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NOAA-TM-NMFS-SWFSC-315

U.S. DEPARTMENT OF COMMERCE
National Oceanic and Atmospheric Administration
National Marine Fisheries Service
Southwest Fisheries Science Center

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ABSTRACT

Hydrographic conditions during three periods of approximately ten days each from mid-May through mid-June 1999 in the coastal ocean bounded by Cypress Pt. (36°35'N) and Pt. Reyes, California (38°10'N), and from the coast to about 75 km offshore, are summarized in a series of horizontal maps and vertical sections. A total of 228 standard conductivity-temperature-depth (CTD) casts were obtained during the NOAA R/V *David Starr Jordan* cruise DSJ9903 over the course of three consecutive sweeps of the region. Data products contained in this report include (1) a master list of CTD stations during the cruise; (2) surface meteorological time series from the region's four National Data Buoy Center (NDBC) meteorological buoys; (3) horizontal maps of sea surface temperatures (SST) from AVHRR satellite images; (4) acoustic Doppler current profiler (ADCP) data; (5) horizontal maps of temperature, salinity, and density (sigma-theta [σ_θ]) at depths of 2 m, 10 m, 30 m, 100 m, 200 m, 300 m, and 500 m; (6) temperature, salinity and σ_θ along four cross-shelf vertical transects; and (7) dynamic height topography (0/500 m and 200/500 m) in the survey region.

INTRODUCTION

The current regime off central California is hydrodynamically complex, composed of both geostrophic and wind-driven forces. The California Current provides the backdrop for large-scale, seasonal circulation patterns (Hickey 1979), while coastal upwelling occurs regionally for most of the year, especially from April to September (Huyer 1983). On the mesoscale (10-100 km), irregularities in the coastline interact with the wind stress field (Kelly 1985), resulting in turbulent jets, eddies and upwelling filaments, all of which are common features along the central California coast (Mooers and Robinson 1984; Flament et al. 1985; Njoku et al. 1985; Rosenfeld et al. 1994). Moreover, wind-driven fluctuations in coastal flow (Chelton et al. 1988) and freshwater discharge from San Francisco Bay add further complexity to the circulation regime.

Since 1983, the National Marine Fisheries (NMFS) Southwest Fisheries Science Center's (SWFSC) Santa Cruz Laboratory has worked on developing a recruitment index for rockfish within the hydrographic region off central California. Annual juvenile rockfish surveys aboard the National Oceanic and Atmospheric Administration (NOAA) research vessel (R/V) *David Starr Jordan* (DSJ) have provided information regarding distributional and abundance patterns of young-of-the-year pelagic juveniles in the area between Monterey Bay and Pt. Reyes (latitude 36°30'-38°10'N) (Wyllie Echeverria et al. 1990). Results of this research show a complex pattern in the spatial distribution of pre-recruits of a variety of commercially significant species (e.g., widow rockfish, *S. entomelas*; chilipepper, *S. goodei*; yellowtail rockfish, *S. flavidus*; and bocaccio, *S. paucispinis*). Moreover, extreme interannual fluctuations in abundance have occurred, with combined back-transformed mean $\log_e$ catches ranging from 0.1-78.6 juvenile rockfish/tow (Adams 1995[1]).

Realizing that a basic description of the physical environment is necessary to better understand the distribution and abundance of young-of-the-year rockfish, collection of conductivity-temperature-depth (CTD) data was initiated in 1987 as part of the NMFS SWFSC Santa Cruz Laboratory's annual juvenile rockfish surveys. The staff of the NMFS SWFSC Pacific Fisheries Environmental Laboratory (PFEL) subsequently began analyzing the CTD data to assist in this recruitment fisheries oceanography study. Ultimately, it is our goal to determine and forecast the manner in which rockfish year-class strength is affected by variations in the physical environment.

This report summarizes results obtained from the CTD data collected in 1999. Due to the large quantity of data analyzed and the extensive array of results presented herein, we make little attempt to provide detailed interpretations of our findings. Reports covering the juvenile rockfish surveys of 1988 (DSJ8804 and DSJ8806), 1989 (DSJ8904), 1990 (DSJ9003 and DSJ9005), 1991 (DSJ9102 and DSJ9105), 1992 (DSJ9203 and DSJ9206), 1993 (DSJ9304 and DSJ9307), 1994 (DSJ9403 and DSJ9406), 1995 (DSJ9506), 1996 (DSJ9606), 1997 (DSJ9707), and 1998 (DSJ9807) have been published (Schwing et al. 1990; Johnson et al. 1992; Sakuma et al. 1994a; Sakuma et al. 1994b; Sakuma et al. 1995a; Sakuma et al. 1995b, Sakuma et al. 1996, Sakuma et al. 1997, Sakuma et al. 1999, Sakuma et al. 2000). A companion volume (Schwing and Ralston 1990[2]) contains individual traces of temperature, salinity, and sigma-t (σ_t, a representation of water density) plotted against depth for each CTD cast conducted in 1989. Further scientific analysis of these data, and their linkages to fisheries recruitment, will be compiled in future peer-reviewed scientific publications (e.g., Schwing et al. 1991).

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[1]Adams, P. B. (editor). 1995. Progress in rockfish recruitment studies. SWFSC Admin. Rep. T-95-01, 51 p., unpublished report.

[2]Schwing, F. B., and S. Ralston. 1990. Individual cast data for CTD stations conducted during cruise DSJ8904 (May 14-June 13, 1989). SWFSC Admin. Rep. PFEG-91-01, 7 p. + figs., unpublished report.

MATERIALS AND METHODS

Meteorological Data

Surface data were obtained from four NOAA National Data Buoy Center (NDBC) moored buoys located within the rockfish survey region. These four buoys are 46013 (Bodega Bay; 38°12'N, 123°18'W), 46026 (Farallones; 37°48'N, 122°42'W), 46012 (Half Moon Bay; 37°24'N, 122°42'W) and 46042 (Monterey Bay; 36°48'N, 122°24'W) (Appendix 2). Daily averages of sea surface temperature (SST) and the east and north wind components were calculated from hourly mean buoy measurements. The angle of the alongshore wind component, relative to north, was determined by a principal component analysis (PCA) of the daily-averaged wind data from each buoy. This angle can be thought of as the predominant direction toward which the wind blows.

Annual climatologies and variance were determined for SST and the alongshore wind component at each buoy with a biharmonic analysis of all daily mean data over the buoy's entire operating period. These operating periods were 1981 to 1999 for buoy 46013, 1982 to 1999 for buoy 46026, 1981 to 1999 for buoy 46012, and 1987 to 1999 for buoy 46042. The annual cycles were estimated by a least squares regression of the data to an annual and semiannual harmonic signal of the form

$$SST(t) = A_0 + A_1 cos(2\pi t) + B_1 sin(2\pi t) + A_2 cos(4\pi t) + B_2 sin(4\pi t)$$

where t is the Julian Day/365 and the A_i and B_i are coefficients determined by regression at each buoy. The fits were not improved significantly by including higher harmonics. Standard errors were calculated for each Julian day, then fit with the same biharmonic model.

SST Data from AVHRR Satellite Imagery

Beginning in February 1998, products generated by the NOAA CoastWatch Group in La Jolla, California were changed from previous years. SSTs were derived from advanced very high resolution radiometer (AVHRR) data from channel 4 and 5 of the NOAA-11 polar orbiting satellite and were designated as non-linear multichannel SST. A cloud masking routine was run on each image file, and then the images were partitioned into different geographic regions along the West Coast. This yielded a high resolution image file which could then be read and analyzed by the personal computer (PC) based Windows Image Manager (WIM) software developed by Mati Kahru of Scripps Institution of Oceanography in La Jolla, California. The image files were compressed and downloaded to the Ship's PC by using a cellular telephone, a cellular telephone modem interface, and a commercial modem communications software. Once an image was received, the WIM software was used to decompress, display and manipulate the satellite image in order to discern SST gradients and areas of upwelling and mesoscale eddy activity. All images which were clear or relatively clear of clouds/fog were saved on a PC and stored at the NMFS SWFSC Santa Cruz Laboratory and at the NMFS SWFSC PFEL as part of the Oceanographic database system.

Juvenile Rockfish Survey Design

Annual cruises aboard the NOAA R/V DSJ began in 1983 and have been conducted during late spring (April-June), a time when most pelagic-stage juvenile rockfishes are identifiable to species, but prior to their settling to nearshore and benthic habitats. Throughout this time, a standard haul consisted of a 15-minute nighttime tow of a large midwater trawl set to a depth of 30 m. Additional tows were made at other depths (i.e., 10 and 100 m) as allowed by constraints imposed by time and bottom bathymetry.

In 1986, the sampling design was altered to permit three consecutive "sweeps" through a study area bounded by Cypress Pt. (36°35'N) and Pt. Reyes (38°10'N), California, and from the coast to about 75 km offshore. Five or six stations along a transect were sampled each night and seven transects were completed for each sweep. Starting in 1987, a CTD cast was conducted at each trawl station occupied. In addition, daytime activities were restructured to permit sampling of a new grid of standard CTD stations (Appendix 2). Standard CTD stations were specific locations where CTD casts were scheduled and repeated for each sweep of each cruise. CTD cast locations that were only specific to a particular sweep during a cruise were considered as additional CTD stations. Although each sweep typically lasts approximately ten days (seven nights of scheduled work plus three nights of additional discretionary sampling), adverse weather conditions can extend the duration of a sweep. Logistical constraints can also restrict the number of casts completed. Discretionary sampling typically was focused on specific bathymetric features, such as Cordell Bank or Pioneer Canyon, or devoted to the intense study of oceanic features or processes that may be key to successful recruitment. CTD casts conducted during discretionary sampling were considered additional stations and not included in the grid of standard CTD stations used in this report.

Collection of ADCP Data at Sea

An Acoustic Doppler Current Profiler (ADCP) manufactured by RD Instruments of San Diego, CA. was operated continuously on each cruise. The ADCP is constructed of naval bronze and is permanently mounted in a sea chest within the hull of the vessel. The unit contains four downward looking 150 kHz transducers pointing at a fixed beam angle in four different directions. RD Instrument's Data Acquisition Software (DAS) was used to log accoustic data to a shipboard PC. The ADCP emits acoustic pulses (pings) which are used to measure velocity, magnitude, and direction of the column of water beneath the ship. Ship heading was obtained from a gyrocompass and positions were obtained by a Global Positioning System (GPS) receiver.

Collection of CTD Data at Sea

CTD data from the 1999 juvenile rockfish survey presented in this report was collected with a Sea-Bird Electronics, Inc., SEACAT-SBE-19 profiler mounted on an SBE-32 water sampler carousel, which interfaced via conducting cable to a SBE-33 deck unit[3]. This allowed for real-time data acquisition. This particular unit was rated to a depth of 600 m and contained 256K of memory. The CTD was also equipped with a WETStar model WS3-030 miniature fluorometer. Four data channels were used to record pressure (0.05% of full scale range [50-5,000 psia]), temperature (0.01 °C from -5 to +35 °C), conductivity (0.001 S/m from 0 to 7 S/m), and fluorometer voltage at a baud rate of 9,600. The temperature and conductivity sensors of the profiler have been recalibrated annually by Sea-Bird Electronics, Inc., prior to its use aboard ship.

During deployment, the vessel was brought to a dead stop and the profiler was attached to a hydrographic winch cable. The profiler was then switched on and suspended underwater at the surface for a period of two minutes to allow the conductivity, temperature, and fluorometer sensors to equilibrate. The rate of descent was 45 m/minute to a depth 10 m off the bottom down to a maximum depth of 500 m. Only data collected on the downcast were ultimately preserved for analysis. During the cast, certain collection information was recorded on data sheets, including (1) the date, (2) time, (3) a profiler-assigned cast number, (4) a cruise-specific consecutive index number, (5) the trawl station number (when appropriate), (6) latitude, (7) longitude, (8) bucket temperature (temperature [°C] of a bucket sample of surface water using a mercury thermometer), (9) bucket salinity (salinity of a bucket sample of surface water using a hand-held portable salinometer), and (10) bottom depth in meters. In addition, a water sample from the chlorophyll maximum layer was collected twice a day (using one of the bottles attached to the SBE-32) for later use in calibrating the WETStar fluorometer dsta. Position fixes were obtained using the GPS. Collection information recorded on the data sheets were eventually entered into data files on a PC.

Data collected from a short series of casts (usually no more than 5-7) were periodically uploaded to a laptop computer. During this step, each cast was stored as a separate file. After uploading, the profiler was reinitialized and the files on the laptop computer were backed up onto a desktop computer on board the vessel.

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[3]Sea-Bird Electronics, Inc., 1808 - 136th Place NE, Bellevue, Washington 98005, USA. Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

An additional source of hydrographic data was the vessel's Sea-Bird Electronics, Inc., thermosalinometer (TS) unit, which provided a continuous data stream of surface temperature and salinity. These data were logged by the vessel's scientific computer system and transferred to a PC for further processing, analysis, and comparison with, and verification of, CTD observations. Position fixes for the TS unit were based on GPS.

ADCP Data Processing

ADCP data were processed using the CODAS 3 software from University of Hawaii [4]. Data from each cruise were scanned and loaded into a cruise-specific CODAS database. The navigation fix data were extracted. Manual screening was done for profiles which included bottom reflection. Calibration and alignment corrections were computed and applied to the database. The absolute reference layer currents were then computed, smoothed, and used to produce absolute current profiles. Currents were plotted as vectors at eight different depth bins using the 'vector' plotting routine in CODAS.

CTD Data Processing

The first step in data processing was to convert the uploaded CTD files to ASCII files. This was accomplished using programs supplied by Sea-Bird Electronics, Inc., in SEASOFT menu-driven release Version 4.227[5]. All files were batch-processed through the SEASOFT modules DATCNV, FILTER, ALIGNCTD, LOOPEDIT, BINAVG, and DERIVE (refer to footnote 4 and past Technical Memorandums, e.g., Sakuma et al. 1995b, for more information) and output as ASCII files macros. All data were averaged into two-meter depth bins. Each CTD ASCII file was subsequently manually edited to remove large outliers (i.e., data spikes) in salinity and/or density, which sometimes occurred near the surface and at the thermocline. Comparisons were made between CTD temperature and salinity from the two-meter depth bin, TS temperature and salinity, bucket temperature, and bucket salinity at each CTD station using a simple regression to check for data outliers and any blatant calibration problems (Appendix 6).

Processed hydrographic data were summarized, by sweep, in a series of horizontal maps and vertical sections. Although additional CTD casts were completed during DSJ9903, only casts from the grid of standard CTD stations and those casts which provided a relatively continuous sampling track within a specific sweep were included in the data summary for the horizontal maps (Appendix 7). This was done in an attempt to generate a relatively synoptic representation of each individual sweep and to spatially standardize hydrographic comparisons among sweeps. Vertical sections from the three sweeps of DSJ9903 were also spatially standardized (Appendix 8). However, the Farallones transect line was less synoptic than the Pt. Reyes, Pescadero, and Davenport transect lines, because casts were combined over a 2- to 3-day time period instead of the more usual 24-hour period. In addition, the Farallones transect line does not follow a straight course, which may lead to some distortion of the vertical section contours nearshore. All contouring of CTD data for horizontal maps and vertical sections was done using SURFER FOR WINDOWS graphics software[6], which estimates values throughout a specified region based on the available data. Kriging was selected as the optimal interpolation method used for the algorithm grid (Cressie 1991).

The TS raw data were edited to provide a nearly continuous sampling track for each sweep of DSJ9903. However, there appeared to be a consistent offset between salinity recorded by the TS

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[4] Firing, E., J. Ranada, and P. Caldwell, 1995. Processing ADCP Data with CODAS Software System. Available electronically from: http://noio.soest.hawaii.edu /pub/codas3/manual.ps.

[5] CTD Data Acquisition software, SEASOFT Version 4.227, October 1997, Sea-Bird Electronics, Inc., 1808 - 136th Place NE, Bellevue, Washington 98005, USA. Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

[6] SURFER FOR WINDOWS, Golden Software, Inc., 809 14th Street, Golden, Colorado 80402, USA. Reference to trade names does not imply endorsement by the National Marine Fisheries Service, NOAA.

and salinity recorded by the CTD at 2-m depth for the entire cruise (Appendix 6). Because the CTD was calibrated annually by the manufacturer, and because problems occurred with the TS unit in the past during DSJ9203, DSJ9304, and DSJ9406, TS salinity values were considered less reliable and, when necessary, were adjusted using a regression comparison with the CTD. That is,

$$TS' = \alpha + \beta(TS)$$

where TS' is the adjusted thermosalinometer value (either temperature or salinity), TS is the unadjusted value, and α and β are the intercept and slope parameters of the regression of 2-m CTD data (temperature or salinity) on the corresponding TS value. TS data were subsequently contoured using SURFER FOR WINDOWS[6].

Satisfactory calibrations for the WETStar fluorometer using the SBE-32 bottle samples from DSJ9903 have yet to be resolved. Due to the lack of an accurate calibration, the fluorometer data for DSJ9903 will not be presented.

Dynamic height was calculated for stations occupied during DSJ9903 using a 500-db base. CTD casts conducted in areas with bottom depths less than 500 m were not included in this analysis. The dynamic height topography of the 0-db surface relative to the 500-db surface and the 200-db surface relative to the 500-db surface for the three sweeps of DSJ9903 were output from the DERIVE module of SEASOFT Version 4.227[5] and these data were gridded in SURFER FOR WINDOWS[6]. A 0.01 contour interval was chosen for the 0 db surface relative to the 500-db surface maps and a 0.005 contour interval for the 200-db surface relative to the 500-db surface (Appendix 9).

To date, no attempt has been made to calculate vertical sections of geostrophic velocity because the large number of shallow stations during the juvenile rockfish surveys necessitates the extrapolation of isopycnals into the shore, a procedure that is subject to great uncertainty. In addition, recent studies (Berryman 1989; Tisch 1990) suggest that geostrophic velocities calculated for stations spaced closer than the internal Rossby radius frequently feature alternating current bands of reversed flow, which are thought to be associated with inertial currents. The Rossby radius in the survey region is generally about 10-20 km, which is similar to the typical station spacing of the rockfish surveys. We are presently investigating the method that best determines geostrophic velocities from dynamic heights, based on closely spaced shallow water stations, before attempting to calculate the geostrophic velocity field during these surveys.

RESULTS

Data Products

Below are a few brief comments on each of the data products contained in this report in the order that they appear.

Appendix 1: List of CTD Stations Summarized from Cruise DSJ9903

The station list includes, from left to right, CTD cast number (only acceptable casts included), date, local military time, latitude and longitude (degrees, minutes), and station bottom depth. Cruise DSJ9903, Sweep 1 (May 10-17) includes 71 standard stations (casts 1-71), Sweep 2 (May 17-24) includes 77 standard stations (casts 73-149), and Sweep 3 (May 28-June 3) includes 80 standard stations (casts 161-240).

Appendix 2: CTD Stations and Bathymetric Maps of Survey Region with Locations of the NDBC Buoys

The locations of the standard CTD stations for DSJ9903 along with the locations of the NDBC buoys, the place names, and the bottom bathymetry of the survey areas are shown.

Appendix 3: Meteorological Time Series

Time series of daily-averaged SST and alongshore wind are presented for January-June 1999 based on data available from the four NOAA NDBC buoys located within the survey region. In each plot, the bold solid line represents the daily-mean values of the parameter. The bold dotted line represents the biharmonic fit to the climatology derived from daily data over the operating period of the buoy to date. The gray shaded envelope about the biharmonic fit line is ±1 standard error of the daily values on each Julian day. Negative values denote southward (upwelling-favorable) winds. The "PCA direction" on the alongshore wind plots represent the direction of the alongshore wind relative to north, which was derived from a principal component analysis.

Appendix 4: AVHRR Satellite Images of Multichannel SST

SSTs along the central and northern California coast from radiances sensed by channel 4 and 5 of the NOAA-11 polar orbiting satellite are presented for each of the three sweeps during DSJ9903. Each image represents a single pass during the afternoon hours, local time. The temperature color spectrum ranges from 7-16°C. Areas experiencing upwelling appear as blue and dark blue, whereas areas with warmer water appear as orange and red. Cloud cover and/or fog appear as blacked out areas.

Appendix 5: ADCP Data

Current velocity fields are presented as a series of horizontal vector plots. A separate set of figures was prepared for each of the three sweeps. Within each set, currents are shown at eight discrete depth layers (21-25 m, 25-75 m, 75-125 m, 125-175 m, 175-225 m, 225-275 m, 275-325 m and 325-375 m). Each current vector represents data collected over a 90 minute time period. The vectors point in the direction of flow and the length of the arrows is proportional to the current speed in cm/second. A velocity scale is provided on each figure.

Appendix 6: Regression Comparisons of CTD, TS, and Bucket

The plots presented show comparisons between CTD, TS, and bucket temperatures and CTD and TS salinities. The solid lines represent the lines of equality in order to show how the different data varied from each other. The regression statistics for each comparison were as follows:

CTD temperature versus TS temperature,
CTDtemp. = TStemp. x 0.993 + 0.060
$R^2 = 0.99$
CTD temperature versus bucket temperature,
CTDtemp. = buckettemp. x 0.982 + 0.053
$R^2 = 0.99$
TS temperature versus bucket temperature,
TStemp. = buckettemp. x 0.989 - 0.007
$R^2 = 0.99$
CTD salinity versus TS salinity,
CTDsal. = TSsal. x 0.995 + 0.064
$R^2 = 0.88$
CTD salinity versus bucket salinity,
CTDsal. = bucketsal. x 0.874 + 4.203
$R^2 = 0.82$
TS salinity versus bucket salinity,
TSsal. = bucketsal. x 0.865 + 4.576
$R^2 = 0.90$

Appendix 7: Horizontal Maps of CTD and TS

a) Maps of TS temperature and salinity

Maps of surface temperature (°C) and salinity obtained from the vessel's TS continuous profiling unit are presented for each sweep of DSJ9903. The TS maps are located in front of the corresponding horizontal map for the CTD at 2 m. The contour intervals are 0.5 °C for temperature and 0.1 for salinity. They are included to provide some verification of hydrographic spatial patterns inferred from the CTD data. The 2-m CTD and surface TS maps display good agreement, despite the fact that the data used to generate each were collected by different instrument packages.

b) Maps of CTD temperature, salinity and density, by depth

Horizontal maps of temperature (°C), salinity, and density (sigma-theta [σ_θ]) (kg/m^3) are presented at depths of 2 m, 10 m, 30 m, 100 m, 200 m, 300 m, and 500 m. The locations of the CTD casts used in generating the horizontal contours are shown by a + symbol. The 2-m depth was selected to represent surface conditions. The 10-m depth was selected to represent near-surface conditions because (1) the quality of data in the first few meters below the surface was not acceptable at some stations, and (2) localized, ephemeral conditions, related to factors such as strong surface heating and low vertical mixing that did not reflect the realistic, longer-term conditions of the region, were generally confined to the upper 5 m (refer to footnote 3). The 30-m depth was contoured to coincide with the standard midwater trawl depth during the surveys. The contour intervals are 0.5°C, 0.1, and 0.1 kg/m^3, respectively for depths 2-100 m. For the 200- to 500-m depths, the contour intervals were lowered to 0.1°C, 0.02, and 0.02 kg/m^3.

Appendix 8: Vertical sections

Vertical sections of temperature, salinity and density are presented for four cross-shelf transects off Pt. Reyes, the Farallones, Pescadero, and Davenport for DSJ9903. Station maps denote the location of each transect and the offshore extent of stations (marked by a +) used to generate plots for each sweep. The locations of CTD casts used in generating the vertical sections are shown on each section by a ◆. The contour intervals are 0.5°C for temperature, 0.1 for salinity, and 0.2 kg/m^3 for density.

Appendix 9: Dynamic Height Topography

Horizontal maps of dynamic height (0/500 m and 200/500 m) are presented for the three sweeps of DSJ9903. Contour intervals are 0.01 for the 0/500 m maps and 0.005 for the 200/500-m maps. The locations of the CTD casts used in generating the horizontal contours are shown by a + symbol. Geostrophic currents have higher dynamic heights on their right, and are proportional to the distance between lines of constant height.

Synopsis of Meteorological and Hydrographic Conditions

Large-scale Oceanic and Atmospheric Climate Patterns

Following the highly unusual conditions associated with the 1997-98 El Niño, the coastal ocean off central California underwent a dramatic change (Schwing et al., 2001). Very strong and persistent coastal upwelling dominated the first half of 1999, replacing warm upper ocean waters with record cool temperatures that extended well offshore. Coastal upwelling indices for central California were their highest on record (Schwing and Moore, 2000; Schwing et al., 2000). Coastal SSTs were 3-4°C below their seasonal mean in spring 1999, and about 10°C cooler than the region experienced in late 1997. Coastal sea level (CSL) anomalies in the northern California Current System (CCS) were the lowest in at least 65 years. A number of population and ecological changes observed in the CCS during this period have been linked to these unusual ocean conditions (Schwing and Moore, 2000; Schwing et al., 2000).

Through much of the 1999 upwelling season, unusually high large-scale atmospheric pressure in the North Pacific High led to vigorous anticyclonic wind stress, including anomalously strong upwelling-favorable winds along the North American west coast (Schwing et al., 2001). This pattern was strongest in early spring 1999. The anomalous wind pattern in 1999 is a typical feature of the La Niña events, and similar to that during the several years prior to the 1976 climate regime shift (Parrish et al., 2000).

A region of cooler than normal SST stretched from the western equatorial Pacific to Baja California, and along the North American west coast into the Gulf of Alaska (Schwing et al., 2001). Negative SST anomalies developed in this horseshoe-shaped region in late 1998 and intensified in spring 1999, particularly in the CCS. This pattern was similar to that seen during many past La Niña events. It also is similar to patterns of surface anomalies seen before the 1976 regime shift (Parrish et al., 2000) and more generally during the negative phase of the Pacific Decadal Oscillation (Mantua et al., 1997). Regional wind anomalies are thought to have led to the extreme upper ocean temperatures in the CCS, through Ekman processes (Schwing et al., 2001).

Regional Circulation and Water Mass Structure

Within the survey region, the 1999 pattern of very strong coastal upwelling is reflected in the time series of buoy alongshore winds and SSTs. Southward alongshore (upwelling-favorable) winds were particularly intense during sweep 1, and contributed to the coolest buoy SSTs of the year. Wind reversals occurred during sweeps 2 and 3. Despite these, buoy SSTs remained below normal during the entire cruise.

Because of strong upwelling winds prior to and during sweep 1, the upper ocean was unusually cool and saline (Table 1), particularly in the early portion of the survey. Conditions were extreme even compared to recent cool years (e.g., 1991, 1994). Upper ocean temperatures and salinities indicated upwelling from 100-150 m deeper than the usual spring levels. During sweep 1, the general current pattern was strongly southward, exceeding 50 cm/s in the upper 100 m. Near-surface offshore flows were as great as 50-75 cm/s south of Pillar Point. Upwelled water is typically confined to narrow jets flowing offshore from Pt. Reyes and Pt. Arena. Satellite imagery in May 1999 suggests the widespread offshore extension of upwelled water of over 200 km into the California Current. This broad, pervasive offshore transport represents a possible key mechanism for the large-scale loss of material, including larvae, from nearshore waters.

Wind reversals during sweeps 2 and 3 appear to have allowed the warmer, fresher water of the California Current to relax back toward the coast and into the outer portion of the survey region, based on hydrographic and satellite data. The front between coastal upwelled and California Current waters is clearer in the AVHRR images from these sweeps. A freshening of the mid-water column (100-300 m) over the continental slope was noted during sweep 2. This may have been due to an onshore transport of California Current water, especially around 37.5-38°N where the onshore flow at these depths was about 30 cm/s. The less saline signature is due to its higher content of subarctic water (Lynn et al., 1982). Cross-shelf transport features such as this may play an important role in larval retention. Unlike recent years, the freshwater signature of San Francisco Bay outflow was minimal in 1999, and confined to the upper few meters in the Gulf of the Farallones.

The Pioneer Seamount Eddy (cf. Baltz, 1997) was indicated in velocity, hydrography, and AVHRR data from sweeps 1 and 2, centered near 37.25°N 123.5°W. Its clockwise circulation, about 30-40 cm/s, is also captured by the more extensive ADCP survey for sweep 2, in higher dynamic heights in the upper 200 m, and by a depression of the density field in its center. The clockwise Monterey Bay Eddy also was present, and particularly clear below the mixed layer. These eddies were evident even below 200 m, where they interfered with the poleward alongshelf flow of the California Undercurrent (cf., sweep 2, ACDP at 175-225 m). The dynamic topography also indicates these features, superimposed on a background field that is 6-10 dynamic cm lower in the upper water column than in 1998. The 200/500-m heights were 1-2 dynamic cm higher than in 1998, indicating a stronger overall equatorward transport and a weaker Undercurrent in 1999.

The Pt. Reyes upwelling jet was enhanced during sweeps 2 and 3. By sweep 3, a pronounced Pt. Reyes eddy (cf. Baltz, 1997) was apparent. An important difference in the character of this northern eddy is its shallow focus. The upper water column became warmer and fresher in sweep 3 in association with the intensification of this eddy. By about 200 m, the rotational nature has been replaced by the Undercurrent signature in the offshore portion of the eddy. This may be due to the inshore side of the eddy encountering the continental shelf. The Pioneer eddy remained off the shelf, and so its signal is apparent deeper than 300 m.

In summary, spring 1999 was by all accounts a record period of coastal upwelling off central California. Compared to long-term climatologies for the region (Table 1), the upper ocean was extremely cool and saline. While these high upwelling rates may have benefitted biological production, the associated high offshore transports, particularly in the upper water column during May, may have resulted in significant losses of larvae and other material to the open ocean. Other characteristics of this unusual year and its effects on the California Current ecosystem are described in Schwing and Moore (2000) and Schwing et al. (2000).

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TABLE 1. Comparison of temperatures and salinities at 10 m and 30 m during 1999 rockfish surveys to previous years. The general range is shown, excluding outliers. 1987-96 means and ranges were determined by analysis of CTD data from annual rockfish CTD surveys for those years (Baltz 1997). Churgin and Halminski (1974) climatologies are averages for the region 36-38°N, 121-126°W for April-June. The 1998 ranges from Sakuma et al. (2000).

