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Oceanography and Meteorology of Shelikof Strait, Alaska, During Spawning Season of Walleye Pollock: Results of Fisheries Oceanography Experiment (FOX)

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Oceanography and Meteorology of Shelikof Strait, Alaska, during Spawning Season of Walleye Pollock: Results of Fisheries Oceanography Experiment (FOX)

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Abstract

The importance of the biology of early life history of fish as well as the interaction between organisms and their abiotic environment has increased rapidly in the last decade to explain recruitment processes/stock variability of fisheries. Since Shelikof Strait was found in 1980 to be the major spawning ground of walleye pollock in the Gulf of Alaska, several investigators have become interested in using the Strait as a 'laboratory' for examining recruitment processes of walleye pollock in the Gulf of Alaska. This interest stimulated a cooperative program between the Northwest and Alaska Fisheries Center (NWAFC) and the Pacific Marine Environmental Laboratory (PMEL) of NOAA, called FOX (Fisheries-Oceanography Experiment) that lead to a newly funded initiative, FOCI (Fisheries-Oceanography Coordinated Investigations) to study recruitment mechanisms of commercially important fishery stocks in relation to the biotic and abiotic environment associated with their reproductive patterns.

CTD casting and mooring current meter data collected by NWAFC and PMEL during the spawning season of walleye pollock were analysed and are described in this report. March is the transitional period in the physical environment of Shelikof Strait. In March or April (i.e., the peak spawning season), the current speeds slow down and the surface layer warms up and becomes less saline. The conspicuous southwestward component of surface wind during winter becomes calmer at this time.

Based on baroclinic flow computations, strong baroclinic transports and speeds were found along the Peninsula side in the northeastern Strait; in the southwestern Strait the main flow was found along the deepest part of the trough or south of the deepest part of trough.

Strong southwestward surface outflow was dominant in the valley between Semidi and Chirikof Islands, and reversal bottom flow from the continental slope to the Strait was found year round. Multi-directed weak flows were present on the bank between Sutwik and Semidi Islands, while the station which was closest to the peninsula had a consistent westward flow in the surface layer.

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Data were collected as part of a cooperative study (Fisheries Oceanography Experiment (FOX) or Fishery Oceanography Coordinated Investigations (FOCI)) between the NWAFC and the PMEL. I thank all FOCI members and ship crews of R/V Miller Freeman and R/V Discoverer for collecting data.

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Oceanography and meteorology of Shelikof Strait, Alaska, during spawning season of walleye pollock

A. Geography and bathymetry

The Gulf of Alaska is located in the northeastern Pacific Ocean where the permanent cyclic Alaskan Gyre occurs (Fig. 1). High mountains range along the North American coast and a relatively broad (75 to 150 km) and deep (150 to 350 m) continental shelf (Niebauer, 1980) forms a half-arc at the perimeter of the Gulf of Alaska. This perimeter is composed of four geographic areas. From British Columbia north to Cross Sound, the southeast Alaska area, there is a narrow shelf and a highly indented coastline; from Cross Sound north to Kayak Island, the Yakutat area, there is a narrow shelf and an open coast; from Kayak Island west to the Shumagin Islands, the northern Gulf, there are numerous troughs with a broad shelf area, islands, and embayments including Prince William Sound, Cook Inlet, and Shelikof Strait; and the area between west Shumagin Islands and east of 176° W along the Alaska Peninsula and Aleutian Islands, the western Gulf, has a narrow shelf. Offshore there is a steep continental slope and a deep and broad abyssal plain. The Gulf of Alaska then is bounded on the south (around 52° N) by the North Pacific Gyre, and on the other sides by the coastal domain.

Shelikof Strait in the northern Gulf is a long (about 340 km) strait between the Alaska Peninsula and several islands--Barren, Afognak, Kodiak, Trinity, and Chirikof Islands (Fig. 1). I regard the Shelikof Strait as the area from Barren I. to Chirikof I. with accordance to the presence of major sea valley considered the most representative characteristic of Strait. I separate it into two subregions with respect to the shapes of area and bottom topography: the northeastern Strait having 180 km in length and 50 km in width; and the southwestern Strait having 160 km and 100 km, respectively. The northeastern tip of Strait faces lower Cook Inlet and Stevenson and

Kennedy Entrances. Kennedy Entrance is narrow (around 22 km) and deep (almost 200 m) while Stevenson Entrance is wider (around 36 km) and shallower (maximum of 120 m). The boundary with lower Cook Inlet is around 50 km wide and 150-200 m deep. The Strait between the Alaska Peninsula and Afognak I. includes two deep (about 200 m) and narrow troughs having NE-SW direction along two extreme sides. The trough on the island side is deeper than the other, and it extends north to southwest Barren Island. The width of Strait between the Alaska Peninsula and Kodiak I. is also narrow (about 50 km) and only one deep trough (around 300 m) is along the peninsula side. There is a very steep slope to coast on west side of the Strait, but a relatively flat and deep topography exists toward the island with a gradual change of depths. The southwestern Strait which is bounded on the northeast by Cape Kekurnoi is broad (about 100 km) and the direction of trough has changed slightly from NE-SW to NNE-SSW. Relatively shallow areas on either side of the Strait are broad. The southern and western boundaries of Strait face two banks and a narrow valley lies between them: to the south, a shallow bank exists between Trinity I. and Chirikof I. with depths of 30-40 m; to the west there is a relatively deep (around 100 m) bank between Sutwik I. and Semidi I.; between two banks (i.e., between Semidi I. and Chirikof I), there is a narrow and deep (around 200 m) valley which connects the water of Shelikof Strait with that of continental slope area.

B. Meteorology and the current systems of the Gulf of Alaska

Three large semi-permanent pressure systems affect the wind, precipitation, runoff, and currents of the Gulf of Alaska throughout the year: the Aleutian low, the Siberian high, and the east Pacific high. The east Pacific high is dominant during the summer (June - August), the Siberian high during the winter (October - March), and the Aleutian low, which is characterized by the

passage of intensive storms, is present in all seasons except summer (Wilson and Overland, 1986).

Winds have different strengths and directions with respect to season and location. In general surface winds in the open ocean are roughly parallel to isobars and strong (8 - 11 m/sec) during the winter but weak (6 - 7 m/sec) during the summer (Schumacher and Wilson, 1985). Because winds flow counter-clockwise around a low pressure center in the northern hemisphere, winds offshore are predominately from the south in the eastern Gulf, from the east in the north-central region, and from the west, but highly variable, near the Aleutian Islands (Brower et al., 1977). In the coastal area, however, the wind characteristics are different from those in open sea, especially during winter storm events which are generated by the intensive Aleutian low. Wind fields are also modified by the presence of coastal mountains. The mean winds during winter generally flow westward along the coast of the northern Gulf, which cause downwelling of water in the coastal area. Schumacher and Wilson (1985) described the large-scale wind patterns of coastal Gulf of Alaska: "If the isobars tend to run parallel to the coastline the wind can continue to flow parallel to the isobars in a near-geostophic momentum balance. If the isobars are perpendicular to the mountainous coastline, the wind will tend to flow from the region of high pressure to the region of low atmospheric pressure. Another special feature of wind in coastal area is 'Katabatic flow' which is a drainage of cold air mass from higher elevation along the fjord or valley by gravity". At mountain passes and valleys, local winds generally blow through the mountains and perpendicular to the coast. These winds can be geostrophically-balanced winds accelerated by passage through the narrow valley, or gap winds blowing down the cross-mountain pressure gradient. Thus the large-scale flow tends to blow parallel to a mountainous coastline.

It is occasionally interrupted by offshore flow from isolated mountain valleys and passes. These local winds are often severe (Macklin, 1986).

High precipitation rates along the Alaskan coast result from the adiabatic ascending of a moist marine air mass over the coastal mountain ranges. The mean annual precipitation for the northern Gulf coast for 1931 - 1960 was 2.27 m, with southeastern Alaska coast receiving 2.48 m for the same time period (Royer, 1979). Generally the maximum monthly mean precipitation (0.08-0.10 m/month) over the Gulf of Alaska occurs during the winter (December, January, and February) in association with the maximum in cyclone activity. The precipitation amount continuously decreases until summer (0.05 m/month) and rises to 0.07 - 0.08 m/month during the fall (Wilson and Overland, 1986).

The amount of runoff into the ocean, however, is controlled not only by the rate and form (rain or snow) of precipitation but also by air temperature over the mountains. Therefore the maximum runoff was shown to occur in September and October due to high precipitation rate and melting water from glaciers (Royer, 1982). In November, as the air temperature drops, the precipitation becomes snow and is stored in mountain glaciers. After the minimum runoff in February and March, a gradual increase in discharge begins in April.

The Subarctic Pacific Current, the extension of the Kuroshio and Oyashio in northwestern Pacific Ocean, flows eastward along 50-52° N until it is blocked and split into two branches by the North American coast (Fig. 1). One branch flows equatorward (California Current). The other (Alaska Current) flows poleward, occupies a broad area (about 400 km), and travels at low speed (10 - 30 cm/sec). But in the northern and western Gulf, it forms into a narrow (<100 km) and fast (sometimes current speed in excess of 100 cm/sec) stream over continental slope called the Alaska Stream. This westward flow

parallels the Alaska Peninsula westward to the Aleutian Islands. The Stream seems to be quite stable but does occasionary undergo large changes (Reed and Schumacher, 1986). Aside from this large scale rotating gyre, another current system is existed in shelf areas from British Columbia to Unimak Pass. This coastal current, the Alaska Coastal Current (ACC), is created by freshwater addition from the continent and wind-induced sea level changes (Schumacher and Reed, 1983). These two factors result in cross-shelf pressure gradients and yield counterclockwise baroclinic flow. While the offshore Alaska Stream does not have large seasonal variation in mass transport (Reed et al., 1980), the ACC has an Autumn maximum baroclinic flow (1,000,000 M^3/sec : 1 Sv) due to maximum discharge during autumn and minimum flow in early summer. The seaward diffusion of low-saline water is limited in the coastal area by wind effects (Royer, 1983).

The most conspicuous baroclinic gradient appears west from Kayak I., along the Kenai Peninsula. This ACC, known as the Kenai Current, occurs mainly within 30 km of shore. Here the ACC has a large seasonal variation in baroclinic transport and maximum surface speed. During October 1977 off the Kenai Peninsula, for example, when the integrated effect of precipitation, river discharge, and melt water attained a maximum, the mean salinity of the coastal flow was about 1.5 g/Kg less than that of seaward shelf waters. Maximum baroclinic transport (1 Sv) and speed (89 cm/sec) occurred at this time, while minimum volume transport (0.1 Sv) and speed (13 cm/sec) were obtained during May 1978 (Schumacher and Reed, 1980).

C. Wind pattern near Shelikof Strait

Whenever geostrophic imbalances occur due to variations in sea surface temperature or small-scale radiation or latent-heat release in clouds over the open sea, a geostrophic adjustment process which returns conditions to a

geostrophically balanced state occurs within about 12 hours. The geostrophic imbalance caused by the coastal mountain arc, however, cannot be adjusted in the same manner, because the wind cannot flow through the mountain barrier; within Rossby radius (e.g., a distance of 80 km of a 1500 - 2000 m coastal mountain range), the wind direction depends upon the direction of isobars in relation to the coastline as mentioned in section II.B. In this case, it is difficult to predict wind strengths from geostrophically balanced pressure gradients. Northeastern Shelikof Strait has a smaller width than the Rossby radius so that winds tend to accelerate parallel to the pressure gradient when isobars are perpendicular to the Strait. Fig. 2 shows an example of this (Macklin et al., 1984): On 4 March 1983, the wind of east Kennedy and Stevenson Entrances roughly parallelled the isobars over the open ocean. The winds in north Shelikof Strait were similar in direction but speeds were accelerated somewhat. In the northeastern Strait area, the winds increased in magnitude toward the southwest as they accelerated down the pressure gradient. As they approached southwestern Strait, they decelerated and the transition from gap winds to geostrophic winds occurred abruptly. The winter condition of continental high pressure over the central Alaska is especially conducive to the southwestward direction of gap winds in Shelikof Strait.

On a large scale, the strong cyclonic systems which migrate across the north Pacific Ocean along the Aleutian Islands and then track northward into the Gulf of Alaska influence the weather of this region. The monthly mean surface wind in southwest Kodiak Island during 1973 - 1980 showed that the southwestward component (240 degree) was conspicuous in winter months (December - February) and northeast components were present in summer and fall (June - November). Between March and May, along-shelf components can be ignored, instead cross-shelf component (330 degree) increased abruptly from March to May (Fig. 3). Note that no noticeable mean winds were observed in March.

The winds in the northern Gulf of Alaska are from the east except for one or two months in summer, and produce coastal convergence. During the summer, upwelling is possible but winds are very weak. Strickland and Sibley (1985) showed that downwelling is clearly indicated in the Shelikof Strait area and east of Kodiak Island during the winter with weak upwelling from May through September.

D. Water properties and current pattern of Shelikof Strait before and after the spawning season of walleye pollock

1. Methods and data

Few observations were made in coastal waters of the Gulf of Alaska before the Outer Continental Shelf Environmental Assessment Program (OCSEAP) started in 1974. For the Shelikof Strait region, conductivity and temperature versus depth (CTD) data have been obtained only since spring of 1977. From 1977 through 1985 a total of 21 cruises by National Oceanographic and Atmospheric Administration (NOAA) -- Northwest and Alaska Fishery Center (NWAFC) and Pacific Marine Environmental Laboratory (PMEL) -- obtained CTD data in Shelikof Strait during the spring spawning season (Table 1). CTD data were collected using Plessey model 9040 systems with model 8400 data loggers. Data were recorded only during the down-cast using a lowering rate of 30 m/min. For temperature and salinity calibration sea water samples were taken on most cruises.

Current data were collected using Aanderaa model RCM-4 current meters on taut wire moorings in and around Shelikof Strait. Among 50 current meter records at selected depths in 17 mooring stations (Table 2), 21 records include information from March through May (i.e., the adult spawning season and drifting period of eggs and larvae). All data collected were stored and analysed in Rapid Retrieval Data Display (R2D2) (Pearson, 1981) in PMEL's

computer system. Raw data were filtered to remove high-frequency noise so that over 99% of the amplitude was passed at periods greater than 5 hours, 50% at 2.86 hours and less than 0.5 % at 2 hours. This time series data includes direction of current, speed, temperature, pressure, and salinity. The resulting series was then passed through a second, low-pass filter to remove most of the tidal energy. The second filter passed more than 99% of the amplitude at periods over 55 hours, 50% at 35 hours and less 0.5% at 25 hours.

Several authors (Mysak et al., 1981; Schumacher and Reed, 1980; Schumacher et al., 1978) have already analysed current and CTD data from 1977 and 1978. Because these data sets were obtained from only a small part of Strait and prior to peak spawning time, we needed more detailed information for fisheries oceanographic purposes. The CTD data sets collected by R/V Miller Freeman during four ichthyoplankton surveys in 1981 (1MF81 - 4MF81) resulted in a good time series (early March - late May) in central region of Strait. The study area was subdivided into eight sub-areas along Strait, hereafter referred to as Strata (Fig. 4). Furthermore, the intensive survey in March 1985 covered all of Shelikof Strait with 189 CTD casts taken on 19 transects (Fig. 4). These data give us some understandings of physical properties of the Strait during the early life periods of pollock. In addition to these, some water property data were collected by a Soviet research vessel (R/V Shantar) during March - May 1981. A total of 235 hydrographic casts at standard depths (0, 10, 20, 30, 50, 75, 100, 150, 200, 250, 300, 400, 500, and 600 m) were made during three 1981 ichthyoplankton surveys (1SH81 - 3SH81). Because the Soviets did not use standard sea water for salinity calibration, only temperature data is presented. Details of ship schedules and area covered by the R/V Miller Freeman and R/V Shantar are in Bates and Clark (1983) and Fadeev and

Borets (1981). Most data analyses and treatments were done on R2D2 of the VAX computer at PMEL. Simple calculations and statistics were done with the Minitab interactive software package (Ryan et al., 1982) of the Burroughs computer at NWAFC.

2. Results and discussion

a) Before the peak spawning season of walleye pollock (March)

As shown in Figure 5a, the water mass near Stevenson Entrance was warmer, saltier, and denser than that of Kennedy Entrance (i.e., the extension of Kenai Current), because Kenai Current is considered to be more influenced by cold and dilute river runoff. In the Strait, the surface water along the Peninsula side is colder and less saline than that on Island side because the discharge from lower Cook Inlet is added to the coastal current close to the Peninsula (Fig. 5c). The waters in Kennedy Entrance, near northwest Barren Is., and in the middle part of the Strait appear to have nearly the same physical properties (i.e., <5° C, <32‰, and less stratification) so that they can be distinguished from other waters nearby. Further evidence that they are the same water masses can be obtained by examining the 0/100 dbar geopotential topographic contour (Fig. 6). The relief across the flow was about 0.03 dynamic meter. The 0.275 and 0.280 dynamic meter contours continue from Kennedy Entrance to Shelikof Strait via north Barren Island while 0.270 and 0.265 isolines in Stevenson Entrance do not extend into Shelikof Strait. Therefore it can be said, as pointed out by Schumacher and Reed (1980) and Muench et al. (1978), that the coastal flow enters Shelikof Strait through Kennedy Entrance and turns south near Cape Douglas. Based on such information, we are able to identify three layers of different water masses and their flow patterns in northeastern end of the Strait: a small amount of water along the west side of the Strait originated from land runoff through lower Cook Inlet

which formed the surface layer (some 50 m deep) with strong thermal and salt stratification (e.g., at CTD station 25 with depth of 76 m, T = 4.08° C, S = 0.88‰); The waters below the surface layer on the west side and in the middle part of the transect, which occupied the biggest portion of water volume in this area, which originated from the ACC via Kennedy Entrance and north and west Barren Islands; a small amount of warm (>5° C) and saline (>32‰) water which existed in the bottom trough west of Stevenson Entrance (Fig. 5c). However, some evidence from the temperature (Fig. 7) and salinity contour (not shown) at 100 m depth suggest that this bottom water mass does not intrude from Stevenson Entrance but extends from the bottom layer of the Strait proper along the deep trough.

The Strait proper (i.e., northeastern Strait) has similar characteristics to the northeastern end in current structure. In general, cold and dilute surface water along the Peninsula was near-homogeneous due to combined wind and thermohaline mixing. The wave-like structure which was explained by Mysak et al. (1981) was also shown as it travels down-strait (Fig. 8). This downstream-traveling wave is probably related to fluctuations of the flow with time scales of a few days. Warm (>5° C) and saline (>32‰) water always occupied the deep Strait (deeper than 150 m) between the Alaska Peninsula and Kodiak Island. Temperature and sigma-t distributions at 150 m suggest where the bottom water came from (Fig. 9). Warm and saline bottom layer water came from the continental slope area via the southwestern valley of the Strait (See below). As shown in the northeastern end, water properties in the middle layer of this region (including the surface layer on the Kodiak Island side) are nearly the same as those found in Kennedy Entrance, which indicates that the source of this water mass is the ACC. Below the surface layer, the isotherms and isohalines at depth show an inclination in transects across the

Strait. This may result from the input of freshwater to the west side of the Strait which causes the isolines to be deepened along the west side of the Strait (Fig. 5e). Another possible explanation comes from the origin of the bottom water inflow. If we regard this Strait as a large estuarine system with ouflow of the upper layer and inflow below defined as in Pickard and Emery (1982), there would be a semi-permanent reversal in the bottom layer. As shown in Figure 9, warm bottom water entered the Strait over the southern sill and was observed in the southern part of the trough and also in the bottom layer on the Kodiak Island side. The inflow phenomenon might be related to earth's rotation. The effect of Coriolis force results in horizontal salinity gradient (freshwater on the left facing upstream in broad estuaries of the Northern Hemisphere), and the inflow at the bottom layer tends to hug the right side of the estuary (Knauss, 1978). Some evidence for estuarine-like flow is shown in current meter data from moorings FOX8401, FOX8402, FOX8403, FOX8407, FOX8408, and FOX8409. For example, current records near the Kodiak coast (FOX8403) during fall through winter 1984 showed a northeastward flow, and more dense water compared to that in Peninsula side (FOX8401). The current records in the valley area (FOX8407, FOX8408, and FOX8409) will be discussed later in this Chapter.

In the southwestern Strait, water properties are similar to those in the northeastern Strait. Relatively large amounts of warm and saline water occupied the bottom layer, and surface cold water along Peninsula side was not conspicuous. The flow pattern might be changed due to the irregular bathymetry and the broaden width of the Strait. Reversal flow shown in Transect 11 (Fig. 10) is possibly caused by a relatively shallow bump near the deep trough. It is not clear whether the water properties of the south trough are influenced by oceanic water through banks in southern boundary or

not. A transect from the 1981 Soviet data shows a distinct discontinuity of water temperature between the Strait and slope area (Fig. 11). Also, the Soviet data show a warm water mass in the south trough, which is thought to be evidence of bottom inflow. In the coastal area during March (e.g., FOX8510) current is directed generally southwestward with reduced speed (Appendix I).

Several islands, banks and valley in the southwestern end of the Strait effect the current and transport patterns. Because the bank between Sutwik and Semidi Islands is shallow (maximum of 130 m) most outbound water flows southward through the valley area between Semidi and Chirikof Islands. This is illustrated by the 0/100 dbar geopotential topography (Fig. 12). As shown above, the temperature distribution at 150 m shows the connection of water masses between the bottom layer of the Strait and the continental slope (Fig. 9). The water mass which had a temperature above 5.5° C continued from the southwestern Strait to the slope area through the valley. The monthly means of current speed and direction from current meters in the valley area show semi-permanent inflow in the bottom layer (e.g., 185 m of FOX8407 and 205 m of FOX8408), which confirm that at times Shelikof Strait has a two layered flow system -- outflow in the upper layer and inflow below.

The isotherms and isohalines along the Strait (the deepest station in each transect was chosen) shown in Figure 13 indicate that the warm and saline water which entered via the southwestern valley (Transect 17), occupied the bottom layer of the Strait, and isotherms and isohalines tended to be deepened continuously to the deepest station of Strait. Figure 13 also shows that the water structure both in the northeastern tip (Transects 4-6) and just outside of the valley (Transects 18-19) are less stratified than that in the central area (Transects 7-17). A very warm core of water existed at about 200 m in the southwestern Strait (Transects 10 - 16) where the width of Strait is greatest.

The baroclinic transport and the baroclinic speed were derived from water property observations (Table 3 and Fig. 10). The calculation is based on the assumption of two-layered flow, i.e., southwestward flow between surface and 150 m, and reversal flow below 150 m. Therefore a depth of no motion of 150 m was assumed at most stations except at the northern tip where 100 m of depth of no motion was applied because of shallow topography. A large amount of water with relatively high baroclinic speed (e.g., transport and speed are 0.14 Sv. and 11.0 cm/sec, respectively) entered the Strait via Kennedy Entrance and north Barren Is., while a very small amount was transported into the Strait via Stevenson Entrance. Actually some outflow occurred there. The baroclinic transport and velocity generally are highest in the surface layer along the deepest part of each transect. The flow direction changed from NE-SW to N-S near east Sutwik I. and increased in its velocity and transport near valley area. Velocities were high in the northeastern Strait (Transects 4 - 9), and the southwestern end (Transects 16 - 19). In the southwestern Strait (Transects 10 - 15), the velocities rapidly decreased and/or reverse-directed currents were found. Large transport, roughly speaking, was shown in the boundary between the northeastern and the southwestern parts of the Strait (Transects 8 - 9) and the southwestern end (Transects 16 - 18), while small transports were in the northeastern tip, and bank areas in the southwest.

