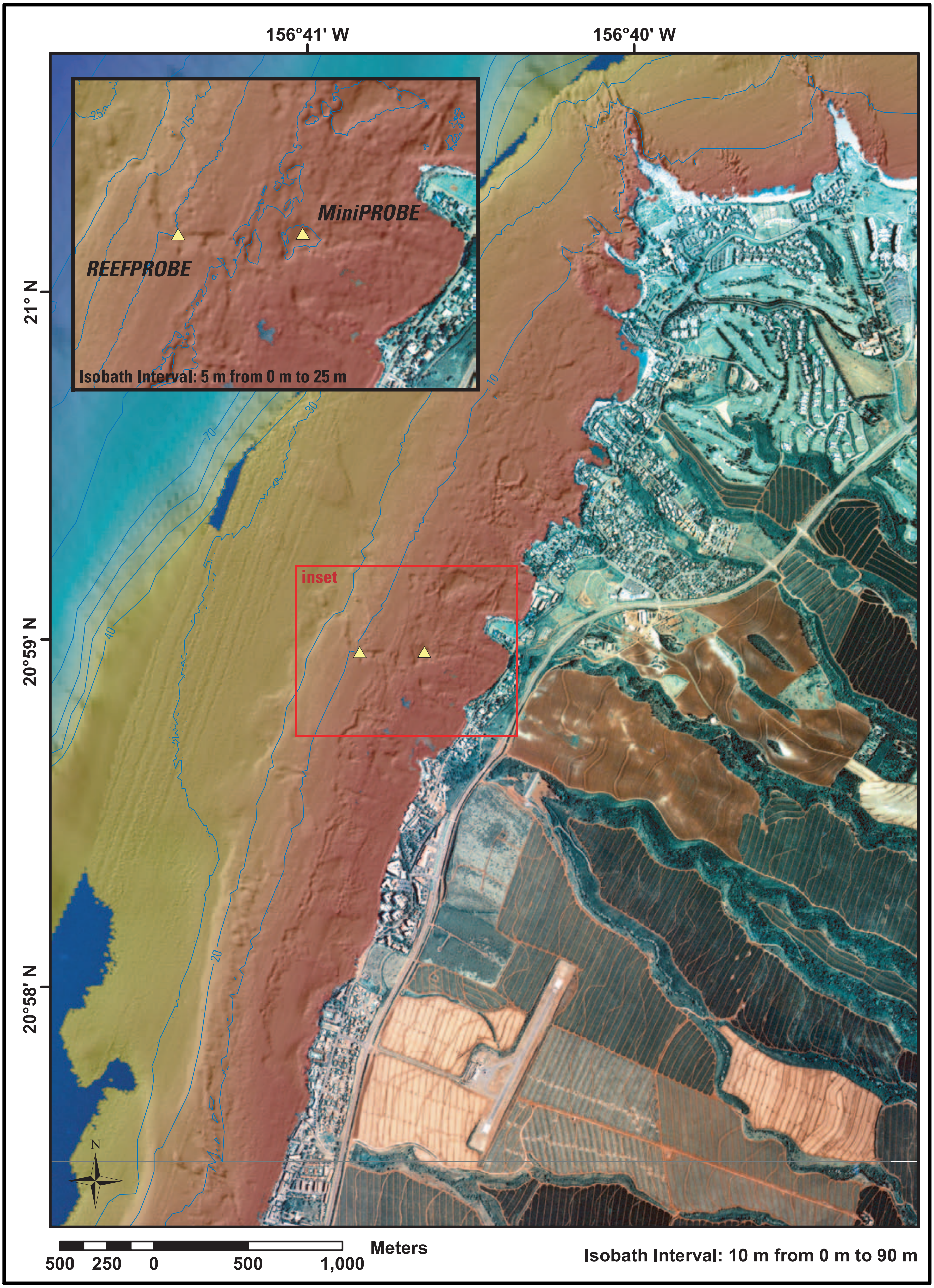

FIGURE 2. *Location of the instrument packages with nearshore bathymetry from SHOALS lidar data and digital elevation model (DEM) data or vertical aerial photography of the terrestrial portion of the study area.*

lying 2 m below the surrounding reef, at a total depth of 4 m. The seafloor sediment at both instrument locations 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 and TABLES 2 and 3 for complete listings of deployment information.

Scientific Party:

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

Equipment and Data Review:

Two primary instruments were used to acquire flow data during these deployments (TABLE 2). The first instrument was a RD Instruments 600 kHz Workhorse Monitor upward-looking Acoustic Doppler Current Profiler (ADCP), which was used to collect vertical profiles of current velocity and acoustic backscatter data. The second primary instrument employed was a downward-looking Sontek 5 MHz ADV-Ocean acoustic Doppler current velocimeter. The ADV-Ocean made near-bed (~0.2 m above the bed) measurements of current velocity in three orthogonal directions (east-west, north-south, up-down), acoustic backscatter and measured the distance from the sensor to the bed. The Sontek Hydra logger collected and stored data from the ADV and four external sensors: a Paroscientific Digiquartz pressure sensor, Seabird SBE-37SI Microcat conductivity-temperature sensor (~0.5 m above the bed) and two D&A Instruments OBS-3 optical backscatter sensors (one ~0.2 m above the bed, the other ~1.0 m above the bed). These external sensors collected single-point measurements on waves and tides, water temperature and salinity, and optical backscatter, respectively. The smaller MiniPROBE package (FIGURE 3a) included a RD Instruments 600 kHz Workhorse Monitor upward-looking Acoustic Doppler Current Profiler (ADCP) similar to the one on the deeper REEFPROBE tripod (FIGURE 3b) and two other sensors: 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.

The instrument packages were typically deployed for 90-100 day periods, as constrained by the power consumption. Sensors connected to the Sontek Hydra logger on the REEFPROBE tripod were measured using three sampling schemes. For deployments 1, 2, 4 and 5, data was collected from all instruments each hour for 512 sec at 2 Hz to allow calculation of mean flows, oscillatory flows, wave heights, salinity, temperature, turbidity (sediment concentration) and sediment flux. For deployment 3,

