Submarine ground water discharge and fate along the coast of Kaloko-Honokohau National Historical Park, Hawaii

Part I:

Time-series measurements of currents, waves, salinity and temperature: November 2005 – July 2006

By M. Katherine Presto, Curt D. Storlazzi, Joshua B. Logan, and Eric E. Grossman

Open-File Report 2007–1310

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

U.S. Department of the Interior
Dirk Kempthorne, Secretary

U.S. Geological Survey
Mark Myers, Director

U.S. Geological Survey, Reston, Virginia 2007

For product and ordering information:
World Wide Web: http://www.usgs.gov/pubprod
Telephone: 1-888-ASK-USGS

For more information on the USGS—the Federal source for science about the Earth, its natural and living resources, natural hazards, and the environment:
World Wide Web: http://www.usgs.gov
Telephone: 1-888-ASK-USGS

Suggested citation:
Presto, M.K., Storlazzi, C.D., Logan, J.B., and Grossman, E.E., 2007. Submarine Groundwater discharge and seasonal trends along the coast of Kaloko-Honokohau National Historic Park, Hawaii, Part I: Time-series measurements of currents, waves and water properties: November 2005 – July 2006. U.S. Geological Survey Open-File Report 2007-1310.

Contents

Figures

Tables

Appendices

Submarine ground water discharge and fate along the coast of Kaloko-Honokohau National Historical Park, Hawaii

Part I

Time-series measurements of currents, waves and water properties: November, 2005 – July, 2006

By M. Katherine Presto, Curt D. Storlazzi, Joshua B. Logan and Eric E. Grossman

U.S. Geological Survey, Pacific Science Center, Santa Cruz, CA 95060 USA

Introduction

The impending development for the west Hawaii coastline adjacent to Kaloko-Honokohau National Historical Park (KAHO) may potentially alter coastal hydrology and water quality in the marine waters of the park. Water resources are perhaps the most significant natural and cultural resource component in the park, and are critical to the health and well being of six federally listed species. KAHO contains ecosystems of brackish anchialine pools, two 11-acre fishponds, and 596 acres of coral reef habitats, all fed by groundwater originating upslope. The steep gradients on high islands, combined with typically porous substrates and high rainfall levels at upper elevations, make these settings especially vulnerable to shifts in submarine groundwater discharge (SGD) and its entrained nutrients and pollutants. Little is known about the magnitude, rate, frequency, and variability of SGD and its influence on contaminant loading to Hawaiian coastal environments.

Recent studies show that groundwater flux through the park is vital to many ecosystem components including anchialine ponds and wetland biota. The function of these ecosystems may be vulnerable to changes in groundwater flow stemming from natural changes (climate and sea level) and land use (groundwater pumping and contamination). Oki et al (1999) showed that increased groundwater withdrawals for urban development since 1978 likely decreased groundwater flux to the coast by 50%. During this same time, the quality of groundwater has been vulnerable to increases in contaminant and nutrient/fertilizer additions associated with industrial, commercial and residential use upslope from KAHO (Oki et al, 1999).

High-resolution measurements of waves, currents, water levels, temperature and salinity were collected in the marine portion of the park from November, 2005, through July, 2006, to establish baseline information on the magnitude, rate, frequency, and variability of SGD. These data are intended to help researchers and resource managers better understand the hydrodynamics of the oceanographic environment in the park's coastal waters as it pertains to the pathway of SGD and associated nutrient and contaminant input to the park's coral reef ecosystem.

Measurements were made of the oceanographic environment (waves, tides, currents, salinity and temperature) using hydrodynamic techniques to characterize and quantify the distribution, input and throughput of freshwater and associated nutrient/contaminant within the near shore environment of KAHO through the emplacement of a series of bottom-mounted instruments deployed in water depths less than 15 m. This study was conducted in support of the National Park Service (NPS) by the U.S. Geological Survey (USGS) Coastal and Marine Geology Program's Coral Reef Project. These measurements support the ongoing studies of the Coral Reef Project to better understand the transport mechanisms of sediment, larvae, nutrients, pollutants and other particles on Pacific coral reefs. Subsequent reports will address the spatial and temporal variability in groundwater input and the associated nutrient flux in the park's waters

Objectives

Researchers from the US Geological Survey, Stanford University, and National Park Service researchers began a collaborative study in 2004, to determine changes and impacts to the KAHO coral reef ecosystem stemming from land use impacts to SGD. To meet these objectives, flow and water column properties off KAHO were investigated using two small instrument packages and 8 temperature/salinity sensors deployed in northern and southern areas of the park. The continuous measurements of waves, currents, tides, temperature and salinity from these instrument deployments provide information on nearshore circulation and the variability in these hydrodynamic properties for the different regions of the park (fig. 1). This data will complement recent, ongoing, and future water quality efforts in KAHO and provide baseline information of the hydrodynamic and oceanographic regime for the marine portion of the park.

Study Area

The wave, current, salinity, and temperature measurements were made at two general locations in the marine waters of KAHO on the Kona (west) coast of the island of Hawaii, USA (fig. 1). The study was designed to characterize the hydrodynamics in an area of SGD and its fate at two prominent discharge areas of KAHO, Kaloko Cut in the north and Honokohau Harbor in the south. All of the measurements were on the inner shelf in water depths less than 15 m. The instruments were deployed in along and cross-shore transects located near the northern and southern ends of the park. The northern transect was located in the embayment offshore of the Kaloko Fishpond in waters depths from 1.5 to 15 m. The southern transect was located off the outer edge of the basalt platform offshore of the Aimakapa fishpond and extended southeast to the entrance of Honokohau Harbor in water depths from 3 to 12 m. The seafloor along both instrument transects was generally composed of barren lava flows with isolated thin veneers of live coral and poorly-sorted carbonate sand. The study areas and design were chosen to determine the transport and fate of SGD in the park's waters, but due to the high wave exposure along this coast, compromises were made to ensure safe deployment and recovery of the deployed instruments. While these time-series temperature and salinity measurements constrain SGD mixing patterns deeper than 3 m in most areas, repeat conductivity, temperature and depth (CTD) profiling data augments our understanding of temporal and spatial patterns closer to the surface (Report 2 of 4).

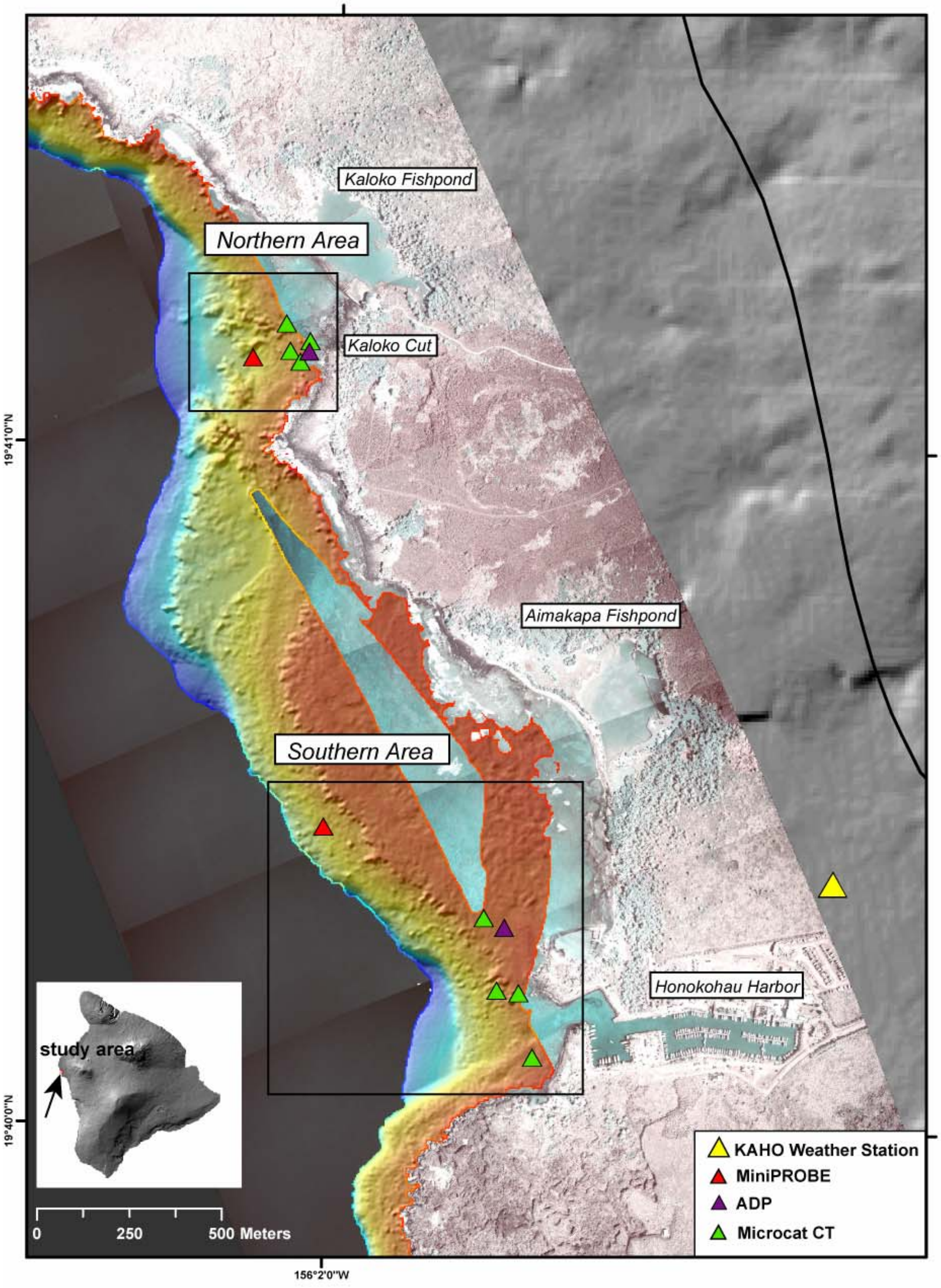

Figure 1. LIDAR, aerial photograph and digital elevation model map of Kaloko-Honokohau National Historical Park (KAHO) with locations of the MiniPROBE, MicrocatCT, ADP, KAHO weather station, and areas discussed in the text are shown on the map.

Operations

This section provides information about the personnel, equipment and vessel used during the instrument deployments. See table 1 for a list of personnel involved in the experiment and tables 2 through 4 for complete listings of instrument and deployment information.

Equipment Summary

At the offshore ends of each cross-shore instrument transect at a depth of approximately 15 m, MiniPROBE packages (fig. 1, 2a,2b) were deployed to acquire information on waves, currents, tides, and water column properties (table 2). The packages included a RD Instruments 600 kHz Workhorse Monitor upward-looking Acoustic Doppler Current Profiler (ADCP) with the WAVES Array package, a Seabird 37SM MicroCat conductivity-temperature sensor (CT) approximately 0.05 m above the bed, and an Aquatec 210TY self-logging optical backscatter sensor (SLOBS) approximately 1.5 m above the bed. Additionally, eight individual CT sensors were deployed inshore of the MiniPROBEs in a cross-shaped array at approximate water depths of 8 m, 5 m, and 3 m to collect single-point measurements on salinity and temperature for the 9 month experiment. A shorter subset of current data was acquired in the Northern and Southern areas during the second deployment using Nortek Aquadopp 2 MHz upward-looking acoustic Doppler profilers (ADP), mounted approximately 0.5 m above the bed. See table 3 and 4 for deployment dates, recovery, locations, and depths for each instrument. All data for the deployments is presented in Julian Year Day, beginning in 2005 and reported continuously through 2006 for consistency throughout the report.

Acoustic Doppler Current Profilers (ADCPs and ADPs)

The two upward-looking ADCPs mounted on the MiniPROBE (fig. 2a, 2b) sampled 36 0.5-m bins from 1.7 m above the seafloor up to the surface for 40 s at 2 Hz every 5 min to allow calculation of mean currents and higher frequency motions such as internal tidal bores and non-linear internal waves. Directional wave data were recorded for 1024 s at 2 Hz every 2 hours; these data included water depth, current speed and current direction every 0.5 s to resolve significant wave height, dominant wave period, mean wave direction and directional spread. Acoustic backscatter data collected from the ADCPs for the current measurements also provide information on the particulates in the water column and are used as a qualitative measurement of turbidity. Weekly and monthly means and standard deviations of current speed and direction, wave height and period were calculated from the 5 min and 2 hour data to examine and compare the short-term to seasonal trends in oceanographic properties between the two sites.

The two upward looking ADP’s sampled 24 0.25-m bins from 0.6 m above the seafloor up to the surface for 60 s at 2 Hz every 10 min. The ADPs were mounted in approximately 6 m water depth in order to better characterize the currents near the inshore temperature and salinity sensors from 03/01/2006-03/05/2006 (Days 425-430).

Temperature and Salinity Sensors (CTs)

The 10 CT sensors (fig. 2c) collected and averaged 8 samples every 5 min to measure water temperature and conductivity from which salinity was calculated. The rapid sampling rate was established in an attempt to record the transient freshwater plumes being advected past the instruments. From the five minute measurements, weekly and monthly means and standard deviations were calculated in order to examine the variability between sites at the northern and southern areas.

The depths and location coordinates are listed in table 5. The sites on the alongshore arrays are all in approximately 1.5 – 4 m water depth, with the increasing depth on the cross-shore transects (fig. 1). The shallowest instrument locations were chosen in areas of observed freshwater discharge to determine the direction of transport of the freshwater plume and whether it was constrained alongshore. Offshore instrument locations were selected to record the distance and mixing of the freshwater plume with oceanic water and to correlate the plume with current measurements at the offshore sites.

Turbidity Sensors (SLOBS)

Self-logging optical backscatter sensors (SLOBS; fig. 2a, 2b) collected an 8-sample burst every 5 min of turbidity data in Nephelometric Turbidity Units (NTU's). The SLOBS were mounted on the MiniPROBE platforms at approximately 1.5 m off the seafloor in order for the turbidity data to be correlated with the acoustic backscatter data from the first bin of the ADCP.

Weather Station

Meteorological data was acquired through the NPS Remote Automatic Weather Station (RAWS; fig. 2e) located in the southeast portion of the park, 7.6 m above ground. Table 6 lists the location, sensors, and serial numbers of the instruments. Hourly measurements of air temperature, barometric pressure, precipitation, wind speed, and wind direction were recorded by the weather station. The hourly wind speed and direction, as well as air temperature and humidity, were obtained from 10 min averages. Precipitation was measured in increments of 0.25 mm each hour. Archives of the meteorological data can be accessed via the internet (Western Regional Climate Center, 2007). Weekly and monthly averages of wind speed, wind direction, and precipitation were calculated for comparison with other oceanographic data collected by the instrument packages and to examine seasonal trends.

Research Platform

The instrument deployments and recoveries were conducted using the 6.7 m NPS Guardian Whaler (fig. 2d). The port side was used for instrument package deployment and recovery operations, which included the use of an electric winch and davit to lift and lower the instrument packages.

