THE PHYSICAL OCEANOGRAPHY OF PORT MOLLER, ALASKA

Final Report

Contract No. 50ABNC800117

Prepared for:

U.S. Department of Commerce
National Oceanic and Atmospheric Administration (NOAA)
National Ocean Service, OMA, OAD
701 C Street, Box 56
Anchorage, Alaska 99513

EG&G
WASHINGTON ANALYTICAL SERVICES CENTER, INC.

OCEANOGRAPHIC SERVICES

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1.1 PROGRAM OVERVIEW

EG&G Washington Analytical Services Center, Inc., Oceanographic Services Department (EG&G) conducted a physical oceanographic study of the Port Moller/Herendeen Bay estuary during the summer of 1989. The purpose of the study, entitled "The Physical Oceanography of Port Moller, Alaska," was to provide information on the physical processes that may affect interannual year-class strength and recruitment in Port Moller crab and fish populations. This program (NOAA research unit number 705), was administered by the Outer Continental Shelf Environmental Assessment Program (OCSEAP) Office of NOAA/NOS in Anchorage, Alaska, with contractual support from the NOAA Western Administrative Support Center in Seattle, Washington.

The study area is located 324 kilometers northeast of Unimak Pass, on the north side of the Alaska Peninsula, bordering on Bristol Bay and the North Aleutian Shelf planning area. The Port Moller/Herendeen Bay complex consists of two branches, each about 38 kilometers long, characterized by primarily shallow water cut by a deep narrow channel leading to their respective heads (Figure 1-1). The western arm, Herendeen Bay, is the deeper of the two bays (100 m) and the focus of sampling and analysis for this study. The effects of tides, meteorological events and water property distributions are analyzed to examine their relative importance in determining the physical processes which govern circulation in the estuary.

The field program consisted of two meteorological stations and five moorings (eight current meters and two tide gauges) deployed from late May to early October 1989. Hydrographic cross- and along-channel sections of temperature, salinity and velocity were also obtained during the deployment and recovery cruises. Satellite images and synoptic weather maps were collected by Fairbanks Image Processing Facility, University of Alaska, over the deployment period to aid in analysis. Ancillary climatological data were obtained to establish an overview of regional characteristics.

Basic results from the 1989 field program were presented at a meeting of the American Geophysical Union in February 1990 (Johnson and Greengrove, 1990). A 9-track data tape containing all current, tide, meteorological, and

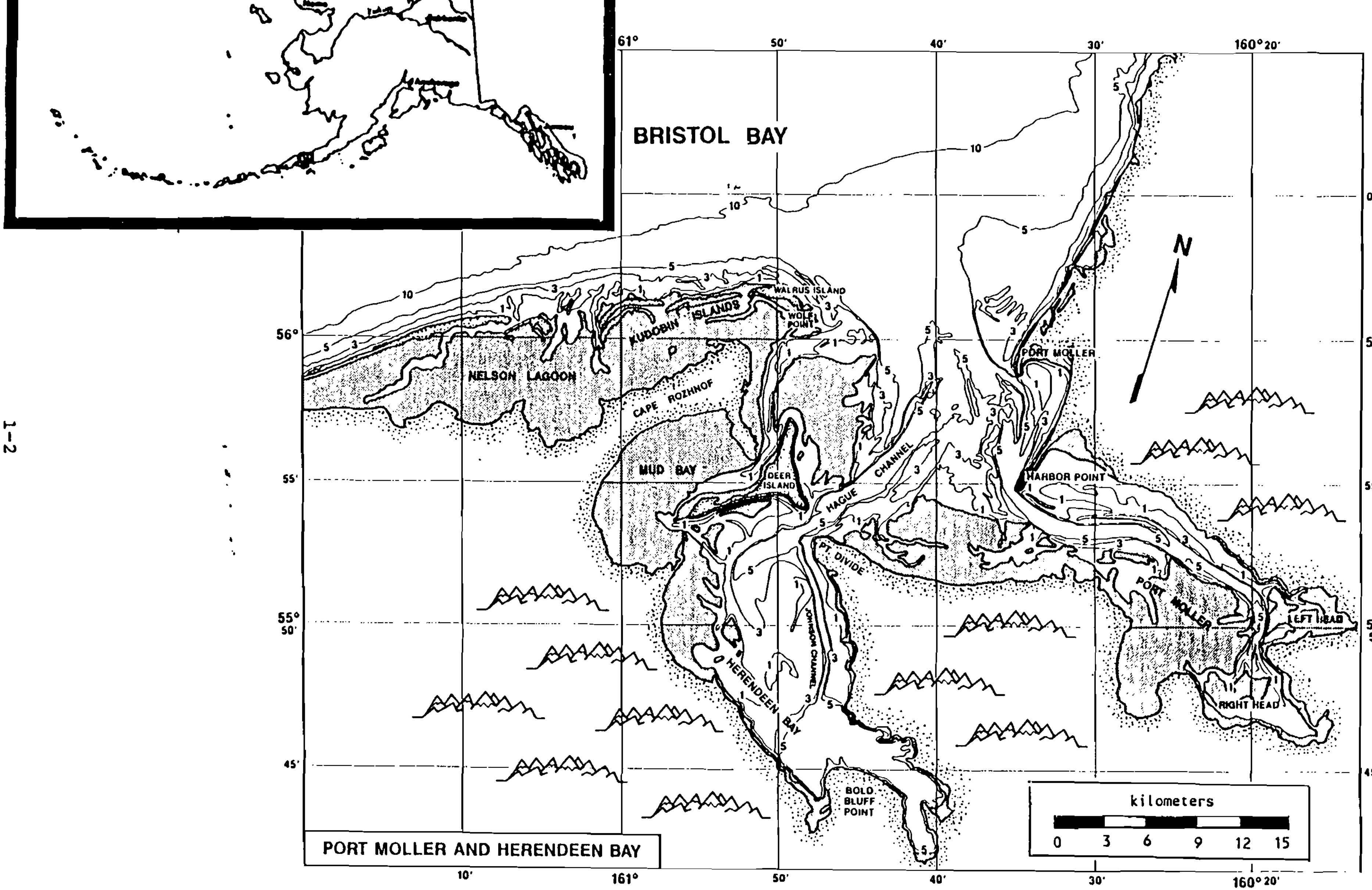


Figure 1-1. Port Moller/Herendeen Bay. Bathymetry is contoured in meters.

the completion of the program. This final report presents the field observations and analysis results from "The Port Moller Physical Oceanography Study." Section 1 presents an overview of the program and objectives; Section 2 reviews the scientific background for this region; Section 3 describes the field measurement program and data return; Section 4 is a discussion of analysis results; and Section 5 contains a summary and recommendations for future work in this area.

1.2 PROGRAM OBJECTIVES

OCSEAP required a physical process study to aid in a concurrent fishery oceanography investigation of the impact of oil and gas development on interannual year-class strength and recruitment in the Pacific herring and king crab populations of the Port Moller/Herendeen Bay/Nelson Lagoon complex.

Although it is unlikely that any oil-related shore facilities will be located in the Port Moller area, the habitat for the maintenance of the commercial fish and shellfish stocks is considered vulnerable to pollutants and oil spills originating at development sites in Bristol Bay or along transportation routes offshore (Bax, 1987). This concern is related to the unique physical processes governing the circulation and transport processes of the Port Moller complex. The swiftly moving tidal currents, frequently occurring storm surges, strong local and synoptic wind events, and high precipitation rates make the complex and its habitats potentially susceptible to damage from oil and other pollutants.

The purpose of the Port Moller physical oceanography study is to quantitatively characterize the circulatory regime of the Port Moller/Herendeen Bay estuary system and its major forcing processes. The field observations and data analysis will aid in the design and interpretation of the fishery investigation and will substantiate a description of coastal and estuarine processes affecting physical transport of released pollutants.

In a comprehensive study, Pace (1986) provided a concise description of the physical processes and biological utilization in the region of the North Aleutian Shelf. The study integrated physical data with ecological information from previous studies to underscore the importance of water transport systems to the maintenance of large populations of commercial fish, shellfish, birds, and marine mammals. The study ascribed the high degree of biological utilization to food availability and suitable habitats, and examined the issues of vulnerability of several species to oil and gas development.

The most vulnerable were those species utilizing habitats contained in the enclosed lagoons where spilled oil could be retained for long time periods, exposing a wide range of organisms to a variety of toxic effects. Of the fishes, Pacific herring were considered to be among the most vulnerable, since they spawn in shallow water and their larvae are known to concentrate close to the surface. Within the Port Moller area, stands of the eelgrass *Zostera* sp. (a potential spawning substrate for herring) extend from Doe Point to Fawn Point (R. Gill, personal communication). The primary invertebrate of concern was the red king crab because of its documented utilization of nearshore areas for spawning and nursery grounds. Also, a relict population of blue king crab resides within Herendeen Bay and is the basis for a local subsistence fishery (L. Incze, personal communication). The food webs necessary for the maintenance of these commercial species were also considered vulnerable since they could be adversely affected by the retention of oil through the physical processes present in the lagoons and nearshore areas.

By contrast, other studies predicted that populations of Pacific herring and king crab would not be catastrophically affected by spilled oil in the offshore areas of the southeastern Bering Sea. Results from the simulations of well blowouts and tanker accidents were coupled with distribution and abundance information to predict the effects on fish and crab populations utilizing the Port Moller, Port Heiden, and Cape Newenham areas (Laevastu and Fukuhara, 1986). The estimated impacts resulting from both types of simulations had no quantifiable effect on the offshore fishery resources in lagoon, and estuary systems were not the focus of these investigations. Thus, a central focus of environmental impact research is to determine the physical and biological response of coastal areas, particularly the highly productive estuaries such as Port Moller, to potential oil spills. The Port Moller physical oceanography study is an important component of this research.

2.1 OVERVIEW

The Bering Sea encompasses an area of 2.3 million square kilometers (Sverdrup et al., 1942) bounded by land to the west (USSR) and east (Alaska). The Bering Strait, a major passage to the Arctic Ocean, marks the northern boundary, while the southern edge is bordered by the Aleutian Islands which act as a barrier between the Bering Sea and the North Pacific Ocean. The Sea is divided along a northwest line from Unimak Pass to Cape Navarin into a set of deep western basins (3,500 m) and a shallow eastern shelf (200 m) (Figure 2-1). The primary sources of freshwater inflow into the eastern Bering Sea are the Yukon River in the north and the Kuskokwim and Kvichak Rivers in the Bristol Bay area. The Yukon is, by far, the single largest source of freshwater runoff to the Bering Sea (Roden, 1967).