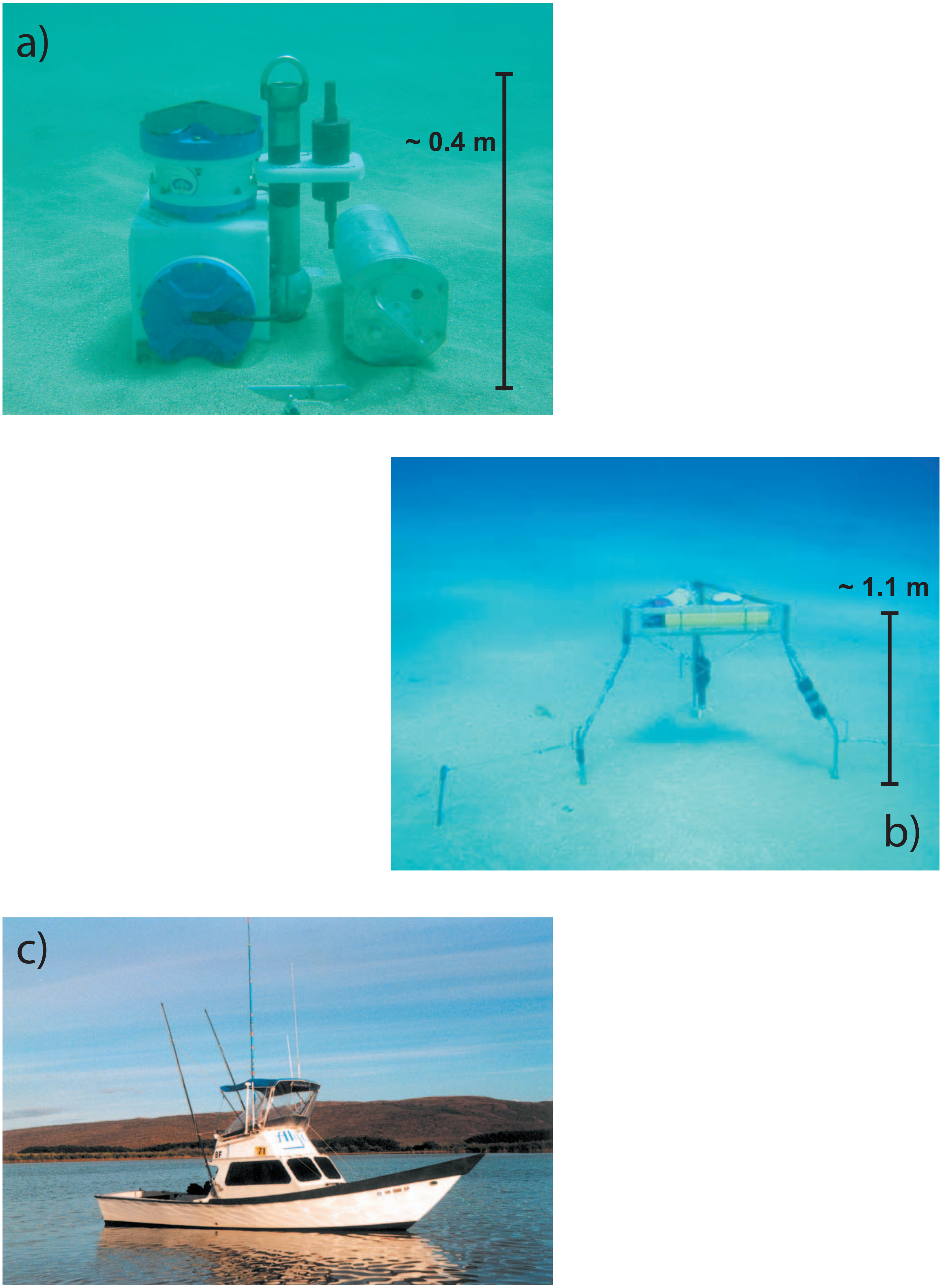

FIGURE 3. *Photographs of instrument packages and the deployment vessel. (a) View of the MiniPROBE instrument package on the seafloor along the 2 m isobath in a 2 m deep sediment-filled depression. (b) View of the REEFPROBE instrument package on the seafloor along the 10 m isobath in a sediment-filled paleo-stream channel. (c) View of the R/V Alyce C.*

data was collected from all instruments each hour for 1024 sec at 2 Hz to allow detection of longer period variations. During all deployments, a third experimental scheme sampled all instruments, except the CTD, every 9 hours for 512 sec at 10 Hz to allow examination of higher-frequency behavior. The upward looking ADCPs mounted on the REEFPROBE tripod and the MiniPROBE sampled for 40 sec every 4 min to allow calculation of mean flows and higher frequency motions like internal tidal bores and non-linear internal waves, while the SCOBS recorded an 8 sample burst every 4 min. The Dobie pressure sensor recorded a 512 sec burst at 2 Hz every hour to provide wave and tide information. The instrument package deployment and recovery log is presented in TABLE 3. The instrument specifics and sampling schemes are listed in APPENDIX 1, APPENDIX 2 and APPENDIX 3 for the ADCP profiler, Hydra system, and other sensors, respectively.

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:

The instrument deployments and recoveries were conducted using a leased vessel, the 28-ft-long *R/V Alyce C.*, owned and operated by Alyce C. Sport Fishing (FIGURE 3c). The *R/V Alyce C.*, which was designed as a sport-fishing boat, was modified for scientific studies. 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.

Deployment/Recovery Operations:

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. 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

Data were acquired 429 days during the 15 month period between 12/05/2001 and 02/27/2003; this was more than 96% data coverage over the entire experiment. The instruments were out of the water for only 19 days during these 15 months for data recovery and instrument refurbishment.

More than 99% of the data were recovered from the ADCP profiler on the REEFPROBE and MiniPROBE tripods. Data quality was generally very high. The

ADCP data near the surface displayed slightly lower correlation due to bubble interference with the transducers. This loss of data from the bins closest to the surface is common to most upward-looking ADCPs and was expected. The raw ADCP data were archived and copies of the data were post-processed to remove all “ghost” data from above the surface and all data when the beam correlation dropped below 70% were discarded for visualization and analysis. Post-processed data were saved and copies were desampled to hourly intervals to better visualize longer-term variability; these desampled copies of the data were also saved and archived.

More than 90% of the Sontek ADV-Ocean and external sensor data on the REEPROBE appeared to be of high quality. This assessment was made by examining plots of mean and standard deviation values of the hourly data and inspection of selected time series while in the field. Data problems were primarily with OBS sensors. OBS sensors, although coated with a transparent antifouling coating on the optical sensors, tended to biofoul towards the end of the deployments, rendering portions of the data unusable. Inspection of 2 Hz OBS data revealed “cross-talk” between sensors. This was a low-amplitude, periodic signal due to electrical interference that was be removed during processing. There was only one failure of all sensors during the experiment. Approximately 1.5 months into the first deployment, the lowest OBS sensor was sheared, causing it to fail. All data was contaminated for a period of about 1 week while the sensor was not completely failed. After the lowest OBS completely failed, data quality for all remaining sensors was high.

We computed turbidity values in National Turbidity Units (NTU) for the SCOBS, OBS and ADCP sensors using Formazin calibration solution and regression statistics. We first made a set of turbidity standards (typically 0, 10, 50, 100 and 200 NTU) by diluting 4000 NTU Formazin solution into calibration tubs. We then calibrated the OBS sensors by placing them in the standards, logging their output voltages over 30 sec and computing an average voltage for each NTU standard. The resulting regression equations were then used to compute NTU values from the recorded OBS voltages (FIGURE 4a). These new calculated NTU values were then correlated to co-located ADCP acoustic backscatter data that had already been processed for beam spreading and attenuation using the methodology proposed by Deines (1999). The resulting regression equation was then used to compute NTU values from the corrected acoustic backscatter data throughout the water column (FIGURE 4b).

RESULTS AND DISCUSSION

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

Tides

The tides off Kahana are of the mixed, semi-diurnal type 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.