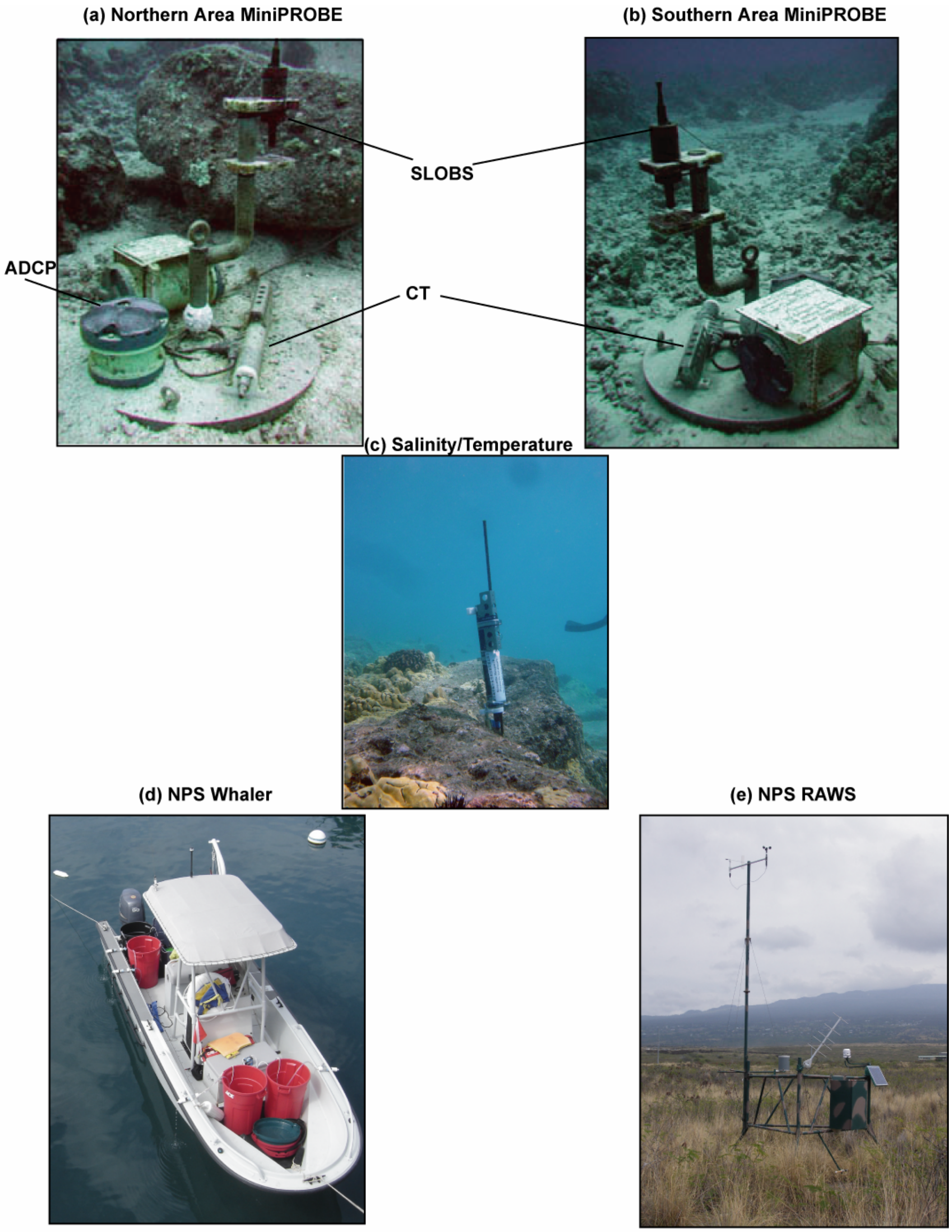

Figure 2. Photographs of instruments and equipment used in the experiment. (a) Northern MiniPROBE; (b) Southern MiniPROBE; (c) Salinity/Temperature sensor; (d) NPS Whaler; and (e) NPS Weather Station (RAWS).

Deployment and Recovery Operations

All vessel operations, including mobilization and demobilization, were based out of Honokohau Harbor, Kona, Hawaii. The deeper instruments packages 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 place and secured it with cables, turnbuckles and sand anchors. Recovery operations employed the same techniques in reverse order.

The instruments for the cross-shore and alongshore CT arrays were attached with hoseclamps to rebar that was cemented and secured into cracks on the basalt seafloor (fig. 2). The rebar allowed the instruments to be mounted vertically approximately 1 m off the seafloor.

Data Acquisition and Quality

Data were acquired for 242 days during the 9 month period between 11/13/2005 and 07/13/2006; this was more than 98% data coverage over the experiment time period. The instruments were out of the water for only 6 days during these 9 months for data recovery and instrument refurbishment. All of the data are presented in Year 2005 julian day to allow for a consistent dating protocol from the beginning to the end of deployment.

At the northern site, ADCP data coverage was 100% for the experiment time period. The battery case at the southern site flooded during the first deployment, resulting in no current or wave data for this site from 11/13/2005 to 02/25/2006. Although direct measurements of currents and waves at the south site were not obtained, previous studies document summer circulation (April – October) at the site (Storlazzi and Presto, 2005) that can be used to describe seasonal variability. The short ADP deployments provided 5 days of water level, current speed and direction, and wave height, period, and direction data

Data coverage for the CT sensors was 100% for almost all of the experiment sites. At the northern study area, the outer (8 m) CT sensor was not deployed for the period from 05/2006 to 07/2006. In addition, the CT sensor at the northern area MiniPROBE site stopped due to battery failure and did not record data during the rest of the deployment from 06/2006 to 07/2006. At the southern study area, the outer (8 m) CT sensor was not deployed for the period from 05/2006 to 07/2006. In addition the CT sensor at the southern area MiniPROBE site was fouled from 12/31/2005 to 02/14/2006, likely due to sediment blocking the sensor.

The SLOBS sensors were mounted on each of the MiniPROBE platforms to measure turbidity near the bed. The SLOBS sensors tended to biofoul over very short time periods and were not used directly in the analysis for this report. At the northern site, during the November 2005 deployment, the SLOBS housing flooded, resulting in no turbidity data. Instead, acoustic backscatter data from the ADCP’s were used as a relative estimate of turbidity in the water column following the methodology of Storlazzi and Jaffe, 2003.

Atmospheric data including hourly air temperature, barometric pressure, wind speed, wind direction, and precipitation, acquired by the NPS RAWS cover the study period and are used in this report in order to characterize the meteorological forcing for the study area during the experiment.

Results

This section reviews the data collected by the instrument packages and arrays and addresses the significance of the findings to better understand the spatial and temporal variability in submarine groundwater mixing and its advection through the KAHO's nearshore waters. It also addresses the variability in response to seasonal changes in environmental forcing, such as waves, winds, and precipitation.

Forcing

Atmospheric

Atmospheric forcing in the Hawaiian Islands is dominated by northeast trade winds created from the North Pacific High during the months from April to November (Moberly and Chaimberlain, 1964). Trade winds on the Kona coast are orographically steered around the island's volcanoes resulting in a southerly direction as measured by the RAWS station. During the experiment from 11/2005 to 07/2006, winds measured at the RAWS station ranged from 0 to 11.18 m/s, with a mean of 2.51 ± 1.10 m/s (fig. 3). Wind direction varied from 0 – 359°, with a mean ± one standard deviation of 161.59 ± 92.5°.

Hourly precipitation at the RAWS station ranged from 0 – 14.3 mm during the experiment, with a mean ± one standard deviation of 0.023 ± 0.31 mm. The highest rainfall occurred during 03/2006 and 05/2006, with an average of 0.10 and 0.06 mm, respectively (fig. 3). Historically, precipitation on the Hawaiian Islands is greatest during the winter months due to the passage of low pressure systems. It is driest during the spring through the fall when the Pacific High is to the northeast of the Hawaiian Islands, creating consistent trade winds, stable weather patterns, and very little precipitation on the leeward sides of the islands (fig. 3).

Oceanographic

The tides off KAHO are micro-tidal (< 2 m) 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 approximately 0.6 m, while the minimum and maximum daily tidal ranges are 0.4 m and 1.0 m, respectively.

Significant wave heights, dominant wave periods and mean wave directions at the northern site ranged from 0.22-2.26 m, 2.9-14.7 s and 0-360°, respectively, with a mean ± one standard deviation of 0.0.56 ± 0.24 m, 6.78 ± 2.56 s and 190.74 ± 105.78°, respectively. The largest significant wave heights were measured during a two-week period between 12/25/2005 and 01/07/2006 (fig. 3; Days 359 – 372). In general the wave heights were greatest during the winter months (fig. 3, Days 320-410).

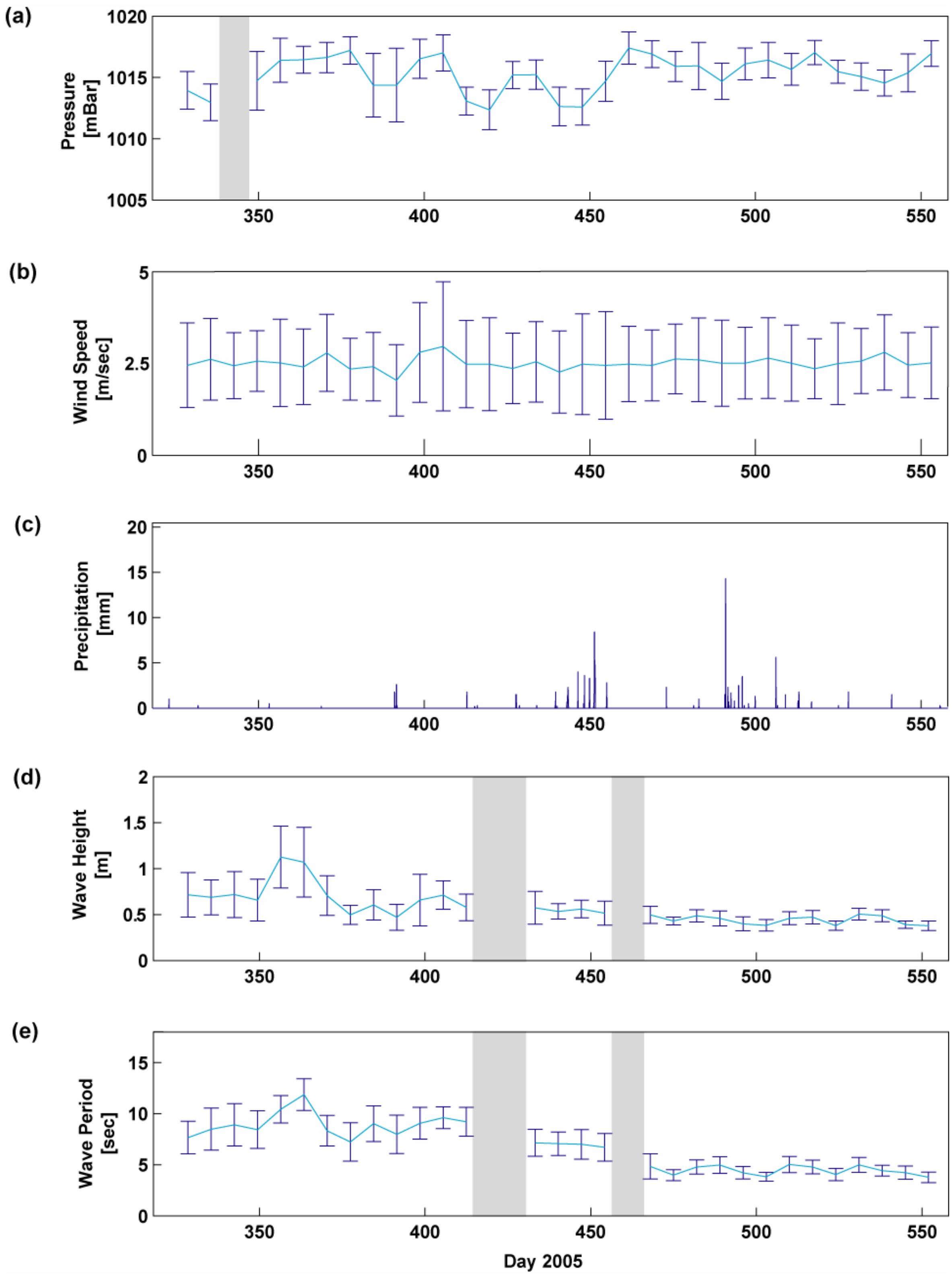

Figure 3. Weekly averages of meteorological and oceanographic conditions for the deployment period from November, 2005, – July, 2006. (a) Atmospheric pressure; (b) Wind speed; (c) Precipitation; (d) Significant wave height; (e) Dominant wave period

Currents

Northern Area

In the absence of other dominant environmental conditions, most of the daily variability in current speed and direction at the 15 m site are due to the tides. At the northern site, as the tide rises (floods), currents flow to the north, generally parallel to shore; conversely, as the tides fall (ebb), the currents reverse and flow to the south alongshore (fig. 4). Near-surface current speeds 1 m below the surface at the northern site ranged between 0.00-0.44 m/s, with the mean speed ± one standard deviation being 0.06 ± 0.05 m/s. Near-bed current speeds 12 m below the surface ranged between 0.00 – 0.18 m/s, with the mean speed ± one standard deviation being 0.03 ± 0.02 m/s. Overall, the weekly average current speed and direction at the northern site varied seasonally due to varying environmental forcing. During the winter months of 11/2005 through 2/2006, the weekly average currents were predominantly to the south and alongshore (fig. 5, Days 340 - 410). Strong southwest flow occurred during the large swell events that occurred in late 12/2005 and early 01/2006 (fig. 5, Days 360-370, 390-410). The strong southwesterly flow, both near the surface and the seafloor is likely subsurface return flow driven by wave setup from the large northwesterly waves breaking on the shallow reef platform during this time. The strong currents near the surface and seafloor, along with the large significant wave heights, correlate with an increase in acoustic backscatter, a relative measure of turbidity, throughout the water column (fig. 5, 360-370). The winds were relatively light, inconsistent in direction, and were not a controlling factor for currents at the northern site during the winter months (fig. 3). During the transition period from late 02/2006 through 03/2006, the weekly average currents flowed to the west, indicating offshore transport in this area (fig. 5, Days 430 – 455). The transition continued into the spring and summer months, with the weekly average current speed and direction predominantly to the northeast in response to the more consistent southwest trade winds during 04/2006 through 07/2006 (fig. 5, Days 460 - 555). Overall the current speeds at the surface are greater than near the bed during the entire deployment at the northern site.

In addition to the currents at the MiniPROBE site, the inner ADP at the northern area measured current speed and direction over 5 days (fig 6, Days 425-430) to help characterize the hydrodynamics closer to the areas of SGD and the temperature and salinity sensors. In the northern area, the net current speeds 1 m below the surface were predominantly to the southwest; at 4 m below the surface, the net currents were slower and to the northwest (fig. 6). Near-surface current speeds ranged between 0.00-0.28 m/s, with the mean speed ± one standard deviation being 0.10 ± 0.05 m/s. Near-bed current speeds 4 m below the surface ranged between 0.00 – 0.09 m/s, with the mean speed ± one standard deviation being 0.03 ± 0.01 m/s. The southwest current speeds near the surface were potentially more influenced by freshwater flow from Kaloko Cut, resulting in a stronger offshore flow at this instrument site.