Mooring data from the northeastern Strait showed that most surface currents headed to the southwest except near the Kodiak coast (e.g., Station FOX8403) where northeastward flow dominated below about 150 m and existed throughout the water column (see Appendix I). High speeds occurred in October - February, but they decreased dramatically in March every year. Monthly mean temperature in the surface layer revealed the lowest values in April, and

after that it warmed until September. Surface minimum salinity was shown in late fall (October - December), was highest in February and became dilute, so that sea water became lighter from March until fall. In the middle and bottom layers, however, no clear seasonal variations in temperature, salinity, and water density were apparent. Some reversals and cross-strait flows were frequently found in these layers. Reduced current speeds appeared over the bank and valley area during the spring time. In the valley the high speeds of winter decreased from February, while over the bank between Sutwik and Semidi Islands the low speeds appeared during the winter and spring. Generally most surface currents flowed to the southwest except at moorings FOX8405 and FOX8406 where low speed with variable direction existed. Lowest temperatures were shown in April and highest salinity and water density in March or April on the bank. Geostrophic current speed and the observed current speed from the southern valley are shown in Figure 14. The geostrophic speeds were lower than observed current speeds because the barotropic current is included in actual measurements and should be significant in this area during spring (Schumacher and Reed, 1980). However, these two speed values seem to have the same trend; on the eastern and central valley the speeds are high in surface layer and reduced with depth, while speeds are low in surface layer and increased in middle layer of western valley.

From the available current and water property time series, it appears that March is the transitional period in the physical environment of Shelikof Strait. From March or April, the current speeds slow down, the surface layer warms up and becomes less saline.

b) During the development of early life stages of walleye pollock (April - May)

The important periods for early life stages (i.e., egg and larva) are their drifting period within the water column from the time they are spawned until they enter nursery grounds. In order to see the changing pattern of oceanography in the central region of the Strait where most spawning occurred, data from four cruises from March to May 1981 by U.S.A., three cruises in southwestern Strait conducted concurrently by the Soviets, and mooring data were examined.

Noticeable changes in temperature and water density took place in the surface layer. As mentioned by Royer (1979, 1981), variations in salinity has a larger effect on water density than does variations in temperature in cold water regions. Therefore, changing patterns of salinity and water density are very similar to each other so that in this section, generally water density will be discussed. From March through May a warm and dilute surface layer was formed through increased insolation and freshwater discharge. The characteristic of this surface water mass is illustrated in the T-S diagram (Fig. 15). This shows enclosed envelopes of all observations from stations located within the study area. The March and early April 1981 envelopes show a cool surface layer overlying a warm bottom layer, while the late April and May 1981 ones show the opposite. Changes in water properties of the bottom layer (below about 200 m) depend upon exchange with slope water. They are likely related to changes in the Alaska Stream which, in turn, is affected by changes in properties of the Subarctic Pacific Current. Average temperatures at the surface, 50 m, and 100 m had increases of 2.5° C, 1.0° C, and 0.5° C, respectively, for this time period (March - May), while the temperature changes below 150 m were not significant (Fig. 16). Temperature differences between the middle layer (150 m) and the bottom layer (250 m) decreased as

the season progressed. The average temperature ranges of these layers from March through May had changed from 5.2 - 5.5° C to 5.3 - 5.4° C. The results based on the interpolated Soviet data at several depths showed almost the same feature; i.e., temperature increases at surface, 50 m, and 100 m from March to May were 2.8° C, 1.4° C, and 0.8° C, respectively. Because of the surface warming and the increased discharge after March (see Section B.) the water density in the surface layer (0 - 50 m) where most of the walleye pollock larvae were found was becoming lighter as time passed (Fig. 16). The mean water density at the surface dropped from 25.1 (unit: sigma-t) in March to 24.7 in May; no changes (some 25.4) with time were detected between 100 m and 150 m; and below 150 m a continuous increase was shown, e.g., at 250 m sigma-t was 25.5 in March and 26.0 in May. See Appendix II for detailed data.

Current meter data sets were used to get monthly average water properties at each instrument depth. From the CTD casts conducted in 1981, it was known that the lowest temperature at the surface was found during March through early April, and the temperature at 50 m was increased at an increment of 0.016° C/day from mid March (1MF81) to late May (4MF81). Unfortunately we have no temperature data from current meters during the spring of 1981. However, the data set from moorings C10 (65 m) and C10B (70 m) in the northeastern strait showed the temperature increment of 0.017° C/day between March and May, 1978. Also the changing pattern of water density shown by CTD observations from March through May--drops in surface layer and increases in bottom layer--is in good agreement with monthly means of density from the current meters. The density from current meters (FOX8407 - FOX8409) in the bottom layer, even though they are sparce, show high densities during the summer and fall, a rapid decrease between December and January, and then an

increase through the spring, while the densities in the surface layer (C10, C10B, and FOX8404 - FOX8408) decrease from March through May (Appendix I). A similar pattern in salinity change was found at 250 m off Seward (Xiong and Royer, 1984) and in the northern Gulf (Royer, 1975).

The average Mixed Layer Depth (MLD) was defined as the depth at which sigma-t had increased by 0.03 units per meter. The MLDs and their variabilities decreased with time due to surface warming, discharge increase, and wind decrease, which results in high value of dynamic height in May (Appendix III). The mean MLD in mid March was 63.2 m with a standard deviation of 50.1 m. It changed to 35.8 m (S.D.= 28.4 m), 30.5 m (S.D.= 33.7 m), and 15.5 m (S.D.= 9.6 m) in early April, late April, and late May, respectively (Table 4). The dynamic heights (0/100 dbar) during this time period were 0.277, 0.289, 0.287, and 0.294 dynamic meters, respectively.

The characteristics of water properties along the strait were also examined (Fig. 17; Appendix II). Generally water temperatures of both surface and bottom layers were higher in the northeastern part of the Strait than in the southwestern part during March - May. Warming rates in Strata II - IV and VI - VII at 50 m depth were 0.017° C/day and 0.014° C/day, respectively. Water temperatures at 200 m seemed to be fairly stable with respect to time and location of sampling. At the boundary between northeastern and southwestern parts of the Strait (Stratum IV) noticeable temperature drops were found always. The surface is colder than the bottom throughout the Strait until early April, and at the end of April the surface temperature exceeds the bottom temperature in the northeastern area. By the end of May the surface is warmer than the bottom in whole Strait. While the water density at surface was decreased rapidly with time, that between 50 m and 150 m showed no big change with time and location, e.g., throughout whole spawning area and

season, the sigma-t ranged from 25.05 to 25.20 at 50 m depth. Below 200 m depth, however, the water density increased very fast in the southwestern valley area after mid April. Most stations between Kodiak I. and the Alaska Peninsula (i.e., northeastern Strait) had shallower MLDs than those in the southwestern part of the Strait (Table 4).

Baroclinic velocities and transports of the surface layer relative to 150 m (0/150 dbar) were calculated and are shown in Figure 18. Generally they were high in the Peninsula side of the northeastern part of Strait (Strata II - IV) and toward the southwestern valley (Strata VII and VIII), while low or negative values were shown in Kodiak Island side of the northeastern Strait (Stratum I) and the southwestern Strait area (Strata V and VI). Comparatively high values occurred in early April and the end of May. Reduced values existed between these two time periods. Even though we could find no consistent temporal or spatial trend in flow pattern from this data, it is obvious in data from several moorings (e.g., C10B, and FOX8404 - FOX8409) that the surface current speeds continuously decreased during the spring and have minima in early summer. The location of main flow or Alaska Coastal Current within the Strait varies with time. Based on Figures 10 and 18, however, we can describe it briefly; in the northeastern Strait the strong baroclinic transports and high speeds usually occurred along the Peninsula, and in the southwestern Strait the main flow occurred south of the deepest part of the valley.

One of the interesting problems with respect to larval transport is where does the water in the Strait flow out? A comparison of time series of component speeds in the bank area between Sutwik and Semidi Islands with those in valley area revealed that strong southwestward surface flows were dominant in the valley (Fig. 19), while weaker flows were present on the bank

during the spring (Fig. 20). Also current strength, which appeared in the bank area during March, diminished with time. Speeds decreased with increasing depth in all areas. Two things to be noted are that currents at station FOX8404 (which was closest to the peninsula) had a consistent westward flow in the surface layer, and that inflow in the bottom was found year round at valley area (Fig. 19). Progressive vector diagrams (PVD) which simulate a Lagrangian path from Eulerian measurements were made based on mooring current data (Fig. 21). At station FOX8404, a westward drift occurred in the surface layer with an average velocity of 7.7 cm/sec during March through May, while drift in the rest of the area of the bank had no directionality. Over the valley, the surface water (0 - 121 m) drifted southwestwardly with average velocity of 8 - 10 cm/sec on the western side and very strong surface current (16.2 cm/sec) was found on the eastern side (56 m depth of FOX8409).

Because the spawning period is almost the same each year, the effects of environmental variations should be investigated to understand variations in the strength of future recruitment. There are large interannual fluctuations in physical properties and current strength. For example, during March 1985, the surface temperature (3.66° C) was colder than that (4.73° C) during March 1981, but the bottom temperature (5.58° C) in 1985 was warmer than that (5.45° C) in 1981. Therefore, the temperature difference between top and bottom was 1.92° C in 1985 and 0.72° C in 1981. In 1985, salinity and sigma-t were higher throughout the water column than in 1981. Because of the presence of cold and saline water in the upper layer in March 1985, dynamic heights in main spawning area were lower than during 1981 (i.e., means of 0.289 and 0.275 dynamic meters in 1981 and 1985, respectively), and there were larger MLDs. The MLD of the central Strait during late March was greater in 1985 (mean and S.D. are of 37.4 m and 26.1 m) compared to 1981 (mean and S.D. are

22.4 m and 15.2 m, respectively) due to the delay of surface warming and possibly an increased wind mixing. The monthly means of current speed, as shown in Appendix I, varies year after year. For example, over the valley area, surface current speeds in March were higher than those in February 1985 (FOX8407 and FOX8408), while speed reduced in March compare to that in February 1978 (K12A).

The amounts of dissolved oxygen (DO) resulting from the photosynthesis by phytoplankton and the diffusion from air mass were determined by the Soviet cruises during March and April, 1981. DOs were not high and decreased with depth in March, however increased DO values were found in the surface layer in April (Fig. 22), which provided evidence that the phytoplankton bloom occurred in April. Especially high DO stations in March roughly coincided with shallow MLD stations and low DO stations with deep MLD stations in 2MF81 (Fig. 23). These stations were located in both the east and west coastal areas in the southwestern part of the Strait and the narrow Strait area between Kodiak Island and the Alaska Peninsula.

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Figure 14.--Estimates of baroclinic speed (0/150 db) and observed speed from mooring current meter. In order to remove tidal effect, the mooring current data (three days before and after CTD cast date) were 35-hour filtered and resampled at 6-hourly intervals. Unit is cm/sec.

Figure 15.--T-S envelopes of Shelikof Strait water in spring (March - May) 1981. The time periods of 1MF81-4MF81 are in Table 1, and the total number of sampling stations used in each cruise are 21, 89, 79, and 80 stations, respectively.

Figure 16.--The changes of average temperature (°C) and density (sigma-t) at selected depths during spring 1981 cruises 1MF81 - 4MF81.

Figure 17.--Temperature and density (sigma-t) distribution along Shelikof Strait at selected depths and their changes with time.

Figure 18.--Baroclinic transport and geostrophic velocity in Shelikof Strait during March - May, 1981. Arrows pointing to the left denote southwestward flow and these to the right northeastward flow: (a) mid March (1MF81), (b) early April (2MF81) (c) late April (3MF81), and (d) late May (4MF81).

Figure 19.--The observed current velocity with the major axis of 190 degree in the valley area. The upright vector stick shows outflow from Shelikof Strait.

Figure 20.--The observed current velocity with the major axis of 250 degree in the bank area. The upright vector stick shows outflow from Shelikof Strait and flows along the Alaska Peninsula.

Figure 21.--Progressive vector diagrams (PVD) made at the boundary of southern Strait (i.e., bank and valley areas) during March through May, 1985.

Figure 22.--Dissolved oxygen (DO) measured by U.S.S.R. R/V Shantar, March - April, 1981. The time periods of 1SH81 and 2SH81 are March 5 - 18, and April 16 - 24, respectively.

Figure 23.--The distribution of dissolved oxygen (DO) at surface in March superimposed on that of mixed layer depth (MLD) during early April, 1981. The shaded area has shallower MLD than the average of all stations. Dots indicate stations which have higher DO values than the average and triangles show lower DO than the average.

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Table 1.--U.S. research cruises in Shelikof Strait during spawning time (March - May) of walleye pollock, 1977 - 1985.

Date	Research vessel	Main purpose
March 27, 1977	Discoverer	General hydrographic survey
March 4 - 17, 1978	Surveyor	General hydrographic survey
March 6 - 24, 1978	Discoverer	General hydrographic survey
April 11 - 14, 1980	Miller Freeman	Hydroacoustic survey
March 3 - 15, 1981	Miller Freeman	Hydroacoustic survey
March 12 - 20, 1981*	Miller Freeman	Egg and larval survey
March 24 - 27, 1981	Miller Freeman	Hydroacoustic survey
March 30 - April 8, 1981*	Miller Freeman	Egg and larval survey
April 4 - 10, 1981	Miller Freeman	Hydroacoustic survey
April 26 - May 2, 1981*	Miller Freeman	Egg and larval survey
May 20 - 24, 1981*	Miller Freeman	Egg and larval survey
March 6 - 20, 1983	Miller Freeman	Hydroacoustic survey
March 24 - April 3, 1983	Chapman	Hydroacoustic survey
April 6 - 13, 1983	Miller Freeman	Hydroacoustic survey
May 16 - 28, 1983	Chapman	Larval survey
March 3 - April 7, 1984	Miller Freeman	Hydroacoustic survey
March 20 - April 8, 1984	Chapman	Egg survey
Feb. 21 - March 28, 1985	Miller Freeman	Hydroacoustic surrvey
March 12 - 28, 1985	Discoverer	General hydrographic survey
April 2 - 11, 1985	Miller Freeman	Egg survey
May 2 - 11, 1985	Miller Freeman	Larval survey

*The four sequential ichthyoplankton surveys in 1981 will be designated elsewhere as 1MF81, 2MF81, 3MF81, and 4MF81, respectively.

Table 2.--Mooring current meters in Shelikof Strait. The letters used in FOX series mooring are shown in Figure 4.

Mooring name	Location Latitude	Longitude	Duration	Meter depth (m)
K1	57.74	154.73	Oct. 1976 - Mar. 1977	100
K2	58.62	153.08	Oct. 1976 - Mar. 1977	20
				100
K12A	55.99	156.30	Oct. 1977 - Mar. 1978	18
				205
C10	58.50	153.19	Oct. 1977 - Mar. 1978	20
				65
K13A	56.34	156.84	Oct. 1977 - Mar. 1978	102
K13B	56.40	156.82	Oct. 1977 - Mar. 1978	111
			May 1978 - Oct. 1978	28
C10B	58.50	153.20	May 1978 - Oct. 1978	25
				70
				165
FOX8401	57.74	154.73	Aug. 1984 - Jan. 1985	26
(A)				56
				106
				165
				240
FOX8402	57.60	155.01	Aug. 1984 - Jan. 1985	26
(B)				56
				106
				165
				220
FOX8403	57.51	154.77	Aug. 1984 - Jan. 1985	26
(C)				56
				106
				165
				220
FOX8404	56.45	156.98	Aug. 1984 - July 1985	26
(D)				56
FOX8405	56.35	156.90	Aug. 1984 - July 1985	26
(E)				56
				106
FOX8406	56.28	156.82	Aug. 1984 - July 1985	26
(F)				56
				75
FOX8407	55.95	156.60	Aug. 1984 - July 1985	26
(G)				56
				106
				185
FOX8408	55.94	156.36	Aug. 1984 - July 1985	26
(H)				56
				121
				205
FOX8409	55.91	156.15	Aug. 1984 - Jan. 1985	26
(I)			Aug. 1984 - July 1985	56
				121
				168
FOX8510A	57.01	156.17	Jan. 1985 - July 1985	26
(J)				105

Table 3.--Baroclinic transport and velocity along Shelikof Strait during March, 1985. Calculation for transport and surface velocity is based on 100 m (Transects 1 - 4) and 150 m (Transects 5 - 19) depth of no motion.

Transect	Total transport (10,000 M^3/sec)	Width of Strait (Km)	Transport in unit distance (1,000 M^3/sec/Km)	Mean speed (cm/sec)
1	2.66	55.6	0.48	1.9
2	4.16	58.5	0.71	2.0
3	7.17	39.2	1.83	5.0
4	10.82	36.0	3.01	6.4
5	15.44	39.5	3.91	7.0
6	16.45	36.0	4.57	6.6
7	16.05	46.0	3.49	4.4
8	34.05	43.7	7.79	8.8
9	34.32	59.5	5.77	8.5
10	11.22	75.5	1.49	1.7
11	17.12	86.5	1.98	3.5
12	25.70	80.0	3.21	3.3
13	20.71	79.5	2.61	3.0
14	15.87	88.0	1.80	1.8
15	23.40	93.0	2.52	2.3
16a	0.71			0.9
16b	35.44	47.6	7.45	8.7
17	26.86	40.5	6.63	5.3
18a	2.45			0.5
18b	39.29	50.0	7.86	7.8
19a	1.35			0.9
19b	15.43	61.0	2.53	6.5

N.B.-The low values of total transport at Transects 1 and 2 are due to significant outward flow at Stevenson Entrance in Transect 1 and incomplete sampling in Transect 2, respectively.

Table 4.--The mean mixed layer depth (MLD) along Strait during spring (March - May), 1981. The time periods of 1MF81 - 4MF81 are in Table 1. The number in parenthesis is one standard deviation.

	Strata								
Cruise	I	II	III	IV	V	VI	VII	VIII	Mean
1MF81		23.7 (6.4)	65.0 (74.5)	100.2 (61.9)		39.0 (37.6)	67.3 (33.3)		63.2 (50.1)
2MF81	5.0 (5.0)	17.7 (23.9)	20.8 (12.1)	36.2 (9.9)	31.6 (19.4)	53.5 (36.0)	33.7 (20.7)	62.1 (39.7)	35.8 (28.4)
3MF81	25.5 (34.7)	18.5 (19.9)	8.7 (11.8)	32.1 (12.5)	44.3 (44.2)	24.5 (31.8)	20.0 (25.0)	57.3 (47.2)	30.5 (33.7)
4MF81	9.0 (9.8)	11.8 (9.5)	8.6 (5.9)	11.6 (6.0)	18.0 (9.2)	19.6 (8.5)	18.4 (12.1)	12.0 (11.9)	15.5 (9.6)

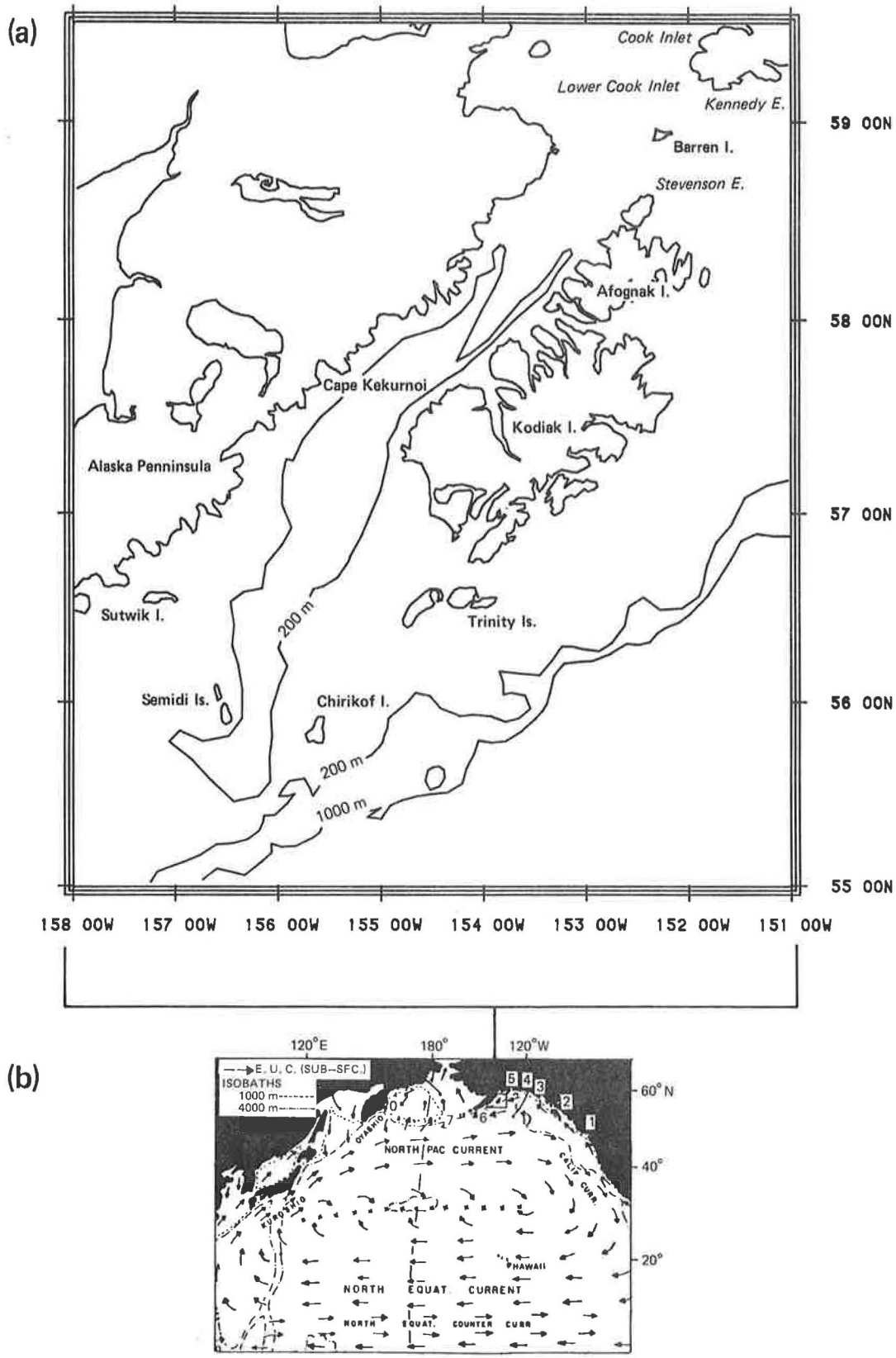


Figure 1.--Geographic setting showing (a) the Shelikof Strait area and (b) the current systems of the North Pacific Ocean (after Pickard and Emery, 1982). The numbers shown in (b) indicate the areas; 1. British Columbia, 2. Cross Sound, 3. Yakutat area, 4. Kayak Island, 5. Prince William Sound, 6. Shumagin Islands, and 7. Aleutian Islands.

