Exxon Valdez Oil Spill
Restoration Project Annual Report

Water Mass Variability and Circulation of PWS

Restoration Project 96320-M
Annual Report

This annual report has been prepared for peer review as part of the *Exxon Valdez* Oil Spill Trustee Council restoration program for the purpose of assessing project progress. Peer review comments have not been addressed in this annual report.

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Study History: Unexpectedly small Prince William Sound pink salmon runs in 1992 and 1993, and the almost complete collapse of the herring fishery in 1993, prompted the EVOS Trustee Council to initiate ecosystem-level studies of the region to investigate possible environmental reasons for these disasters. A collaborative effort involving the University of Alaska Fairbanks, the Prince William Sound Science Center, the Prince William Sound Aquaculture Corporation, and Alaska Department of Fish and Game resulted in the development of a coordinated plan in the fall of 1993. After substantial review. Sound Ecosystem Assessment (SEA) was approved for funding April 11, 1994. A scope of work for SEA was projected over 5-8 years at that time. Annual reports were issued in 1995 by D. K. Salmon entitiled Descriptive Physical Oceanography (project number 94320-M), and in 1996 by S. L Vaughan entitiled Observational Physical Oceanography in Prince William Sound and the Gulf of Alaska (project number 95320-M), both as chapter contributions to the single compiled report of all SEA FY94 and FY95 projects. Project results were presented in 1996 at one professional meeting (Vaughan, S.L. and D.K. Salmon, 1996: The Upper Layer Density Structure at the Entrance to Prince William Sound. Presented at the AGU Ocean Sciences Meeting, San Diego, CA). A journal article was submitted for publication in 1996 (Gay, S.M., 1996: Seasonal Changes in Hydrography of Embayments and Fjords of Prince William Sound, Alaska during Spring and Summer 1994, Fall 1995, and Late Winter 1996. In IAPSO Conference Proceedings).

Abstract: Hydrographic surveys and current velocity measurements in 1994 through 1996 show significant seasonal and interannual variability in water mass properties and circulation patterns in Prince William Sound (PWS). Cruises were conducted in April, June, September, and December 1996. Conditions are coldest and saltiest in April, and warmest and freshest in September. The upper 20 meter layer was warmer and saltier in 1996 than 1995. In April 1996, a small anticyclonic circulation seemed to form at Hinchinbrook Entrance. Outflow at Montague Straight is confined to a small surface jet in April. In June 1996, deep inflow appears to be present at Hinchinbrook Entrance. June outflow at Montague Straight is generally weak. In September at Montague Straight, the flow was southwestward except for a shallow layer of surface inflow. A cyclonic circulation in the central Sound appears in September of all years. In December at Hinchinbrook Entrance, there was inflow in the upper 150 m and outflow below. Physical data (temperature, salinity, density, and current velocity) will be correlated with phytoplankton, zooplankton, and nekton distibution and abundance. These data will also be incorporated into a numerical circulation model. The goal of this project is to identify physical factors that control the production of pink salmon and Pacific herring in PWS.

Key Words: physical oceanography, temperature, salinity, circulation, Prince William Sound.

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Executive Summary

Large scale hydrographic cruises were conducted in PWS in spring. summer, and fall months of 1994, 1995, and 1996. One winter cruise was conducted in 1996. Measurements of temperature (T), salinity (S), oxygen, current velocities, fluourescence, nutrient content, phytoplankton abundance, and zooplankton abundance were collected on nearly all cruises. Seasonal means of temperature and salinity were created and compared to the numerical model predictions. Dynamic height contours were created and used to infer the general circulation patterns. Profiles and vertical section contours were used to show the appearence of upper level stratification in the spring of each year, and differences in the deepening of the mixed layer. T/S diagrams were used to identify different water masses. and identify regions of mixing.

Horizontal current vectors calculated from towed acoustic Doppler current profiler (ADCP) measurements were plotted for each cruise at various depths. In 1996, repeat ADCP transects during periods of maximum flood and maximum ebb tide were made at critical transport regions in Hinchinbrook Entrance, Montague Straight, and Knight Island Passage. Velocities were averaged over both tide stages to remove the tidal contribution. Vertical sections of north/south and east/west velocities were created for each cruise.

To capture the physical processes that affect juvenile Pacific herring, measurements were taken on several nearshore research cruises conducted by the SEA herring project (320-T). Temperature, salinity, oxygen, current velocity, fluourescence, and zooplankton data were collected in several bays and fjords around PWS starting in October 1995. In 1996, the number of bays was reduced to 4: Whale Bay, Eaglek Bay, Simpson Bay, and Zaikof Bay. Vertical sections of temperature, salinity, density, and current velocity were created for each cruise. Horizontal contours of temperature, salinity, and density, and horizontal velocity vector plots were also created.

Throughout 1996, the upper 20 meter layer was both warmer and saltier than in 1995. Maximum differences occured in fall. The fall 1996 T/S properties were similar to fall 1994 (both warmer and saltier than 1995). Deeper layers showed less variability. The dynamic heights suggest that in 1996, the Sound was subject to greater flushing than in 1995. Dynamic height contours also reveal the existance of a closed cyclonic circulation in the fall of all three years. Vertical T/S sections show upper layer stratification in the spring of 1996, not present in spring of 1995. The water mass properties at Hinchinbrook Entrance are dependent on tide stage, resembling Gulf of Alaska (GOA) water during flood tide, and central Sound water during ebb tide.

The current velocity vector plots show that velocities at 100 meters were not negligable as assumed in previous work, but could be significant and opposite in direction to surface flows. Velocity sections in 1996 show weak flow below 20 meters in northern Montague Straight, previously thought to be a region of strong outflow. Sections averaged over both stages of the tide in 1996 show significant seasonal differences. In April the flow on the western side of Hinchinbrook Entrance was northward, while the flow on the east side was southward. This is consistant with the circulation of an anticyclonic eddy. Dynamic height contours suggest an anticyclonic eddy located in Hinchinbrook Entrance in April 1996. In June, a strong northward flow is present near the bottom at Hinchinbrook Entrance. In southern Montague Straight, the April averaged repeat sections show an intense southwestward jet down to about 50 meters on the western side. In June, the flow is more uniform. In

September, the mean flow in Montague Straight is actually northward in the upper 30 meter layer, and southwestward below. In December at Hinchinbrook Entrance the mean flow is northward in the upper 150 meters, and southward below.

The nearshore oceanographic data from the bays in PWS is just now starting to be compiled. Evidences of density fronts exist, along with horizontal current velocity shear. Large differences in temperature and salinity exist between bays at the same time of year. Vertical sections of velocity show the currents in these bays to be extremely complex and seasonally variable. Differences exist between the head and the mouth of the bay in nearly all cases. No anoxic deep layers were found.

Introduction

The Sound Ecosystem Assessment (SEA) is aimed at identifying the primary factors that control the production of pink salmon and Pacific herring in Prince William Sound (PWS). A main hypothesis of SEA is that physical conditions, such as ocean temperature and salinity, current velocities, and atmospheric forcing, primarily determine the survival of embryos and juvenile fish. Processes that control the physical environment include tidal motions, wind stress, seasonal heating and cooling, precipitation, river/glacial runoff, inflow and outflow of Gulf of Alaska (GOA) water, and longer term events like El Nino and the Southern Oscillation (ENSO). Time scales of these processes range from hours to decades, and space scales range from tens of meters to O(100 km). The purpose of this research is to identify the dominant physical processes that influence the distribution and abundance of pink salmon and Pacific herring in PWS.

Background

A great deal of work has been done on the GOA and the Alaska Coastal Current (ACC) since the 1970s. The seasonal variations of quantities such as dynamic height, baroclinic geostrophic transport, wind forcing, freshwater discharge, and coastal upwelling, have been described (e.g. Royer and Emery, 1987; Johnson et al, 1988; Royer, 1981a,b; Royer, 1979; Royer et al, 1990). Only one manuscript has been published dedicated to the physical oceanography of PWS (Niebauer et al (1994)). They focused on two periods: 1977-1979, and 1989, after the Exxon-Valdez oil spill. Hydrographic data were used to created dynamic topographies (0/100 meter). Monthly means of baroclinic geostrophic transport (relative to 100 m) were calculated at Hinchinbrook Entrance and Montague Straight. Current meter moorings deployed over 15 months from 1977 to 1979 in both Hinchinbrook Entrance and Montague Straight collected data from 4 or 5 depths. Current velocity shears (20 meter values minus 100 meter values) from acoustic Doppler current profiler (ADCP) transects made in 1989 were also presented. Based on estimates of transports in various pressure layers, and estimates of the total volume of the layer, Niebauer et al (1994) made estimates of flushing rates of PWS. They concluded that about 40% of PWS was flushed from May through September, and that the Sound was flushed two to four times from October to April.

Previous EVOS Work (FY94 and FY95)

Work in this and previous years has focused on seasonal and interannual variability. Large scale hydrographic cruises were conducted in PWS in spring, summer, and fall months of 1994, and 1995. Measurements of temperature (T), salinity (S), oxygen, current velocities, and fluourescence were made with simultaneous measurements of nutrient content, phytoplankton abundance, and zooplankton abundance. Seasonal means of temperature and salinity were created and compared to the numerical model predictions. Dynamic height contours were created and used to infer the general circulation patterns. Profiles and vertical section contours were used to show the appearence of upper level stratification in the spring of each year, and differences in the deepening of the mixed layer. Profiles and vertical section contours also showed the presence of a temperature minimum layer in spring, and the errosion of this layer in summer and fall. T/S diagrams were used to identify different water masses, and identify regions of mixing. Horizontal current vectors calculated from towed acoustic Doppler current profiler (ADCP) measurements were plotted for each cruise at various depths, and used to calculate the baroclinic component of the velocity.

In addition to the large scale hydrographic cruises, an ADCP mooring was deployed in Hinchinbrook Entrance from June 1995 to October 1995. Spectral analysis revealed a weak diurnal tidal component to the deep flow in addition to the strong semi-diurnal component present throughout the water column. Velocities filtered to remove the tidal component showed outflow from near the surface to about 120 meters depth, and inflow below.

Work in FY96

The large scale circulation patterns and water mass properties of PWS in spring, summer, fall, and winter of 1996 are described in this report. Basin scale hydrographic surveys, and ADCP transects were conducted on four cruises in 1996. An upward looking ADCP mooring was deployed in Hinchinbrook Entrance to collect current velocity data. Two satellite tracked drifting buoys were released to track upper layer currents. These data are used to describe the seasonal evolution of the water mass properties (temperature, salinity, and density) and general circulation of PWS.

Objectives

The fundamental premise of the SEA research program in Prince William Sound is that information describing how ecosystem-level processes control the production of pink salmon and Pacific herring is needed to effect an informed restoration of non-recovering species. The main objective of the Observational Physical Oceanography program is to identify the dominant physical processes (tides, storms, seasonal heating, exchange with the GOA, etc.) that influence pink salmon and Pacific herring production in PWS. Specific goals for FY96 listed in the FY96 DPD were:

1. Determine the seasonal and interannual variability of the large scale (O(50 km)) water mass properties (temperature, salinity, and potential density) of PWS.

2. Document the current velocities and transport through Hinchinbrook Entrance as a function of time and depth.

3. Document the current velocities and transport through Hinchinbrook Entrance and Montague Straight as a function of horizontal distance, and depth.

4. Document the variability of the large scale meteorological variables (atmospheric pressure, air temperature, wind speed, wind velocity, etc.).

5. Document mesoscale structures (<O(10km)), such as eddies and density fronts, and correlate with zooplankton and nekton distributions in PWS.

6. Document small scale structures (O(1km)) in the nearshore regions and correlate with fish distributions.

7. Characterize the herring overwintering environment.

8. Use large scale physical oceanographic measurements (hydrographic and current velocity) and meteorological data to characterize 'river' and 'lake' conditions.

9. Provide the large scale physical oceanographic data to validate the numerical circulation model, and later for assimilation into the model.

10. Use the model results to identify critical regions and time periods for data collection.

Nearly all of these objectives were met. Objectives that were not met, or only partially met are noted below. Work remains to be done correlating the biological and physical data, especially in the nearshore regions (tasks 5, 6, and 7). Model validation and hypothesis testing (8, 9) is ongoing. Identifying critical times and regions for data collection (10) is partially completed.

Methods

Large scale oceanographic cruises were conducted in April, June, September, and December of 1996. Station locations and transects for each cruise are shown in Figure 1 (a)-(d). Samples collected at each station for each cruise are in Tables 1-4. The cruise dates are listed below.

April	15 - 21
June	15 - 21
September	10 - 16
December	5 - 11

The hydrographic data was collected using a SeaBird 911 CTD. Conductivity, temperature, and oxygen as a function of pressure were recorded at 1 dbar intervals. Salinity was calculated from conductivity using standard SeaBird software. The CTD sensors were calibrated annually by SeaBird Electronics. The CTD salinities and oxygens were not calibrated with bottle samples because of minimal annual sensor drift rate. In December, XCTDs (expendable CTDs) were used when conditions were too rough to use the CTD. Potential density was calculated from temperature, pressure, and salinity.

Instantaneous current velocity transects were collected using an RDI 150 kHz broadband acoustic Doppler current profiler (ADCP) deployed from the stern of the ship in a towed body. Most transects were in water less than 400 m depth so that bottom tracking was available. The bin length was 8 m for most of the data. The ADCP generally measured flows from about 20 m depth to the bottom.

To calculate a coarse approximation of the mean flow without the tidal component, repeat ADCP transects were made during periods of maximum flood and maximum ebb tide at critical transport regions in Hinchinbrook Entrance, Montague Straight, and Knight Island Passage. The tidal component was assumed to be barotropic. Mean velocities were calculated by averaging over both tide stages. Vertical sections of north/south and east/west velocities were created for each cruise.

A time series of current velocities as a function of depth will be obtained from an upward looking ADCP mooring (RDI 150 kHz broadband) deployed in Hinchinbrook Entrance in September 1996. Velocities are recorded every 30 minutes using an 8 m bin length. The mooring is scheduled for retrieval in May 1997. Data from this mooring will not be presented in this report.

During the mooring deployment. 4 bottom pressure gauges were deployed in Hinchinbrook Entrance. Pressure gradients across the Entrance may be used to calculate coarse estimates of the transport through the Entrance. Bottom pressure gauges could be a cost effective monitoring tool if velocities calculated from the pressure differences agree with the ADCP velocities. The pressure gauges were retrieved in March 1997, but the data have not been analyzed at the time of this report. Pressure gauge data will not be presented in this report.

Two satelite tracked ARGOS drifting buoys were deployed in Hinchinbrook Entrance in August 1996. The buoys were drogued with an approximately 6 meter long canvas 'sock', extending from about 12 meters to 18 meters below the surface. The drifters followed currents at roughly 15 meters. The position of the drifters were tracked by a satellite (ARGOS) and transmitted to the lab.

Meteorological data from C-MAN stations in PWS is available from the National Data Buoy Center (NDBC). The stations are located at Bligh Reef, Potato Point, Seal Rocks, and Mid-Sound (in the central Sound). Wind speed, wind direction, wave height, barometric pressure, air temperature, water temperature, dew point temperature, and visibility are measured every 30 minutes. The buoys became operational in May 1995, and have collected mostly uninteruped data since then.

To capture the physical processes that affect juvenile Pacific herring, measurements were taken on several nearshore research cruises conducted by the SEA herring project (320-T). Temperature, salinity, oxygen, current velocity, fluourescence, and zooplankton data were collected in several bays and fjords around PWS starting in October 1995. In 1996, the number of bays was reduced to 4: Whale Bay, Eaglek Bay, Simpson Bay, and Zaikof Bay. Cruises took place in March, July, August, October, and November. Vertical profiles and sections of temperature, salinity, density, and current velocity were created for each cruise. Horizontal contours of temperature, salinity, and density, and horizontal velocity vector plots were also created.

To relate temperature and salinity to zooplankton distributions and fluorescence in mesoscale and small scale features, a combined instrument designed by Chelsea Instruments called an Aquashuttle was towed from the ship on both the large scale cruises and the nearshore herring cruises. The Aquashuttle consists of a Focal Technologies optical plankton counter (OPC), to measure zooplankton, and a Chelsea Instruments Aquapack, which measures temperature, salinity, and fluorescence. The Aquashuttle is raised and lowered vertically from the surface to about 50 meters as it is towed, sampling continuously.

Results

Large Scale Water Mass Properties

Temperature, salinity, and potential density collected at the stations listed in Tables 1-4, were averaged over depth layers of roughly 20 meters, and contoured using GMT Version 3 programs (Wessel and Smith, 1995). The upper 20 meter mean temperatures for each cruise are shown in Figure 2(a)-(d). Mean salinities are in Figure 3(a)-(d), and mean potential densities are in Figure 4(a)-(d).

The upper 20 meter layer is coldest and saltiest in April. September is the warmest and freshest month. Temperature, salinity, and potential density are fairly uniform in the upper 20 meters in April. In June, a cold, salty, dense layer is centered just north of Montague Island. Fresher, warmer water is present at the northern and eastern periphery of the Sound. Large gradients in temperature and salinity are present. In September, a dome of colder, saltier water appears in the central Sound. Large salinity gradients exist, but temperature is fairly uniform. In December, both temperature and salinity are more uniform, but not as cold and salty as in April.

Figure 5 shows a time series of the upper 20 meter mean temperatures and salinities averaged over all stations for each cruise in 1995 and 1996. The upper layer in 1996 was both warmer and saltier than in 1995. The differences are slight in April, but by September the mean temperatures differ by about 1.6^oC, and salinities by about 1.8.

Vertical sections (0 to 100 m) of temperature, salinity, and potential density, from a north/south transect of the central Sound are shown for April, June, and September 1996 in Figures 6, 7, and 8. In April (Figure 6) a temperature minimum layer is centered at about 40 m. This layer was present throughout the Sound in April 1996, in various thicknesses and horizontal extent. A weak horizontal density front is present in April, separating fresher surface waters to the north of about NS4 (see Figure 1) from the well mixed southern half. In June (Figure 7), a doming of the deeper isopycnals is present, along with a density front at the surface. The sloping of the isopycnals is consistant with cyclonic circulation north of about CS12. By September (Figure 8), a homogeneous surface temperature layer has formed. The outcroping of the isopycnals is consistant with cyclonic circulation centered at about NS4.

The deepening of the mixed layer, and the appearance of vertical stratification with time is shown for one station in the central Sound (NS4) in Figure 9. During the winter and early spring months (December through April), the Sound is vertically homogeneous. December is very weakly stratified. By June a shallow mixed layer has formed. Stratification is maximum in September. The step patterns in the June and September profiles are remnants of mixing events.

Dynamic heights (0/100 m) for April, June, and September 1996 are shown in Figure 10(a)-(c). Dynamic heights contours indicate the sense and relative strength of the geostrophic current shear from 100 m to the surface. If velocities at 100 m are weak, the dynamic heights represent the sense and relative strength of the geostrophic current at the surface. Gradients are weak in April, but some suggestion of an anticyclonic circulation at Hinchinbrook Entrance is present (Figure 10(a)). In June, a pattern consistant with a basin scale cyclonic circulation appears, with inflow at Hinchinbrook Entrance and weak outflow at Montague Straight (Figure 10(b)). In September, strong inflow in Hinchinbrook Entrance is suggested, with a smaller, weaker cyclonic circulation in the central basin (Figure 10(c)). The contours in September show weak or no outflow at Montague Straight.

Large Scale Circulation

Actual current velocities were measured by a towed, downward looking 150 kHz ADCP. Velocity vectors at the 20 m level and the 100 m level for April, June, September, and December 1996 are shown in Figures 11-14. Only velocities calculated using bottom tracking are included. Tides have not been removed from these velocities. Interpretation of these figures is complicated by the tidal contribution, especially at Hinchinbrook Entrance and lower Montague Straight.

In the central Sound and in Hinchinbrook Entrance, the April (Figure 11) velocities are weaker at depth, but generally in the same direction as those at 20 m. The strongest velocities at both depths are at and just inside Hinchinbrook Entrance. Some suggestion of cyclonic curvature is present in the northern Sound. In June (Figure 12), except at Hinchinbrook Entrance and lower Montague Straight, velocities at 100 m are very weak. A current reversal is present along the north/south GOA transect. The flow in the central Sound at 20 m is generally northward. In September (Figure 13), the deep velocities in the central Sound are weak. Flow at Hinchinbrook Entrance and Montague Straight are still dominated by tides. A weak cyclonic circulation is present in the central Sound at 20 m. Flow in Knight Island Passage is northward at both depths. In December (Figure 14), the inflow at Hinchinbrook Entrance is very strong. At least part of the outflow in lower Montague straight comes from Knight Island Passage. The flow in the western half of the central Sound is mostly barotropic and to the west. These velocities require more careful analysis to separate tides from the mean flow.

The tidal contribution was removed at several locations in the Sound by averaging sections from repeat ADCP transects made during maximum flood and maximum ebb tide. Sections of mean north and east velocities, without the tidal component, from Hinchinbrook Entrance in April and December are shown in Figures 15(a) and (c). Velocity sections from the ebb tide only in June are shown in Figure 15(b) (no flood tide transect was made in June). No repeat transects were made in Hinchinbrook Entrance in September. Sections of mean north and east velocities from lower Montague Straight in April, June, and September are shown in Figures 16(a)-(c). Velocity sections from the ebb tide only in December are shown in Figure 16(d) (no flood tide transect was made in December). The sections for Hinchinbrook Entrance were from stations HE13 to HE11, and from stations SEA31 to SEA33 for the Montague Straight sections (see Figure 1).

At Hinchinbrook Entrance in April, the mean flow above about 100 m was northeastward on the western side of the Entrance, and southeastward on the eastern side (Figure 15(a)). This pattern is consistant with the circulation of an anticyclonic eddy centered just south of the transect line. The June velocities (Figure 15(b)) from the ebb tide only were mostly southwestward except near the bottom. The weaker southward flow near the bottom (and the stronger eastward component) on an ebb tide suggests that the deep mean flow is northward or into the Sound in June. The mean velocities in December (Figure 15(c)) show a northwestward upper layer flow (above 100 to 150 m), overlying a deep southwestward flow. The velocities are more uniform horizontally across the Entrance in December than in April and June. Magitudes are greater in December than in April.

At Montague Straight in April, a strong southwestward jet was present on the westward side of the Straight (Figure 16(a)). Velocities were weak elsewhere. By June, the jet had disappeared (Figure 16(b)). Velocities were weak southwestward everywhere, except for a shallow surface layer of northeastward flow. By September, the shallow northeastward surface layer had deepened and intensified (Figure 16(c)). Flow in the deeper layers was southward. The ebb tide velocities in December are southwestward everywhere except for a mid-depth northwestward flowing layer (Figure 16(d)). Southward velocities are intensified at the surface. The appearance of a northward flow during an ebb tide, and a weaker southward flow at depth could mean that the mean deep transport in Montague Straight in December is very weak outflow or perhaps inflow.

An attempt to document the large scale circulation of PWS using satellite tracked drifting buoys was made in August 1996. Two ARGOS tracked drogued drifters were released just inside Hinchinbrook Entrance, off Bear Cape, on August 2. The mean depth of the drogues was 15 m. Both drifters flowed north for about 2 days, then turned southward and exited the Sound on August 5. One drifter (25651) stopped transmitting soon afterward. Part of the path of the second drifter (25652) is shown in Figure 17. The drifter flowed south, then west past Montague Straight and Resurrection Bay. It finally stopped transmitting just east of Cook Inlet.

Meteorological Data

Wind speeds from the NDBC C-MAN Mid-Sound buoy for April, June, September, and December 1996, are shown in Figure 18(a)-(d). The julian hours for each cruise based on midnight of the first day of each month are listed below.

April:	336-504
June:	336-504
September:	216-384
December:	96-264

Except for December, the mid-Sound winds were light to moderate during all cruises. Winds during the April and June cruises were generally 5 m/s or less, which may account for the formation of surface stratification in those months (see Figures 6 and 7). In September, with sustained wind of around 10 m/s, a shallow surface mixed layer appeared (Figure 8). During the December cruise, periods of 10 - 15 m/s winds were not uncommon.

Nearshore Bay and Fjord Water Mass Properties and Circulation

Hydrographic measurements were made for 4 nearshore areas in March, July, August, October, and November 1996. Current velocity measurements were made in March, August, and October. Two areas, Whale Bay and Eaglek Bay, are fjords, and two, Simpson Bay and Zaikof Bay, are bays. Station locations are shown in Figures 19(a)-(d). To demonstrate the seasonal evolution of the water mass properties, temperature and salinity were averaged at each depth over the entire bay for each cruise. Profiles are shown in Figures 20 - 23. Unlike most of PWS, Eaglek Bay and Whale Bay (both fjords) retain their upper layer stratification throughout the year (Figures 20 and 21). In March, the stratification is weakened, but still present. The fresh, cold suface layer is never entirely mixed. Temperature maximum layers exist in the fjords in October and November. In contrast, Simpson Bay and Zaikof Bay (both bays) resemble the neutrally stratified majority of PWS in March (Figures 22 and 23). In October and November, Zaikof Bay is more thoroughly mixed than Simpson Bay.