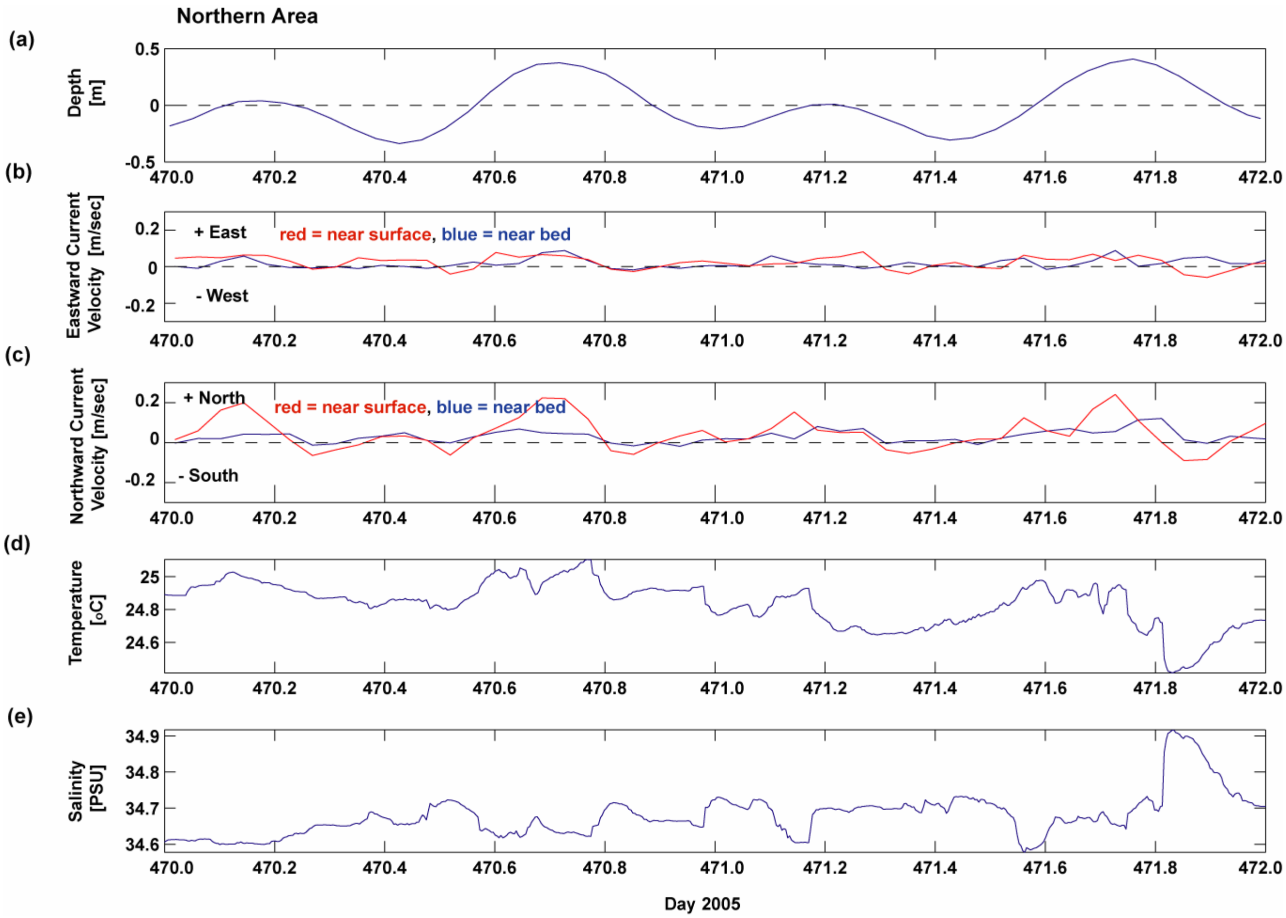

Figure 4. Variability in tides, flow and water column properties at the northern MiniPROBE site. (a) Tide; (b) Eastward current velocity; (c) Northward current velocity; (d) Temperature; and (e) Salinity for 2005 Year Days 470 - 472 during the experiment. Velocity measurements are shown in red for near-surface currents and blue for near-bed currents. This 2-day snapshot shows the variability in currents and water column properties at the 15m site due to tides in the northern area.

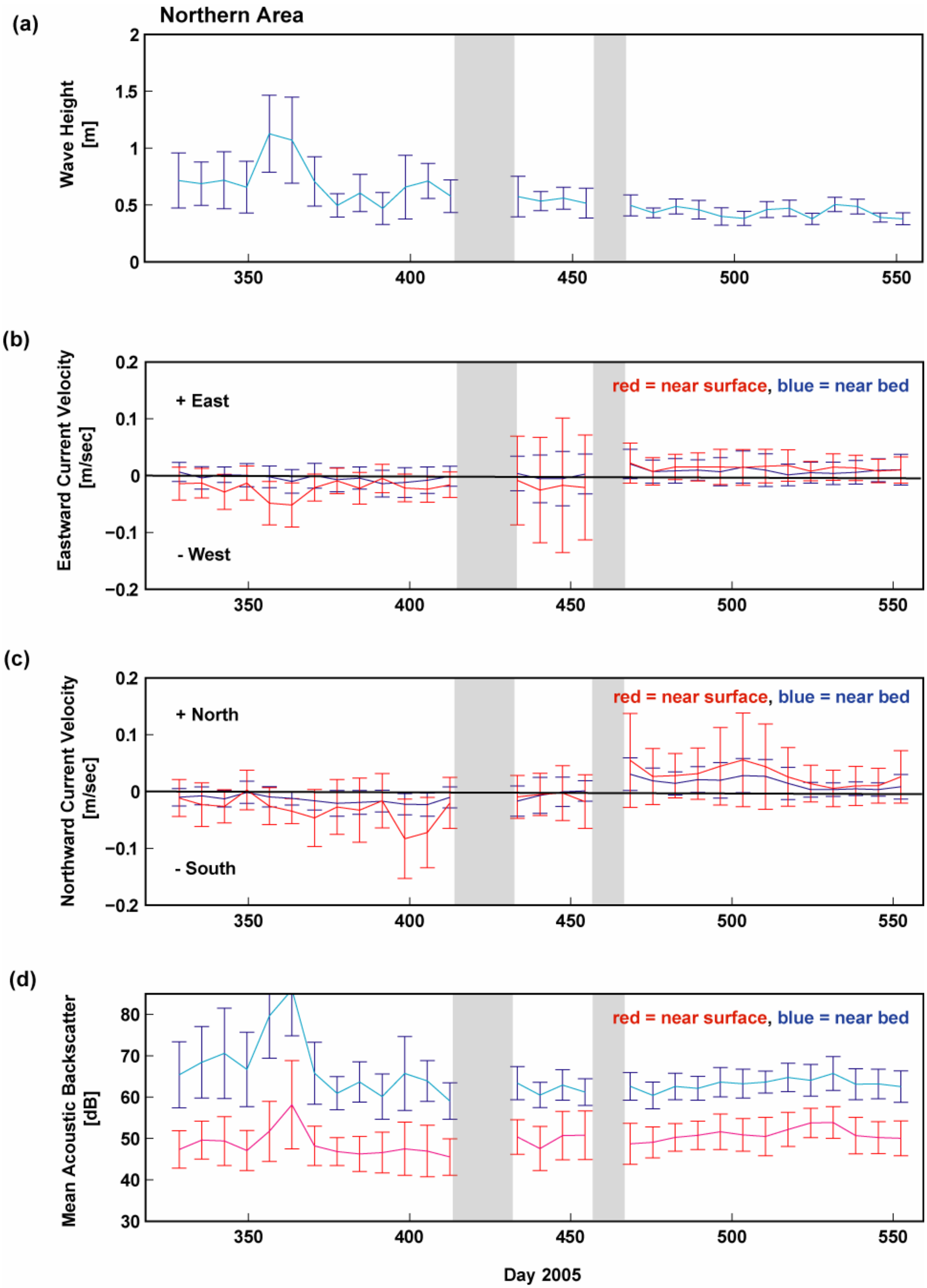

Figure 5. Weekly variability in waves and flow at the northern MiniPROBE site. (a) Wave height; (b) Eastward current velocity; (c) Northward current velocity; (d) Acoustic backscatter. Velocity measurements are shown in red for near-surface currents and blue for near-bed currents. The weekly averages show the variability in currents and acoustic backscatter in response to wave forcing in the northern area at the 15 m site.

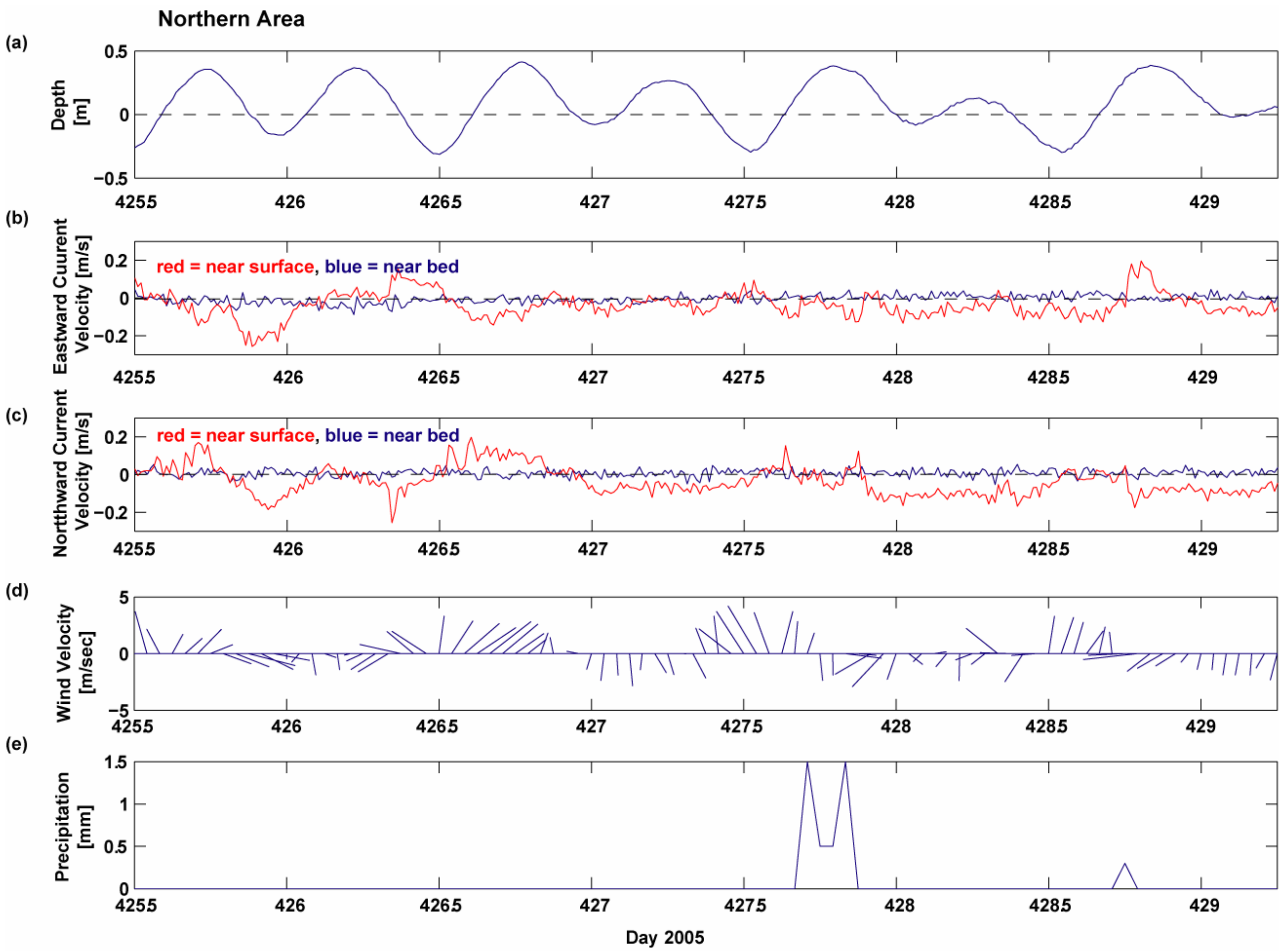

Figure 6. Variability in water depth, flow and wind and, precipitation at the northern ADP site. (a) Tide; (b) Eastward current velocity;(c) Northward current velocity; (d) Wind; and (e) Precipitation for Year Days 425 - 430. Velocity measurements are shown in red for near surface currents and blue for near bed currents. The 5 day deployment shows the variability in flow in response to tides, winds and precipitation in closer proximity to the temperature and salinity sensors and areas of active SGD in the northern area

Southern Area

Due to instrument failure at the southern site, current speeds and directions were recorded only during the spring and summer months of 2006. At the southern site, as the tide rises (floods), currents flow to the north and east, primarily alongshore; conversely, as the tide falls (ebbs), the currents reverse and flow to the south and west (fig. 7). Current speeds at the southern site ranged between 0.00-0.56 m/sec; the mean speed ± one standard deviation 1 m below the surface was 0.08 ± 0.07 m/s and 12 m below the surface ranged between 0.00-0.26 m/s was 0.07 ± 0.05 m/s. The weekly average currents during late 02/2006 through early 04/2006, were very small and primarily to the north (fig. 8, Days 430 - 455). Currents 1 m above the seafloor were slightly faster than the near surface currents and correlated with higher acoustic backscatter near the bed, during this time period (fig. 8, Days 430 - 455). Weekly average currents during the spring and summer months of 2006 were highly variable, with the near surface and near bottom currents often flowing in opposite directions, creating vertical velocity shear. Currents 1 m above the bed better correlated with higher acoustic backscatter than the surface currents (fig. 8 Days 475-550), potentially indicating seafloor sediment was resuspended due to the greater currents near the bed.

In addition to the currents measured at the MiniPROBE site, the inner ADP in the southern area measured current speed and direction for 5 days (fig. 9, Days 425-430) to help characterize the hydrodynamics closer to the areas of SGD. Near- surface current speeds 1 below the surface ranged between 0.00-0.39 m/s, with the mean speed ± one standard deviation being 0.12 ± 0.09 m/s. Near- bed current speeds 3 m below the surface ranged between 0.00-0.10 m/s, with the mean speed ± one standard deviation being 0.03 ± 0.02 m/s. In the southern area, the current speeds 1 m below the surface were predominantly controlled by the winds, with a surface flow predominantly following the wind direction on a daily basis (fig. 9, Days 425.5 – 427.5). Following the precipitation event the currents were smaller due to the low wind speeds during this time.