	10m T (°C)	10m S	30m T (°C)	30m S
1999 RANGE				
sweep 1	7.5-10.5	33.0-33.9	7.5-10.5	33.2-34.0
sweep 2	8.5-11.0	33.2-33.8	8.0-11.0	33.2-33.8
sweep 3	9.5-11.0	33.2-33.9	9.0-10.5	33.2-33.9
1998 RANGE	11.5-14.0	32.4-33.3	10.0-14.0	32.6-33.5
1987-96 MEAN	11.6	33.45	10.4	33.55
1987-96 RANGE			8.5-12.0	33.1-33.8
Churgin and Halminski (1974)	10.9	33.17	11.01	33.29

APPENDIX 1: LIST OF CTD STATIONS SUMMARIZED FROM CRUISE DSJ9903

DSJ9903 Sweep 1

CAST	DATE:TIME	LATITUDE	LONGITUDE	DEPTH(M)
1	10MAY99:00:41	37 47.7	122 51.7	56
2	10MAY99:01:48	37 42.1	122 54.6	56
3	10MAY99:20:40	36 50.8	121 59	87
4	10MAY99:23:10	36 45.8	121 52.2	76
5	11MAY99:00:03	36 44.6	121 58.7	348
6	11MAY99:02:27	36 42.6	121 54.6	86
7	11MAY99:03:16	36 38.5	121 51.4	36
8	11MAY99:06:00	36 39.7	121 57.6	92
9	11MAY99:07:25	36 40	122 9.8	1100
10	11MAY99:08:55	36 46.4	122 15.7	753
11	11MAY99:10:30	36 40	122 22.2	1700
12	11MAY99:12:15	36 46.3	122 28.2	2050
13	11MAY99:13:45	36 40.1	122 34.6	2360
14	11MAY99:15:50	36 34.1	122 40.9	2735
15	11MAY99:17:50	36 33.7	122 28.6	2858
16	11MAY99:19:30	36 33.8	122 16.3	2013
17	11MAY99:21:00	36 34.8	122 10.7	2300
18	11MAY99:23:55	36 34.2	122 1.1	440
19	12MAY99:01:00	36 38.8	122 3.2	994
20	12MAY99:03:44	36 40.5	122 5.5	1920
21	12MAY99:05:45	36 47.7	122 8.6	450
22	12MAY99:06:45	36 52.8	122 10	97
23	12MAY99:08:12	36 52.6	122 22	1200
24	12MAY99:10:05	36 52.8	122 34.5	1523
25	12MAY99:12:25	36 52.7	122 47.4	1128
26	12MAY99:14:05	36 52.5	122 59.3	2891
27	12MAY99:15:45	36 58.9	122 53	1374
28	12MAY99:17:20	37 5	122 47.2	621
29	12MAY99:18:55	37 4.9	122 34.8	113
30	12MAY99:20:13	37 5.1	122 22.4	60
31	12MAY99:21:10	36 58.9	122 17.5	87
32	13MAY99:00:02	36 56.8	122 20.9	171
33	13MAY99:01:09	36 58.9	122 25.5	404
34	13MAY99:04:42	36 56.2	122 34.1	1000
35	13MAY99:07:45	37 10.6	122 28.7	72
36	13MAY99:09:40	37 10.7	122 40.7	112
37	13MAY99:11:13	37 11	122 53	408
38	13MAY99:13:05	37 10.7	123 5.1	795
39	13MAY99:15:40	37 16.4	123 11.6	1194
40	14MAY99:09:45	37 22.5	122 28.3	32
41	14MAY99:11:22	37 22.5	122 40.5	85
42	14MAY99:13:00	37 22.3	122 53.1	190

CAST	DATE:TIME	LATITUDE	LONGITUDE	DEPTH(M)
43	14MAY99:14:42	37 22.4	123 5.2	754
44	14MAY99:20:40	37 16.3	122 33.5	83
45	14MAY99:23:31	37 14.5	122 37.6	95
46	15MAY99:01:13	37 16.6	122 48.9	175
47	15MAY99:04:20	37 14.9	122 57.3	437
48	15MAY99:07:25	37 30.8	122 59.2	200
49	15MAY99:09:10	37 30.9	123 11.2	1400
50	15MAY99:11:15	37 30.9	123 23.8	2324
51	15MAY99:13:10	37 30.9	123 36.1	3111
52	15MAY99:14:50	37 38.5	123 36.9	3294
53	15MAY99:16:20	37 46.1	123 36.1	3964
54	15MAY99:17:50	37 46.3	123 24.2	1395
55	15MAY99:20:30	37 53.2	123 30.2	1300
56	15MAY99:23:31	37 50.7	123 16.3	103
57	16MAY99:00:47	37 44.6	123 8.2	72
58	16MAY99:02:48	37 38.5	123 1.5	114
59	16MAY99:04:15	37 39.7	123 12.6	1251
60	16MAY99:09:05	38 1.6	123 17.8	116
61	16MAY99:10:35	38 1.7	123 29.9	131
62	16MAY99:12:03	38 1.6	123 42.4	2562
63	16MAY99:13:40	38 1.5	123 54.5	3477
64	16MAY99:15:35	38 10.1	124 7.2	5856
65	16MAY99:17:25	38 18.5	123 54.8	2805
66	16MAY99:18:52	38 18.7	123 42.3	1285
67	16MAY99:21:13	38 10	123 22.2	183
68	17MAY99:00:08	38 8.8	123 15.4	112
69	17MAY99:00:59	38 10	123 10	90
70	17MAY99:02:37	38 8.4	123 3.8	70
71	17MAY99:03:50	38 9.4	122 59.7	50

DSJ9903 Sweep 2

CAST	DATE:TIME	LATITUDE	LONGITUDE	DEPTH(M)
73	17MAY99:20:03	36 53	121 55.9	37
74	17MAY99:20:40	36 50.8	121 58.9	86
75	17MAY99:23:28	36 44.8	121 52.9	79
76	18MAY99:00:10	36 44.5	121 58.5	300
77	18MAY99:01:54	36 41.9	121 53.5	79
78	18MAY99:02:28	36 38.5	121 51.7	43
79	18MAY99:04:43	36 39.6	121 56.9	84
80	18MAY99:06:07	36 39.9	122 10.1	1080
81	18MAY99:07:27	36 46.4	122 16.1	791

CAST	DATE:TIME	LATITUDE	LONGITUDE	DEPTH(M)
82	18MAY99:09:04	36 39.4	122 23.1	1800
83	18MAY99:10:31	36 46.3	122 28.6	2100
84	18MAY99:11:51	36 40.1	122 34.6	2315
85	18MAY99:13:42	36 40.1	122 47	2763
86	18MAY99:15:09	36 33.8	122 40.6	2772
87	18MAY99:16:40	36 33.8	122 28.5	2741
88	18MAY99:18:09	36 33.7	122 16.1	2562
89	18MAY99:20:35	36 34.4	122 10.4	2300
90	18MAY99:23:14	36 35.5	122 4.2	790
91	19MAY99:00:09	36 38.9	122 3.1	1517
92	19MAY99:02:10	36 42.5	122 7.9	1537
93	19MAY99:05:13	36 47.4	122 9.4	599
94	19MAY99:06:44	36 52.9	122 10.1	96
95	19MAY99:08:04	36 52.8	122 22.3	1070
96	19MAY99:09:45	36 52.7	122 34.5	1610
97	19MAY99:11:30	36 52.7	122 47.3	2300
98	19MAY99:12:53	36 52.7	122 59.3	2714
99	19MAY99:14:25	36 59	122 53.1	1378
100	19MAY99:15:47	37 5.1	122 47	611
101	19MAY99:17:12	37 5.1	122 34.9	112
102	19MAY99:18:24	37 4.9	122 22.4	61
103	19MAY99:20:45	36 58.9	122 17.5	85
104	19MAY99:23:02	36 57.7	122 20.9	126
105	19MAY99:23:41	36 59	122 25.4	384
106	20MAY99:04:18	36 58	122 34.6	500
107	20MAY99:06:25	37 10.6	122 28.3	70
108	20MAY99:07:50	37 10.7	122 40.6	110
109	20MAY99:09:15	37 10.7	122 52.8	406
110	20MAY99:10:55	37 10.7	123 5.1	813
111	20MAY99:12:36	37 16.4	123 11.4	1190
112	20MAY99:14:10	37 22.3	123 5.2	765
113	20MAY99:15:36	37 22.4	122 53	190
114	20MAY99:16:55	37 22.4	122 40.7	86
115	20MAY99:18:04	37 22.4	122 28.4	32
116	20MAY99:20:44	37 17.1	122 34.1	83
117	20MAY99:23:12	37 14.7	122 38.1	94
118	21MAY99:00:39	37 16.6	122 49.2	180
119	21MAY99:03:28	37 14.8	122 57.8	456
120	21MAY99:05:15	37 13.1	123 1.9	706
121	21MAY99:08:51	37 30.8	122 59.3	210
122	21MAY99:10:25	37 30.8	123 11.3	1300
123	21MAY99:12:25	37 31	123 23.8	2416
124	21MAY99:14:19	37 31	123 36.2	2983
125	21MAY99:16:12	37 38.5	123 35.2	3300

CAST	DATE:TIME	LATITUDE	LONGITUDE	DEPTH(M)
126	21MAY99:18:49	37 46.2	123 36.3	2962
127	21MAY99:20:33	37 46.3	123 24	1281
128	21MAY99:23:35	37 42.5	122 55	54
129	22MAY99:01:33	37 47.1	122 51	54
130	22MAY99:02:29	37 51.7	122 45	37
131	22MAY99:06:55	38 1.9	123 5.4	64
132	22MAY99:08:17	38 1.8	123 17.7	118
133	22MAY99:09:34	38 1.6	123 30.1	140
134	22MAY99:10:53	38 1.6	123 42.2	2496
135	22MAY99:12:30	38 1.6	123 54.6	3480
136	22MAY99:14:26	38 10.1	124 7	3624
137	22MAY99:16:19	38 18.4	123 54.8	2836
138	22MAY99:18:16	38 18.5	123 42.6	1464
139	22MAY99:19:48	38 18.3	123 30.2	258
140	22MAY99:21:22	38 9.8	123 22.1	181
141	23MAY99:00:30	38 9.1	123 16.5	117
142	23MAY99:01:14	38 10	123 9.9	89
143	23MAY99:02:55	38 9	123 3.7	69
144	23MAY99:03:25	38 10.6	123 0.5	58
145	23MAY99:20:37	37 39.4	123 2.7	108
146	23MAY99:23:30	37 41.1	123 12.7	1164
147	24MAY99:00:33	37 44.6	123 8.2	72
148	24MAY99:03:10	37 53.5	123 19.6	97
149	24MAY99:05:16	37 55.2	123 30	1042

DSJ9903 Sweep 3

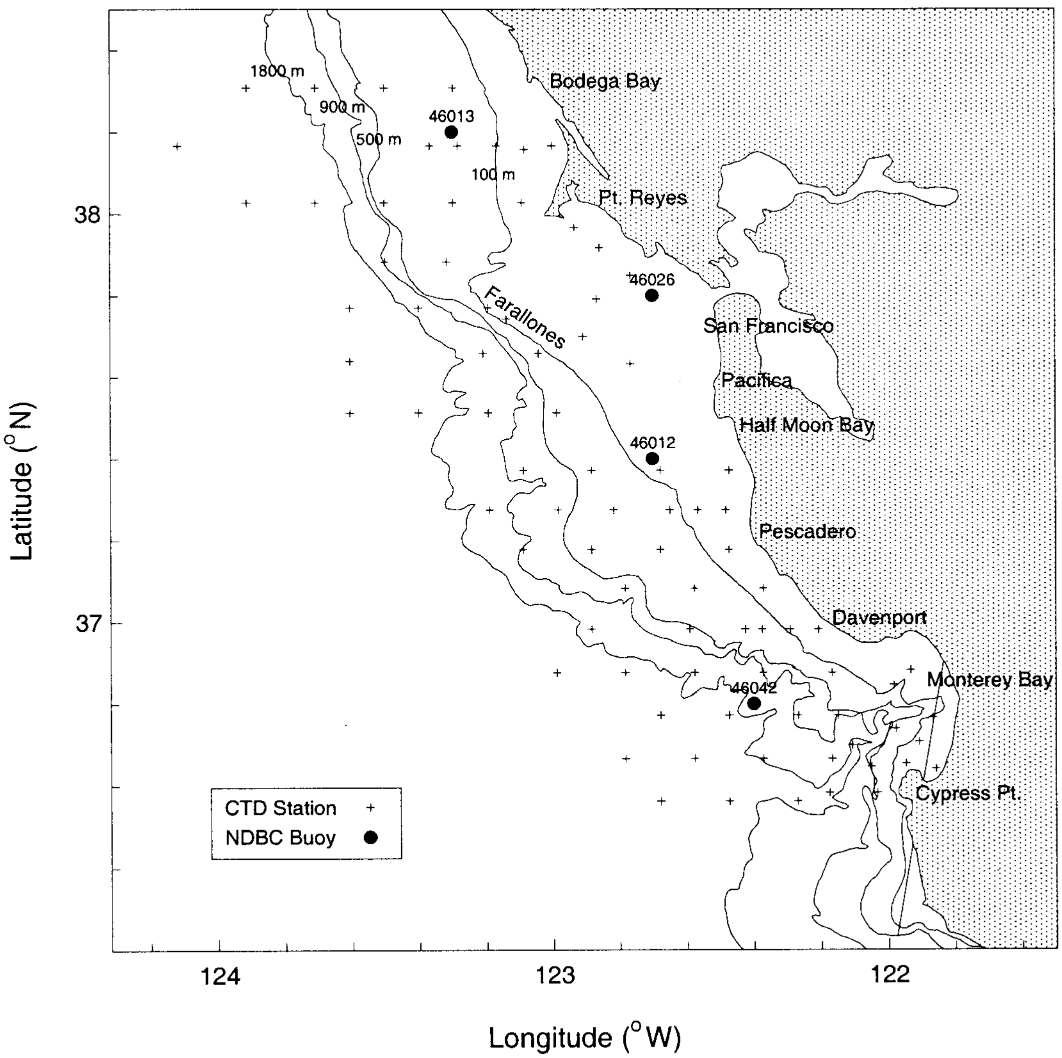
CAST	DATE:TIME	LATITUDE	LONGITUDE	DEPTH(M)
161	28MAY99:20:10	36 53	121 56	37
162	28MAY99:20:54	36 50.6	121 59.1	87
163	28MAY99:23:10	36 45.4	121 50.1	46
164	29MAY99:00:00	36 44.5	121 58.8	370
165	29MAY99:01:45	36 42.1	121 53.7	80
166	29MAY99:02:22	36 38.5	121 51.6	40
167	29MAY99:04:54	36 39.4	121 56.6	75
168	29MAY99:06:29	36 40	122 9.9	1110
169	29MAY99:08:02	36 46.4	122 16.1	804
170	29MAY99:09:30	36 40.1	122 22.5	1706
171	29MAY99:11:08	36 46.5	122 28.6	2104
172	29MAY99:12:37	36 40.2	122 34.6	2379
173	29MAY99:14:00	36 46.4	122 40.7	2090
174	29MAY99:15:25	36 40.1	122 46.9	2837

CAST	DATE:TIME	LATITUDE	LONGITUDE	DEPTH(M)
175	29MAY99:16:40	36 33.5	122 40.7	2780
176	29MAY99:18:06	36 33.9	122 28.5	2745
177	29MAY99:19:35	36 33.8	122 16.3	2560
178	29MAY99:20:39	36 35	122 10.5	2333
179	29MAY99:23:10	36 34.1	122 0.7	430
180	30MAY99:00:09	36 38.8	122 3.1	915
181	30MAY99:02:11	36 42	122 6.4	1922
182	30MAY99:04:08	36 46.1	122 7.1	830
183	30MAY99:06:25	36 52.9	122 9.9	93
184	30MAY99:07:42	36 52.5	122 22.8	915
185	30MAY99:09:13	36 52.9	122 34.7	1565
186	30MAY99:10:45	36 52.7	122 46.9	2324
187	30MAY99:12:22	36 52.7	122 59.3	2810
188	30MAY99:13:40	36 59.2	122 52.9	1344
189	30MAY99:14:50	37 5.2	122 46.9	617
190	30MAY99:16:20	37 4.9	122 34.6	111
191	30MAY99:17:34	37 5.1	122 22.3	55
192	30MAY99:20:35	36 59.1	122 17.4	82
193	30MAY99:22:44	36 58.9	122 24.1	130
194	30MAY99:23:05	36 58.9	122 25.7	620
195	31MAY99:01:24	36 59.3	122 35.8	384
196	31MAY99:03:12	36 59.3	122 45.4	966
197	31MAY99:07:11	37 10.7	122 28.3	66
198	31MAY99:08:24	37 10.7	122 40.9	110
199	31MAY99:09:38	37 10.9	122 53.2	418
200	31MAY99:11:33	37 10.7	123 5.5	845
201	31MAY99:12:52	37 16.5	123 11.4	1254
202	31MAY99:14:07	37 22.5	123 5.2	755
203	31MAY99:15:43	37 22.4	122 52.9	187
204	31MAY99:17:03	37 22.3	122 40.6	83
205	31MAY99:18:17	37 22.3	122 28.2	28
206	31MAY99:20:30	37 16.4	122 34.1	82
207	31MAY99:22:57	37 13.8	122 40.1	98
208	31MAY99:23:42	37 13.9	122 46.6	171
209	01JUN99:02:04	37 16.7	122 59.4	532
210	01JUN99:04:47	37 16.5	123 7.6	804
211	01JUN99:06:48	37 30.8	122 59.4	213
212	01JUN99:08:08	37 30.7	123 11.8	1357
213	01JUN99:09:43	37 30.8	123 23.9	2433
214	01JUN99:11:22	37 30.9	123 36.2	3330
215	01JUN99:13:00	37 38.8	123 36.3	3312
216	01JUN99:14:17	37 46.2	123 36.4	2882
217	01JUN99:15:49	37 46.1	123 24.2	1429
218	01JUN99:17:20	37 46.3	123 11.6	108

CAST	DATE:TIME	LATITUDE	LONGITUDE	DEPTH(M)
219	01JUN99:20:30	37 39.6	123 2.4	99
220	01JUN99:23:19	37 39	123 11.6	1144
221	02JUN99:00:28	37 44.6	123 8.3	73
222	02JUN99:03:00	37 52.7	123 18.3	104
223	02JUN99:05:08	37 51.7	123 28.5	1184
224	02JUN99:07:05	38 1.6	123 30.1	141
225	02JUN99:08:26	38 1.8	123 42.5	2448
226	02JUN99:09:57	38 1.6	123 54.9	3550
227	02JUN99:12:02	38 10.1	124 6.8	3633
228	02JUN99:13:47	38 18.4	123 54.7	2800
229	02JUN99:15:13	38 18.6	123 42.1	1365
230	02JUN99:16:37	38 18.5	123 29.9	248
231	02JUN99:17:53	38 18.6	123 17.8	105
232	02JUN99:20:33	38 10	123 22.3	184
233	02JUN99:23:00	38 9.7	123 15.8	111
234	02JUN99:23:41	38 10	123 10.1	88
235	03JUN99:01:26	38 9.6	123 3.6	69
236	03JUN99:01:55	38 10.3	123 0.7	57
237	03JUN99:04:00	38 1.6	123 5.6	62
238	03JUN99:05:22	38 1.6	123 17.8	116
239	03JUN99:21:14	37 42	122 54.4	55
240	03JUN99:23:24	37 46.5	122 50	52

APPENDIX 2: DSJ9903 CTD STATIONS AND BATHYMETRIC MAP OF SURVEY REGION WITH LOCATIONS OF THE NDBC BUOYS

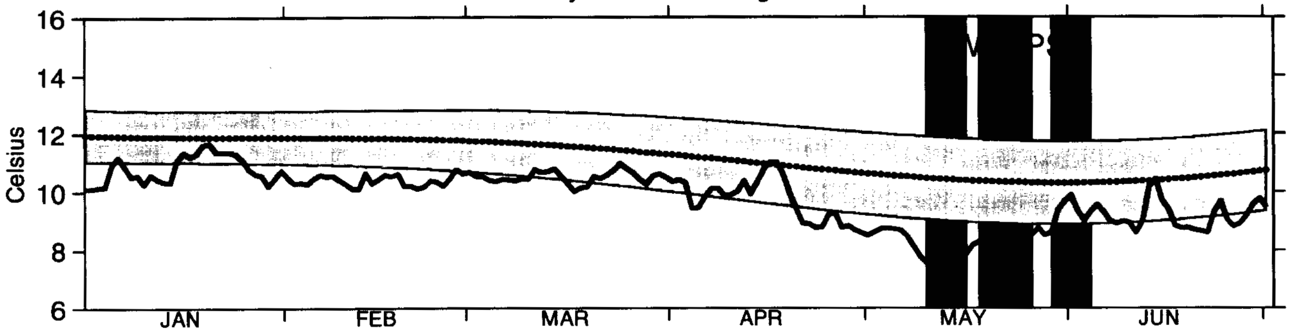
Standard CTD Station Locations



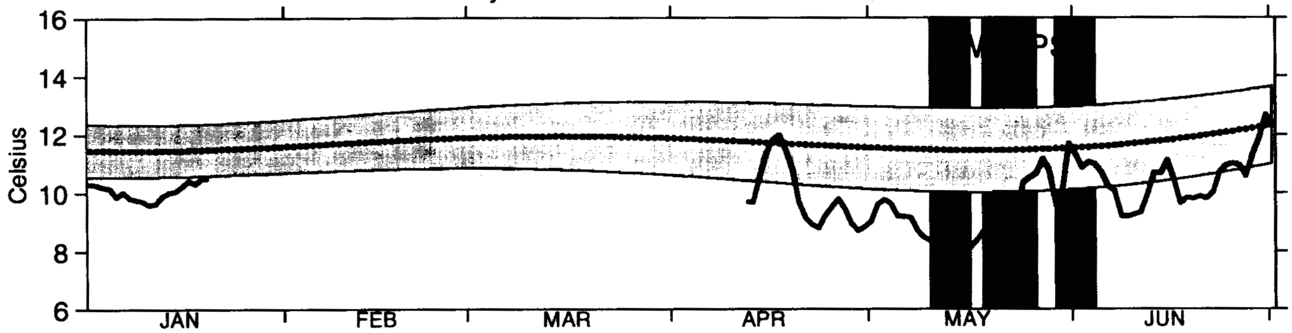
APPENDIX 3: METEOROLOGICAL TIME SERIES

Sea Surface Temperatures from NOAA/NDBC Buoys ~1999

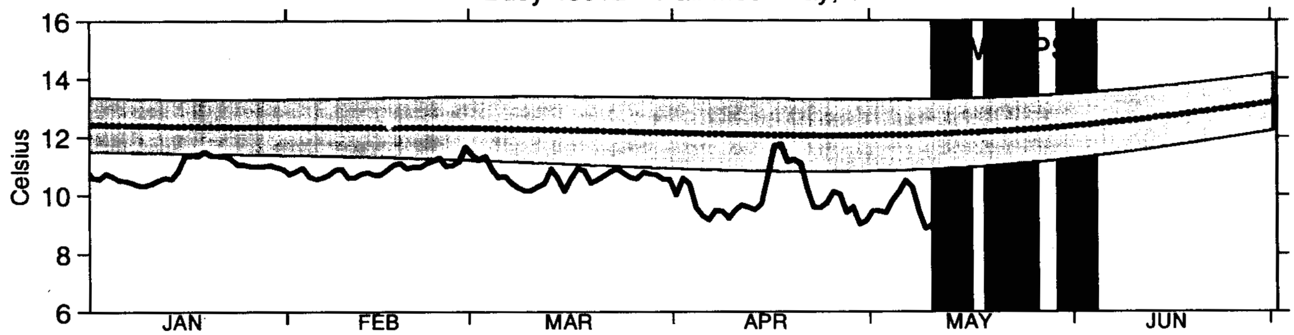
Buoy 46013 ~ Bodega, CA



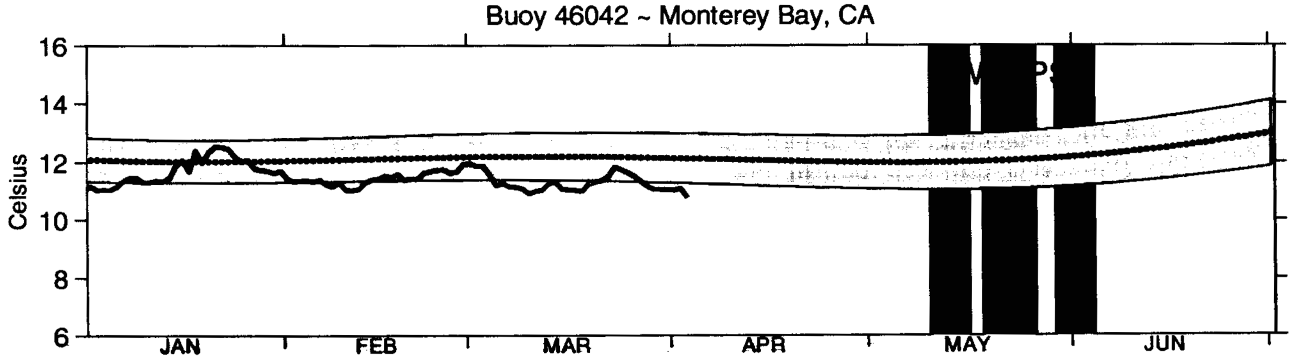
Buoy 46026 ~ Gulf of the Farallones, CA



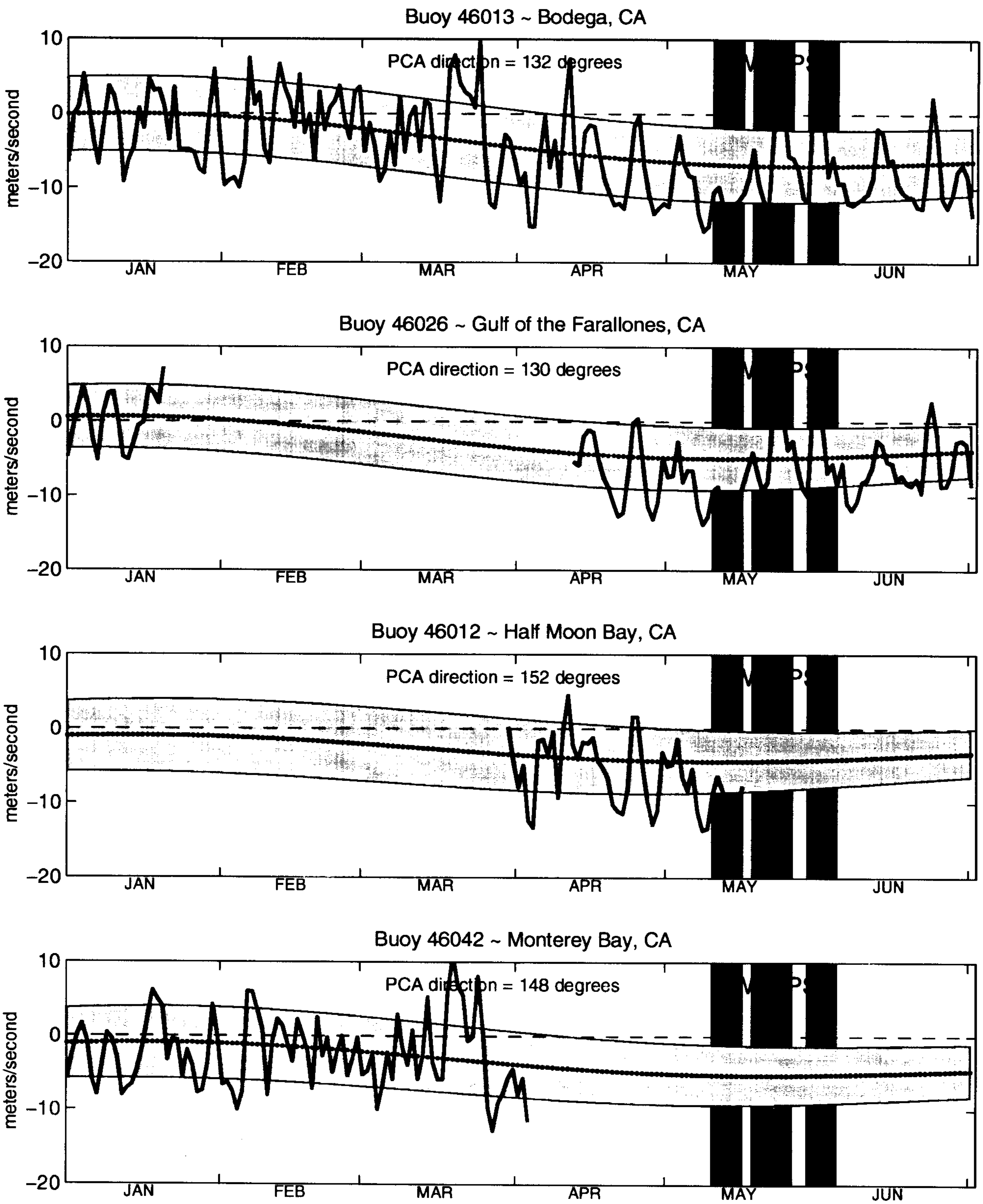
Buoy 46012 ~ Half Moon Bay, CA



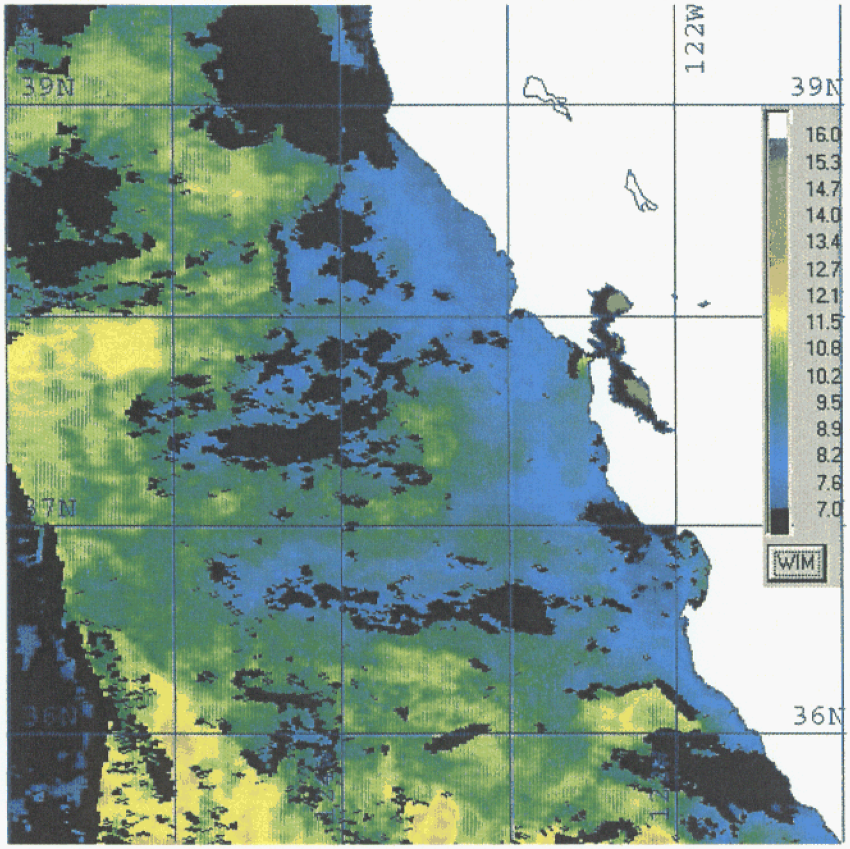
Buoy 46042 ~ Monterey Bay, CA



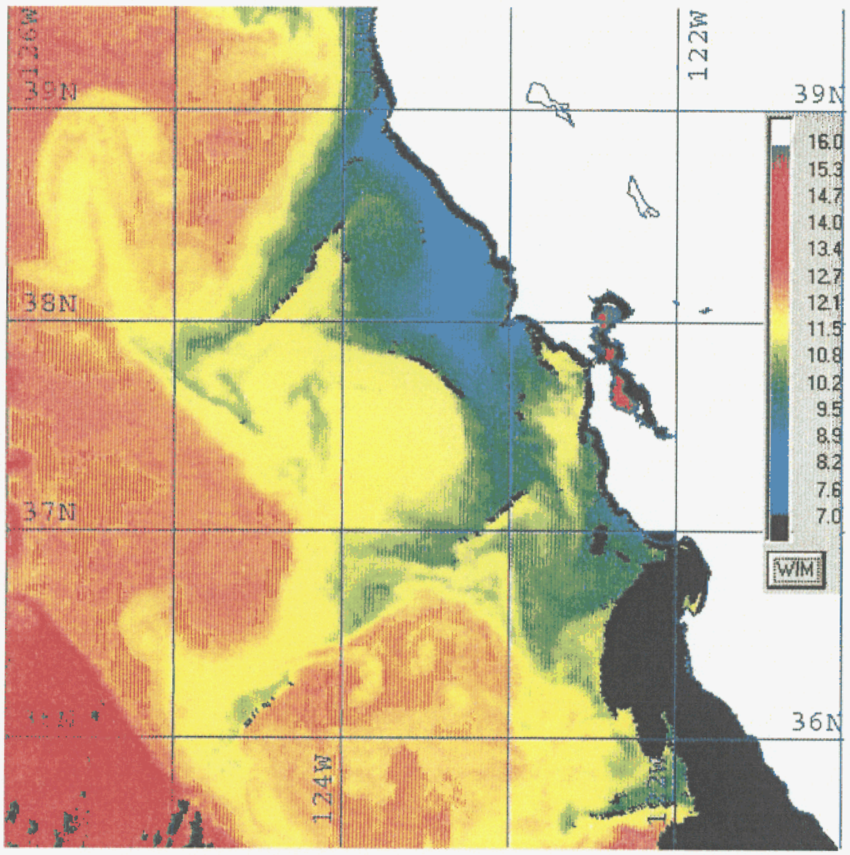
Alongshore Winds from NOAA/NDBC Buoys ~ 1999