Differences in March temperatures and salinities for a given bay between 1995 and 1996 were slight. Differences in October temperatures and salinities were also slight in all bays except Whale Bay. In October 1995, the upper 20 m of Whale Bay was both colder and fresher than in October 1996.

Magnitudes of temperature and salinity vary greatly between the bays and fjords. Figures 24 and 25 show mean March temperatures and salinities averaged over the upper 10 m for each of the 4 bays. Simpson Bay is the warmest, followed by Zaikof and Whale (Figure 24). Eaglek Bay is the coldest in this layer. Zaikof Bay is the saltiest, followed by Simpson and Eaglek (Figure 25). Whale Bay is the freshest. A temperature and salinity (and density) front is present at the mouth of Zaikof Bay (Figures 24(d) and 25(d)) in March 1996.

Current velocity vectors at the 10 m level for a flood tide in March and an ebb tide in October 1996 are shown in Figures 26 and 27 for each bay. Except for Eaglek Bay, the currents are generally weaker at the head than at the mouth of the bays. The currents at the mouths of the bays have a strong tidal component, especially Simpson and Zaikof Bay. The flow at the mouth of Whale Bay even during ebb tide is inward (Figures 27(b)). A strong current shear exists at the mouth of Zaikof Bay on both tides. These features at the mouths of the bays could be responsible for the retention of zooplankton and juvenile fish in the bay. An anticlyclonic eddy is present at the mouth of Zaikof Bay in October (Figure 27(d)), which could also act as a retention mechanism. These hydrographic features and circulation patterns will be compared to zooplankton and juvenile fish distribution and abundance (SEA project 320-T).

OPC and Aquapack Data

Results from a west to east transect in Orca Bay in May 1996 are shown in Figure 28(a)-(e). The transect starts at 60.58 N, 146.41 W and runs roughly 9 nm east to 60.58 N, 146.13 W. Temperature, salinity, and fluorescence (Figures 28(a)-(c)) were measured by the Aquapack. Total particles and *Neocalanus*-sized particles (Figures 28(d) and (e)) were measured by the OPC. *Neocalanus* spp copepods are a main food source for planktivorous fishes in PWS.

Figure 28(a) shows a deep (20 m) warm layer toward the western side (left side of Figure 28) of the transect, and a thermocline that rises from 20 m to about 10 m on the eastern side of the transect. Also in the eastern portion of the transect is a shallow low salinity layer (Figures 28(b)). The transect passes through a horizontal density front, going from a well mixed region in the west to a vertically stratified region in the east.

Figure 28(c) shows a layer of high fluorescence, or chlorophyll content, near the thermocline. The layer follows the thermocline, shoaling and becoming more concentrated going from west to east. The OPC total particle count Figure 28(d) has a similar pattern. Particles were deeper in the west, then shallower and more concentrated in the east. Total counts includes all size ranges, and probably includes some phytoplankton in addition to zooplankton. *Neocalanus*-sized counts (particles with equivalent spherical diameters between 1 and 4 mm) are also concentrated near the chlorophyll maximum (Figure 28(e)).

Discussion

The dynamic height (0/100m) contours from June 1996 (Figure 10(b)) are similar in pattern and magnitude to those calculated by Niebauer et al (1994) for June 1976. The Niebauer et al results suggested northward flow in June also. Values in 1976 ranged from 325 - 350 dyn-cm. Values in 1996 ranged from 310 to 340 dyn-cm. The September 1996 dynamic heights were lower than those found by Niebauer et al in September 1978. Values ranged from 380 - 420 dyn-cm in 1996, and from 420 - 450 dyn-cm in 1978. Dynamic heights from September 1995 were more similar to those in 1978. Values from Septmeber 1995 ranged from 420 -460 dyn-cm. The contours in September of all 3 years (1996, 1995, and 1978) suggested cyclonic circulation.

The dynamic height contours may be compared with the ADCP velocities even though the dynamic heights represent flow at the surface, and the most shallow ADCP velocity depth is 20 m. The dynamic height contours from April 1996 suggested an anticyclonic circulation at Hinchinbrook Entrance, and a weak outflow through Montague Straight (Figure 10(a)). Mean velocities (without tides) from repeat ADCP transects at Hinchinbrook Entrance (Figure 15(a)) were consistent with an anticyclonic circulation there. Mean velocities (without tides) from repeat ADCP transects at Montague Straight (Figure 16(a)) showed the presence of a shallow, narrow southward jet, with weaker velocities throughout most of the section.

The temperature minimum layer (T $< 4^oC$) present in April 1996 (Figure 6) was also present in April and May 1995, and to a lesser extend in June 1995. The layer was not present in June 1996. In March 1995, a cold layer with T $< 4^oC$ extended from the surface down to about 200 m.

In June 1996, vertical sections of potential density (Figure 7) suggested a cyclonic circulation in the central Sound. Dynamic height contours in June (Figure 10(b)) also indicated the presence of a cyclonic circulation. Figure 10(b) also indicated strong inflow at Hinchinbrook Entrance and weak outflow at Montague Straight. The towed ADCP velocities at 20 m showed strong northward flow on the eastern side of the central basin (Figure 12). Weak outflow at Montague Straight was confirmed by the mean ADCP velocities (Figure 16(b)) in June. In April through June 1978, Niebauer et al (1994) found the 30 meter flow at Montague Straight to be light and variable.

In June 1994 and 1995, dynamic heights did not indicate strong inflow at Hinchinbrook Entrance, or the existance of a cyclonic circulation. The dynamic height gradients were weak everywhere. The July 1994 dynamic heights did show northward flow in the central Sound.

The ARGOS satellite tracked drifting buoy released in August 1996, showed that the currents near Hinchinbrook Entrance in the 12 to 18 m depth range were southward. Southward flow at Hinchinbrook Entrance in August is consistant with the moored ADCP measurements in the summer of 1995, and with the measurements of Niebauer et al in summer 1978. Weak, often southward upper layer flow was found to overlie a strong northward deep flow (Niebauer et al, 1994).

In September 1996, vertical sections of potential density (Figure 8) suggested a weak cyclonic circulation in the central Sound. Dynamic height contours in September (Figure 10(c)) also indicated the presence of a weak cyclonic circulation, as did ADCP velocities at 20 m (Figure 13). The September 1994 and 1995 dynamic heights showed well defined cyclonic circulations in central PWS.

The 1996 dynamic heights showed strong inflow at Hinchinbrook Entrance in September. No mean ADCP velocities (without tides) were obtained for September, but the December mean ADCP velocity sections (Figure 15(c)) showed strong inflow above about 100 m. In September and December 1978, Niebauer et al (1994) found strong upper layer inflow (above 100m) at Hinchinbrook Entrance, overlying weak and variable deep flow.

Mean ADCP velocities at Montague Straight in September 1996 showed a shallow surface inflow overlying a deeper outflow. Niebauer et al (1994) found a similar pattern at Montague Straight in August and September 1978. The flow at 30m was northeastward, and southwestward below.

The observation that Eaglek Bay and Whale bay (both fjords) retain their upper layer stratification in March, while the majority of the Sound is homogeneous, may mean that these regions are less connected to the Sound than bays such as Simpson and Zaikof. Differences in temperature and salinity exist between the 4 bays in 1996, but differences between 1995 and 1996 for a single bay were small. Some evidence of potential retention mechanisms (fronts, eddies) exist, but these features need to be correlated with fish data before any conclusions can be made.

Conclusions

Conclusions are listed for each of the objectives listed previously.

1. Seasonal and interannual differences in the large scale water mass properties have been demonstrated. Vertical sections and horizontal contours of temperature and salinity illustrate the magnitude of the seasonal differences for April, June, September, and December 1996. The upper 20 m layer was warmer and saltier in 1996 than in 1995. Dynamic heights in June 1996 were similar to those in June 1976. Dynamic heights in September 1995 were similar to those in Septmeber 1978 (Niebauer et al. 1994).

2. The ADCP moored in Hinchinbrook Entrance will be retrieved in May 1997. Current velocities and transports through Hinchinbrook Entrance as a function of time and depth will be presented in a separate publication.

3. Mean current velocities in Hinchinbrook Entrance and Montague Straight, with the tidal component removed, were presented for April, June, September, and December 1996. At Hinchinbrook Entrace in April, half the transect shows inflow and half outflow. In June, a deep inflow may be present near the bottom. In December, the upper 100 m layer was flowing in, while deeper layer was flowing out. Niebauer et al (1994) found a similar December pattern in 1978. At Montague Straight, April outflow was confined to a narrow surface jet. June outflow was more uniform and weak. In September, the surface flow was into the Sound, and opposite to the deep flow. Niebauer et al (1994) found similar patterns in June and September 1978.

4. An example of one meteorological variable (wind) was presented. Other variables are available for comparison to the observed water mass and circulation changes.

5. Mesoscale features (eddies, fronts) are evident in the upper layer temperature and salinity contour plots (e.g. an eddy north of Montague Island in June), and in the ADCP current vector plots. An example of a correlation between the thermocline depth and plankton concentrations was shown for May 1996. The phytoplankton and zooplankton

were concentrated near the thermocline. The plankton were deeper on the mixed side of a density front, and rose with the thermocline. More rigorous correlation of physcial features with zooplankton and fish distributions remains to be done.

6. Small scale features (eddies, fronts) are evident in the nearshore temperature and salinity contours (the front at the mouth of Zaikof Bay), and in the ADCP current vector plots. Correlating these features with juvenile herring distributions remains to be done.

7. At least from 1995 to 1996, no large differences in the herring overwintering environment (in each bay) was observed. Further analysis is required to state conclusions confidently.

Work on the remaining objectives, characterizing 'river' and 'lake' conditions, validating the numerical circulation model, and identifing critical times and regions for data collection, is ongoing. Research in FY97 will focus on these tasks.

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Table 1: April 1996 Oceanography Cruise Stations

cast	stn	date	time	lat	long	samples
1	OB2	4/15/96	1445	60 35.20	146 24.60	CTD/phyto/zoop
2	CS9	4/15/96	1800	60 35.10	146 44.40	CTD/phyto/zoop
3	CFOS13	4/15/96	2015	60 35.07	146 55.68	CTD/phyto/zoop
4	CS6	4/16/96	0040	60 35.10	147 8.60	CTD
5	CFOSBY	4/16/96	0120	60 36.30	147 12.20	CTD/phyto/zoop
6	CS1	4/16/96	0355	60 34.50	147 21.90	CTD/phyto
7	NS5	4/16/96	0710	60 46.80	147 9.00	CTD/phyto
8	NWS4	4/16/96	0850	60 46.80	147 22.20	CTD/phyto/zoop
9	NWS4A	4/16/96	1230	60 50.00	147 22.20	CTD
10	SEA22C	4/16/96	1455	60 45.00	147 41.00	CTD
11	SEA22	4/16/96	1635	60 40.50	147 41.00	CTD/phyto/zoop
12	SEA22D	4/16/96	1837	60 36.00	147 41.00	CTD
13	SEA16	4/16/96	2130	60 31.10	147 54.50	CTD
14	SEA18	4/16/96	2220	60 31.10	147 50.00	CTD/phyto/zoop
15	SEA18B	4/17/96	0000	60 31.10	147 45.00	CTD
16	SEA25	4/17/96	0430	60 18.10	147 58.00	CTD/phyto/zoop
17	SEA26	4/17/96	0600	60 12.80	147 59.60	CTD
18	SEA27	4/17/96	0715	60 10.20	147 53.60	CTD/phyto/zoop
19	SEA39	4/17/96	1030	60 3.90	147 55.40	CTD/phyto
20	SEA28	4/17/96	1243	60 8.20	147 46.10	CTD/phyto
21	SEA29	4/17/96	1410	60 6.80	147 48.30	CTD/phyto
22	SEA31	4/17/96	1850	60 2.80	147 47.10	CTD/phyto
23	SEA32	4/17/96	1930	60 1.90	147 44.40	CTD/phyto/zoop
24	SEA33	4/17/96	2030	60 0.90	147 41.90	CTD/phyto
25	HE13	4/18/96	0750	60 15.70	146 53.50	CTD/phyto
26	HE12	4/18/96	0910	60 15.70	146 49.40	CTD/phyto/zoop
27	HE11	4/18/96	1015	60 15.70	146 45.30	CTD/phyto
28	GOA0	4/18/96	1445	60 13.00	146 40.00	CTD/phyto/rad
29	CS5	4/18/96	2020	60 22.50	146 47.50	CTD/phyto
30	CS12	4/18/96	2230	60 22.30	146 56.20	CTD/phyto
31	MS5	4/19/96	0600	60 8.40	147 30.60	CTD/phyto
32	MS5A	4/19/96	0700	60 10.00	147 36.00	CTD/phyto
33	MS5B	4/19/96	0830	60 11.50	147 41.00	CTD/phyto
34	MS7	4/19/96	2300	60 21.00	147 30.00	CTD/phyto
35	MS10	4/20/96	0115	60 30.00	147 30.00	CTD/phyto
36	MS9	4/20/96	0250	60 27.00	147 21.00	CTD/phyto
37	MS8	4/20/96	0455	60 24.00	147 12.00	CTD/phyto
38	NS4	4/20/96	1930	60 31.20	146 55.80	CTD/phyto
39	CFOS13	4/20/96	2100	60 35.07	146 55.68	CTD/phyto/zoop
40	NS3	4/20/96	2240	60 39.00	146 55.80	CTD/phyto
41	NS2	4/21/96	0005	60 43.20	146 55.80	CTD/phyto
42	NS1	4/21/96	0100	60 46.80	146 55.80	CTD/phyto/zoop

Table 2: June 1996 Oceanography Cruise Stations

cast	stn	date	time	lat	long	samples
1	OB2	6/15/96	1115	60 35.20	146 24.60	CTD/phyto/zoop1
2	CS9	6/15/96	2000	60 35.10	146 44.40	CTD/phyto/zoop1
3	CFOS13	6/15/96	2015	60 35.07	146 55.68	CTD/phyto/zoop1
4	CS6	6/16/96	0030	60 35.10	147 8.60	CTD/phyto
5	CFOSBY	6/16/96	0120	60 36.30	147 12.20	CTD/phyto/zoop1
6	CS1	6/16/96	0300	60 34.50	147 21.90	CTD/phyto
7	NS5	6/16/96	0710	60 46.80	147 9.00	CTD/phyto
8	NWS4	6/16/96	0925	60 46.80	147 22.20	CTD/phyto/zoop1/zoop2
9	NWS4A	6/16/96	1110	60 50.00	147 22.20	CTD/phyto
10	SEA4	6/16/96	1700	60 46.20	147 64.90	CTD/phyto/zoop1/zoop2
11	SEA22C	6/16/96	2130	60 45.00	147 41.00	CTD/nutr
12	SEA22	6/16/96	2315	60 40.50	147 41.00	CTD/phyto/zoop1/zoop2
13	SEA22D	6/17/96	0210	60 36.00	147 41.00	CTD
14	SEA18	6/17/96	0440	60 31.10	147 50.00	CTD/phyto/zoop1
15	SEA23D	6/17/96	0810	60 25.00	147 52.50	CTD/phyto
16	SEA23C	6/17/96	0845	60 25.00	147 54.50	CTD/phyto
17	SEA23B	6/17/96	0920	60 25.00	147 56.50	CTD
18	SEA25	6/17/96	1445	60 18.10	147 58.00	CTD/phyto/zoop1/zoop2
19	SEA26	6/17/96	1645	60 12.80	147 59.60	CTD/phyto
20	SEA27	6/17/96	1750	60 10.20	147 53.60	CTD/phyto/zoop1
21	SEA29	6/17/96	1930	60 6.80	147 48.30	CTD/phyto
22	SEA31	6/17/96	2105	60 2.80	147 47.10	CTD
23	SEA32	6/17/96	2140	60 1.90	147 44.40	CTD/phyto/zoop1/zoop2
24	SEA33	6/17/96	2250	60 0.90	147 41.90	CTD
25	MS5B	6/18/96	1444	60 11.50	147 41.00	CTD/phyto
26	MS5A	6/18/96	1535	60 10.00	147 36.00	CTD/phyto/zoop1
27	MS5	6/18/96	1630	60 8.40	147 30.60	CTD/phyto
28	MS7	6/18/96	2245	60 21.00	147 30.00	CTD/phyto/zoop1
29	MS10	6/19/96	0055	60 30.00	147 30.00	CTD/phyto
30	MS9	6/19/96	0250	60 27.00	147 21.00	CTD/phyto/zoop1/zoop2
31	MS8	6/19/96	0405	60 24.00	147 12.00	CTD/phyto
32	GOA0	6/19/96	2200	60 13.00	146 40.00	CTD/phyto
33	GOA3	6/20/96	0010	60 7.00	146 40.00	CTD/phyto
34	GOA6	6/20/96	0220	60 0.00	146 40.00	CTD/phyto/zoop1/zoop2
35	HE11	6/20/96	0900	60 15.70	146 45.30	CTD/phyto
36	HE12	6/20/96	1009	60 15.70	146 49.40	CTD/phyto/zoop1
37	HE13	6/20/96	1106	60 15.70	146 53.50	CTD/phyto
38	CS5	6/20/96	1245	60 22.50	146 47.50	CTD/phyto
39	CS12	6/20/96	1350	60 22.30	146 56.20	CTD/phyto
40	NS4	6/20/96	1545	60 31.20	146 55.80	CTD/phyto
41	CFOS13	6/20/96	1650	60 35.07	146 55.68	CTD/zoop1/zoop2
42	NS3	6/20/96	1840	60 39.00	146 55.80	CTD/phyto
43	NS2	6/20/96	2000	60 43.20	146 55.80	CTD/phyto
44	NS1	6/20/96	2140	60 46.80	146 55.80	CTD/phyto/zoop1
	OB2	6/21/96	0730	60 35.20	146 24.60	zoop2

Table 3: September 1996 Oceanography Cruise Stations

cast	stn	date	time	lat	long	samples
1	OB2	9/10/96	1935	60 35.20	146 24.60	CTD
2	CS9	9/10/96	2235	60 35.10	146 44.40	CTD
3	CFOS13	9/11/96	0003	60 35.07	146 55.68	CTD
4	CS6	9/11/96	0148	60 35.10	147 8.60	CTD
5	CFOSBY	9/11/96	0242	60 36.30	147 12.20	CTD
6	CS1	9/11/96	0440	60 34.50	147 21.90	CTD
7	NS5	9/11/96	0825	60 46.80	147 9.00	CTD
8	NWS4	9/11/96	0957	60 46.80	147 22.20	CTD
9	NWS4A	9/11/96	1143	60 50.00	147 22.20	CTD
10	SEA22C	9/11/96	1431	60 45.00	147 41.00	CTD
11	SEA22	9/11/96	1605	60 40.50	147 41.00	CTD/zoop
12	SEA22D	9/11/96	1956	60 36.00	147 41.00	CTD
13	SEA18	9/11/96	2208	60 31.10	147 50.00	CTD
14	SEA23D	9/11/96	2355	60 25.00	147 52.50	CTD
15	SEA23C	9/12/96	0019	60 25.00	147 54.50	CTD
16	SEA23B	9/12/96	0100	60 25.00	147 56.50	CTD
17	SEA25	9/12/96	1309	60 18.10	147 58.00	CTD/zoop
18	SEA26	9/12/96	1647	60 12.80	147 59.60	CTD
19	SEA27	9/12/96	1829	60 10.20	147 53.60	CTD
20	SEA29	9/12/96	1952	60 6.80	147 48.30	CTD
21	SEA31	9/12/96	2106	60 2.80	147 47.10	CTD
22	SEA32	9/12/96	2146	60 1.90	147 44.40	CTD
23	SEA33	9/12/96	2237	60 0.90	147 41.90	CTD
24	MS5B	9/13/96	1050	60 11.50	147 41.00	CTD
25	MS5A	9/13/96	1142	60 10.00	147 36.00	CTD
26	MS5	9/13/96	1228	60 8.40	147 30.60	CTD
27	MS7	9/13/96	1527	60 21.00	147 30.00	CTD
28	MS10	9/13/96	1759	60 30.00	147 30.00	CTD
29	MS9	9/13/96	1927	60 27.00	147 21.00	CTD
30	MS8	9/13/96	2054	60 24.00	147 12.00	CTD
31	NS1	9/14/96	0403	60 46.80	146 55.80	CTD
32	NS2	9/14/96	0458	60 43.20	146 55.80	CTD
33	NS3	9/14/96	0603	60 39.00	146 55.80	CTD
34	CFOS13	9/14/96	0707	60 35.07	146 55.68	CTD
35	NS4	9/14/96	0825	60 31.20	146 55.80	CTD
36	CS12	9/14/96	1142	60 22.30	146 56.20	CTD
37	CS5	9/14/96	1343	60 22.50	146 47.50	CTD
38	HE13	9/14/96	1600	60 15.70	146 53.50	CTD
39	HE12	9/14/96	1700	60 15.70	146 49.40	CTD
40	HE11	9/14/96	1749	60 15.70	146 45.30	CTD
41	GOA0	9/14/96	1854	60 13.00	146 40.00	CTD
42	GOA3	9/14/96	2013	60 7.00	146 40.00	CTD

Table 4: December 1996 Oceanography Cruise Stations

cast	stn	date	time	lat	long	samples
1	OB2	12/5/96	1640	60 35.20	146 24.60	CTD
2	CS9	12/5/96	2051	60 35.10	146 44.40	CTD/zoop50
3	SEA22	12/7/96	0913	60 40.50	147 41.00	CTD/XCTD/XBT/ zoop50/zoop700/ zoop400/zoop200
	SEA23C	12/7/96	1445	60 25.00	147 54.50	XBT
4	SEA25	12/7/96	1614	60 18.10	147 58.00	CTD/zoop50/ zoop400/zoop200
5	SEA26	12/7/96	1902	60 12.80	147 59.60	CTD
6	SEA27	12/7/96	2029	60 10.20	147 53.60	CTD
7	SEA29	12/7/96	2204	60 6.80	147 48.30	CTD
8	SEA31	12/7/96	2323	60 2.80	147 47.10	CTD
9	SEA32	12/8/96	0011	60 1.90	147 44.40	CTD/zoop50
10	SEA33	12/8/96	0101	60 0.90	147 41.90	CTD
	HE12	12/10/96	0400	60 15.70	146 49.40	XCTD
11	CS5	12/10/96	1207	60 22.50	146 47.50	CTD
12	CS12	12/10/96	1340	60 22.30	146 56.20	CTD
13	NS4	12/10/96	1642	60 31.20	146 55.80	CTD
14	CFOS13	12/10/96	1841	60 35.07	146 55.68	CTD
15	NS3	12/10/96	2005	60 39.00	146 55.80	CTD
	NS2	12/10/96	2148	60 43.20	146 55.80	XCTD
	NS1	12/10/96	2249	60 46.80	146 55.80	XCTD/zoop50
	NS5	12/11/96	0100	60 46.80	147 9.00	XCTD
	CFOSBY	12/11/96	0320	60 36.30	147 12.20	XCTD