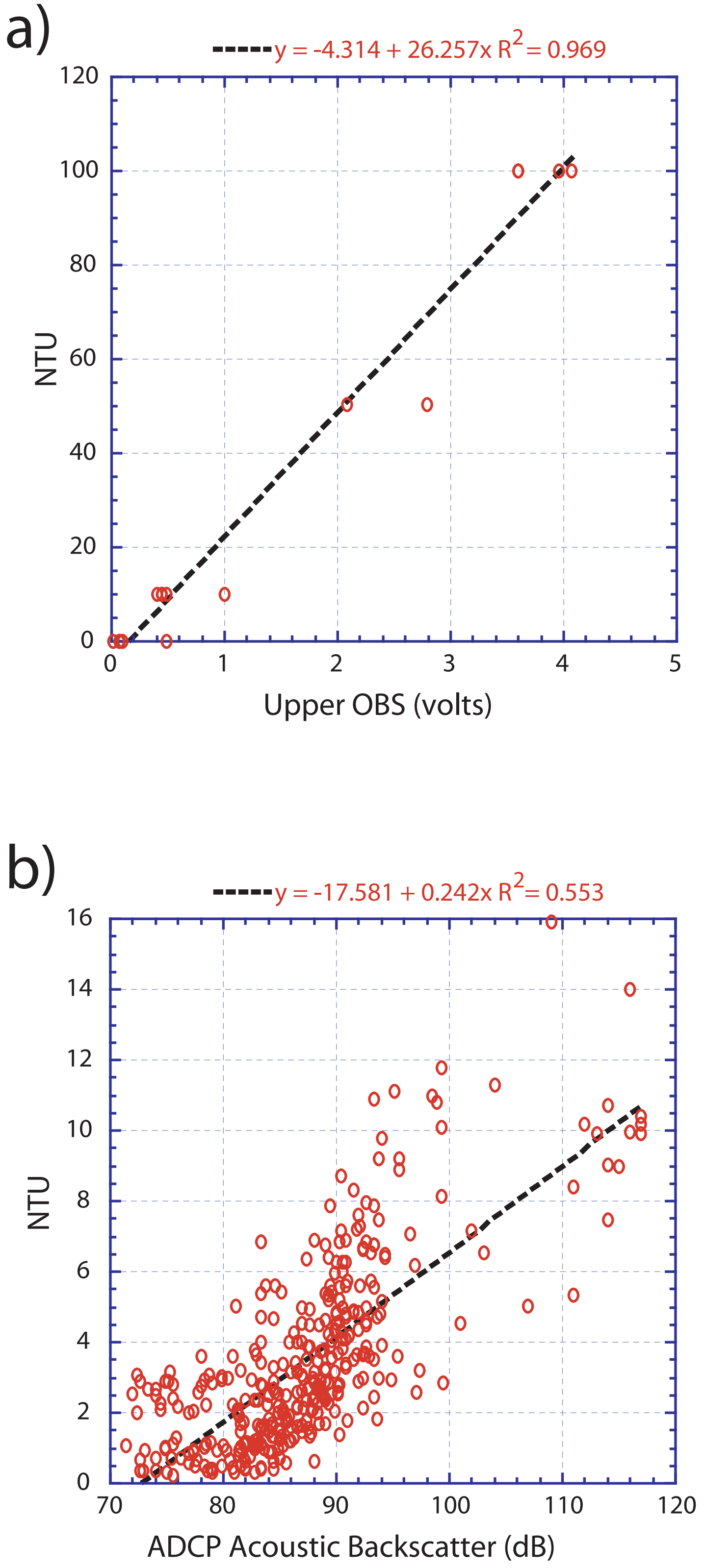

FIGURE 4. *Regressions used to calibrate the different sensors for turbidity. (a) Regression statistics and equation used to compute NTU values from the upper OBS (~1.05 m above the bed) voltages using Formazin solution. (b) Regression statistics and equation used to compute NTU values from the ADCP acoustic backscatter data using the regression data from the co-located upper OBS sensor shown above.*

Currents

Most of the daily variability in current speed and direction at the study site are due to the tides. As the tide rises (floods), currents off Kahana flow to the northeast roughly parallel to shore; conversely, as the tides fall (ebb), the currents flow to the southwest roughly parallel to shore. This pattern is set by the location of the tidal node (amphidrome) to the west of the Hawaiian Island chain and the counter-clockwise sweep of the tidal bulge around the amphidromic point. Mean tidal current speeds ± one standard deviation 5 m above the bed are 0.17 ± 0.10 m/sec at the site along the 10 m isobath and 0.05 ± 0.06 m/sec at the site along the 2 m isobath (FIGURE 5). 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 and more consistent in the alongshore direction at the 10 m site than inshore along the 2 m isobath. During the winter when the deep-water wave heights are large, the currents, which are flow primarily alongshore (shore-parallel), taken on a more offshore component. This is especially true at the inshore site along the 2 m isobath where mean currents are almost always directed offshore when the significant wave height at the site exceeds 0.6 m. This is likely caused by wave- and wave-breaking induced onshore transport of the surface waters, which causes water to pile up at the shoreline and, in turn, drives offshore-directed return flow through most of the water column down to near the bed.

While waves cause the majority of flow modification at the shallow site, the dominant factor driving flow other than the tides at the deeper 10 m site are the winds or wind-induced sea-surface-height variations. When the Trade winds blow at 5-15 m/sec to the southwest as they typically do during most of the year, especially during the spring and summer, they force water in the Pailolo Channel between Maui and Molokai to the southwest. Under normal Trade wind conditions, there was very little net alongshore flow at the site, with a very slight offshore component of net flow. When the Trade winds decrease in strength or are replaced by winds out of the south or west, as often occurs during the fall and winter months, we observed net flow to the northeast at the site along the 10 m isobath (FIGURE 6). This suggests that either (a) net flow in the Pailolo Channel along the 10 m isobath of West Maui is to the north, possibly driven by larger-scale oceanic flow, or (b) that there is some type of large-scale relaxation that occurs when the Trade winds decrease in strength, with the water that has been piled-up by Trade winds in the channels between Maui, Molokai, Lanai and Kahoolawe (the Maui Nui group) being relaxed and flowing back out through the Pailolo Channel. These return flows may be due to the passage of an island-trapped wave (ITW), as suggested by Flament and Lumpkin (1996) and Merrifield et al. (2002). The currents' energy spectra during the 2002-2003 winter, while dominated by the semi-diurnal and diurnal tidal components, do show increased energy in the 55-65 hour ITW band (FIGURE 7). Flament and Lumpkin (1996) observed a similar peak in the ITW band from current meters deployed in 235 m of water roughly 5 km northwest of the study area, suggesting that the flow observed along the 10 m isobath are likely due to the passage of ITWs. We do not have enough information at this time to indicate which process or combination of processes is responsible for the observed northeasterly flow.