The general area of concern for this study is in the southeastern Bering Sea, near Bristol Bay, along the North Aleutian Shelf, which extends along the entire north shore of the Alaska Peninsula from False Pass to the Kvichak River. Together, the Aleutian Islands and the Alaska Peninsula form the Aleutian Arc, a volcanic chain of mountains created by subduction of one oceanic plate beneath another. As with most plate boundaries, this is a tectonically active region of volcanoes and earthquakes (Sykes, 1971).

The Alaska Peninsula extends 700 km southwestward from the mainland to Unimak Pass and contains several major embayments along its otherwise relatively straight north shore: Bechevin Bay and Isanotski Strait, which separate Unimak Island from the peninsula; Izembek/Moffet Lagoon located north of Cold Bay; the Nelson Lagoon/Port Moller/Herendeen Bay complex (Figure 2-2); and Port Heiden. The bays flow onto the North Aleutian Shelf where the 50-m isobath parallels the relatively straight coastline at a distance of 20-40 km offshore.

The Alaska Peninsula acts as a meteorological dividing line that steers storms generated by large-scale atmospheric circulation patterns along either its north or south shore (Overland, 1981). The frequency of storms along the peninsula makes this an event-dominated area with relatively high precipitation due to orographic effects. The embayments, which are surrounded

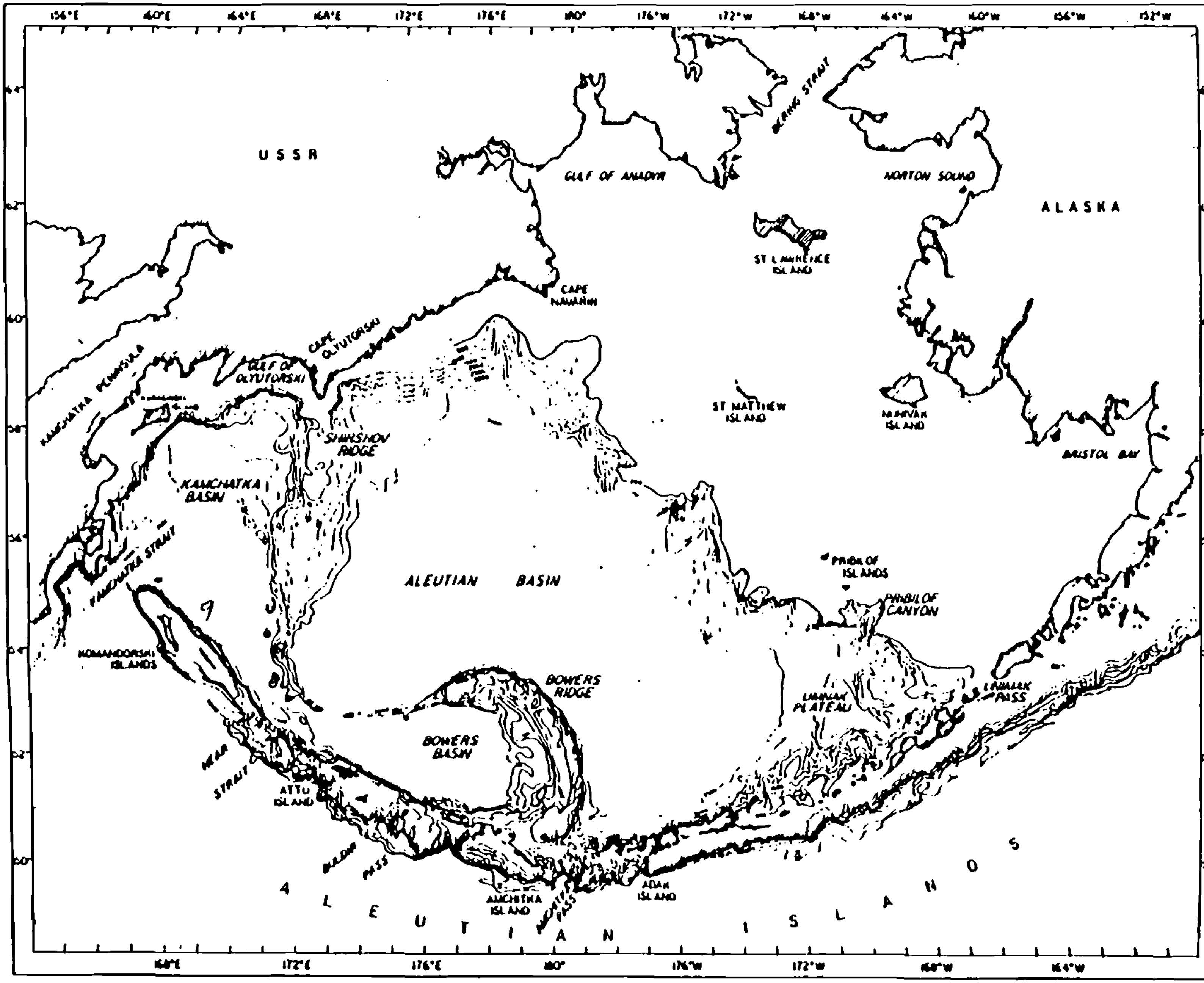


Figure 2-1. The Bering Sea (Kinder, 1981).

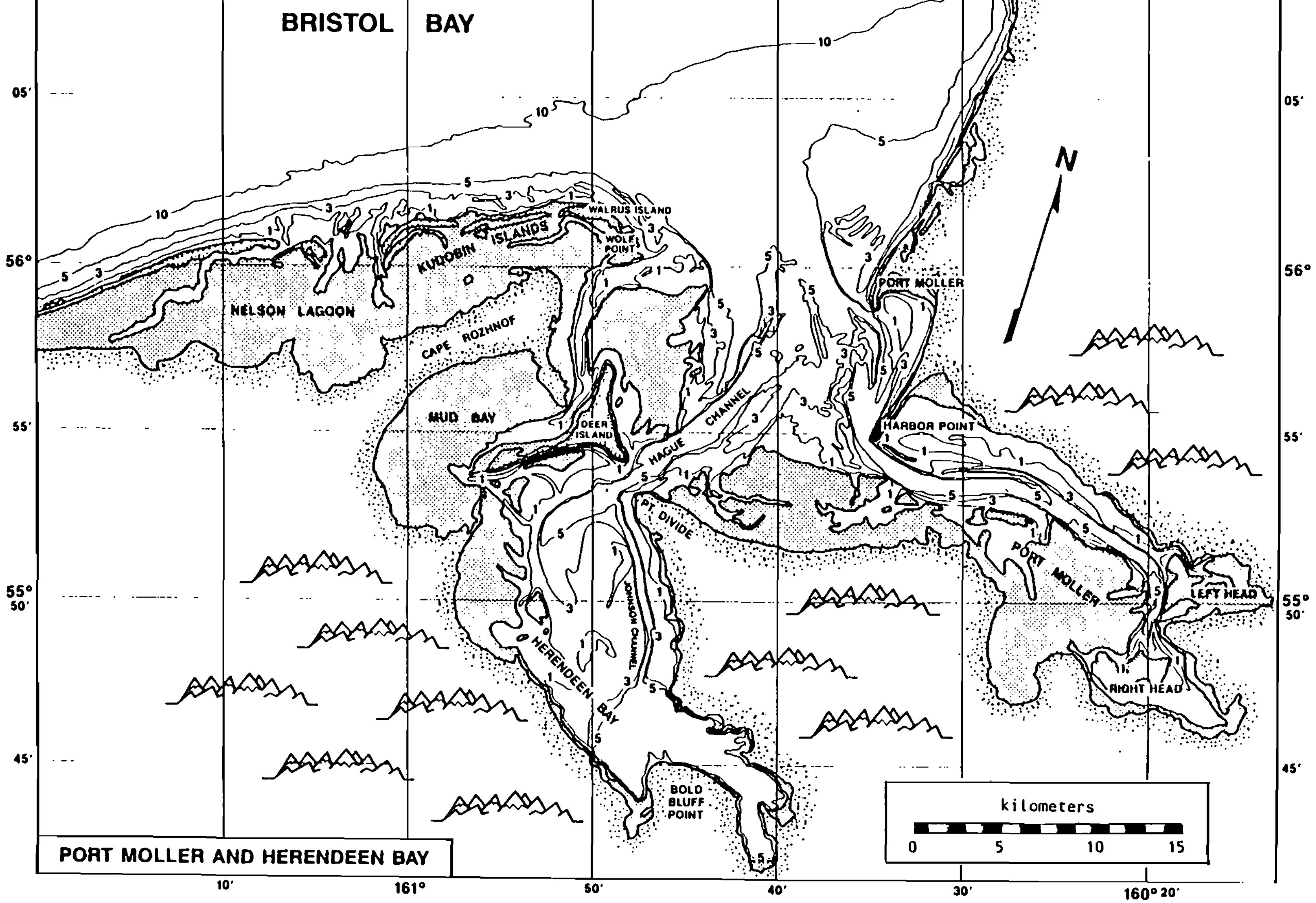


Figure 2-2. Port Moller/Herendeen Bay. Bathymetry is contoured in meters.

this runoff. In addition, the surrounding mountains dramatically modify local wind patterns (Schumacher and Moen, 1983).

The exchange between these estuaries and the North Aleutian Shelf is primarily storm-event and tidally dominated (Schumacher and Moen, 1983; Cline et al., 1982). Strong tidal mixing, as well as runoff, leads to increased suspended sediment and nutrient concentrations in and near the bays. This, in conjunction with local tidal flats and their sheltered geography, makes these embayments ideal spawning and feeding grounds for many biological species in the area (Pace, 1986). These biologically rich habitats are also the most vulnerable to damage from oil. If an oil spill were to occur near an embayment, it could be trapped for longer periods in these enclosed lagoons thus increasing its overall toxic effect (Pace, 1986).

The most likely sources of oil in the southeastern Bering Sea lie off the North Aleutian Shelf in the Amak and Bristol Bay Basins and the Black Hills Ridge (Figure 2-3). The basins are geologic structural depressions filled with Cenozoic sediments kilometers thick (Marlow et al., 1980). The Black Hills Ridge is an extension of the Black Hills structural high near the western end of the Alaska Peninsula. These potential sources of oil are located just offshore of three of the four major bay/lagoon complexes along north shore of the Alaskan Peninsula. Thus, it is necessary that the circulation and exchange rates be determined and the biological environments be characterized for each embayment in order to properly assess the impact of a possible oil spill.