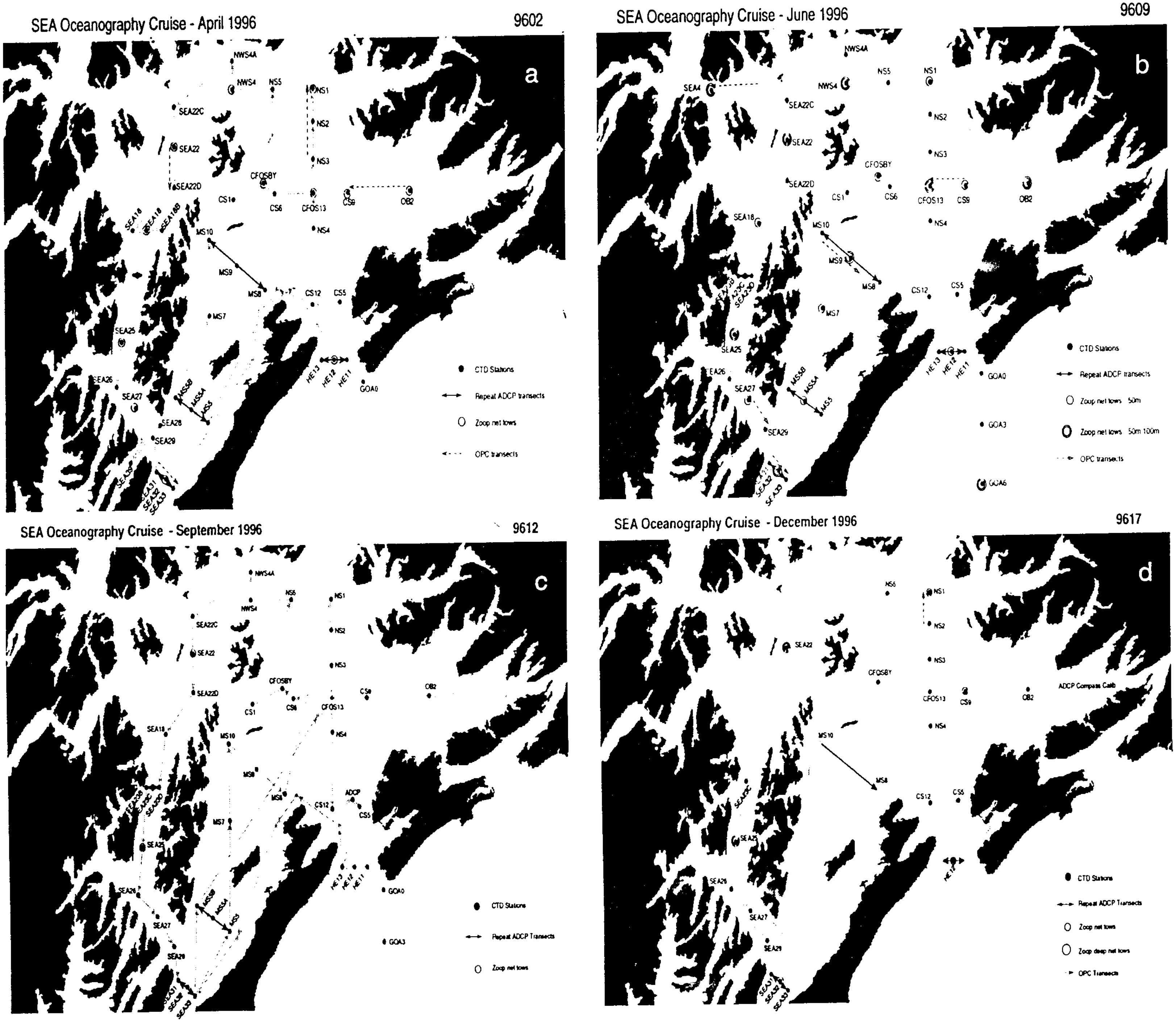
SEA Oceanography Cruise - April 1996
9602
a
CTD Stations
Repeat ADCP transects
Zoop net tows
OPC transects
SEA Oceanography Cruise - June 1996
9609
b
CTD Stations
Repeat ADCP transects
Zoop net tows 50m
Zoop net tows 50m 100m
OPC transects
SEA Oceanography Cruise - September 1996
9612
c
CTD Stations
Repeat ADCP Transects
Zoop net tows
SEA Oceanography Cruise - December 1996
9617
d
ADCP Compass Calib
CTD Stations
Repeat ADCP Transects
Zoop net tows
Zoop deep net tows
OPC Transects

Figure 1

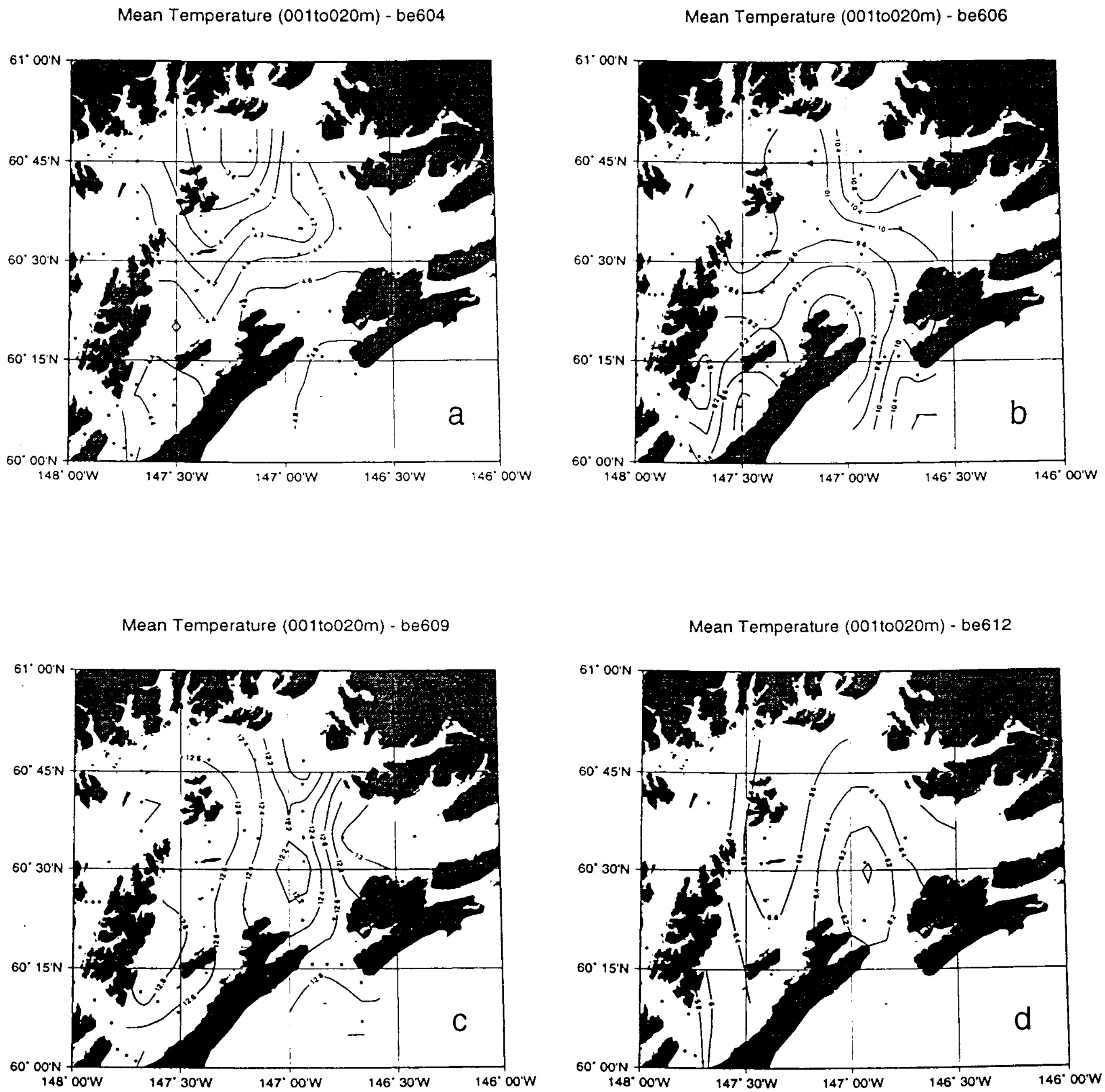

Figure 2: Upper 20m mean temperatures for (a) April, (b) June, (c) September, and (d) December, 1996.

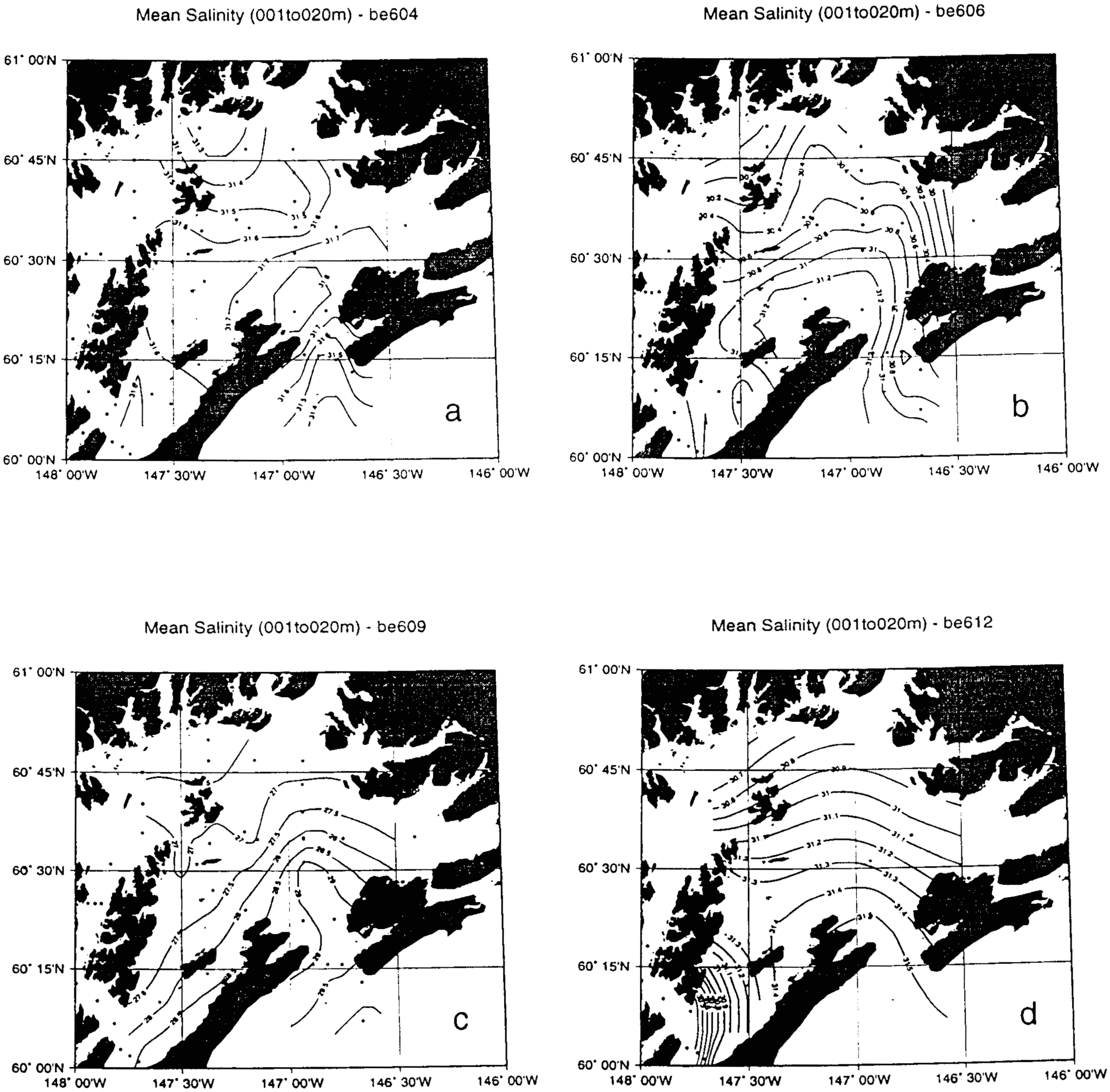

Figure 3: Upper 20m mean salinities for (a) April, (b) June, (c) September, and (d) December, 1996.

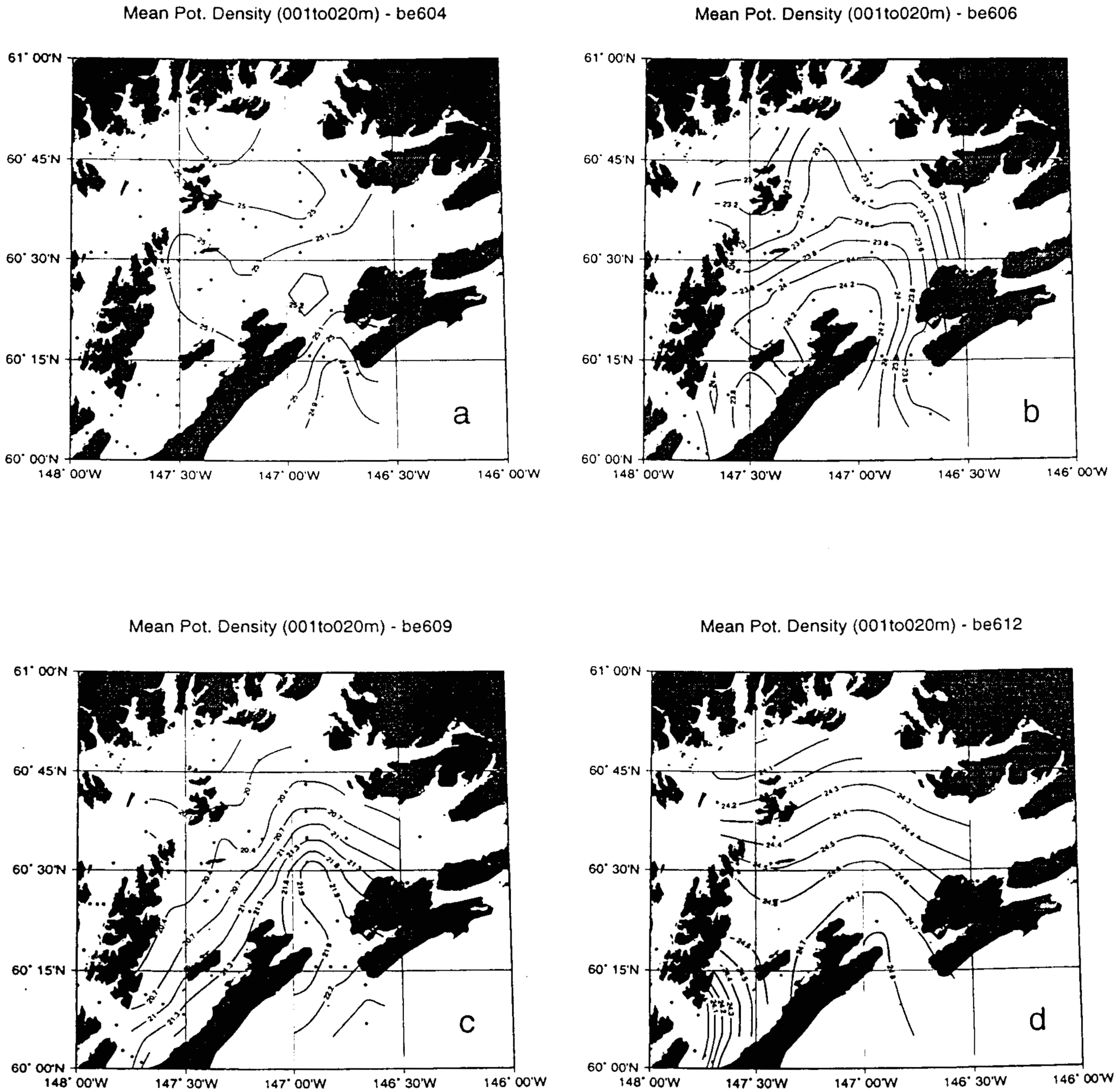

Figure 4: Upper 20m mean potential densities for (a) April, (b) June, (c) September, and (d) December, 1996.

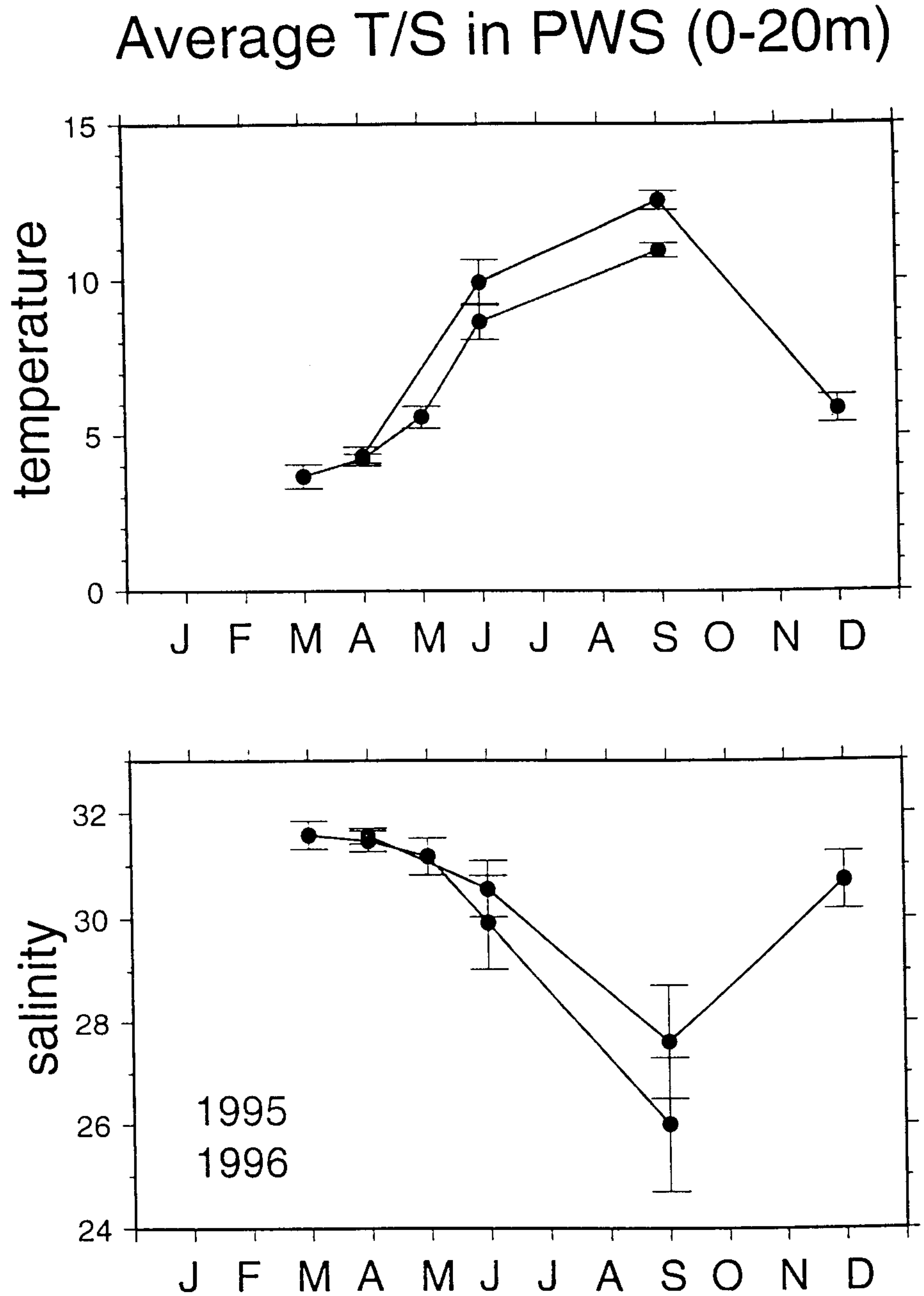

Figure 5: Time series of mean 0 to 20 m layer temperatures and salinities averaged over the entire Sound. Error bars are standard error.

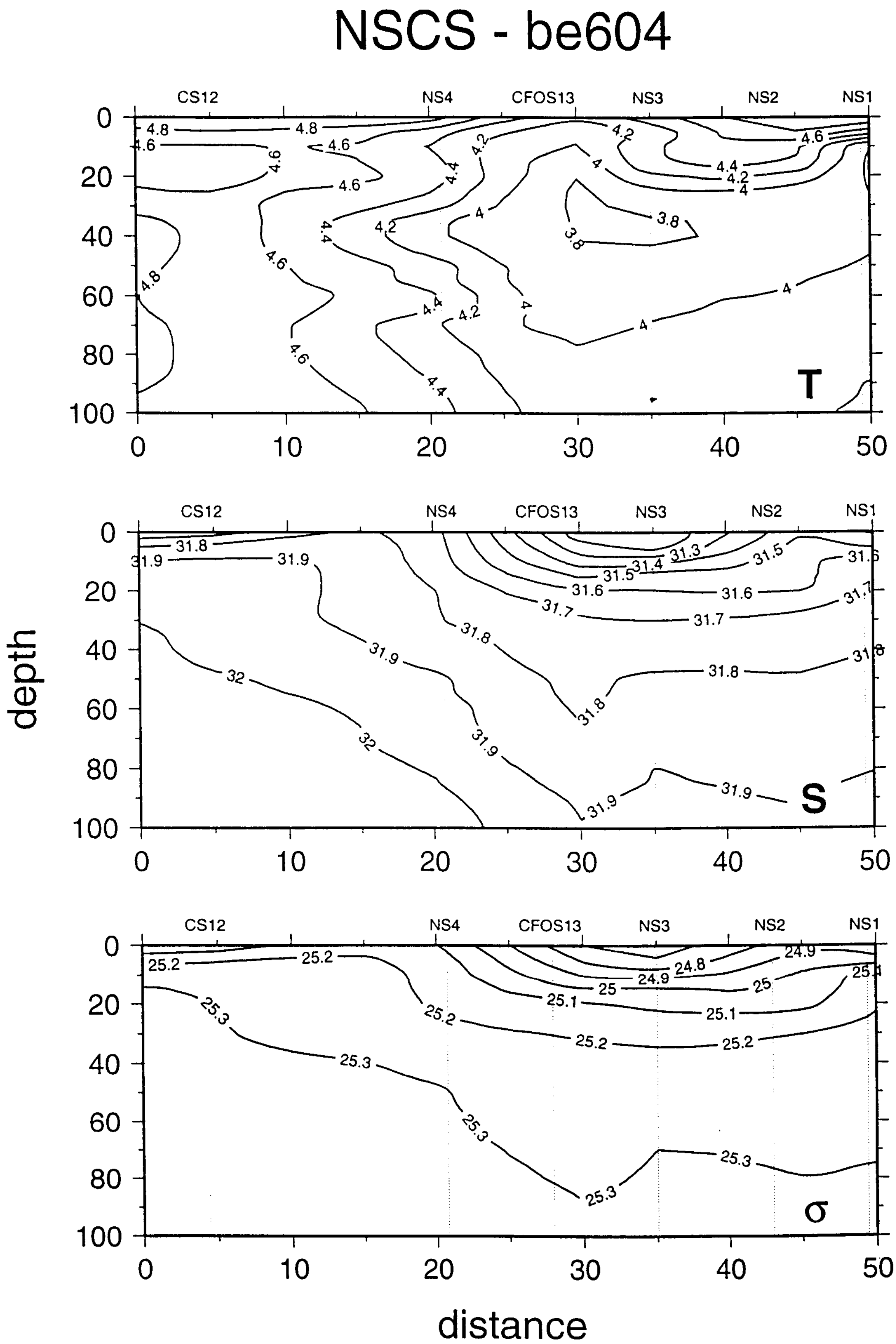

Figure 6: North/south sections of temperature, salinity, and potential density for April 1996.

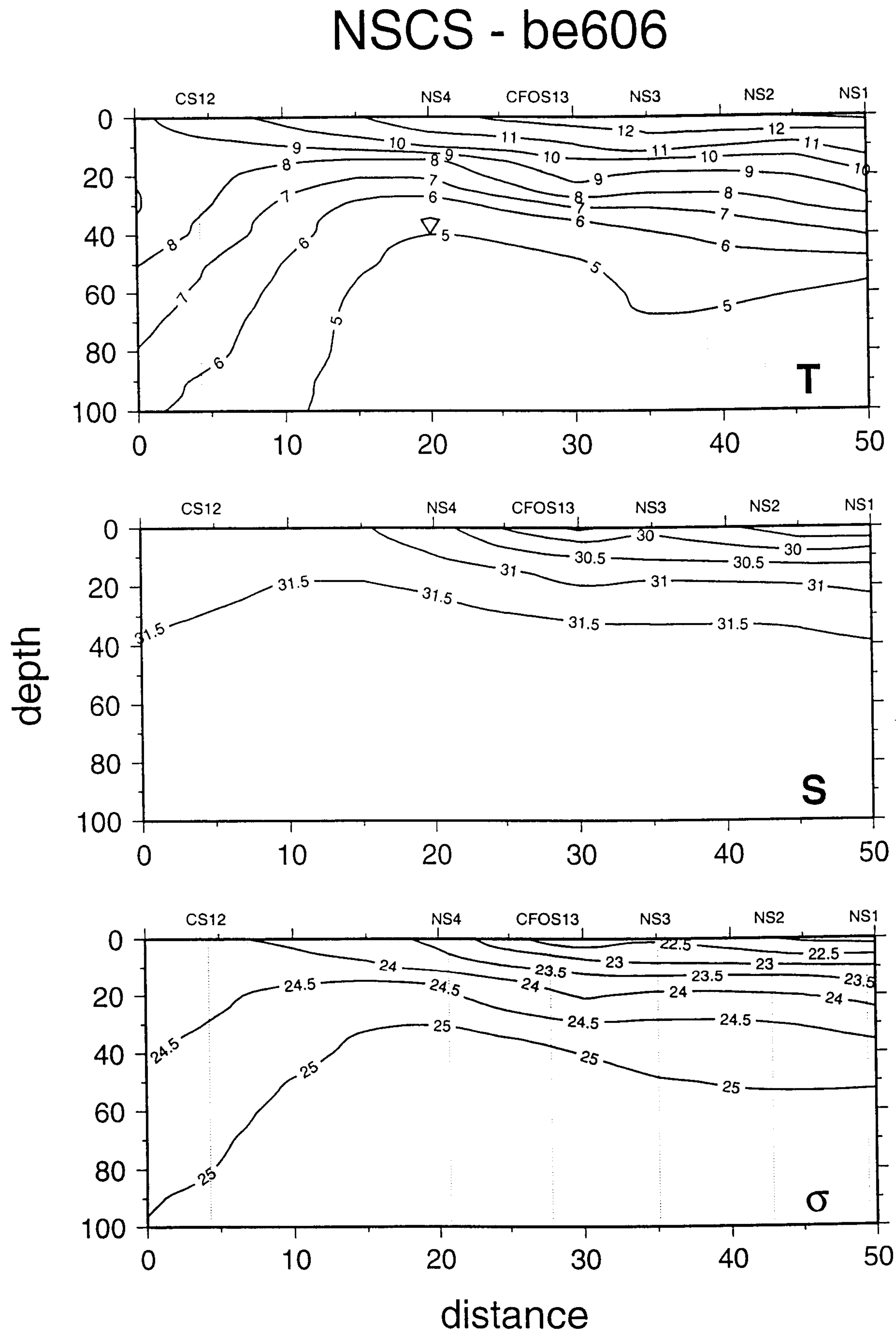

Figure 7: North/south sections of temperature, salinity, and potential density for June 1996.