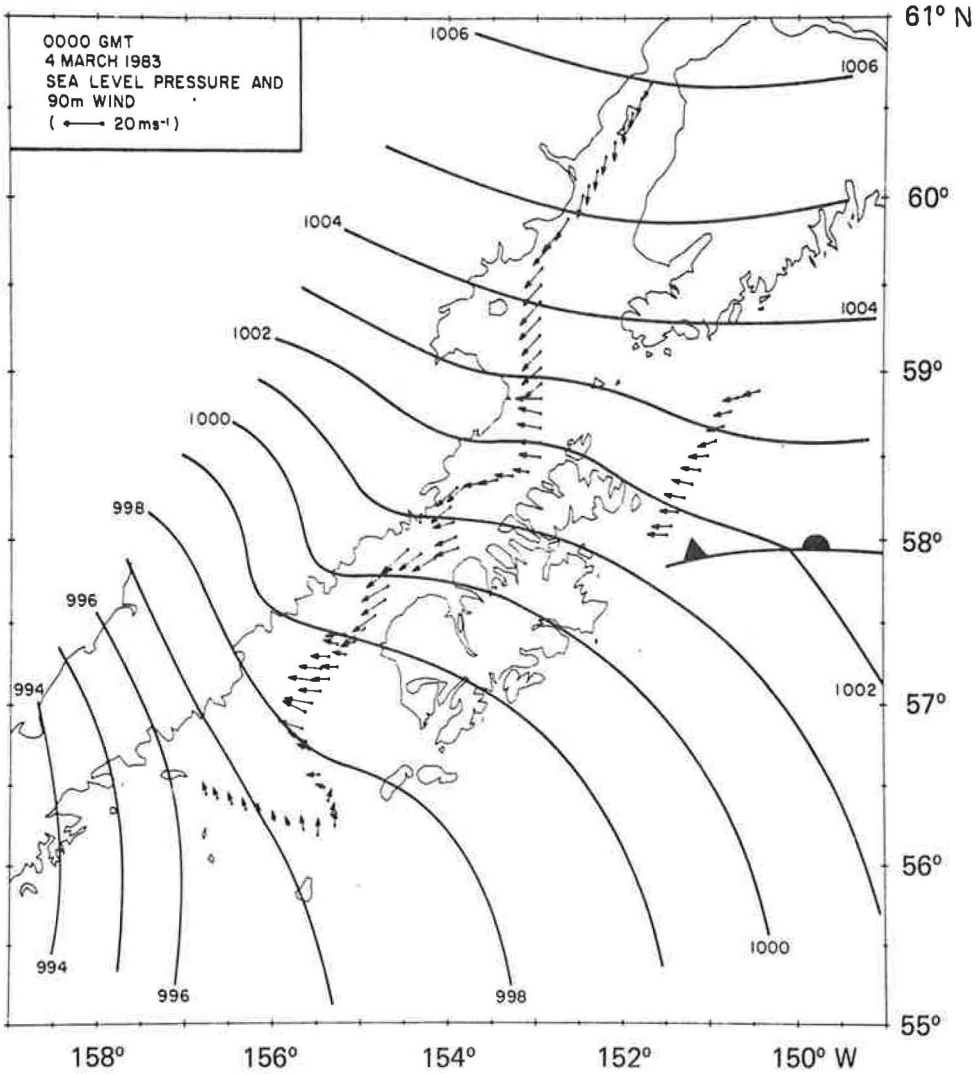


Figure 2.--Surface winds and sea level pressure collected from the NOAA WP-3D aircraft in March, 1983 (from Macklin et al., 1984).

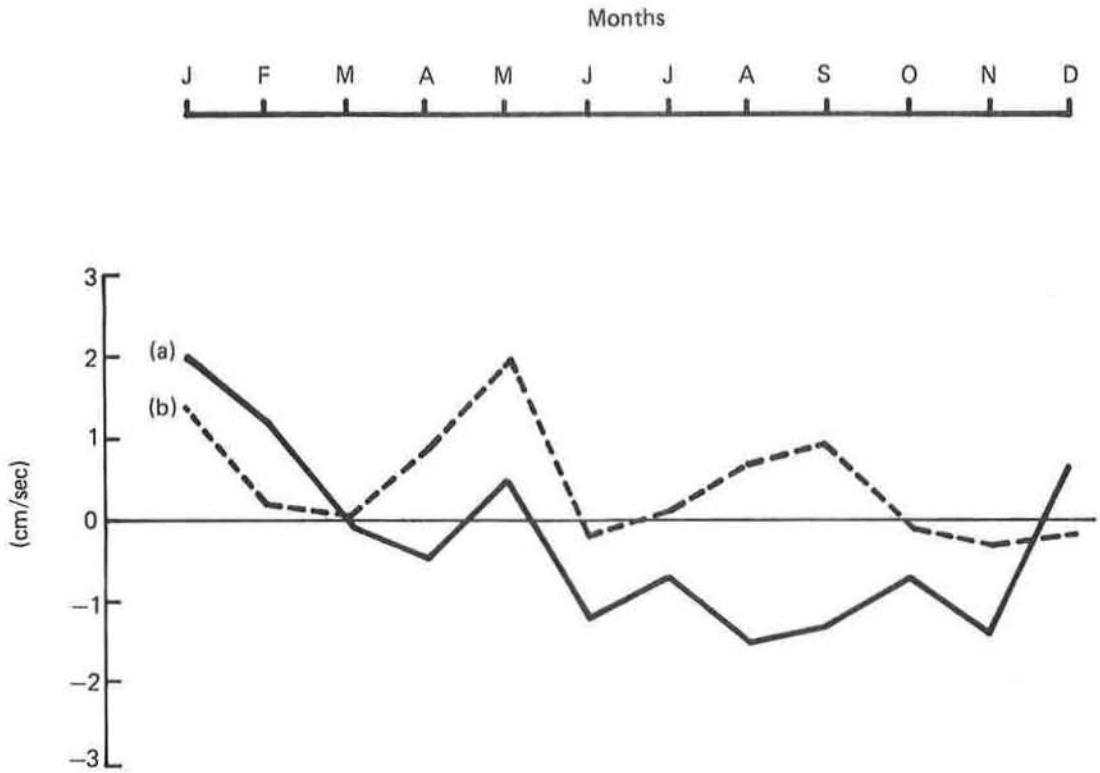


Figure 3.--Monthly mean surface wind (1973/1980) from southwest Kodiak Island (a) along shelf (240 degree) and (b) cross shelf (330 degree).

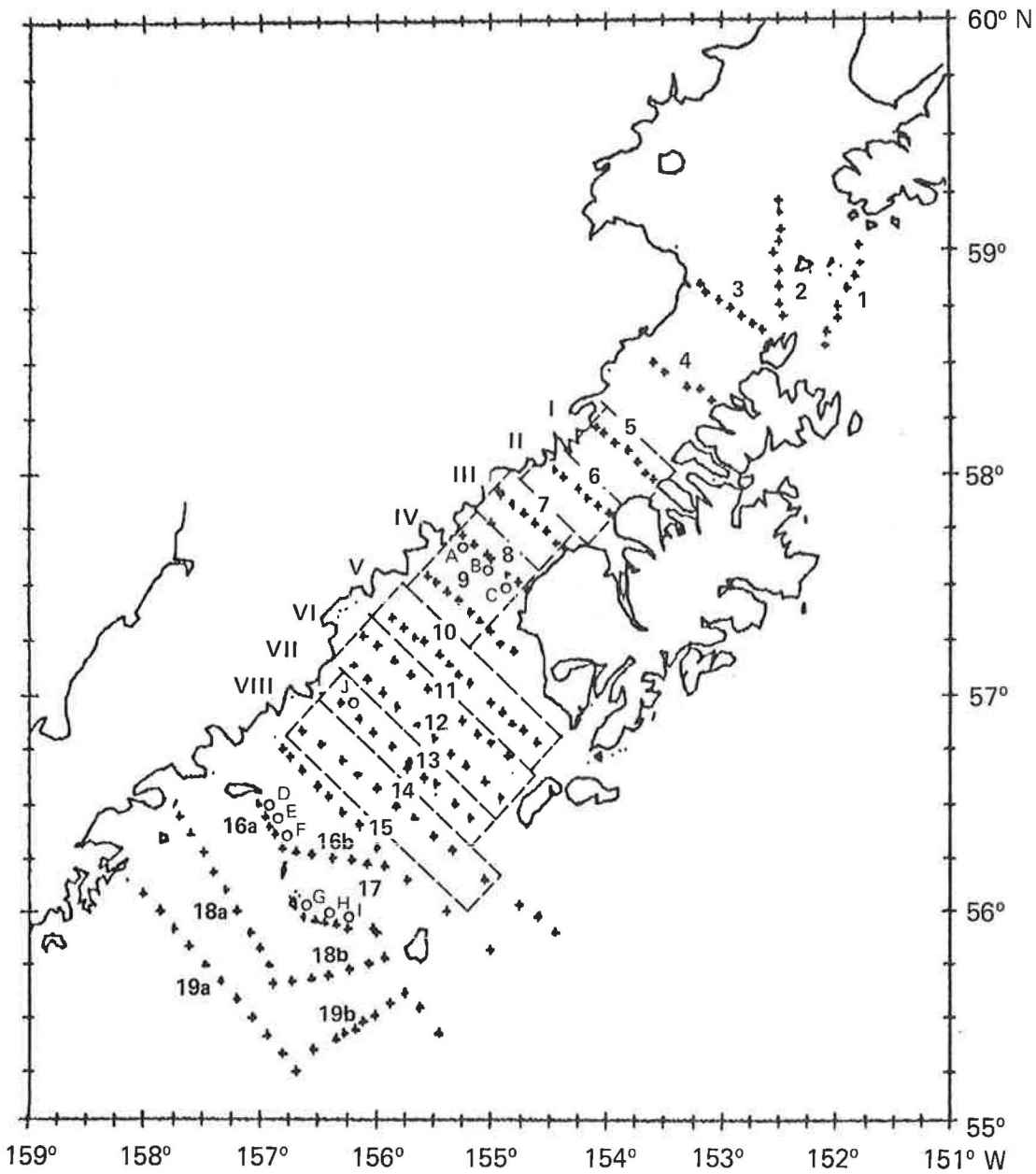


Figure 4.--The location of mooring current meter (o), CTD cast stations (+) and transects (arabic numerals) conducted in March, 1985. The eight sub-areas along Strait (Latin numerals) for examining 1981 CTD observations are also shown. The letters used in mooring location are shown in Table 2.

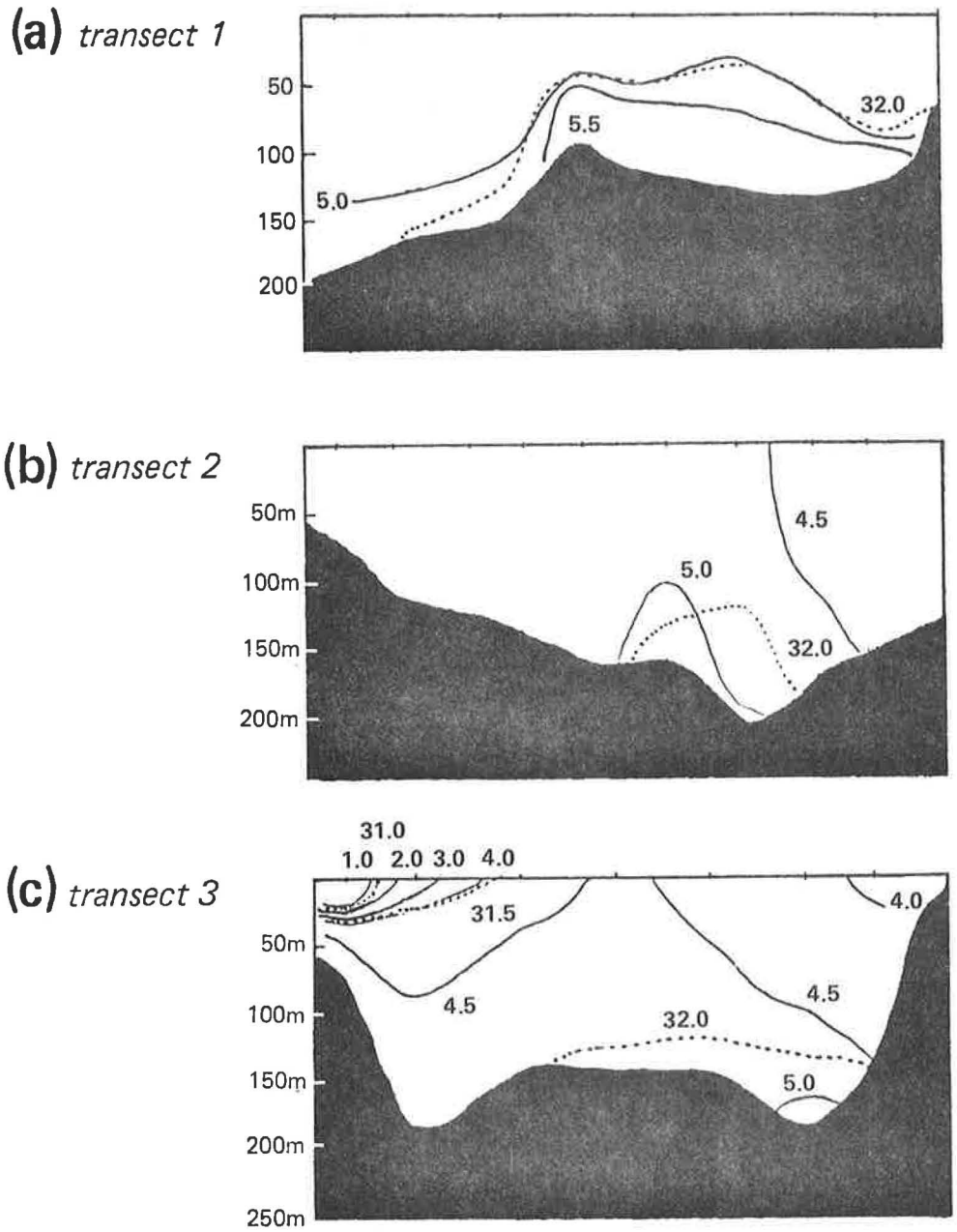
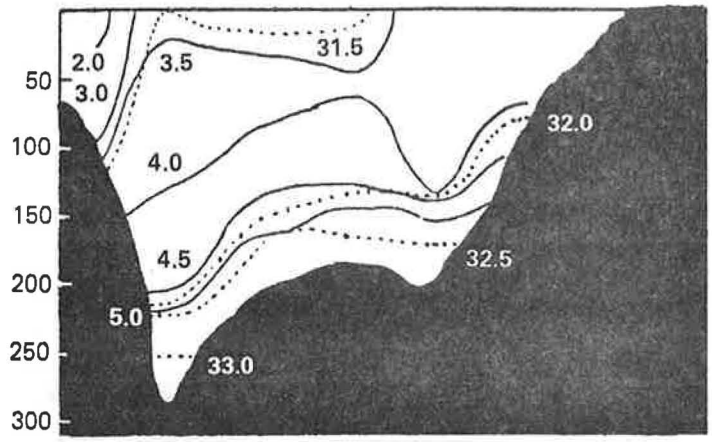
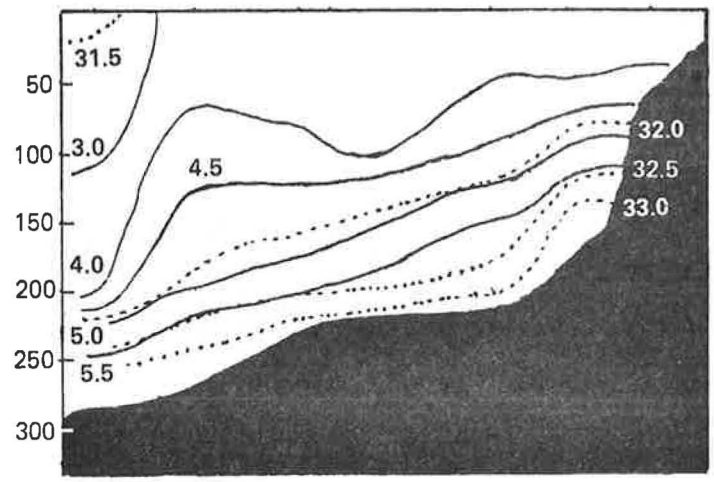


Figure 5.--Vertical sections of temperature (°C) and salinity (‰) along and cross Shelikof Strait: (a) Transect 1, (b) Transect 2, (c) Transect 3, (d) Transect 6, (e) Transect 8, (f) Transect 11, (g) Transect 14, (h) Transect 16, and (i) Transect 17. Kodiak Island end of the Transects to the right.

(d) *transect 6*



(e) *transect 8*



(f) *transect 11*

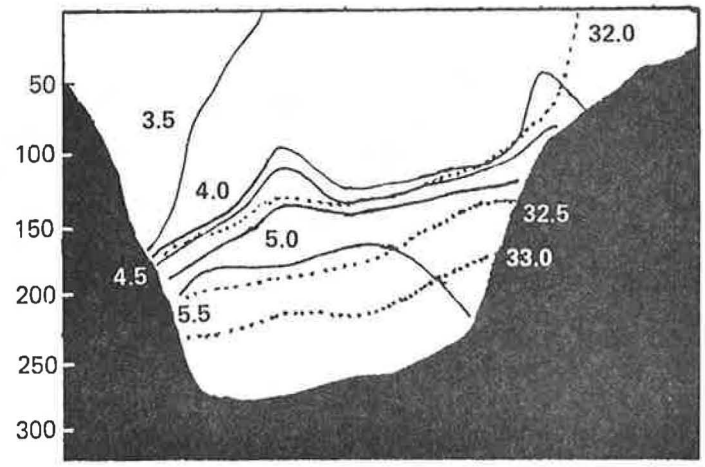
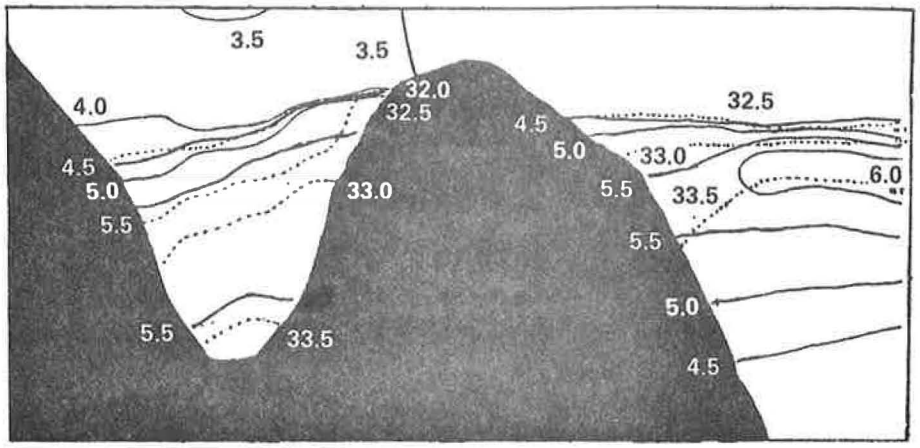
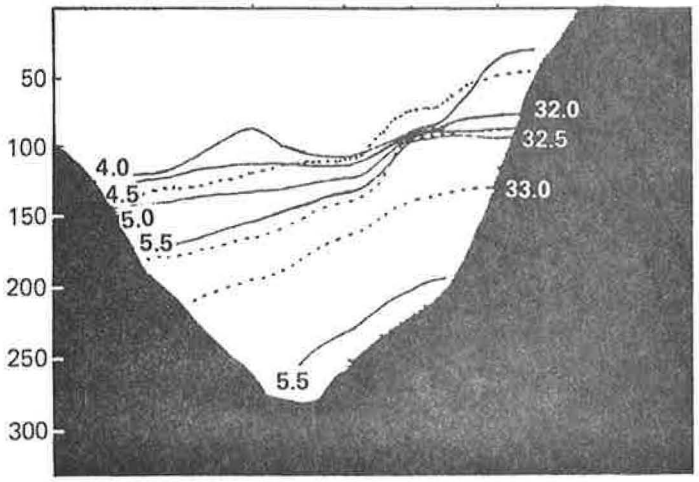


Figure 5.--(continued) Vertical sections of temperature (°C) and salinity (‰) along and cross Shelikof Strait: (a) Transect 1, (b) Transect 2, (c) Transect 3, (d) Transect 6, (e) Transect 8, (f) Transect 11, (g) Transect 14, (h) Transect 16, and (i) Transect 17. Kodiak Island end of the Transects to the right.

(g) *transect 14*



(h) *transect 16*



(i) *transect 17*

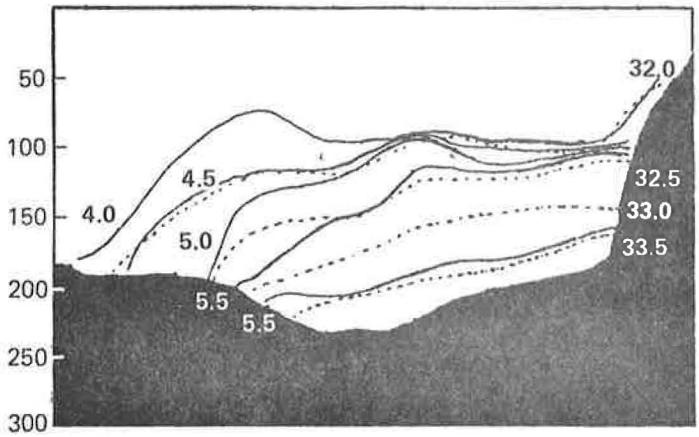


Figure 5.--(continued) Vertical sections of temperature (°C) and salinity (‰) along and cross Shelikof Strait: (a) Transect 1, (b) Transect 2, (c) Transect 3, (d) Transect 6, (e) Transect 8, (f) Transect 11, (g) Transect 14, (h) Transect 16, and (i) Transect 17. Kodiak Island end of the Transects to the right.

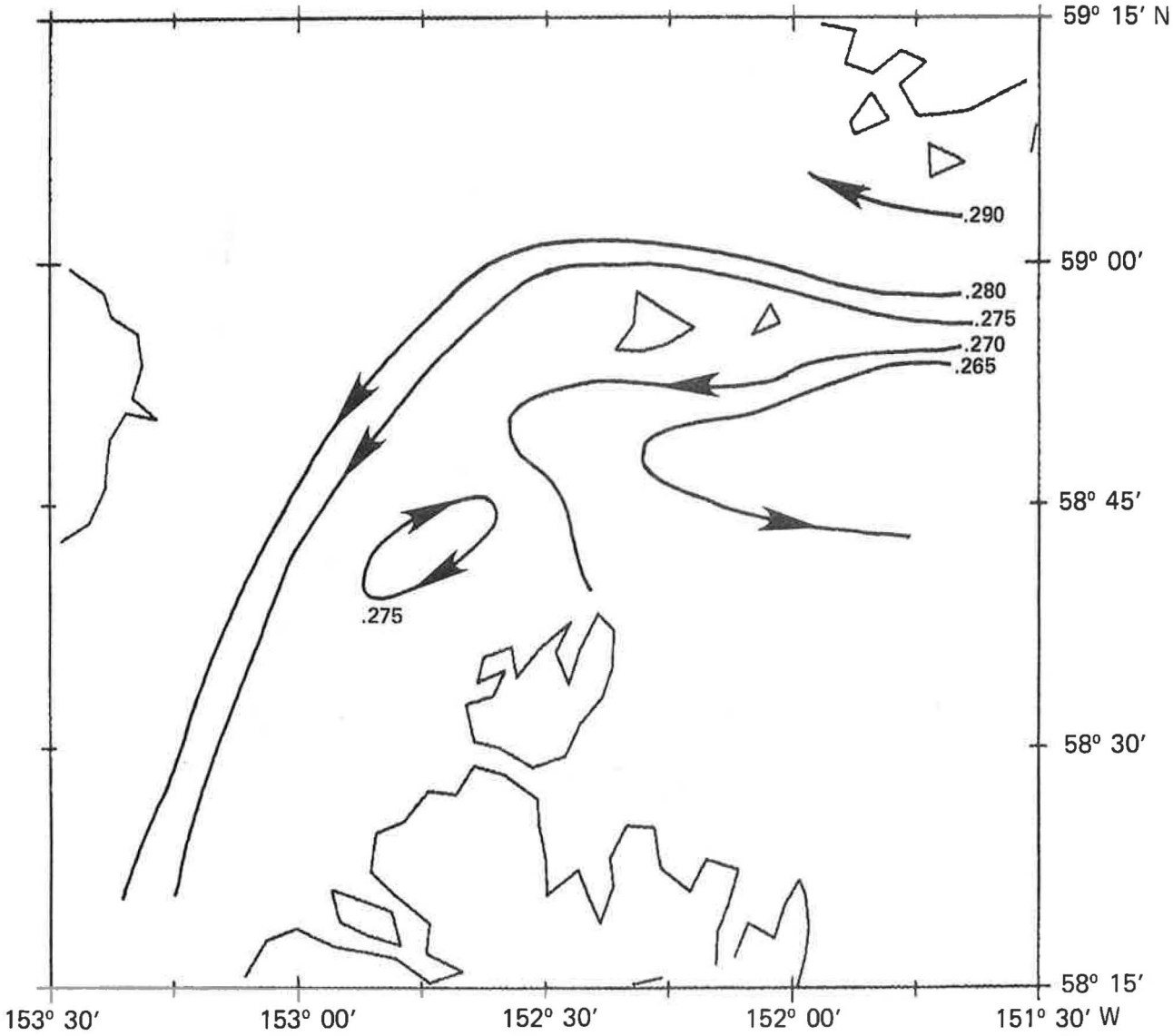


Figure 6.--Geopotential topography (0/100 dbar, in dynamic meter) observed near Kennedy and Stevenson Entrance during March, 1985.