Accordingly, the purpose of this study is to determine the general circulation and exchange rate, as well as the physical processes (tides, storms, runoff) that control these general flow patterns for one of these estuaries, the Port Moller complex.

2.2 METEOROLOGY AND CLIMATOLOGY OF THE BERING SEA, BRISTOL BAY, AND THE NORTH ALEUTIAN SHELF

The marine climatology of the Bering Sea has been reviewed by Overland (1981), and specific data are summarized in a climatic atlas of the Bering Sea by Brower et al. (1988). Bering Sea climatology is influenced by three air

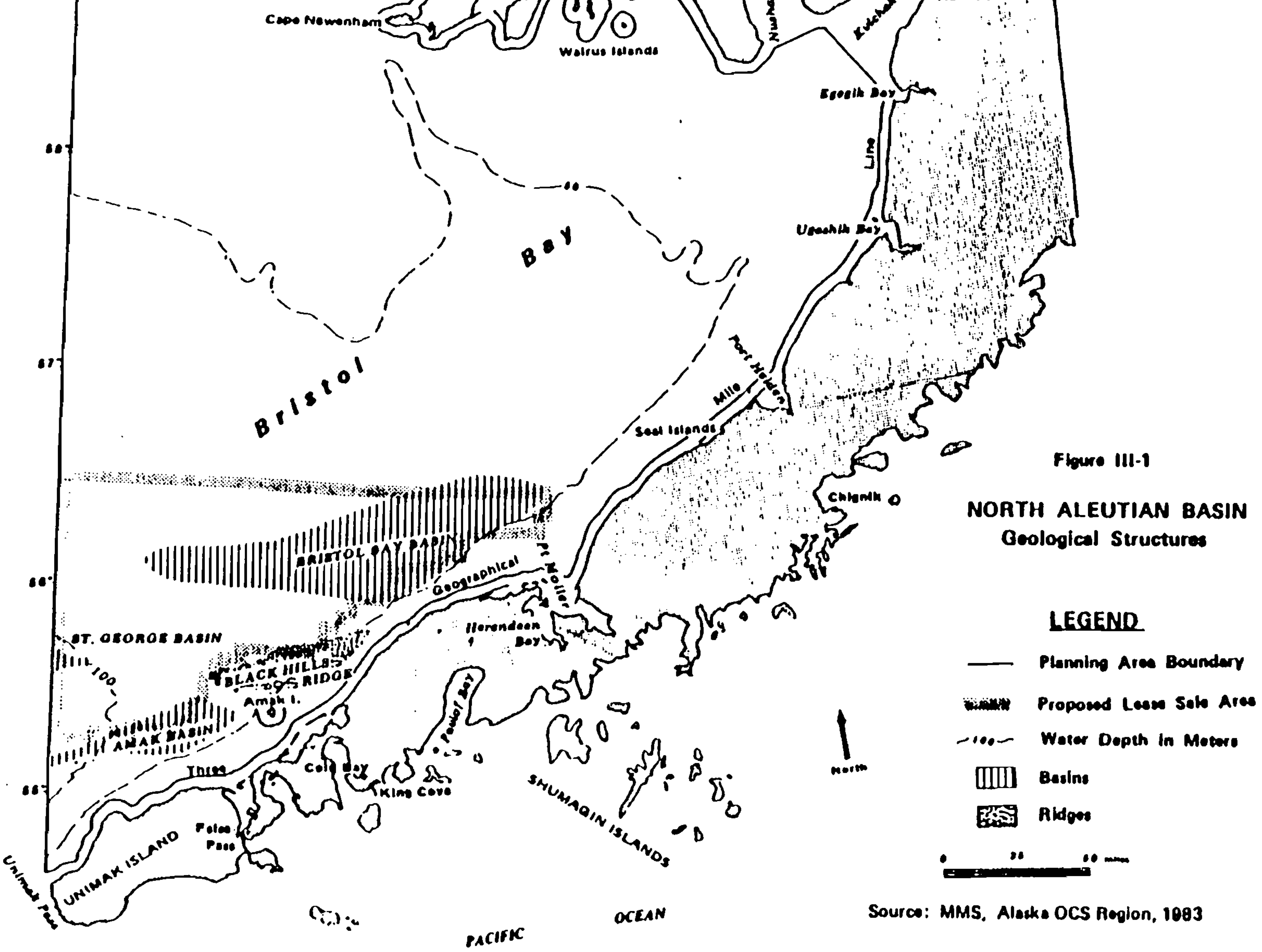


Figure 2-3. Location of potential oil sites (MMS, 1983).

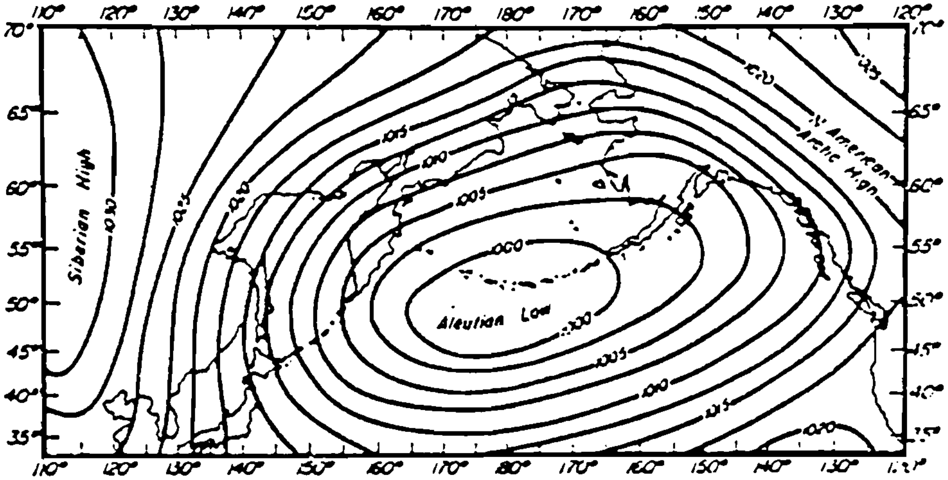
the presence of an Arctic high-pressure air mass over the northern Bering Sea from September through May. The remaining summer months are dominated by maritime air masses from the Pacific.

The regional circulation is strongly influenced by the Aleutian Low, a statistical low-pressure system, with an east-west oriented elliptical center, which moves from north (central Bering Sea) in the summer to south (over the Aleutian Arc) in the winter (Figure 2-4, Dodimead et al., 1963). This pressure pattern results in predominantly southwesterly winds in the summer and northeasterly winds in the winter along the Aleutian Shelf. Surface wind speeds for both seasons are shown in Figure 2-5 (Overland, 1981).

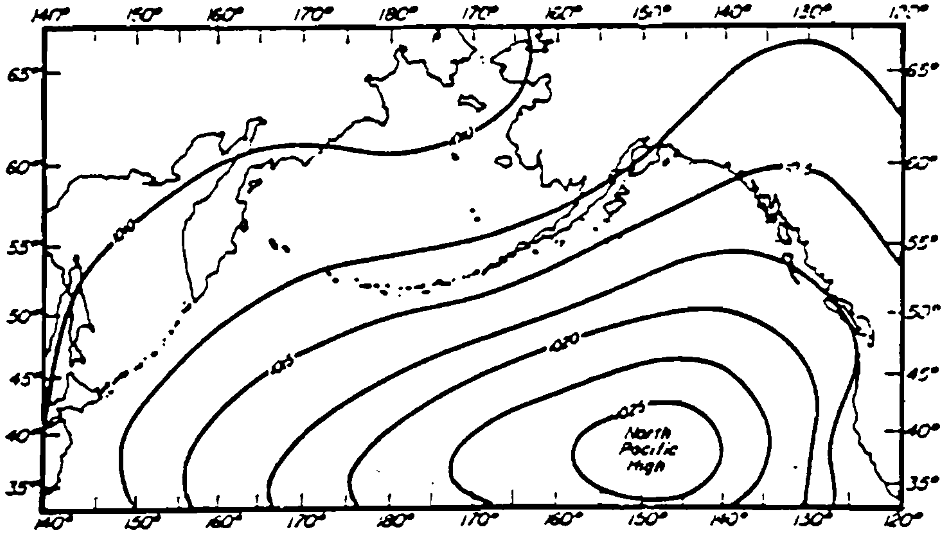
The low pressure along this feature's axis is associated with the frequent passage of storms tracking along the Aleutian archipelago, a natural topographic barrier. The tracks primarily follow the southern side of the peninsula into the Gulf of Alaska during the winter months and along the northern shore into the Bering Sea in summer (Figure 2-6). The southeastern Bering Sea is storm-event dominated. Storm activity for this area averages four to five a month in the winter and three to four in the summer. The effects of frequent intense winter storms can be seen by the relatively even distribution of winds in area C of Figure 2-5 (Overland, 1981).

The distribution of sea ice in the Bering Sea is seasonal and shows large interannual variability. In summer, the entire Bering Sea is ice free. By early November, sea ice extends up to the Bering Strait with maximum extent occurring in late March (Figure 2-7). Sea ice formation in the southeastern Bering Sea occurs predominantly along the northern shore of Bristol Bay, where the winds are offshore and thus favorable for ice formation. The interannual variability of ice is a function of storm track and frequency, which, in turn, is tied to the large-scale atmospheric circulation (Overland and Pease, 1982; Niebauer, 1981).