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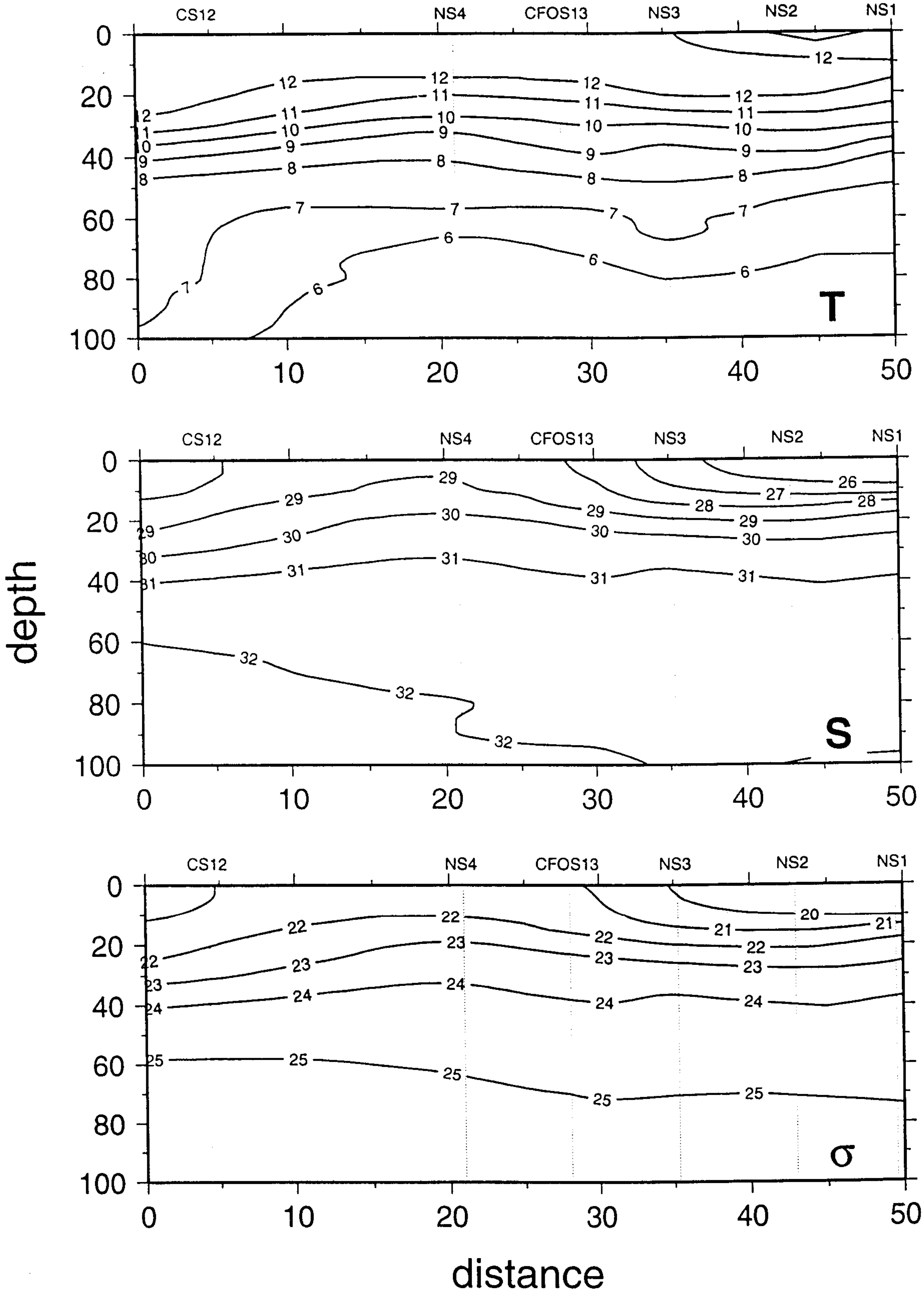


Figure 8: North/south sections of temperature, salinity, and potential density for September 1996.

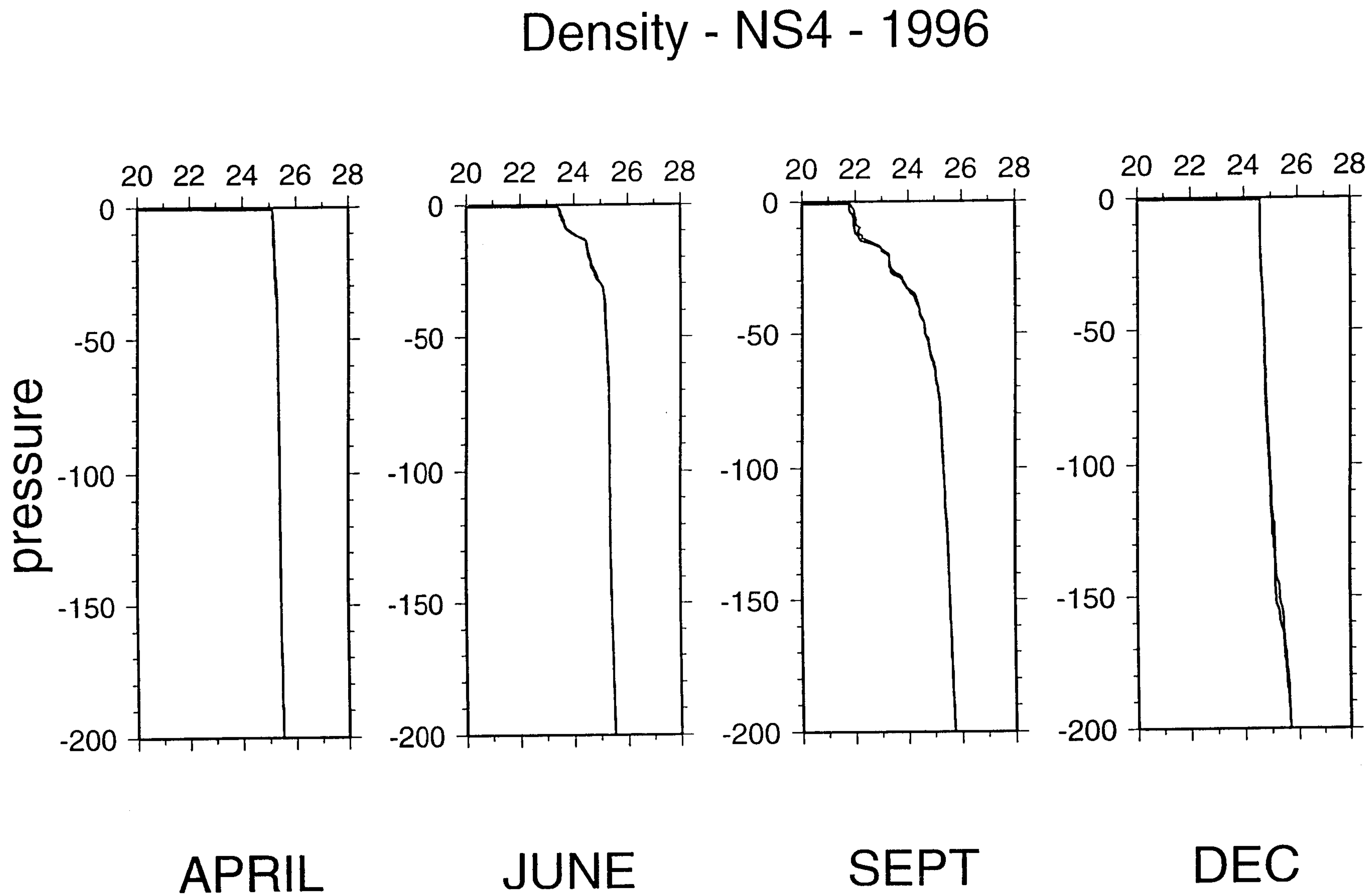


Figure 9: Vertical profiles of potential density.

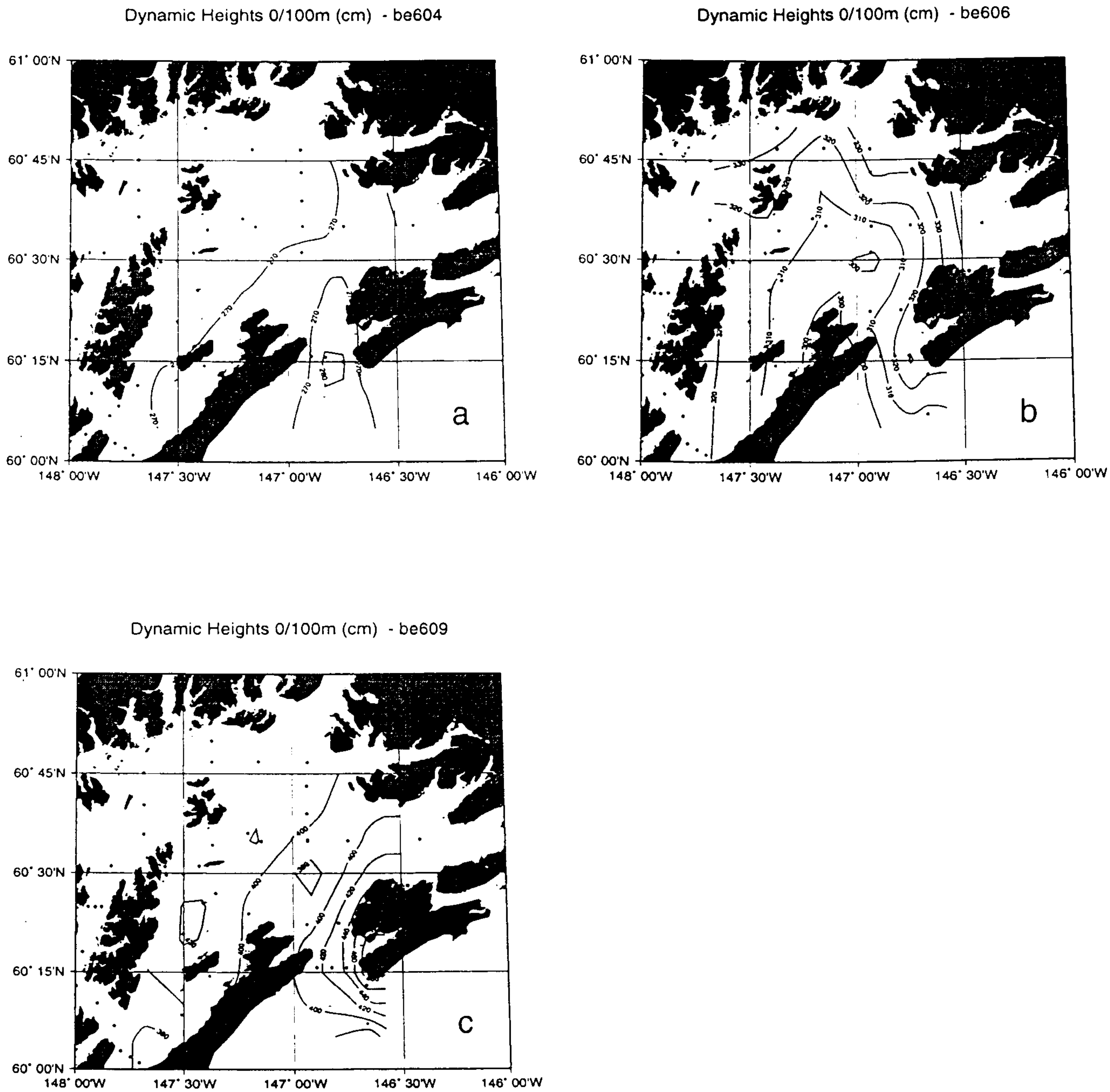


Figure 10: Dynamic heights 0/100 m (in cm) for (a) April, (b) June, and (c) September 1996.

April 1996

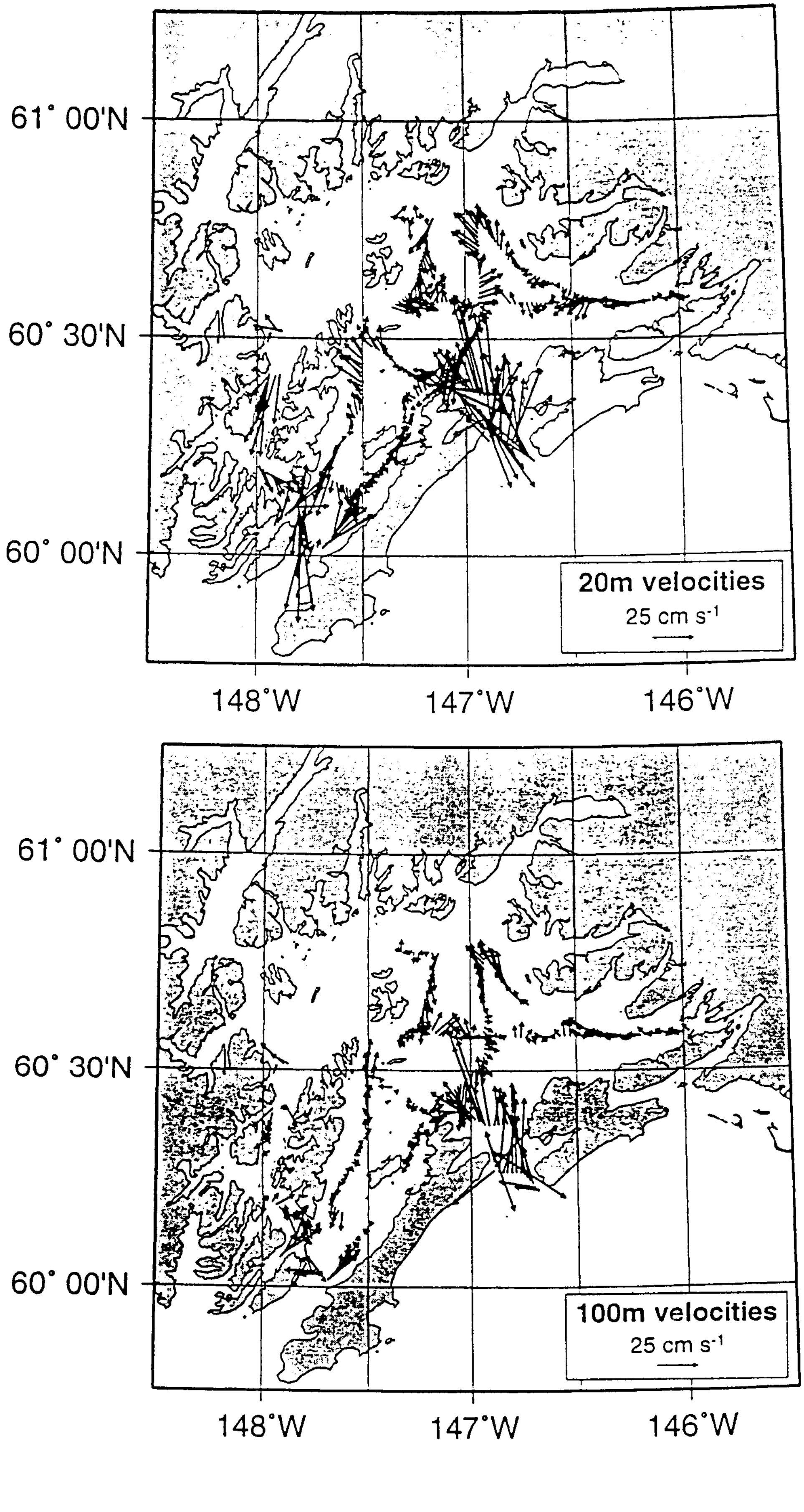


Figure 11: ADCP velocity vectors at 20 m and 100 m in April 1996.

June 1996

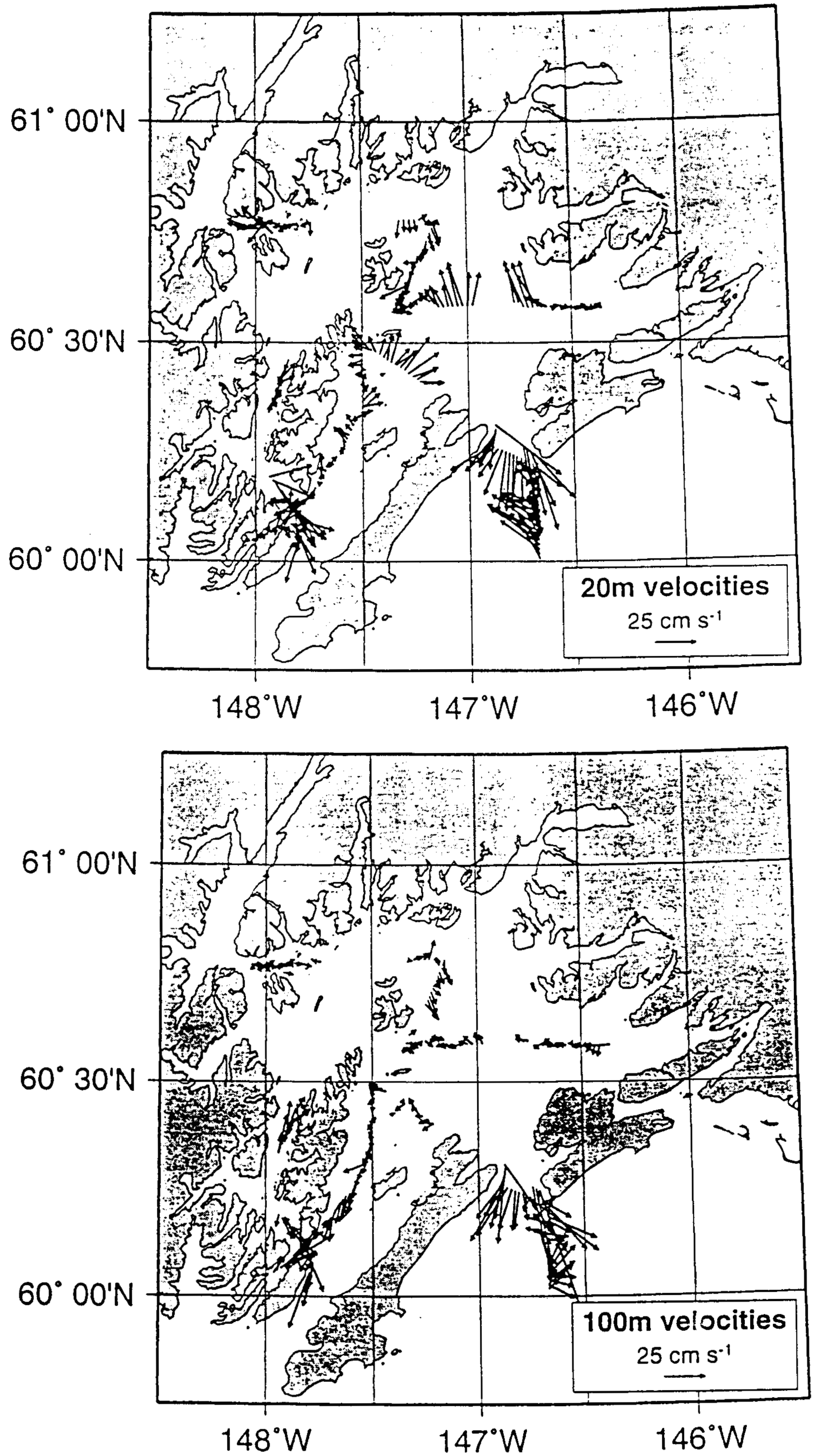


Figure 12: ADCP velocity vectors at 20 m and 100 m in June 1996.

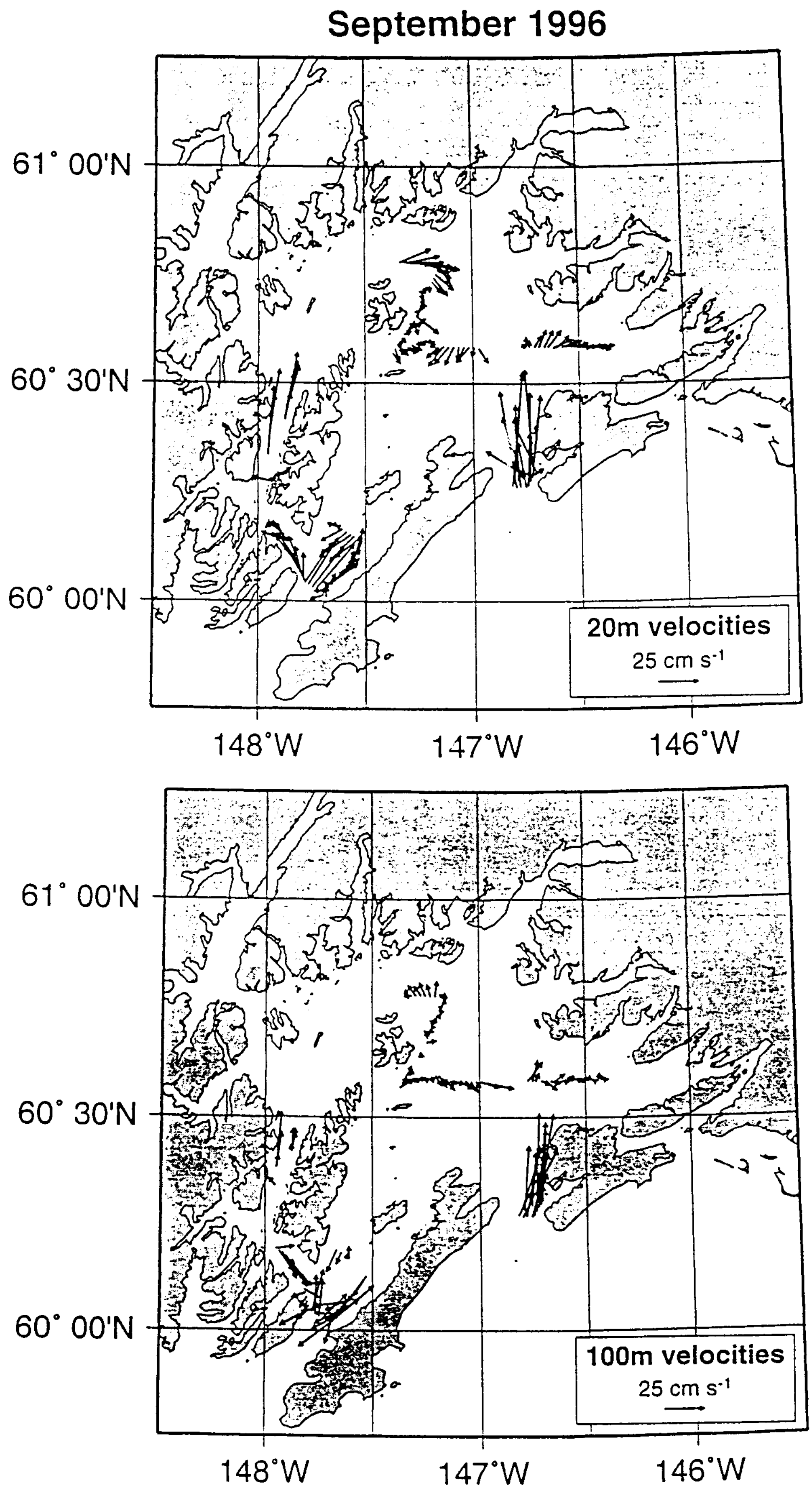


Figure 13: ADCP velocity vectors at 20 m and 100 m in September 1996.