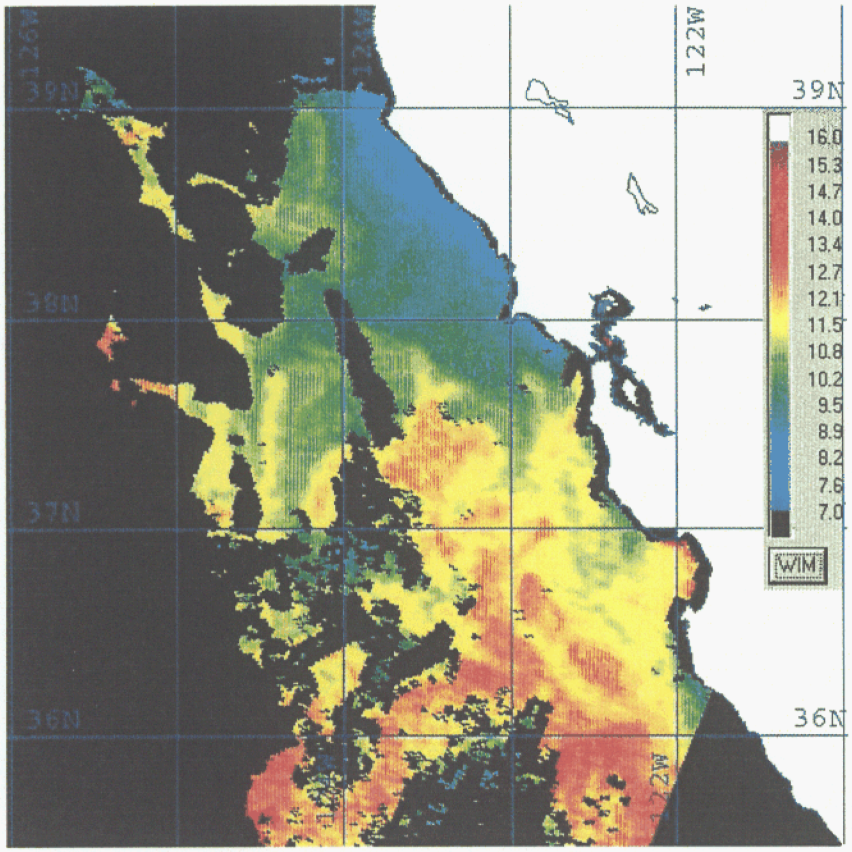
APPENDIX 4: AVHRR SATELLITE IMAGES OF MULTICHANNEL SST



AVHRR Satellite Image Multi-channel SST
May 10, 1999 1112 hrs.



AVHRR Satellite Image Multi-channel SST
May 22, 1999 1218 hrs.

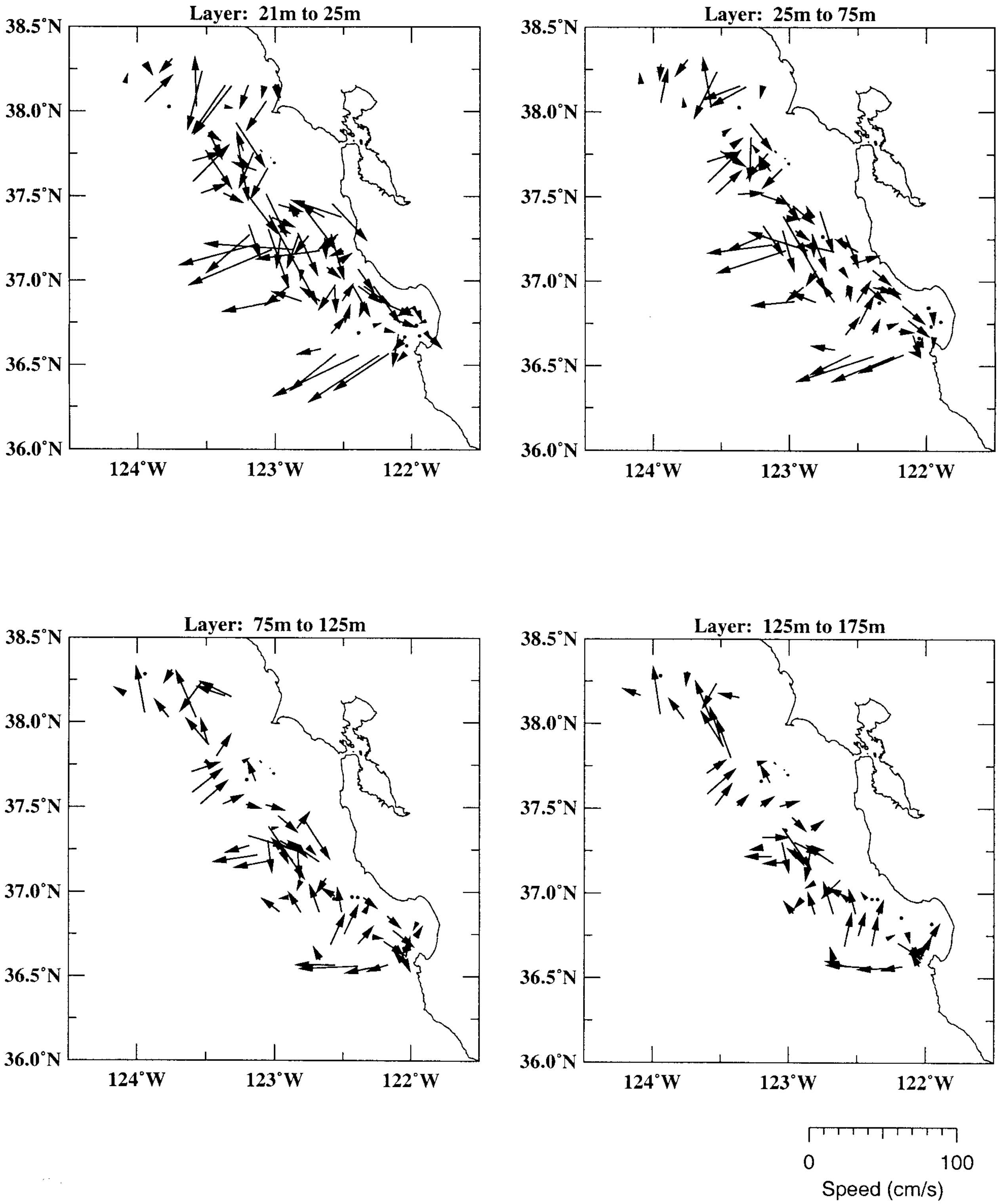


AVHRR Satellite Image Multi-channel SST
June 7, 1999 1240 hrs.