The seasonal variability of ice cover plays a major role in determining the climate of the Bering Sea. Increased winter ice cover inhibits air/sea interaction, thus allowing the Arctic continental air mass to establish itself over a much larger oceanic area. This air mass brings with it increased daily and seasonal temperature ranges and decreased precipitation. During the summer season, the entire Bering Sea is under the influence of a maritime air

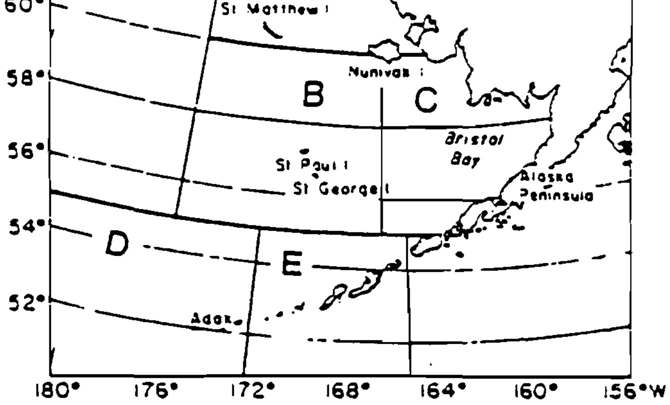


Mean Sea Level Pressure (Millibars), Winter

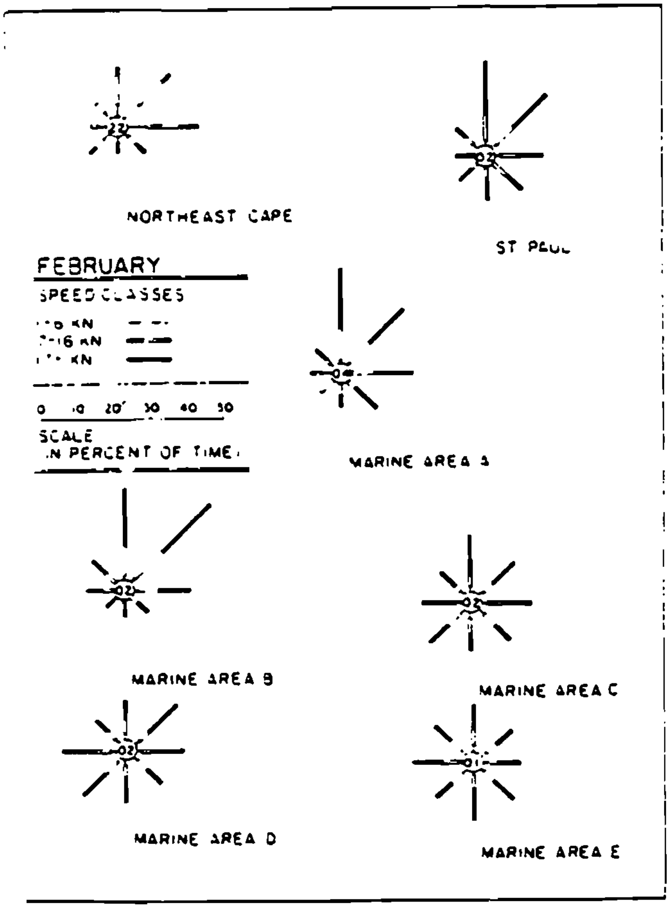


Mean Sea Level Pressure (Millibars), Summer

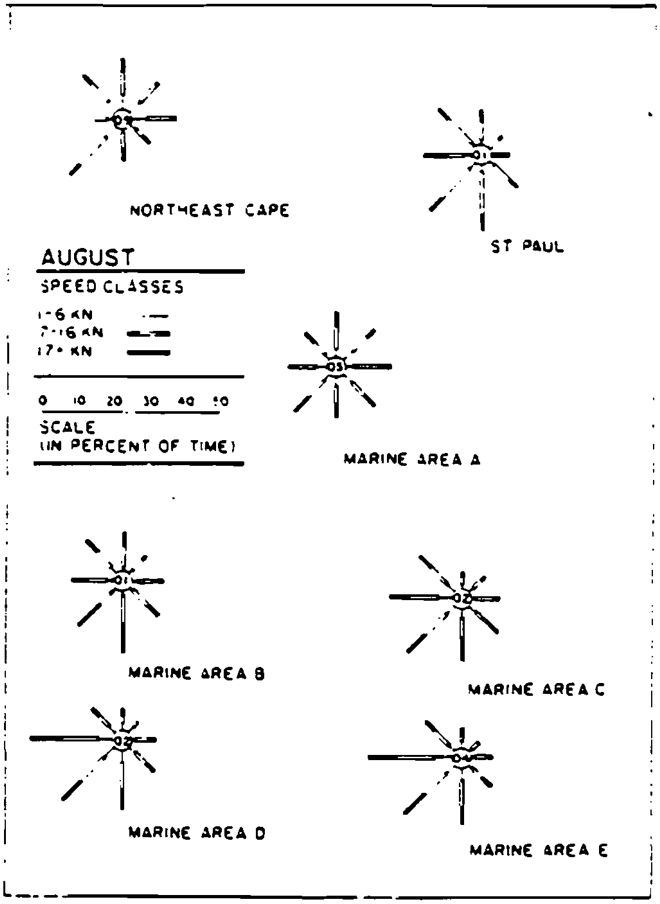
Figure 2-4. Mean atmospheric pressure distributions over the North Pacific for winter and summer (after Dodimead, Favorite, and Hirano, 1963).



Location map for the eastern Bering Sea.



February wind roses.
(Direction from which
the wind is blowing.)



August wind roses.
(Direction from which
the wind is blowing.)

Figure 2-5. Surface winds in the Bering Sea (Overland, 1981).

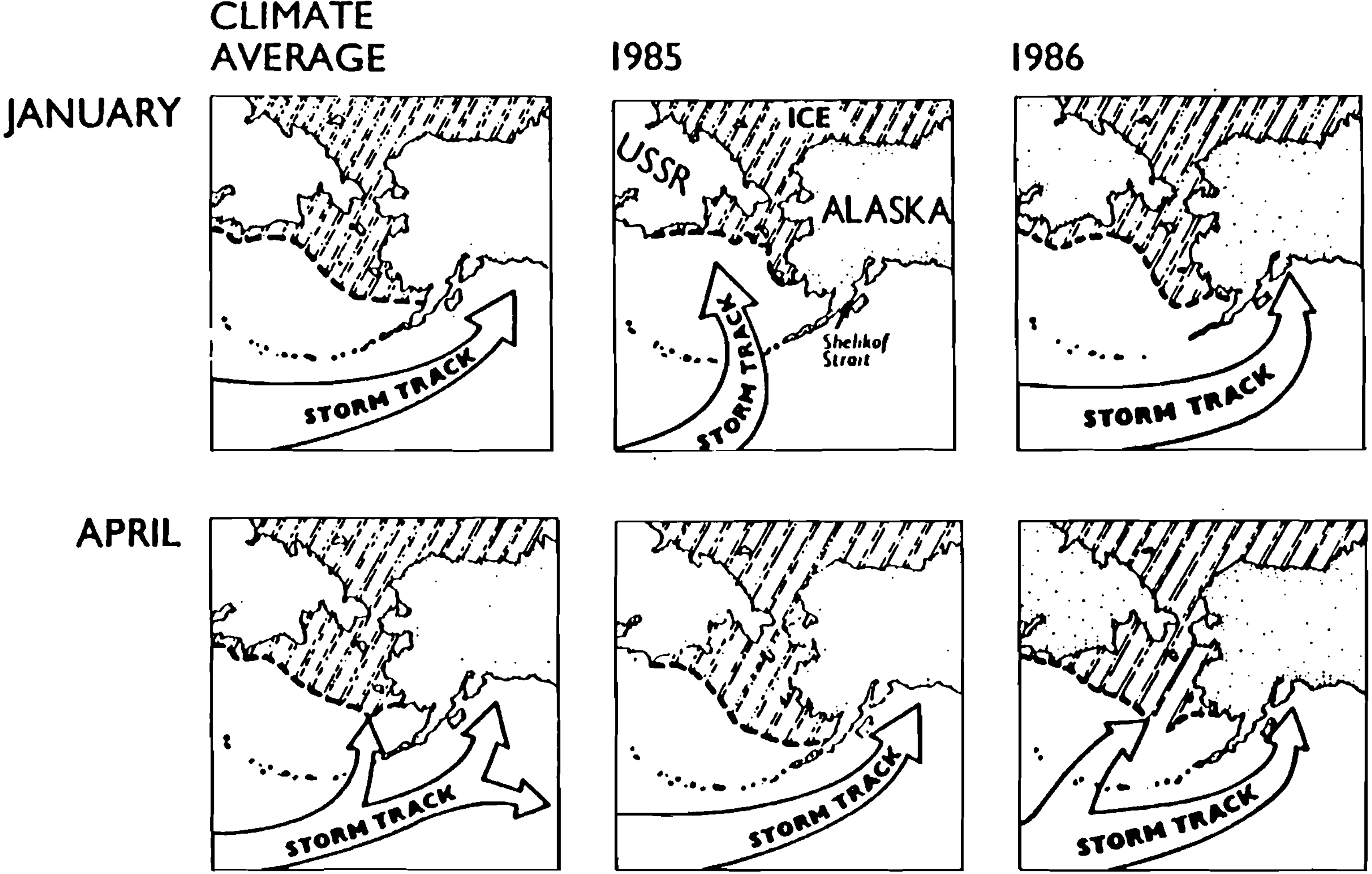


Figure 2-6. A comparison of storm tracks in the Gulf of Alaska in 1985 and 1986 with the climate average (U.S. Dept. of Commerce).

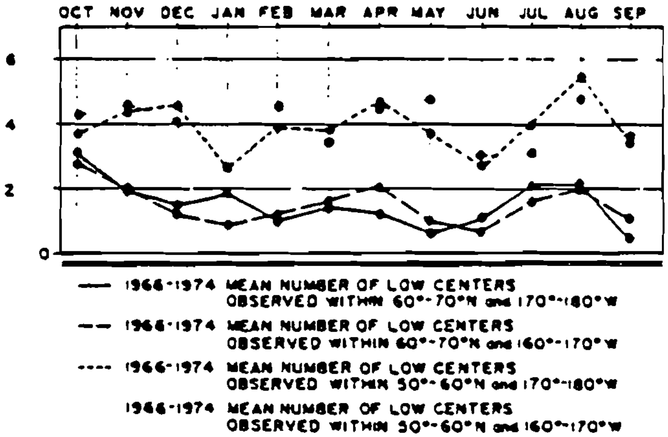


Figure 2-6. (Continued) Frequency of low-pressure systems by month for the northern and southern Bering Sea (Overland, 1981).