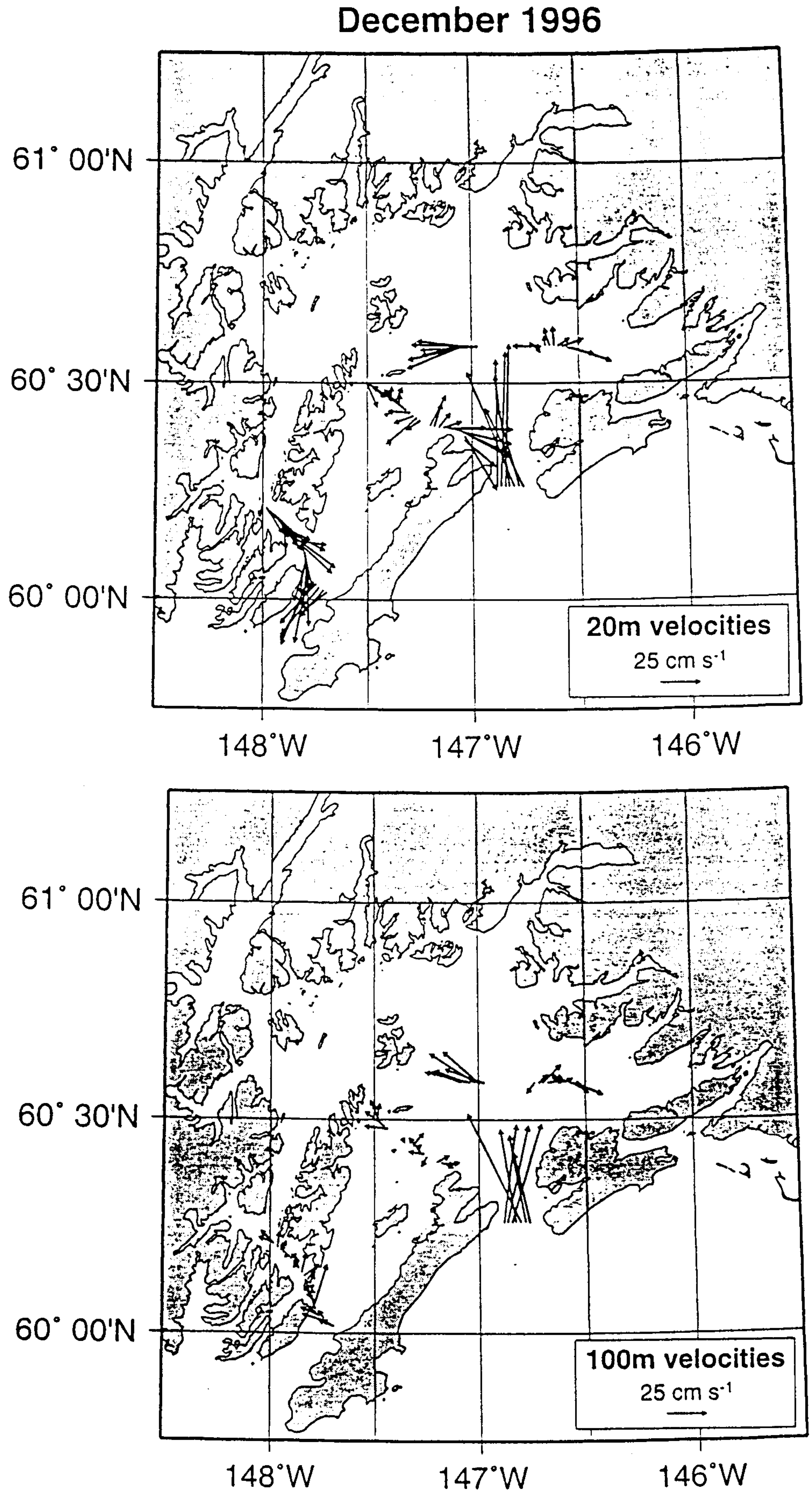


Figure 14: ADCP velocity vectors at 20 m and 100 m in December 1996.

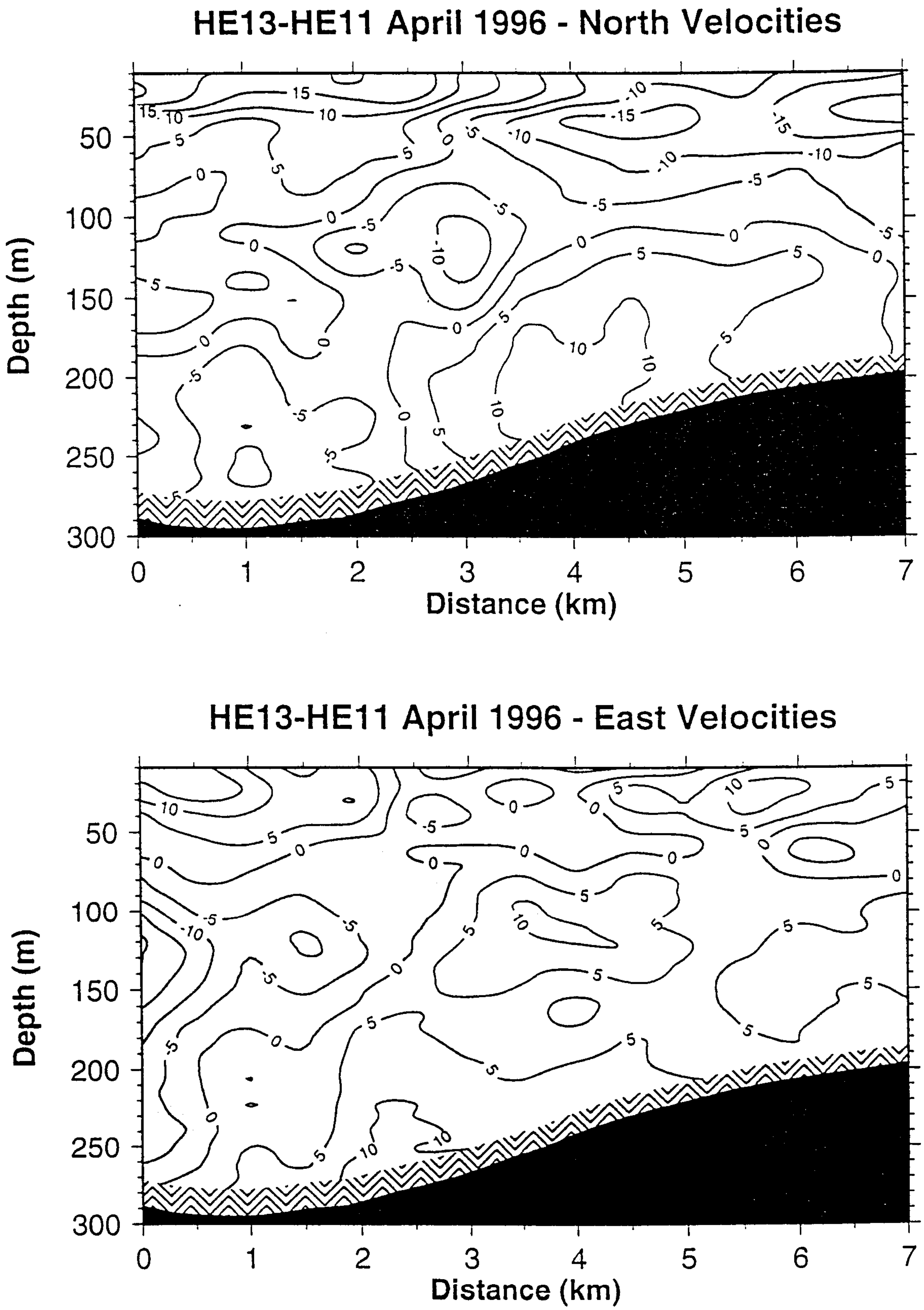
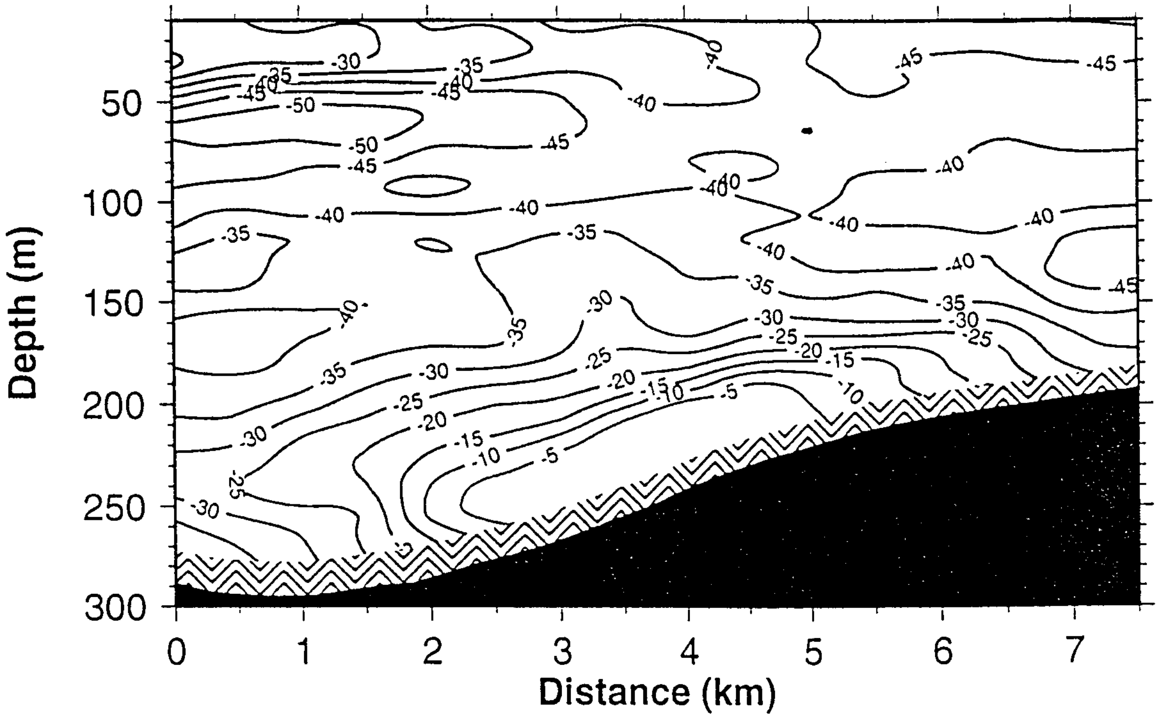


Figure 15(a): Mean ADCP velocities at Hinchinbrook Entrance in April 1996.

HE13-HE11 June 1996 - North Velocities



HE13-HE11 June 1996 - East Velocities

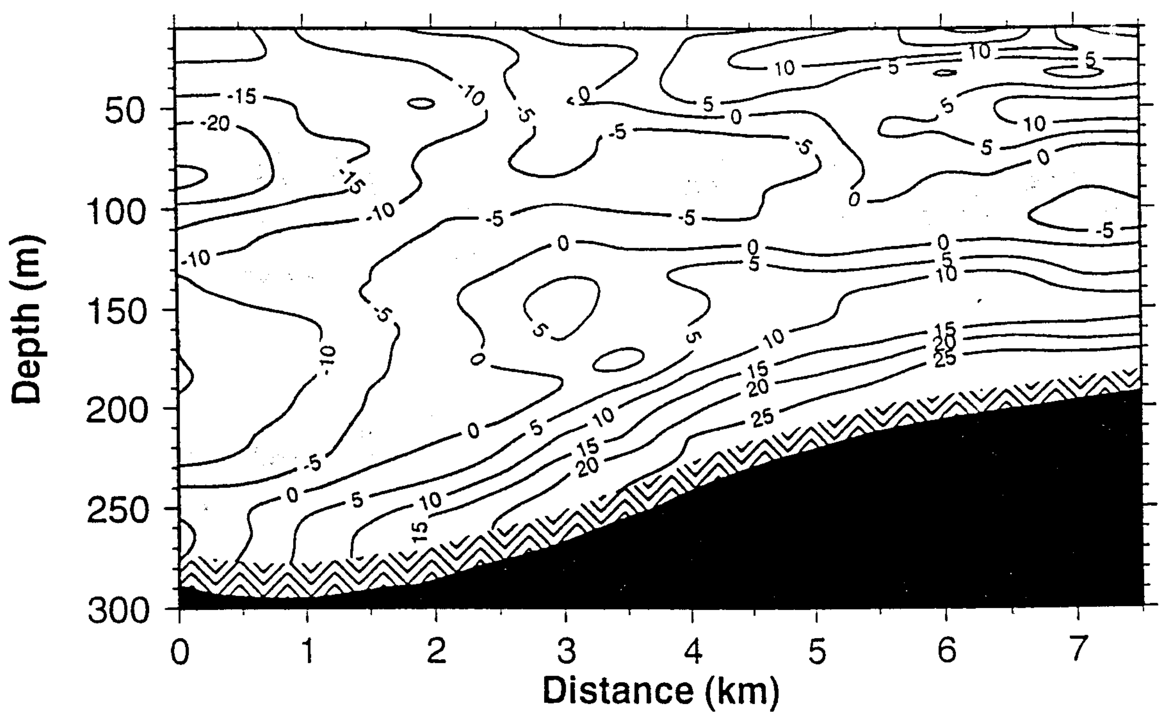
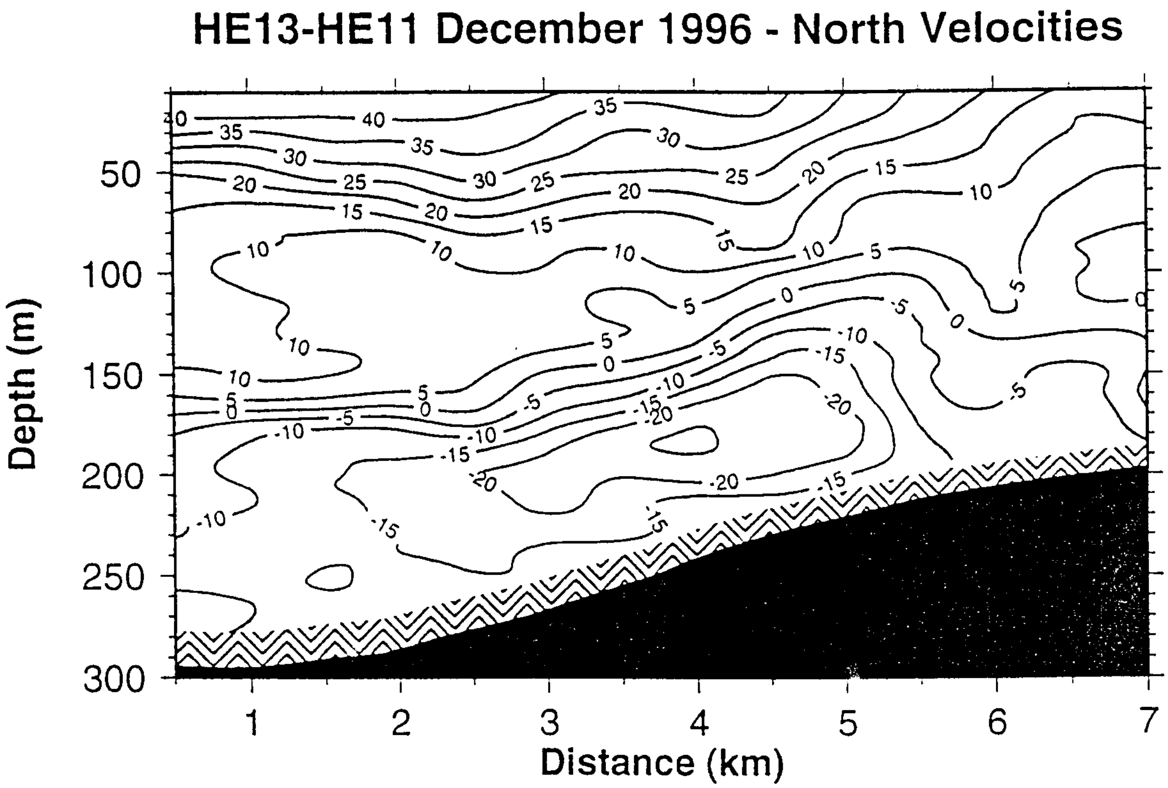


Figure 15(b): ADCP velocities for ebb tide at Hinchinbrook Entrance in June 1996.



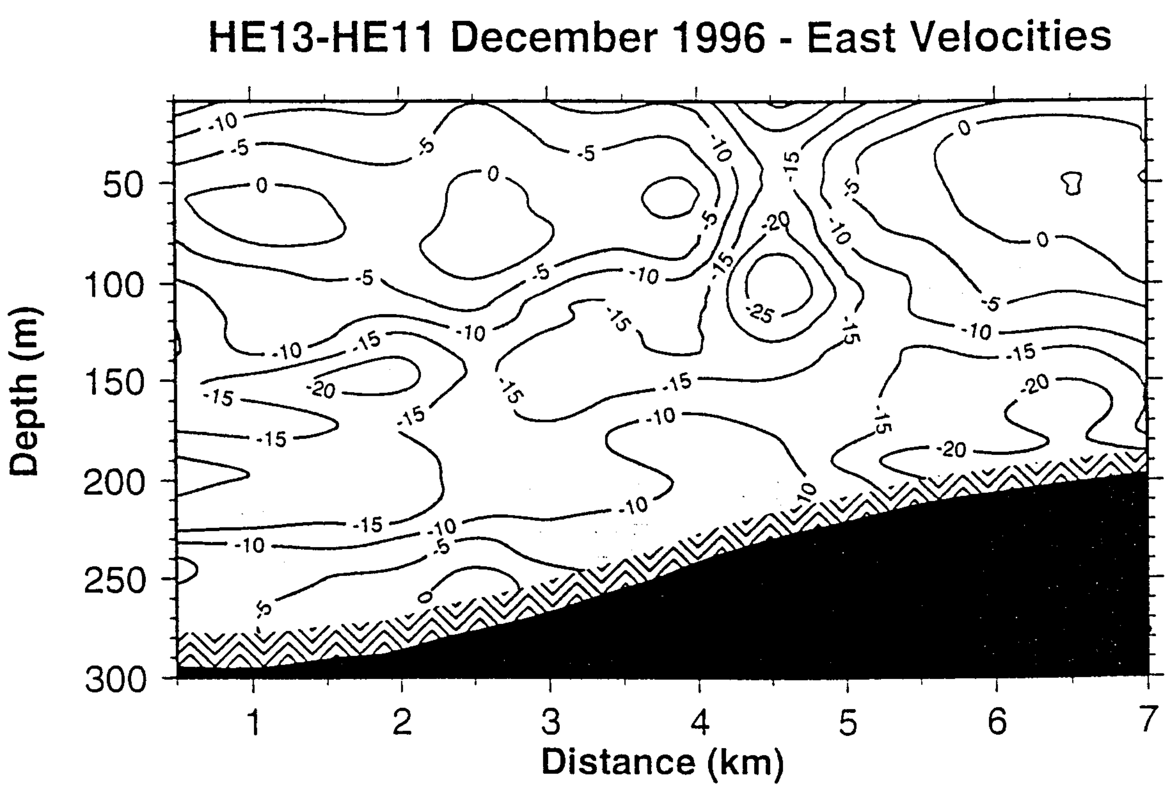


Figure 15(c): Mean ADCP velocities at Hinchinbrook Entrance in December 1996.

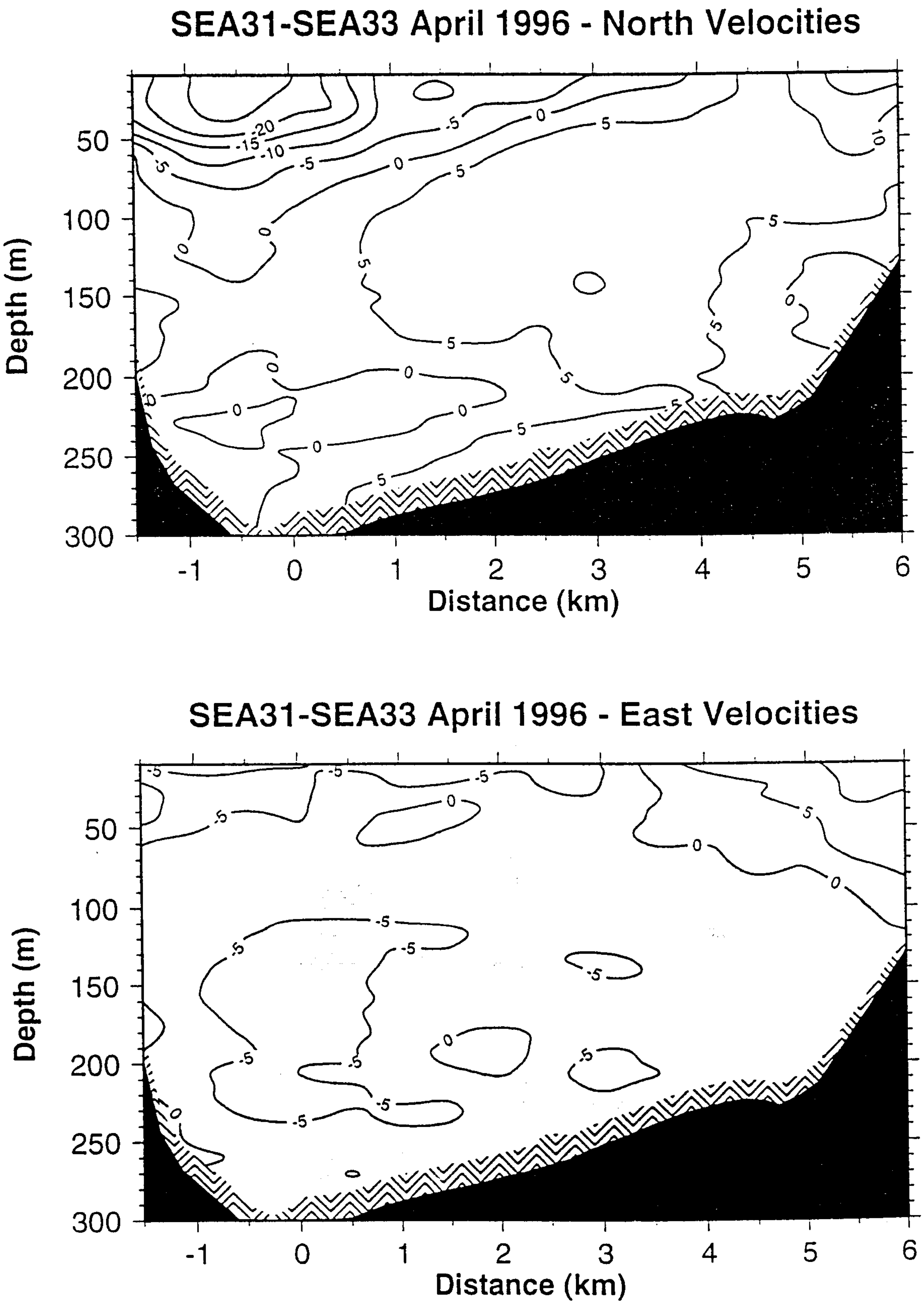
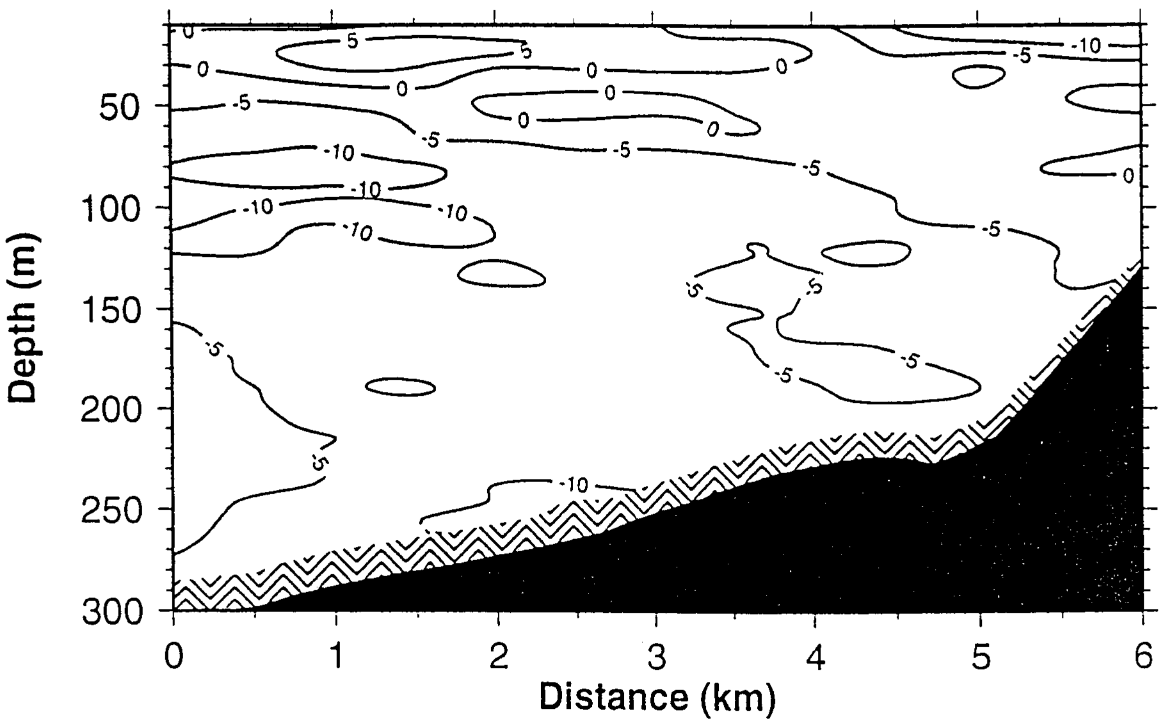


Figure 16(a): Mean ADCP velocities at Montague Straight in April 1996.