APPENDIX 5: ADCP DATA

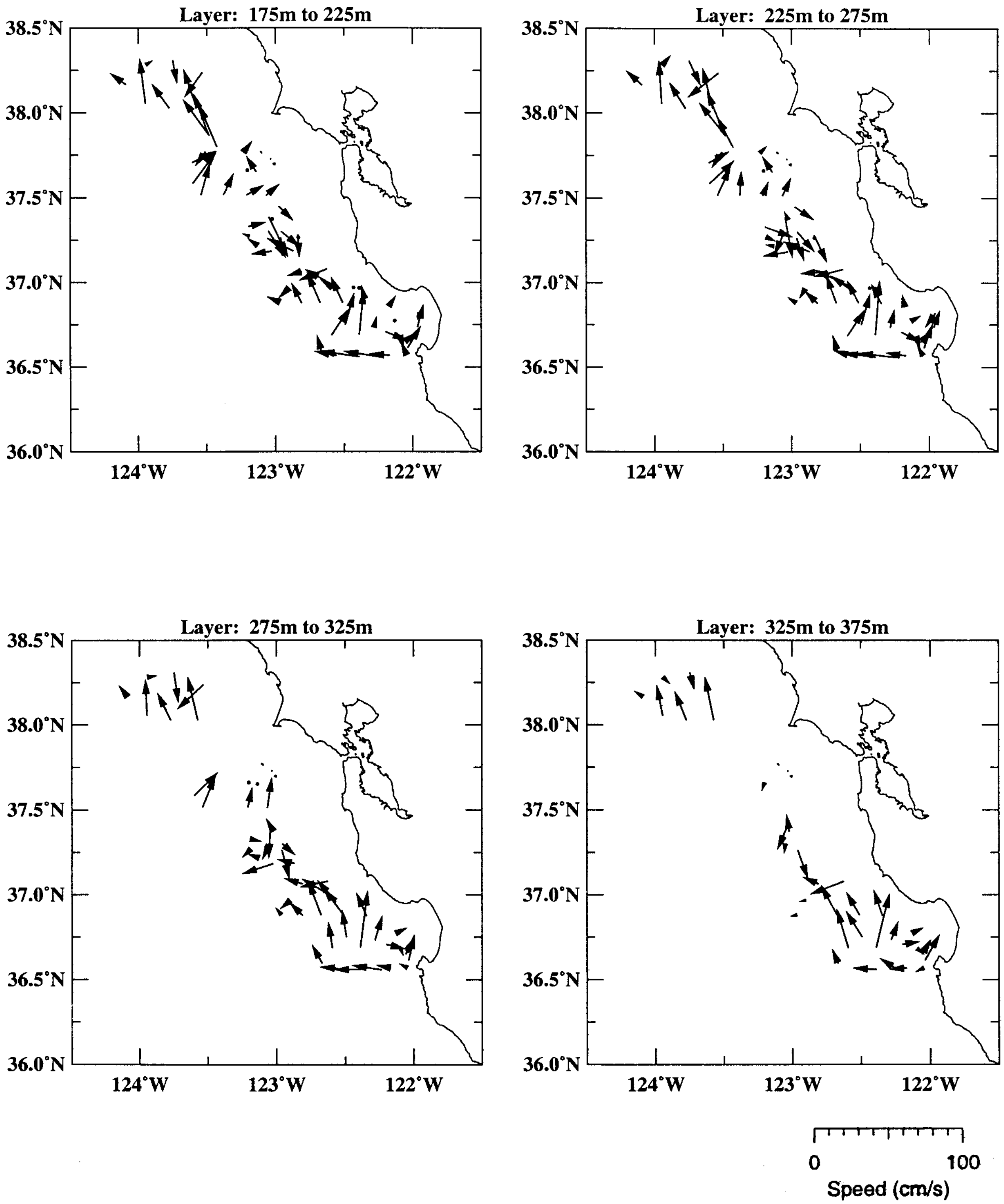
CRUISE DSJ9903 -- ADCP

Sweep 1



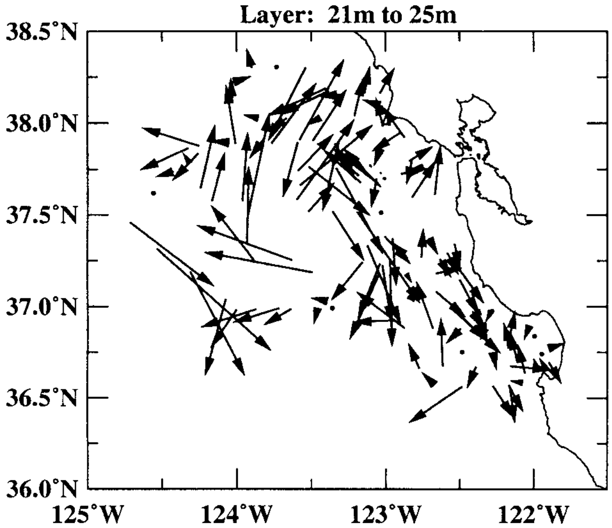
CRUISE DSJ9903 -- ADCP

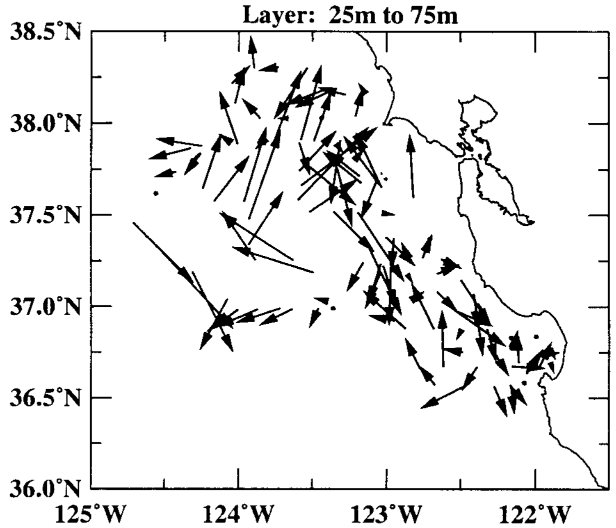
Sweep 1

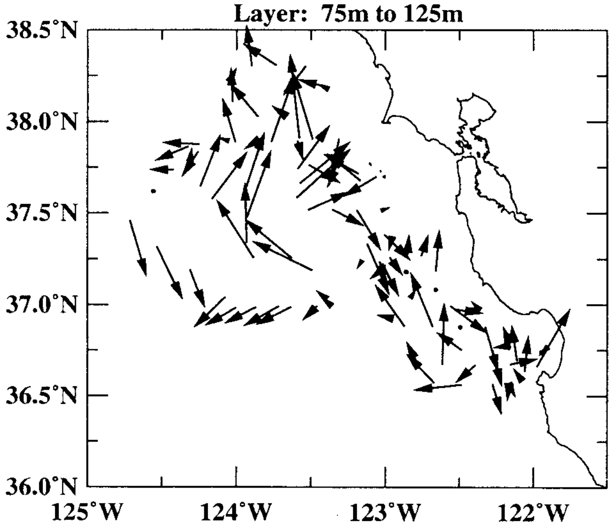


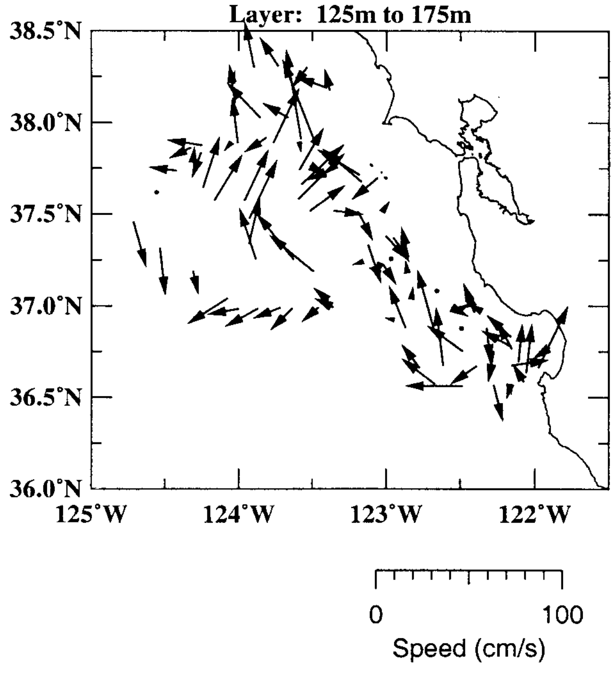
CRUISE DSJ9903 -- ADCP

Sweep 2



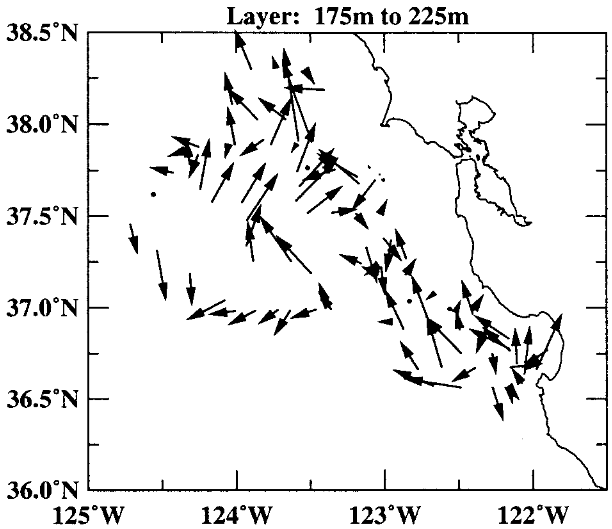


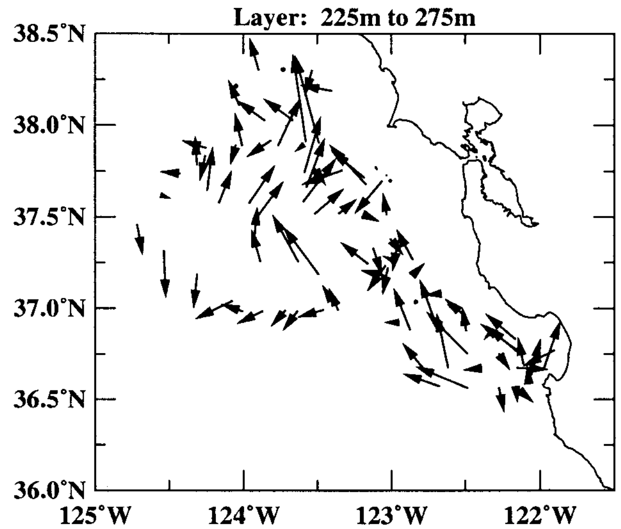


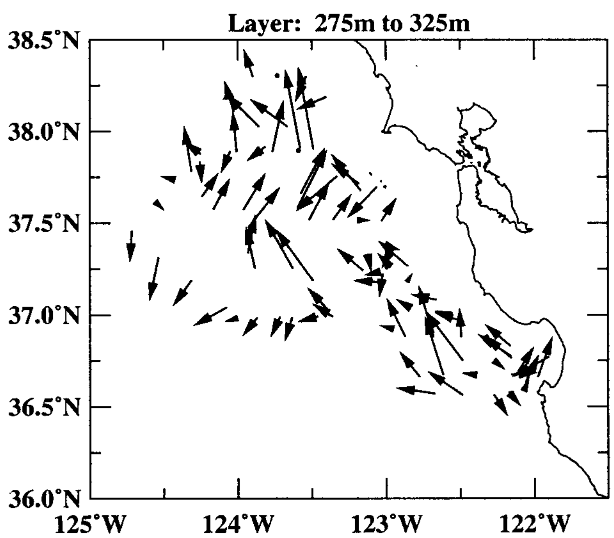


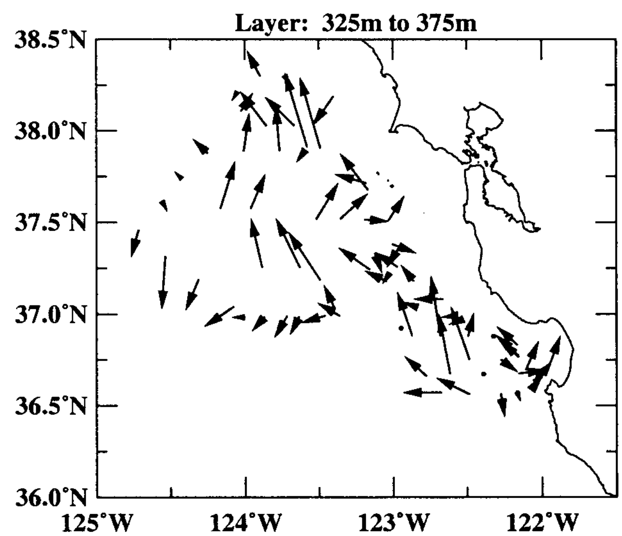
CRUISE DSJ9903 -- ADCP

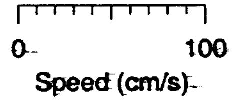
Sweep 2





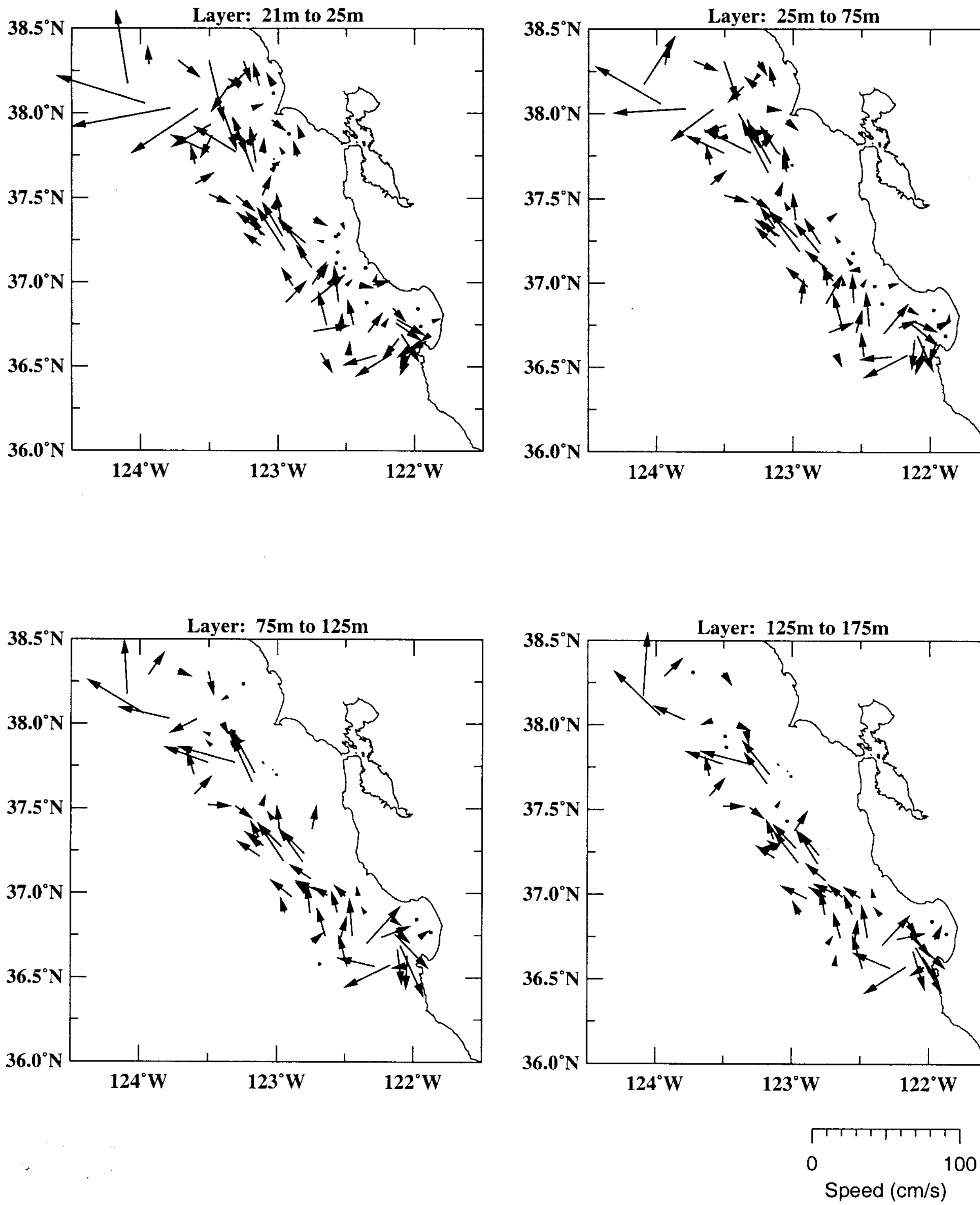






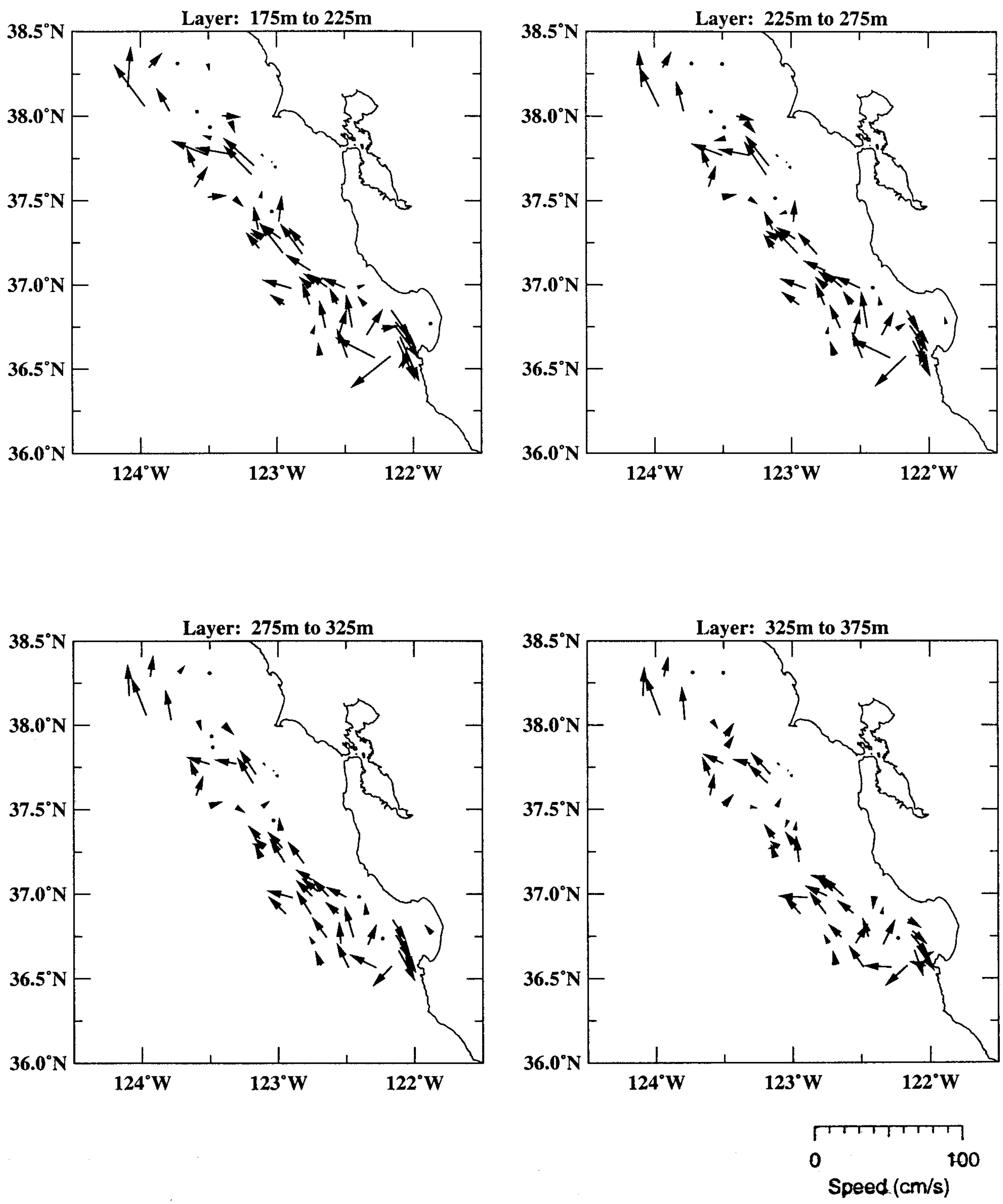
CRUISE DSJ9903 -- ADCP

Sweep 3



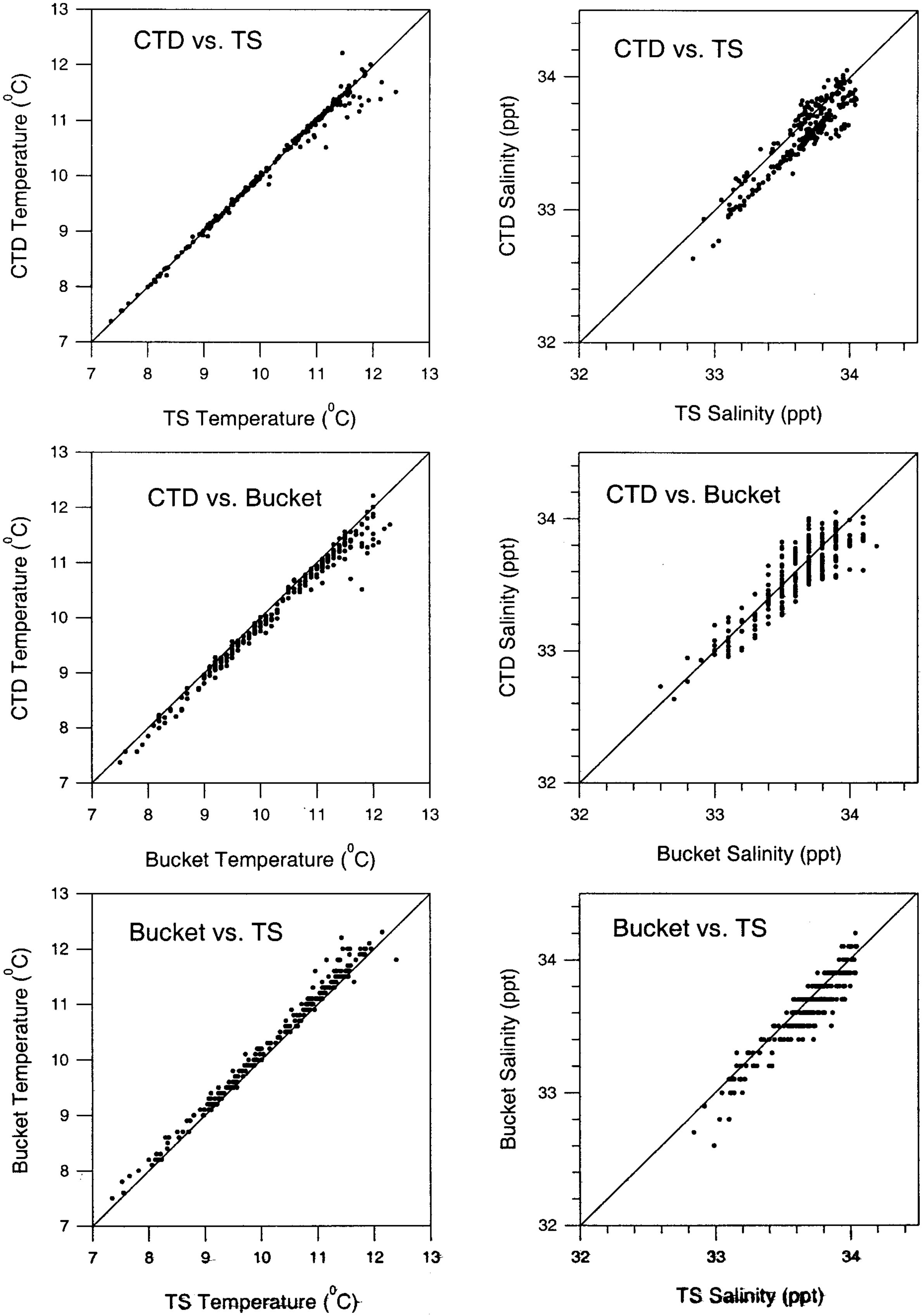
CRUISE DSJ9903 -- ADCP

Sweep 3

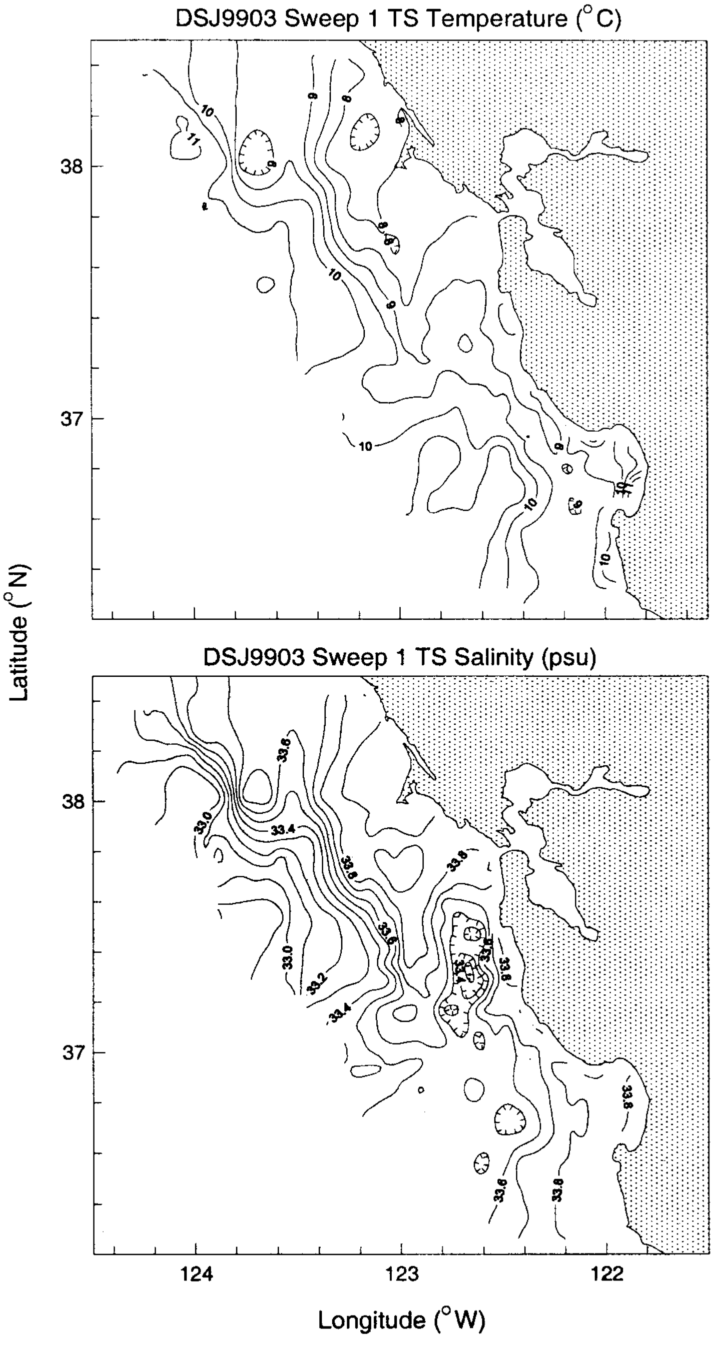


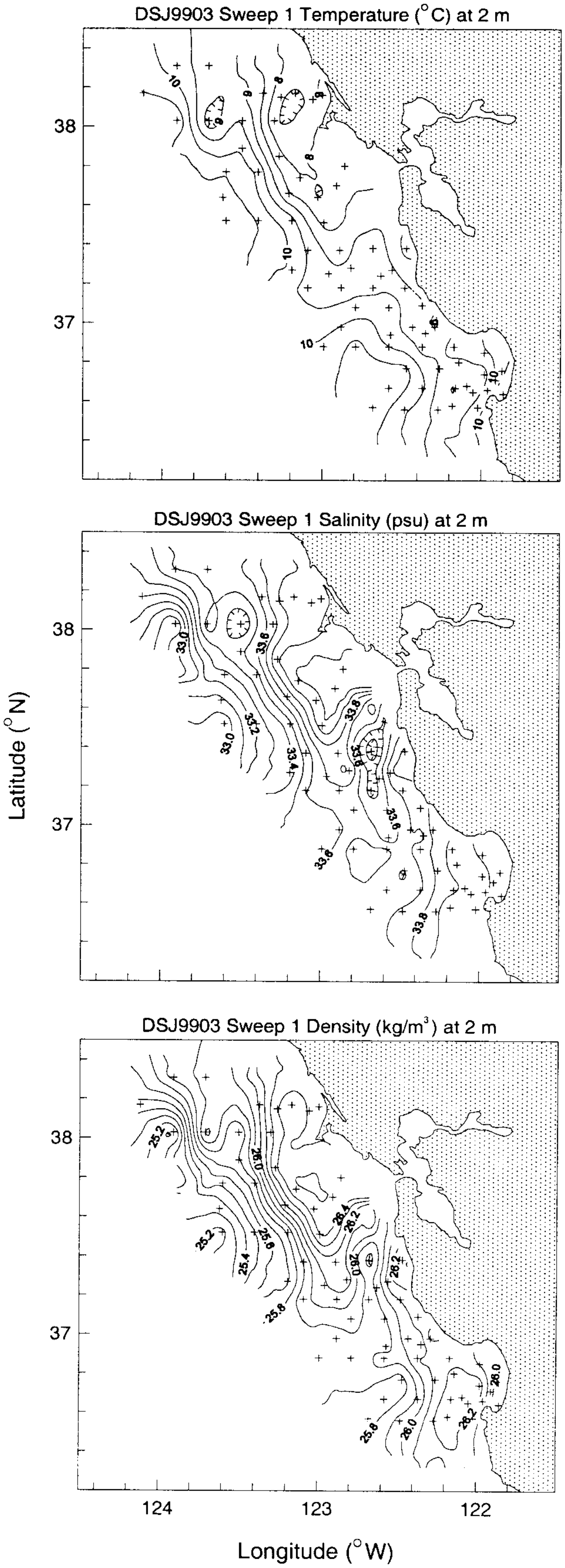
APPENDIX 6: REGRESSION COMPARISONS OF CTD, TS, AND BUCKET FOR DSJ9903

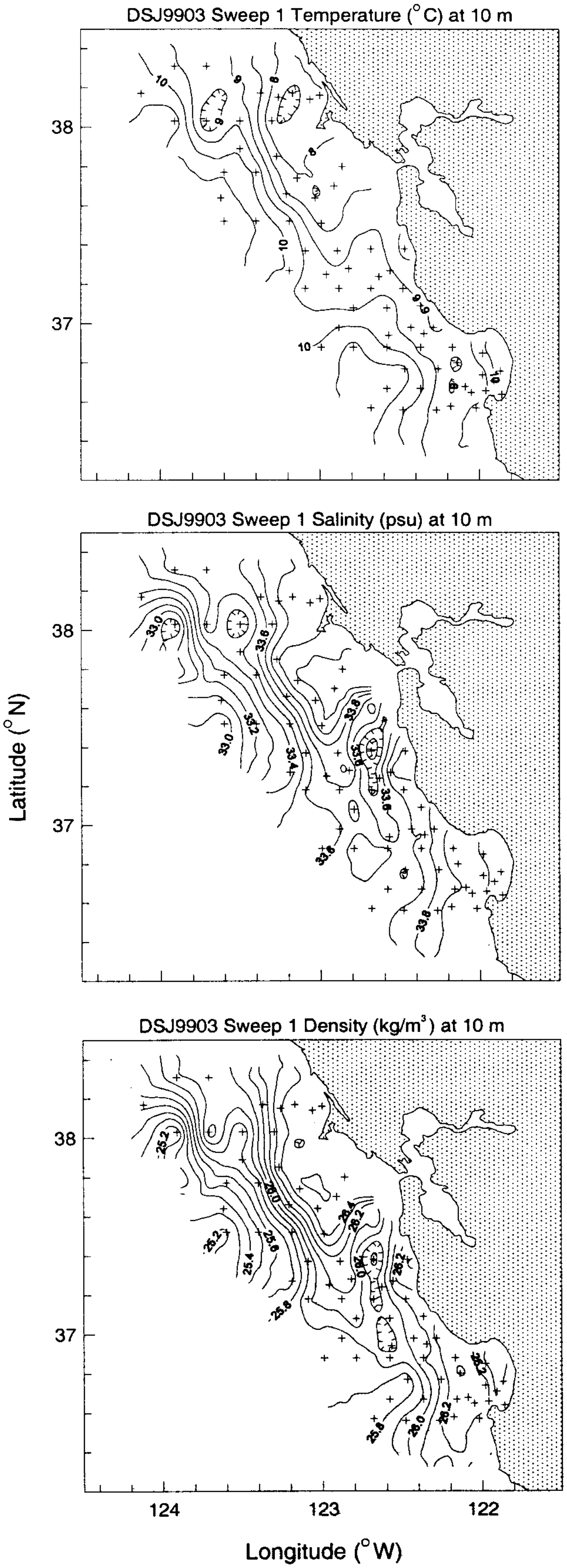
DSJ9903

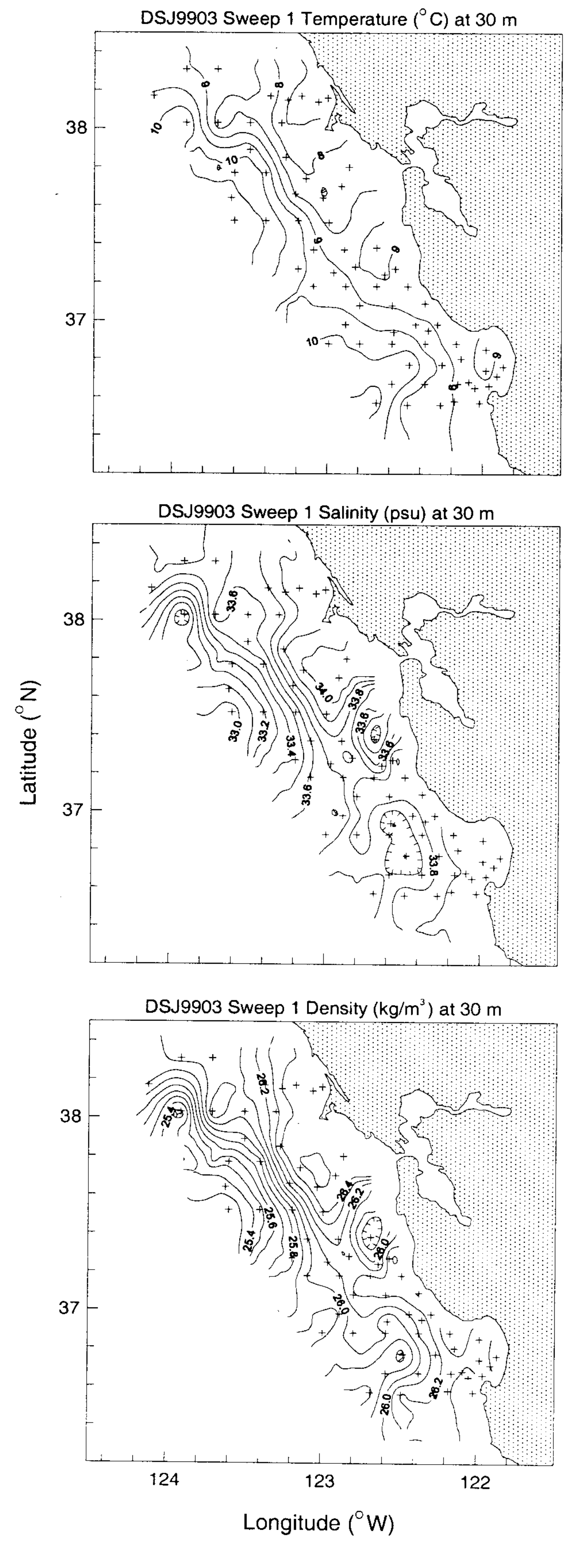

CTD vs. TS
CTD Temperature (°C)
TS Temperature (°C)
7
8
9
10
11
12
13
CTD vs. TS
CTD Salinity (ppt)
TS Salinity (ppt)
32
33
34
CTD vs. Bucket
CTD Temperature (°C)
Bucket Temperature (°C)
CTD vs. Bucket
CTD Salinity (ppt)
Bucket Salinity (ppt)
Bucket vs. TS
Bucket Temperature (°C)
TS Temperature (°C)
Bucket vs. TS
Bucket Salinity (ppt)
TS Salinity (ppt)

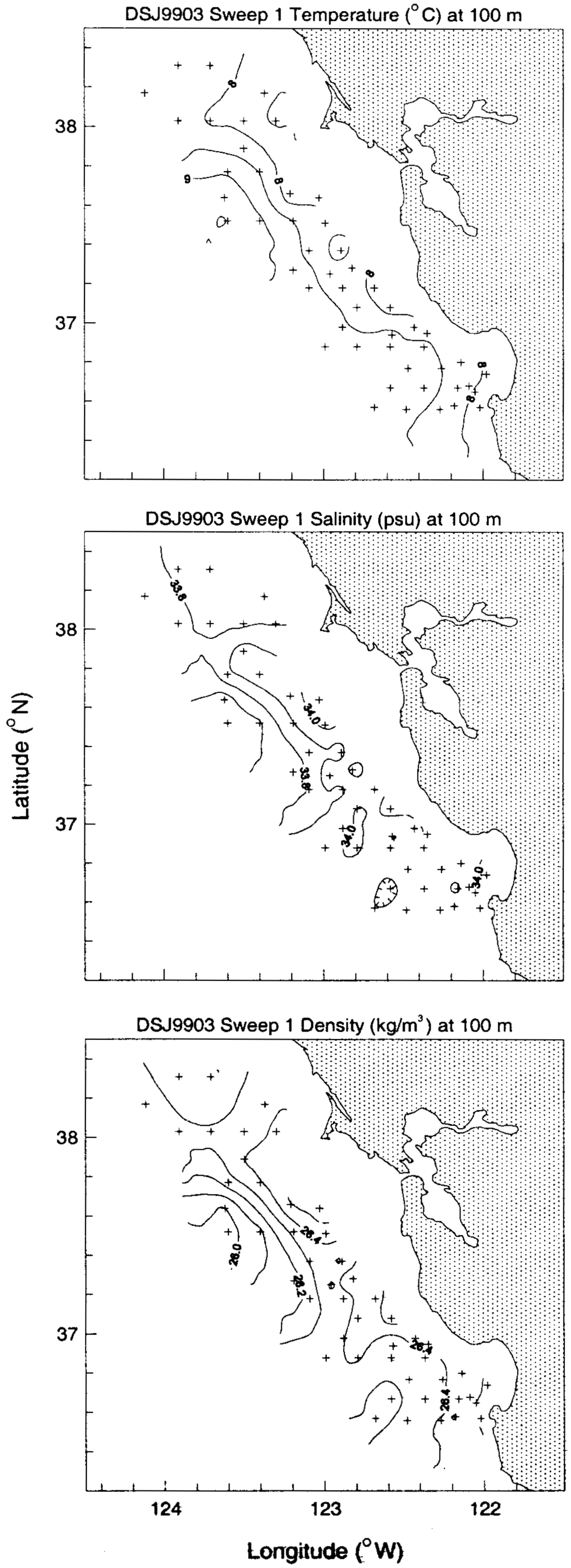
APPENDIX 7.1: HORIZONTAL MAPS OF CTD AND TS FOR DSJ9903, SWEEP 1

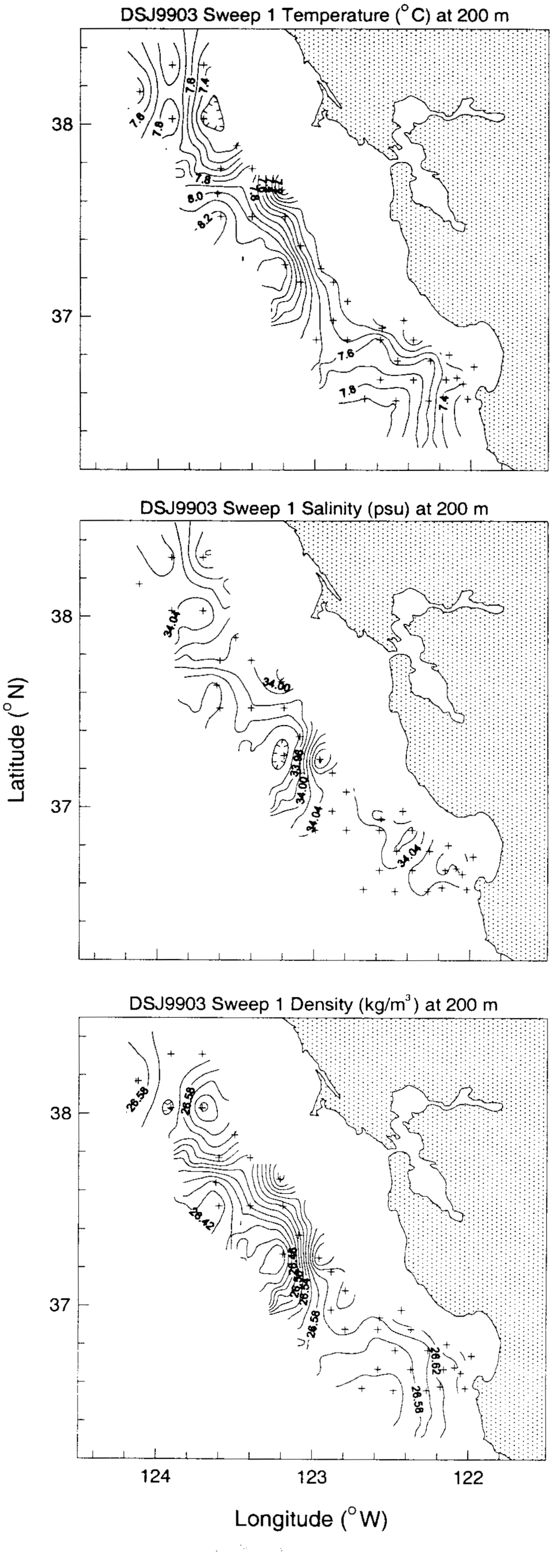

DSJ9903 Sweep 1 TS Temperature (°C)
DSJ9903 Sweep 1 TS Salinity (psu)
Latitude (°N)
Longitude (°W)
38
37
124
123
122
10
11
9
8
33.0
33.2
33.4
33.6
33.8

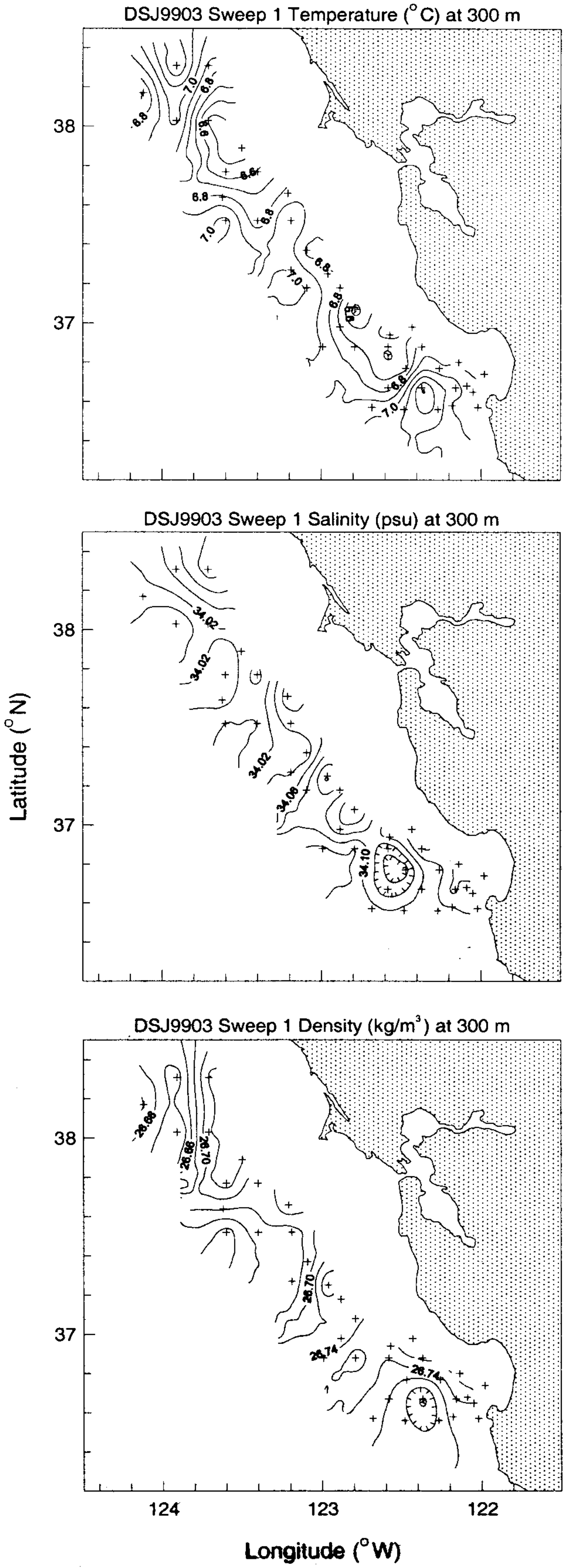

DSJ9903 Sweep 1 Temperature (°C) at 2 m
DSJ9903 Sweep 1 Salinity (psu) at 2 m
DSJ9903 Sweep 1 Density (kg/m³) at 2 m
Latitude (°N)
Longitude (°W)
38
37
124
123
122

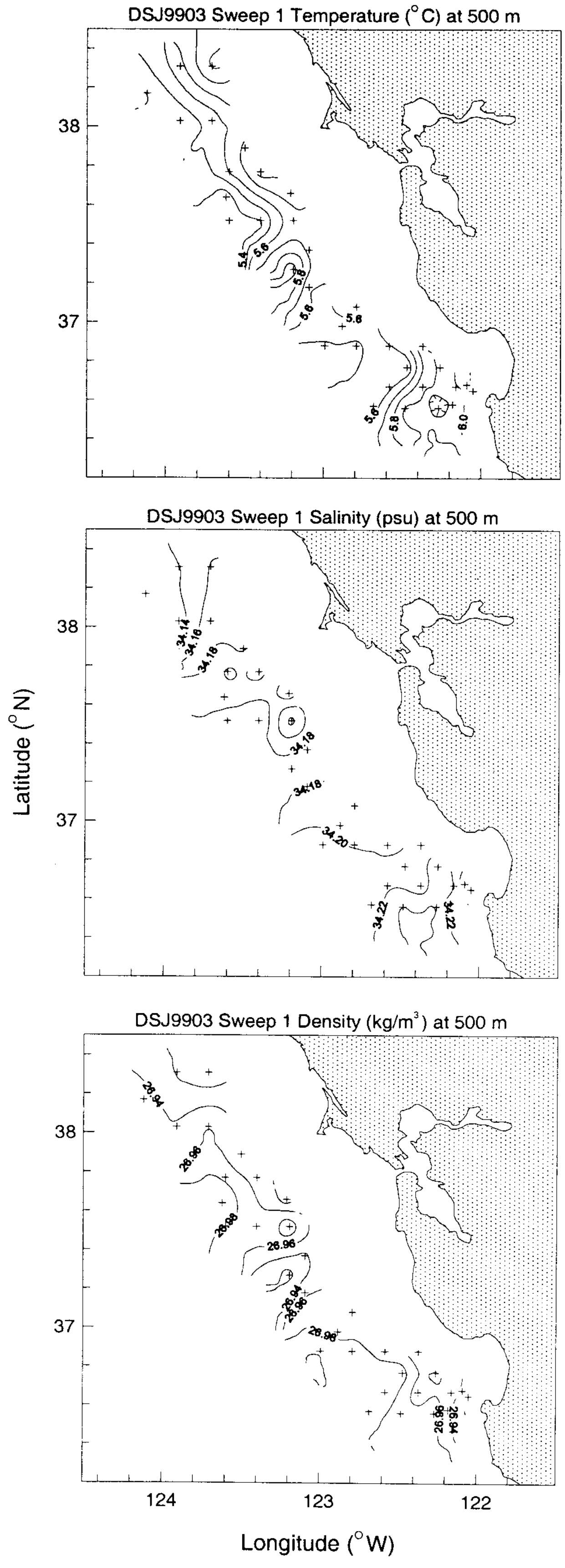

DSJ9903 Sweep 1 Temperature (°C) at 10 m
DSJ9903 Sweep 1 Salinity (psu) at 10 m
DSJ9903 Sweep 1 Density (kg/m³) at 10 m
Latitude (°N)
Longitude (°W)
38
37
124
123
122


DSJ9903 Sweep 1 Temperature (°C) at 30 m
DSJ9903 Sweep 1 Salinity (psu) at 30 m
DSJ9903 Sweep 1 Density (kg/m³) at 30 m
Latitude (°N)
38
37
124
123
122
Longitude (°W)