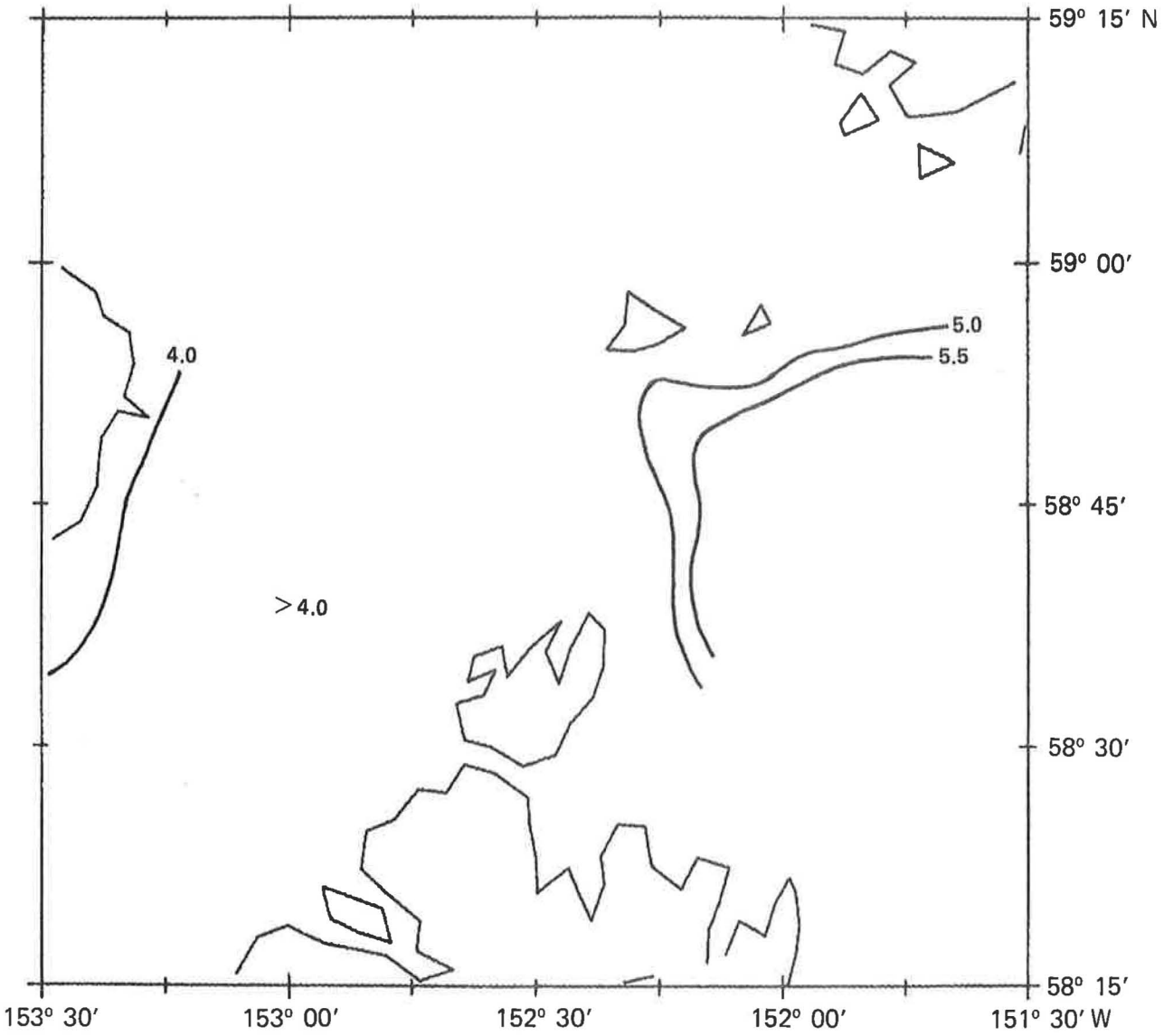


Figure 7.--Horizontal sections of temperature (°C) at 100 m near Kennedy and Stevenson Entrance during March, 1985.

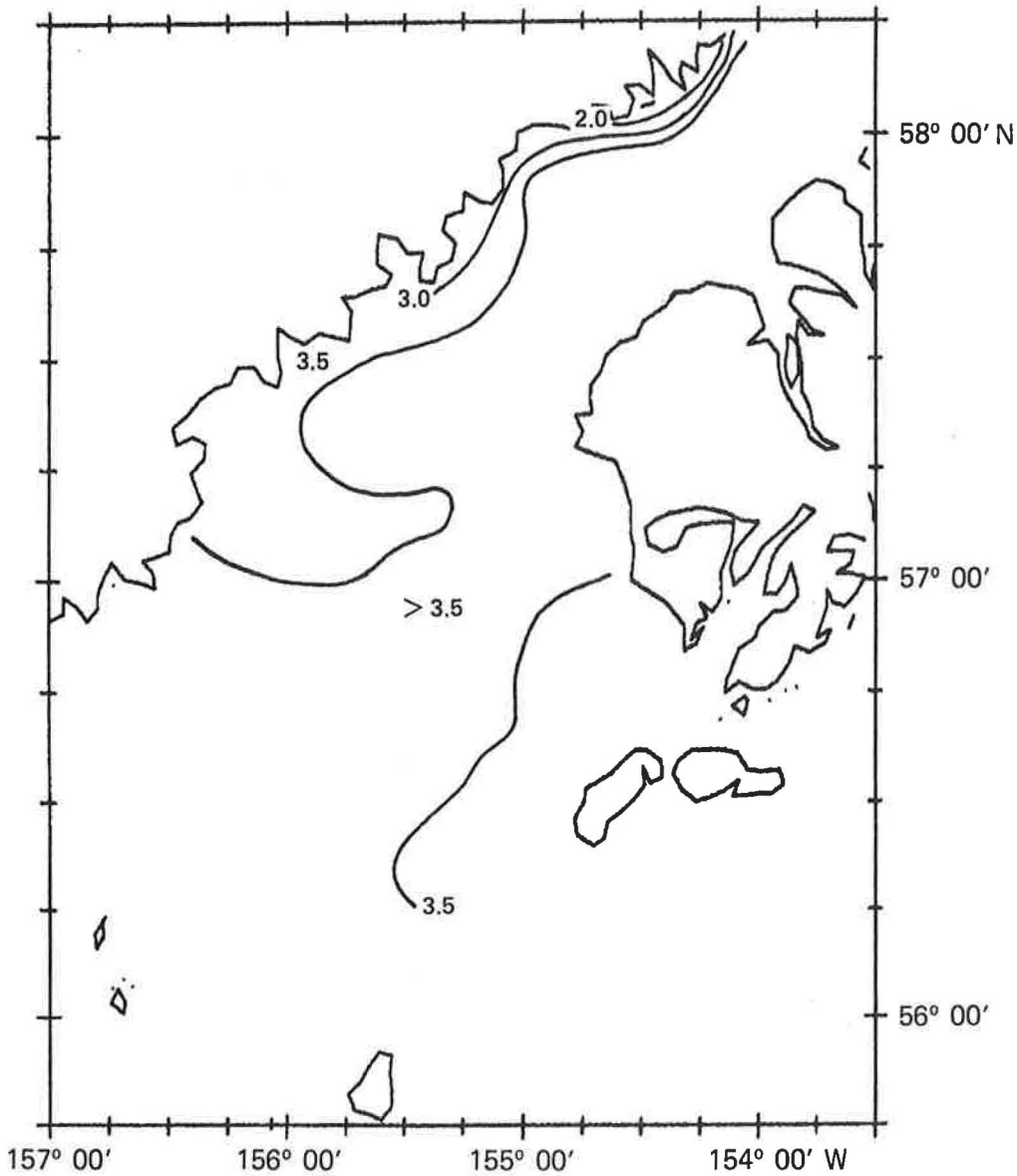


Figure 8.--Horizontal sections of temperature (°C) at 50 m in Shelikof Strait during March, 1985.

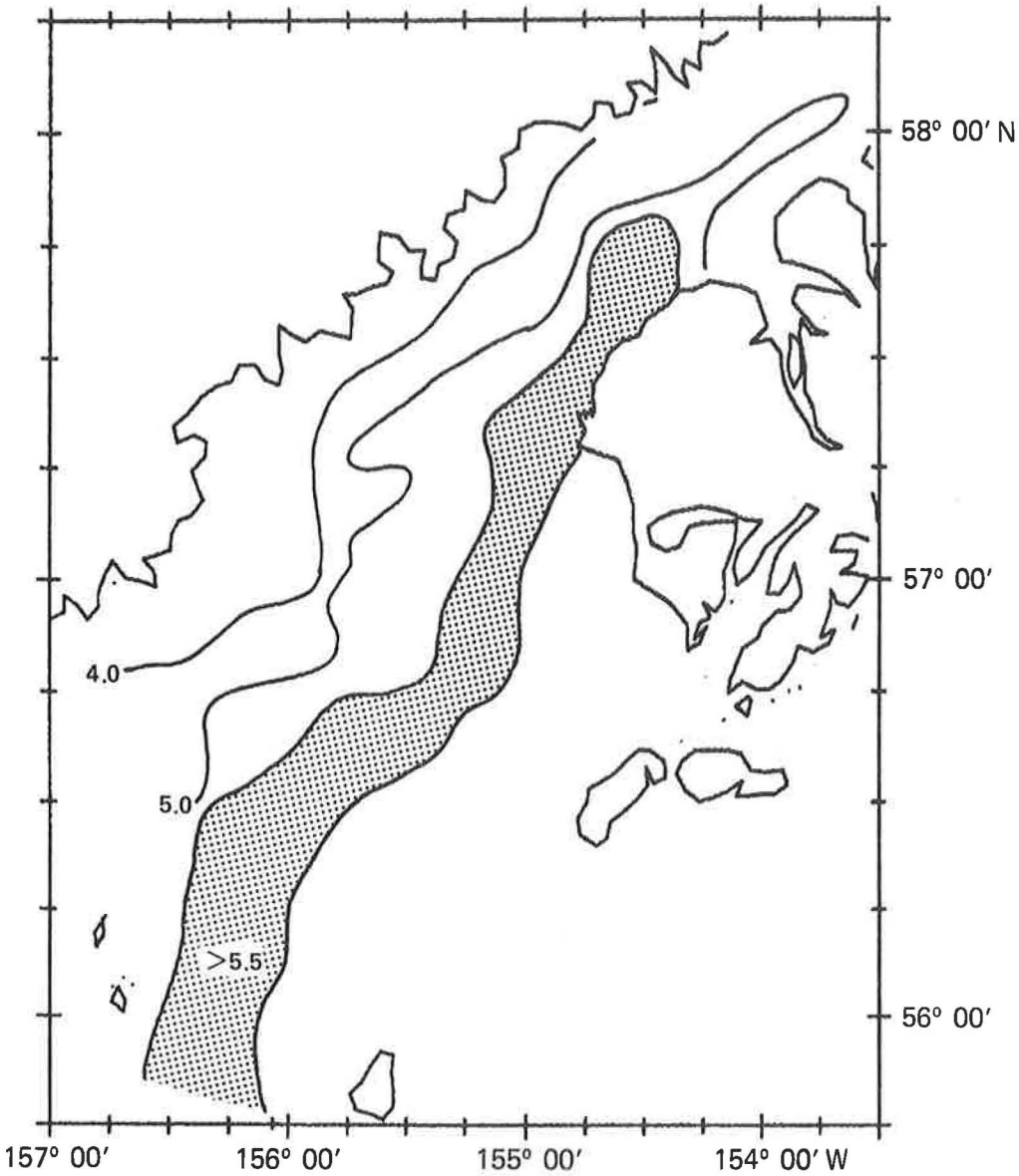


Figure 9.--Horizontal sections of temperature (°C) at 150 m in Shelikof Strait during March, 1985.

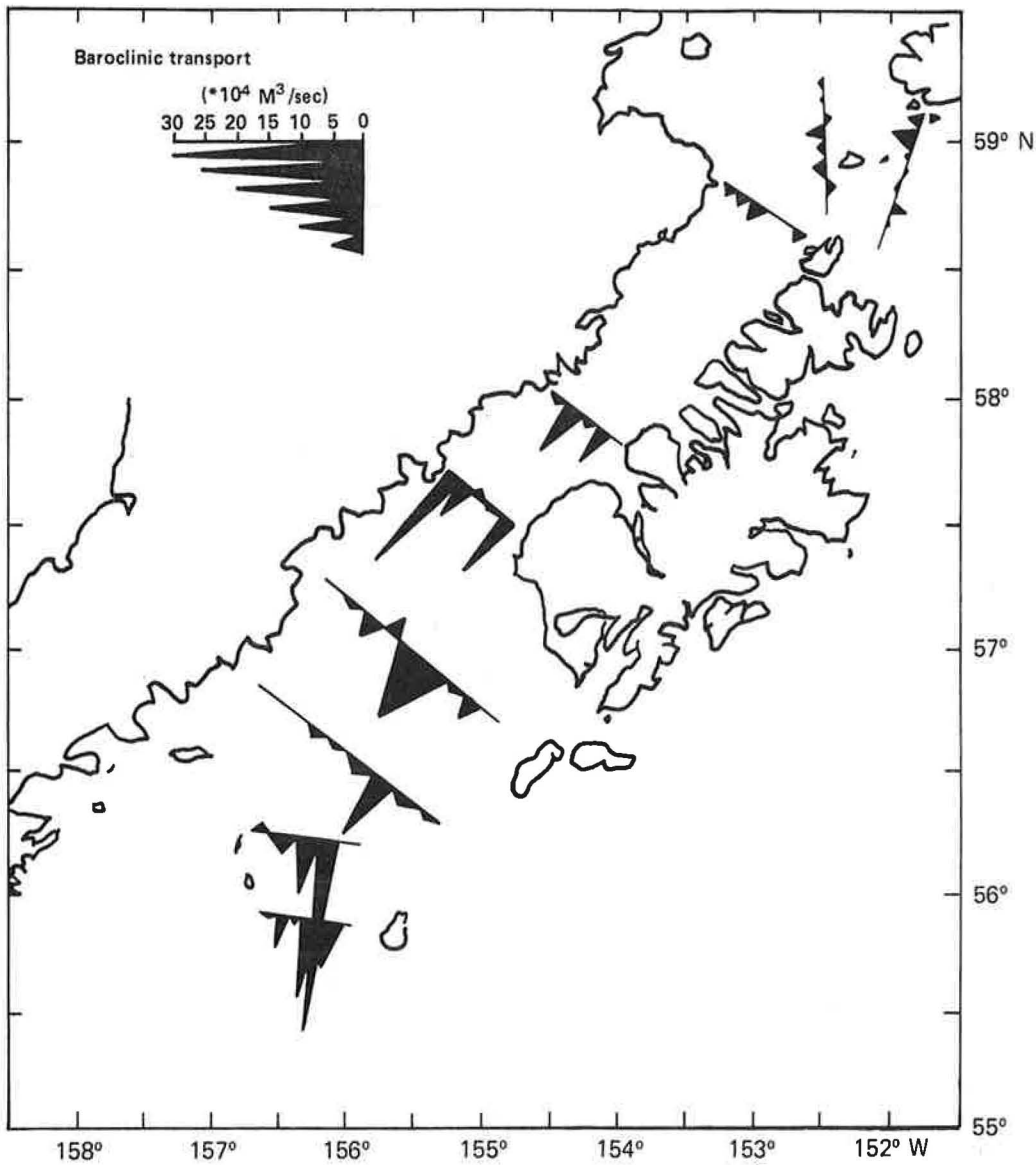


Figure 10.--Baroclinic transport (0 - 150 m) in Shelikof Strait during March, 1985.

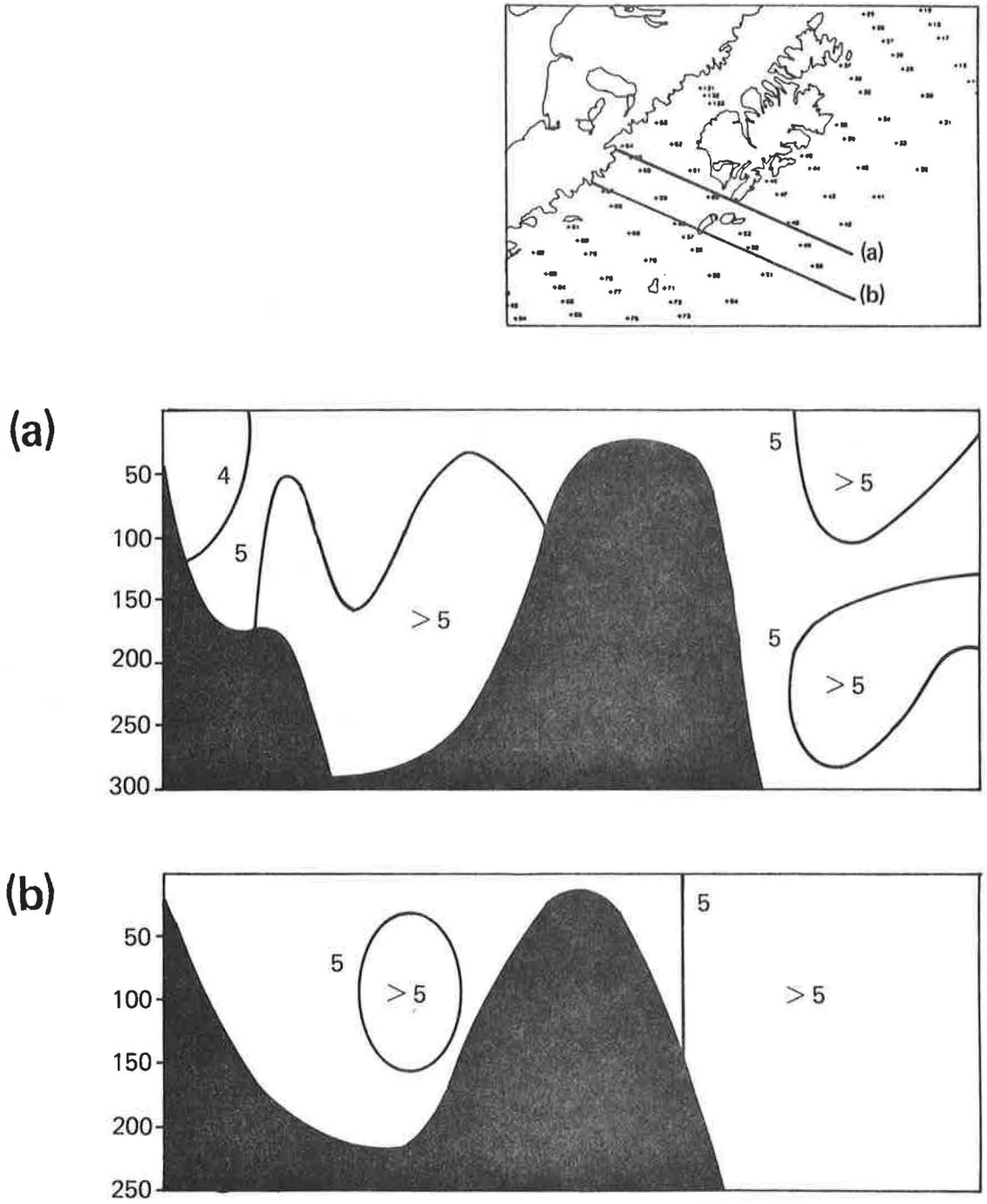


Figure 11.--Temperature (°C) profiles in the southwestern Shelikof Strait taken by U.S.S.R. research vessel Shantar, March 1981. Alaska Peninsula end of transects to the left.

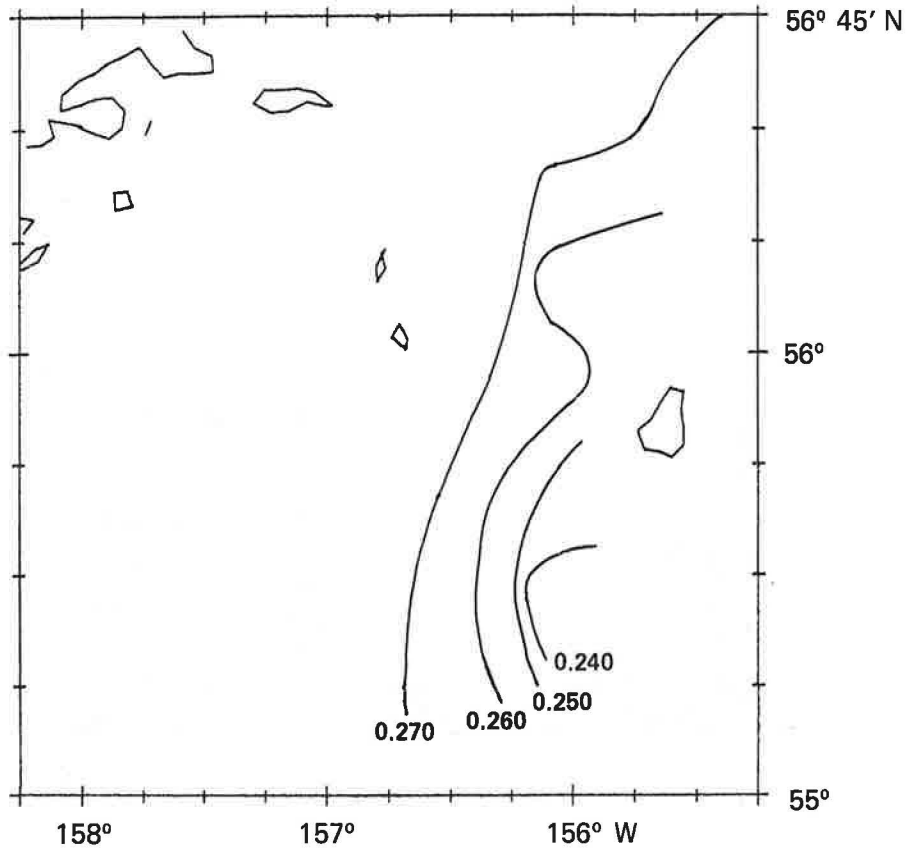


Figure 12.--Geopotential topography (0/100 dbar, in dynamic meter) observed near the valley area during March, 1985.