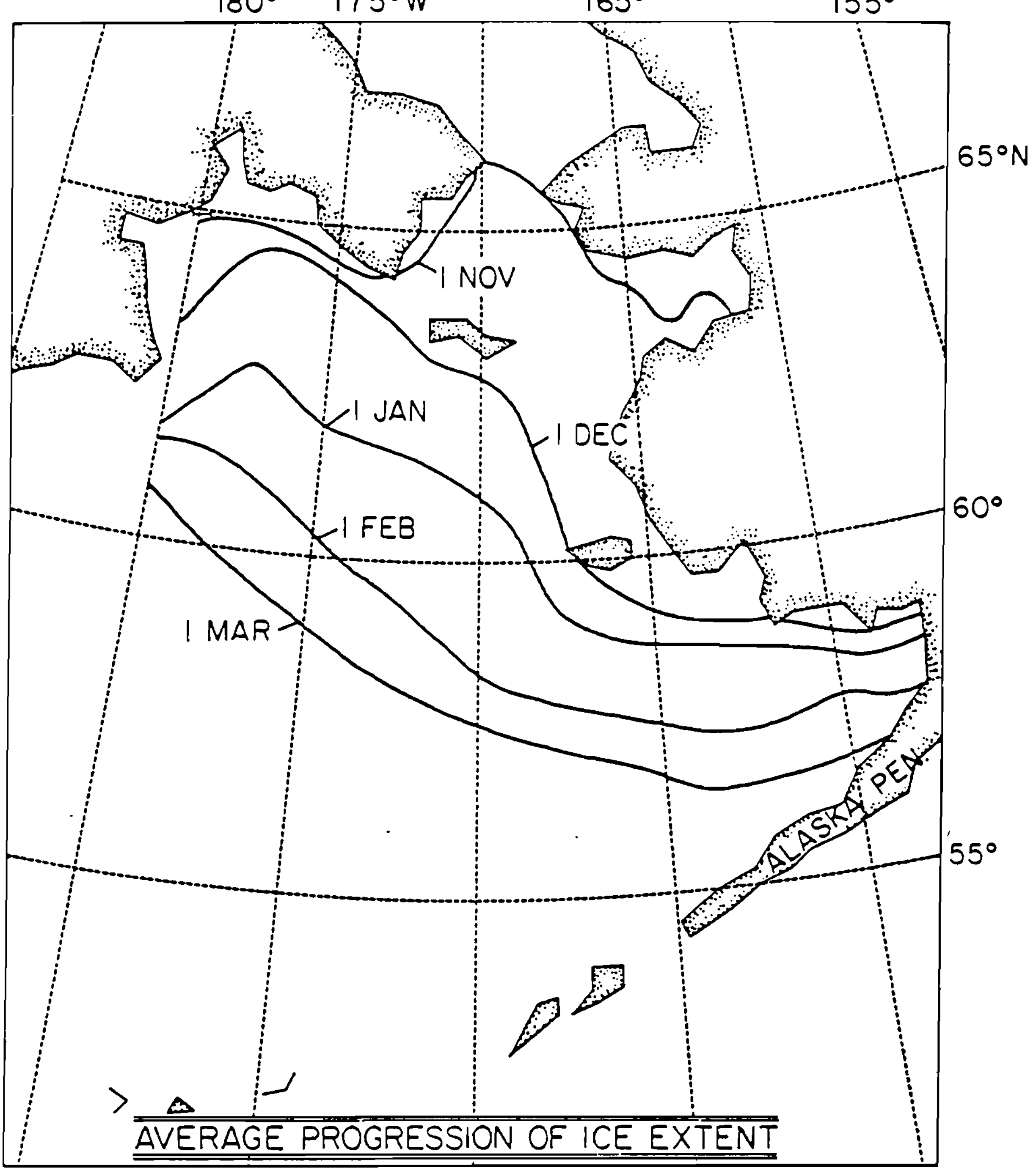


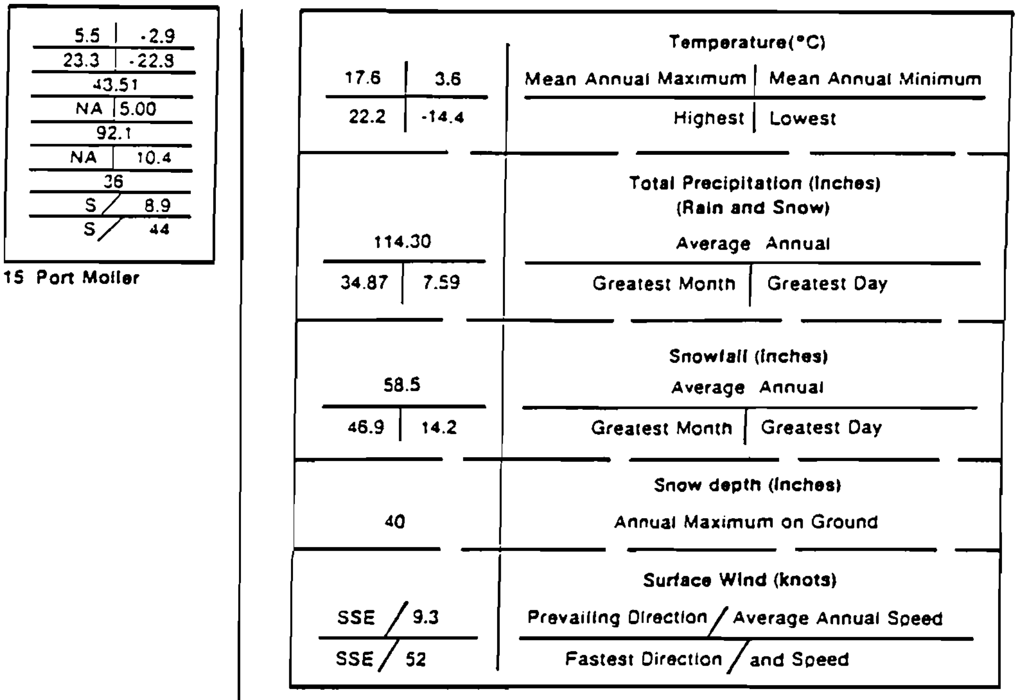
Figure 2-7. Average progression (50% probability) of ice extent during the growth season, based on 1972-1979 ice extents (from Pease et al., 1982).

(Figure 2-8). The southern Bering Sea is dominated by this air mass year round, with total yearly precipitation decreasing from west to east (toward the mainland) along the Aleutian Chain.

2.3 PHYSICAL OCEANOGRAPHY, CIRCULATION, HYDROGRAPHY, AND TIDES OF THE SOUTHEASTERN BERING SEA

The circulation of the North Aleutian Shelf and the Port Moller region is forced by winds, freshwater input, tides, and seasonal sea ice. Each of these forcing functions has a profound effect on the flow of the water. Research on the hydrography and circulation in the southeast Bering Sea was reviewed and summarized by Kinder and Schumacher (1981a, b), Schumacher and Kinder (1983), and Coachman (1986).

The hydrographic structure in the southeast Bering Sea has been described has having three major domains: offshore, middle and coastal, separated by fronts (Figures 2-9 and 2-10; Tables 2-1 and 2-2). The coastal domain and the coastal front correspond approximately with the area between the coast and the 50-m depth contour. In this domain, tidal mixing and wind mixing produce intense stirring, which usually results in vertically homogeneous water properties and horizontal gradients (Coachman and Charnell, 1977). Because the middle domain has low advection, it is a source of cold, higher salinity water at the bottom in the summer. This water remains beneath the comparatively warm fresh surface water in a nearly two-layer structure. In the outer part of the middle domain, frequent observations of fine structure in temperature and salinity have been made (Coachman and Charnell, 1977). A coastal water mass is evident, particularly in the summer. It is warmer and fresher than the water in the middle domain, which is strongly stratified. Upwelling favorable winds can bring cold water to the surface at the inner front (Schumacher and Kinder, 1983). When sufficient fresh water enters the coastal domain, vertical stratification results, which supports a baroclinic coastal current flowing alongshore. The rate of advection in the coastal domain is considered to be low, with long-term mean velocities of 3 to 5 cm/s (Schumacher and Kinder, 1983). This allows local heating and freshwater runoff from the coast to produce a large annual variation in the water temperature and salinity near the coast (Schumacher et al., 1979).



Where the mean annual temperature (average of the mean annual maximum and minimum) is less than zero some type of permafrost will probably be present.

These data can be used for long-range planning and design criteria. More detailed information can be obtained from the National Climatic Data Center and the Arctic Environmental Information and Data Center in Anchorage.

NA = Information is not available

Prepared from NOAA/NESDIS and Canadian AES data.

Figure 2-8. Climatic parameters (Brower et al., 1988).

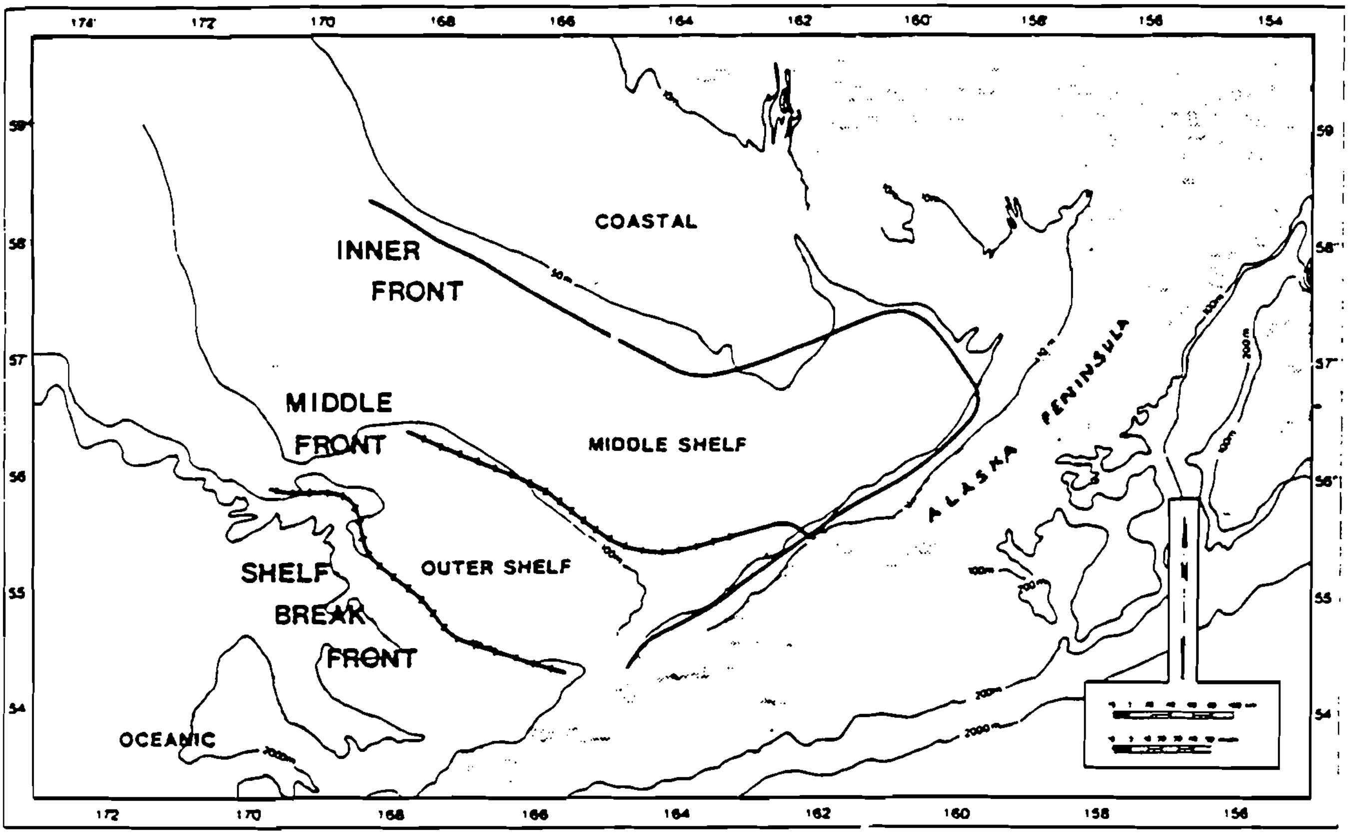
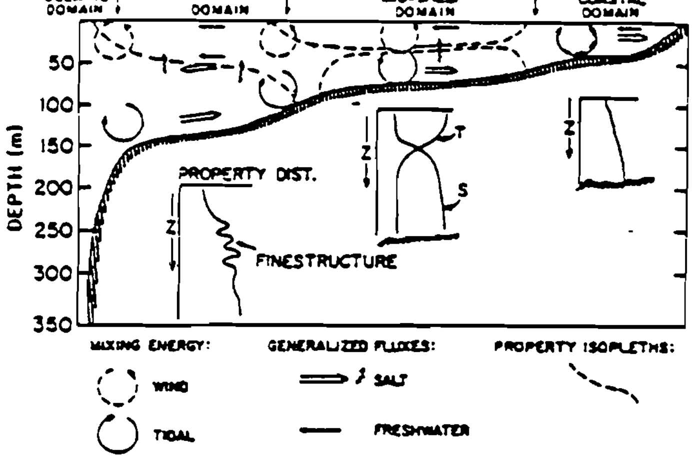