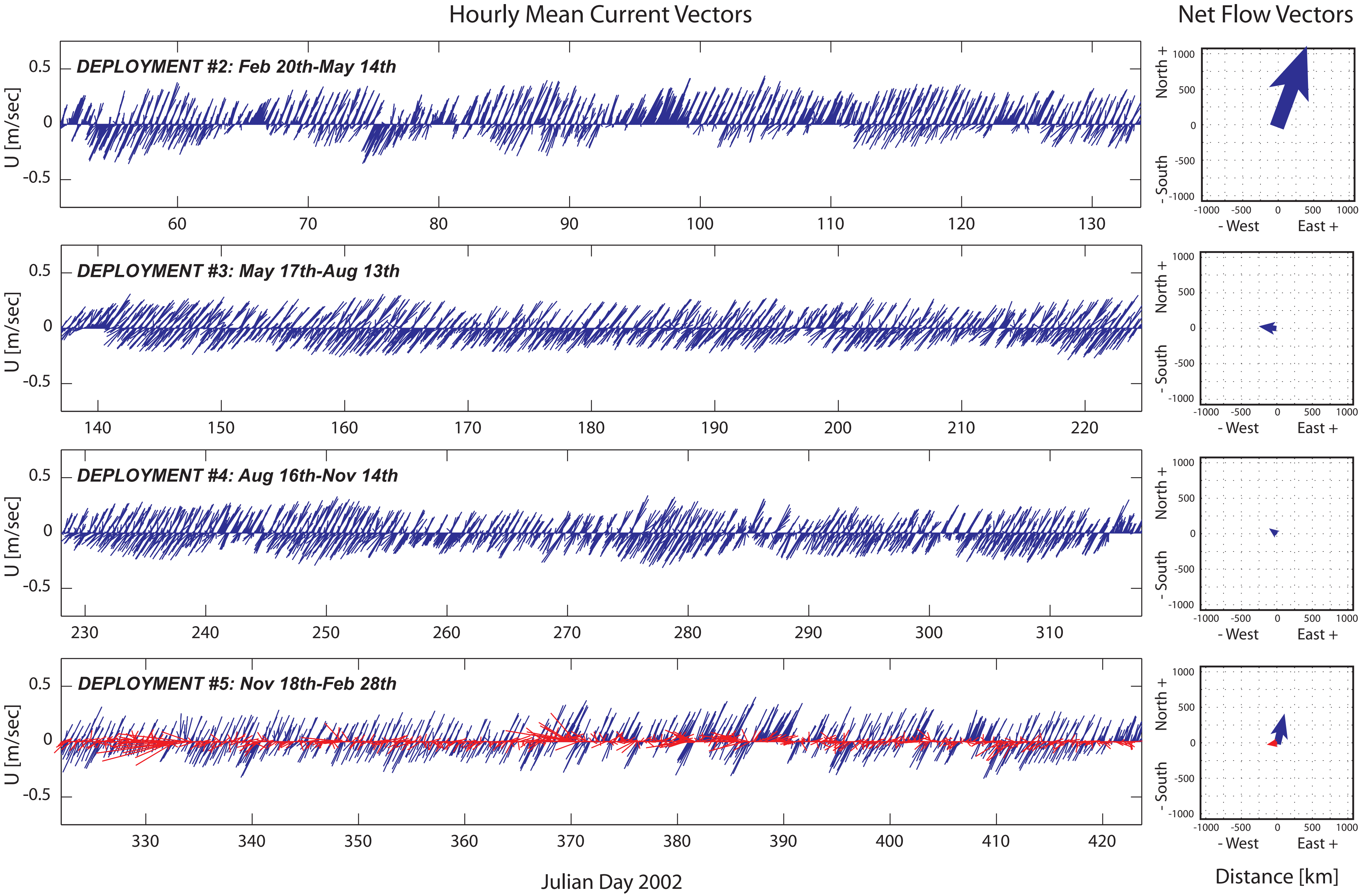

FIGURE 5. *Hourly mean current speeds and directions and the net flow roughly 5 m above the bed over four three-month deployments. Blue data are from the instrument package along the 10 m isobath while the red data are from the shallower instrument package along the 2 m isobath. During the spring and summer when the Trade winds blow consistently, there is little net flow at the long-term deeper (10 m) station. When the Trade winds become more variable or weaken in the fall and winter, however, net flow at the site along the 10 m isobath is to the northeast.*

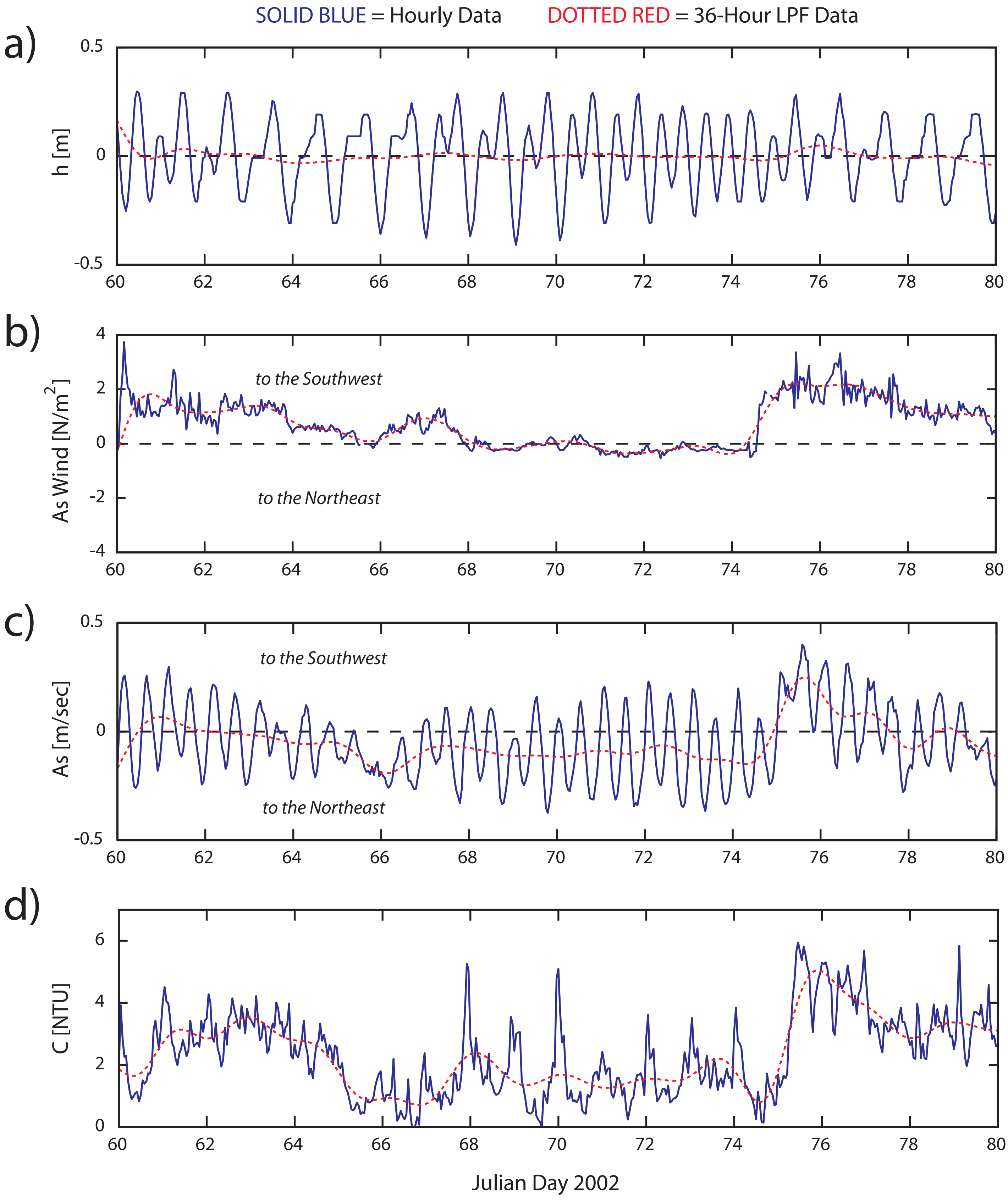

FIGURE 6. *Wind forcing of currents and turbidity at the deeper instrument package along the 10 m isobath. (a) Tidal height. (b) Alongshore wind stress from the Kahalui Airport, with positive values downcoast to the southwest. (c) Alongshore currents approximately 2 m above the bed, with positive values downcoast to the southwest. (d) Turbidity roughly 2 m above the bed, calculated from the ADCP. When the Trade winds blow at high speed to the southwest (JD 62-64 and 76-78), net water flow is to the southwest and turbidity tends to be high. When the Trade winds relax, net flow is to the northeast and turbidity tends to be lower. These longer-term patterns can be seen in the low-pass filtered data (only those signals that occur at periods greater than the tides, >36 hours) in red are overprinted by the semi-diurnal tides, which are apparent in the hourly data shown in blue.*