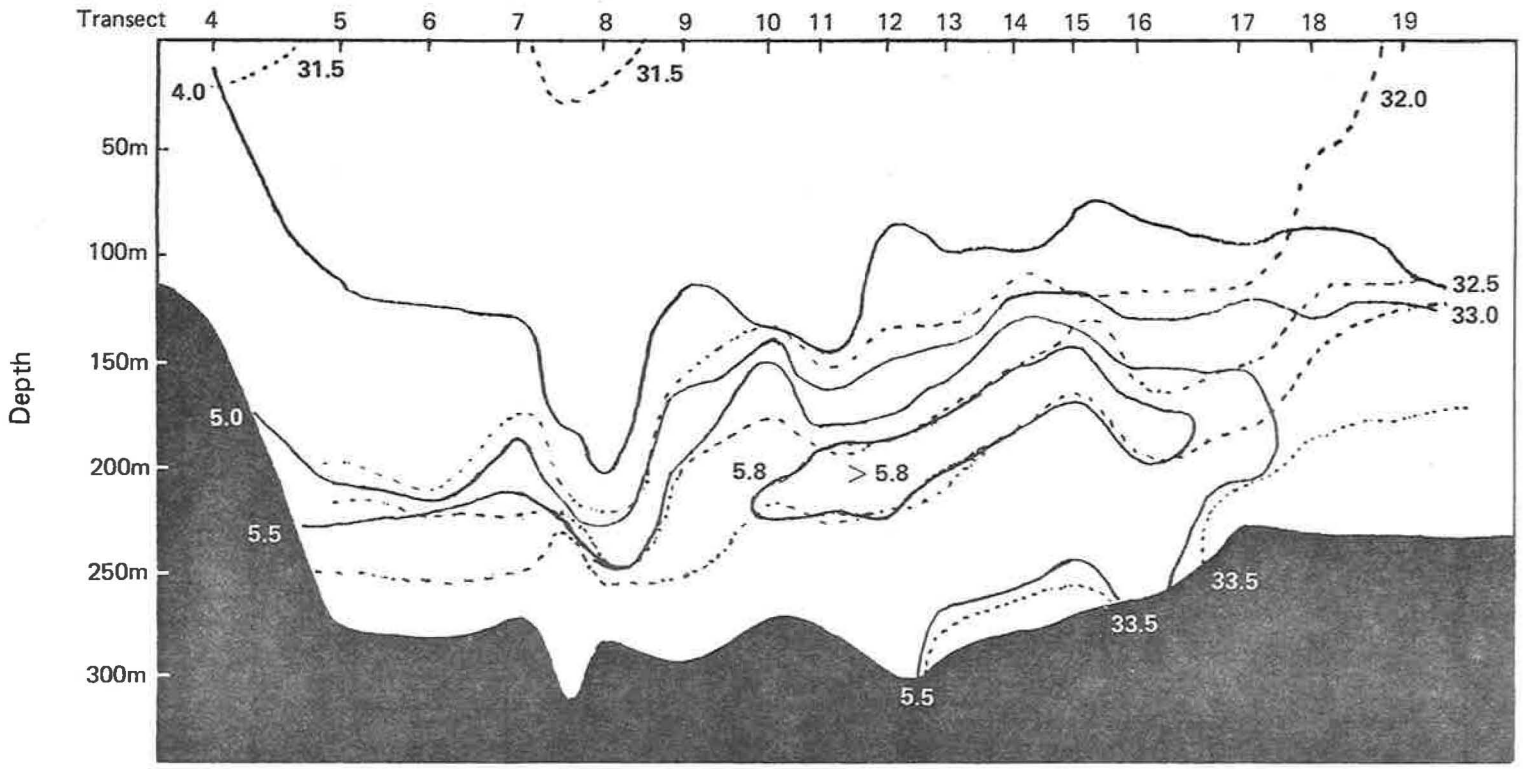


Figure 13.--Temperature and salinity profiles along Shelikof Strait at the deepest part of each transect.

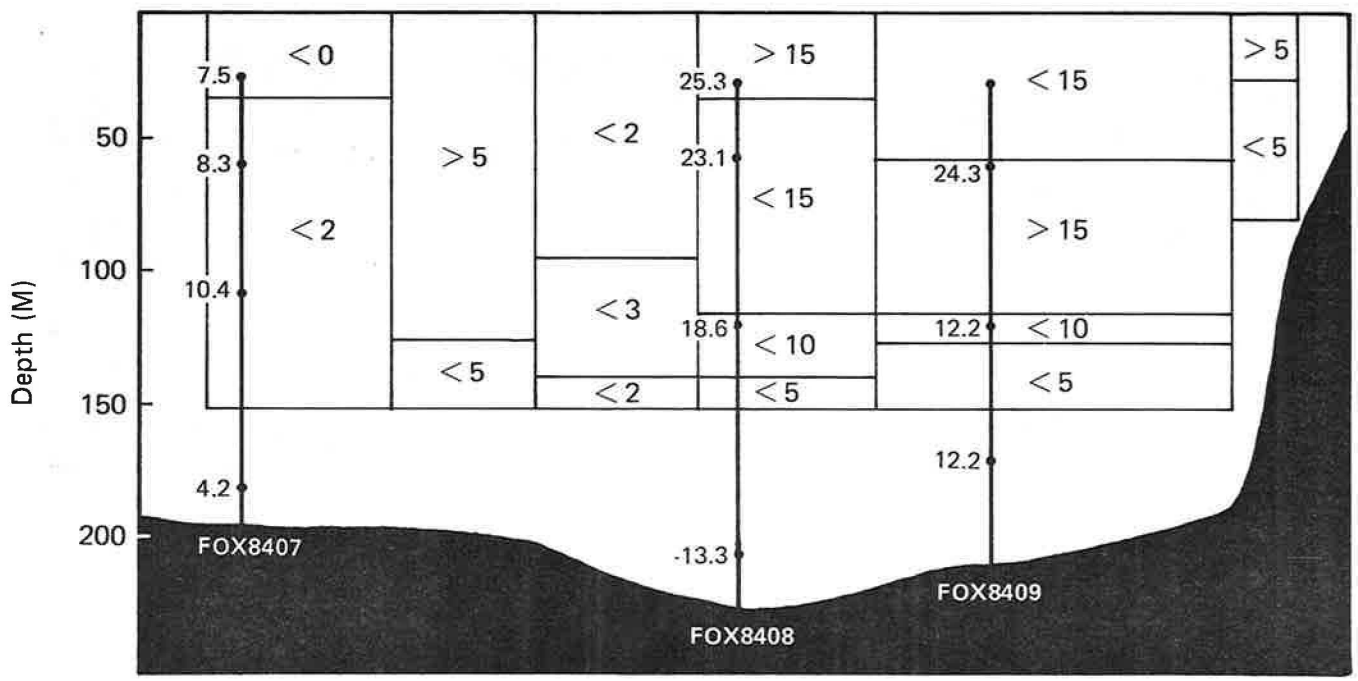


Figure 14.--Estimates of baroclinic speed (0/150 db) and observed speed from mooring current meter. In order to remove tidal effect, the mooring current data (three days before and after CTD cast date) were 35-hour filtered and resampled at 6-hourly intervals. Unit is cm/sec.

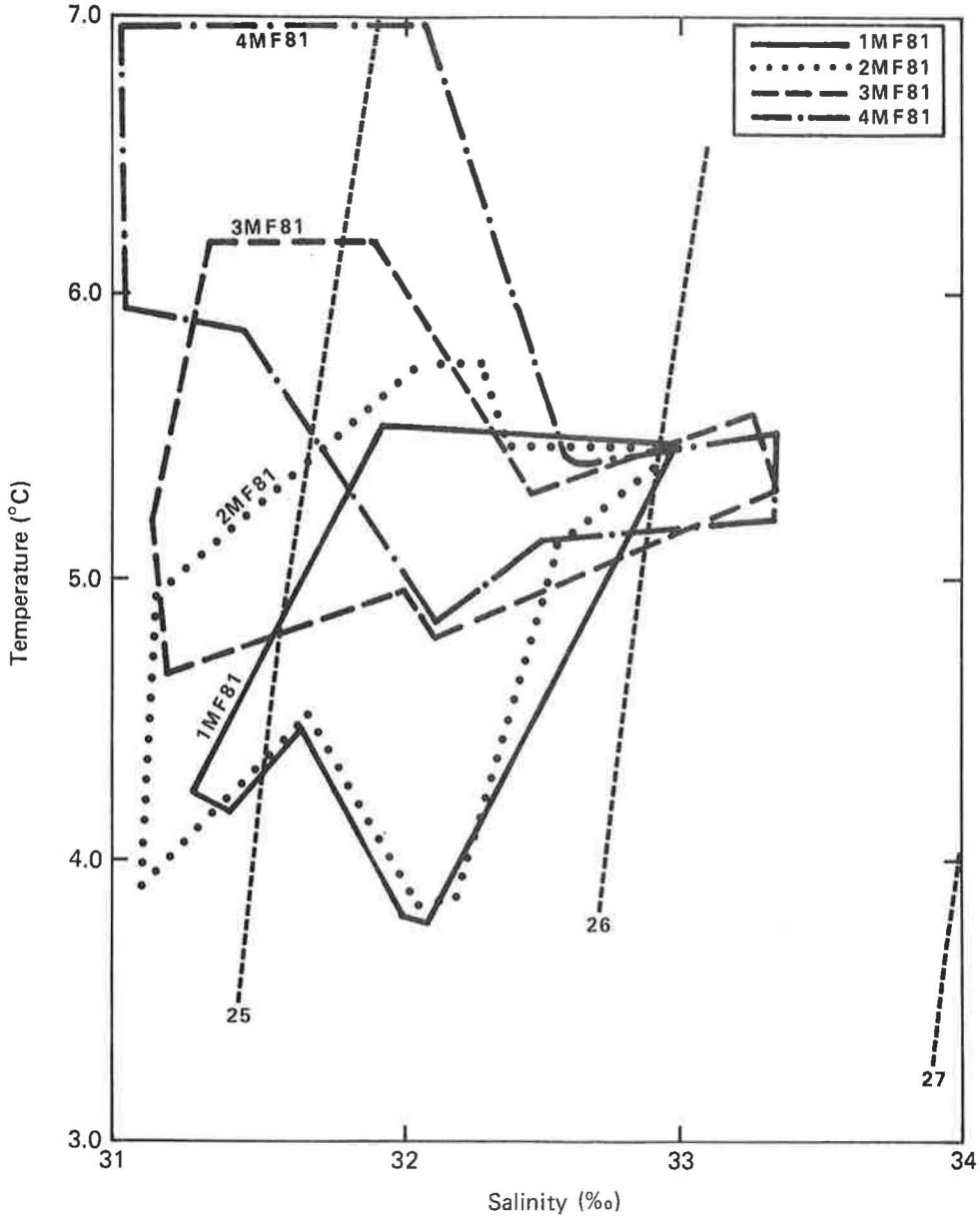


Figure 15.--T-S envelopes of Shelikof Strait water in spring (March - May) 1981. The time periods of 1MF81-4MF81 are in Table 1, and the total number of sampling stations used in each cruise are 21, 89, 79, and 80 stations, respectively.

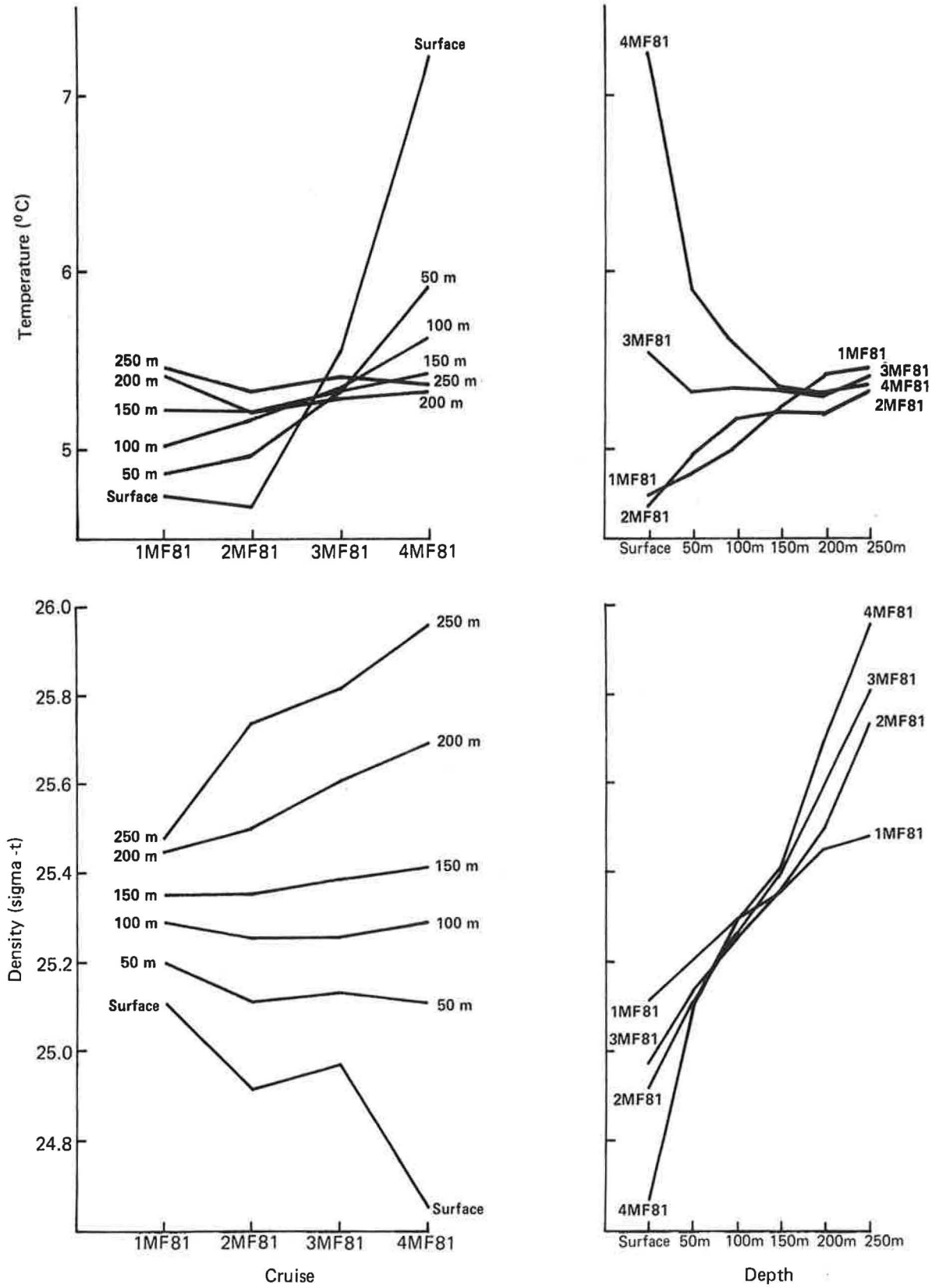


Figure 16.--The changes of average temperature (°C) and density (sigma-t) at selected depths during spring 1981 cruises 1MF81 - 4MF81.

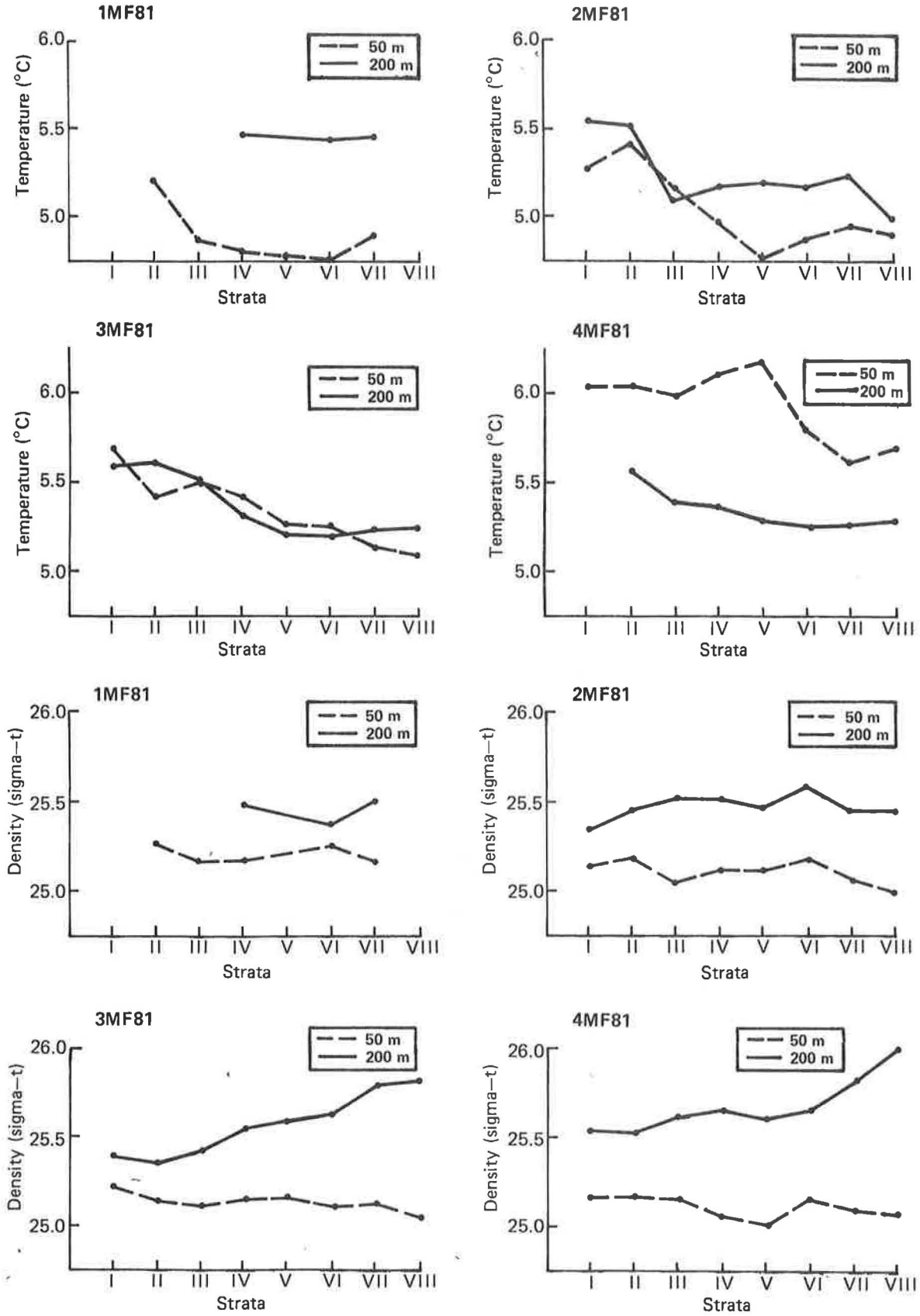


Figure 17.--Temperature and density (sigma-t) distribution along Shelikof Strait at selected depths and their changes with time.

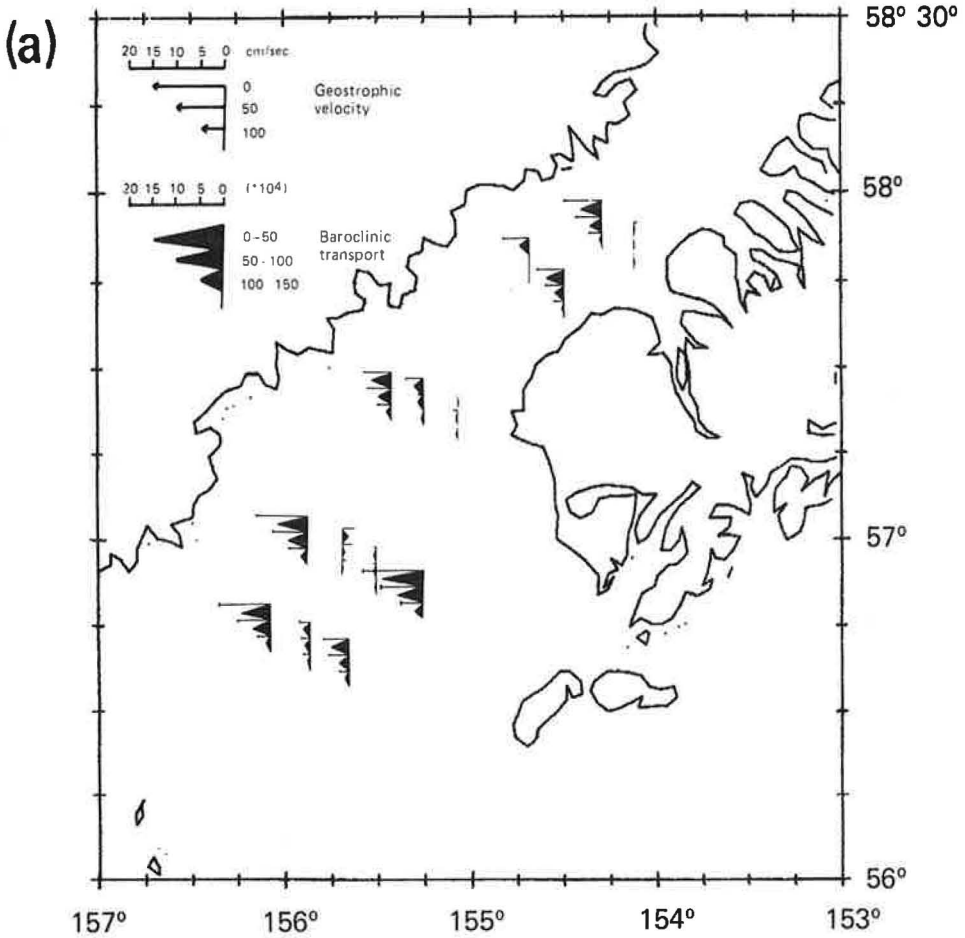


Figure 18.--Baroclinic transport and geostrophic velocity in Shelikof Strait during March - May, 1981. Arrows pointing to the left denote southwestward flow and these to the right northeastward flow: (a) mid March (1MF81), (b) early April (2MF81) (c) late April (3MF81), and (d) late May (4MF81).