Figure 2-9. Approximate boundaries separating the three shelf (coastal, middle, outer) and the oceanic hydrographic domains. The boundaries are three fronts: inner, middle, and shelf break. These fronts roughly coincide with the 50-m isobath, the 100-m isobath, and the 200-m isobath (shelf break) (Kinder and Schumacher, 1981).



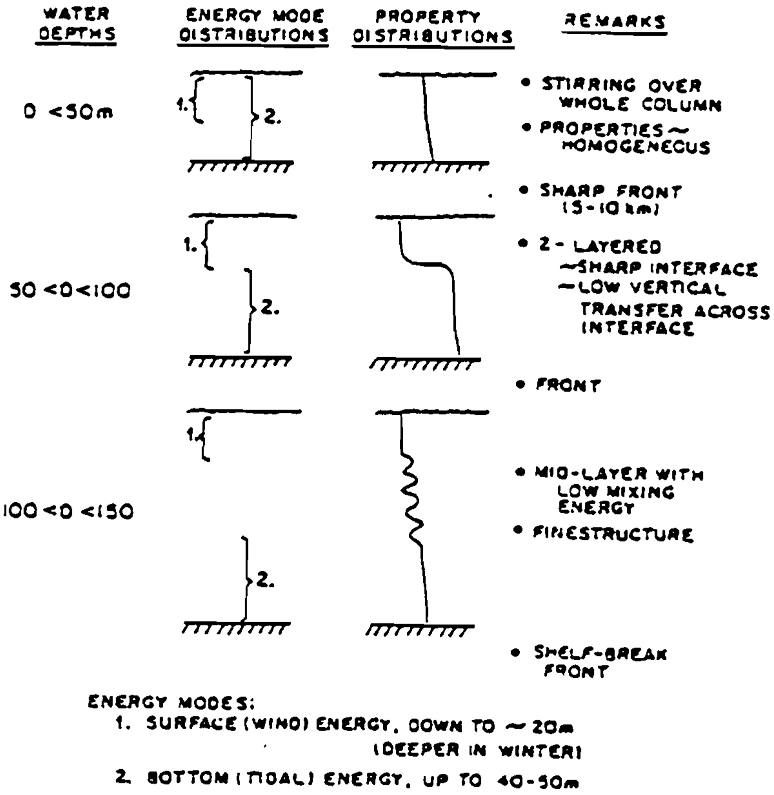


Figure 2-10. Schematic diagram of energy mode distributions by depth ranges and accompanying water column structure. The inner front, being closely associated with the 50-m depth contour, does not appear in the area of deeper, outer Bristol Bay (Coachman and Charnell, 1977).

	Outer (100m-shelfbreak)	Middle (50-100m)	Coastal (Coast-50m)
1. Mean	1-10 cm/sec along isobaths, counterclockwise (due both to baroclinicity and tide-bathymetry interactions. 1-5 cm/sec across isobaths, shoreward (due primarily to oceanic forcing)	Not statistically significant except along middle and outer fronts	1-6 cm/sec, counterclockwise (due both to baroclinicity and tide-bathymetry interaction
2. Fluctuating horizontal kinetic energy	81% tidal-remainder equally due to meteorological and oceanic forcing	92% tidal-remainder primarily meteorological in form of rotating current	94% tidal-remainder primarily meteorological in form of Ekman divergence and associated longshore geostrophic current pulses

	Outer	Central	Coastal
I. General characterization	Advective–diffusive; with lateral water mass interaction	Diffusive	Advective–diffusive
II. Energy			
A. Kinetic	Tidal ~85% Low. freq. ~10%	Tidal ~95%	Tidal >90% Low freq. ~5%
B. Turbulent for mixing	upper layer, wind mid-layer, none lower layer, tidal	upper layer, wind lower layer, tidal	wind and tidal
III. Property fluxes			
A. Vertical	Enhanced by finestructure ($K_v \sim 5$ cm^2 s^{-1})	Summer: suppressed by pycnocline ($K_V \sim 0.1$ cm^2 s^{-1}) Winter: some vertical convection	Greatly enhanced (large K_V)
B Horizontal			
1. Along-shelf			
surface layers	Wind, advection	Wind	Wind, advection
lower layers	Advection	Diffusion ($K_H \sim 10^6$ cm^2 s^{-1})	
2. Cross-shelf			
surface layer	Wind	Wind	Wind; diffusion ($K_H \sim 0.5 \times 10^6$ cm^2 s^{-1})
mid-layer	Off-shelf with finestructure		
lower layer	Diffusion (on-shelf) ($K_H \sim 10 \times 10^6$ cm^2 s^{-1})	Diffusion ($K_H > 10^6$ cm^2 s^{-1})	
IV. Hydrographic regime			
A. Freshwater	Melting of ice (precipitation)	Melting of ice (precipitation)	Runoff (precipitation)
B. Salt resupply			
upper layer	Up diffusion	Up diffusion	Freezing of ice: advection from near Unimak Pass
lower layers	Shelf basin mixtures: basin water at shelf break	Lateral diffusion across fronts: freezing in polynyas (northern area)	
C. Heating			
upper	Surface exchange	Surface exchange	Surface exchange: vertical mixing
lower	Shelf-basin mixtures: basin water at shelf break	Vertical exchange (very slow)	
D. Cooling	Surface exchange	Surface exchange: ice melting	Surface exchange: ice formation

much as 11°C in late summer. The salinity can vary from as low as $31.2^{0}/_{00}$ in late summer to as much as $32.0^{0}/_{00}$ near the coastal front in winter (Kinder and Schumacher, 1981a).

The circulation is controlled by the frontal-domain structure. The middle domain has very small alongshore currents, with essentially zero net transport. The offshore and coastal domains have modest mean speeds of 1 to 10 cm/s, and relatively large (10-20 cm/s) tidal currents. A coastal current is observed from Unimak Pass, where water enters the Bering Sea from the Gulf of Alaska, northeastward along the Alaska Peninsula toward Bristol Bay (Schumacher and Kinder, 1983). The flow within the 50-m depth contour has an alongshore component of 2 to 5 cm/s (Figure 2-11). Near Port Moller, Schumacher and Kinder (1983) observed reverse flow adjacent to the coast, which had a significant cross-isobath onshore component (Figure 2-12).

Wind forcing, particularly associated with storm events, contributes significantly to the variance of the currents (Schumacher and Moen, 1983; Schumacher and Kinder, 1983). The spectrum estimates have shown significant low frequency and meteorological frequency energy, particularly on the North Aleutian Shelf (Schumacher and Kinder, 1983; their Table 2, moorings TP-2, TP-5 and TP-8). The wind mixing energy adds to the tidal mixing to reduce the stratification. The wind forcing also produces Ekman fluxes, if the wind is upwelling favorable, resulting in colder, more saline middle shelf water being transported into the coastal domain (Schumacher and Moen, 1983).