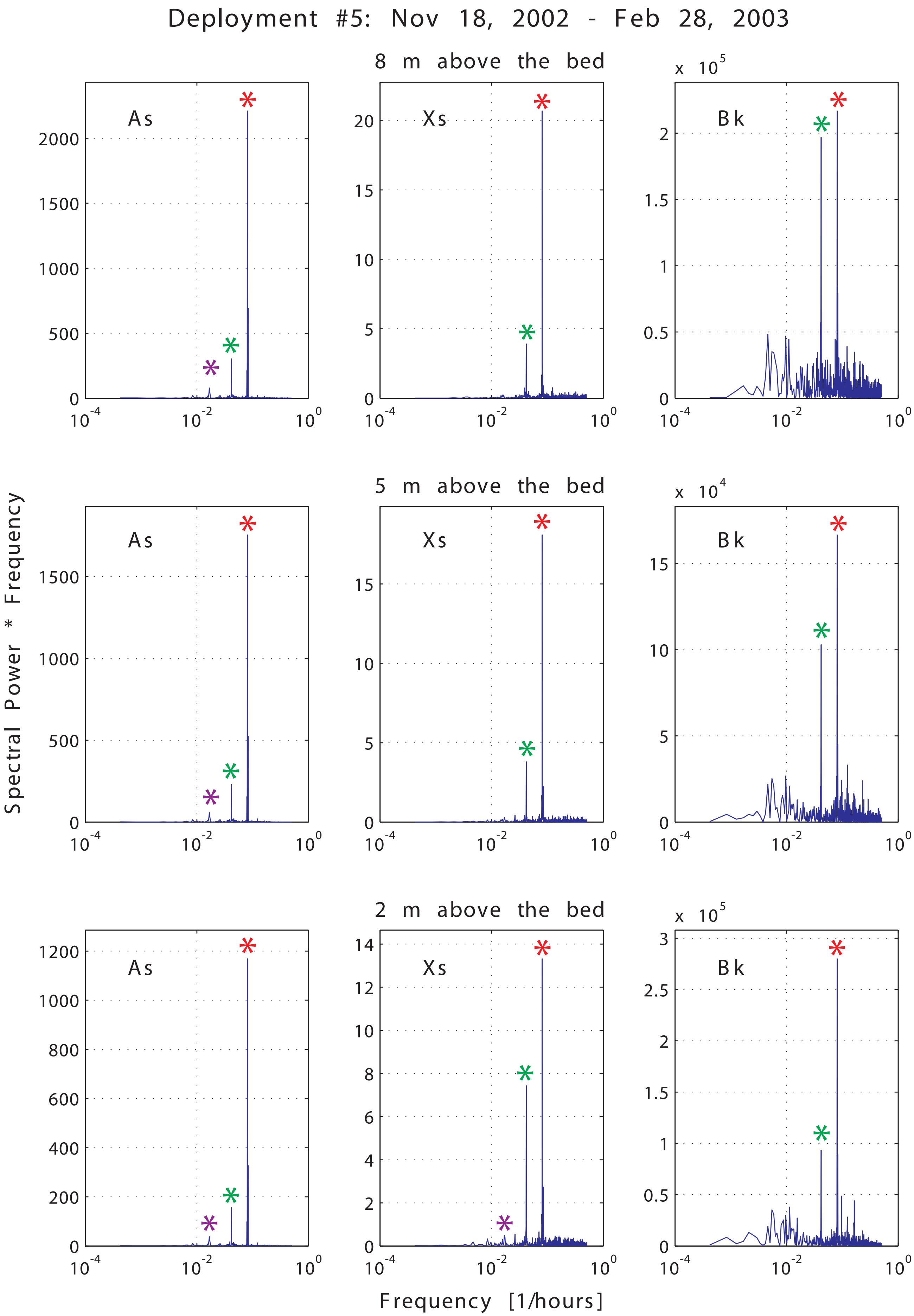

FIGURE 7. *Variance-conserving power spectra for parameters along the 10 m isobath during the 2002-2003 winter deployment. The alongshore currents ('As'), cross-shore currents ('Xs') and acoustic backscatter ('Bk') measurements were made 2 m, 5 m and 8 m above the bed. The red stars denote the peaks in energy at the semi-diurnal tidal period (~ 12.4 hours), the green stars denote the peaks in energy at the diurnal tidal period (~ 24.8 hours) and the purple stars denote the peaks in energy in the island-trapped wave period band (55-65 hours). Note the varying magnitude of the y-axes.*

Water Column Properties

The water column properties that were collected included variations in temperature (ºC), salinity (PSU), optical backscatter (NTU) and acoustic backscatter (dB).

Temperature:

Water temperatures were on average slightly cooler and less variable at the deeper 10 m site than along the 2 m isobath at the shallow instrument site (FIGURE 8). Over the period of study, the water temperatures roughly 0.5 m above the bed at the site along the 10 m isobath ranged between 22.54 °C and 27.33 °C, with a mean temperature ± one standard deviation of 25.25 ± 0.41 °C. During the last deployment (#5), the water temperatures at the site along the 2 m isobath ranged between 23.16 °C and 26.50 °C, with a mean temperature ± one standard deviation of 24.72 ± 0.61 °C. At both sites the water typically warmed 0.2-0.4 °C during the day due to insolation. Over time scales longer than tidal periods (>24 hours), we observed long-term cooling due to flow from offshore to the north moving onshore to the south; conversely, long-period warming occurred during net flow to the northeast. These long-period decreases in water temperature may be due to the excursion of deeper, cooler water from the north outside of the Maui Nui group (Maui, Molokai, Lanai and Kahoolawe) into the Pailolo Channel. At tidal periods (12-24 hours), water temperatures typically increased when the tidal elevation fell. This may be in part caused by water warmed in the shallows closer to the shoreline being advected obliquely offshore out past the deeper instrument package along the 10 m isobath.

Another very interesting feature was often observed in the high-frequency (every 4 min) temperature records recorded by the ADCP at the 10 m site. During spring and summer when the Trade winds blew consistently, roughly once per day very rapid (typically <16-32 min) warming or cooling was observed at the deeper site (FIGURE 9). The water temperature typically changed by more than 0.5 °C and frequently by more than 1.0 °C. These rapid changes in water temperature occurred during all but the spring phases (new and full moon) of the lunar tidal cycle and during all phases (low, rising, high and falling) of the diurnal tidal cycle. Almost all of these features were proceeded by relatively high cross-shore shear in the water column (typically >0.07 m/sec difference over 4 m of the water column). At the time of the rapid change in water temperature, the flow in the water column would rapidly switch direction, with onshore near-surface flow changing to offshore near-surface flow and near-bed offshore flow changing to onshore near-bed flow, or visa versa. A rapid warming typically occurred when near-surface waters moved onshore and near-bed waters moved offshore while rapid cooling typically occurred when near-surface waters moved offshore and near-bed waters moved onshore. These features are very similar to internal bores observed off the West Coast of the United States (e.g. Storlazzi et al., 2003). There is a lack of strong stratification during the times when the bores were observed off Kahana (Storlazzi et al., 2003), which is dissimilar to observations of bores