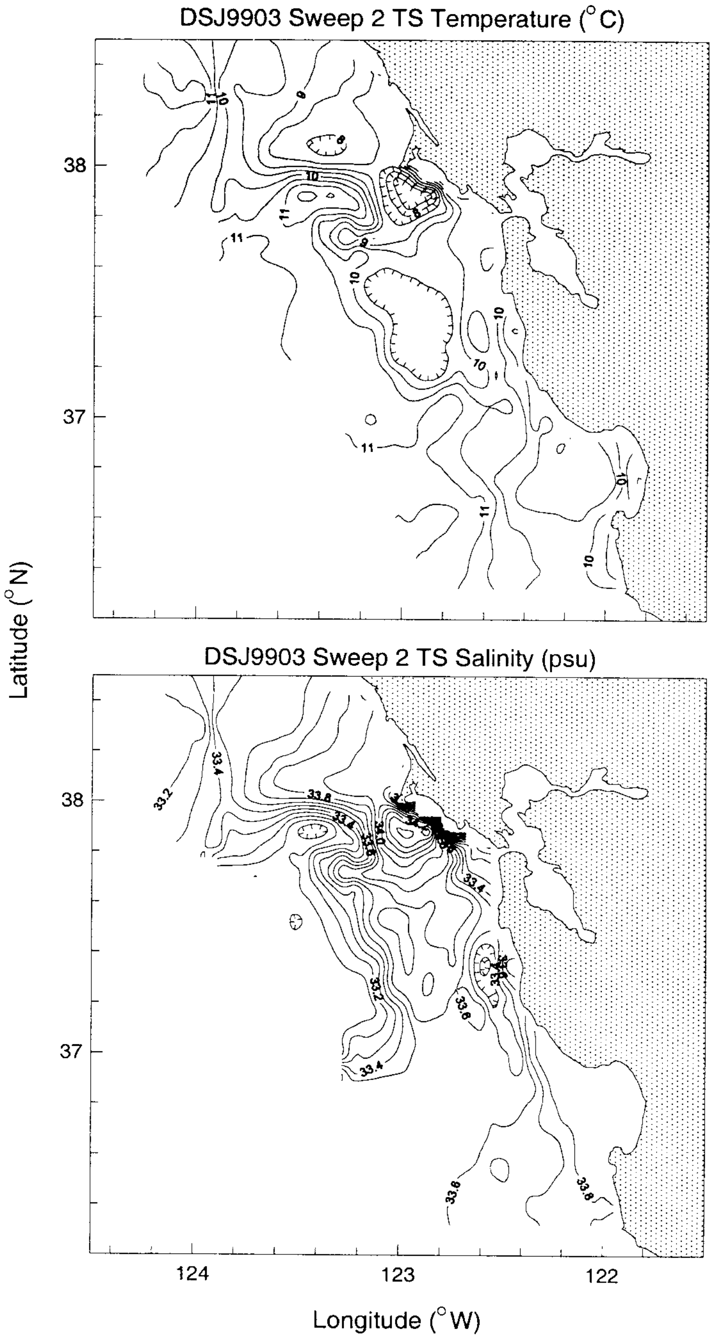

DSJ9903 Sweep 1 Temperature (°C) at 100 m
DSJ9903 Sweep 1 Salinity (psu) at 100 m
DSJ9903 Sweep 1 Density (kg/m³) at 100 m
38
37
124
123
122
Latitude (°N)
Longitude (°W)
9
8
33.8
34.0
26.0
26.2
26.4

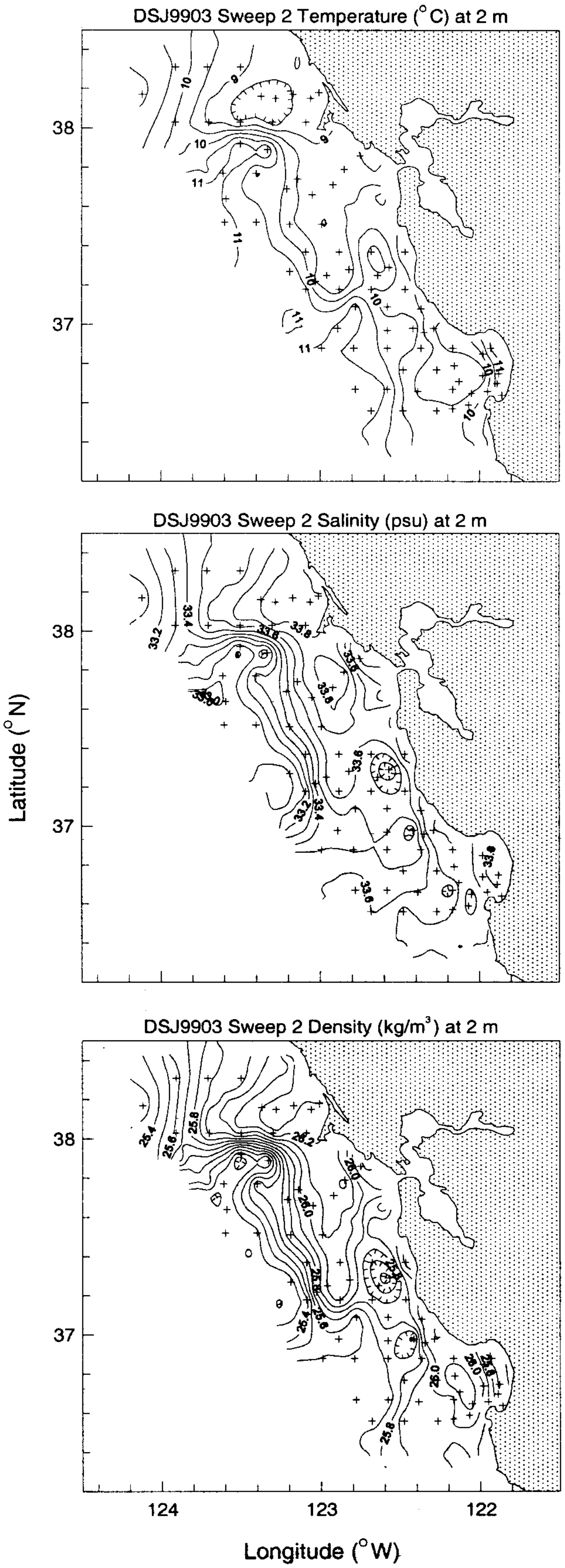

DSJ9903 Sweep 1 Temperature (°C) at 200 m
7.8
7.4
8.0
8.2
7.6
DSJ9903 Sweep 1 Salinity (psu) at 200 m
34.04
34.00
33.98
DSJ9903 Sweep 1 Density (kg/m³) at 200 m
26.58
26.42
26.62
Latitude (°N)
38
37
124
123
122
Longitude (°W)

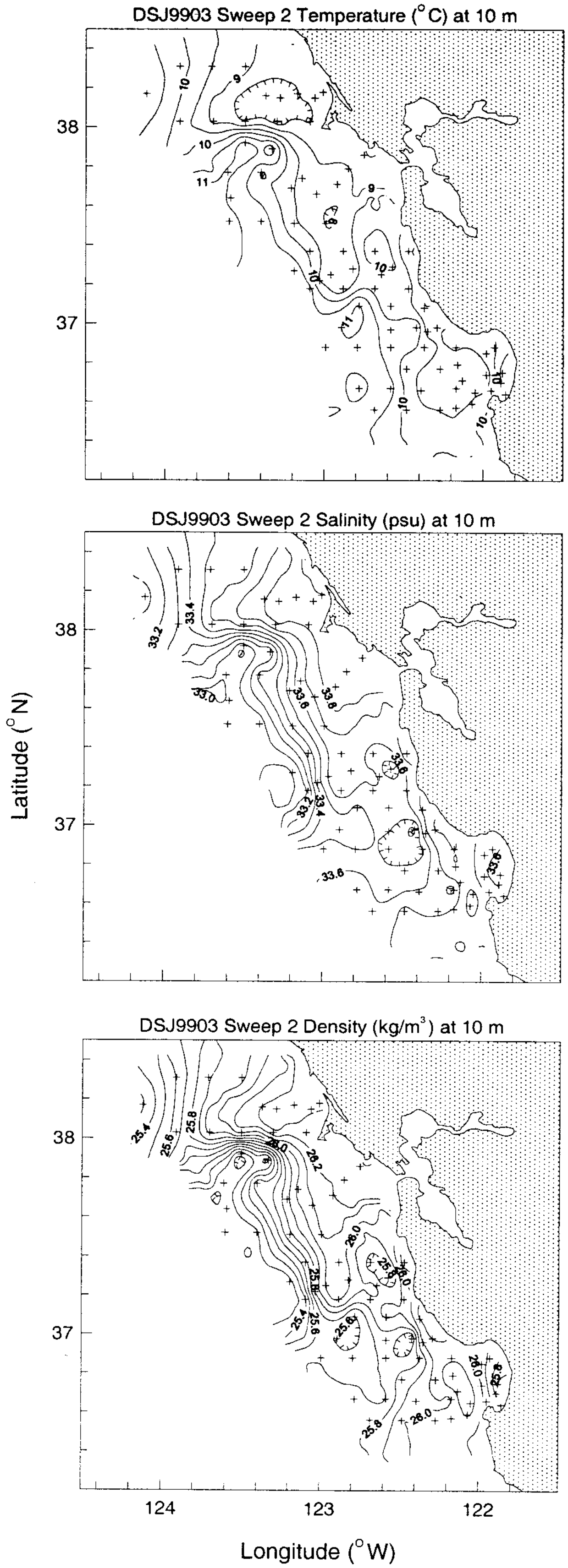

DSJ9903 Sweep 1 Temperature (°C) at 300 m
DSJ9903 Sweep 1 Salinity (psu) at 300 m
DSJ9903 Sweep 1 Density (kg/m³) at 300 m
Latitude (°N)
Longitude (°W)
38
37
124
123
122
7.0
6.8
34.02
34.06
34.10
26.68
26.70
26.74

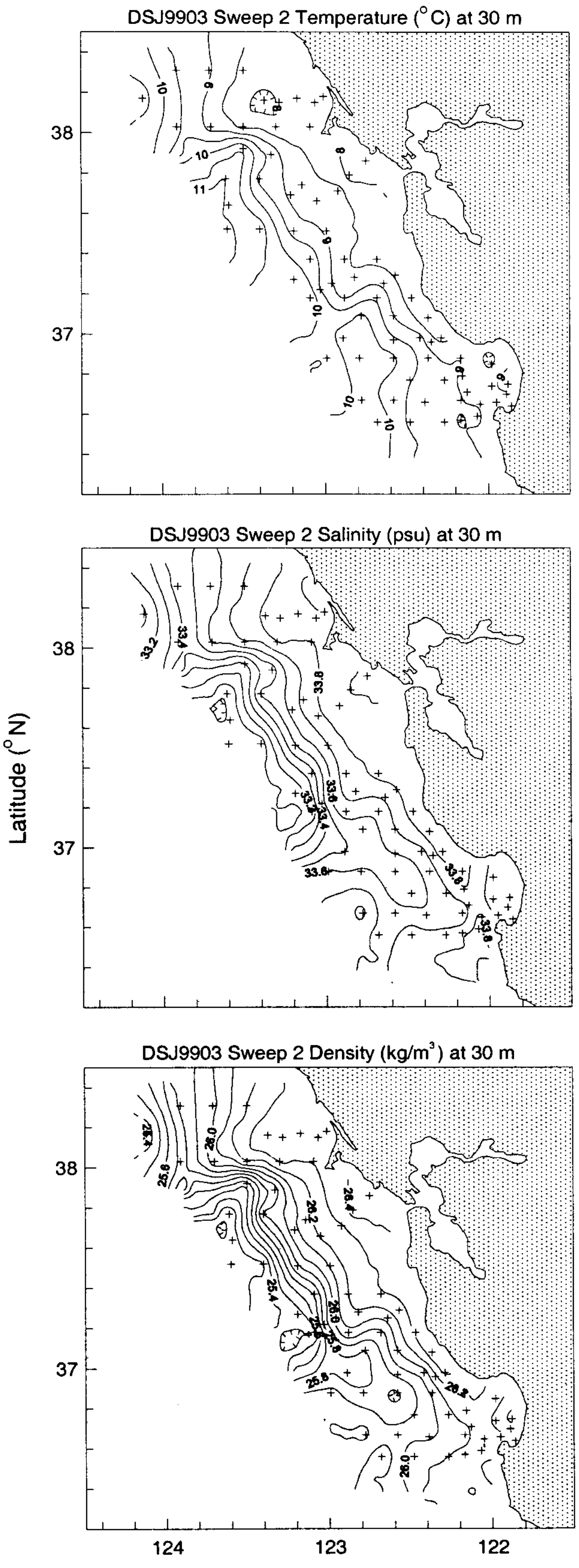

DSJ9903 Sweep 1 Temperature (°C) at 500 m
DSJ9903 Sweep 1 Salinity (psu) at 500 m
DSJ9903 Sweep 1 Density (kg/m³) at 500 m
Latitude (°N)
38
37
124
123
122
Longitude (°W)

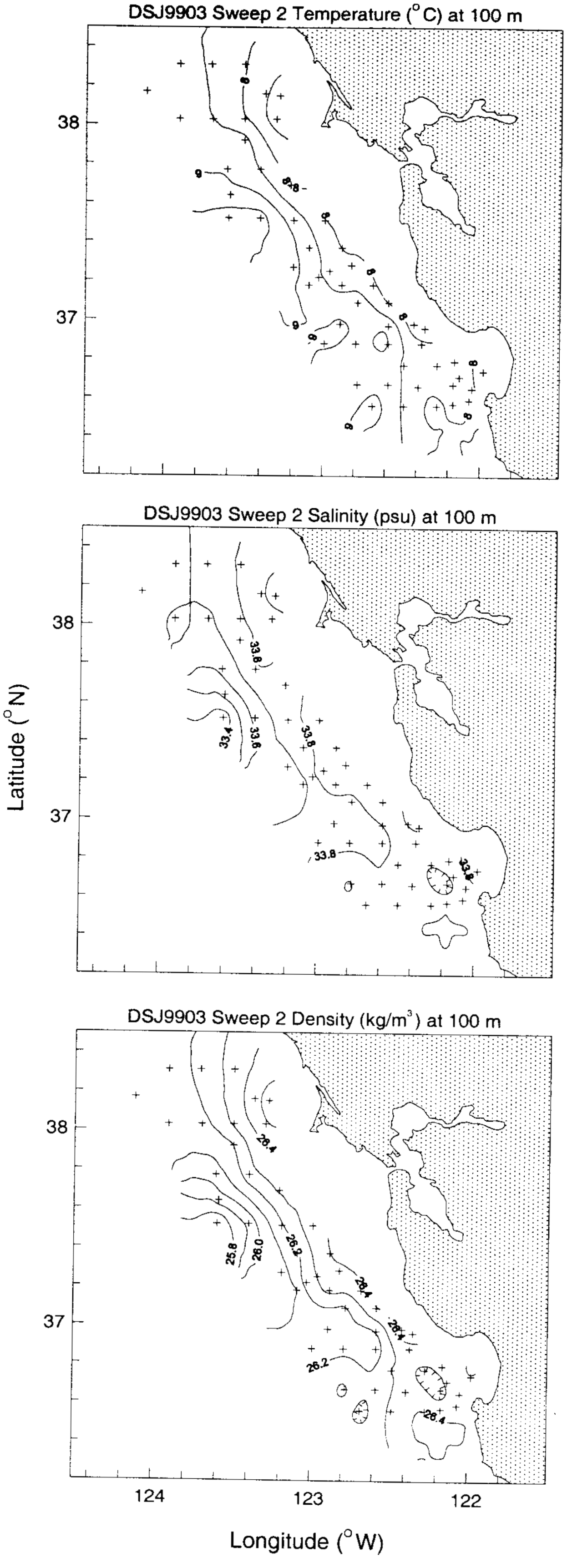
APPENDIX 7.2: HORIZONTAL MAPS OF CTD AND TS FOR DSJ9903, SWEEP 2

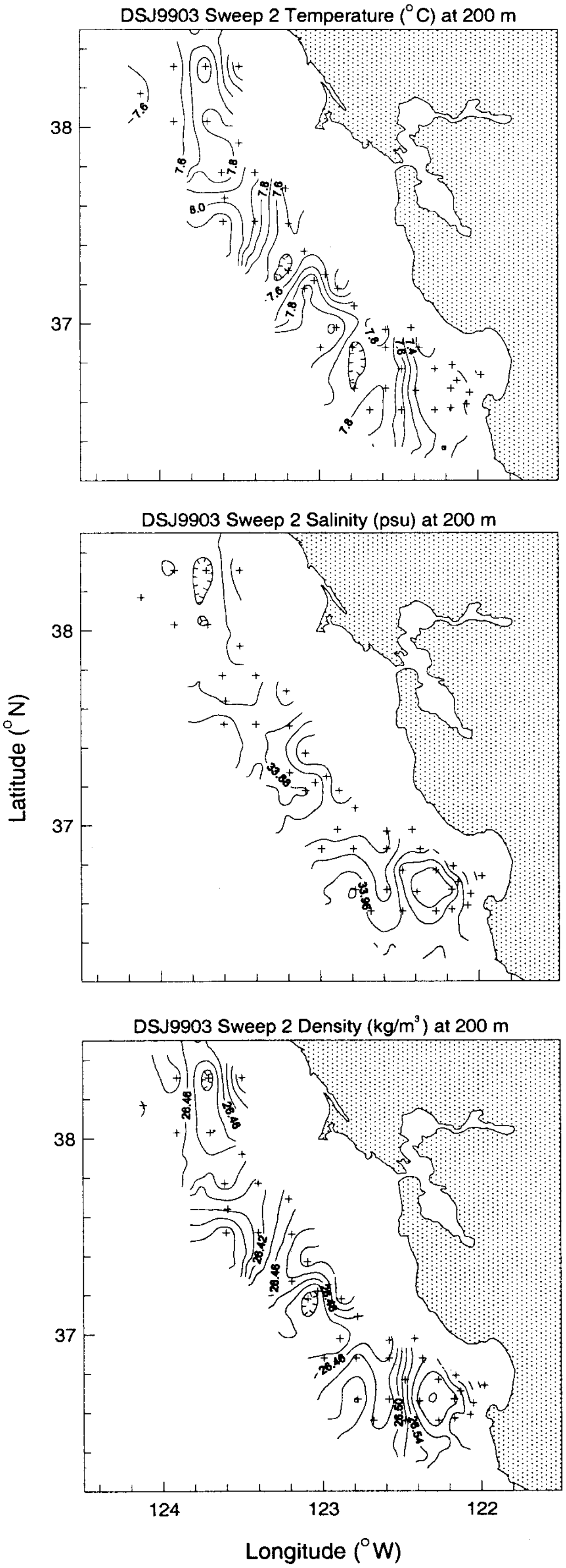

DSJ9903 Sweep 2 TS Temperature (°C)
DSJ9903 Sweep 2 TS Salinity (psu)
Latitude (°N)
Longitude (°W)
38
37
124
123
122
33.2
33.4
33.8
33.6

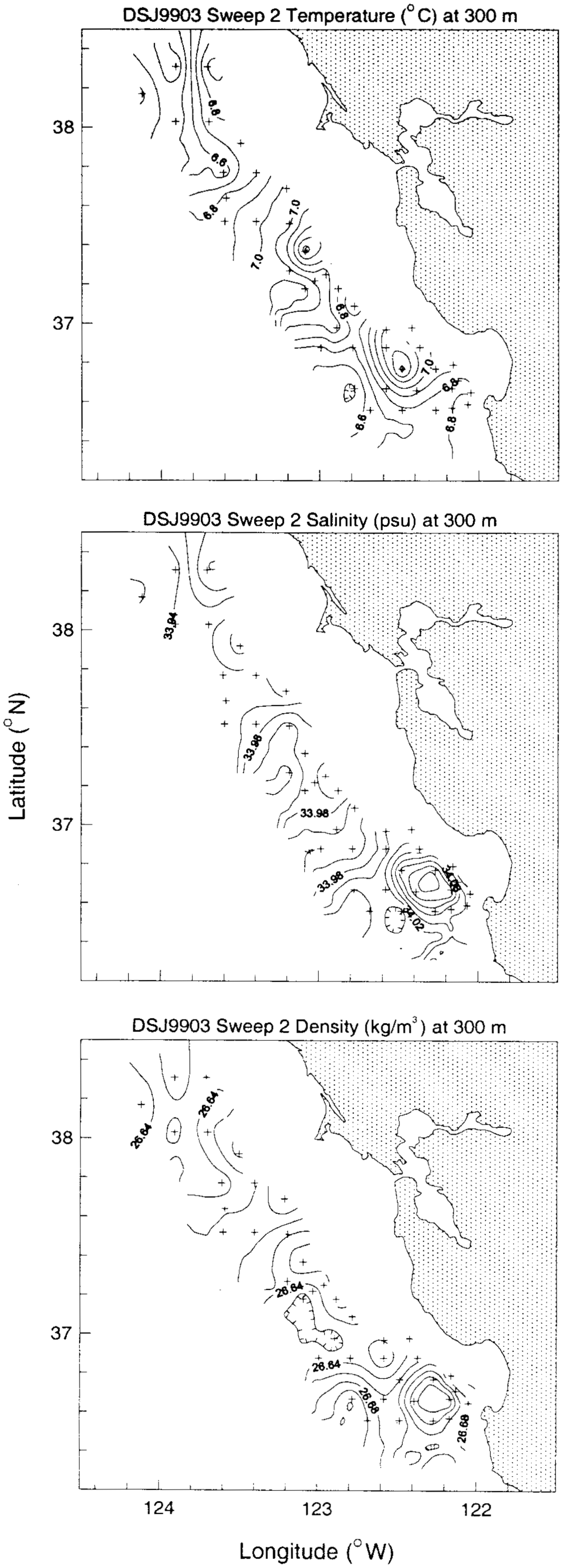

DSJ9903 Sweep 2 Temperature (°C) at 2 m
DSJ9903 Sweep 2 Salinity (psu) at 2 m
DSJ9903 Sweep 2 Density (kg/m³) at 2 m
Latitude (°N)
38
37
124
123
122
Longitude (°W)

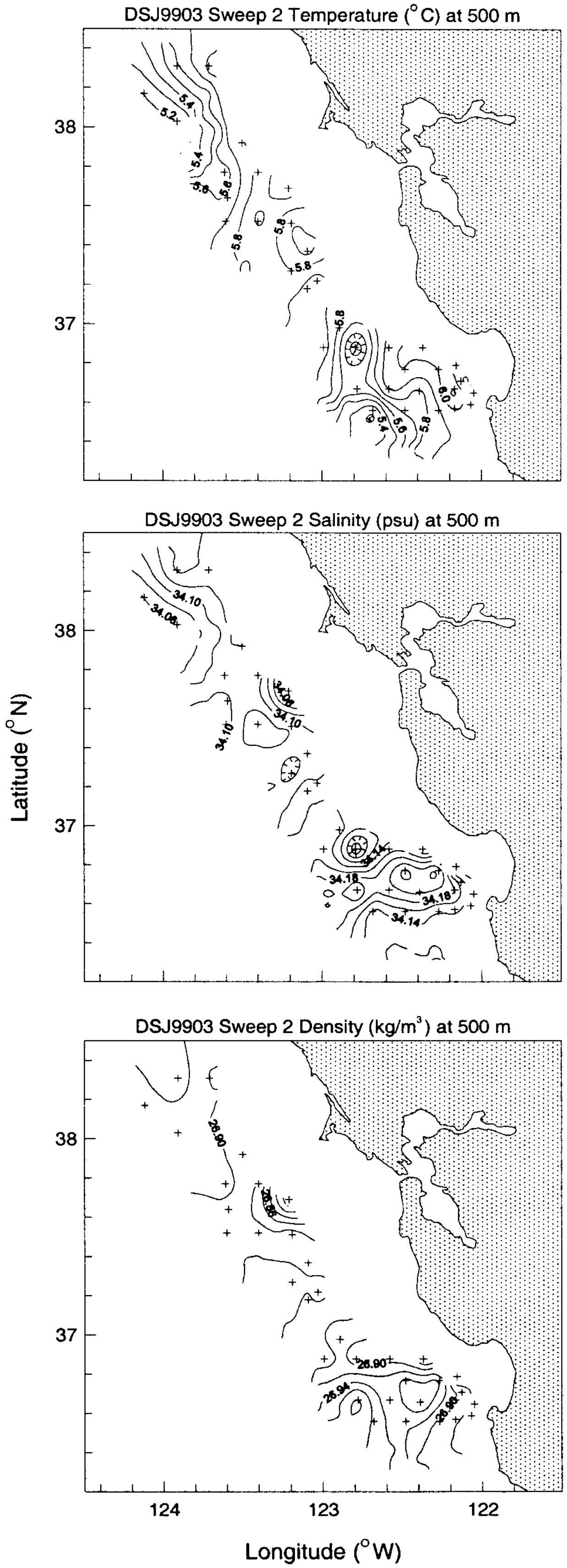

DSJ9903 Sweep 2 Temperature (°C) at 10 m
DSJ9903 Sweep 2 Salinity (psu) at 10 m
DSJ9903 Sweep 2 Density (kg/m³) at 10 m
Latitude (°N)
38
37
124
123
122
Longitude (°W)


DSJ9903 Sweep 2 Temperature (°C) at 30 m
DSJ9903 Sweep 2 Salinity (psu) at 30 m
DSJ9903 Sweep 2 Density (kg/m³) at 30 m
Latitude (°N)
38
37
124
123
122
Longitude (°W)

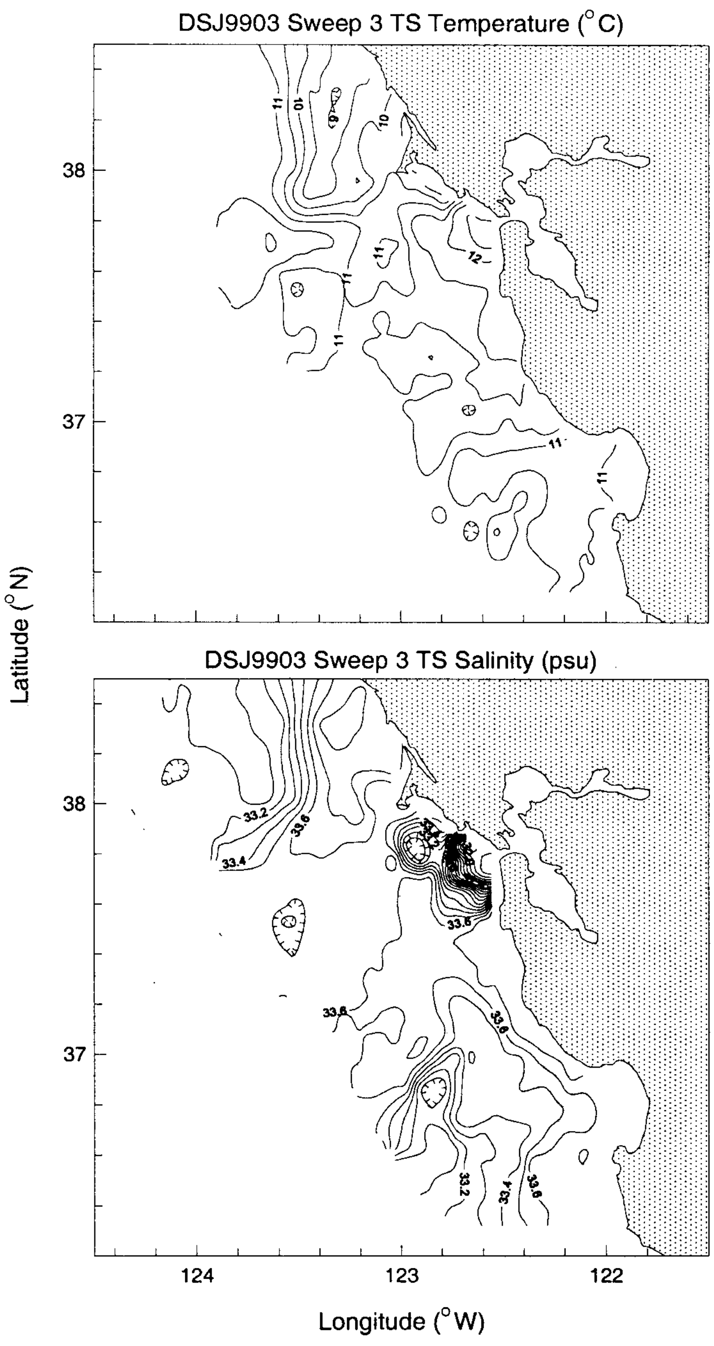

DSJ9903 Sweep 2 Temperature (°C) at 100 m
DSJ9903 Sweep 2 Salinity (psu) at 100 m
DSJ9903 Sweep 2 Density (kg/m³) at 100 m
Latitude (°N)
38
37
124
123
122
Longitude (°W)

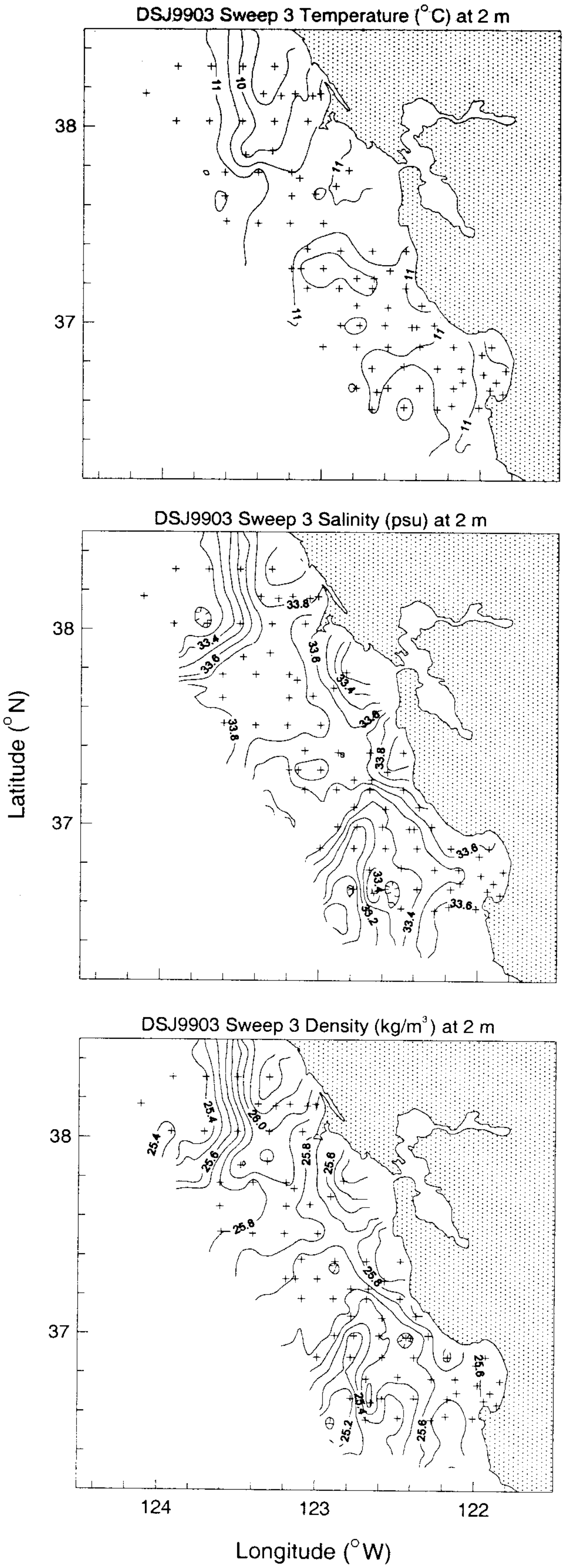

DSJ9903 Sweep 2 Temperature (°C) at 200 m
DSJ9903 Sweep 2 Salinity (psu) at 200 m
DSJ9903 Sweep 2 Density (kg/m³) at 200 m
Latitude (°N)
38
37
124
123
122
Longitude (°W)