The tides in the southeast Bering Sea are a dominant part of the oceanography of the region. The tides propagate onto the southeast Bering Sea shelf from the deep basin of the Bering Sea (Pearson et al., 1981). In the vicinity of the Alaska Peninsula, the semidiurnal tide is primarily progressive, with the current nearly in phase with the tidal level, particularly near Port Moller (Pearson et al., 1981). The progressive wave advances as a Kelvin wave along the Alaska Peninsula from the vicinity of Unimak Pass towards Bristol Bay (Figure 2-13). The basin geography of Bristol Bay results in amplitude amplification in the embayments at the head of the bay of 5 to 7 m (NOAA Tide Tables). The mooring station near Port Moller had the largest M_2 tidal currents (35 cm/s) and had nearly rectilinear motion (Pearson et al., 1981). Combined tidal currents within Port Moller may reach

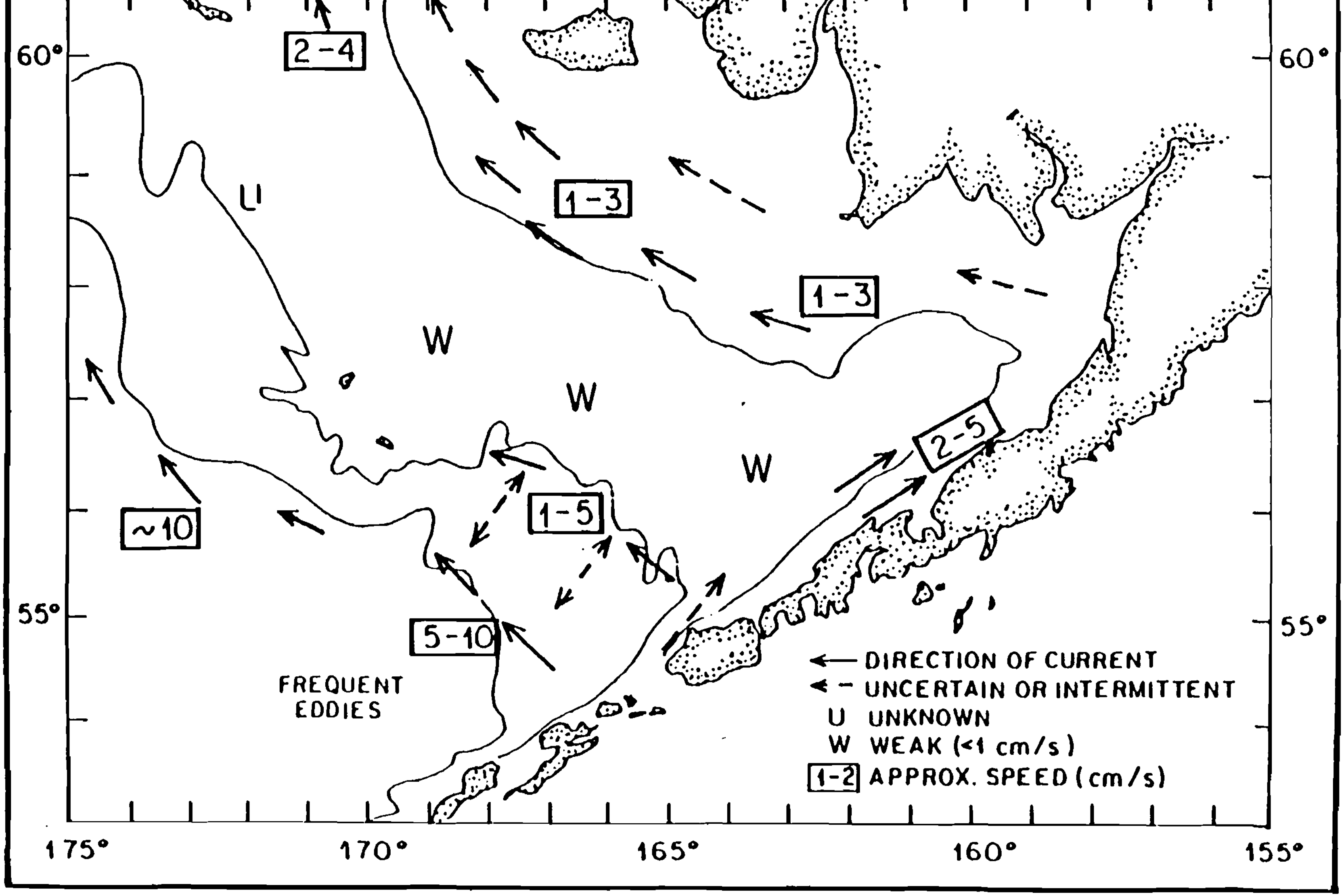


Figure 2-11. Estimated longer-term (mean) circulation (Coachman, 1986).

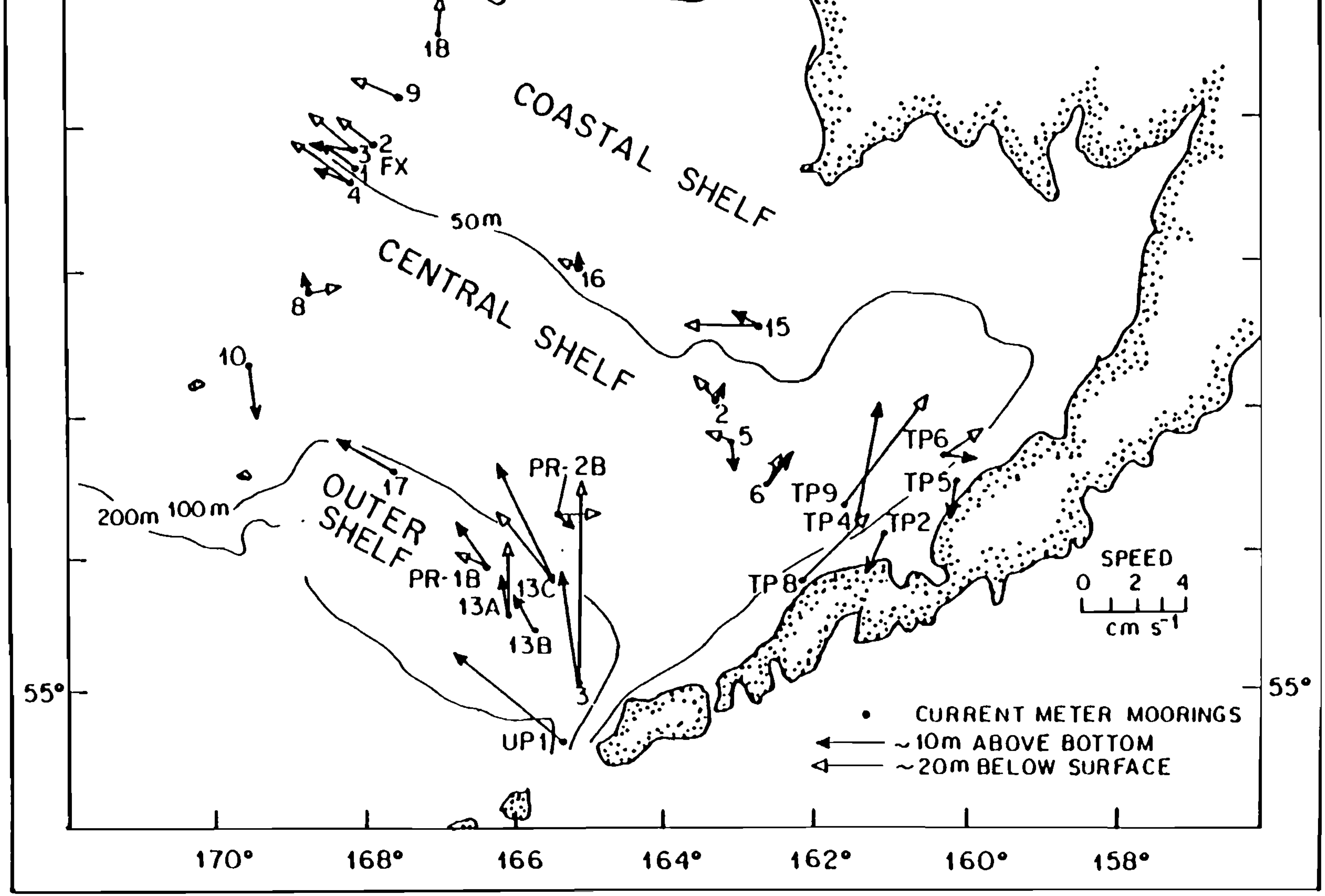


Figure 2-12. Vector mean flows from long-term current data (Schumacher and Kinder, 1983).

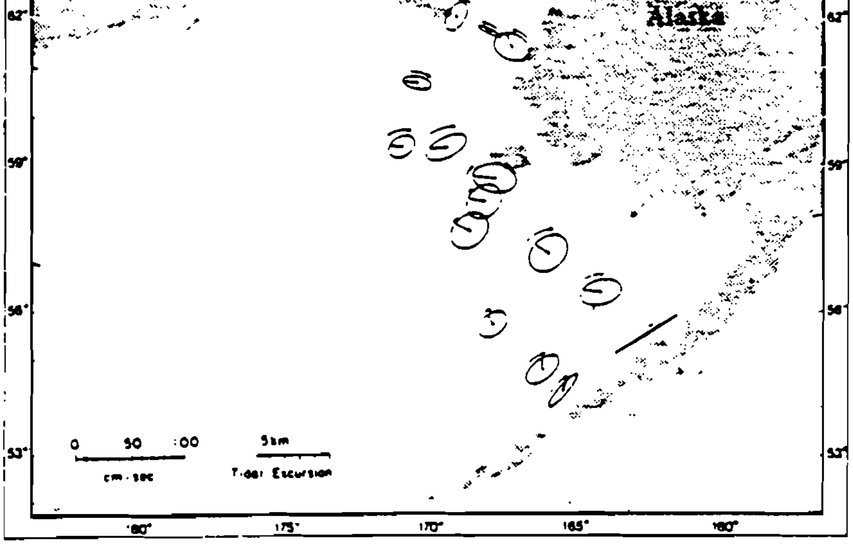


Figure 2-13a. M_2 current ellipses. For stations with records from two depths, the ellipse for the deeper meter is plotted. Ellipses are centered on station location; line from center indicates constituent current vector when the M_2 Greenwich equilibrium phase angle is 0°. Arrows indicate sense of rotation (Pearson, Mofjeld, and Tripp, 1981).

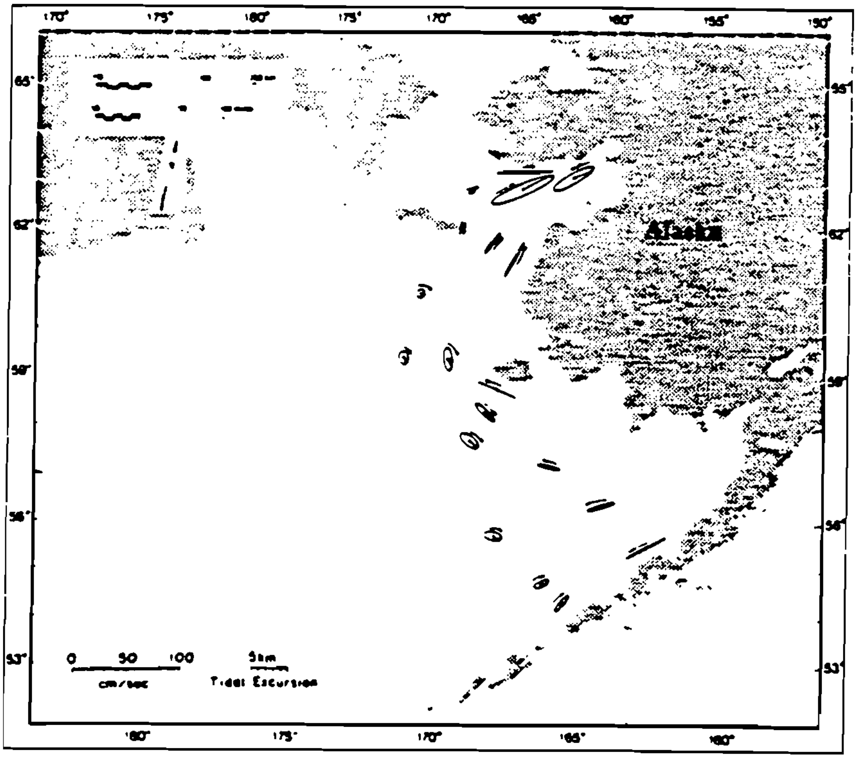


Figure 2-13b. Same as 2-13a, but for K_1 (Pearson, Mofjeld, and Tripp, 1981).