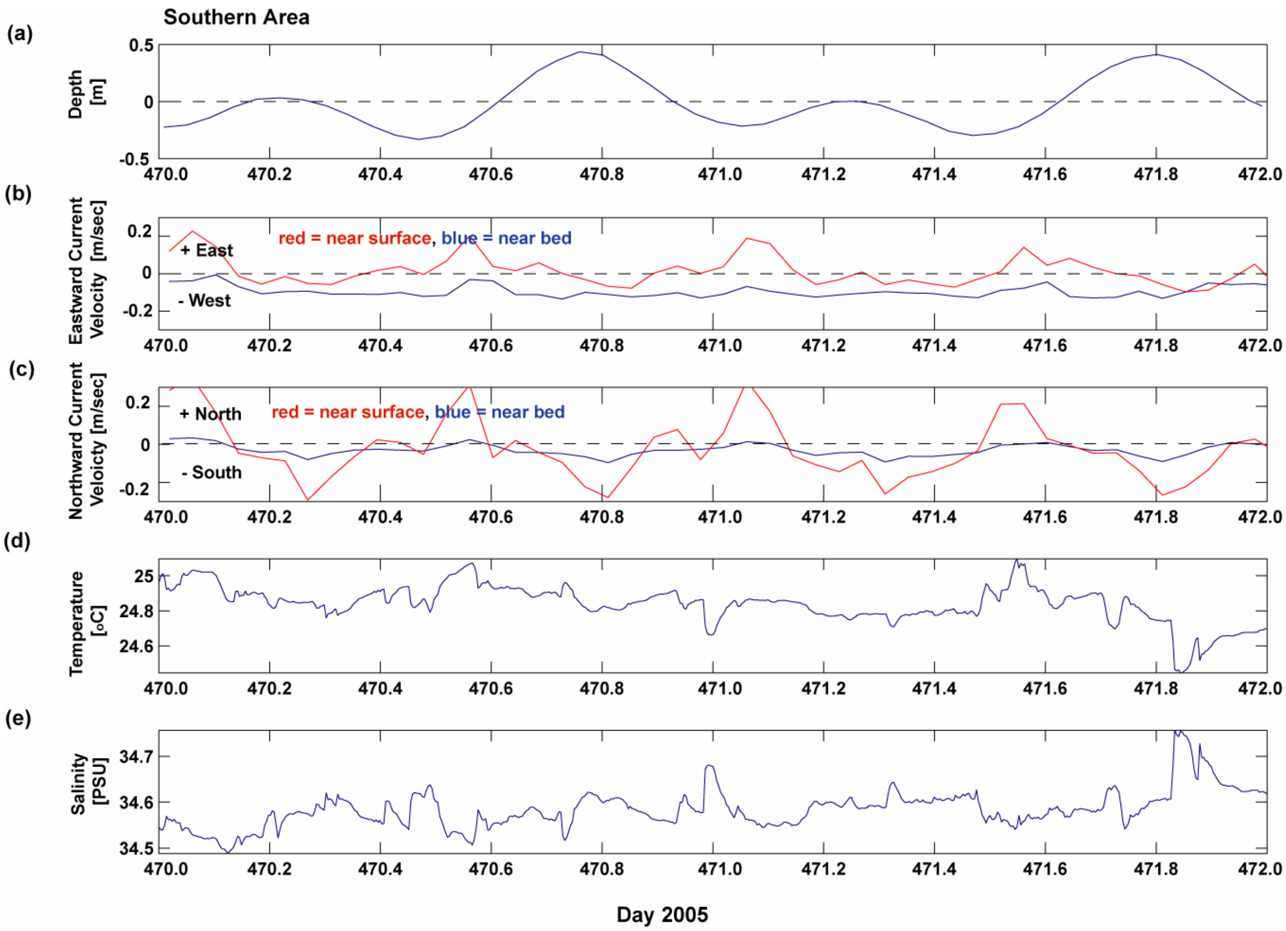

Figure 7. Variability in tides, flow and water column properties at the southern MiniPROBE site. (a) Tide; (b) Eastward current velocity; (c) Northward current velocity; (d) Temperature; and (e) Salinity for 2005 Year Days 470 - 472 during the deployment. Velocity measurements are shown in red for near surface currents and blue for near bed currents. This 2-day snapshot shows the variability in currents and water column properties at the 15 m site due to tides in the southern area.

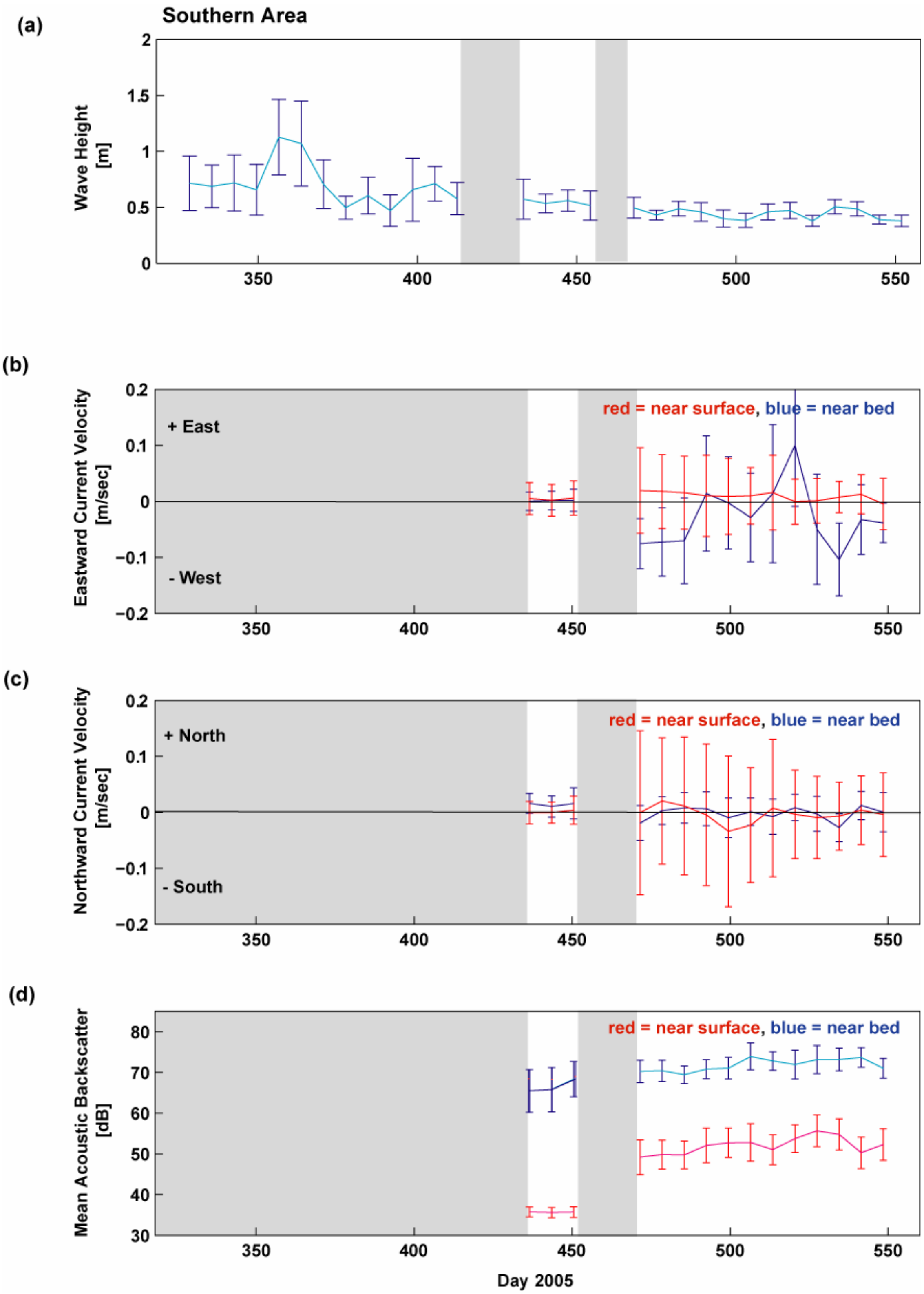

Figure 8. Weekly variability in waves and flow at the southern MiniPROBE site. (a) Wave height; (b) Eastward current velocity; (c) Northward current velocity; (d) Acoustic backscatter. Velocity measurements are shown in red for near-surface currents and blue for near-bed currents. The weekly averages show the variability in currents and acoustic backscatter in response to wave forcing in the southern area at the 15 m site.

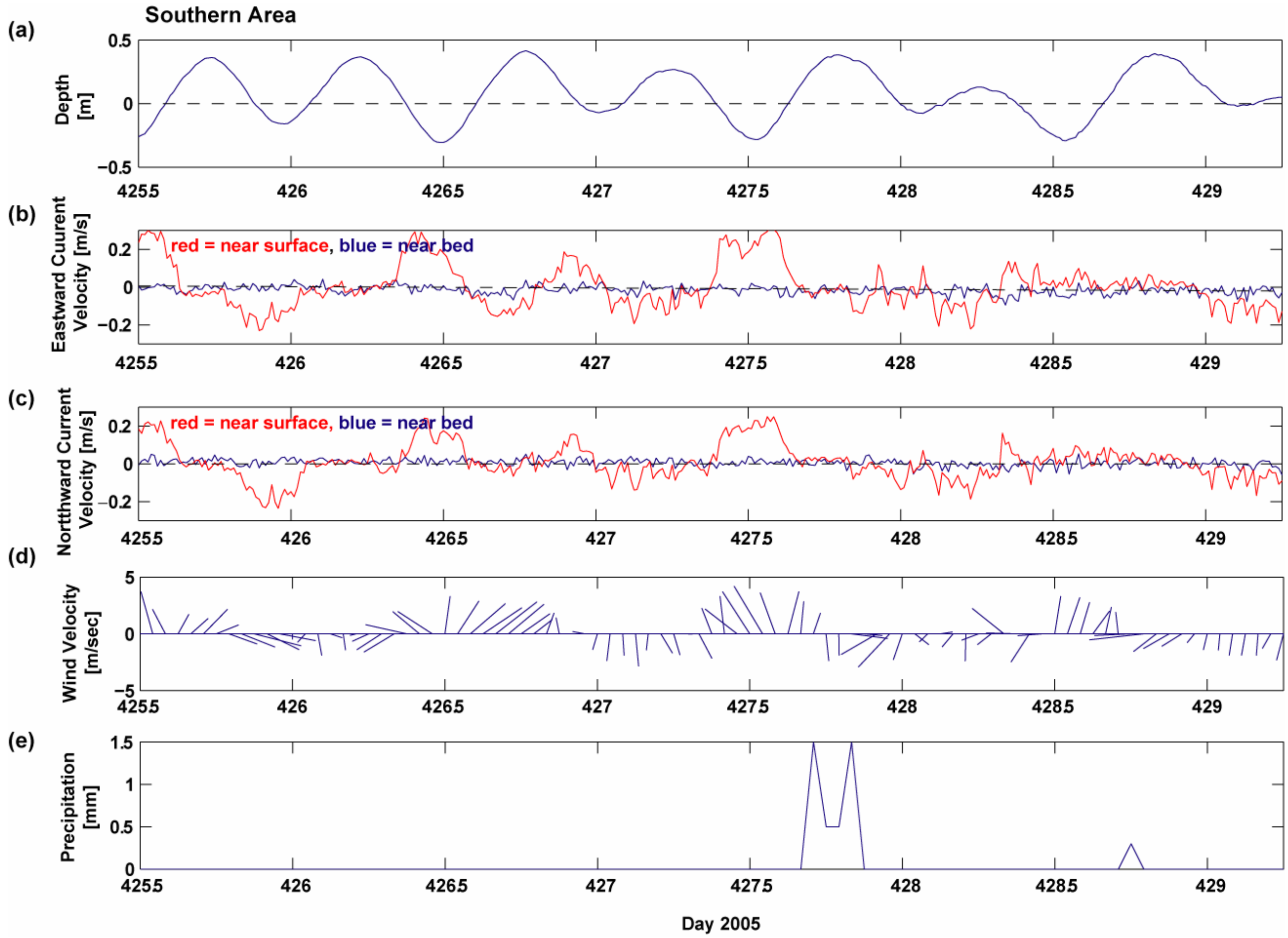

Figure 9. Variability in water depth, flow and wind and, precipitation at the southern ADP site. (a) Tide; (b) Eastward current velocity; (c) Northward current velocity; (d) Wind; and (e) Precipitation for Year Days 425 - 430 during the deployment. Velocity measurements are shown in red for near surface currents and blue for near bed currents. The 5 day deployment shows the variability in flow in response to tides, winds and precipitation in closer proximity to the temperature and salinity sensors and areas of active SGD in the southern area.

Temperature

Northern Area

Over the period of study, the water temperature at all 5 CT sensors in the northern array ranged between 23.16 °C and 27.69 °C, with a mean ± one standard deviation of 25.33 ± 0.48 °C (fig. 10). Spatial trends from the weekly averages from the 5 salinity/temperature sites at the northern transect show the seasonal decrease in temperature of approximately 2 °C from 11/2005 through 03/2006, and increase in temperature from 04/2006 through 07/2006, of approximately 2 °C (fig. 10, Days 320-450 and 460-550). The largest decreases in temperature occurred between the months of 12/2005, and 01/2006, while the largest increases in temperature occurred between the months of 05/2006 and 06/2006 (fig. 10). The greatest variation in temperature occurred at the inner site where it was more exposed to low-density groundwater discharge after the frequent rainfalls during 04/2006 (fig. 10, Days 460-550).

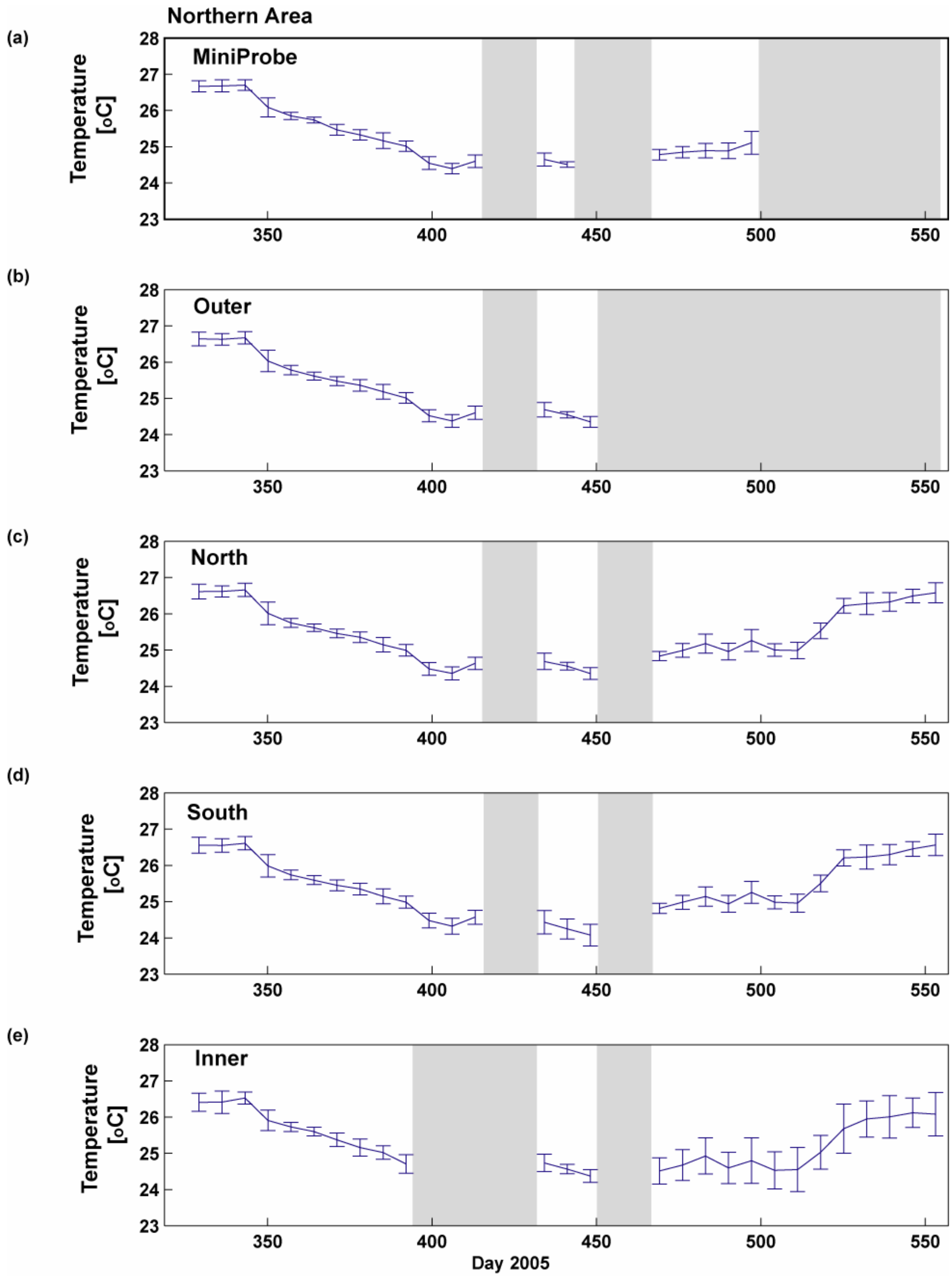

Figure 10. Weekly mean temperatures in the northern area during the experiment. (a) MiniPROBE, (b) Outer, (c) North, (d) South, (e) Inner. The weekly averages show the seasonal cooling and warming trend at the 5 sites in the northern area.