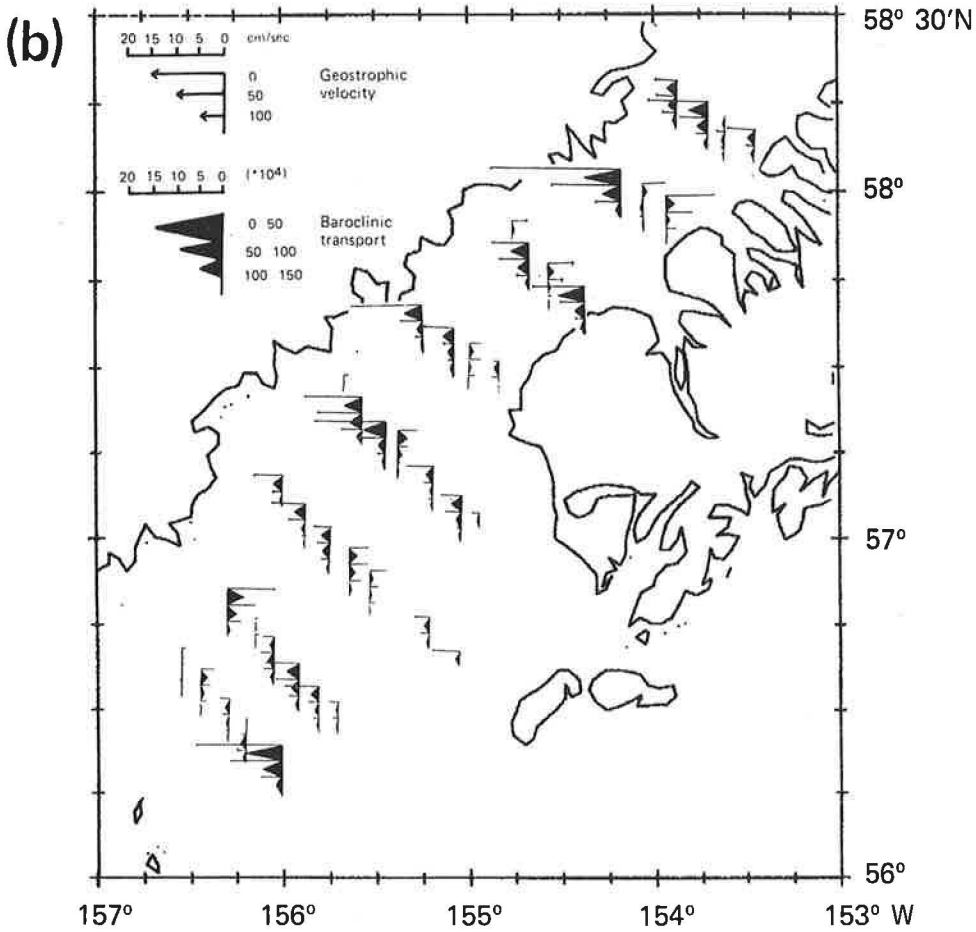


Figure 18.--(continued) Baroclinic transport and geostrophic velocity in Shelikof Strait during March - May, 1981. Arrows pointing to the left denote southwestward flow and these to the right northeastward flow: (a) mid March (1MF81), (b) early April (2MF81) (c) late April (3MF81), and (d) late May (4MF81).

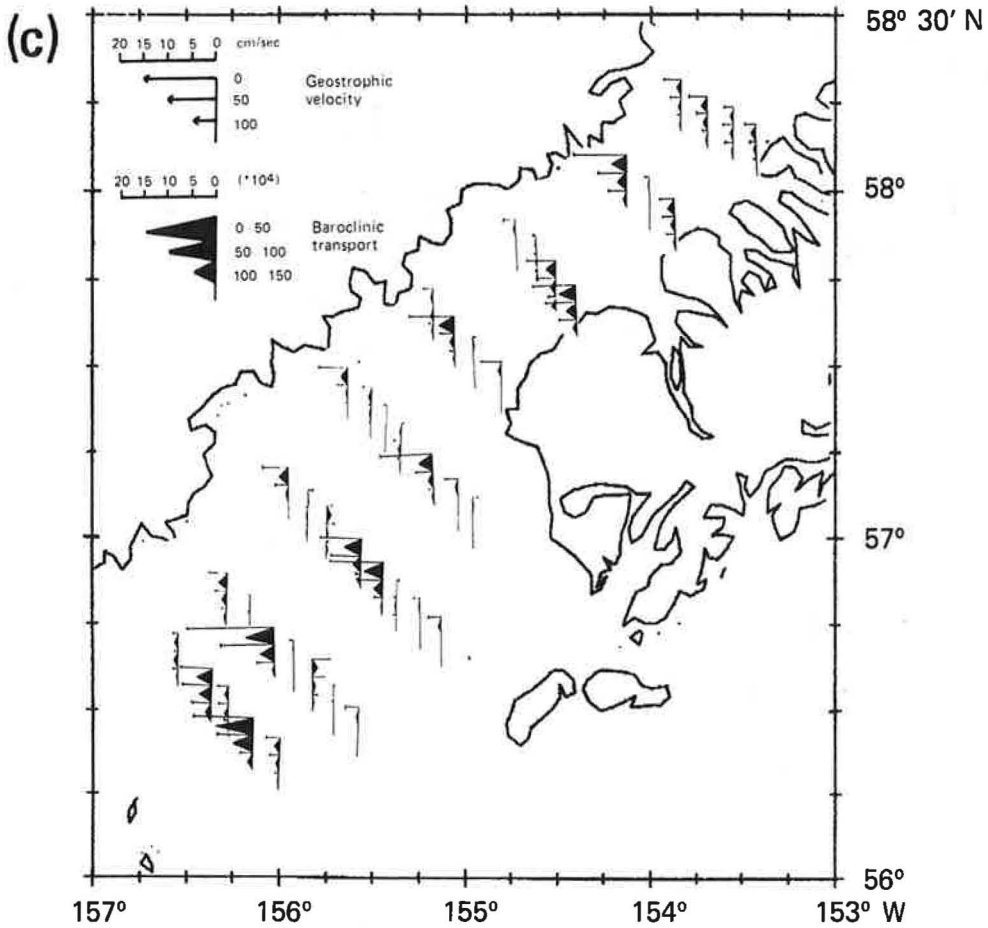


Figure 18.--(continued) Baroclinic transport and geostrophic velocity in Shelikof Strait during March - May, 1981. Arrows pointing to the left denote southwestward flow and these to the right northeastward flow: (a) mid March (1MF81), (b) early April (2MF81) (c) late April (3MF81), and (d) late May (4MF81).

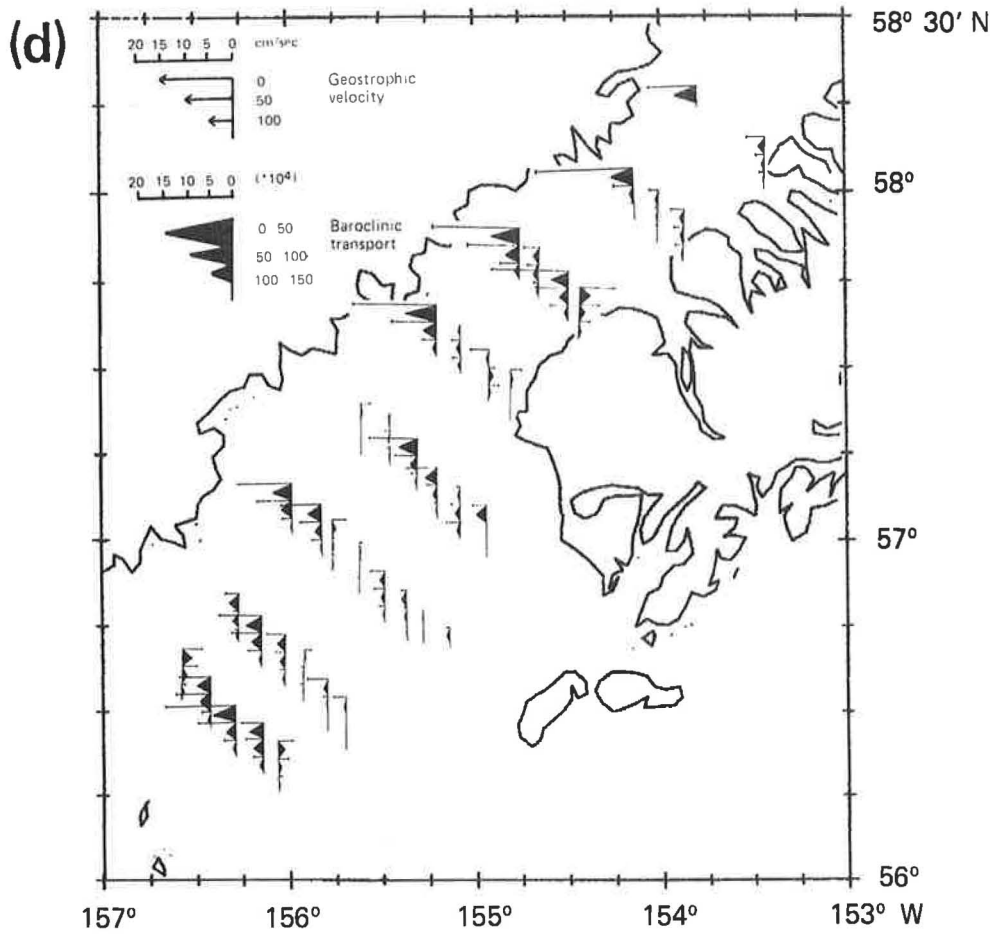


Figure 18.--(continued) Baroclinic transport and geostrophic velocity in Shelikof Strait during March - May, 1981. Arrows pointing to the left denote southwestward flow and these to the right northeastward flow: (a) mid March (1MF81), (b) early April (2MF81) (c) late April (3MF81), and (d) late May (4MF81).

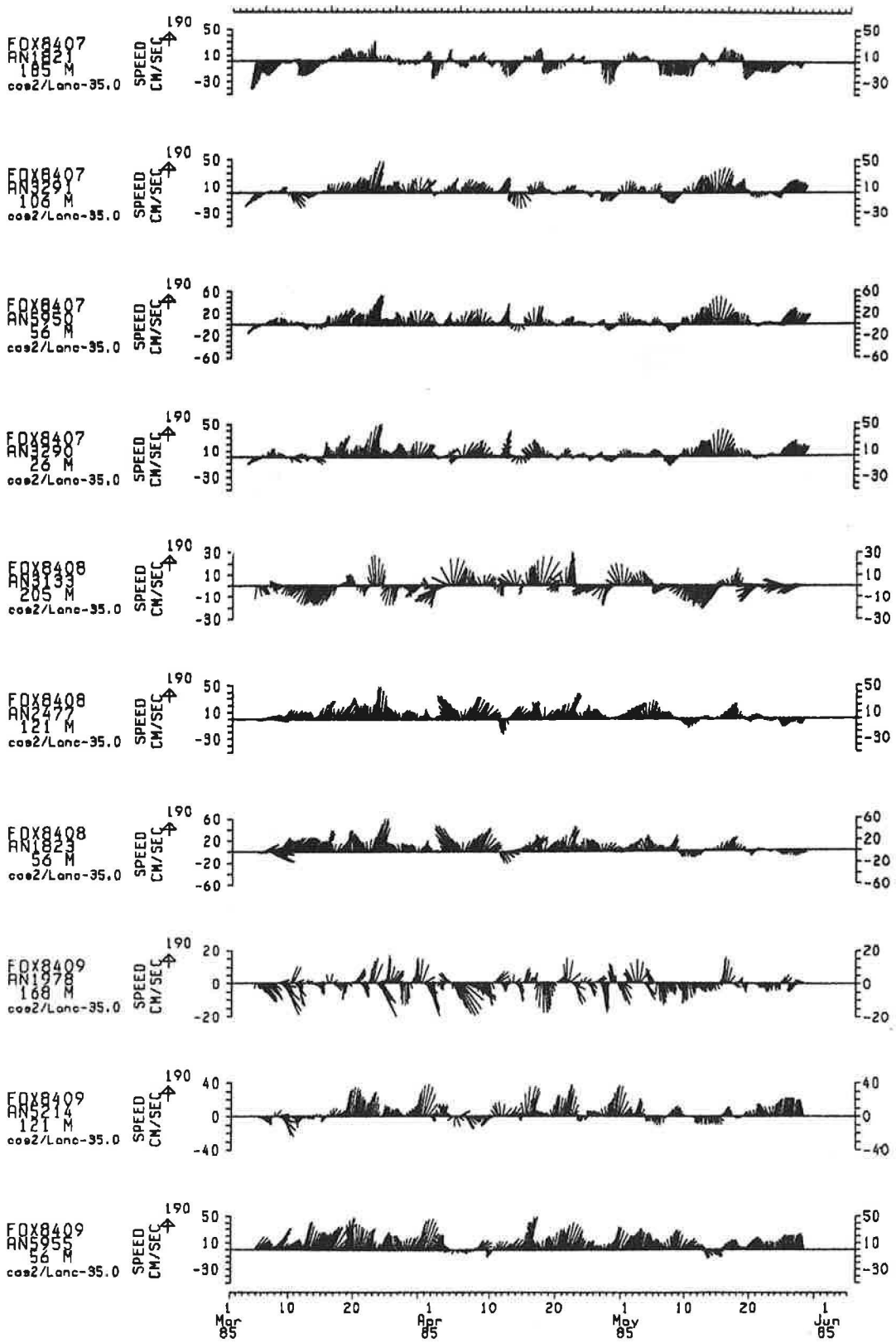


Figure 19.--The observed current velocity with the major axis of 190 degree in the valley area. The upright vector stick shows outflow from Shelikof Strait.

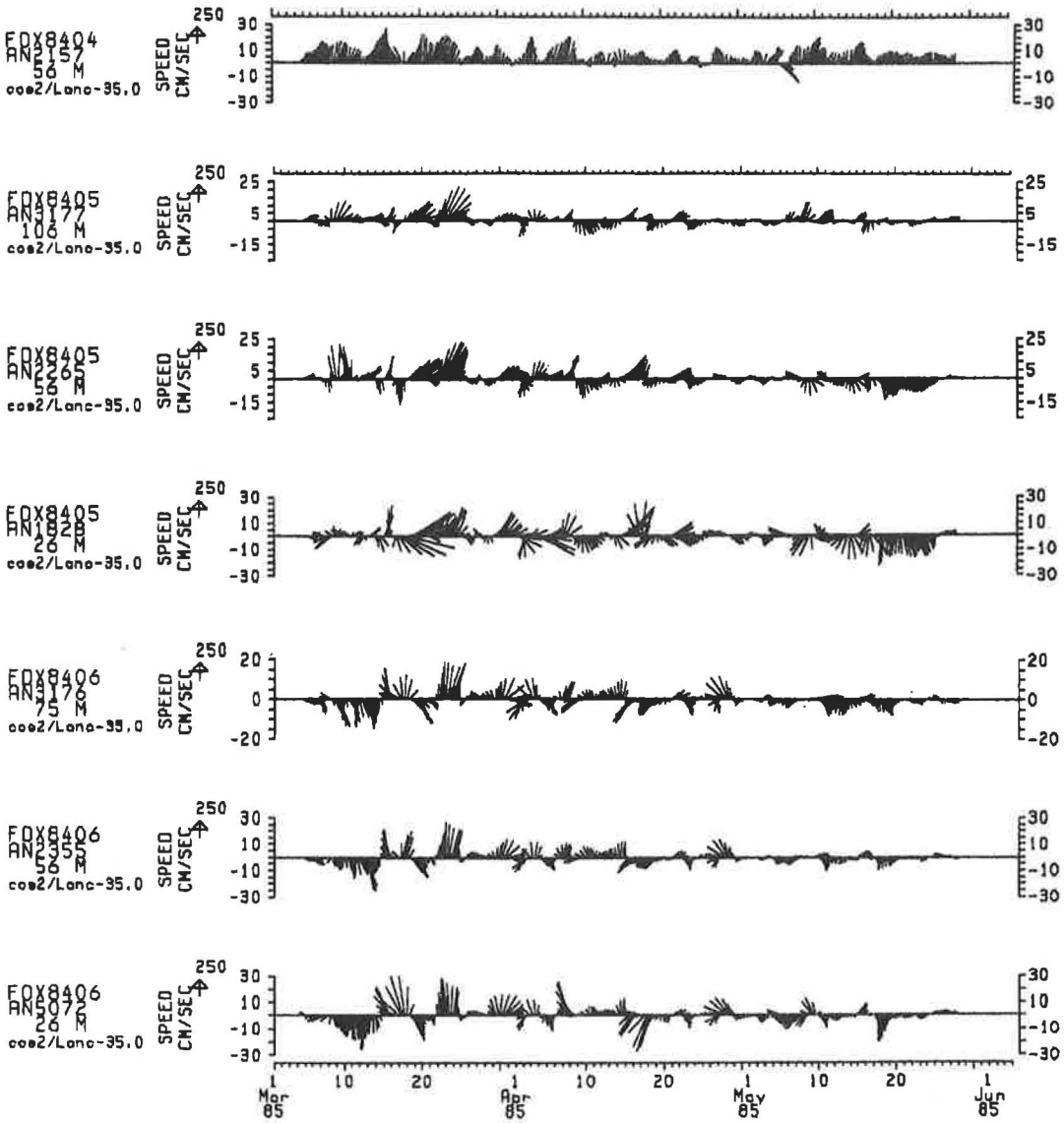


Figure 20.--The observed current velocity with the major axis of 250 degree in the bank area. The upright vector stick shows outflow from Shelikof Strait and flows along the Alaska Peninsula.

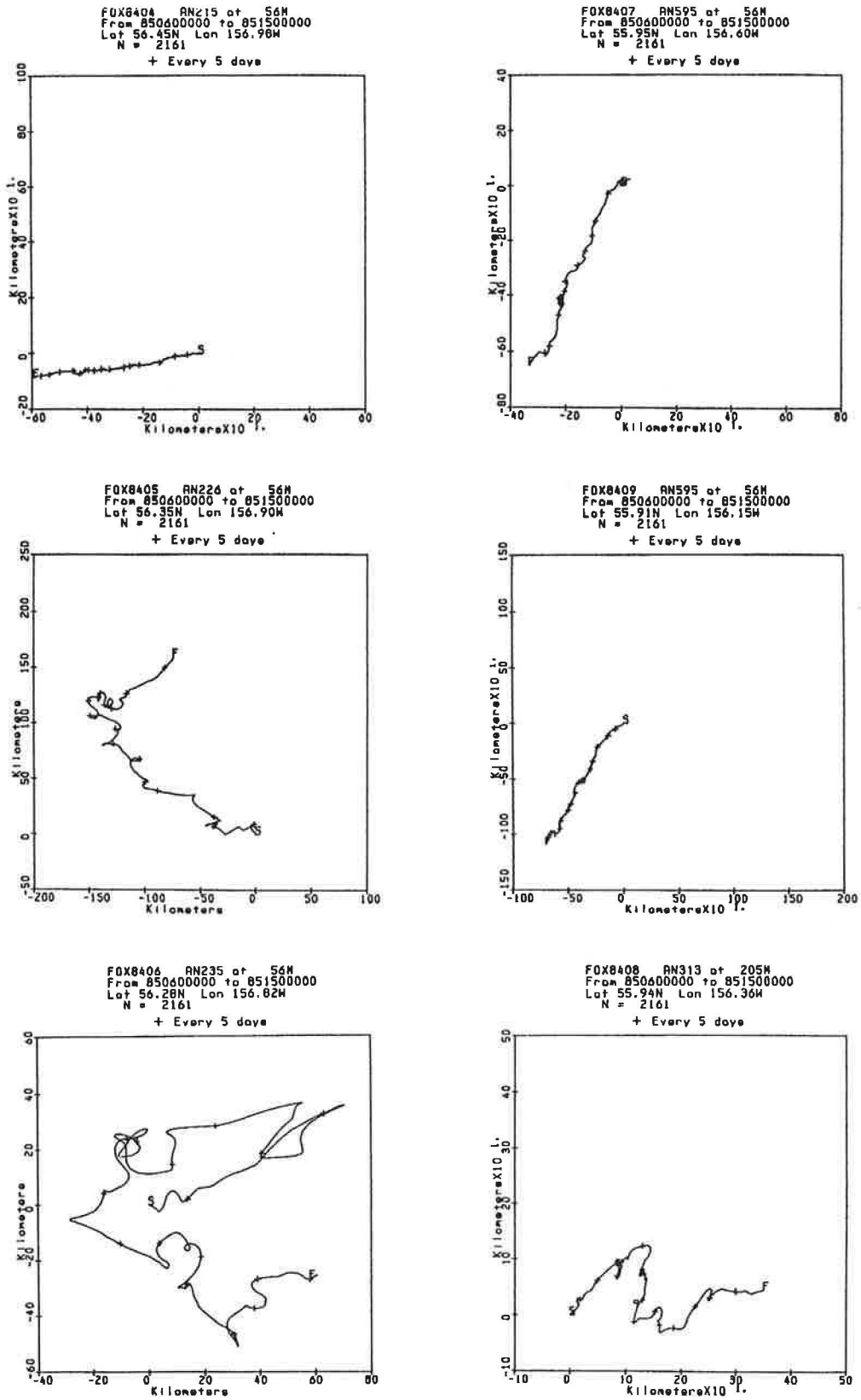


Figure 21.--Progressive vector diagrams (PVD) made at the boundary of southern Strait (i.e., bank and valley areas) during March through May, 1985.

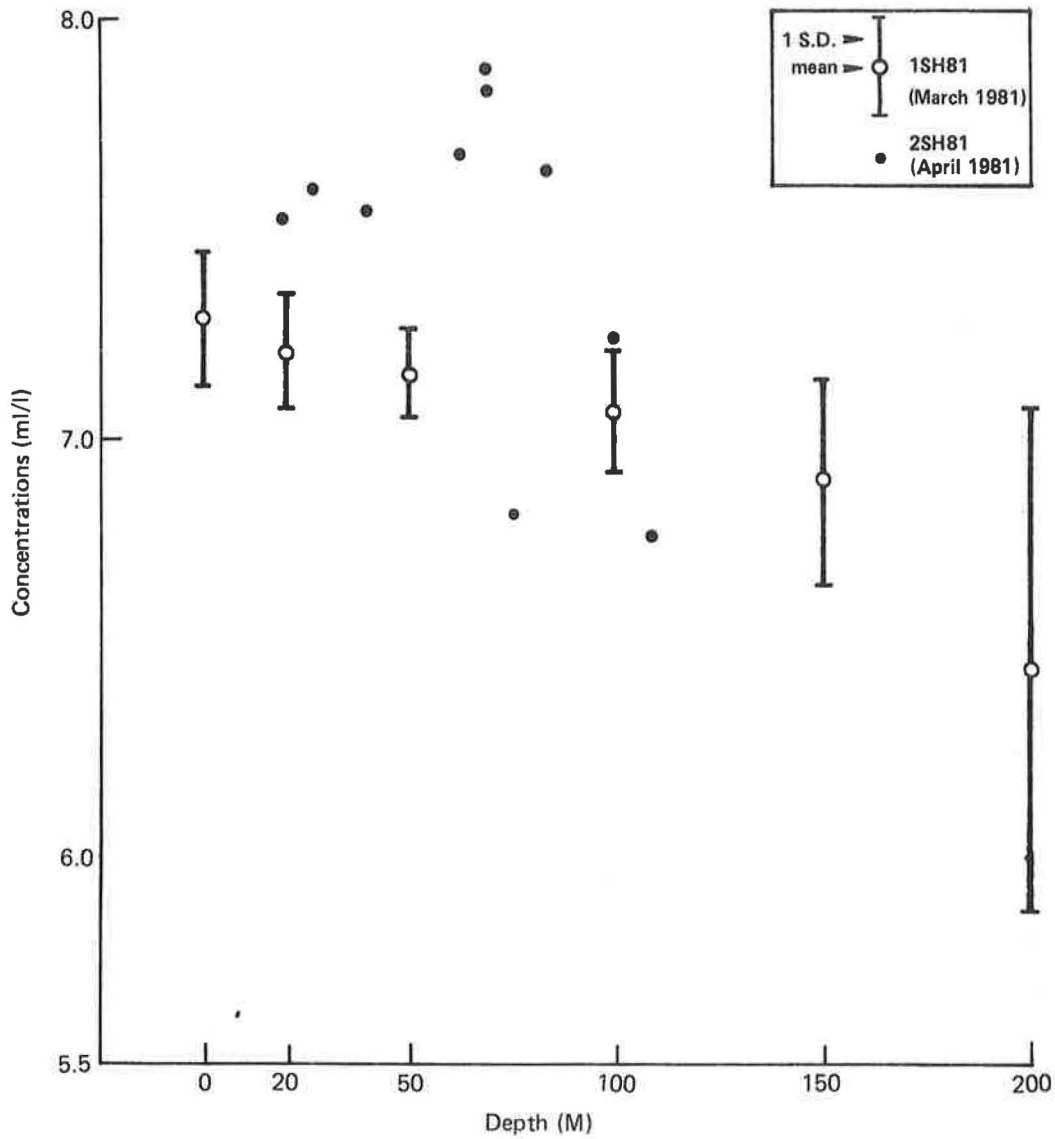


Figure 22.--Dissolved oxygen (DO) measured by U.S.S.R. R/V Shantar, March - April, 1981. The time periods of 1SH81 and 2SH81 are March 5 - 18, and April 16 - 24, respectively.