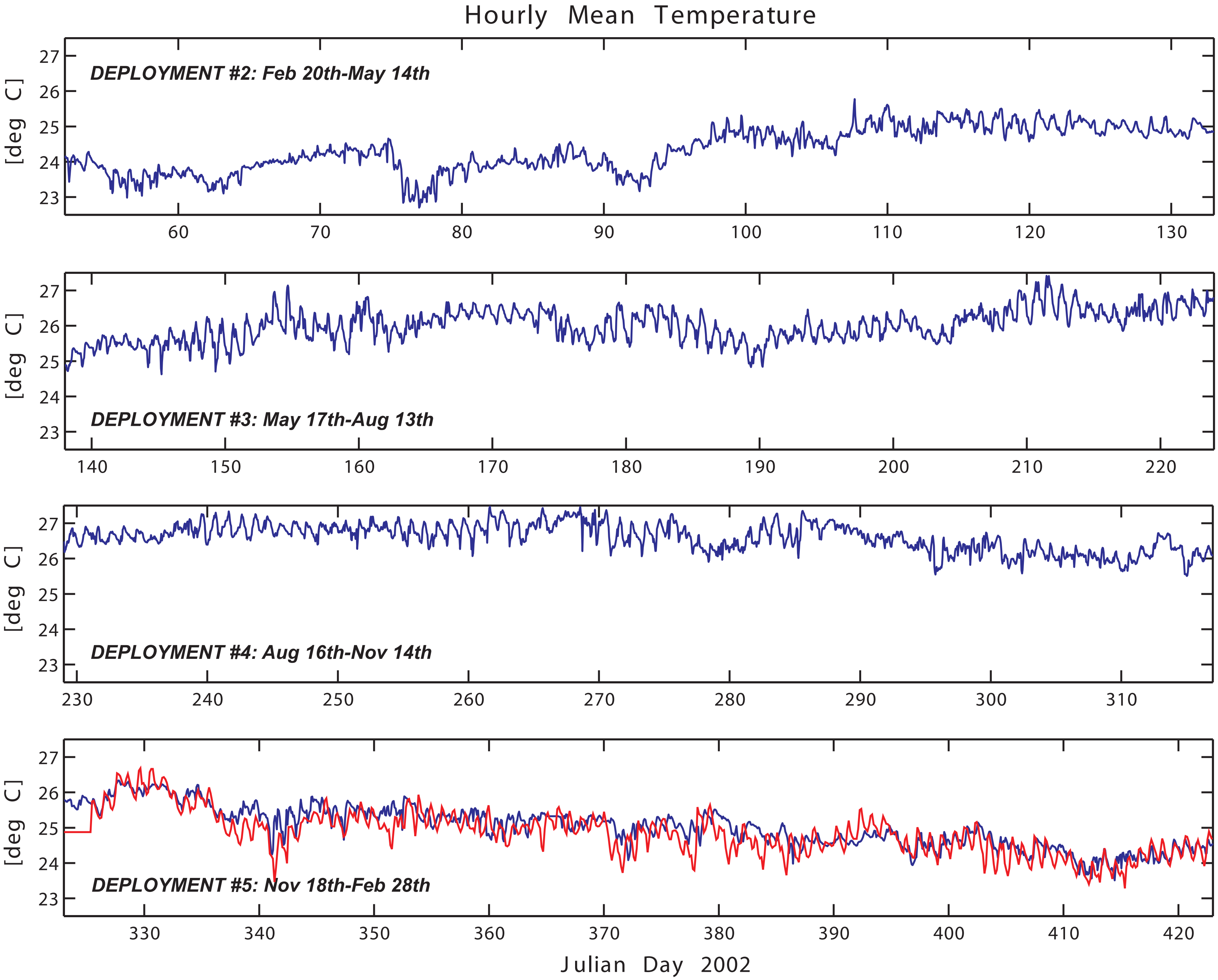

FIGURE 8. *Hourly mean water temperatures in the study area over four three-month deployments. Blue data are from the instrument package along the 10 m isobath while the red data are from the shallower instrument package along the 2 m isobath. During the periods when the Trade winds blow consistently, there is high diurnal variablity at the long-term deeper (10 m) station. When the Trade winds become more variable or weaken in the fall and winter, however, there is much less diurnal variability. During sustained periods of flow to the southwest (SEE FIGURE 4), the water column typically cools while the water column warms during sustained flow to the northeast.*

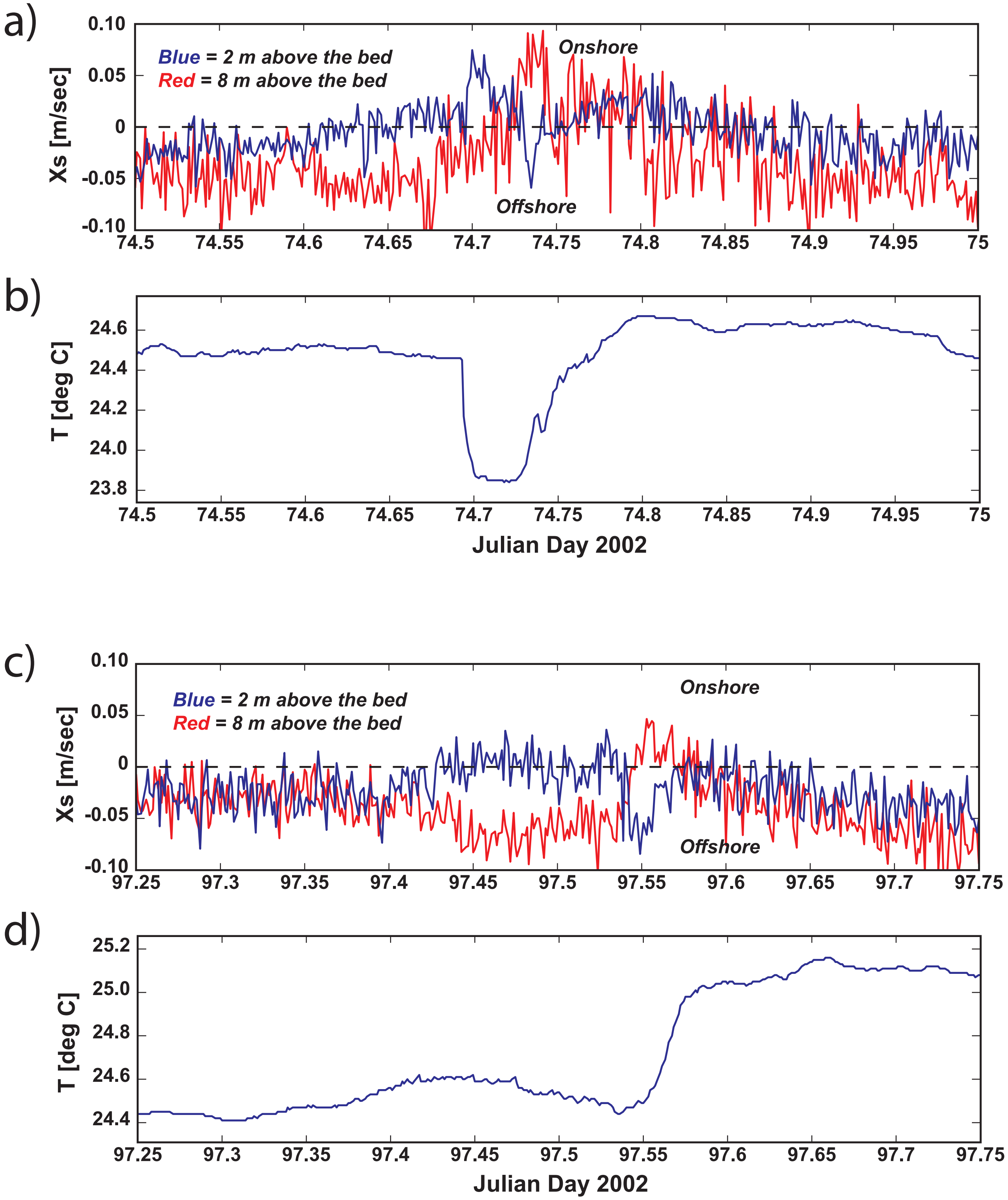

FIGURE 9. *Two examples of possible internal tidal bores driving a rapid temperature change at the deeper instrument package along the 10 m isobath. (a,c) Cross-shore current velocities, with positive flow onshore. (b,d) Temperature roughly 1.2 m above the bed. Top: Internal bore causing a sharp decrease in water temperature followed by a rapid increase in water temperature, causing no little net change. Bottom: Internal bore causing a rapid increase in water temperature. Note the velocity shear (difference between near-surface and near-bed current speed and direction) proceeding and during these events that led to the rapid changes in temperature as different water masses were advected by the instrument package.*

made elsewhere. Similar internal bores have been shown to episodically transport deep, subthermocline nutrients from offshore up on to the coral reefs in the Florida Keys (Leichter et al., 2003). Without concurrent, co-located nutrient sampling, however, we cannot determine if these internal bores are delivering nutrients to the reefs along Northwest Maui and contributing to the algal blooms discussed by Dollar and Andrews (1997) and the West Maui Watershed Management Project (1996).