Southern Area

In the southern deployment area the water temperatures for the 5 CT sensors ranged between 23.02 and 27.54 °C, with a mean temperature ± one standard deviation of 25.43 ± 0.78 °C (fig. 11). The spatial trends from the weekly averages at the southern site also show a seasonal decrease in temperature of approximately 2°C from 11/2005 to 03/2006, and an increase from 03/2006 through 07/2006. The southern site was slightly warmer than the northern site, and the greatest decrease in temperature was recorded from 12/2005 to 01/2006; the greatest increase in temperature was recorded from 05/2006 to 06/2006. The average lowest temperature was recorded at the MiniPROBE site, which may be attributed to the greater influence of deeper and colder oceanic water. The greatest variation in temperature occurred at the north site, which may be attributed to its proximity to Aimakapa fishpond. Overall, the temperature trend for all five sites followed a similar trend of cooling in the 2005-2006 winter followed by warming in the summer of 2006.

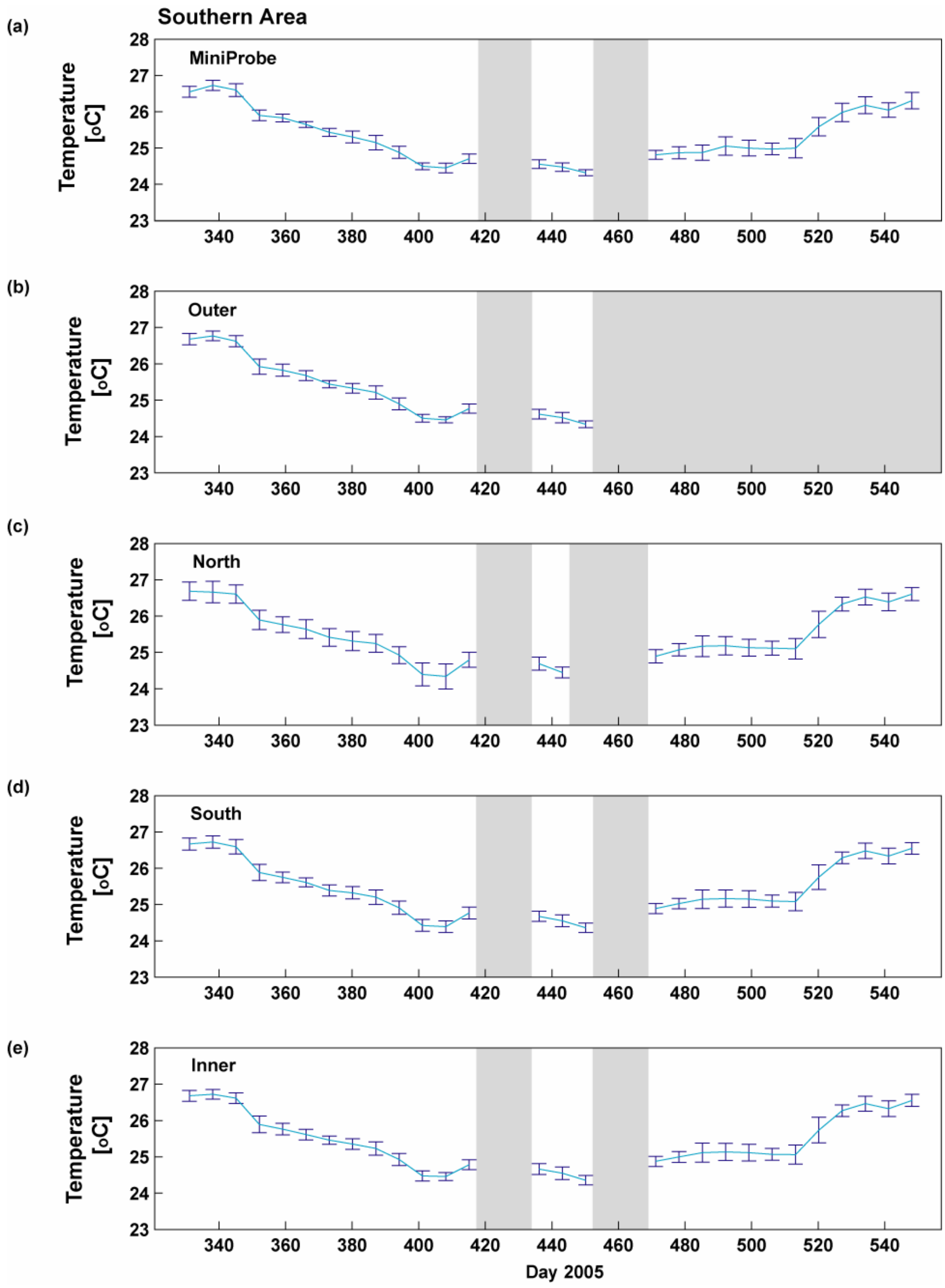

Figure 11 Weekly mean temperatures in the southern area during the experiment. (a) MiniPROBE, (b) Outer, (c) North, (d) South, (e) Inner. The weekly averages show the seasonal cooling and warming trend at the 5 sites in the southern area.

Salinity

Northern Area

Over the period of study in the northern area, the water salinities for the 5 CT sensors ranged between 22.91 and 35.03 PSU, with a mean ± one standard deviation of 34.40 ± 0.79 PSU (fig. 12). The lowest salinity was recorded at the inner site due to its proximity to sources of submarine groundwater discharge. The greatest variability in salinity occurred at the MiniPROBE site when large waves impacted the area during the winter months. This may be a function of greater mixing due to larger wave orbital velocities associated with the large wave heights and long wave periods during this time. Throughout the deployment the greatest variation in the weekly average of salinity occurred at the inner site. The location of the inner site was very close to areas of known SGD, and much lower salinities were observed after precipitation events. The salinity variation and values at the other sites were independent of SGD and precipitation events, but showed a response of decreased salinity depending on tidal and wind driven currents. The frequent rainfall during 03/2006 and 05/2006 (fig. 3) caused a significant decrease in salinity at the inner site but only minor decreases at the northern and southern sites. Overall, the salinity signals at the 5 sites are dissimilar to one another and therefore salinity can be used as a proxy for determining the flux and fate of SGD in the northern area.

Southern Area

In the southern area, the salinities ranged between 29.52 PSU and 35.01 PSU, with a mean ± one standard deviation of 34.51 ± 0.30 PSU (fig. 13). The 5 sites had similar trends in salinity throughout the deployment period and did not have a major response to precipitation events in 03/2006 and 05/2006. The variation at the MiniPROBE site during the winter months may be in response to the greater wave heights during this time. The only site that showed substantial variation in salinity was the north site, and may be a result of its proximity to sources from Honokohau Harbor and Aimakapa fishpond. The minor changes in salinity during precipitation events and the lack of long-term current data for this area limit the understanding of SGD flux and fate in this area.

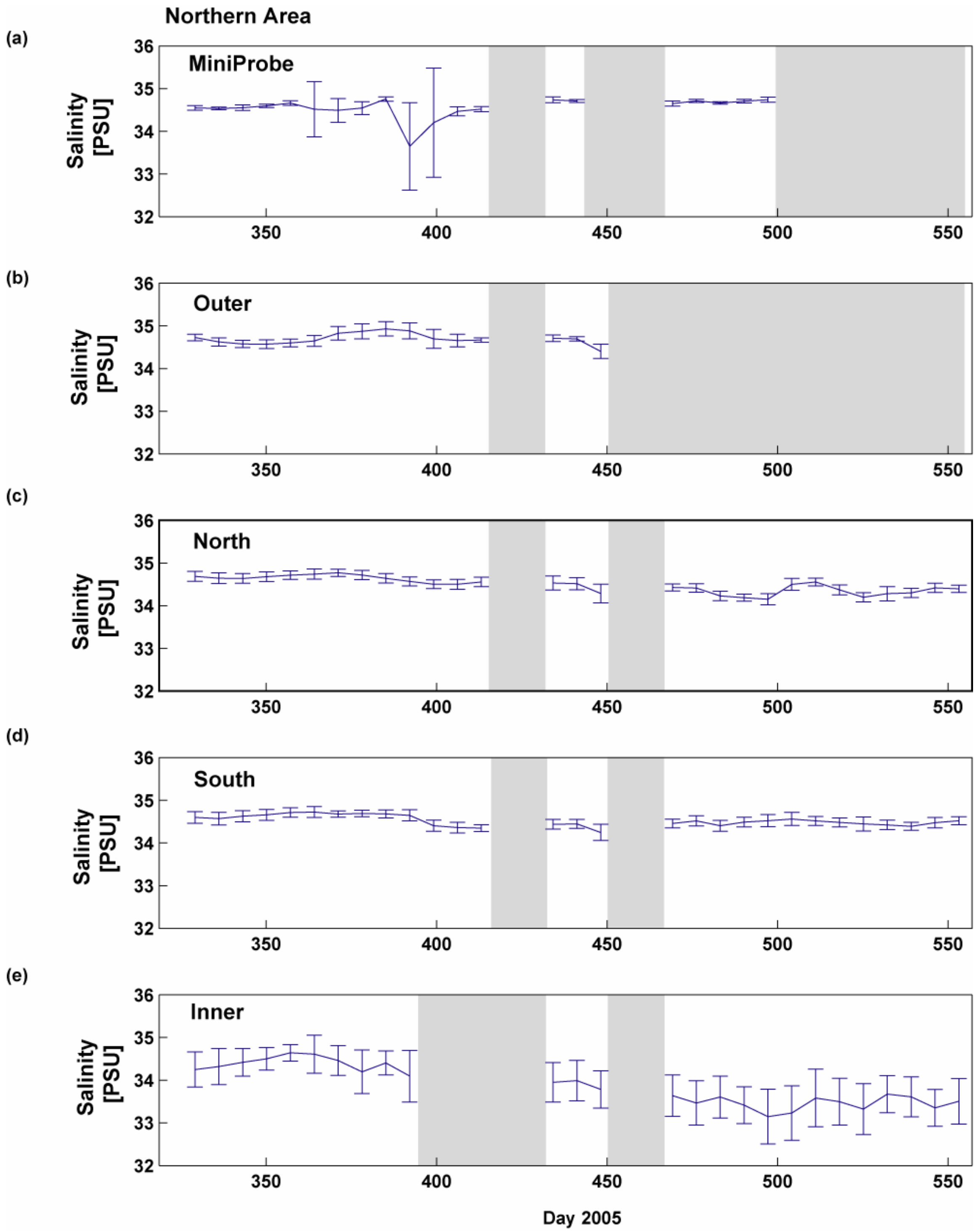

Figure 12. Weekly mean salinities in the northern area during the experiment. (a) MiniPROBE, (b) Outer, (c) North, (d) South, (e) Inner. The weekly averages of salinity show the variability between sites in the northern area due to proximity to active SGD and seasonal forcings.

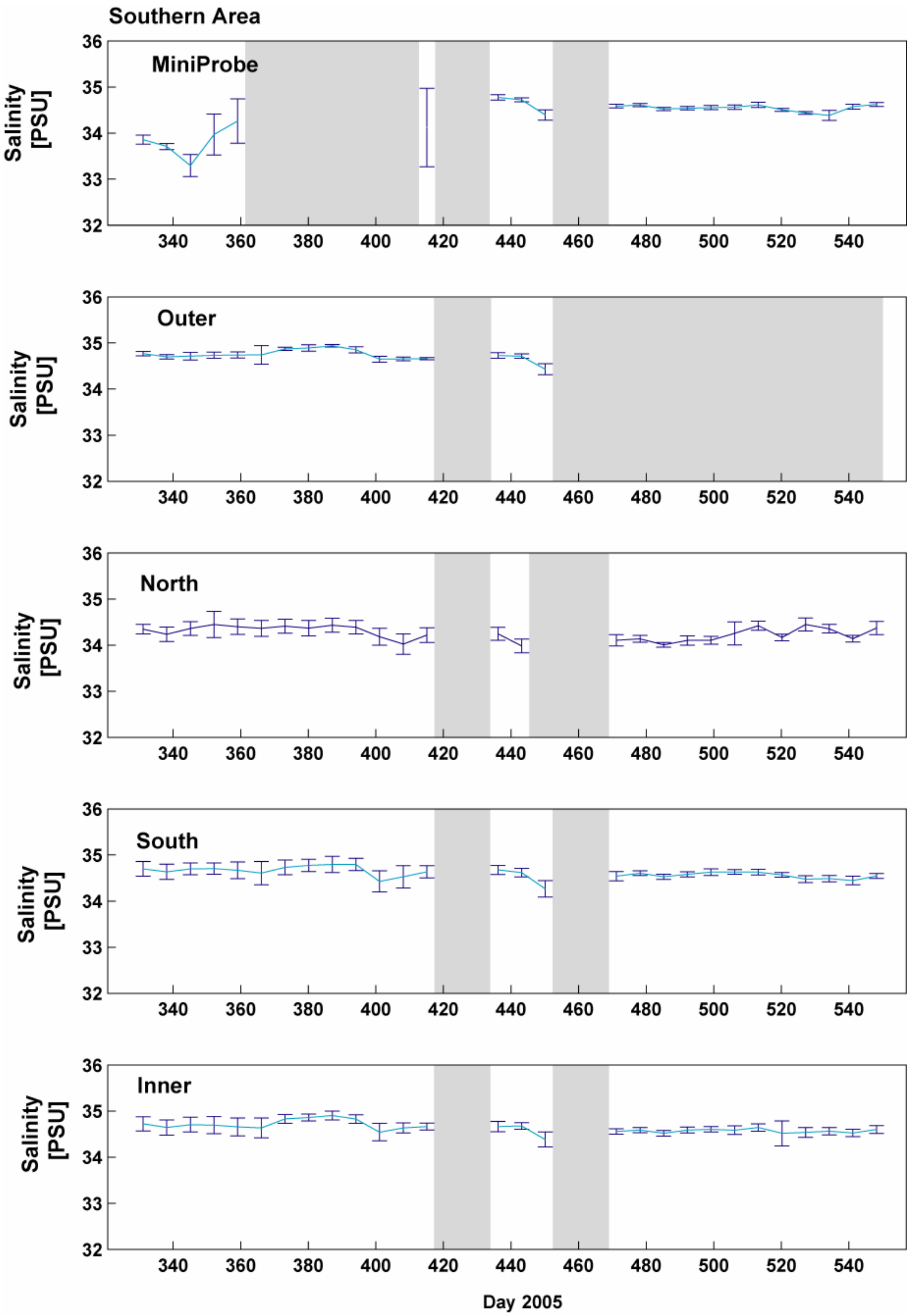

Figure 13. Weekly mean salinities in the southern area during the experiment. (a) MiniPROBE, (b) Outer, (c) North, (d) South, (e) Inner. The weekly averages of salinity show the variability between sites in the southern area due to proximity to active SGD and seasonal forcings.