SEA31-SEA33 June 1996 - North Velocities



SEA31-SEA33 June 1996 - East Velocities

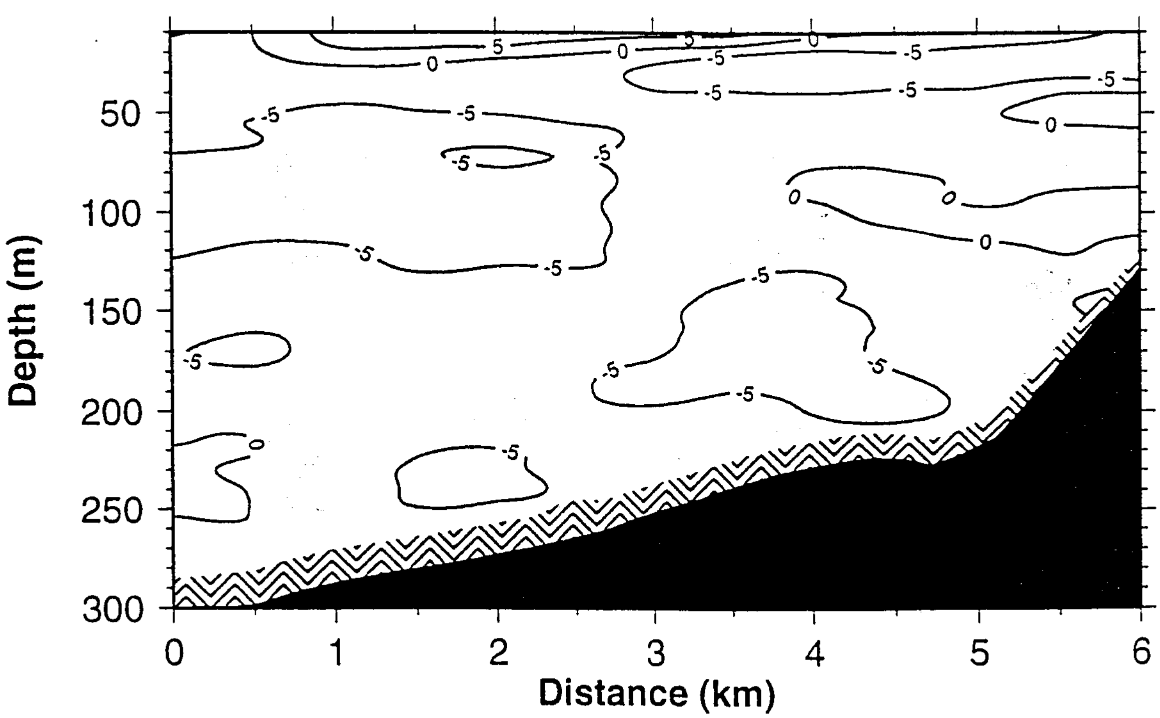


Figure 16(b): Mean ADCP velocities at Montague Straight in June 1996.

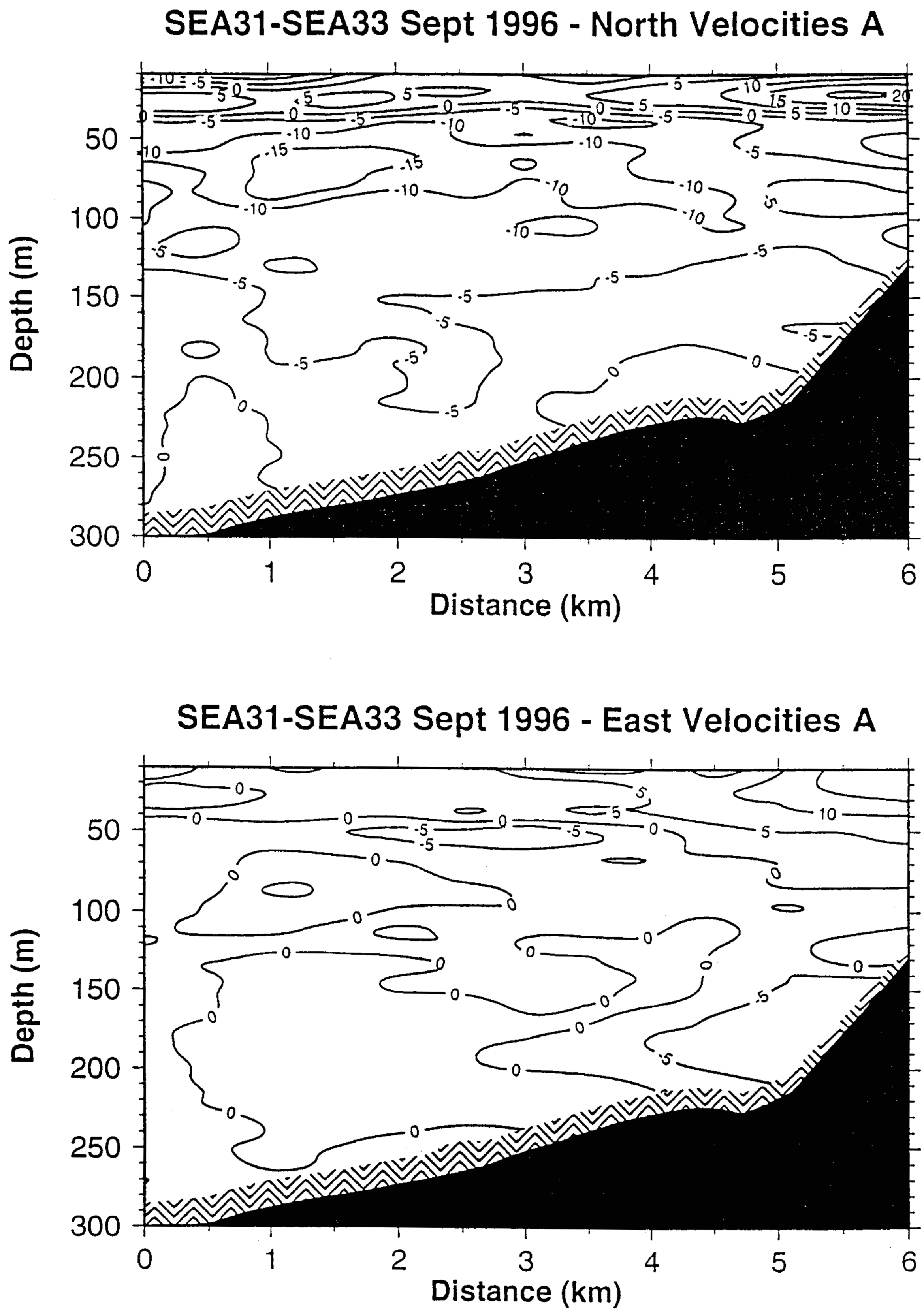
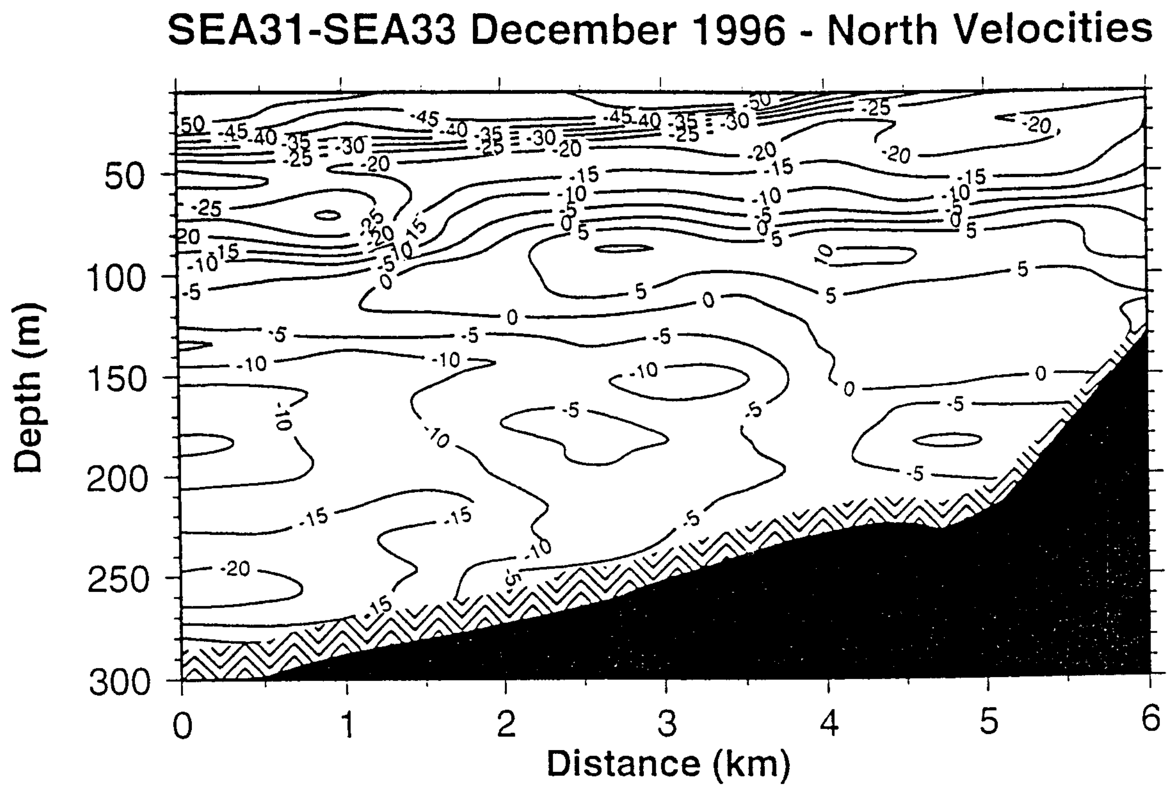


Figure 16(c): Mean ADCP velocities at Montague Straight in September 1996.



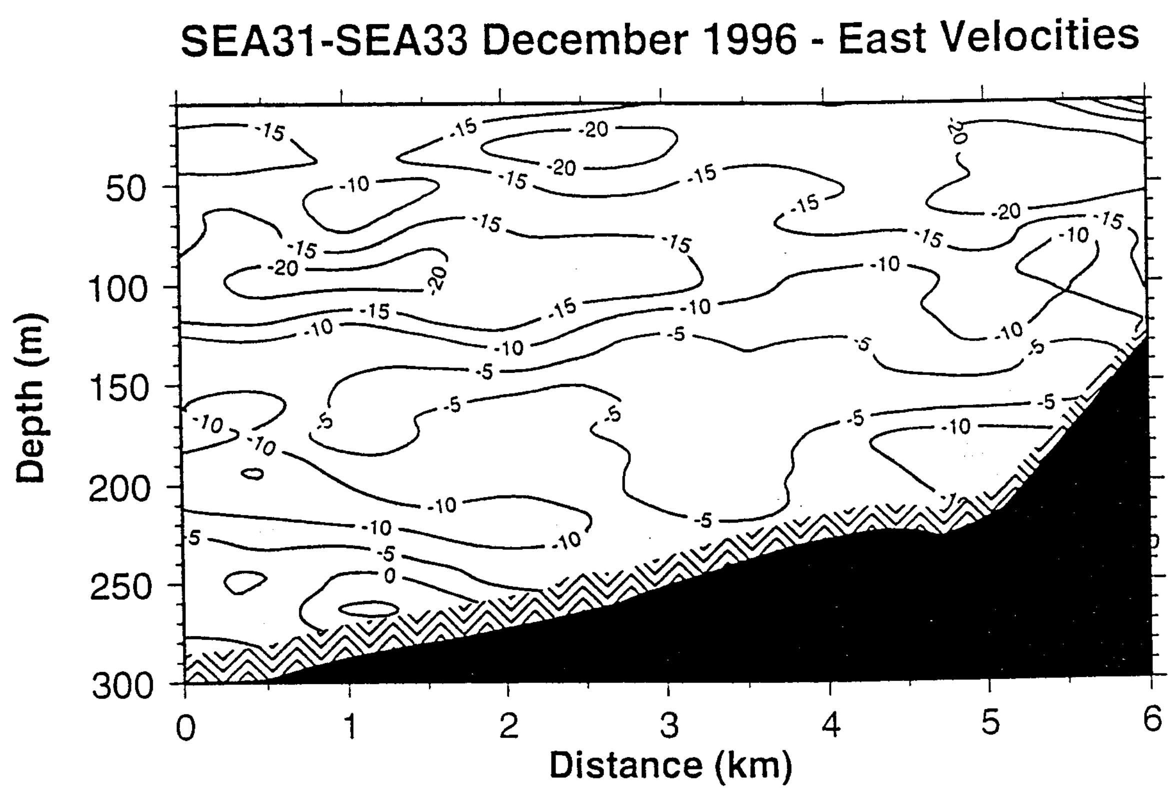


Figure 16(d): Mean ADCP velocities at Montague Straight in December 1996.

Drifter Track: 25652

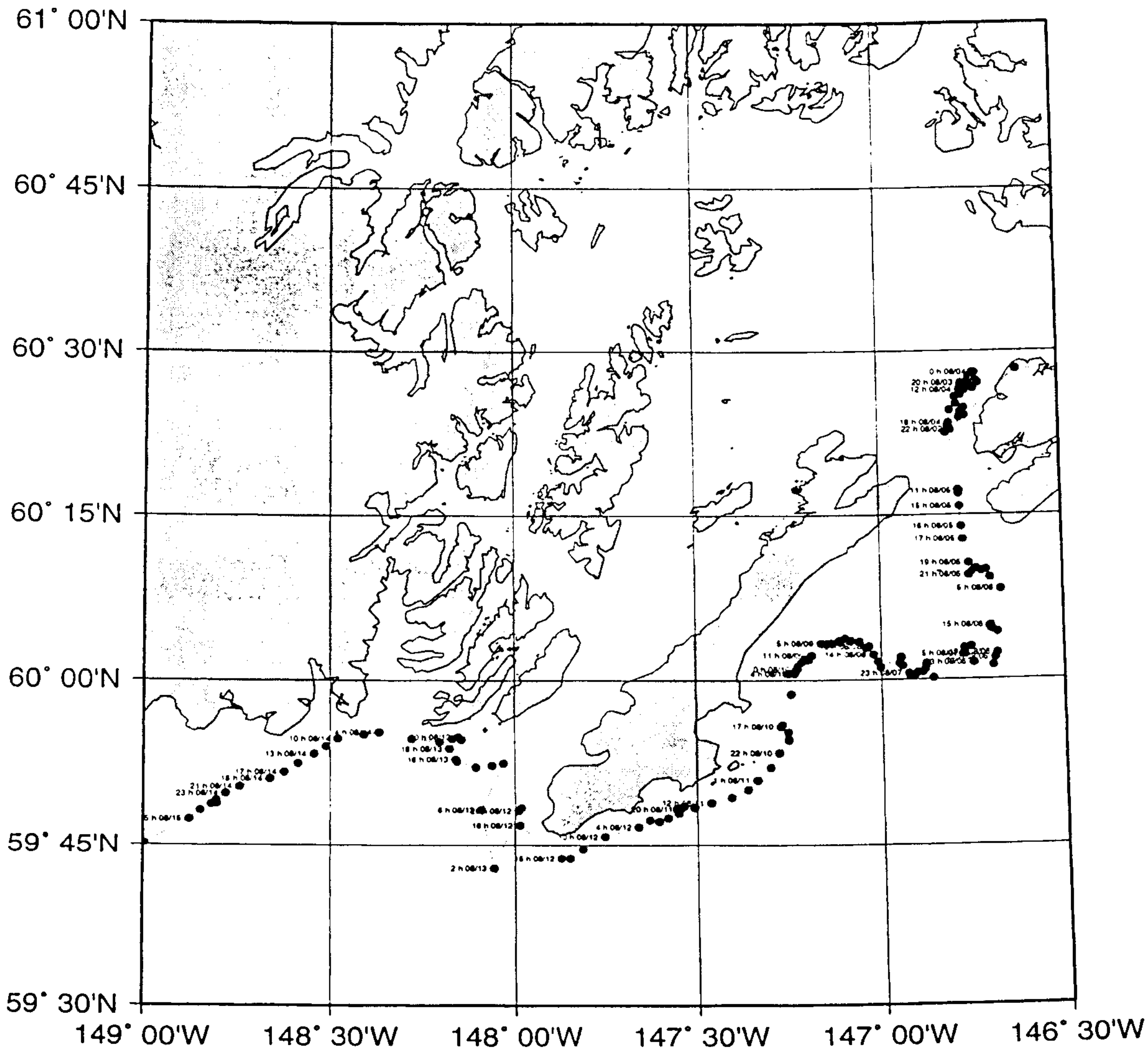


Figure 17: Path of ARGOS drifter drogued at 15 m released August 1996.

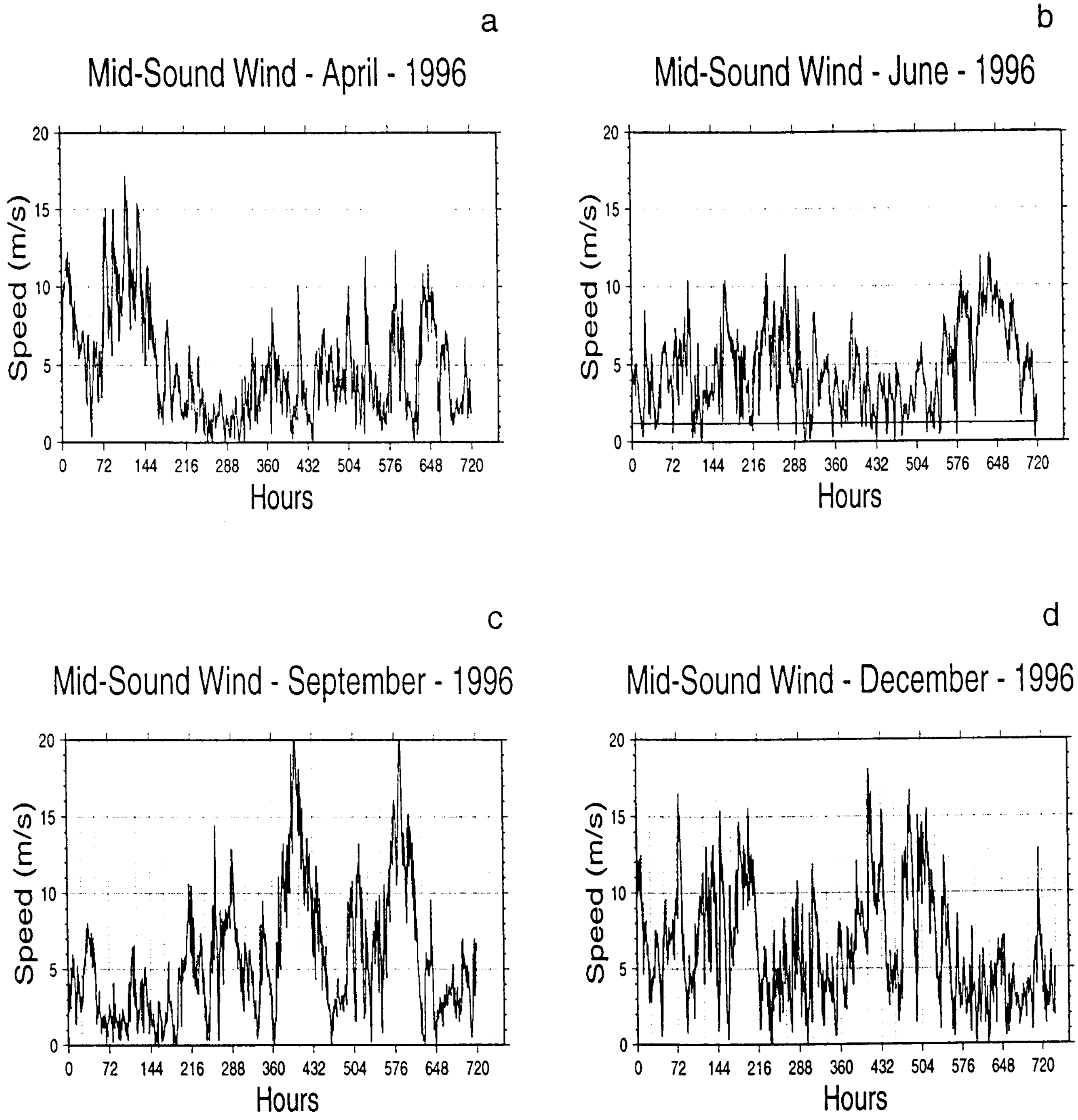


Figure 18: Wind speeds from NDBC Mid-Sound buoy for (a) April, (b) June, (c) September, (d) and December, 1996.

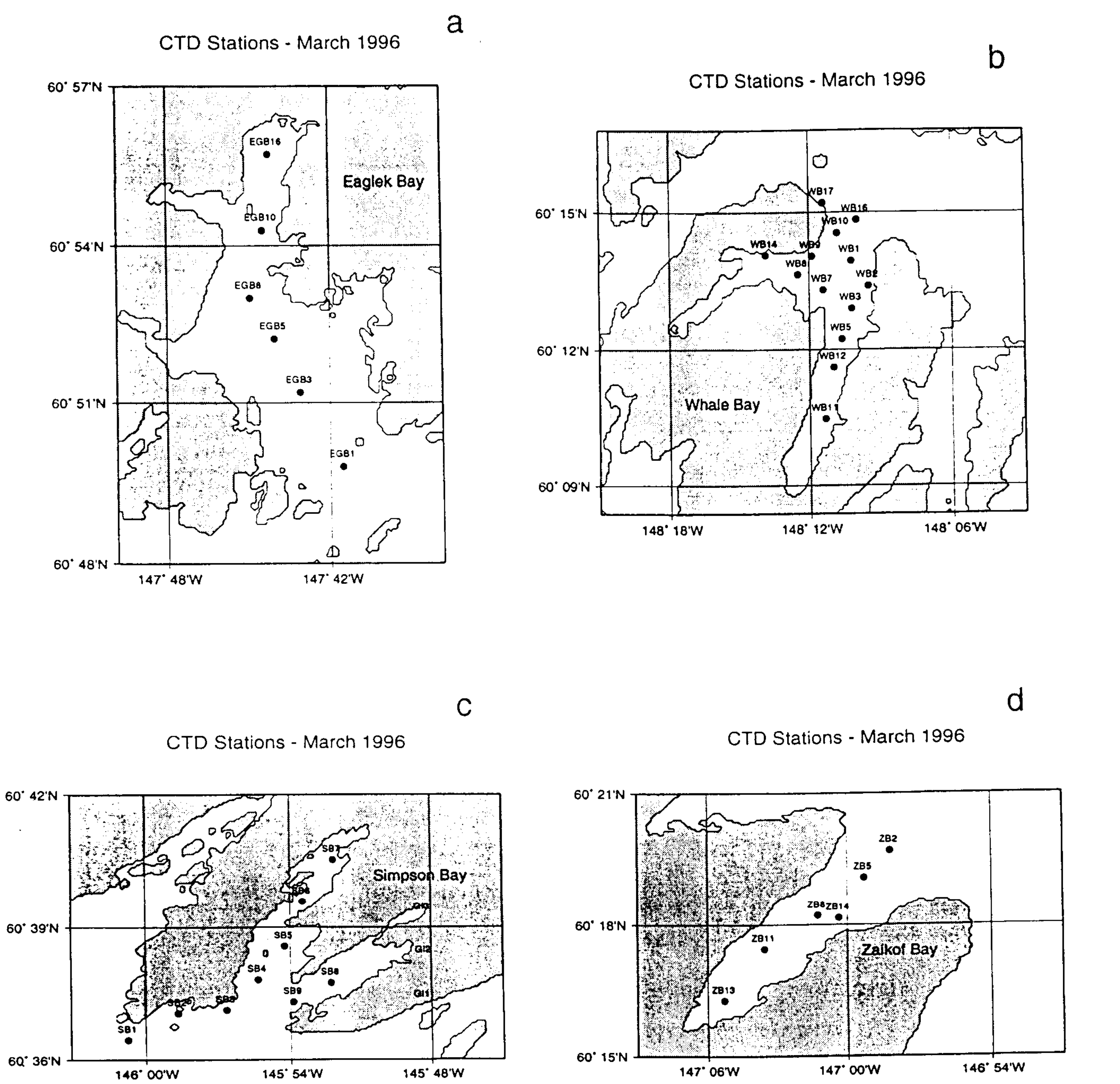


Figure 19: Station locations for (a) Eaglek Bay, (b) Whale Bay, (c) Simpson Bay, and (d) Zaikof Bay.