Salinity:

Over the period of study, the water salinities roughly 0.5 m above the bed at the site along the 10 m isobath ranged between 32.18 PSU and 35.19 PSU, with a mean salinity ± one standard deviation of 34.73 ± 0.12 PSU. Higher-salinity water typically moved onshore with the rising tide. Infrequent low-salinity pulses were observed and correlated with offshore flow; these may have been the signal of freshwater discharge from onshore drainages or fresh groundwater diffusing out of the shallower portions of the reef and being advected out past the instrument site along the 10 m isobath. Becasue we did not have a salinity sensor at the shallower 2 m site, however, we cannot test this hypothesis.

Turbidity:

Turbidity was generally both more intense and more variable closer to the bed at the deeper 10 m site and inshore along the 2 m isobath at the shallow instrument site than higher above the bed at the 10 m site. 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 163.9 NTU, with a mean turbidity ± one standard deviation of 2.8 ± 4.1 NTU. Approximately 1.0 m above the bed at the 10 m instrument site, the turbidity ranged between 0.0 NTU and 73.2 NTU, with a mean turbidity ± one standard deviation of 1.0 ± 1.3 NTU. At the shallower instrument location, the turbidity at the site along the 2 m isobath ranged between 0.0 NTU and 138.6 NTU, with a mean turbidity ± one standard deviation of 3.6 ± 3.7 NTU. While most of the variability in turbidity was due to the tides (FIGURE 7), the highest turbidity values were related to large wave events, high rainfall events, or both. It is not clear whether the high turbidity during large wave events was caused by the waves resuspending the surrounding 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 and imaged by the optical backscatter sensors (FIGURE 10).

Water and Turbidity Fluxes:

Net flow roughly 0.2 m above the bed at the deeper site along the 10 m isobath was to the northeast over the period of study, with little net flow during the spring and summer and the majority of the net flow occurring during Trade wind relaxations in the fall and winter (FIGURE 5). Over the much shorter period of record (just one winter season), flow along the 2 m isobath at the shallower site was primarily offshore in the response to large wave events. Due to phasing with the tides (higher turbidity during falling tides, likely being advected out from the shallower portions of the reef) turbidity fluxes at the deeper 10 m site were primarily to the southwest, however, roughly 180 degrees from the net water flux to the northeast. Net turbidity fluxes at the shallower

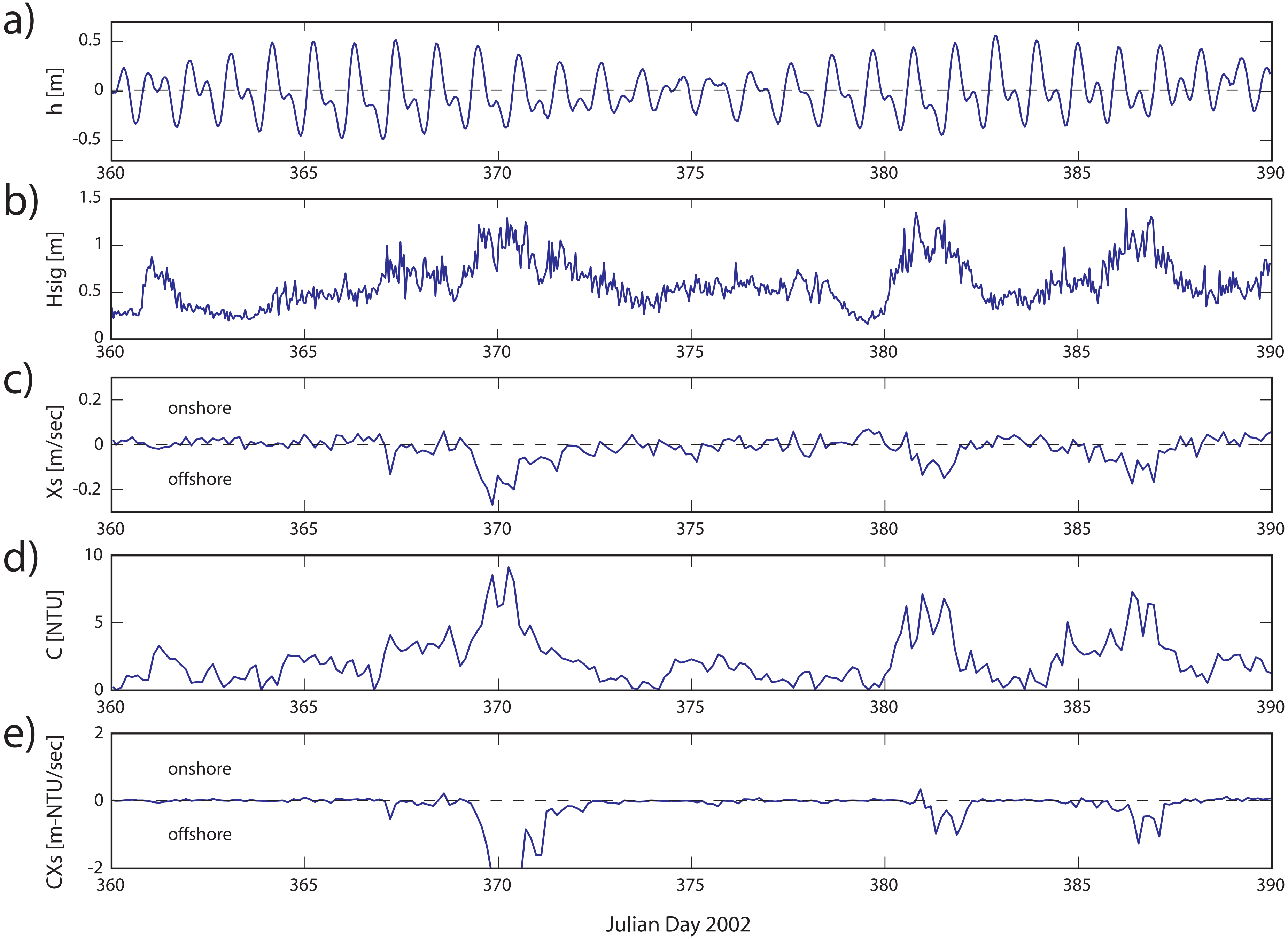

FIGURE 10. *Wave-driven resuspension of sediment at the shallower instrument site along the 2 m isobath and its offshore transport. (a) Tidal height. (b) Significant wave height. (c) Cross-shore current velocities roughly 2 m above the bed, with positive flow onshore. (d) Turbidity roughly 2 m above the bed, calculated from the ADCP. (e) Cross-shore turbidity flux roughly 2 m above the bed, with positive flow onshore. While there is some low background turbidity, note that when the significant wave height exceeds 0.4 m the turbidity increases. Note the strong offshore flow during these large wave events, which drives the higher turbidity water offshore.*

site were primarily offshore, but these data were only recorded during the winter months and thus the offshore direction of net flux might be very different if a whole year of data had been collected.