Discussion

Monthly Trends in Winds, Currents, Precipitation, Temperature and Salinity

Monthly trends were examined to identify seasonal variations in water column and meteorologic properties. Wind speed and direction were on average from the southwest at 2-4 m/s for the month of 11/2005 and 04/2006 through 07/2006 (fig. 14). The months from 12/2005 through 03/2006 had less consistent wind speeds and directions. The monthly means in precipitation were relatively small, except for the months of 03/2006 and 05/2006.

Monthly mean net current speeds and directions show flow was primarily alongshore (north-south) at the northern area offshore of Kaloko Fishpond and cross-shore (east-west) at the southern area offshore of Aimakapa Fishpond (fig. 14). The alongshore currents in the northern area were in response to the wind speed and direction. During the winter months of 12/2005 through 02/2006, the winds were relatively light and inconsistent in direction. From 04/2006 through 07/2006, the winds were greater and more consistent in direction from the southwest. The MiniPROBE in the northern area was more exposed to the southwest winds and this is reflected in the current speed and direction, with the currents primarily alongshore to the north. From 04/2006 through 07/2006, the current direction was primarily from the southwest towards the northeast in response to the strong winds out of the southwest. This is important for understanding which areas are most affected by the transport of SGD in the park. At the southern area the monthly mean current direction was primarily cross-shore to the west, and did not show a significant response to the southwest winds.

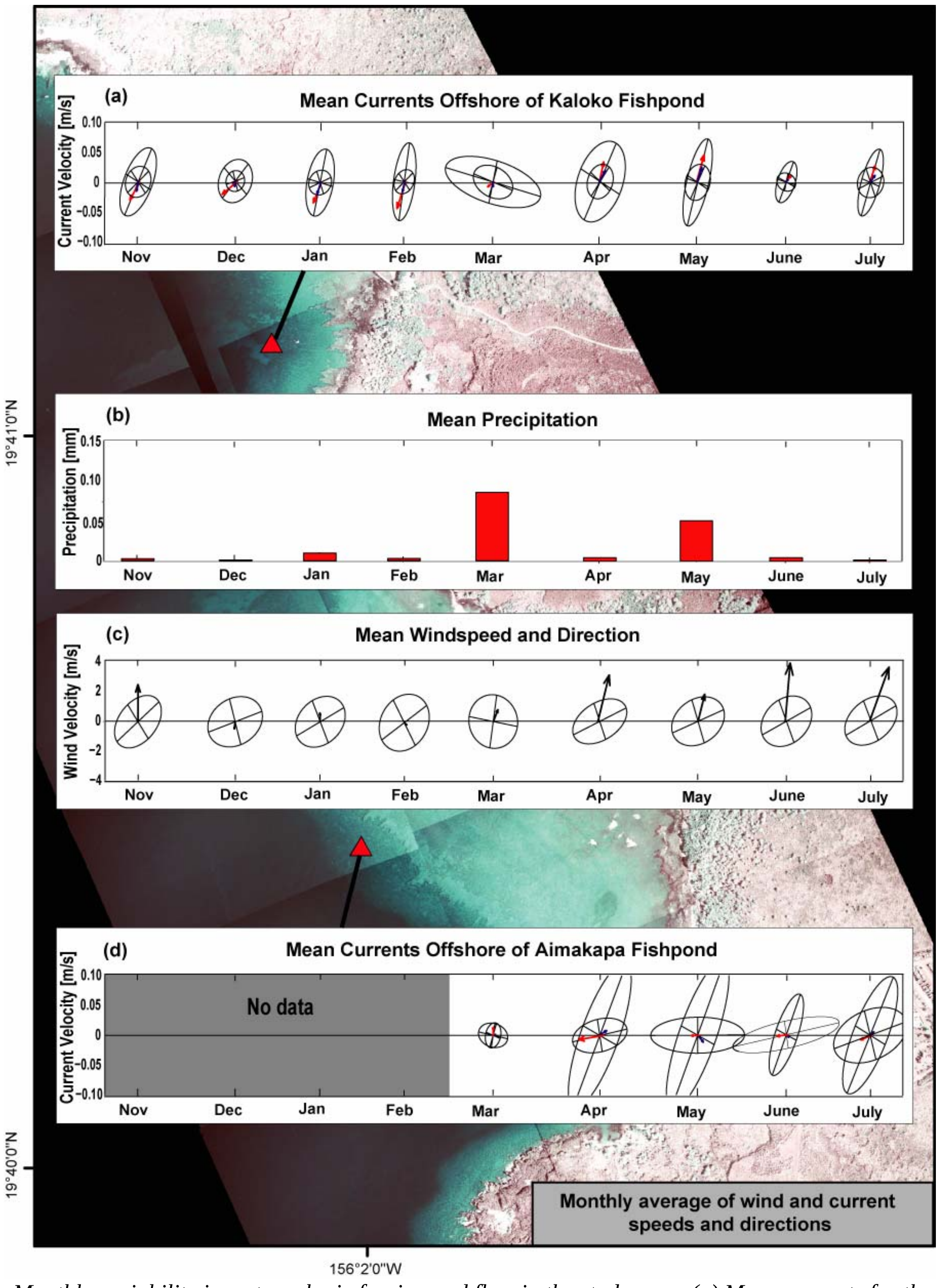

Figure 14. Monthly variability in meteorologic forcing and flow in the study area. (a) Mean currents for the near surface (red) and near bed (blue) in the northern area offshore of Kaloko Fishpond, 15 m site. The ellipses indicate the principal axes and directions of the currents near the surface and near the bed; (b) Mean precipitation at the RAWS weather station; (c) Mean windspeed and direction at the RAWS weather station; and (d) Mean currents for the near surface (red) and near bed (blue) in the southern area offshore of Aimakapa Fishpond, 15 m site. The ellipses indicate the principal axes and directions of the currents near the surface and near the bed. Monthly averages of flow show the overall seasonal and spatial trends for the northern and southern areas.

Monthly trends in temperature and salinity at the northern and southern areas are shown in comparison to the overall area mean to identify trends in the data and to decipher areas with greater influence from SGD. Establishing the standard for the area shows whether the monthly average at each site falls above or below this standard. In the northern area, the comparison of monthly means to the overall average mean temperature (25.33 ºC) shows there was a similar trend at all of the sites showing the cooling in the winter and warming in the summer (fig. 15). The largest decrease in temperature was at the inner (1.5 m) site, which was exposed to colder freshwater on a monthly basis.

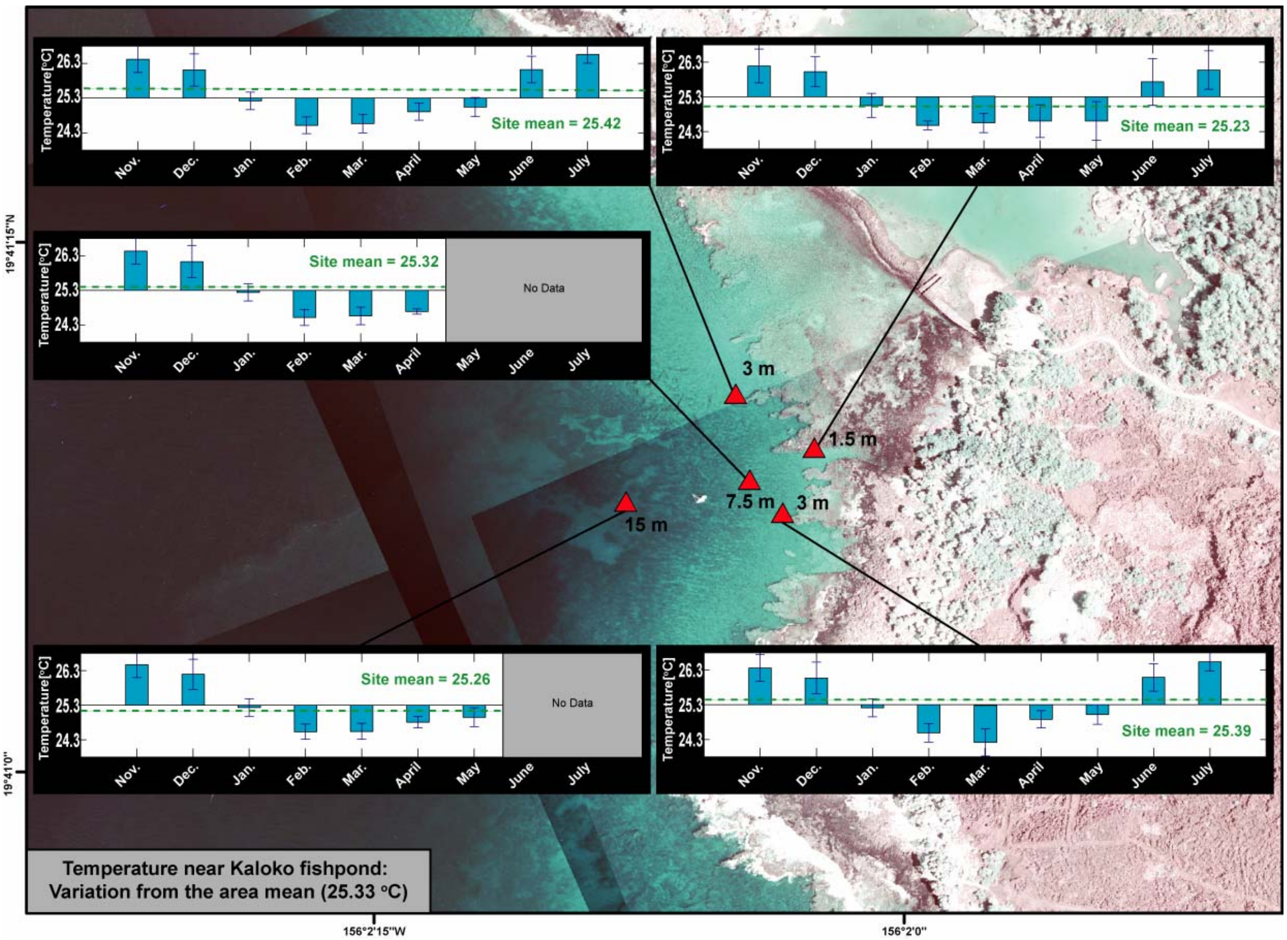

Figure 15. Comparisons of monthly mean temperature at the five northern CT sites to the overall area mean temperature for the entire northern area. The monthly averages and standard deviations for each month shows trends in cooling and warming in comparison to each site.

The comparison of monthly means to the overall area mean (25.43ºC) for the southern area also shows the same seasonal trend of cooling and warming from winter through the spring months observed in the northern area (fig. 16).

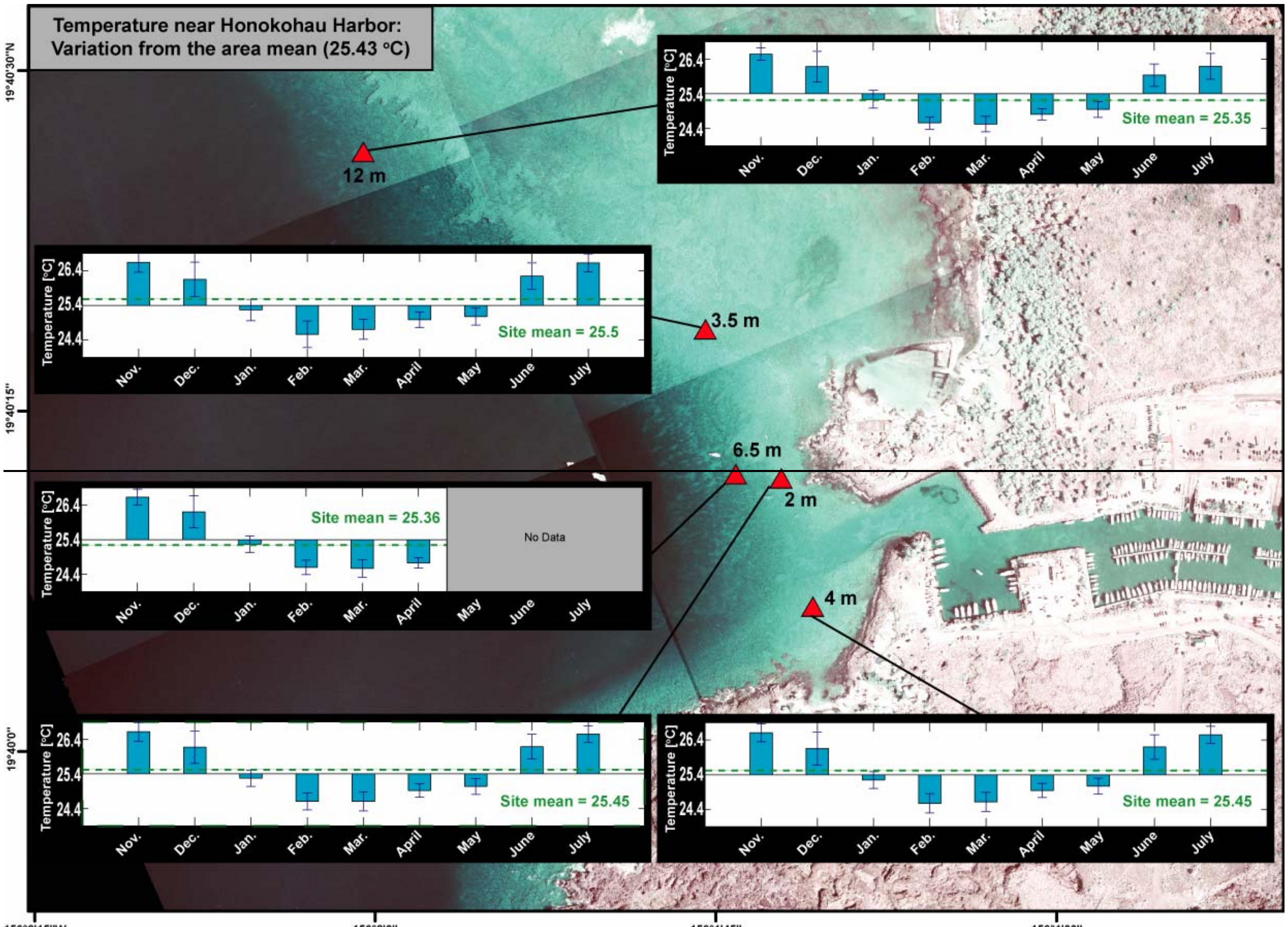

Figure 16. Comparisons of monthly mean temperature at the five southern CT sites to the overall area mean temperature for the entire southern area. The monthly averages and standard deviations for each month shows trends in cooling and warming in comparison to each site.

The overall salinity mean for the northern area (34.40 PSU) was compared to the monthly mean at each site (fig.17) in order to establish SGD influence at each site. The comparison shows the inner site had much lower salinities and greater variability than the other sites for the majority of the experiment. This comparison also shows precipitation events had a significant effect on the salinity at the inner, northern, and southern sites.