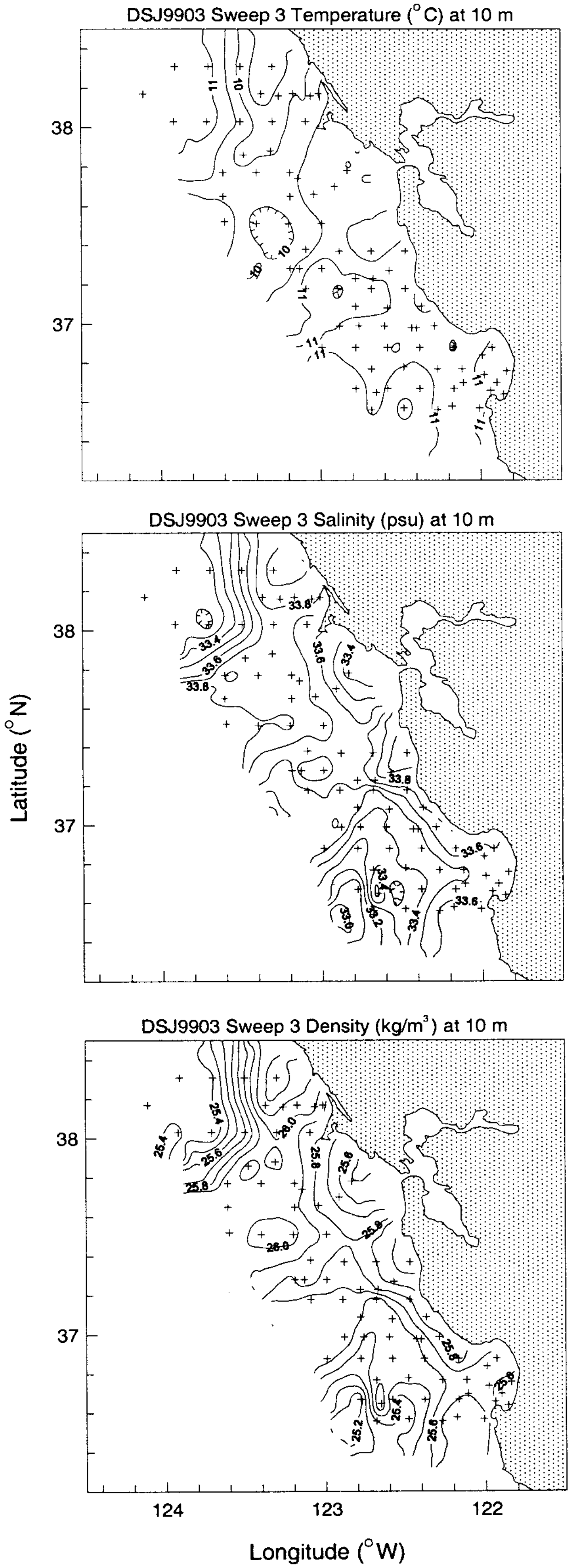

DSJ9903 Sweep 2 Temperature (°C) at 300 m
6.8
6.6
7.0
DSJ9903 Sweep 2 Salinity (psu) at 300 m
33.94
33.98
34.02
DSJ9903 Sweep 2 Density (kg/m³) at 300 m
26.64
26.68
38
37
124
123
122
Latitude (°N)
Longitude (°W)

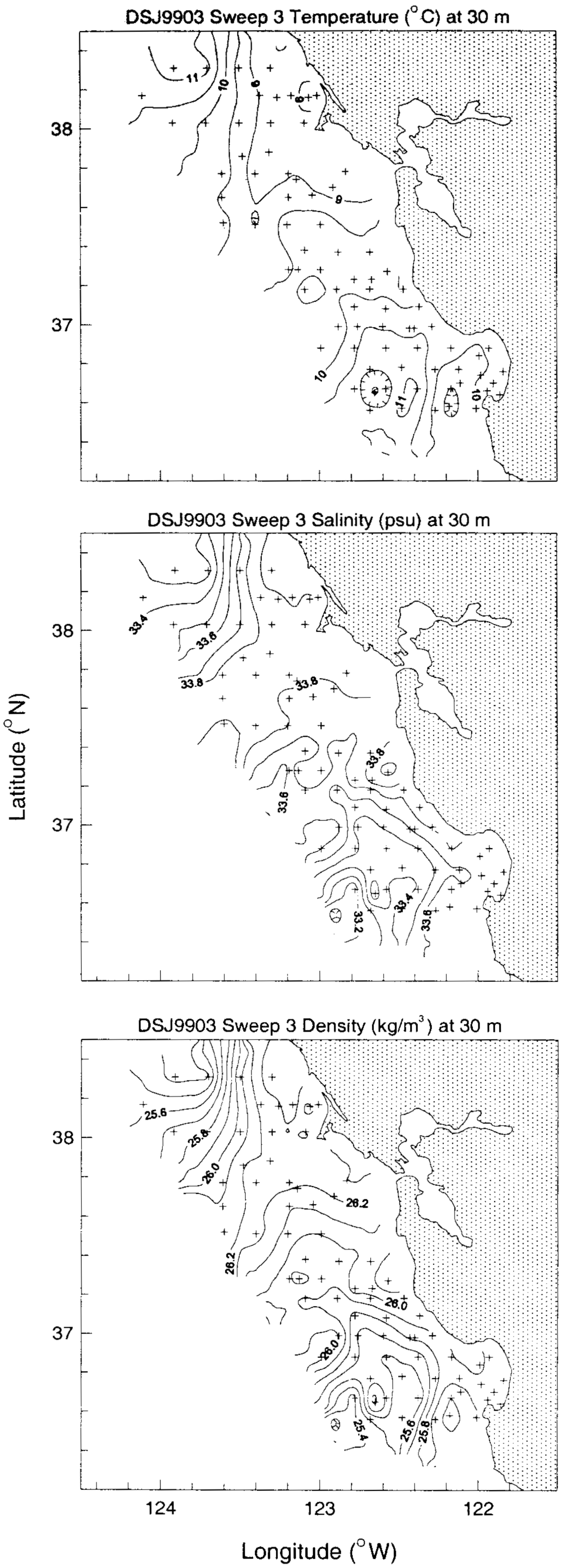

DSJ9903 Sweep 2 Temperature (°C) at 500 m
DSJ9903 Sweep 2 Salinity (psu) at 500 m
DSJ9903 Sweep 2 Density (kg/m³) at 500 m
Latitude (°N)
38
37
124
123
122
Longitude (°W)

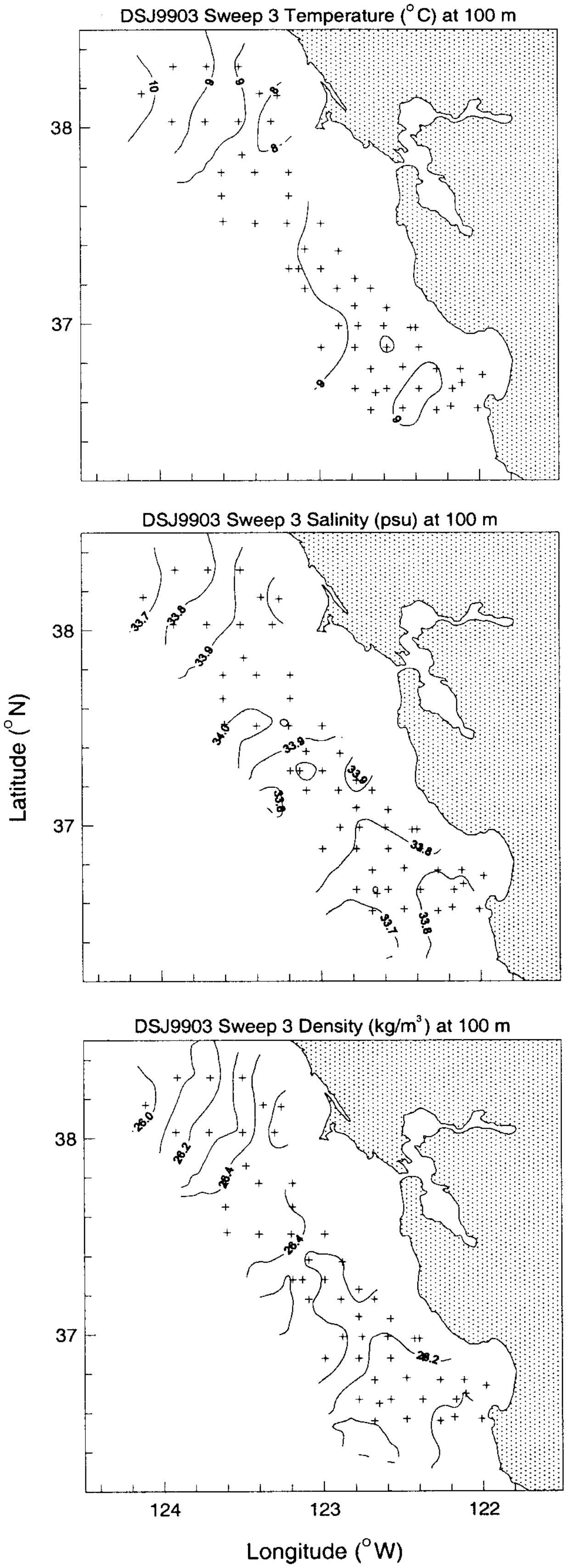
APPENDIX 7.3: HORIZONTAL MAPS OF CTD AND TS FOR DSJ9903, SWEEP 3


DSJ9903 Sweep 3 TS Temperature (°C)
DSJ9903 Sweep 3 TS Salinity (psu)
Latitude (°N)
Longitude (°W)
38
37
124
123
122
11
10
9
12
33.2
33.4
33.6

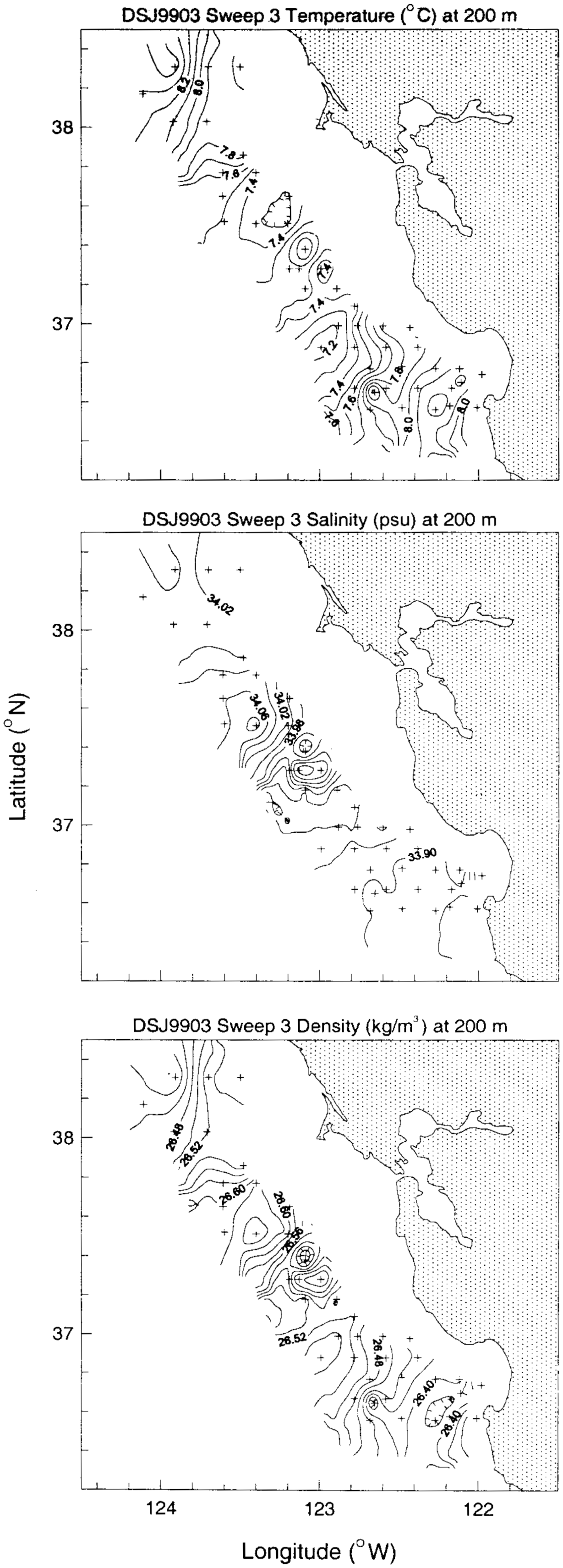

DSJ9903 Sweep 3 Temperature (°C) at 2 m
DSJ9903 Sweep 3 Salinity (psu) at 2 m
DSJ9903 Sweep 3 Density (kg/m³) at 2 m
38
37
Latitude (°N)
124
123
122
Longitude (°W)

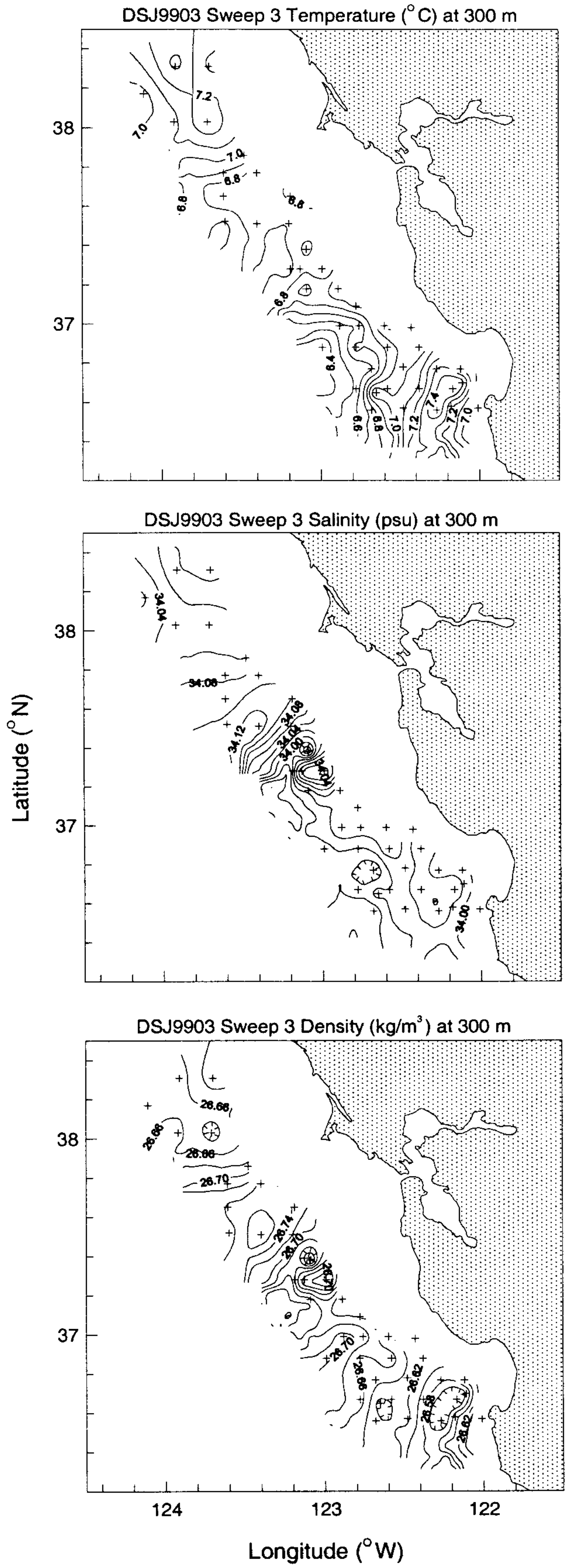

DSJ9903 Sweep 3 Temperature (°C) at 10 m
DSJ9903 Sweep 3 Salinity (psu) at 10 m
DSJ9903 Sweep 3 Density (kg/m³) at 10 m
Latitude (°N)
38
37
124
123
122
Longitude (°W)

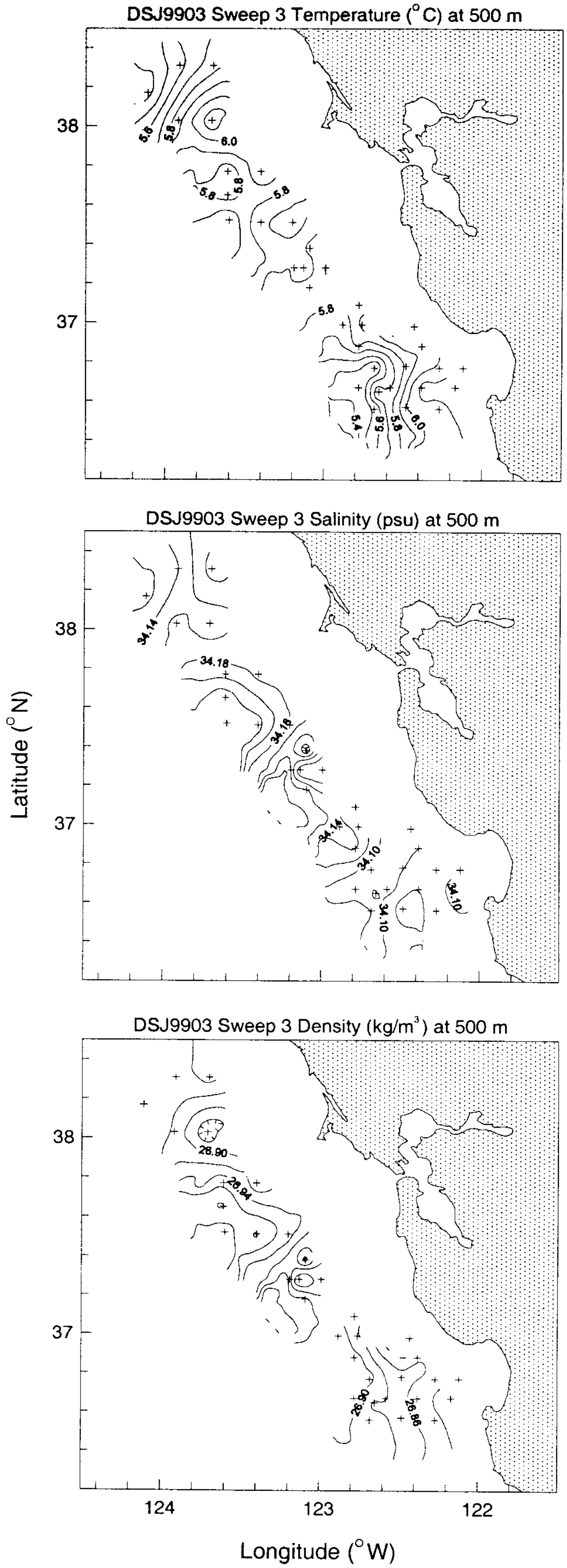

DSJ9903 Sweep 3 Temperature (°C) at 30 m
DSJ9903 Sweep 3 Salinity (psu) at 30 m
DSJ9903 Sweep 3 Density (kg/m³) at 30 m
Latitude (°N)
Longitude (°W)
38
37
124
123
122
33.4
33.6
33.8
33.2
25.6
25.8
26.0
26.2
25.4



DSJ9903 Sweep 3 Temperature (°C) at 100 m
DSJ9903 Sweep 3 Salinity (psu) at 100 m
DSJ9903 Sweep 3 Density (kg/m³) at 100 m
Latitude (°N)
Longitude (°W)
38
37
124
123
122


DSJ9903 Sweep 3 Temperature (°C) at 200 m
8.2
8.0
7.8
7.6
7.4
7.2
DSJ9903 Sweep 3 Salinity (psu) at 200 m
34.02
34.06
33.98
33.90
DSJ9903 Sweep 3 Density (kg/m³) at 200 m
26.48
26.52
26.60
26.56
26.40
38
37
124
123
122
Latitude (°N)
Longitude (°W)

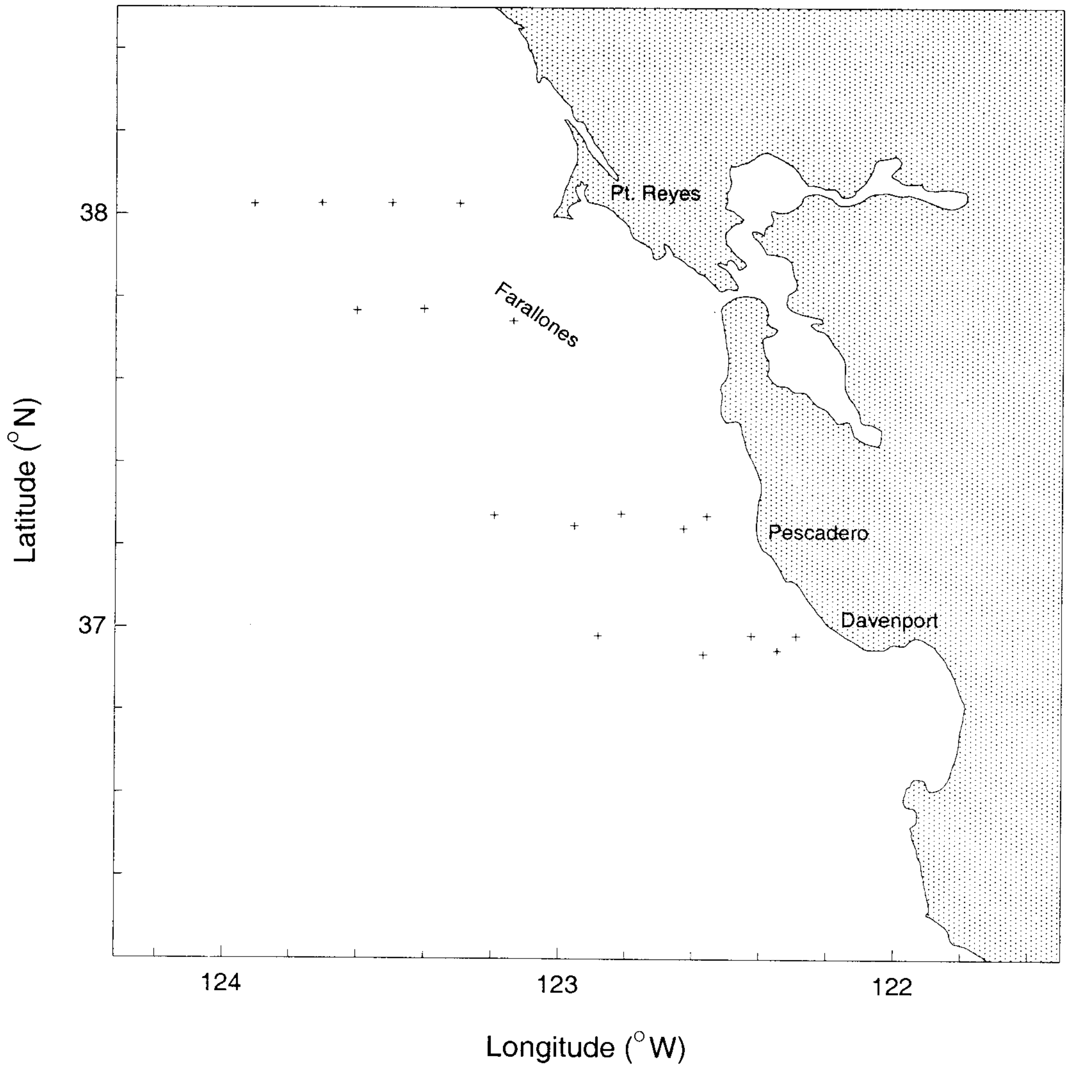

DSJ9903 Sweep 3 Temperature (°C) at 300 m
DSJ9903 Sweep 3 Salinity (psu) at 300 m
DSJ9903 Sweep 3 Density (kg/m³) at 300 m
38
37
Latitude (°N)
124
123
122
Longitude (°W)



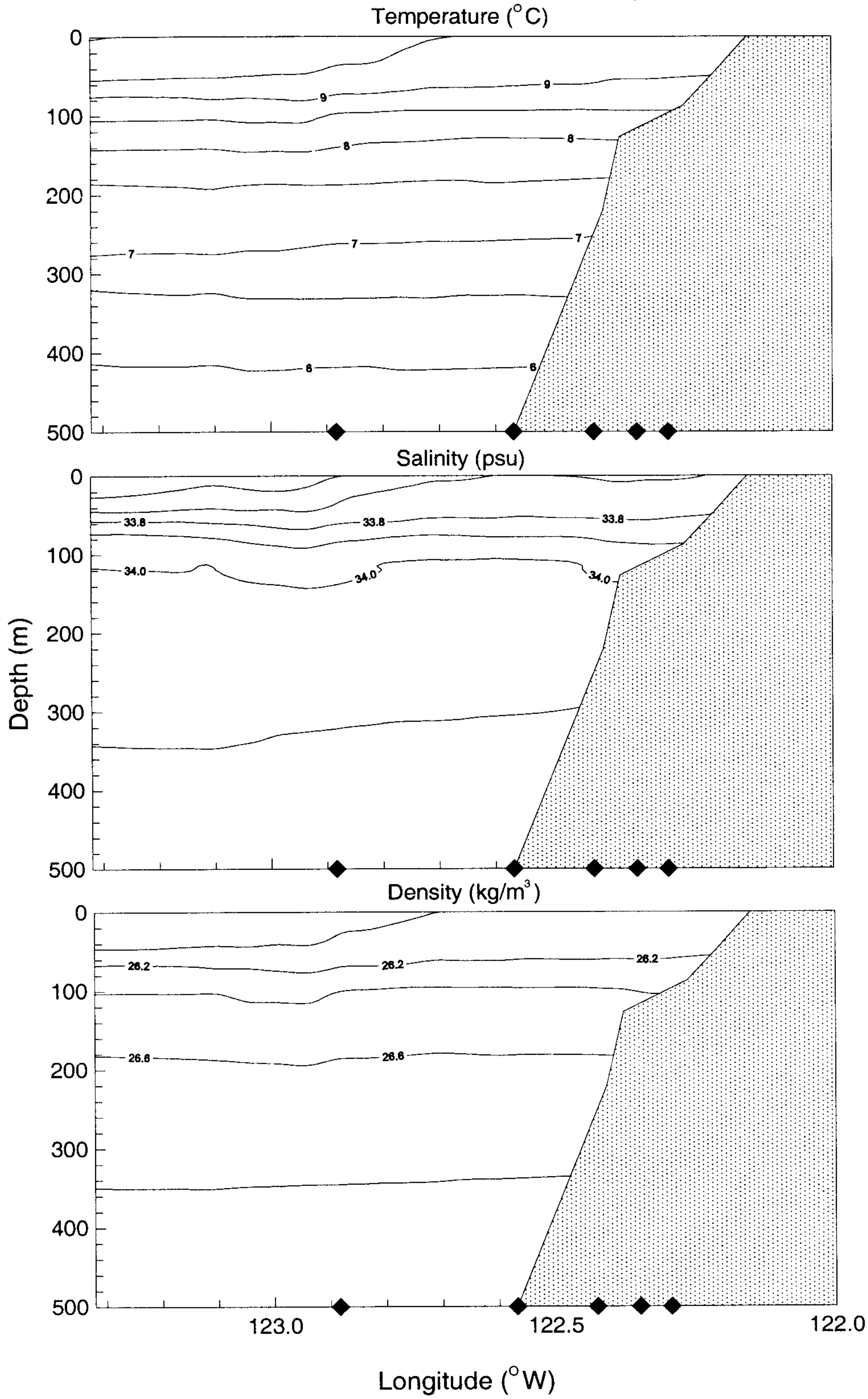
DSJ9903 Sweep 3 Temperature (°C) at 500 m
5.8
6.0
5.4
DSJ9903 Sweep 3 Salinity (psu) at 500 m
34.14
34.18
34.10
DSJ9903 Sweep 3 Density (kg/m³) at 500 m
26.90
26.94
26.88
38
37
Latitude (°N)
124
123
122
Longitude (°W)