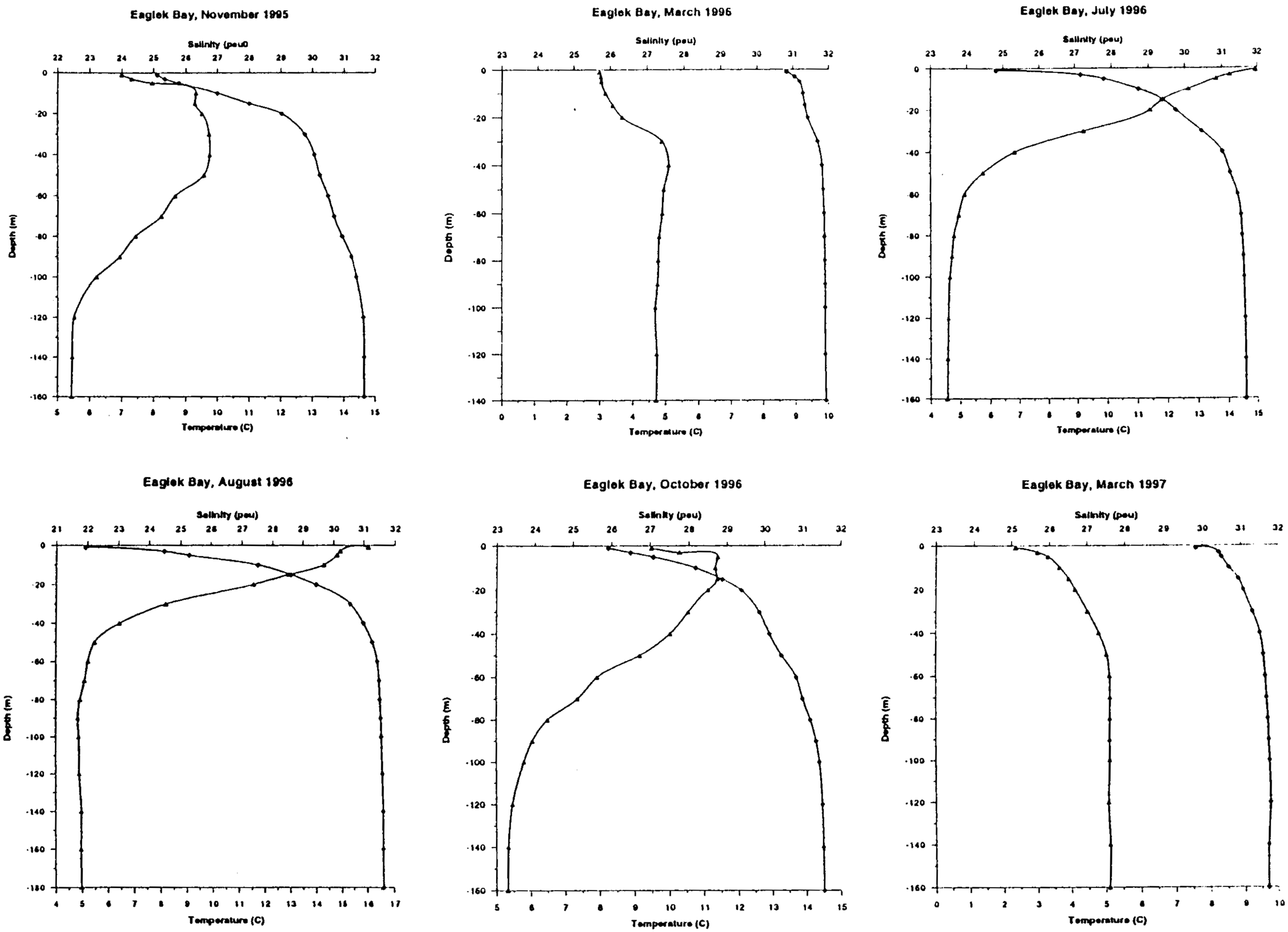


Figure 20: Mean temperature (triangles) and salinity (diamonds) of Eaglek Bay, Alaska from November 1995 to March 1997

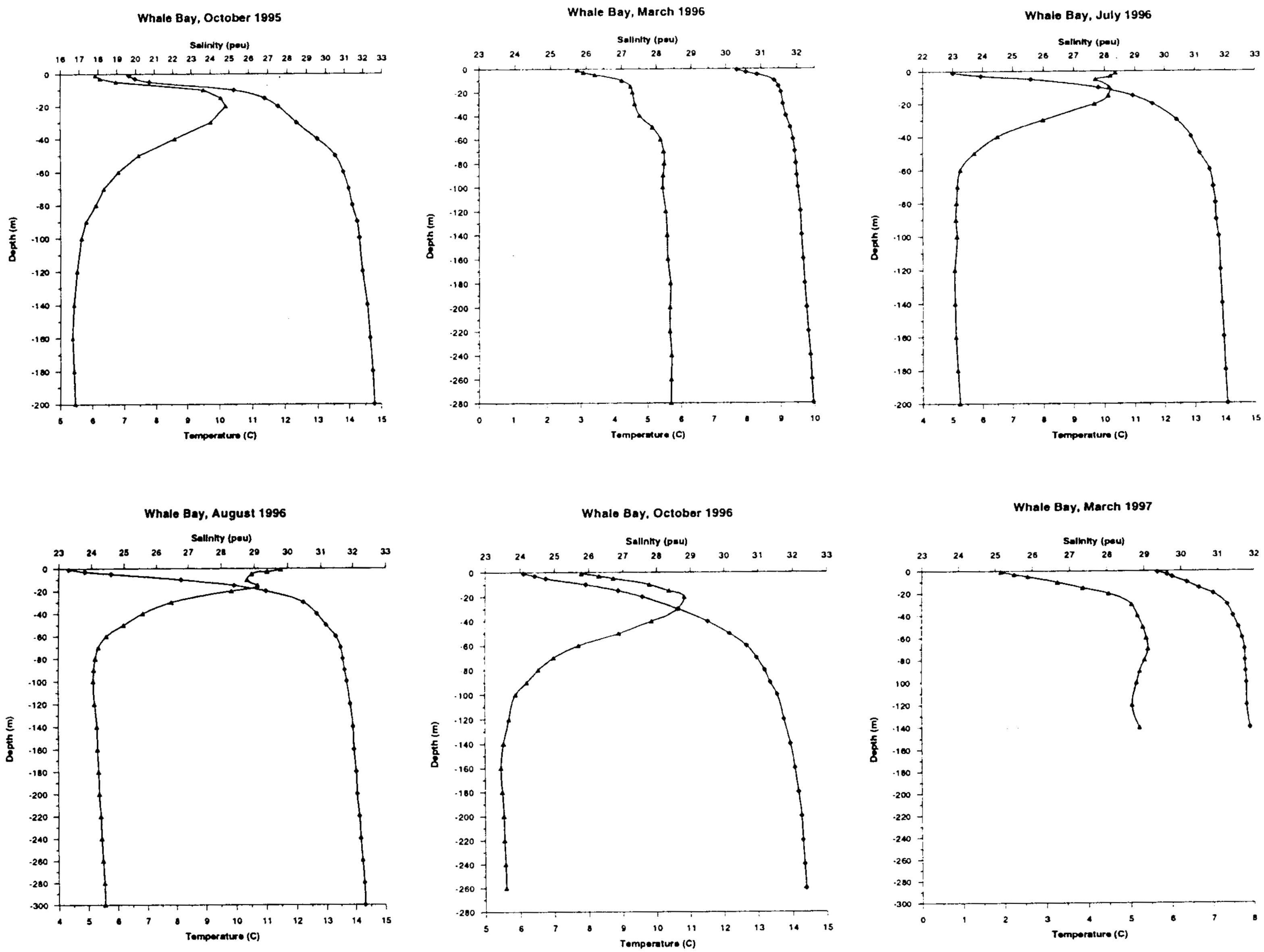


Figure 21: Means of temperature (triangles) and salinity (diamonds) for Whale Bay, Alaska from October 1995 to March 1997.

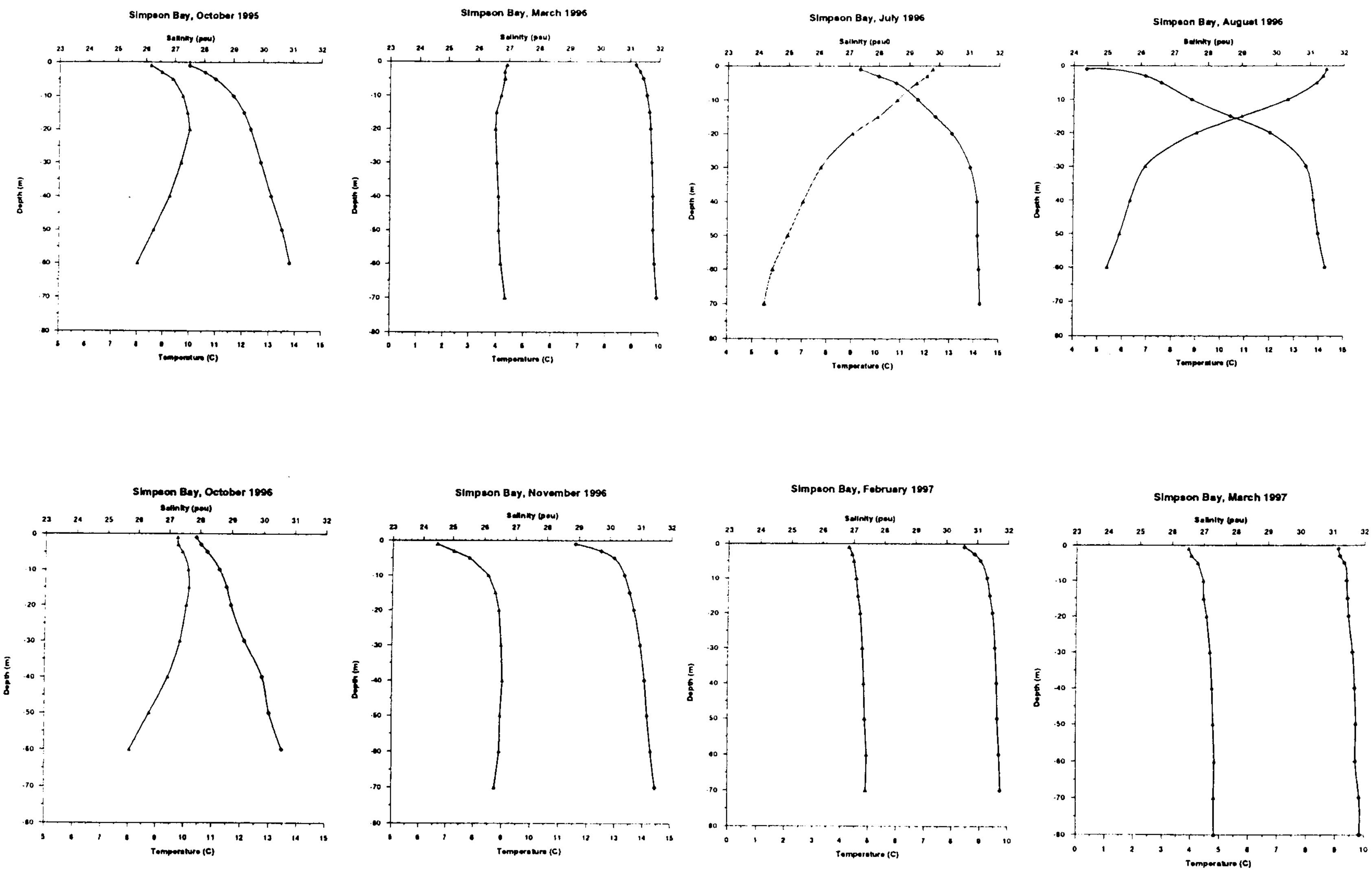


Figure 22: Means of temperature (triangles) and salinity (diamonds) for Simpson Bay, Alaska from October 1995 to March 1997.

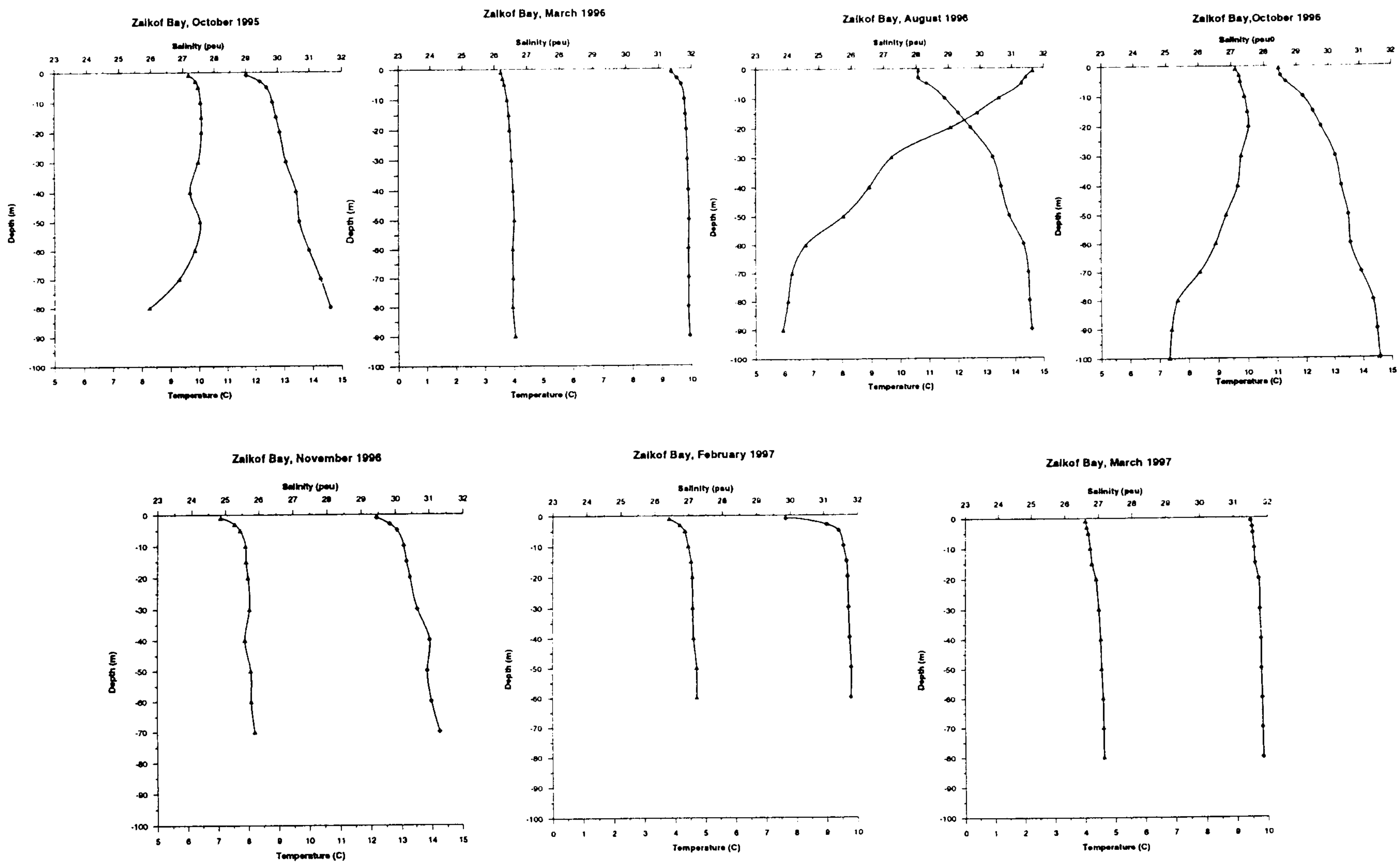


Figure 23: Means of temperature (triangles) and salinity (diamonds) for Zaikof Bay, Alaska from October 1995 to march 1997.

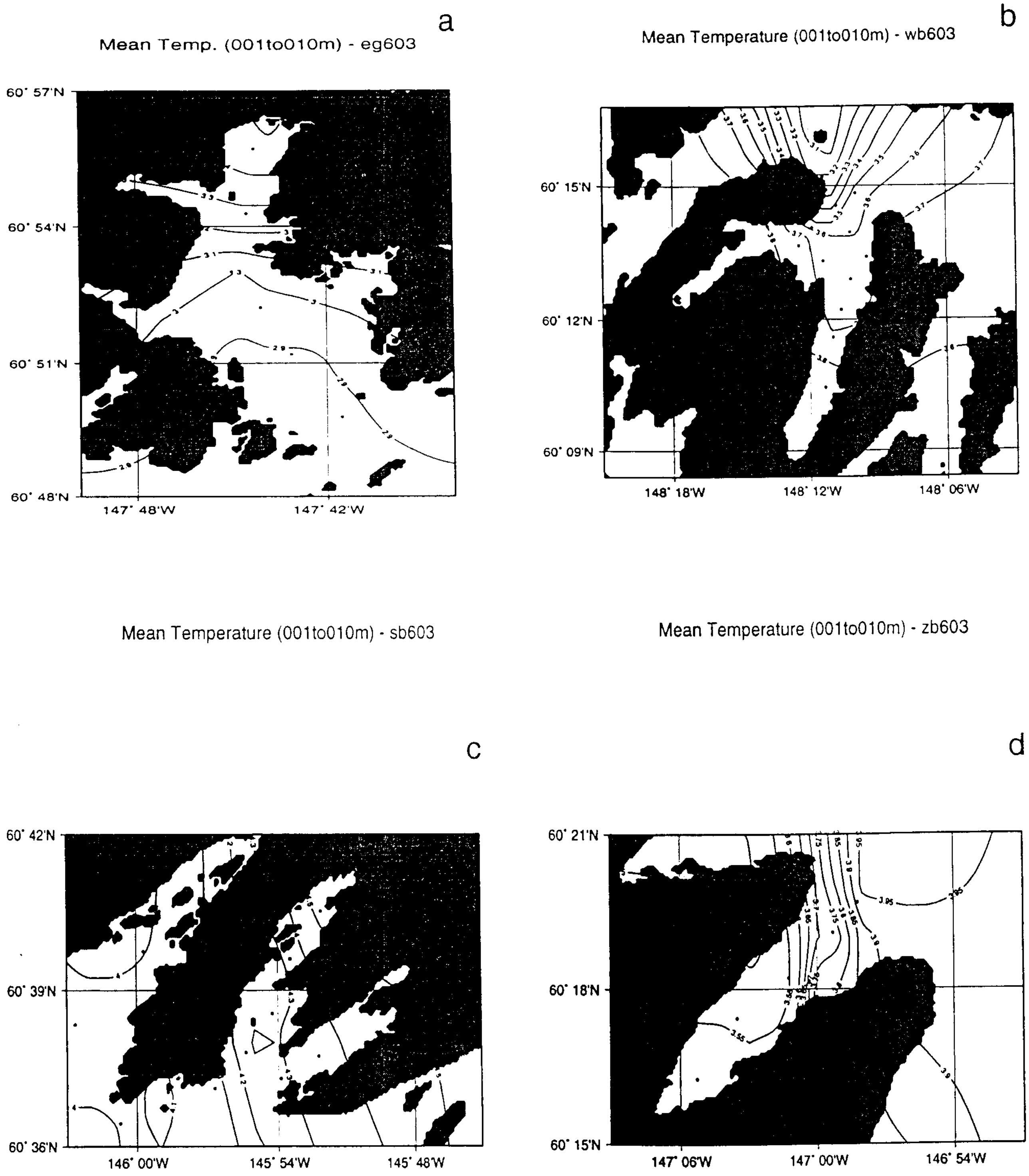


Figure 24: Upper 10m mean temperatures in March for (a) Eaglek, (b) Whale, (c) Simpson, and (d) Zaikof Bay. Station locations are shown as dots.

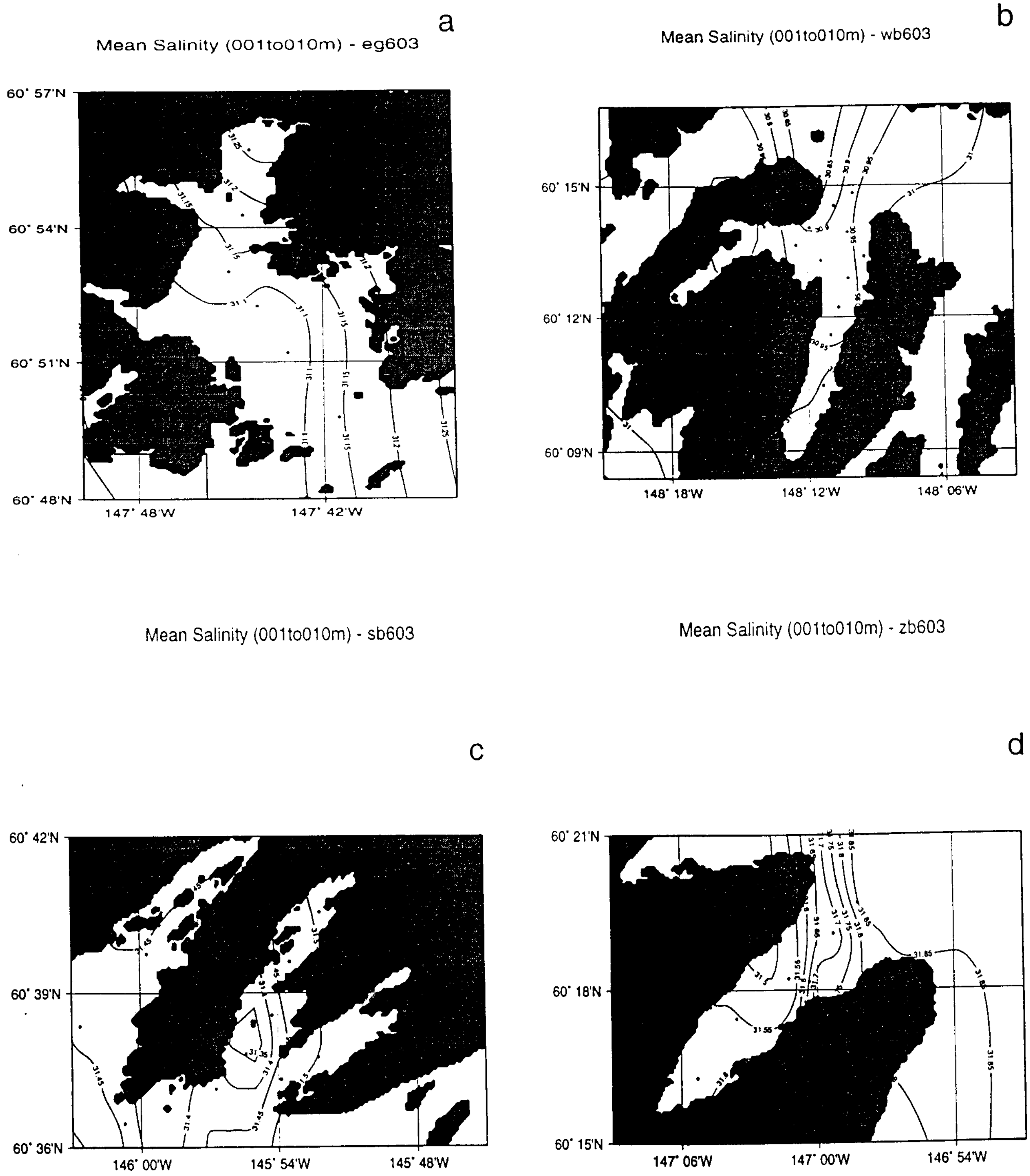


Figure 25: Upper 10m mean salinities in March for (a) Eaglek, (b) Whale, (c) Simpson, and (d) Zaikof Bay. Station locations are shown as dots.

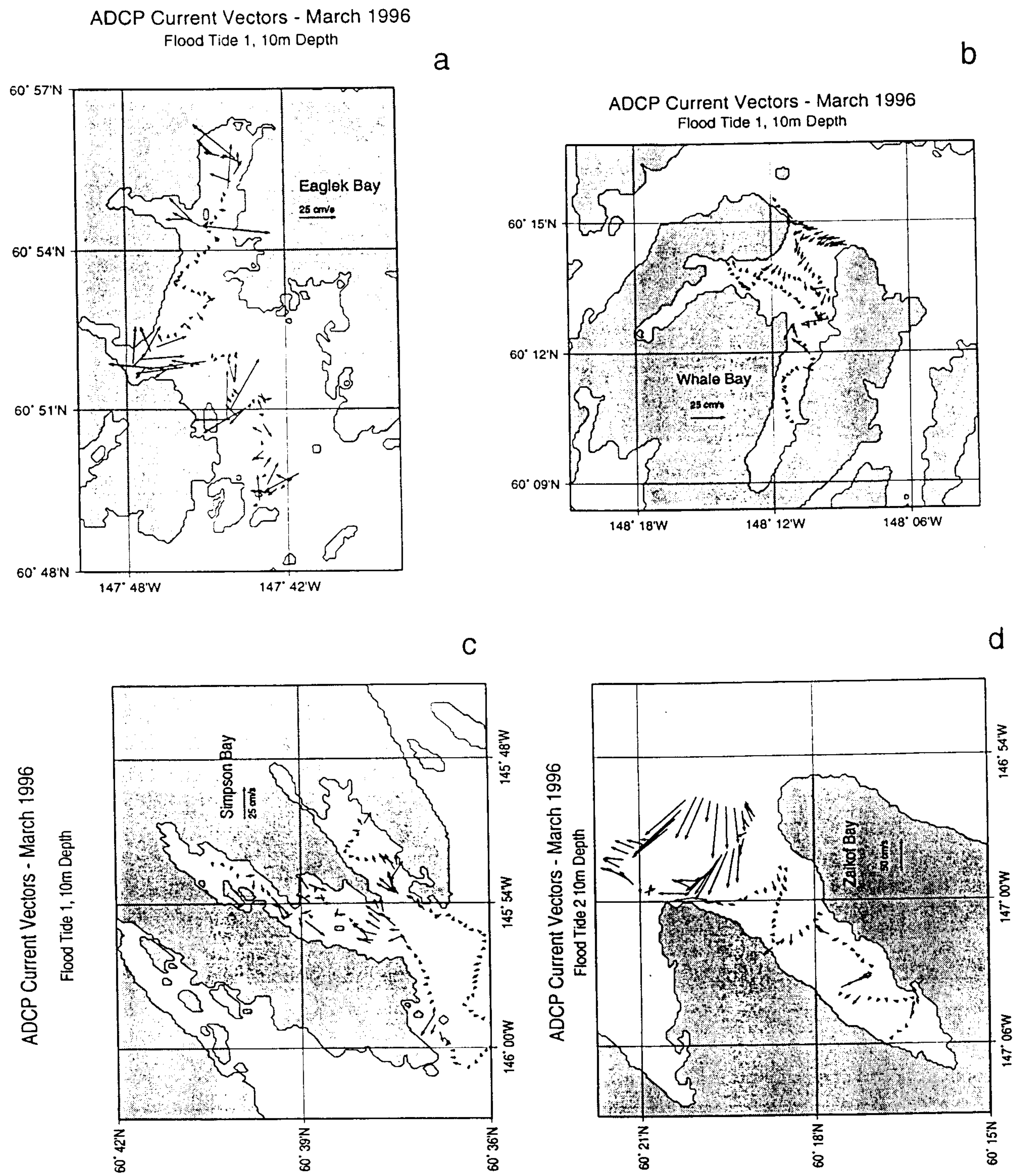


Figure 26: Velocity vectors at 10m for (a) Eaglek, (b) Whale, (c) Simpson, and (d) Zaikof Bay in March 1996 during flood tide.