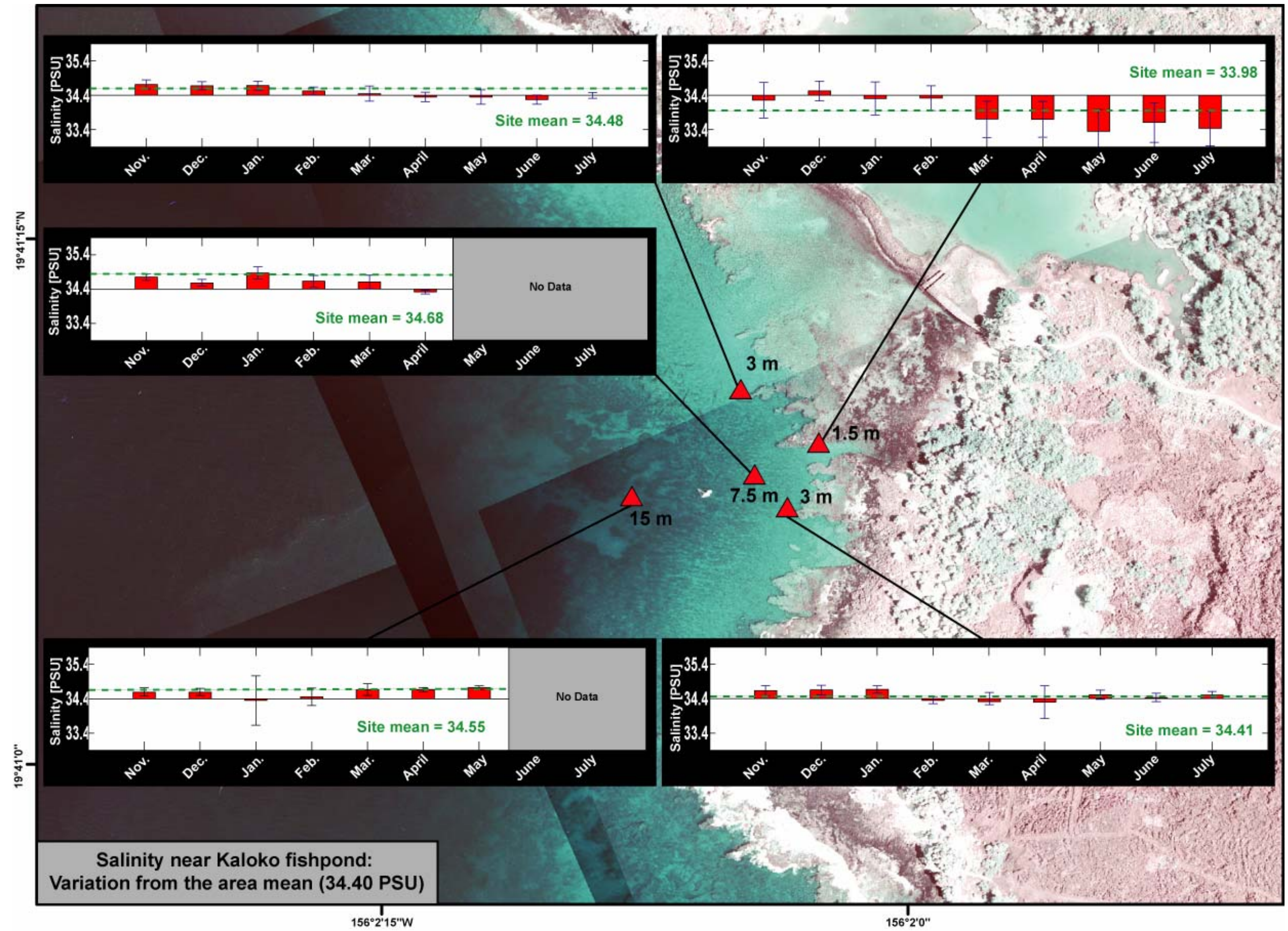

Figure 17. Comparisons of monthly mean salinity at the five northern CT sites to the overall area mean salinity for the entire northern area. The monthly averages and standard deviations for each month at each site provides information on which sites measured greater changes in salinity.

In the southern area, the monthly means at each site were compared to the overall salinity mean (34.51 PSU) for this area (fig. 18). The northern and MiniPROBE sites show monthly mean salinities lower than the other sites, but at different times and not in response to precipitation events in March and May, 2006. Furthermore, the monthly means at the outer, inner, and south sites showed a very similar relationship in comparison to the area mean and did not have a lower salinity signal in response to local precipitation events.

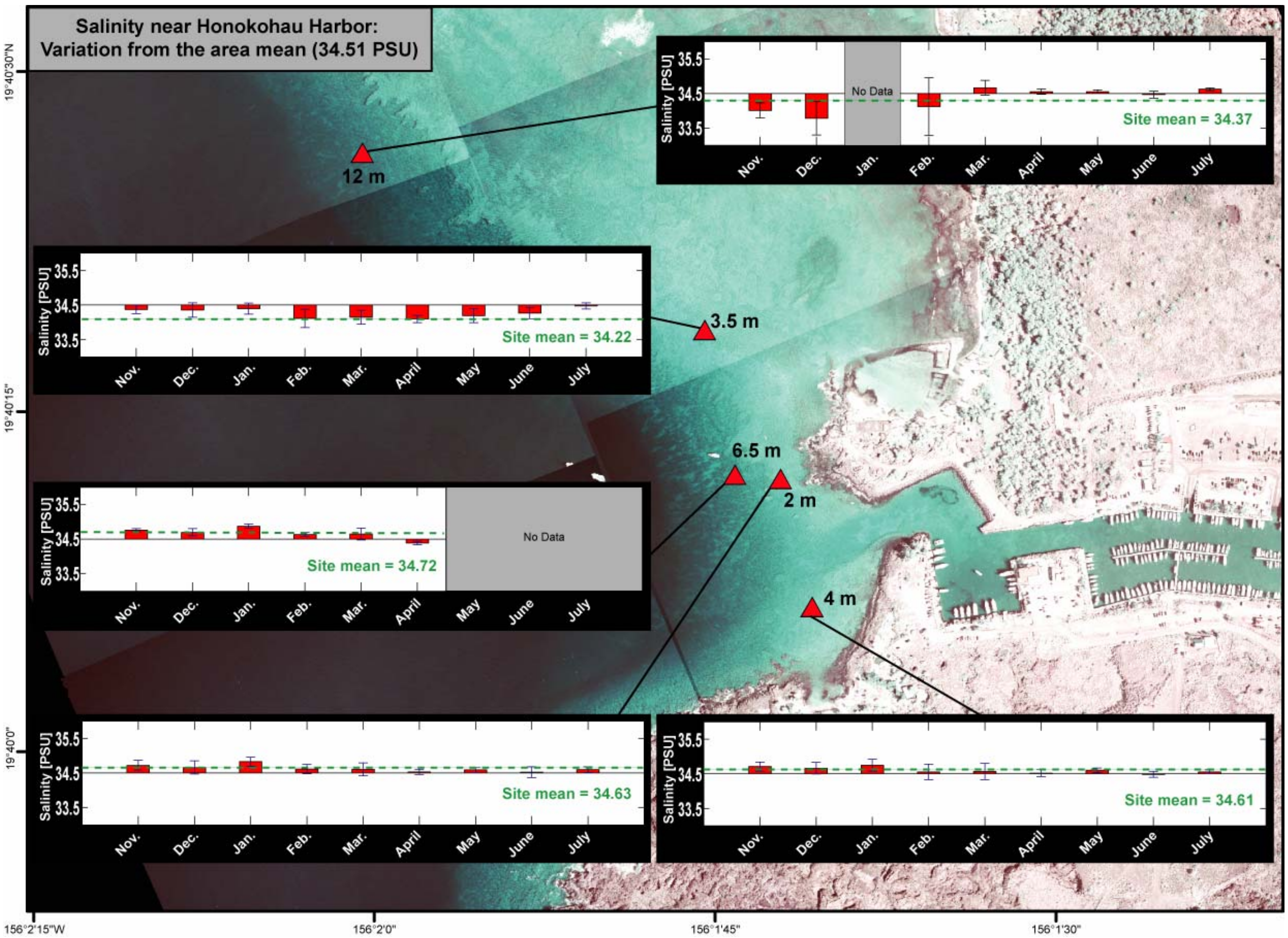

Figure 18. Comparisons of monthly mean temperature at the five southern CT sites to the overall area mean temperature for the entire southern area. The monthly averages and standard deviations for each month at each site provides information on which sites measured greater changes in salinity.

Correlations

Correlation of water elevation and water column properties provides information on the importance of tidal forcing in circulation of KAHO's nearshore waters. Due to widely varying forcing over the course of the experiment, the correlation of temperature, salinity and water depth due to tides at the five sites was examined on a monthly basis for the northern and southern areas.

In the northern area near Kaloko Fishpond, a significant positive correlation existed between temperature and water depth at the northern, southern, and inner sites during the months from 03/2006 through 07/2006. The positive correlation indicates that as the water depth decreased with a falling tide, the temperature decreased at these sites, likely as a result of freshwater discharge being advected offshore past the CT sensors. The strongest correlation between temperature and water depth was recorded at the inner site for these months. The other sites and other months of the deployment did not show a significant correlation of temperature with water depth.

In the southern area offshore of Aimakapa fishpond, the relationship between temperature and water depth at the 5 sites in the southern area did not show a significant correlation during the entire deployment. This indicates that the tides did not exert significant control on temperature variability in this area.

A cross-correlation of tidal height and salinities at the 5 sites through the deployment shows a response of the salinity to rising and falling tide in the northern area. During the months of 11/2005 through 01/2006 there was a significant positive correlation between salinity and water depth at the inner, northern, and southern sites. As the water depth decreased with a falling tide, the salinity decreased at these sites, indicating that the lower water levels allow more SGD to be advected through the study area. This positive correlation can be seen throughout the experiment at the inner (1.5 m) site and is more significantly correlated during the months of 03/2006 through 04/2006 due to an increase in local and upland precipitation. This correlation between salinity and the tides indicates that the tide and water depth has a strong influence on the salinity at the inner site through most of the year, as well as the northern and southern sites during the winter months and spring months.

The cross-correlation of salinity and tide elevation at the 5 sites in the southern area was examined monthly through the deployment. Overall, there was very little correlation between salinity and water depth most of the sites through the deployment. An exception where a significant positive correlation between salinity and tide elevation was observed occurred at the inner and southern sites from 11/2005 through 01/2006. The positive correlation indicates that as the water depth increased with the rising tide, the salinity increased at these sites, likely as a result of more saline water from the deep ocean being advected onshore during rising tide. The correlation between salinity and tide elevation was not significant at the other sites during the deployment, potentially a result of due to their further distance offshore in deeper water where the water column is well mixed and/or greater dispersion of SGD.

Groundwater Fluxes

The fate of SGD in the marine portion of KAHO is dependent on the meteorologic and oceanographic forcing that drive water circulation relative to the sources of SGD. In the northern area, a major source of freshwater discharge is near Kaloko Cut, south of Kaloko Fishpond. Although there were not direct measurements of the SGD, the strength of the freshwater discharge appeared to be influenced by both local and upland precipitation on the Hualalai volcano as seen from the temperature and salinity signal at the inner site located in Kaloko Cut. The currents offshore of the fishpond at the MiniPROBE site are extrapolated to the entire area in order to discuss the transport of SGD at the other sites in the northern region. Currents in the northern area were primarily alongshore and were driven by the tides and wind (fig. 14). The northern area was more exposed to the southwest winds, and the near surface and near bottom currents respond to the strength and duration of the winds. The precipitation events during 03/2006 provide more insight into the transport and fate of SGD in the northern area of the park. Following the rainfall in 03/2006, the largest decrease in salinity was observed at the inner site in comparison to the other sites for the months of 03/2006 through 05/ 2006 (fig. 17). During this time the currents were very slow but directed to the south. The southerly current direction was also measured at the ADP site over a 5 day period in early 03/2006 during one of the rainfall events. A large decrease in salinity was next seen in 04/2006 at the inner site for the next 4 months, as well a smaller decrease in salinity at the north site. This may be due to the currents shifting to the north in response to the stronger winds out of the southwest. The outer and MiniPROBE sites did not experience a decrease in salinity as a result of the currents being primarily alongshore to the north.

Unfortunately the incomplete current and wave data set in the southern area, along with very little variability in salinity and temperature sensors in response to periods of local precipitation events, provides very little information on the flux and fate of SGD in this portion of the park. As the currents were primarily cross-shore in this area, it could be hypothesized that most of the SGD in the area would be transported offshore with the tidal currents and mix with the oceanic water, thus masking the freshwater signal (fig. 14). The currents measured over a 5 day period at the inner ADP site also showed a predominant tidal signal with flows moving across-shore (northeast – southwest) with flooding and ebbing tides. Another possible mechanism driving offshore transport of SGD may be near-bed, offshore-directed return flow across the broad shallow reef balancing onshore-directed wave set-up during periods of large waves from the north and south.

Conclusions

Currents and thus the circulation of both marine waters and SGD in KAHO are dependent on tide, winds, and waves. A schematic of currents for the northern and southern areas shows the general direction of currents during different types of forcing (fig. 19). The small tidal currents offshore of the park direct the transport and dispersal of SGD, although are masked during periods of strong winds and waves. The general direction of transport during ebb tide is to the south at the northern and southern areas and to the north during flood tides. Trade winds are a consistent mechanism driving flow throughout the Hawaiian Islands and off the Kona coast, and directly influence the currents in this area on a daily basis during most of the year. The general direction of transport during trade wind periods for the northern area is to the northeast and to the southwest in the southern area, potentially creating an area of divergence between the two regions. During periods when large swells impact the study area, the general direction of transport is to the southwest in the northern area; although not directly measured in this study due to instrument failure, currents at the southern site are presumed to be offshore due to wave-driven set-up and offshore return flow off the basalt platform.