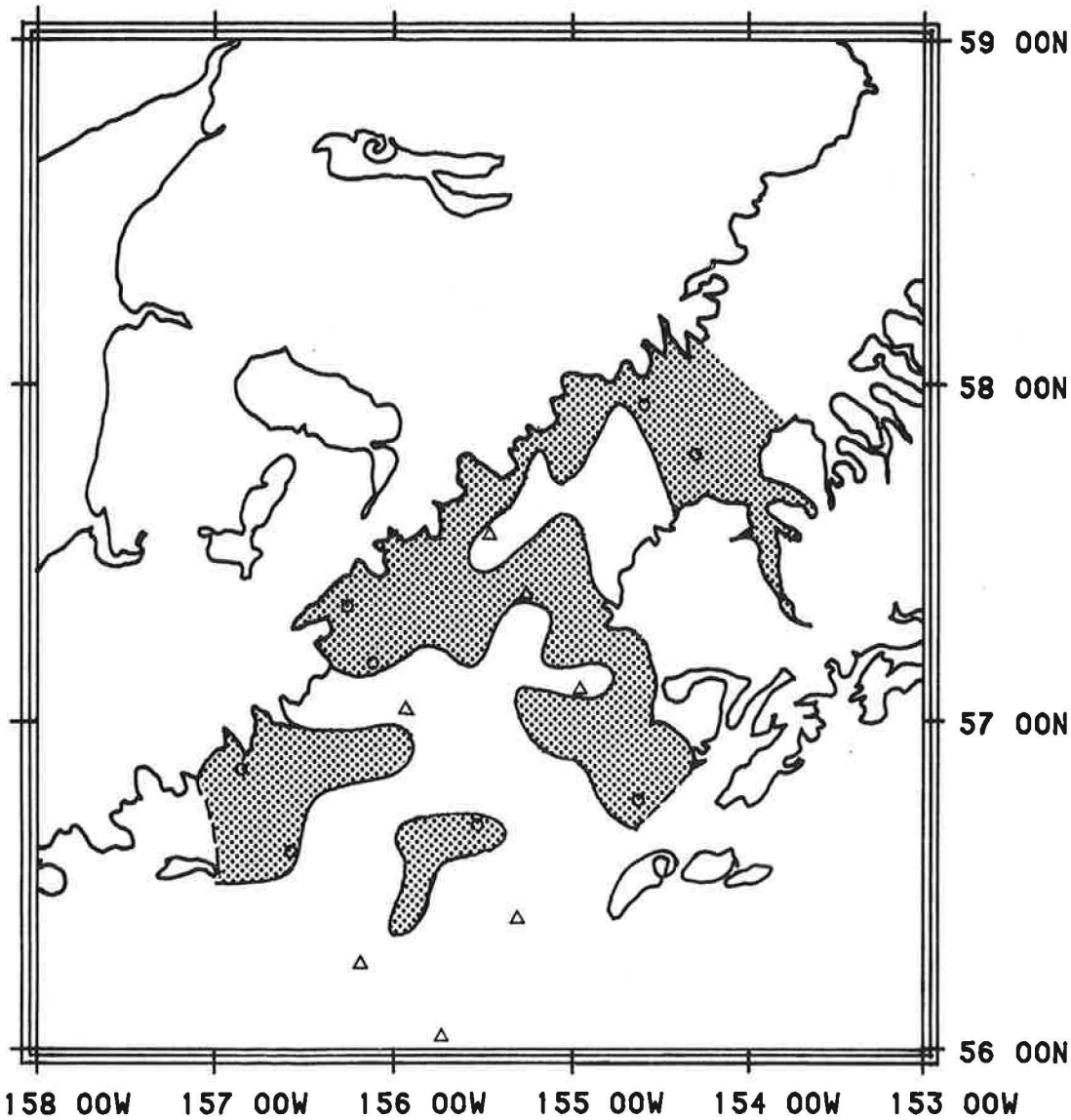


Figure 23.--The distribution of dissolved oxygen (DO) at surface in March superimposed on that of mixed layer depth (MLD) during early April, 1981. The shaded area has shallower MLD than the average of all stations. Dots indicate stations which have higher DO values than the average and triangles show lower DO than the average.

Appendix I.--Monthly means of; (1) Vel = current velocity (cm/sec), (2) Dir = direction (degree), (3) Temp = water temperature (°C), (4) Sal = Salinity (‰), and (5) Sig-t = density (Sigma-t) observed from mooring meters in Table 2.

Northeastern Shelikof Strait

K2: October 1976 - March 1977

	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
20 m												
Vel			31.00	60.30	52.20	38.90	40.40	22.00				
Dir			216.90	212.40	212.00	214.70	212.90	225.70				
Temp			8.15	7.34	6.71	6.30	6.02	5.26				
Sal			31.40	31.68	31.81	31.92	31.97	31.87				
Sig-t			24.45	24.79	24.97	25.11	25.18	25.19				
100 m												
Vel			14.00	36.80	30.70	26.60	28.90	14.00				
Dir			226.90	221.10	220.10	221.80	222.20	239.40				
Temp			7.36	7.11	6.71	6.30	6.08	5.54				
Sal			32.05	32.04	32.10	32.08	32.07	32.03				
Sig-t			25.09	25.10	25.20	25.24	25.25	25.29				

Northeastern Shelikof Strait, continued

C10: October 1977 - March 1978

	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
20 m												
Vel			46.90	25.20	18.20	25.10	34.70	7.40				
Dir			224.90	225.80	234.00	230.00	230.90	246.90				
Temp			8.06	6.54	5.32	5.29	4.71	4.39				
Sal			31.42	31.67	31.91	32.17	32.29	32.22				
Sig-t			24.48	24.88	25.21	25.43	25.58	25.56				
65 m												
Vel			36.50	17.90	15.40	24.40	31.30	7.90				
Dir			225.10	226.90	231.30	229.80	230.80	238.10				
Temp			7.40	6.75	5.62	5.41	4.79	4.61				
Sal			32.14	32.10	31.98	32.24	32.29	32.25				
Sig-t			25.13	25.19	25.24	25.47	25.57	25.57				

Northeastern Shelikof Strait, continued

C10B: May 1978 - October 1978

	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
25 m												
Vel	10.30	26.50	20.50							18.10	5.40	15.30
Dir	229.60	222.80	220.90							216.20	199.80	221.40
Temp	9.34	9.81	9.44							5.96	6.82	8.40
Sal	31.55	30.17	28.82							32.15	31.84	31.73
Sig-t	24.39	23.24	22.25							25.33	24.98	24.67
70 m												
Vel	7.50	23.70	27.60							18.40	3.00	11.30
Dir	233.90	220.80	217.60							216.70	231.40	214.80
Temp	7.62	8.47	8.28							5.65	6.03	7.21
Sal	31.95	30.19	30.26							32.25	32.18	32.00
Sig-t	24.96	23.46	23.54							25.45	25.35	25.05
165 m												
Vel	1.10	9.60	15.50							15.60	1.30	4.90
Dir	208.90	209.60	215.70							208.60	239.60	158.10
Temp	5.15	5.82	5.69							5.48	5.34	5.30
Sal	32.49	32.63	32.78							32.35	32.40	32.37
Sig-t	25.69	25.73	25.86							25.54	25.60	25.58

Northeastern Shelikof Strait, continued

K1: October 1976 - March 1977

	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
100 m												
Vel			19.10	37.70	29.90	25.90	29.80	17.00				
Dir			231.10	237.70	234.90	234.20	234.80	260.70				
Temp			7.33	7.01	6.75	6.24	6.06	5.72				
Sal			32.17	32.14	32.11	32.15	32.12	32.19				
Sig-t			25.17	25.19	25.20	25.30	25.30	25.40				

Northeastern Shelikof Strait, continued

Fox 8401: August 1984 - January 1985

	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
26 m												
Vel	16.10	32.10	21.60	28.40	11.80	38.00						
Dir	226.30	215.00	217.60	213.80	220.30	214.20						
Temp	10.23	10.97	9.31	7.28	6.48	5.04						
Sal	31.33	30.42	30.28	30.02	30.44	30.50						
Sig-t	24.07	23.24	23.40	23.49	23.92	24.14						
56 m												
Vel	11.60	25.40	19.40	26.30	14.30	35.60						
Dir	229.80	222.30	220.50	220.10	223.90	217.70						
Temp	6.07	6.71	6.24	5.41	4.84	3.91						
Sal												
Sig-t												
106 m												
Vel	0.70	10.10	12.20	19.30	16.00	30.40						
Dir	2.00	220.80	221.40	221.70	221.00	222.30						
Temp	6.90	8.25	8.81	7.93	6.88	5.53						
Sal	31.87	31.55	31.38	31.25	30.77	30.92						
Sig-t	24.99	24.54	25.34	24.36	24.13	24.41						

Northeastern Shelikof Strait, continued

Fox 8401: August 1984 - January 1985, continued

	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
165 m												
Vel	8.50	1.70	8.30	6.40	8.20	16.20						
Dir	49.30	210.70	219.70	218.20	218.90	220.10						
Temp	5.44	5.48	6.44	7.07	6.98	6.18						
Sal	32.88	32.70	32.49	32.37	31.87	31.27						
Sig-t	25.97	25.82	25.54	25.36	24.98	24.61						
240 m												
Vel	3.60	4.20	4.00	2.40	5.60	7.90						
Dir	223.80	230.20	228.30	224.10	229.00	223.20						
Temp	5.47	5.47	5.54	5.57	5.85	5.78						
Sal	33.07	32.98	32.95	32.90	32.23	32.02						
Sig-t	26.11	26.05	26.01	25.97	25.41	25.25						

Northeastern Shelikof Strait, continued

Fox 8402: August 1984 - January 1985

	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
26 m												
Vel												
Dir												
Temp	10.46	10.17	9.04	7.44	6.55	5.66						
Sal	31.46	31.39	30.94	30.11	30.48	30.32						
Sig-t	24.14	24.13	23.96	23.54	23.95	23.92						
56 m												
Vel	14.00	12.00	26.50	21.10	25.20	28.20						
Dir	251.00	243.70	219.10	233.20	231.80	217.50						
Temp	7.97	8.49	8.76	7.95	6.92	5.98						
Sal	31.88	31.75	31.53	31.48	31.37	31.33						
Sig-t	24.85	24.67	24.47	24.54	24.60	24.69						
106 m												
Vel	11.60	8.50	18.40	16.40	20.40	24.50						
Dir	261.10	248.00	219.10	239.50	235.60	218.00						
Temp	6.00	6.61	7.73	7.55	7.28	6.53						
Sal	32.18	32.11	32.08	32.01	31.22	31.08						
Sig-t	25.35	25.21	25.04	25.01	24.43	24.42						

Northeastern Shelikof Strait, continued

Fox 8402: August 1984 - January 1985, continued

	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
165 m												
Vel	3.80	2.60	4.90	9.10	9.50	11.60						
Dir	282.10	249.40	203.00	241.60	244.80	208.40						
Temp	5.41	5.42	5.57	6.11	6.27	6.14						
Sal	32.61	32.60	32.71	32.61	32.66	32.69						
Sig-t	25.76	25.75	25.82	25.67	25.69	25.73						
220 m												
Vel	3.10	0.90	2.90	4.60	0.90	5.10						
Dir	334.40	254.60	182.70	234.60	256.60	169.80						
Temp	5.50	5.51	5.54	5.59	5.58	5.59						
Sal	33.01	32.98	33.04	33.01	32.94	32.50						
Sig-t	26.07	26.04	26.08	26.05	26.00	25.65						

Northeastern Shelikof Strait, continued

Fox 8403: August 1984 - January 1985

	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
26 m												
Vel	3.50	4.90	2.20	0.90	7.50	3.40						
Dir	27.20	34.20	2.90	187.50	216.80	18.90						
Temp	10.74	10.46	8.87	7.41	6.57	5.85						
Sal	31.60	31.50	31.52	31.23	31.42	31.43						
Sig-t	24.20	24.17	24.44	24.42	24.68	24.78						
56 m												
Vel	4.60	2.60	3.20	1.00	5.40	3.40						
Dir	60.30	48.40	58.40	58.40	229.90	56.10						
Temp	7.71	9.01	8.30	7.79	6.87	6.02						
Sal	31.97	31.88	31.90	31.62	30.97	31.32						
Sig-t	24.96	24.69	24.82	24.68	24.29	24.67						
106 m												
Vel	3.10	4.30	2.20	0.90	2.70	5.50						
Dir	17.20	230.70	30.00	325.80	255.20	63.30						
Temp	5.71	6.84	6.86	7.59	7.13	6.70						
Sal	32.07	31.93	32.08	31.95	31.59	31.46						
Sig-t	25.30	25.05	25.16	24.96	24.74	24.70						

Northeastern Shelikof Strait, continued

Fox 8403: August 1984 - January 1985, continued

	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
165 m												
Vel	5.80	1.90	5.40	5.50	8.20	9.00						
Dir	35.00	22.00	43.50	37.10	42.10	51.30						
Temp	5.41	5.47	5.53	5.64	5.71	5.87						
Sal	32.76	32.84	32.92	32.92	32.99	32.73						
Sig-t	25.88	25.93	25.99	25.98	26.03	25.80						
220 m												
Vel	4.60	0.40	8.80	7.00	10.60	10.80						
Dir	38.50	332.90	38.40	37.90	40.90	44.00						
Temp	5.43	5.48	5.54	5.60	5.65	5.78						
Sal	32.68	32.77	32.84	32.86	32.83	32.43						
Sig-t	25.81	25.88	25.93	25.93	25.91	25.57						

Northeastern Shelikof Strait, continued

Fox 8510: January 1985 - July 1985

	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
26 m												
Vel						12.90	5.60	3.40	3.50	1.40	8.10	16.10
Dir						230.80	157.90	208.00	108.30	270.30	227.50	220.60
Temp						5.49	4.52	3.73	3.11	3.77	6.04	8.06
Sal						31.57	31.62	31.74	31.70	31.76	31.60	31.19
Sig-t						24.93	25.07	25.24	25.27	25.25	24.88	24.29
105 m												
Vel						10.70	2.20	4.60	2.50	4.40	7.30	5.40
Dir						227.90	276.50	257.60	311.20	291.90	259.60	282.60
Temp						5.76	4.81	3.92	3.29	3.61	5.23	5.84
Sal												
Sig-t												

Southwestern Shelikof Strait

Bank area

K13A: October 1977 - March 1978

	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
102 m												
Vel			13.00	2.70		5.50	3.60	0.50				
Dir			263.20	298.20		293.00	296.00	141.60				
Temp			7.70	2.43		4.38	4.27	3.89				
Sal			31.41			31.55	32.04	31.99				
Sig-t			24.53			25.03	25.43	25.43				

Southwestern Shelikof Strait, continued

Bank area, continued

K13B: May 1978 - October 1978

	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
28 m												
Vel	15.50	24.80	12.30							6.30	7.90	10.60
Dir	215.30	227.00	275.70							228.30	213.00	208.70
Temp	8.95	10.00	9.36							5.59	6.38	7.71
Sal	31.64	30.71	30.12							31.96	31.86	31.65
Sig-t												
111 m												
Vel	2.50	4.30	5.10							1.60	3.00	4.10
Dir	218.40	183.90	236.40							248.20	259.80	152.60
Temp	5.84	6.85	7.01							4.84	4.94	5.58
Sal	32.07	31.83	31.82							32.04	32.14	32.06
Sig-t	25.28	24.96	24.93							25.37	25.44	25.30

Southwestern Shelikof Strait, continued

Bank area, continued

Fox 8404: August 1984 - July 1985

	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
26 m												
Vel	16.10	3.40	13.20	11.90	15.70	15.90	18.60	13.90	7.70	7.40	6.10	8.50
Dir	258.40	249.20	247.10	276.50	248.80	263.50	259.90	254.00	252.70	256.60	258.70	253.70
Temp	10.08	10.80	9.42	7.53	6.41	5.65	4.65	3.89	3.03	3.69	5.66	7.60
Sal	31.62	31.15	30.77	31.03	30.90	31.19	31.56	31.68	31.49	31.37	31.14	31.00
Sig-t	24.32	23.84	23.77	24.25	24.29	24.61	25.01	25.18	25.10	24.96	24.57	24.21
56 m												
Vel	11.60	4.70	8.30	9.30	10.40	10.30	11.50	10.90	6.10	7.50	5.00	8.00
Dir	258.60	238.10	252.40	272.30	260.30	259.60	266.50	260.10	262.20	262.60	253.60	246.90
Temp	8.51	10.22	9.43	7.68	6.60	5.71	4.75	3.93	3.05	3.69	5.28	6.82
Sal	31.72	31.07	30.43	30.00	30.03	30.52	30.71	30.75	30.54	30.41	29.98	29.87
Sig-t	24.65	23.87	23.50	23.42	23.58	24.07	24.33	24.44	24.35	24.19	23.69	23.42

Southwestern Shelikof Strait, continued

Bank area, continued

Fox 8405: August 1984 - July 1985

	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
26 m												
Vel	5.50	17.40	16.70	7.60	9.30	7.20	7.60	6.70	4.00	3.80	1.70	5.00
Dir	169.60	228.20	230.40	310.00	291.60	353.50	294.30	308.70	345.60	86.80	211.50	234.90
Temp	10.57	10.54	9.30	7.54	6.47	5.66	4.72	3.95	3.22	3.46	5.75	7.37
Sal	31.51	31.15	30.89	30.97	30.83	31.23	31.41	31.58	31.44	31.33	31.26	31.30
Sig-t	24.15	23.89	23.88	24.20	24.23	24.64	24.89	25.10	25.05	24.94	24.65	24.48
56 m												
Vel	2.20	11.30	13.60	9.80	11.10	3.10	5.40	5.30	2.70	2.30	1.60	2.70
Dir	115.60	219.70	226.34	326.70	290.60	343.20	330.80	301.20	336.70	63.50	203.30	244.70
Temp	7.98	9.33	9.32	7.72	6.63	5.71	4.79	3.94	3.18	3.39	5.01	6.18
Sal	31.63	31.23	30.96	30.70	30.29	30.82	31.20	31.34	31.25	31.19	31.17	31.02
Sig-t	24.65	24.13	23.93	23.97	23.78	24.31	24.71	24.91	24.91	24.84	24.67	24.41
106 m												
Vel	3.00	2.70	7.80	6.70	7.80	4.40	6.80	5.00	1.90	2.30	1.80	2.00
Dir	290.00	203.80	246.50	297.90	288.20	289.30	311.10	312.00	6.70	312.90	184.50	214.50
Temp	6.21	7.18	8.70	8.02	7.16	6.03	5.08	4.24	3.25	3.61	4.41	5.10
Sal	32.14	32.05	31.80	31.70	31.61	31.64	31.79	31.85	31.69	31.67	31.30	30.87
Sig-t	25.29	25.09	24.68	24.70	24.75	24.92	25.15	25.28	25.25	25.20	24.83	24.42

Southwestern Shelikof Strait, continued

Bank area, continued

Fox 8406: August 1984 - July 1985

	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
26 m												
Vel	9.40	15.90	15.30	0.50	2.00	3.20	4.20	1.30	3.30	2.60	5.20	4.90
Dir	133.10	230.10	217.90	280.80	85.60	289.90	173.90	165.10	161.70	114.20	210.50	176.10
Temp	9.73	10.09	9.26	7.58	6.49	5.72	4.75	3.89	3.19	3.45	5.60	7.11
Sal	31.62	31.31	31.15	30.99	31.24	31.34	31.50	31.59	31.51	31.47	31.43	31.34
Sig-t	24.38	24.08	24.09	24.21	24.55	24.72	24.95	25.11	25.12	25.05	24.80	24.55
56 m												
Vel	3.80	8.30	7.50	0.10	2.10	2.50	1.00	0.90	2.20	2.10	4.00	3.20
Dir	81.50	219.50	209.10	181.70	33.50	253.30	137.00	0.80	157.40	86.10	200.40	193.50
Temp	7.67	8.51	9.21	7.83	6.71	5.82	4.91	3.95	3.25	3.41	4.88	5.54
Sal	31.94	31.79	31.55	31.24	31.25	31.33	31.51	31.43	31.52	31.40	31.37	31.36
Sig-t	24.94	24.70	24.41	24.37	24.53	24.70	24.94	24.97	25.11	25.01	24.84	24.75
75 m												
Vel	4.20	4.50	5.10	2.80	3.20	2.40	1.70	1.20	1.70	2.30	2.30	1.00
Dir	52.30	202.60	203.00	34.80	20.00	267.90	27.00	12.30	139.20	56.20	194.30	165.90
Temp	7.21	7.60	8.87	7.98	6.88	5.92	4.98	3.99	3.28	3.44	4.64	5.11
Sal	32.06	32.03	31.79	30.73	31.04	31.45	31.47	31.30	30.92	30.54	29.94	29.82
Sig-t	25.10	25.01	24.65	23.95	24.34	24.79	24.91	24.87	24.63	24.32	23.73	23.58

Southwestern Shelikof Strait, continued

Valley area

K12A: October 1977 - March 1978

	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
18 m												
Vel			34.50	26.40	18.70	24.30	32.70	7.40				
Dir			189.20	187.30	209.30	211.50	206.90	151.60				
Temp			7.26	6.22	4.30	3.99	3.95	3.95				
Sal			31.53	31.47	31.96	31.89	32.13	32.17				
Sig-t			24.68	24.76	25.36	25.34	25.53	25.57				
205 m												
Vel			3.30	3.90	2.20	11.30	16.70	7.40				
Dir			161.80	96.30	210.80	201.50	180.00	72.40				
Temp			5.00	5.07	5.16	5.08	4.93	4.79				
Sal			33.66	33.76	33.56	33.14	32.74	32.64				
Sig-t			26.64	26.71	26.54	26.21	25.92	25.85				