APPENDIX 8: VERTICAL SECTIONS FOR DSJ9903

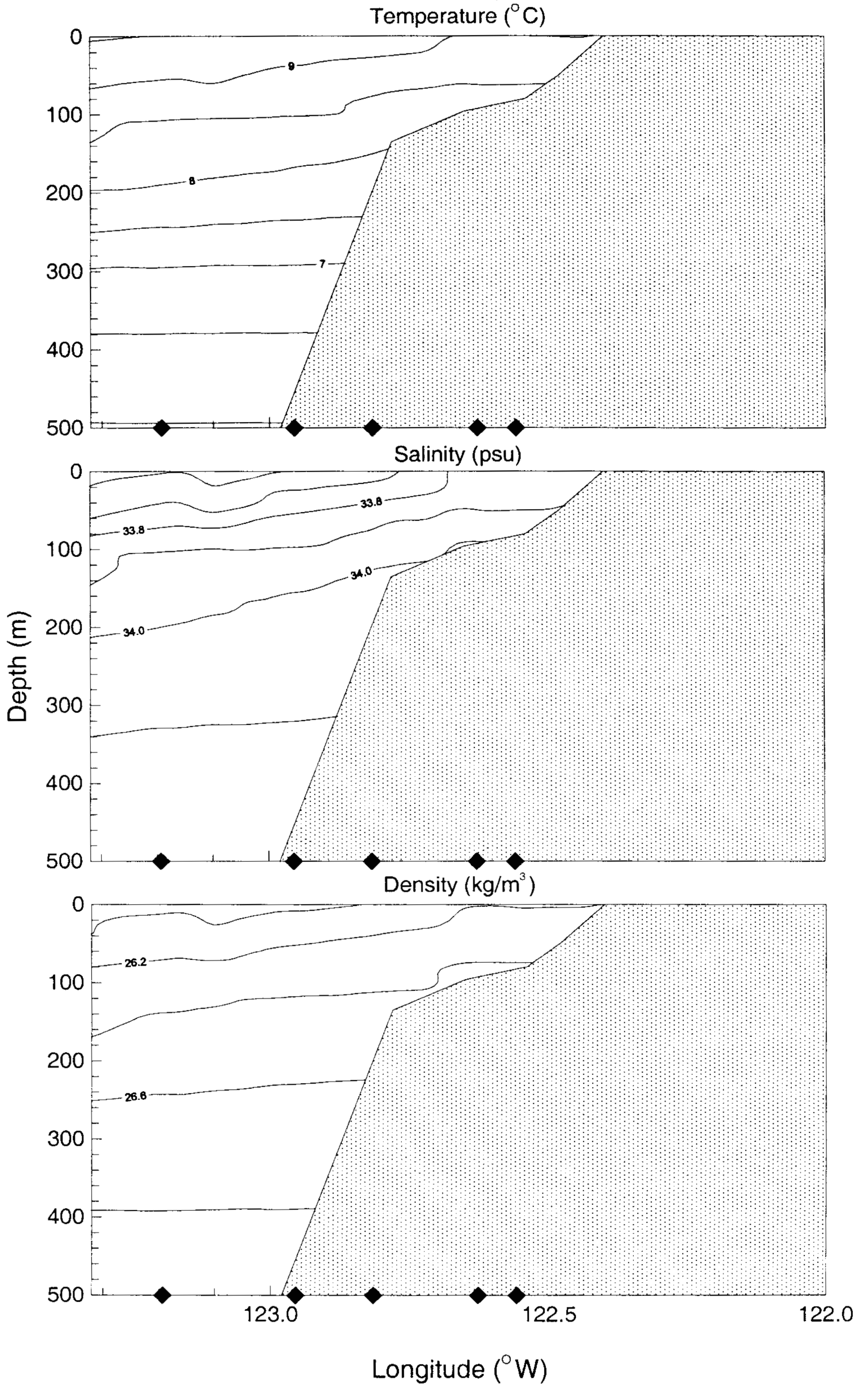
DSJ9903 Sweep 1 Vertical Transect Stations

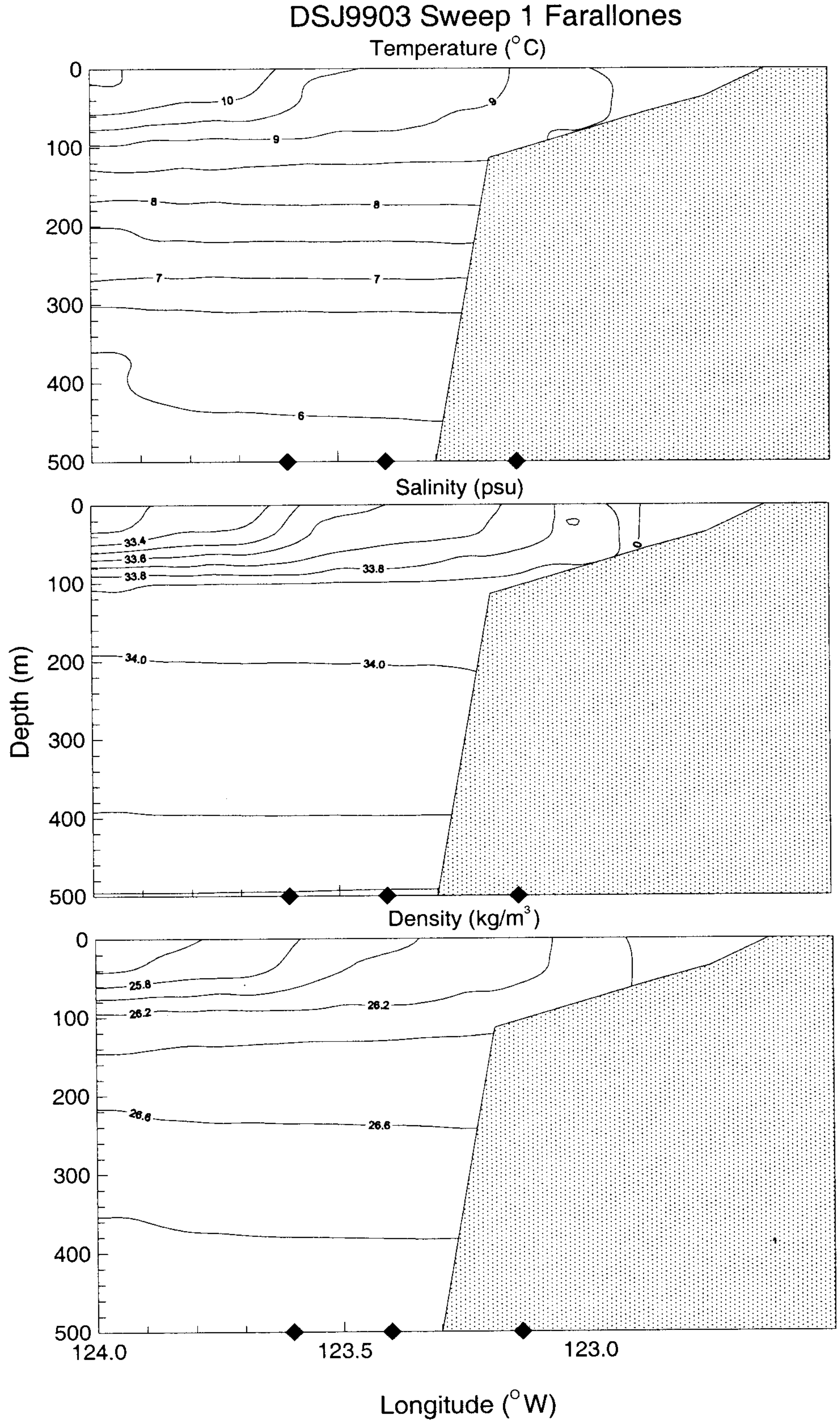


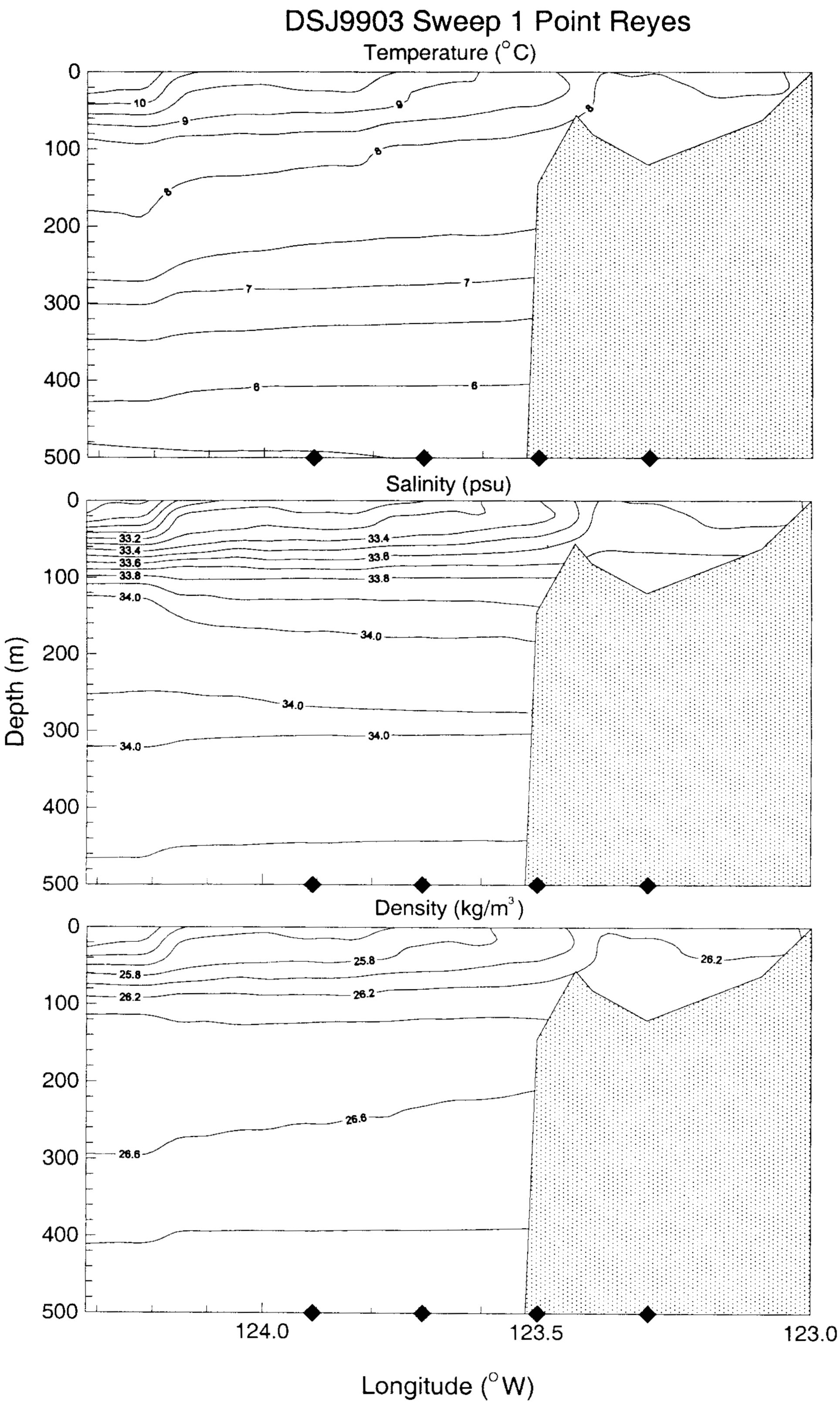
DSJ9903 Sweep 1 Davenport



DSJ9903 Sweep 1 Pescadero

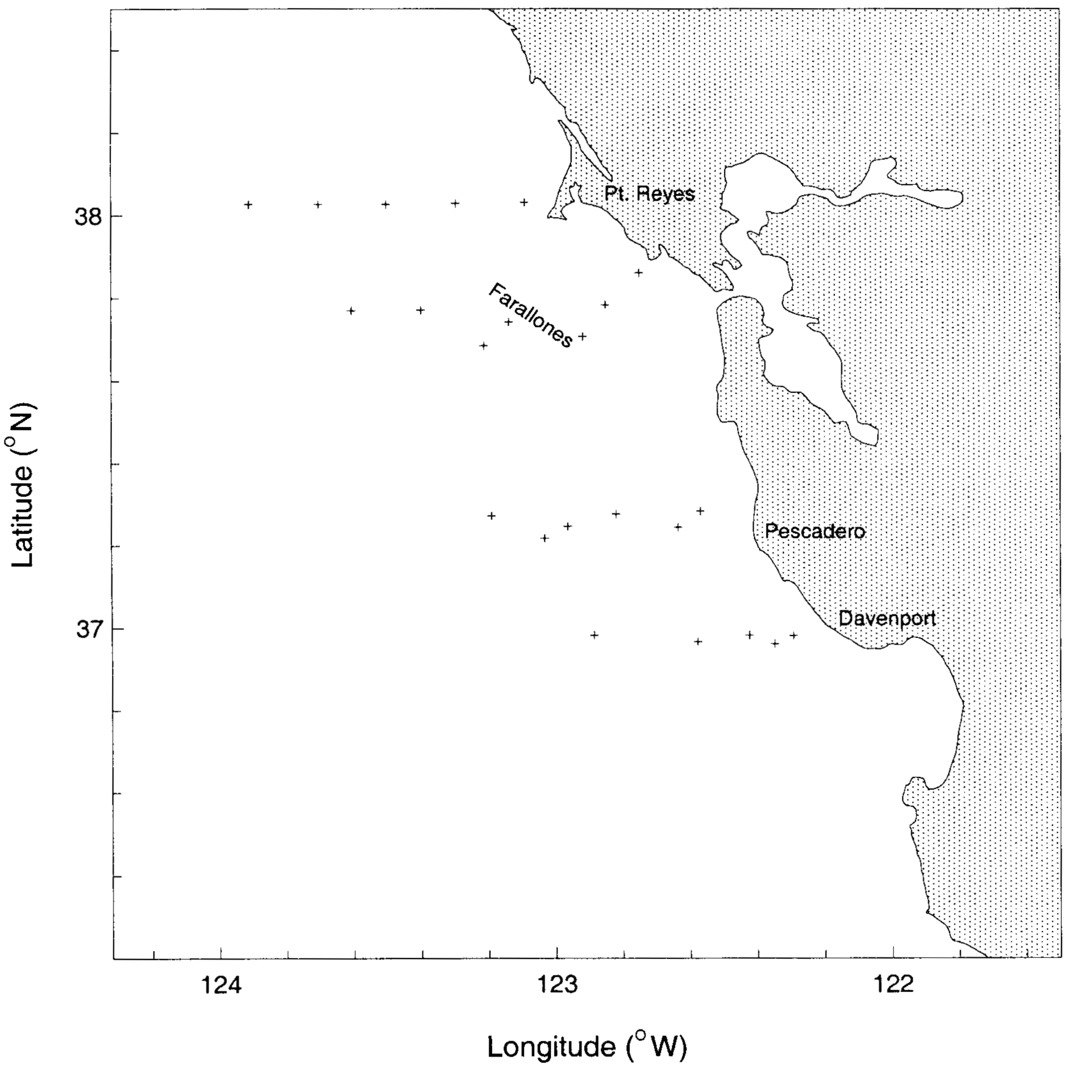


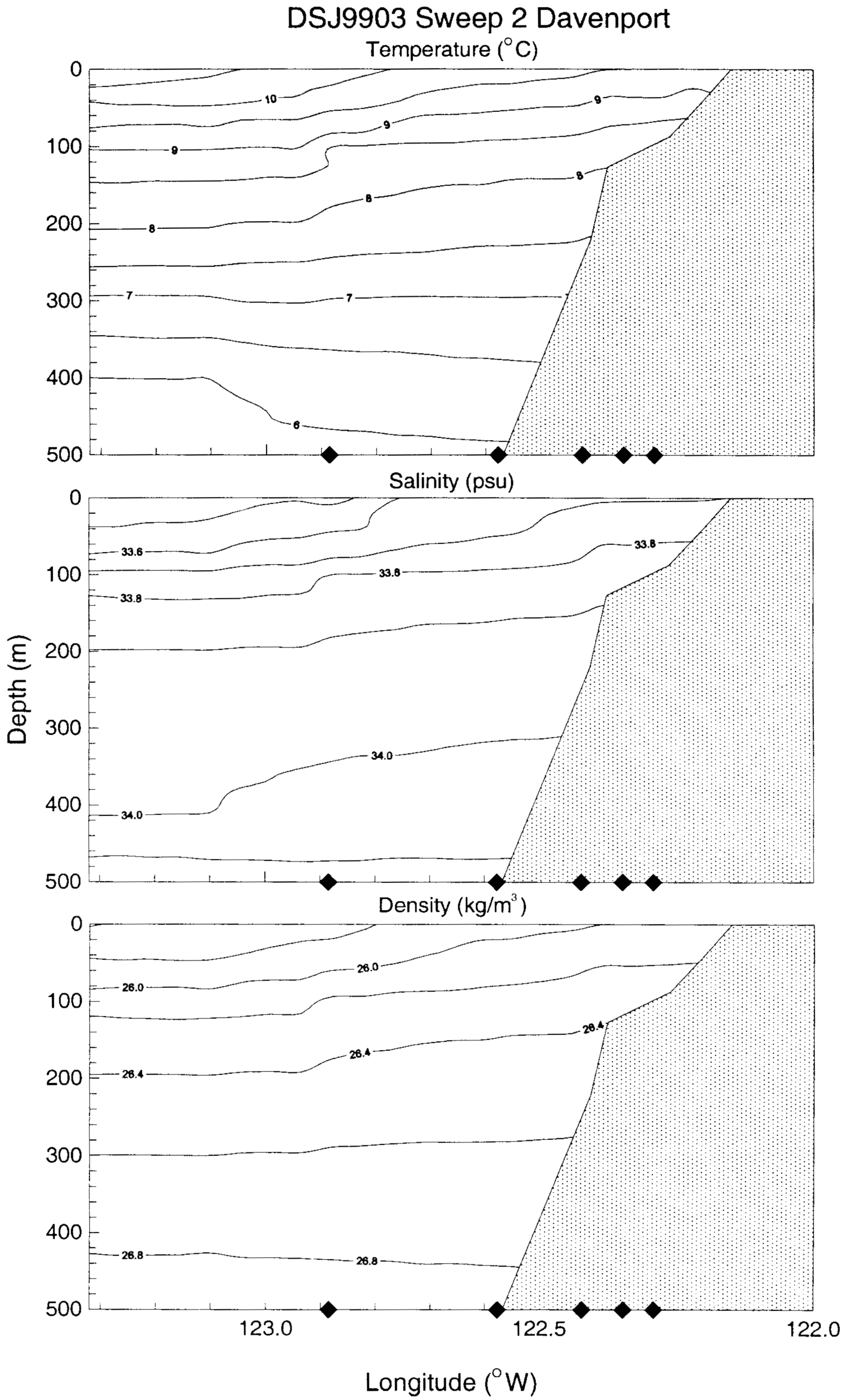

DSJ9903 Sweep 1 Farallones
Temperature (°C)
10
9
9
8
8
7
7
6
Salinity (psu)
33.4
33.6
33.8
33.8
34.0
34.0
Density (kg/m³)
25.8
26.2
26.2
26.6
26.6
Depth (m)
0
100
200
300
400
500
124.0
123.5
123.0
Longitude (°W)

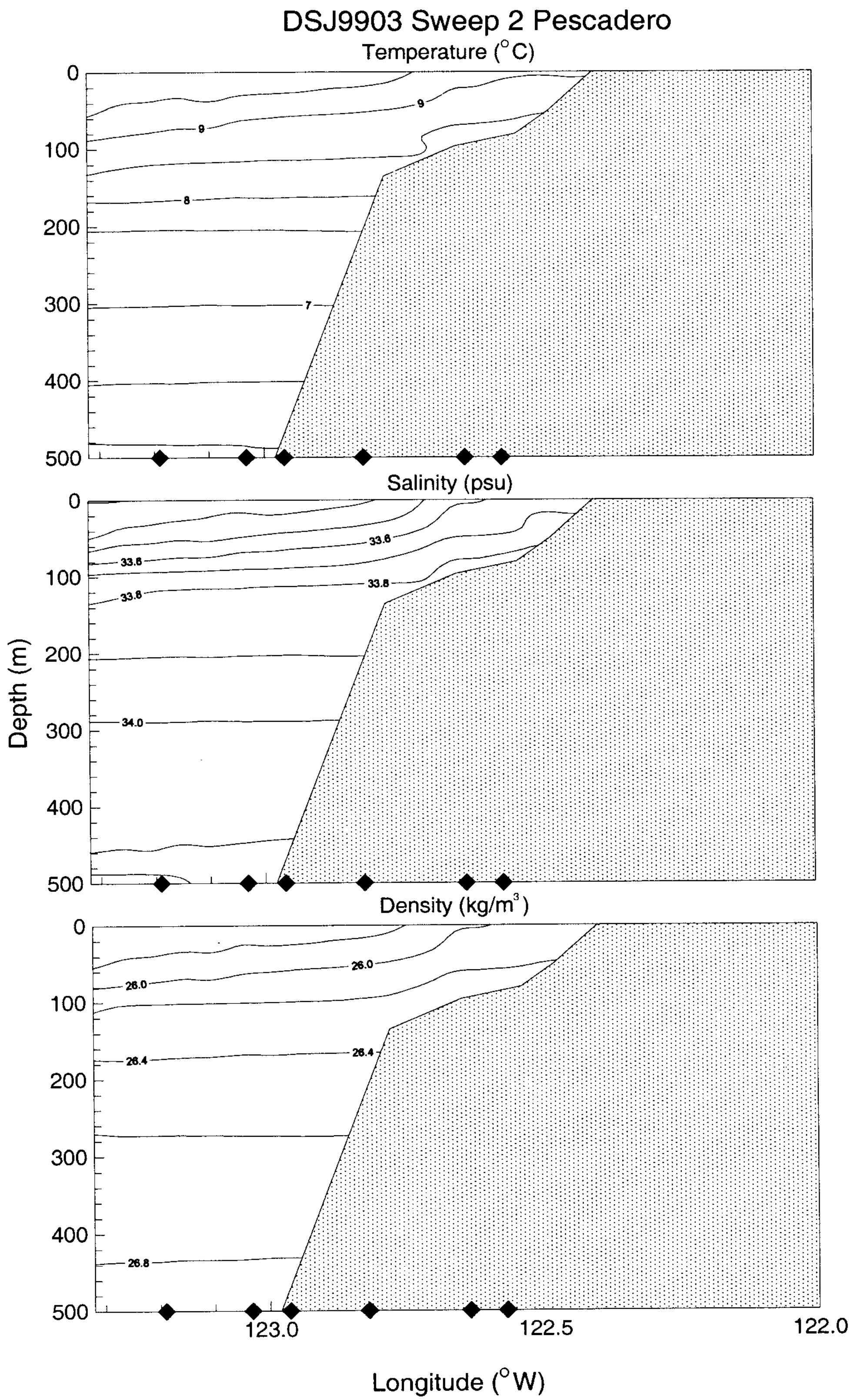


DSJ9903 Sweep 1 Point Reyes
Temperature (°C)
Salinity (psu)
Density (kg/m³)
Depth (m)
Longitude (°W)
0
100
200
300
400
500
124.0
123.5
123.0
10
9
8
7
6
33.2
33.4
33.6
33.8
34.0
25.8
26.2
26.6

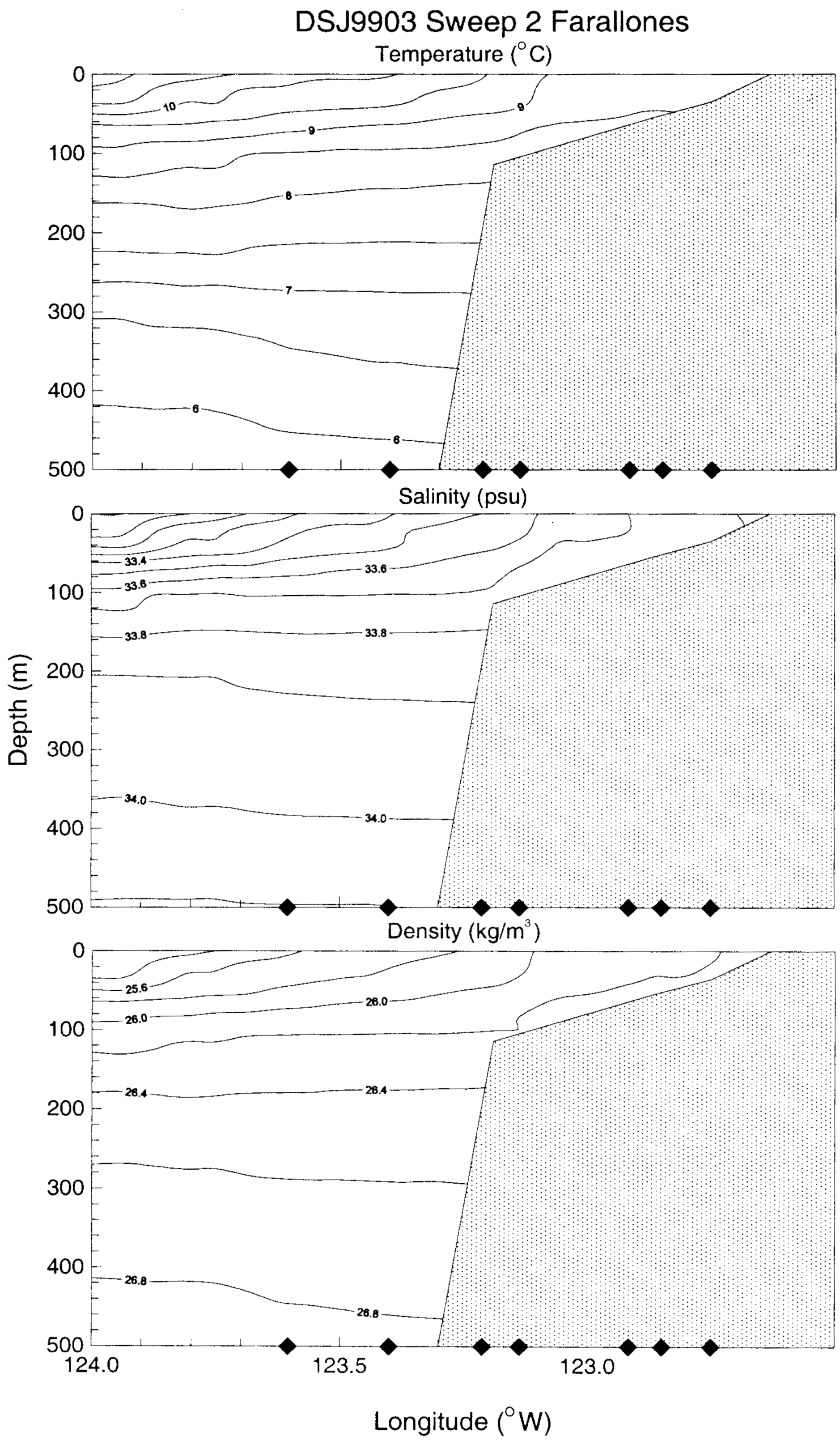
DSJ9903 Sweep 2 Vertical Transect Stations



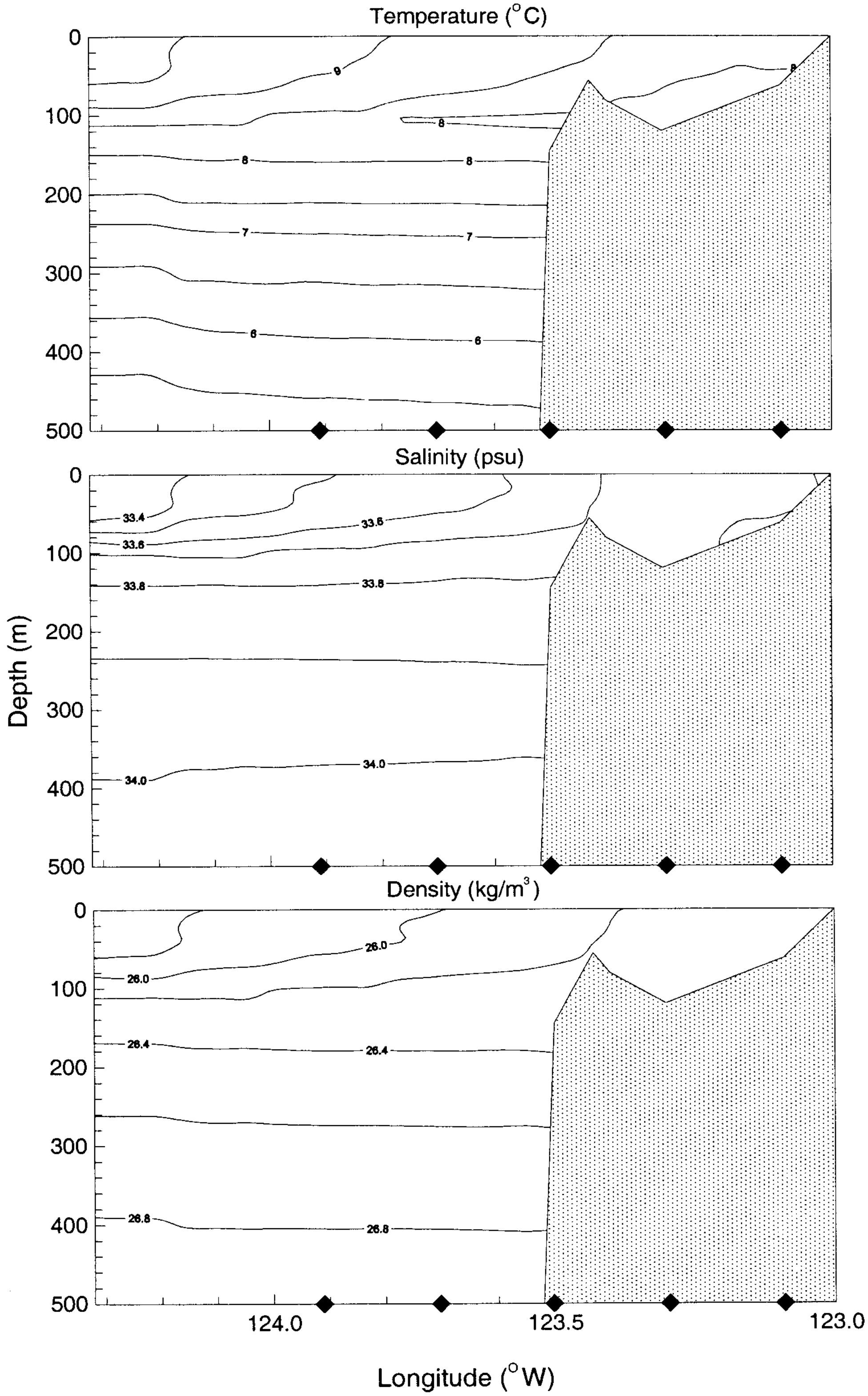

DSJ9903 Sweep 2 Davenport
Temperature (°C)
Salinity (psu)
Density (kg/m³)
Depth (m)
Longitude (°W)
0
100
200
300
400
500
123.0
122.5
122.0
10
9
8
7
6
33.6
33.8
34.0
26.0
26.4
26.8