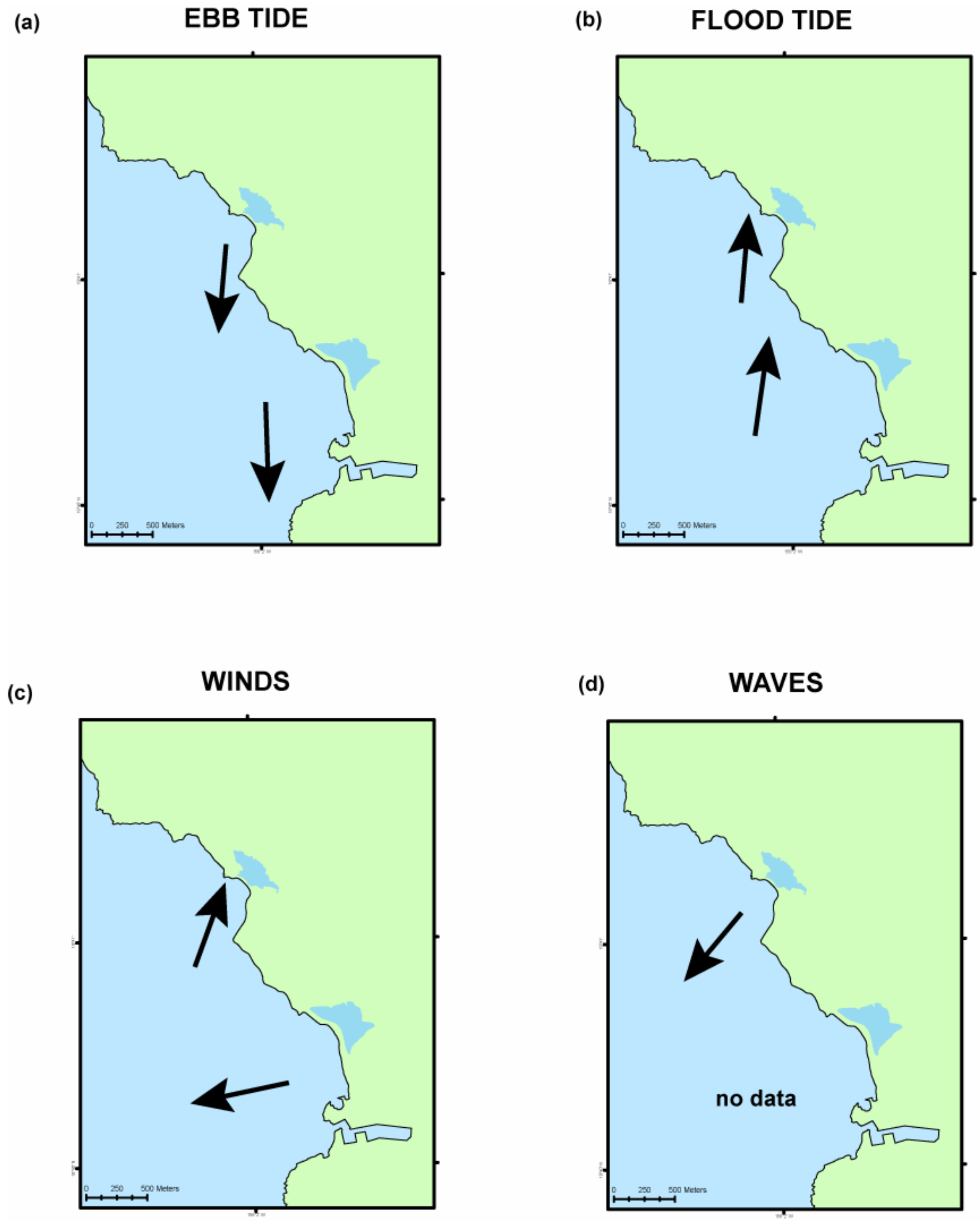

Figure 19. Schematic of average currents at the northern and southern areas during different forcing conditions. (a) Ebb tide; (b) Flood tide; (d) Strong winds; and (d) Large waves. The schematic shows overall net trends at the northern and southern areas and categorizes each forcing to show the flow during those times.

The temperature and salinity measurements by the CT sensors depict the SGD to be ephemeral, localized, and dependent on the proximity to an active SGD source. Precipitation in the study area or upslope on the Hualalai volcano results in delivery of SGD, and potentially nutrients and/or contaminants dissolved in the freshwater, to the park's waters. It was determined that temperature is not a good proxy for identifying SGD, as it primarily showed seasonal trends of warming and cooling not related to a SGD signal, possibly due to the placement of most of the CT sensors 3 m or more below the water's surface. Additional information on the buoyant freshwater surface plume will be presented from CTD profiling in the second report of this series. Kaloko Cut, just south of Kaloko fishpond, appears to be a stronger point source of SGD than the smaller, diverse sources at the southern area off Aimakapa fishpond and the harbor. The resulting flux was difficult to determine at the depth of our CT sensors and may be better quantified in remaining reports that examine the spatial extent of the buoyant freshwater plume and the nutrient fluxes in the KAHO. Overall, the signal of SGD at depths of 1.5 m and greater appear to be stronger during times of active, local precipitation, and the fate of the SGD and the nutrients and/or contaminants it potentially conveys is dependent on the local atmospheric and oceanic conditions.

Acknowledgements

This research was conducted as part of interagency agreement F2380060092 entitled "Determining subterranean groundwater nutrient input to Kaloko-Honokohau National Historical Park's coastal ocean ecosystem" between the USGS and NPS. The project was funded by the NPS Water Resources Division and the USGS Western Region Coastal and Marine Geology Team's Coral Reef Project as part of an effort in the U.S. and its trust territories to better understand the effect of geologic processes on coral reef systems. Michael Field (USGS) and Sallie Beavers (NPS) deserve special thanks for providing us with the opportunity and support to carry out these deployments. NPS staff contributed as part of the ongoing NPS/State of Hawaii Department of Aquatic Resources (DAR) Cooperative Program. A number of the NPS rangers and administrators at Kaloko-Honokohau National Historic Park provided us with space to work, vehicles and support, and went out of their way to help us carry out this experiment. We are also very grateful to the NPS Pacific Islands Coral Reef Program for use of their instruments in this experiment. We would also like to thank Li Erikson (USGS) and Andrew Stevens (USGS), who contributed numerous excellent suggestions and a timely review of our work. Use of trademark names does not imply USGS endorsement of products.

Additional Digital Information

For additional information on the instrument deployments, please see:
http://walrus.wr.usgs.gov/infobank/w/w105hw/html/w-1-05-hw.meta.html
http://walrus.wr.usgs.gov/infobank/w/w106hw/html/w-1-06-hw.meta.html
http://walrus.wr.usgs.gov/infobank/w/w206hw/html/w-2-06-hw.meta.html

For an online PDF version of this report, please see:
http://pubs.usgs.gov/of/2007/1310/

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/

Direct Contact Information

Regarding this report:
Dr. Eric Grossman
egrossman@usgs.gov

Regarding Oceanography in this report:
Dr. Curt Storlazzi
cstorlazzi@usgs.gov

Regarding the US Geological Survey Coral Reef Project:
Dr. Mike Field
mfield@usgs.gov

References Cited

Moberly, R.M., Chaimberlain, T., 1964. Hawaiian Beach Systems. University of Hawaii, 95pp.

Oki, D, S., Tribble, G.W., Souza, W.R, Bolke, E.L. 1999 Ground-Water Resources in Kaloko-Honokohau National Historical Park, Island of Hawaii, and Numerical Simulation of the Effects of Ground-Water Withdrawls. Water Resources Investigation Report 99-4070, pp 49.

Presto, M.K., Ogston, A.O., Storalazzi, C.D., Field, M.E. 2006. Temporal and spatial variability in the flow and dispersal of suspended-sediment on a fringing reef flat, Molokai, Hawaii. Estuarine Coastal and Shelf Science, 67, 67-81.

Storlazzi, C.D. and Presto, M.K. 2005. Coastal Circulation and Water Column Properties along Kaloko-Honokohau National Historical Park, Hawaii. Part I: Measurements of waves, currents, temperature, salinity and turbidity: April – October 2004. *U.S. Geological Survey Open-File Report 2005-1161.*

Storlazzi, C.D. and Jaffe, B.E., 2003. "Coastal Circulation ant 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. Geological Survey Open File Report 03 – 482, 28p.*

Western Regional Climate Center, 2007. Online digital data. *http://www.wrcc.dri.edu/cgi-bin/rawMAIN.pl?hiHKAL*

Table 1. Experiment personnel.

Person	Affiliation	Responsibilities
Eric Grossman	USGS	Chief Scientist, diver
Curt Storlazzi	USGS	Co-Chief Scientist, diver
Joshua Logan	USGS	Geographer, diver
Kathy Presto	USGS	Oceanographer
Sallie Beavers	NPS	NPS-KAHO scientist, field assistant, diver
Rebecca Most	NPS	Field Assistant, diver

Table 2. Instrument package sensors.

Instrument	Sensors
MiniPROBE (S)	RD Instruments 600 kHz Workhorse Monitor acoustic Doppler current profiler (upward looking) Aquatec/Seapoint 210-TY optical backscatter sensor Seabird SBE-37SM Microcat conductivity-temperature sensor
MiniPROBE (N)	RD Instruments 600 kHz Workhorse Monitor acoustic Doppler current profiler (upward looking) Aquatec/Seapoint 210-TY optical backscatter sensor Seabird SBE-37SM MicroCat conductivity-temperature sensor
CT Transect (S)	Seabird SBE-37SM MicroCat conductivity-temperature sensor (4)
CT Transect (N)	Seabird SBE-37SM MicroCat conductivity-temperature sensor (4)

Table 3. MiniPROBE deployment log: 11/2005 – 07/2006

Instrument	Island ID	Depth (m)	Deployment Date	Recovery Date	Latitude (dd)	Longitude(dd)
MiniPROBE (S)	HA	12	11/13/2005	02/25/2006	19.6740031	-156.0334844
			02/28/2006	04/04/2006		
			04/06/2006	07/15/2006		
MiniPROBE (N)	HA	15	11/13/2005	02/25/2006	19.6854603	-156.0355242
			02/28/2006	04/04/2006		
			04/06/2006	07/15/2006		

Table 4. ADP deployment log: 03/2006.

Instrument	Island ID	Depth (m)	Deployment Date	Recovery Date	Latitude (dd)	Longitude(dd)
ADP (S)	HA	3	03/01/2006	03/05/2006	19.6716438	-156.0289402
ADP (N)	HA	4	03/01/2006	03/05/2006	19.6856765	-156.0342858

Table 5. Salinity/Temperature Arrays deployment log: 11/2005 – 07/2006.

Instrument	Island ID	Depth (m)	Deployment Date	Recovery Date	Latitude (dd)	Longitude(dd)
South - Inner site	HA	2	11/13/2005	02/25/2006	19.6700040	-156.0283711
			02/28/2006	04/04/2006		
			04/06/2006	07/15/2006		
South - South site	HA	4	11/13/2005	02/25/2006	19.6684371	-156.0279857
			02/28/2006	04/04/2006		
			04/06/2006	07/15/2006		
South - North site	HA	3.5	11/13/2005	02/25/2006	19.6718321	-156.0293011
			02/28/2006	04/04/2006		
			04/06/2006	07/15/2006		
South - Outer site	HA	6.5	11/13/2005	02/25/2006	19.6700564	-156.0289307
			02/28/2006	04/04/2006		
			04/06/2006	07/15/2006		
North - Inner site	HA	1.5	11/13/2005	02/25/2006	19.6858826	-156.0340454
			02/28/2006	04/04/2006		
			04/06/2006	07/15/2006		
North - South site	HA	3	11/13/2005	02/25/2006	19.6853719	-156.0342911
			02/28/2006	04/04/2006		
			04/06/2006	07/15/2006		
North - North site	HA	3	11/13/2005	02/25/2006	19.6863057	-156.0346620
			02/28/2006	04/04/2006		
			04/06/2006	07/15/2006		
North - Outer site	HA	7.5	11/13/2005	02/25/2006	19.6856302	-156.0345535
			02/28/2006	04/04/2006		
			04/06/2006	07/15/2006		

Table 6. NPS RAWS Weather Station: 11/2005 – 07/2006 (Latitude: 19.6728 , Longitude: -156.0203).

Instrument	Serial Number
Temperature/Humidity Sensor	THS-2000:3
Rain Gauge	RG-T-TRI
Wind Speed Sensor	WSM-30
Wind Direction Sensor	WDM-30
Barometric Pressure	SDI-B1-S
Fuelstick Moisture Sensor	FS-11
Solar Radiation Sensor	SDI-SR-PYR

APPENDIX 1

MiniPROBE Acoustic Doppler Current Profiler (ADCP) Information

Instrument:

RD Instruments 600 kHz Workhorse Monitor (north 11/2005 – 02/2006); s/n: 2074
RD Instruments 600 kHz Workhorse Monitor (south 11/2005 – 02/2006); s/n: 2432
RD Instruments 600 kHz Workhorse Monitor (north 02/2006 – 04/2006); s/n: 2074
RD Instruments 600 kHz Workhorse Monitor (south 02/2006 – 04/2006); s/n: 2432
RD Instruments 600 kHz Workhorse Monitor (north 04/2006 – 07/2006); s/n: 7449
RD Instruments 600 kHz Workhorse Monitor (south 04/2006 – 07/2006); s/n: 3648

Transmitting Frequency:	614 kHz
Depth of Transducer:	14.6 m (north) /12.7 m (south)
Blanking Distance:	0.25 m
Height of First Bin above Bed:	0.75m
Bin Size:	0.5m
Number of Bins:	36
Operating Mode:	High-resolution, broad bandwidth
Sampling Frequency:	2 Hz
Beam Angle:	20 deg
Time per Ping:	00:00:00.30
Pings per Ensemble:	100
Ensemble Interval:	03:00:00.00
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 60% 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

MiniPROBE External Sensor Information

Instruments:

North MiniPROBE

Seabird MicroCat SBE-37SM CT; s/n: 3372; calibrated 07/2004
Seabird MicroCat SBE-37SM CT; s/n: 1161; calibrated 04/2004
Seabird MicroCat SBE-37SM CT; s/n: 4221; calibrated 11/2005

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

South MiniPROBE

Seabird MicroCat SBE-37SM CT; s/n: 1161; calibrated 04/2004
Seabird MicroCat SBE-37SM CT; s/n: 3372; calibrated 07/2004
Seabird MicroCat SBE-37SM CT; s/n: 2792; calibrated 12/2005

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

North MiniPROBE

Aquatec/Seapoint 210-TY OBS; s/n: 371-014; calibrated 08/17/2002
Aquatec/Seapoint 210-TY OBS; s/n: 371-013; calibrated 08/17/2002
Aquatec/Seapoint 210-TY OBS; s/n: 371-024; calibrated 08/17/2002

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

South MiniPROBE

Aquatec/Seapoint 210-TY OBS; s/n: 371-013; calibrated 08/17/2002
Aquatec/Seapoint 210-TY OBS; s/n: 371-026; calibrated 08/17/2002
Aquatec/Seapoint 210-TY OBS; s/n: 371-013; calibrated 08/17/2002

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

Position Information:

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

APPENDIX 3

Salinity and Temperature Sensor Information

Instruments:

North Array (11/2005 – 07/2006)

Seabird MicroCat SBE-37SM CT; s/n: 4089; calibrated 06/2005
Seabird MicroCat SBE-37SM CT; s/n: 3825; calibrated 06/2005
Seabird MicroCat SBE-37SM CT; s/n: 3830; calibrated 06/2005
Seabird MicroCat SBE-37SM CT; s/n: 3800; calibrated 10/2004

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

South Array (11/2005 – 07/2006)

Seabird MicroCat SBE-37SM CT; s/n: 4088; calibrated 06/2005
Seabird MicroCat SBE-37SM CT; s/n: 4087; calibrated 06/2005
Seabird MicroCat SBE-37SM CT; s/n: 3833; calibrated 06/2005
Seabird MicroCat SBE-37SM CT; s/n: 3801; calibrated 10/2004

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

APPENDIX 4

Nortek Acoustic Doppler Current Profiler (ADP) Information

Instrument:

Nortek Instruments 2 MHz upward-looking monitor (03/01/2006 – 03/05/2006); s/n: 1861 (north), 1862 (south)

Depth of Transducer:	4 m (north) / 3 m (south)
Blanking Distance:	0.20 m
Height of First Bin above Bed:	0.45m
Bin Size:	0.25m
Number of Bins:	24
Average interval:	120 s
Profile interval:	900 s
Wave interval:	3600 s
Wave cell size:	1 m
Operating Mode:	High-resolution
Vertical Velocity Precision:	0.4 cm/s
Horizontal Velocity Precision:	1.3 cm/s
Sound Speed Calculation:	Measured assumed salinity of 35 ppt
Temperature via sensor	

Data Processing:

The data were averaged over 24-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 60% were removed for visualization and analysis.

Position Information:

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