Southwestern Shelikof Strait, continued

Valley area, continued

Fox 8407: August 1984 - July 1985

	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
26 m												
Vel	13.50	22.50	20.80	31.90	19.20	24.20	2.70	9.10	6.50	10.00	8.70	1.60
Dir	238.80	209.90	198.10	196.30	194.70	197.40	251.30	198.90	199.00	209.50	210.60	324.80
Temp	10.97	10.22	9.19	7.54	6.57	5.70	4.90	3.99	3.34	3.80	5.74	7.50
Sal	31.70	31.50	31.27	31.15	31.35	31.41	31.62	31.62	31.50	31.52	31.43	31.06
Sig-t	24.23	24.21	24.20	24.34	24.63	24.78	25.03	25.13	25.09	25.06	24.79	24.28
56 m												
Vel	6.80	18.30	18.70	30.30	19.50	30.50	3.10	9.40	7.50	12.20	13.30	2.20
Dir	230.10	207.50	201.20	200.50	205.00	199.80	260.30	208.40	203.80	214.70	208.80	342.60
Temp	8.80	8.69	9.22	7.76	6.73	5.79	4.97	4.03	3.40	3.70	5.01	6.08
Sal	32.10	31.87	31.58	31.42	31.42	31.50	31.65	31.71	31.71	31.82	31.80	31.83
Sig-t	24.90	24.74	24.43	24.52	24.66	24.84	25.05	25.20	25.25	25.32	25.16	25.06
106 m												
Vel	7.10	5.30	6.70	21.30	11.50	26.40	1.80	7.00	4.60	8.70	5.00	4.30
Dir	16.60	224.10	212.60	200.60	204.90	204.40	355.10	209.60	223.80	214.70	209.80	25.10
Temp	6.24	6.00	7.07	7.77	7.14	6.27	5.26	4.29	3.74	4.05	4.28	4.99
Sal	32.60	32.22	32.02	31.90	31.80	31.66	31.66	31.62	31.62	31.82	31.71	31.74
Sig-t	25.65	25.38	25.08	24.90	24.91	24.91	25.02	25.09	25.15	25.28	25.17	25.12
185 m												
Vel	11.70	2.70	3.80	3.20	5.10	14.50	6.10	3.50	3.00	5.30	0.90	9.20
Dir	35.80	81.70	39.20	190.10	40.20	192.80	47.20	40.30	17.40	39.00	145.00	39.80
Temp	5.51	5.50	5.55	6.02	6.07	6.28	5.81	5.39	5.04	5.14	4.61	5.29
Sal	33.41	32.78	32.85	32.67	32.82	31.69	32.40	32.57	32.61	32.80	31.97	32.31
Sig-t	26.38	25.88	25.93	25.74	25.84	24.93	25.55	25.73	25.80	25.94	25.34	25.53

Southwestern Shelikof Strait, continued

Valley area, continued

Fox 8408: August 1984 - July 1985

	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
26 m												
Vel	16.90	9.40	20.20	28.90	22.00	37.30	7.20	21.50	1.90			
Dir	254.70	206.10	191.00	191.00	197.30	195.80	182.10	210.20	161.50			
Temp	10.90	10.36	9.24	7.50	6.49	5.72	4.92	3.98	3.39	3.82	5.68	7.34
Sal	31.89	31.83	31.44	31.22	30.74	31.30	31.60	31.64	31.69	31.61	31.26	29.44
Sig-t	24.39	24.44	24.32	24.40	24.15	24.69	25.02	25.14	25.24	25.13	24.66	23.03
56 m												
Vel	13.20	8.30	17.50	23.50	18.60	35.90	6.30	19.50	18.30	4.60	14.90	10.80
Dir	301.00	193.10	190.00	191.40	198.20	196.50	191.40	211.50	214.50	212.40	187.30	144.70
Temp	14.77	15.48	15.84	14.57	13.03	11.83	10.63	9.25	8.48	8.72	10.07	11.93
Sal												
Sig-t												
121 m												
Vel	6.30	4.40	3.70	12.20	9.70	28.00	3.50	12.80	13.60	2.50	10.60	6.00
Dir	338.60	186.30	171.90	195.20	186.30	201.10	148.60	290.10	207.90	169.50	187.30	125.80
Temp	6.23	5.81	5.89	6.71	6.82	6.38	5.30	4.82	4.16	4.43	4.40	4.80
Sal	32.59	32.30	32.20	32.32	32.29	31.80	30.91	30.79	30.70	30.84	31.32	31.97
Sig-t	25.64	25.47	25.38	25.37	25.33	25.00	24.43	24.38	24.38	24.46	24.85	25.32
205 m												
Vel	3.30	4.60	6.40	0.10	7.80	13.20	6.50	7.30	4.90	8.40	6.50	12.30
Dir	10.50	67.50	71.10	282.40	60.20	204.30	74.40	51.40	154.80	80.40	71.70	67.00
Temp	5.43	5.41	5.39	5.54	5.45	5.78	5.80	5.40	5.28	5.22	5.16	5.40
Sal	33.63	33.48	33.45	33.41	33.53	33.10	33.20	33.48	33.40	33.45	33.31	33.48
Sig-t	26.56	26.44	26.42	26.38	26.48	26.10	26.18	26.45	26.40	26.44	26.34	26.45

Southwestern Shelikof Strait, continued

Valley area, continued

Fox 8409: August 1984 - July 1985

	Aug.	Sept.	Oct.	Nov.	Dec.	Jan.	Feb.	Mar.	Apr.	May	June	July
26 m												
Vel	16.30	8.30	9.50	4.60	15.60	17.50						
Dir	311.40	288.80	208.20	216.30	216.70	220.10						
Temp	10.68	10.23	9.24	7.50	6.45	5.77						
Sal	31.88	31.90	31.68	30.94	29.85	30.43						
Sig-t	24.42	24.52	24.51	24.18	23.46	24.00						
56 m												
Vel	5.90	5.70	10.30	0.80	11.00	15.00	18.40	24.50	15.60	14.20	10.90	15.70
Dir	331.10	265.20	192.00	266.80	221.00	210.00	205.90	214.40	209.10	206.30	196.30	124.40
Temp	7.73	9.19	8.62	7.68	6.62	5.83	5.01	4.05	3.59	3.83	4.77	5.50
Sal	32.25	32.08	31.94	31.96	31.81	31.82	31.85	31.86	31.91	32.01	32.07	31.98
Sig-t	25.17	24.82	24.80	24.96	24.98	25.09	25.20	25.31	25.39	25.45	25.40	25.25
121 m												
Vel	5.30	9.30	7.40	3.70	1.60	6.30	7.90	8.20	8.20	7.00	9.10	10.70
Dir	4.30	185.60	175.20	357.90	194.20	216.30	190.70	213.00	196.60	195.90	196.30	183.60
Temp	6.03	6.36	5.83	6.69	6.34	6.04	5.43	5.29	4.57	4.66	4.90	4.98
Sal	33.25	32.85	32.82	32.77	32.86	32.49	31.69	32.50	32.53	32.68	32.63	32.56
Sig-t	26.19	25.83	25.87	25.73	25.84	25.59	25.03	25.68	25.78	25.90	25.83	25.77
168 m												
Vel	9.00	1.20	2.20	6.30	4.90	3.10	4.80	3.90	4.00	1.40	1.70	1.80
Dir	315.70	289.40	292.10	352.30	359.20	302.30	339.20	316.90	326.90	343.60	250.20	357.70
Temp	5.75	5.63	5.55	5.92	5.84	5.89	5.90	5.56	5.25	5.22	5.31	5.57
Sal	33.22	33.24	33.34	33.23	33.38	32.85	32.78	33.45	33.38	33.39	33.34	33.48
Sig-t	26.20	26.23	26.32	26.19	26.32	25.89	25.84	26.40	26.38	26.40	26.35	26.43

Appendix II.--The average temperature (°C), salinity (‰), and density (sigma-t) at selected depths along Shelikof Strait during 1MF81 - 4MF81. Standard deviation and number of sample observed are in parenthesis.

1MF81	Strata I	II	III	IV	V	VI	VII	VIII	AVERAGE
Temperature									
50 m		5.20 (0.259, 3)	4.87 (0.456, 3)	4.80 (0.278, 5)		4.73 (0.474, 6)	4.90 (0.347, 4)		4.87 (0.374)
100 m		5.34 (0.123, 3)	5.22 (0.035, 2)	5.02 (0.302, 5)		4.85 (0.449, 6)	4.91 (0.478, 4)		5.02 (0.376)
150 m		5.38 (0.105, 3)	5.39 (0.064, 2)	5.35 (0.144, 5)		5.23 (0.215, 6)	4.86 (0.625, 4)		5.22 (0.344)
200 m				5.42 (0.058, 5)		5.40 (0.154, 5)	5.41 (0.012, 3)		5.41 (0.096)
250 m				5.46 (0.052, 3)		5.44 (0.042, 2)			5.45 (0.039)
Salinity									
50 m		31.94 (0.072, 3)	31.77 (0.340, 3)	31.77 (0.079, 5)		31.87 (0.148, 6)	31.78 (0.173, 4)		31.83 (0.166)
100 m		32.05 (0.101, 3)	32.06 (0.120, 2)	31.92 (0.176, 5)		31.98 (0.137, 6)	31.86 (0.175, 4)		31.96 (0.151)
150 m		32.12 (0.093, 3)	32.14 (0.007, 2)	32.05 (0.171, 5)		32.10 (0.234, 6)	31.94 (0.177, 4)		32.07 (0.180)
200 m				32.27 (0.297, 5)		32.12 (0.189, 5)	32.29 (0.403, 3)		32.22 (0.273)
250 m				32.24 (0.335, 3)		32.43 (0.382, 2)			32.26 (0.315)

Appendix II.--Continued.

1MF81	I	II	III	IV	V	VI	VII	VIII	AVERAGE
				Strata					
Density									
50 m		25.25 (0.064, 3)	25.16 (0.225, 3)	25.17 (0.080, 5)		25.25 (0.141, 6)	25.16 (0.124, 4)		25.20 (0.127)
100 m		25.32 (0.091, 3)	25.35 (0.092, 2)	25.26 (0.153, 5)		25.32 (0.142, 6)	25.22 (0.153, 4)		25.29 (0.131)
150 m		25.38 (0.084, 3)	25.43 (0.057, 2)	25.33 (0,133, 5)		25.38 (0.199, 6)	25.29 (0.174, 4)		25.35 (0.148)
200 m				25.49 (0.235, 5)		25.37 (0.136, 5)	25.50 (0.318, 3)		25.45 (0.213)
250 m				25.46 (0.272, 3)		25.61 (0.311, 2)			25.48 (0.255)

Appendix II.--Continued

2MF81	Strata I	II	III	IV	V	VI	VII	VIII	AVERAGE
Temperature									
50 m	5.27	5.40	5.16	4.96	4.76	4.86	4.95	4.90	4.98
	(0.257, 6)	(0.198, 6)	(0.285, 9)	(0.276, 12)	(0.158, 13)	(0.184, 17)	(0.146, 12)	(0.105, 8)	(0.270)
100 m	5.42	5.43	5.31	5.12	5.13	5.05	5.08	5.09	5.17
	(0.199, 6)	(0.186, 6)	(0.385, 8)	(0.255, 12)	(0.216, 9)	(0.303, 14)	(0.153, 12)	(0.114, 8)	(0.268)
150 m	5.55	5.51	5.09	5.16	5.19	5.16	5.23	4.97	5.21
	(0.117, 6)	(0.116, 6)	(0.501, 7)	(0.261, 11)	(0.195, 9)	(0.240, 11)	(0.150, 9)	(0.224, 8)	(0.291)
200 m	5.54	5.52	5.33	5.15	5.11	5.17	5.11	5.20	5.20
	(0.085, 2)	(0.140, 3)	(0.157, 4)	(0.361, 10)	(0.423, 7)	(0.226, 10)	(0.200, 7)	(0.152, 3)	(0.293)
250 m				5.24	5.41	5.38	5.29		5.33
				(0.304, 6)	(0.036, 3)	(0.091, 8)	(0.156, 4)		(0.181)
Salinity									
50 m	31.79	31.88	31.68	31.74	31.72	31.80	31.67	31.56	31.73
	(0.124, 6)	(0.153, 6)	(0.191, 9)	(0.147, 12)	(0.241, 13)	(0.241, 17)	(0.119, 12)	(0.124, 8)	(0.173)
100 m	31.98	32.02	31.97	31.97	31.91	31.98	31.89	31.78	31.94
	(0.119, 6)	(0.127, 6)	(0.110, 8)	(0.105, 12)	(0.117, 9)	(0.072, 14)	(0.149, 12)	(0.157, 8)	(0.133)
150 m	32.13	32.16	32.07	32.11	32.04	32.14	32.04	31.88	32.07
	(0.134, 6)	(0.065, 6)	(0.102, 7)	(0.104, 11)	(0.106, 9)	(0.063, 11)	(0.077, 9)	(0.166, 8)	(0.127)
200 m	32.08	32.23	32.29	32.26	32.20	32.36	32.18	32.20	32.25
	(0.255, 2)	(0.064, 3)	(0.128, 4)	(0.167, 10)	(0.079, 7)	(0.173, 10)	(0.075, 7)	(0.410, 3)	(0.169)
250 m				32.45	32.64	32.64	32.53		32.57
				(0.256, 6)	(0.232, 3)	(0.138, 8)	(0.159, 4)		(0.194)

Appendix II.--Continued.

2MF81	Strata I	II	III	IV	V	VI	VII	VIII	AVERAGE
Density									
50 m	25.13	25.18	25.05	25.12	25.12	25.18	25.07	24.99	25.11
	(0.102, 6)	(0.108, 6)	(0.137, 9)	(0.118, 12)	(0.190, 13)	(0.097, 17)	(0.092, 12)	(0.091, 8)	(0.132)
100 m	25.26	25.30	25.26	25.29	25.24	25.30	25.22	25.14	25.25
	(0.102, 6)	(0.093, 6)	(0.087, 8)	(0.076, 12)	(0.088, 9)	(0.051, 14)	(0.114, 12)	(0.119, 8)	(0.099)
150 m	25.37	25.39	25.37	25.41	25.34	25.41	25.33	25.23	25.36
	(0.109, 6)	(0.061, 6)	(0.072, 7)	(0.052, 11)	(0.069, 9)	(0.055, 11)	(0.051, 9)	(0.127, 8)	(0.090)
200 m	25.33	25.45	25.52	25.52	25.47	25.59	25.46	25.45	25.50
	(0.212, 2)	(0.070, 3)	(0.121, 4)	(0.107, 10)	(0.078, 7)	(0.125, 10)	(0.045, 7)	(0.309, 3)	(0.130)
250 m				25.65	25.78	25.78	25.71		25.73
				(0,174, 6)	(0.179, 3)	(0.097, 8)	(0.112, 4)		(0.136)

Appendix II.--Continued

3MF81	Strata I	II	III	IV	V	VI	VII	VIII	AVERAGE
Temperature									
50 m	5.69	5.42	5.50	5.42	5.28	5.25	5.15	5.09	5.31
	(0.151, 6)	(0.092, 6)	(0.183, 7)	(0.156, 8)	(0.148, 13)	(0.154, 15)	(0.187, 11)	(0.147, 8)	(0.223)
100 m	5.62	5.64	5.64	5.51	5.28	5.20	5.12	5.10	5.34
	(0.209, 6)	(0.094, 6)	(0.073, 6)	(0.071, 7)	(0.098, 10)	(0.098, 11)	(0.116, 10)	(0.104, 8)	(0.238)
150 m	5.65	5.66	5.59	5.39	5.20	5.17	5.12	5.16	5.33
	(0.140, 6)	(0.117, 6)	(0.148, 6)	(0.149, 7)	(0.139, 10)	(0.098, 9)	(0.110, 7)	(0.076, 8)	(0.242)
200 m	5.60	5.61	5.51	5.32	5.21	5.20	5.24	5.25	5.30
	(0.262, 2)	(0.134, 2)	(0.153, 3)	(0.134, 4)	(0.122, 9)	(0.125, 8)	(0.174, 5)	(0.189, 3)	(0.191)
250 m				5.37	5.32	5.42	5.40		5.41
				(0.042, 2)	(0.124, 4)	(0.044, 6)	(0.045, 3)		(0.126)
Salinity									
50 m	31.97	31.83	31.80	31.84	31.83	31.77	31.78	31.67	31.80
	(0.040, 6)	(0.058, 6)	(0.134, 7)	(0.141, 8)	(0.209, 13)	(0.235, 15)	(0.237, 11)	(0.262, 8)	(0.201)
100 m	32.04	32.03	31.98	32.03	32.02	31.93	31.94	31.83	31.97
	(0.061, 6)	(0.055, 6)	(0.093, 6)	(0.115, 7)	(0.099, 10)	(0.139, 11)	(0.238, 10)	(0.257, 8)	(0.164)
150 m	32.15	32.13	32.05	32.17	32.15	32.11	32.17	32.11	32.13
	(0.092, 6)	(0.086, 6)	(0.108, 6)	(0.069, 7)	(0.086, 10)	(0.062, 9)	(0.042, 7)	(0.221, 8)	(0.109)
200 m	32.17	32.13	32.19	32.33	32.38	32.42	32.63	32.67	32.40
	(0.134, 2)	(0.134, 2)	(0.145, 3)	(0.137, 4)	(0.137, 9)	(0.178, 8)	(0.313, 5)	(0.485, 3)	(0.255)
250 m				32.65	32.60	32.78	33.01		32.67
				(0.057, 2)	(0.220, 4)	(0.086, 6)	(0.280, 3)		(0.288)

Appendix II.--Continued.

3MF81	Strata I	II	III	IV	V	VI	VII	VIII	AVERAGE
Density									
50 m	25.22	25.14	25.11	25.15	25.16	25.11	25.13	25.05	25.13
	(0.040, 6)	(0.044, 6)	(0.090, 7)	(0.110, 8)	(0.161, 13)	(0.182, 15)	(0.174, 11)	(0.195, 8)	(0.149)
100 m	25.29	25.27	25.24	25.29	25.31	25.25	25.26	25.18	25.26
	(0.060, 6)	(0.055, 6)	(0.072, 6)	(0.084, 7)	(0.080, 10)	(0.115, 11)	(0.178, 10)	(0.208, 8)	(0.124)
150 m	25.37	25.35	25.29	25.39	25.31	25.39	25.44	25.39	25.39
	(0.088, 6)	(0.083, 6)	(0.099, 6)	(0.048, 7)	(0.299, 10)	(0.057, 9)	(0.045, 7)	(0.174, 8)	(0.097)
200 m	25.39	25.36	25.42	25.55	25.59	25.63	25.79	25.82	25.60
	(0.134, 2)	(0.120, 2)	(0.135, 3)	(0.120, 4)	(0.105, 9)	(0.128, 8)	(0.230, 5)	(0.368, 3)	(0.204)
250 m				25.80	25.76	25.89	26.08		25.81
				(0.042, 2)	(0.158, 4)	(0.061, 6)	(0.221, 3)		(0.231)

Appendix II.--Continued

4MF81	Strata I	II	III	IV	V	VI	VII	VIII	AVERAGE
Temperature									
50 m	6.03	6.04	5.98	6.11	6.17	5.80	5.62	5.70	5.92
	(0.223, 5)	(0.174, 6)	(0.254, 7)	(0.309, 8)	(0.274, 14)	(0.366, 15)	(0.368, 11)	(0.390, 9)	(0.364)
100 m	5.95	5.95	5.85	5.80	5.65	5.54	5.32	5.38	5.64
	(0.252, 4)	(0.203, 6)	(0.205, 7)	(0.220, 8)	(0.138, 10)	(0.265, 12)	(0.196, 9)	(0.166, 8)	(0.295)
150 m	5.80	5.82	5.55	5.49	5.40	5.24	5.22	5.22	5.42
	(0.193, 3)	(0.097, 6)	(0.140, 7)	(0.129, 7)	(0.167, 10)	(0.173, 10)	(0.117, 8)	(0.109, 8)	(0.249)
200 m		5.57	5.39	5.36	5.29	5.25	5.26	5.29	5.32
		(0.262, 2)	(0.118, 6)	(0.084, 7)	(0.097, 9)	(0.079, 9)	(0.103, 5)	(0.067, 4)	(0.119)
250 m				5.39	5.32	5.38	5.34		5.36
				(0.014, 2)	(0.034, 5)	(0.057, 6)	(0.021, 3)		(0.054)
Salinity									
50 m	31.94	31.96	31.93	31.83	31.79	31.91	31.82	31.80	31.86
	(0.075, 5)	(0.103, 6)	(0.121, 7)	(0.097, 8)	(0.242, 14)	(0.133, 15)	(0.165, 11)	(0.197, 9)	(0.169)
100 m	32.11	32.10	31.07	31.02	32.01	32.05	32.05	32.01	32.05
	(0.021, 4)	(0.046, 6)	(0.099, 7)	(0.079, 8)	(0.071, 10)	(0.094, 12)	(0.088, 9)	(0.118, 8)	(0.088)
150 m	32.20	32.20	32.17	32.16	32.15	32.16	32.19	32.21	32.18
	(0.015, 3)	(0.017, 6)	(0.086, 7)	(0.096, 7)	(0.010, 10)	(0.082, 10)	(0.140, 8)	(0.152, 8)	(0.116)
200 m		32.34	32.43	32.49	32.41	32.47	32.66	32.94	32.53
		(0.120, 2)	(0.182, 6)	(0.213, 7)	(0.282, 9)	(0.191, 9)	(0.351, 5)	(0.392, 4)	(0.303)
250 m				32.70	32.69	32.93	33.14		32.84
				(0.113, 2)	(0.169, 5)	(0.159, 6)	(0.187, 3)		(0.239)

Appendix II.--Continued.

4MF81	Strata I	II	III	IV	V	VI	VII	VIII	AVERAGE
Density									
50 m	25.16	25.17	25.16	25.06	25.02	25.16	25.11	25.08	25.11
	(0.080, 5)	(0.094, 6)	(0.113, 7)	(0.109, 8)	(0.207, 14)	(0.131, 15)	(0.166, 11)	(0.198, 9)	(0.158)
100 m	25.30	25.30	25.28	25.25	25.26	25.31	25.33	25.29	25.29
	(0.029, 4)	(0.044, 6)	(0.092, 7)	(0.087, 8)	(0.067, 10)	(0.091, 12)	(0.089, 9)	(0.105, 8)	(0.082)
150 m	25.39	25.39	25.40	25.39	25.40	25.42	25.45	25.46	25.41
	(0.032, 3)	(0.022, 6)	(0.084, 7)	(0.088, 7)	(0.093, 10)	(0.082, 10)	(0.120, 8)	(0.127, 8)	(0.092)
200 m		25.53	25.62	25.66	25.62	25.67	25.81	26.03	25.69
		(0.120, 2)	(0.155, 6)	(0.174, 7)	(0.218, 9)	(0.143, 9)	(0.268, 5)	(0.308, 4)	(0.225)
250 m				25.83	25.83	26.02	26.18		25.96
				(0.085, 2)	(0.131, 5)	(0.121, 6)	(0.146, 3)		(0.194)

Appendix III.--Dynamic heights based on different depth of no motion at Shelikof Strait during spring season of 1977, 1981, and 1985

		Mean	Standard Deviation	n
1977 March				
	0/50	0.148	0.002	6
	0/100	0.289	0.006	6
	0/150	0.421	0.006	6
	100/200	0.257	0.003	6
	150/200	0.125	0.001	6
1981 March - May				
1MF81				
	0/50	0.141	0.005	21
	0/100	0.277	0.010	20
	0/150	0.410	0.016	20
	100/200	0.264	0.012	13
	150/200	0.130	0.007	13
2MF81				
	0/50	0.149	0.007	84
	0/100	0.289	0.011	76
	0/150	0.423	0.014	68
	100/200	0.262	0.007	47
	150/200	0.128	0.004	47
3MF81				
	0/50	0.147	0.007	74
	0/100	0.287	0.012	64
	0/150	0.420	0.015	59
	100/200	0.258	0.010	36
	150/200	0.126	0.007	36
4MF81				
	0/50	0.155	0.008	75
	0/100	0.294	0.012	66
	0/150	0.427	0.015	59
	100/200	0.254	0.011	43
	150/200	0.123	0.007	43
1985* March				
	0/50	0.138	0.003	45
	0/100	0.275	0.005	45
	0/150	0.406	0.010	45
	100/200	0.248	0.019	45
	150/200	0.117	0.013	45

*The stations were selected from central strait among 189 CTD stations