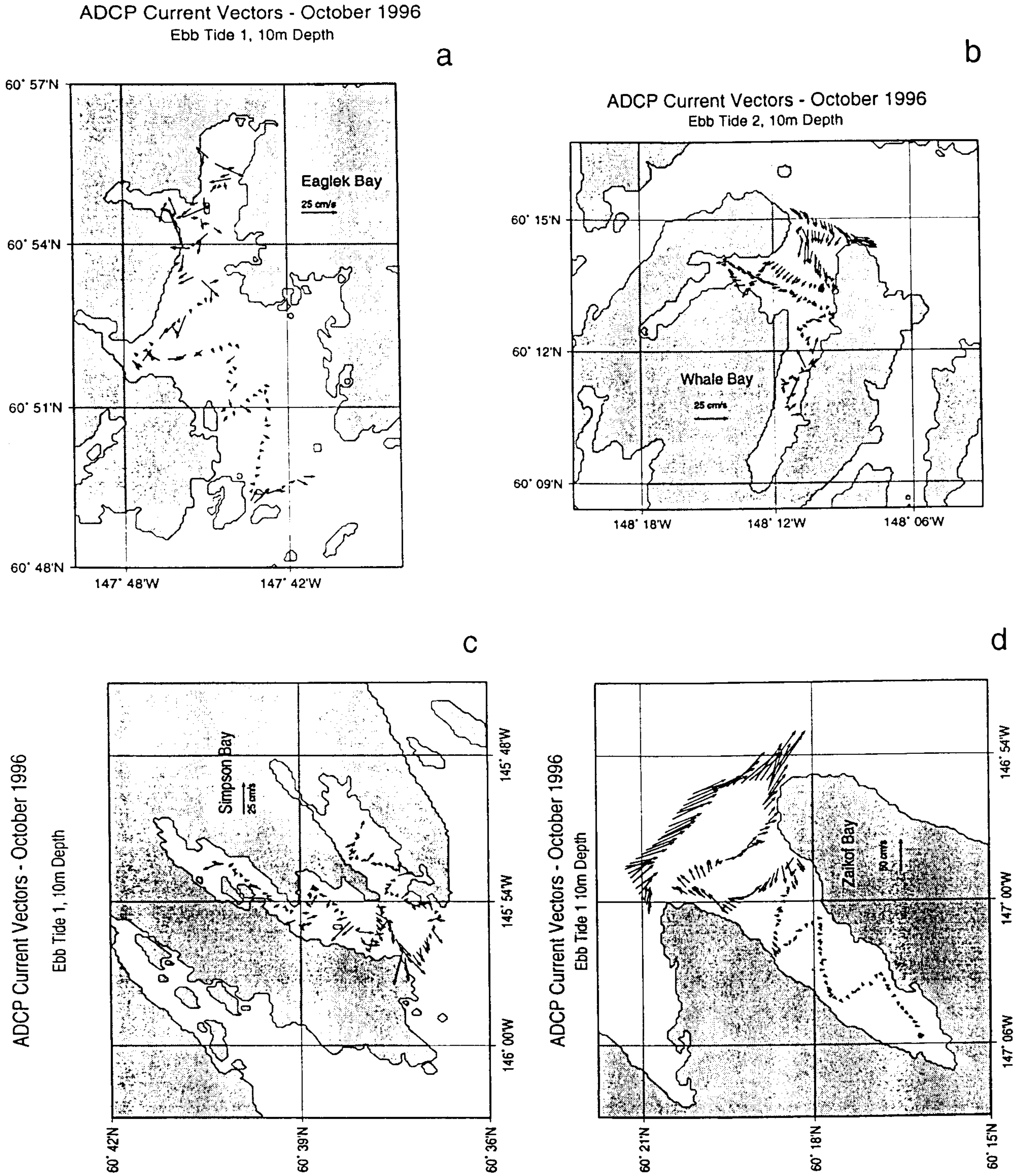


Figure 27: Velocity vectors at 10m for (a) Eaglek, (b) Whale, (c) Simpson, and (d) Zaikof Bay in October 1996 during ebb tide.

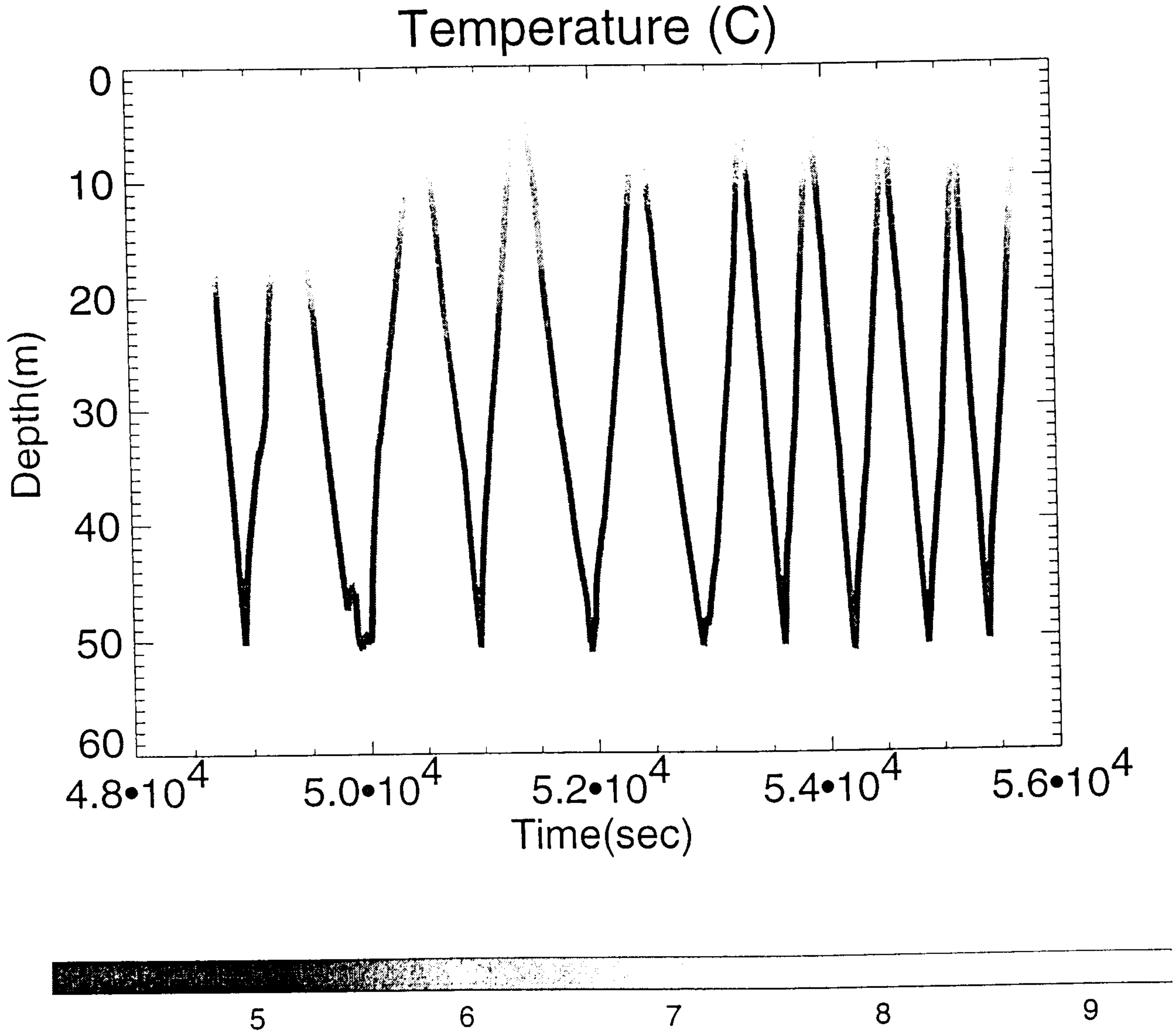


Figure 28(a): Temperature along west to east transect in Orca Inlet in May 1996.

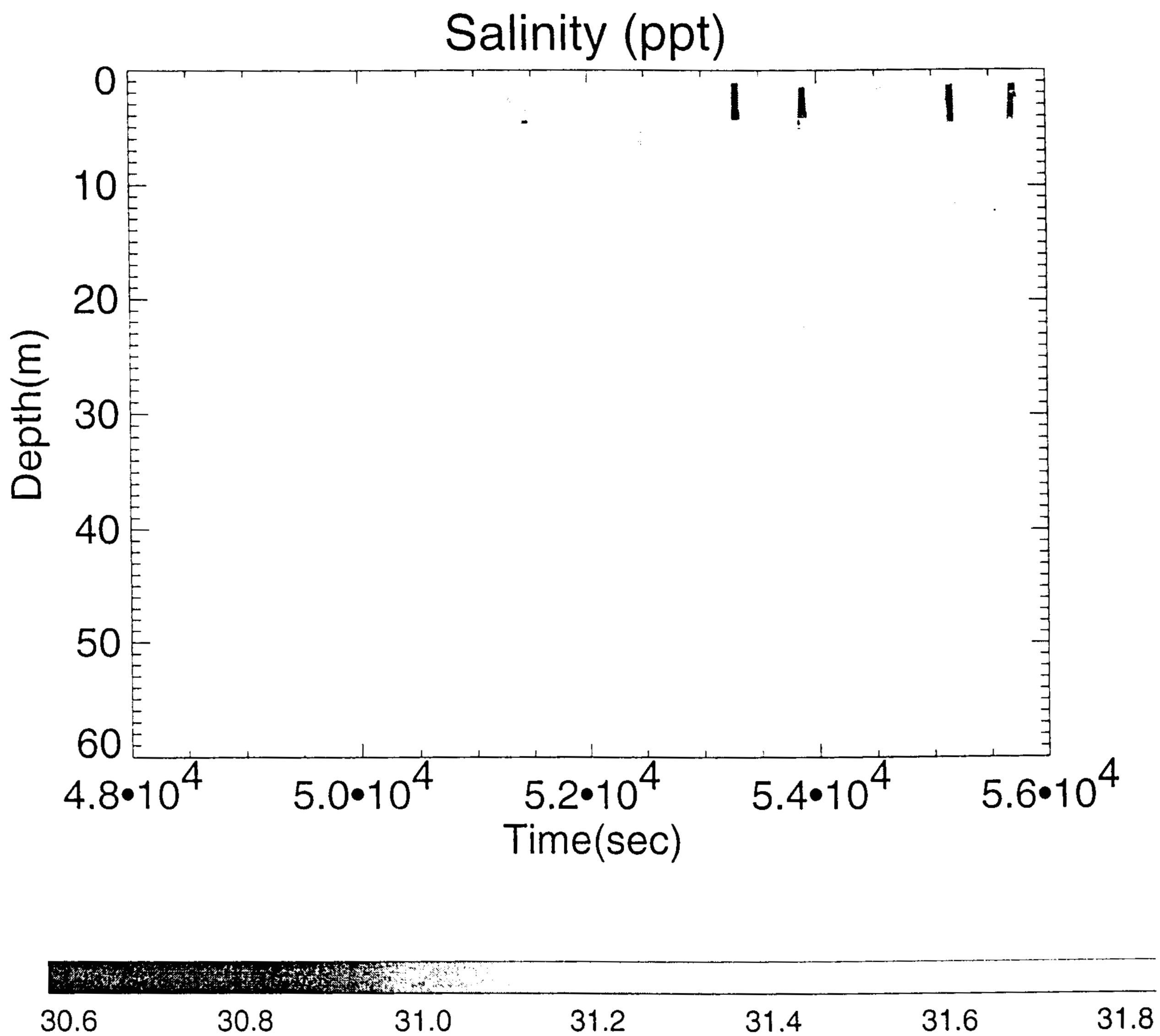


Figure 28(b): Salinity along west to east transect in Orca Inlet in May 1996.

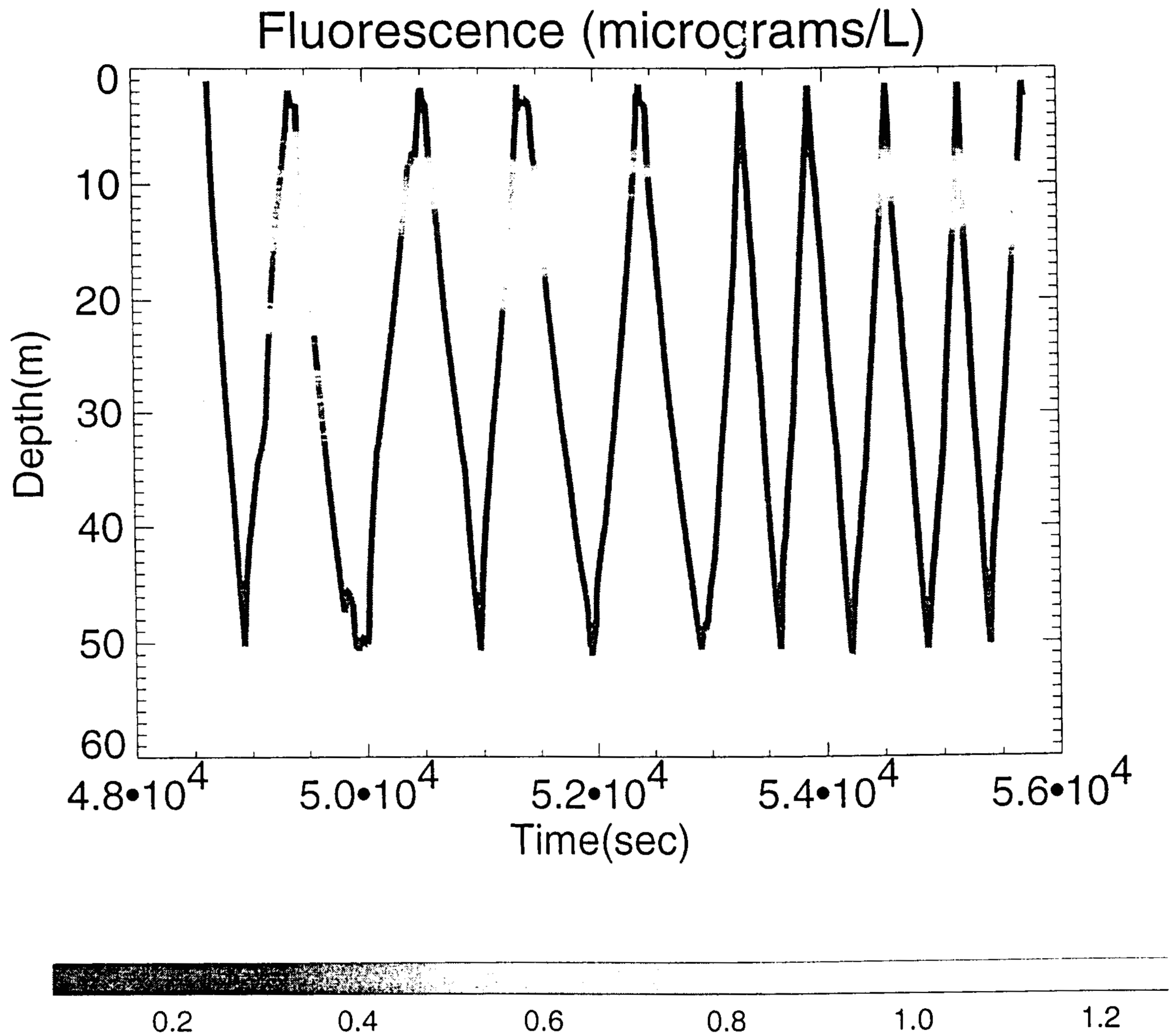


Figure 28(c): Fluorescence along west to east transect in Orca Inlet in May 1996.

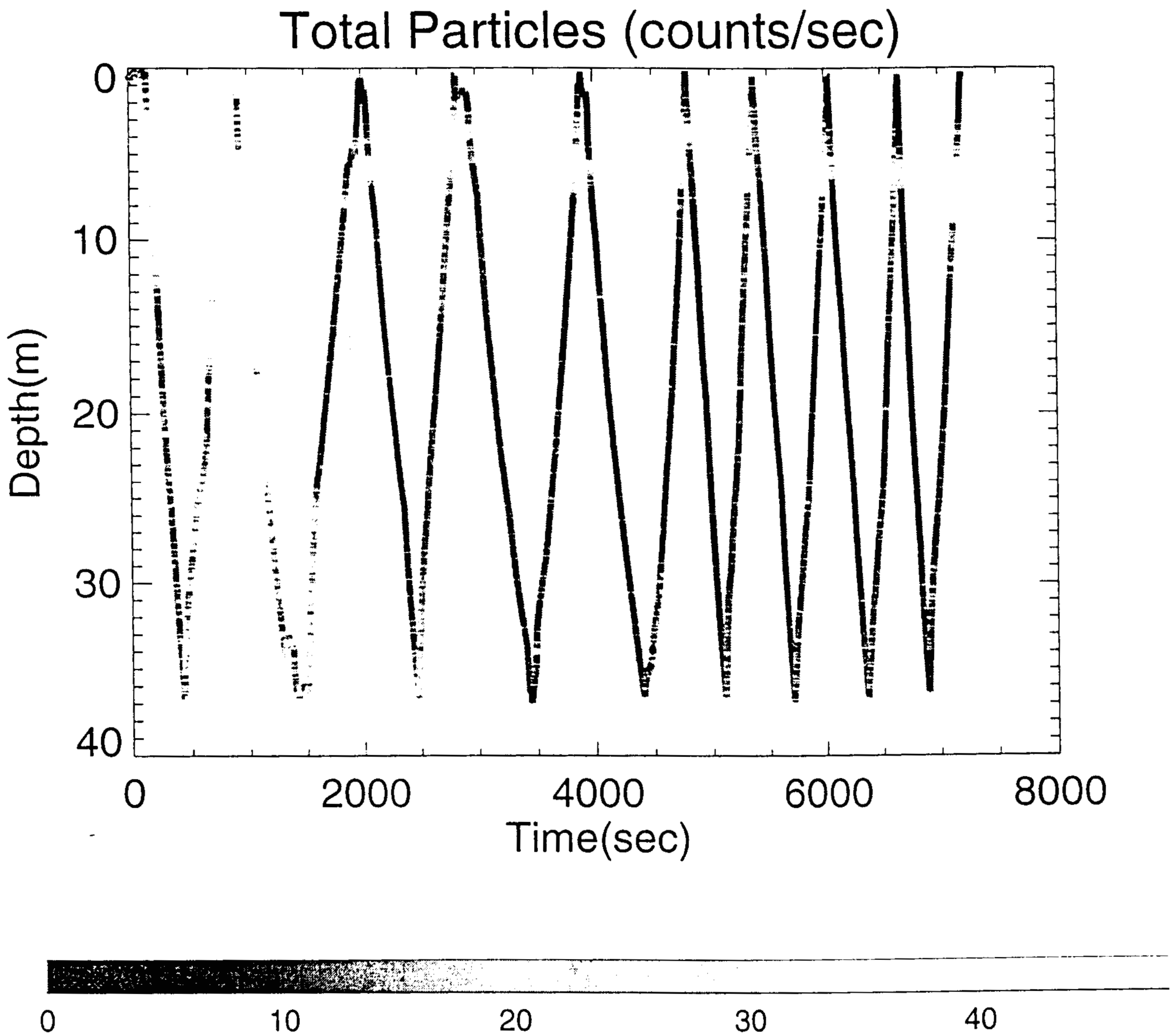


Figure 28(d): Total OPC counts along west to east transect in Orca Inlet in May 1996.

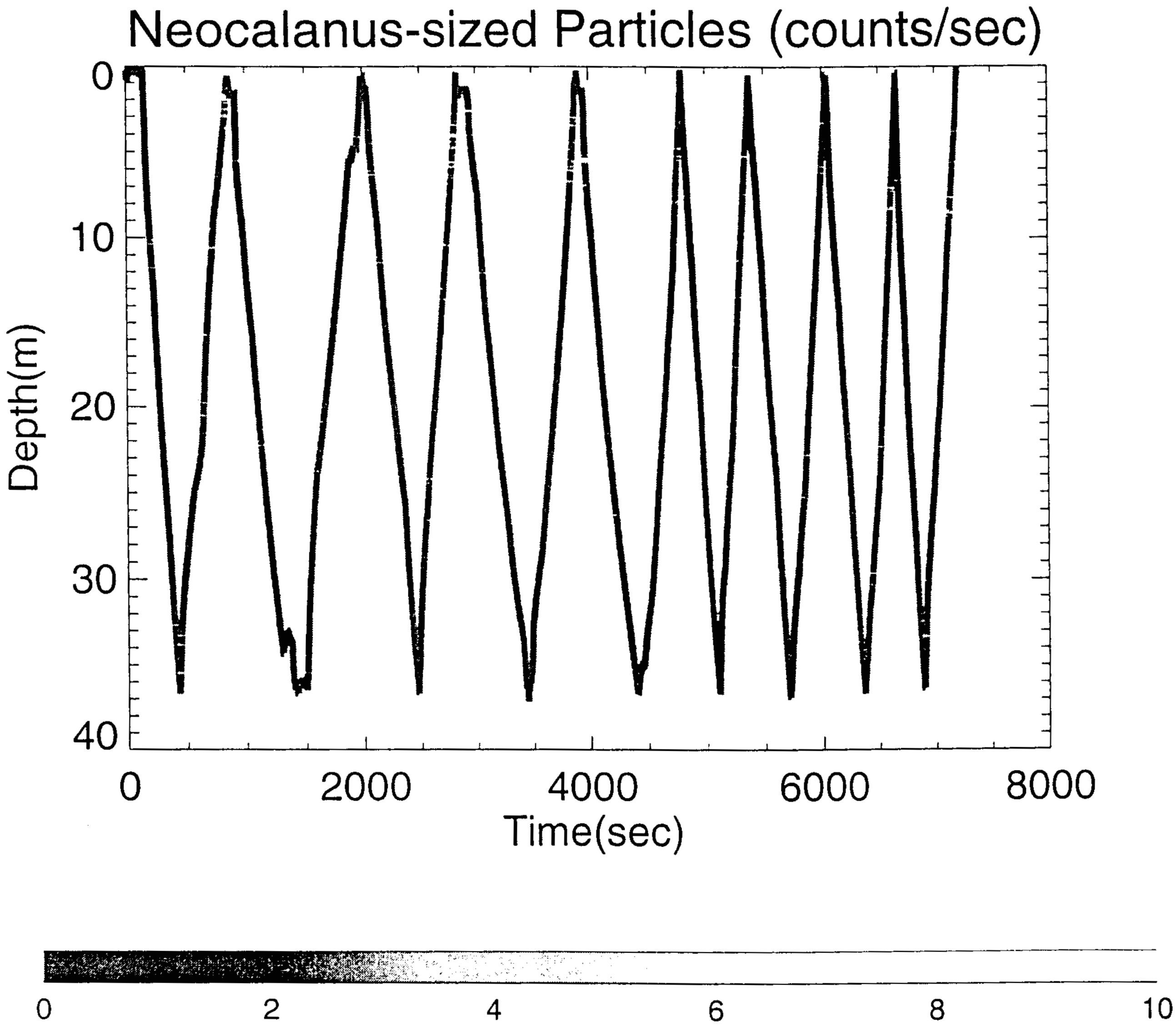


Figure 28(e): Neocalanus-sized particles along west to east transect in Orca Inlet in May 1996.