As stated earlier, the seafloor sediment at both instrument sites was a relatively well-sorted carbonate sand. Sediment traps, with their openings placed roughly 0.8 m above the bed, were attached to the instrument packages during the last deployment (11/2002-02/2003) at both locations. While the coarse-grained sediment collected in both traps was relatively clean carbonate sand (>74% carbonate), suggesting that it came from the surrounding seafloor, the fine-grained component in both traps was primarily (>64%) terrigenous in origin and contained numerous (>4%) organic particles. These results suggest that while the energetics (primarily surface waves) of the environment are too great to allow for the deposition of fine-grained silts and clays on the bed, large quantities of fine-grained terrigenous sediment do move through the study area. Fine-grained terrestrial sediment is generally not present at depths less than 10 m because of the high wave energy.

CONCLUSIONS

In all, more than 29,300 hourly observations of currents, waves and water column properties were collected per day for 429 days over the course of 15 months between November 2001 and February 2003 off Northwest Maui, Hawaii, USA. Key findings from these measurements and analyses include:

(1) Flow at the 10 m REEFPROBE site is primarily controlled by the tides and the Trade winds. Further inshore along the 2 m isobath, flow is more variable, less influenced by the tides and appears to be dominated by large surface wave-induced flows.

(2) During the summer months when the Trade winds consistently blow to the southwest, there is little to no net flow along the 10 m isobath.

(3) During the winter months when the Trade winds are less consistent and typically weaker, net flow along the 10 m isobath is upcoast to the northeast while net flow along the 2 m isobath in downcoast to the southwest, demonstrating a inshore wave-driven jet downcoast to the southwest and net mean flow further offshore upcoast to the northeast. These flows may be due to the passage of island-trapped waves (ITWs).

(4) Tidal currents rise to the northeast and fall to the southwest. As the tides fall, they typically draw warm, turbid water offshore and drive it downcoast to the southwest.

(5) Higher turbidity is typically observed during large wave events, strong Trade winds, and falling tides.

(6) What are interpreted to be internal bores were observed throughout the year but primarily during the spring and summer and caused cross-shore transport in the study area.

These data provide us with a much clearer picture of the nature of and controls on flow and suspended sediment flux in the study area. A number of interesting phenomena were observed that indicate the complexity of coastal circulation off West Maui and may help to better understand the implications of the processes on coral reef health.

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TABLE 1. Experiment personnel

Person	Affiliation	Responsibilities
Curt Storlazzi	USGS	Co-chief scientist, led instrument and scuba diving operations
Bruce Jaffe	USGS	Co-chief scientist, scuba diver
Joshua Logan	USGS	Oversaw navigation, co-led scuba diving operations
Michael Field	USGS	Project chief, scuba diver
Thomas Reiss	USGS	Dive safety officer, instrument support
Eric Grossman	USGS	Scuba diver, instrument support
Susie Cochran	USGS	Instrument support
Rebecca Stamski	UCSC	Instrument support
Eric Thompson	USGS	Instrument support
Joe Reich		Captain, *R/V Alyce C.*

TABLE 2. Instrument package sensors

Instrument	Sensors
REEFPROBE	RD Instruments 600 kHz Workhorse Monitor acoustic Doppler current profiler (upward-looking) Sontek Hydra 5 mHz ADV-Ocean acoustic Doppler current meter (downward-looking) Paroscientific Digiquartz pressure sensor Seabird SBE-37SI Microcat conductivity-temperature sensor D&A Instuments OBS-3 optical backscatter sensor D&A Instuments OBS-3 optical backscatter sensor
MiniPROBE	RD Instruments 600 kHz Workhorse Monitor acoustic doppler current profiler (upward-looking) NIWA Dobie-A strain gauge pressure sensor Aqautec/Seapoint 200-TY optical backscatter sensor

TABLE 3. Instrument package deployment log: 11/2001 - 02/2003

Instrument	Island ID	Depth (m)	Deployment Date	Recovery Date	Latitude (dd)	Longitude (dd)
REEFPROBE	MA	10	12/06/01	02/17/02	20.98252	-156.68112
REEFPROBE	MA	10	02/21/02	05/14/02	20.98252	-156.68112
REEFPROBE	MA	10	05/17/02	08/13/02	20.98252	-156.68112
REEFPROBE	MA	10	08/18/02	11/14/02	20.98252	-156.68112
REEFPROBE	MA	10	11/18/02	02/27/03	20.98252	-156.68112
MiniPROBE	MA	4	11/18/02	02/27/03	20.98249	-156.67782

APPENDIX 1

REEFPROBE and MiniPROBE Acoustic Doppler Current Profiler (ADCP) Information

Instrument:

RD Instruments 600 kHz Workhorse Monitor (REEFPROBE); s/n: 3098
RD Instruments 600 kHz Workhorse Monitor (MiniPROBE); s/n: 2432

Transmitting Frequency:	614 kHz
Depth of Transducer:	10 m/4 m*
Blanking Distance:	0.25 m
Height of First Bin above Bed:	1.50 m/0.75 m*
Bin Size:	1.0 m/0.5 m*
Number of Bins:	12
Operating Mode:	High-resolution, broad bandwidth
Sampling Frequency:	4 Hz
Beam Angle:	20 deg
Time per Ping:	00:00:00.30
Pings per Ensemble:	1
Ensemble Interval:	00:04:00.00
Sound Speed Calculation:	Set salinity, updating temperature via sensor

Deployments: 5/1*

* - First number corresponds to the deeper REEFPROBE tripod, the second number corresponds to the shallower MiniPROBE package

Data Processing:

The data were averaged over 20-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

Instruments on the REEFPROBE Logged by the Sontek Hydra

Instruments:

Sontek Hydra ADV-Ocean; s/n: B137H; calibrated 12/1999

Transmitting Frequency:	5 mHz
Depth of Transducer:	10 m
Blanking Distance:	0.18 m
Initial Height of Measurement above Bed:	0.30 m
Operating Mode:	High-resolution, broad bandwidth
Sampling Frequency:	2 Hz and 10 Hz
Measurements per Burst:	1024
Time Between Bursts:	01:00:00.00
Sound Speed Calculation:	Set salinity, updating temperature via sensor

Paroscientific Pressure Sensor; s/n: T60005; calibrated 11/2001

Seabird Microcat SBE-39SI CT; s/n: 7072-0275; calibrated 11/2001

D&A Instruments OBS-3 (lower); s/n: 1104, 1143,1242, 1428; calibrated before and after each deployment; initial height ~ 0.20 m above the bed

D&A Instruments OBS-3 (upper); s/n: 926, 929,1135; calibrated before and after each deployment; initial height ~ 1.05 m above the bed

Deployments: 5

Position Information:

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

APPENDIX 3

MiniPROBE External Sensor Information

Instruments:

NIWA Dobie-A Pressure Sensor; s/n: 2000-14; calibrated 05/2001

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 OBS; s/n: 371-015; calibrated 08/17/2002

Sampling Frequency:	2 Hz
Measurements per Burst:	30
Time Between Bursts:	00:04:00.00