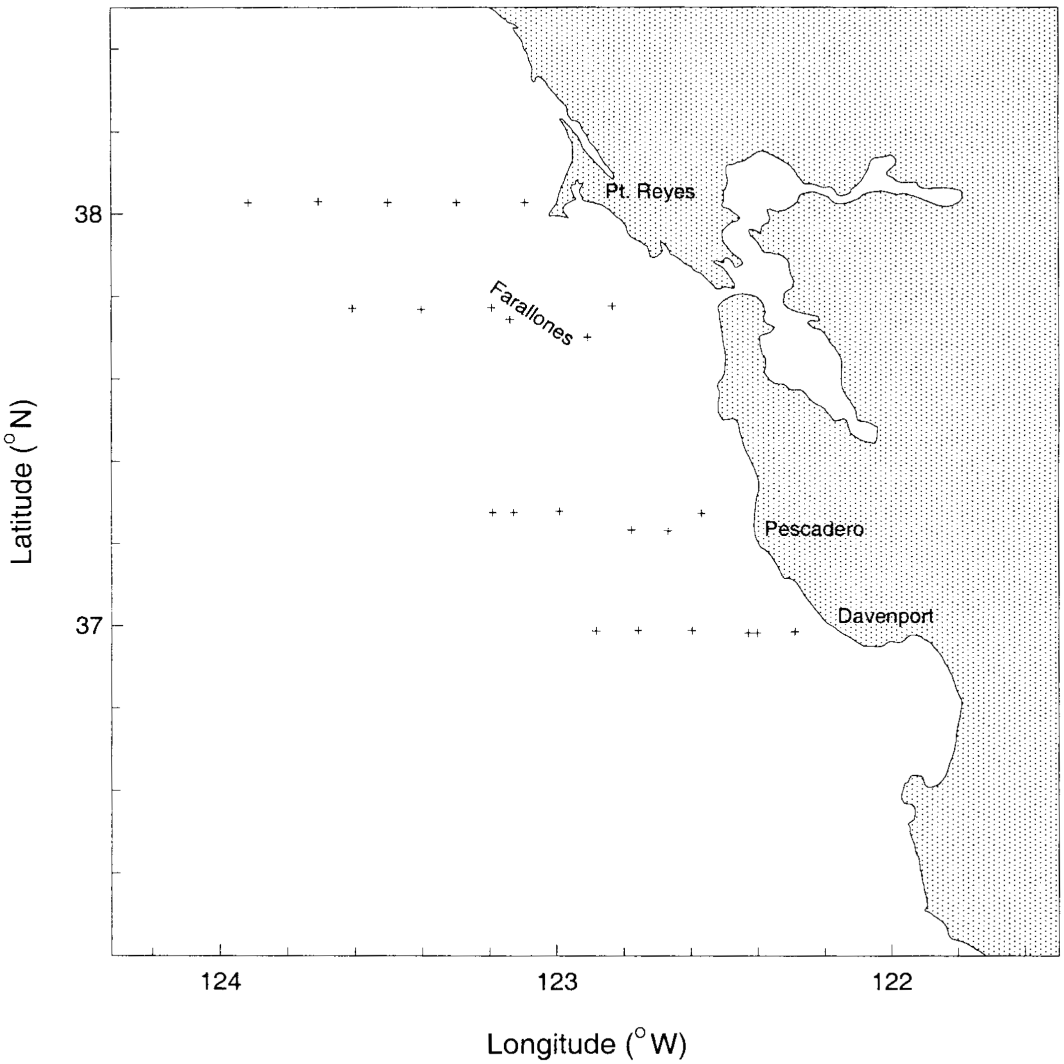
DSJ9903 Sweep 2 Pescadero
Temperature (°C)
Salinity (psu)
Density (kg/m³)
Depth (m)
Longitude (°W)
0
100
200
300
400
500
9
8
7
33.6
33.8
34.0
26.0
26.4
26.8
123.0
122.5
122.0

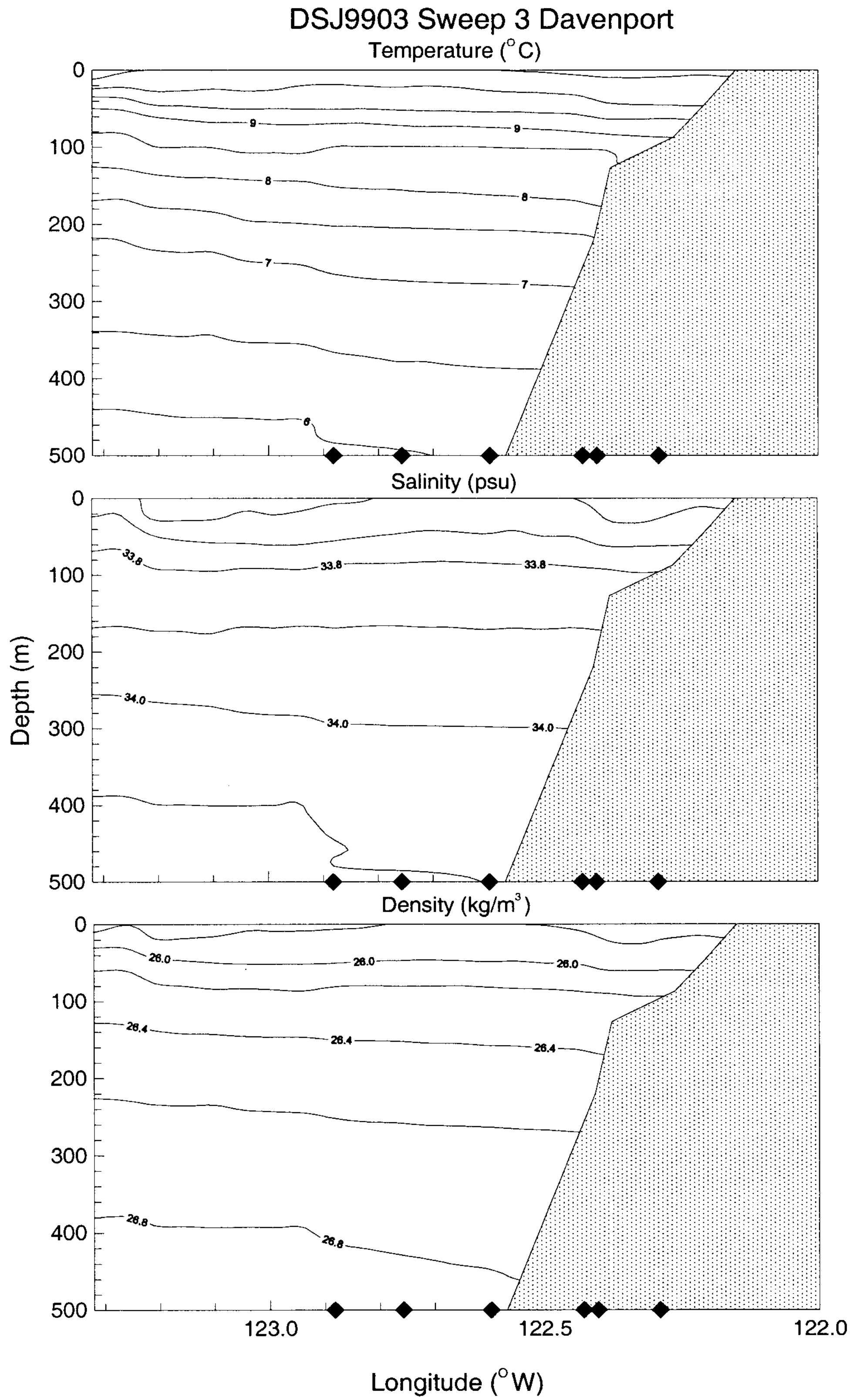

DSJ9903 Sweep 2 Farallones
Temperature (°C)
10
9
9
8
7
6
6
Salinity (psu)
33.4
33.6
33.6
33.8
33.8
33.8
34.0
34.0
Density (kg/m³)
25.6
26.0
26.0
26.4
26.4
26.8
26.8
Depth (m)
0
100
200
300
400
500
124.0
123.5
123.0
Longitude (°W)

DSJ9903 Sweep 2 Point Reyes

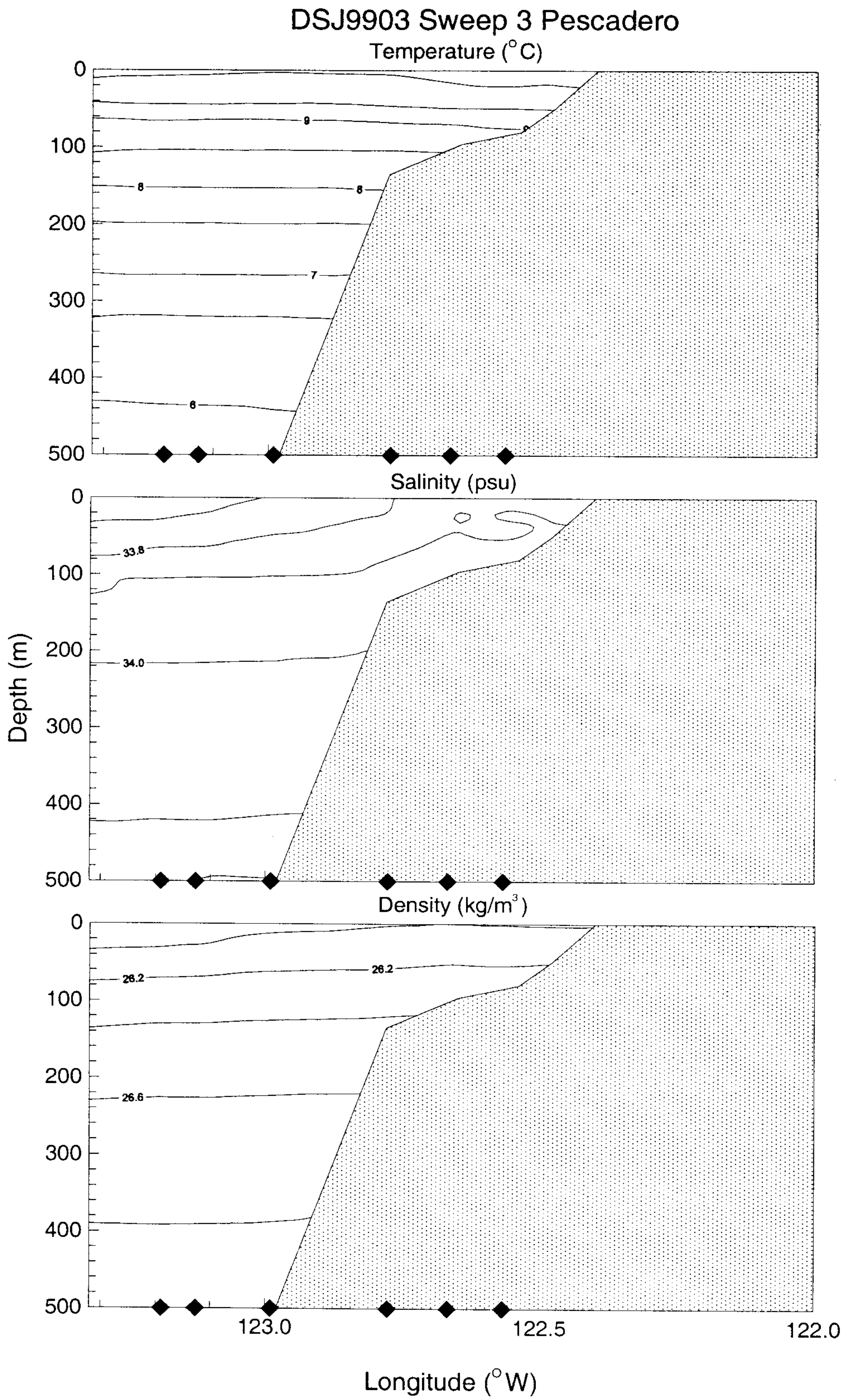


DSJ9903 Sweep 3 Vertical Transect Stations

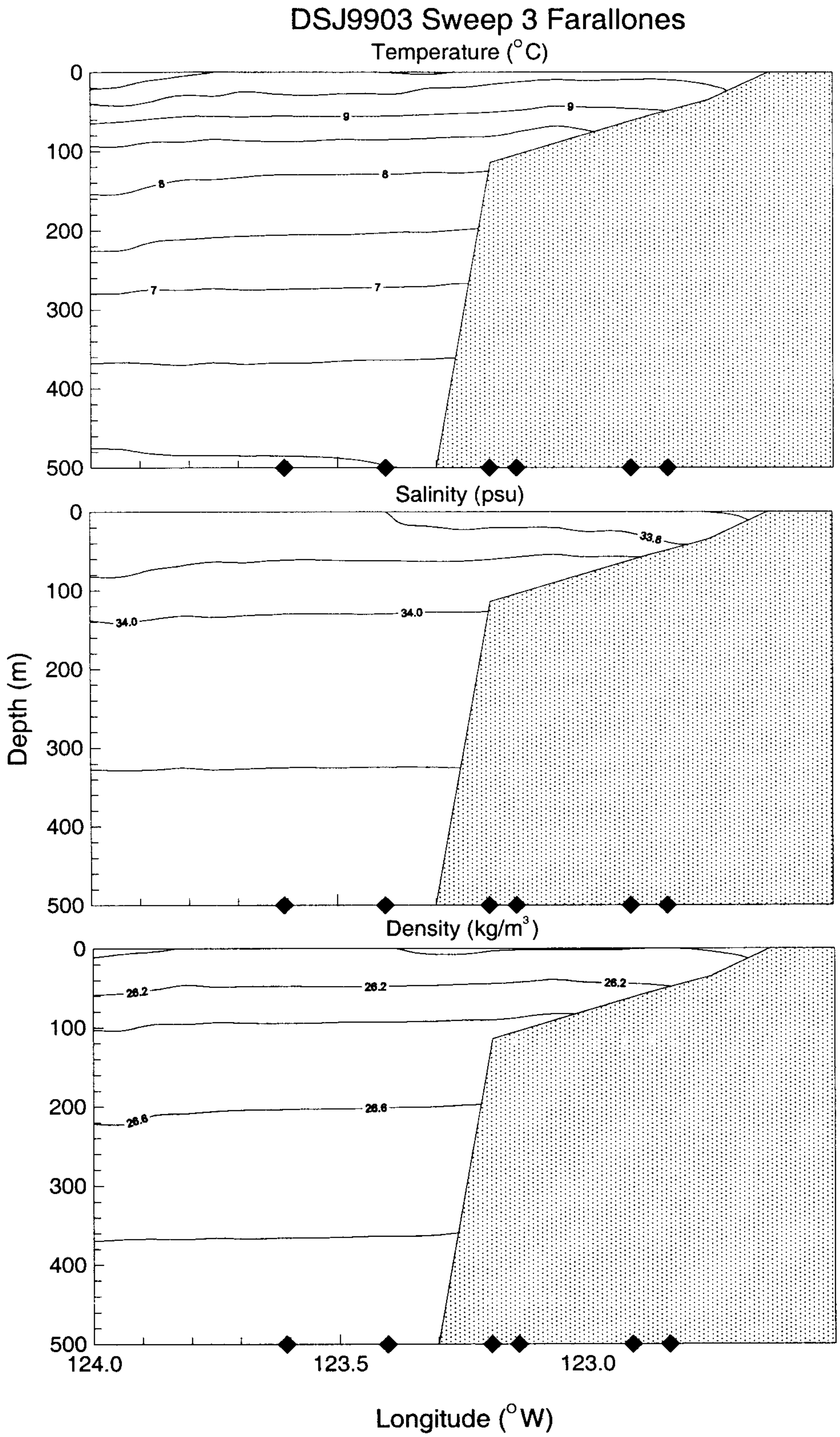




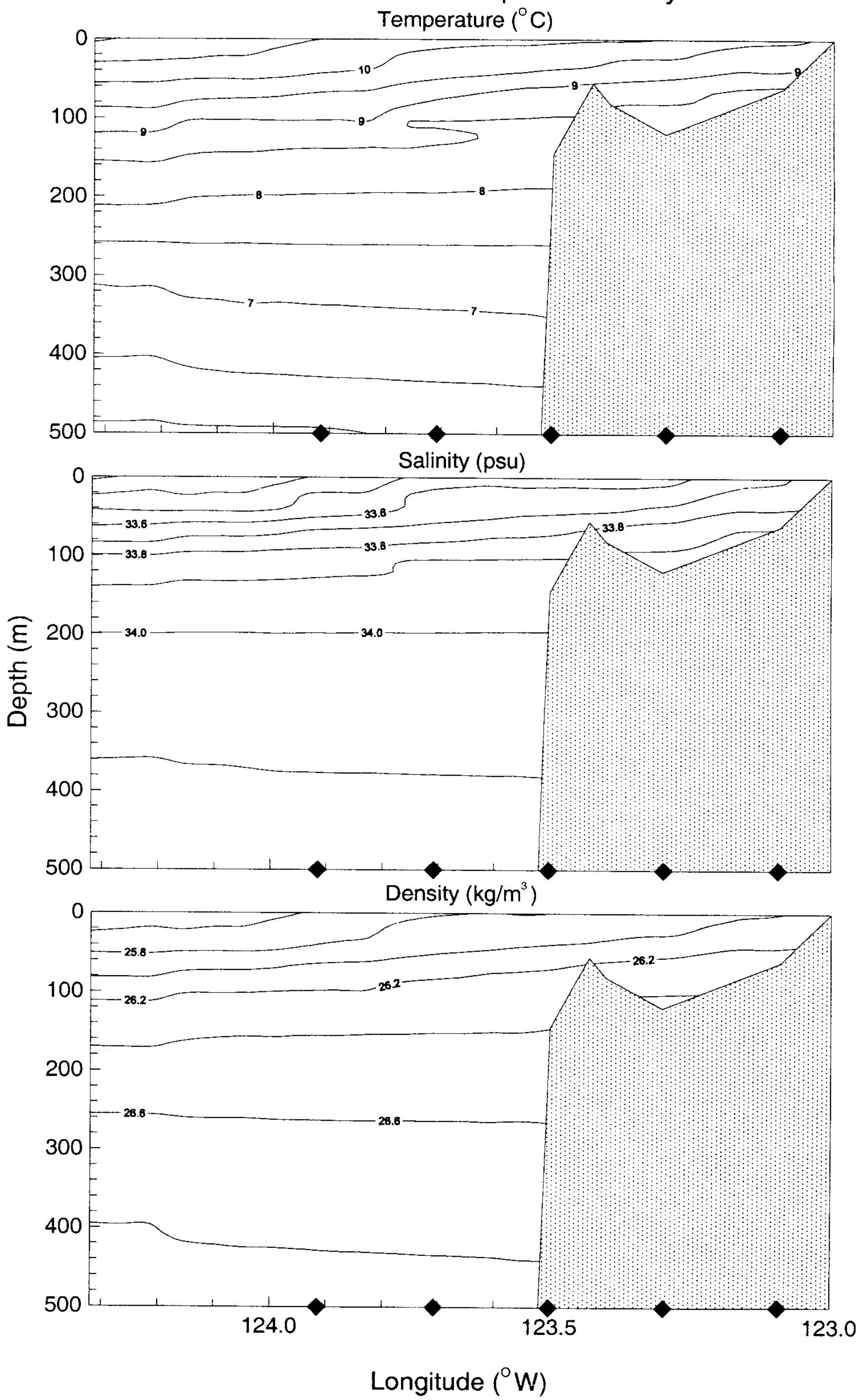
DSJ9903 Sweep 3 Davenport
Temperature (°C)
Salinity (psu)
Density (kg/m³)
Depth (m)
Longitude (°W)
0
100
200
300
400
500
123.0
122.5
122.0
9
8
7
6
33.8
34.0
26.0
26.4
26.8



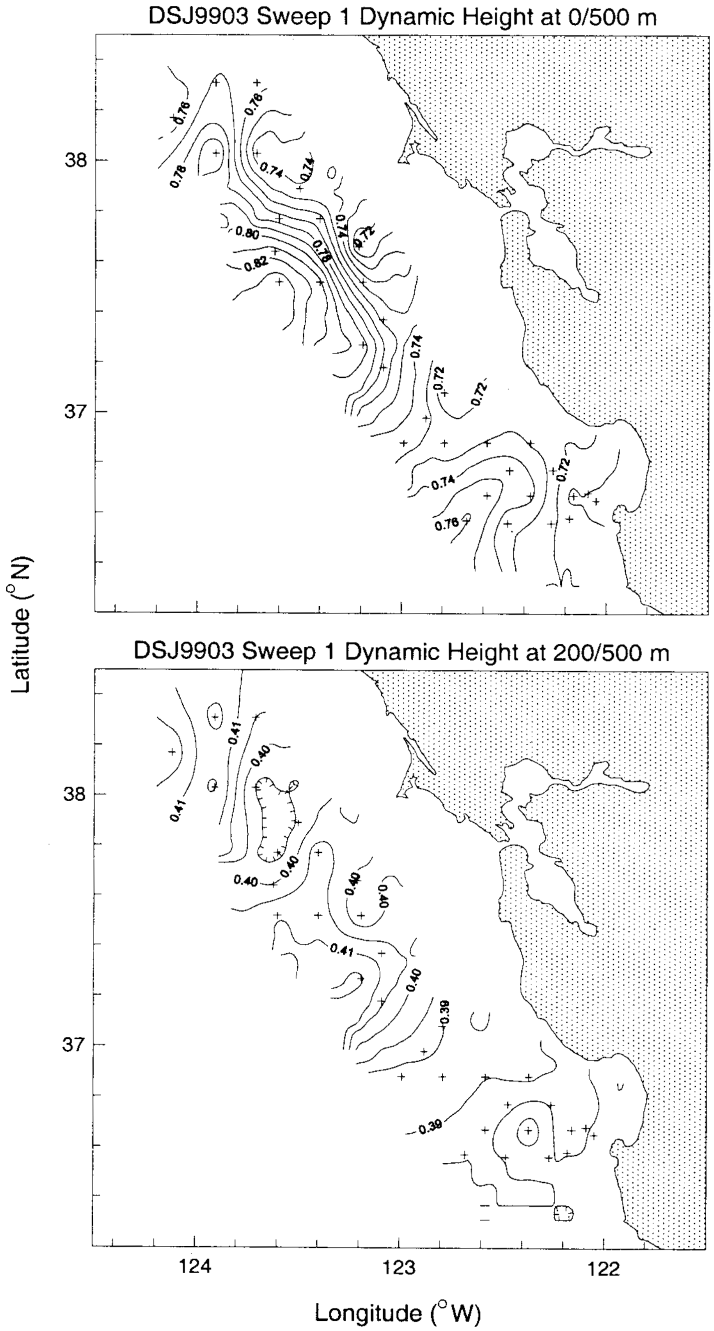
DSJ9903 Sweep 3 Pescadero
Temperature (°C)
9
8
8
7
6
Salinity (psu)
33.8
34.0
Density (kg/m³)
26.2
26.2
26.6
Depth (m)
0
100
200
300
400
500
123.0
122.5
122.0
Longitude (°W)

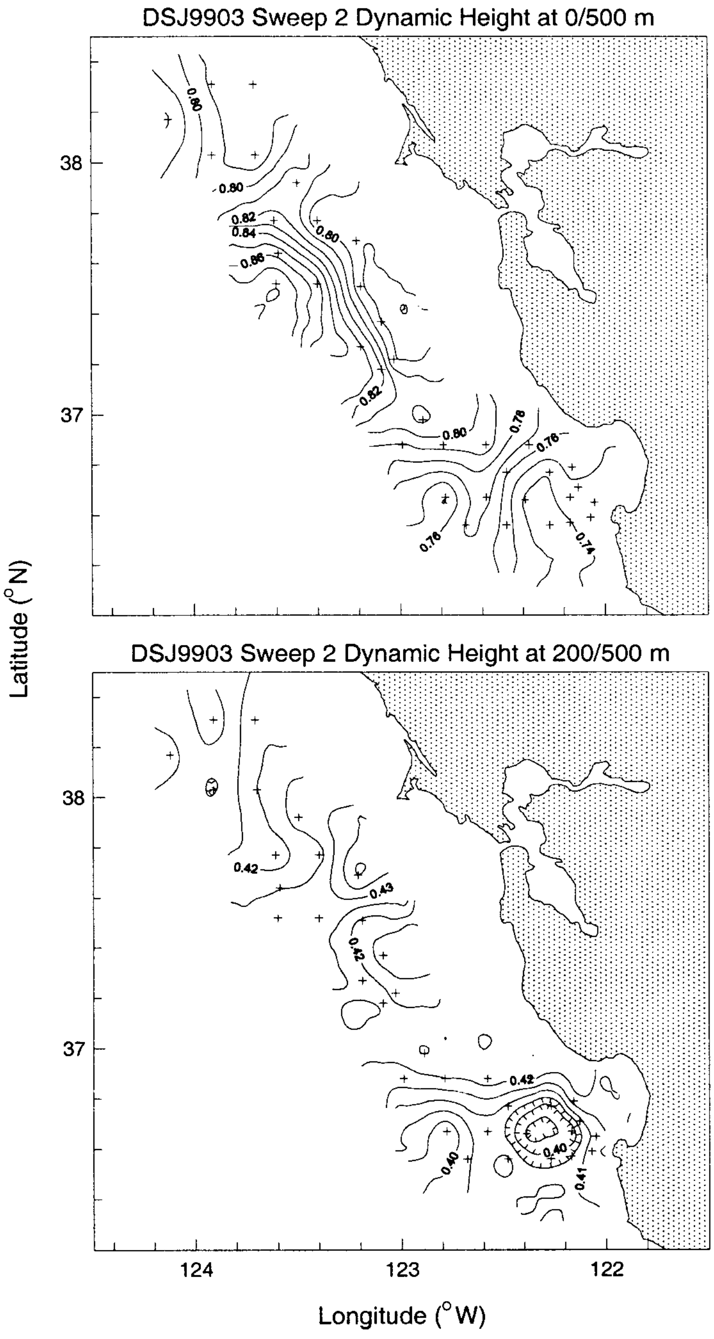

DSJ9903 Sweep 3 Farallones
Temperature (°C)
9
9
8
8
7
7
Salinity (psu)
33.8
34.0
34.0
Density (kg/m³)
26.2
26.2
26.2
26.6
26.6
Depth (m)
0
100
200
300
400
500
124.0
123.5
123.0
Longitude (°W)

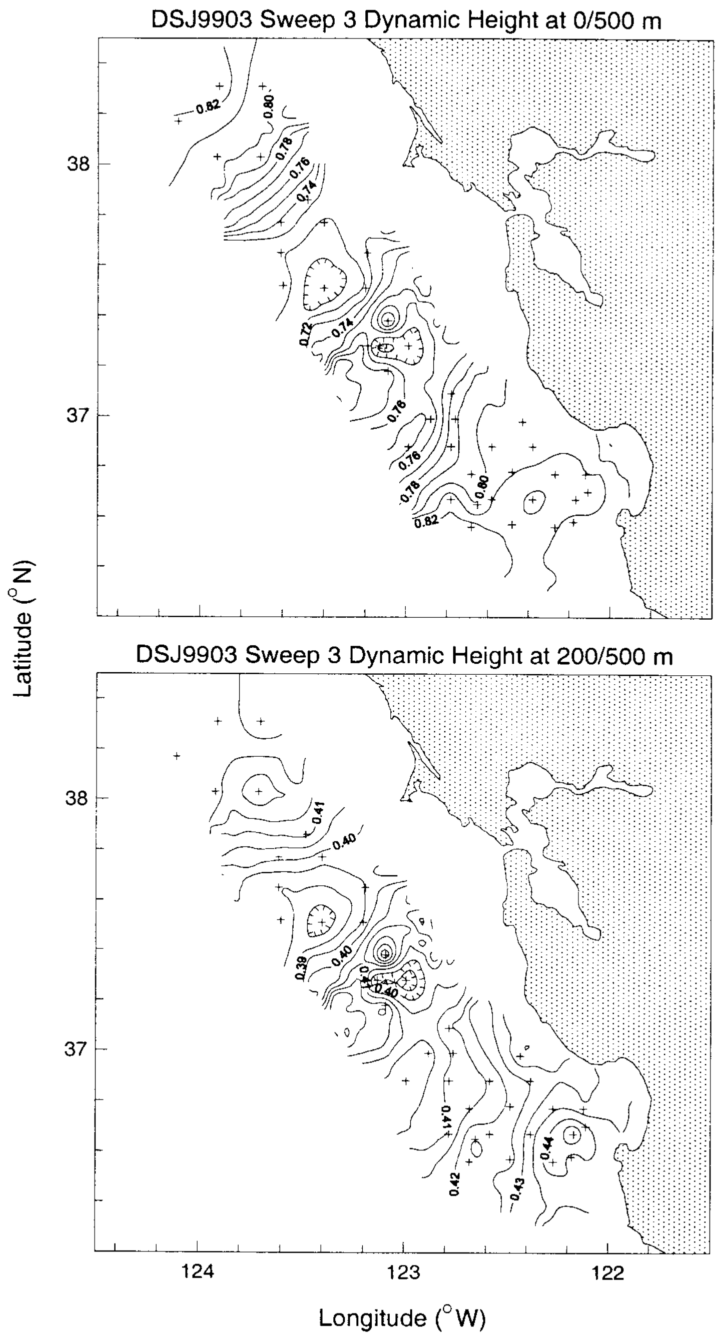
DSJ9903 Sweep 3 Point Reyes



APPENDIX 9: DYNAMIC HEIGHT TOPOGRAPHY FOR DSJ9903


DSJ9903 Sweep 1 Dynamic Height at 0/500 m
DSJ9903 Sweep 1 Dynamic Height at 200/500 m
Latitude (°N)
38
37
Longitude (°W)
124
123
122


DSJ9903 Sweep 2 Dynamic Height at 0/500 m
0.80
0.82
0.84
0.86
0.78
0.76
0.74
38
37
Latitude (°N)
DSJ9903 Sweep 2 Dynamic Height at 200/500 m
0.42
0.43
0.40
0.41
124
123
122
Longitude (°W)


DSJ9903 Sweep 3 Dynamic Height at 0/500 m
DSJ9903 Sweep 3 Dynamic Height at 200/500 m
Latitude (°N)
Longitude (°W)
38
37
124
123
122

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