The M_2 tidal amplitude at Port Moller is approximately 1 m. The maximum tidal range is estimated to be about 3 m. These large tides are a major source of mixing energy, both horizontal and vertical. Schumacher and Kinder (1983) calculated the Stokes nonlinear residual for the Alaska Peninsula, and estimated that it could be as large as 5 cm/s, hence equal in magnitude to the mean velocity. Particularly since the vector mean currents are small, the importance of the tidal motions cannot be overstated.

The nearshore ice conditions of Bristol Bay and the North Aleutian Shelf have been described by Stringer (1981). The Port Moller area is generally south of the seasonal sea ice edge, but storms occasionally force pack ice onto the shelf in the area, particularly in heavy ice years (Stringer, 1981). Shorefast ice is also found in parts of the area (Stringer, 1981). The melting of this ice in the spring supplements the freshwater runoff, and provides stratification due to the low salinity water at the surface, which is reinforced by the solar heating. This stratification is important to the spring phytoplankton production, since it increases the effective light level (Sambrotto, 1983).

2.4 GENERAL CHARACTERISTICS OF PORT MOLLER

The principal embayment along the North Aleutian Shelf is the Port Moller/Herendeen Bay complex located 324 km northeast of Unimak Pass. The estuary has two branches, each about 38 km long, characterized by primarily shallow water (less than 6 m) cut by a deep (average 20-30 m) narrow channel leading to their respective heads (see Figure 2-2). These channels are presumed to be maintained by strong tidal currents. The western arm, Herendeen Bay, is the deeper of the two branches, with depths of about 100-m in a smaller inner basin near the head. The eastern branch, as well as Mud Bay and Nelson Lagoon, are predominantly tidal flats. The sediments in the channel of each arm and the mouth of the estuary are predominantly gravel and sand (Sharma, 1974), scoured by the strong tidal currents. The channels and the extensive shoals just inside the bay entrance are subject to frequent change. The effect of strong tidal currents can also be seen by the high concentration of suspended sediment and the large plume emanating from the

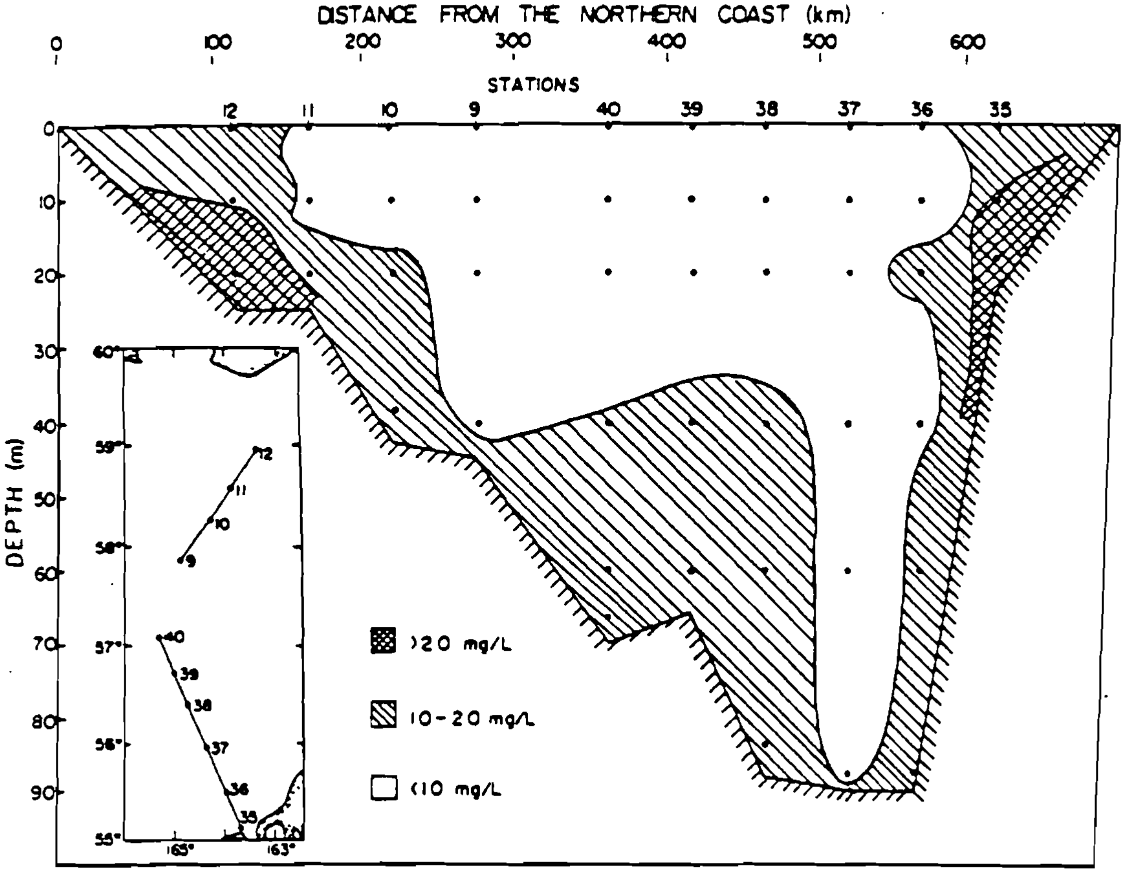


Figure 2-14. Vertical cross section of the distribution of total suspended matter for stations 9 through 12 and 35 through 40 (Cape Newenham to Port Moller) in the southeastern Bering Shelf (Cruise RP-4-MW-76B-VII, 24 June-9 July 1976) (Fealy et al., 1981).

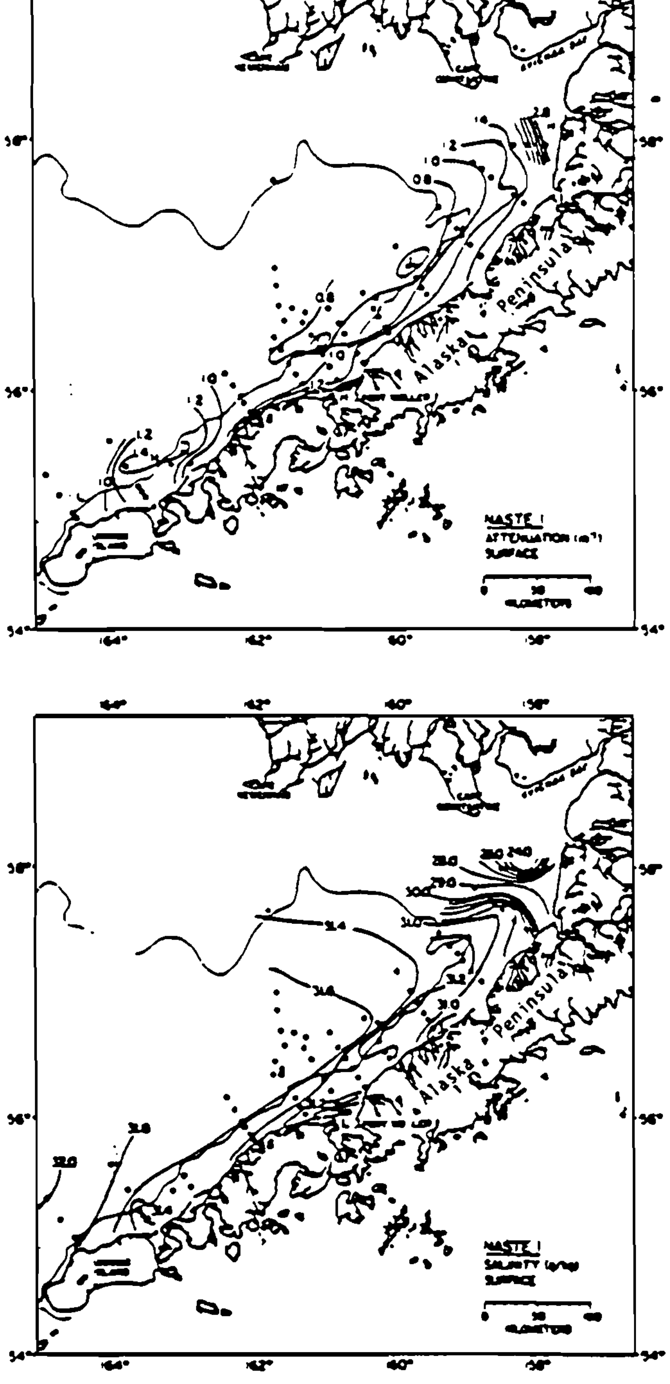


Figure 2-15. Areal maps of light attenuation (top) and salinity (bottom) at the surface during August 1980. Contour interval is 0.2 m^{-1} for attenuation and 0.2$^{o}/_{oo}$ for salinity (Baker, 1983).

Aleutian Shelf towards Port Heiden (Feely et al., 1981; Baker, 1981).

Tidal currents at Port Moller are 1.5 to 2 knots with a diurnal tidal range of about 3 m. Between Point Divide on the mainland and Doe Point on Deer Island, where the channel contracts to 640 m, tidal currents can reach up to 4 knots during spring flood (U.S. Dept. of Commerce).

The average annual wind speed and direction at Port Moller is out of the south at 8.9 knots with air temperatures ranging from 23.3 to -22.8°C (see Figure 2-8). Ice forms in the bay during winter. The area is surrounded by mountains and receives 110 cm of rain annually. Most of the runoff from the surrounding mountainous area collects into the estuary via overland and aquifer flow. Although it is not one of the primary freshwater inputs to Bristol Bay, the Port Moller outflow does result in a substantial freshwater signal out onto the shelf.

Accompanying this freshwater outflux is a maximum in methane concentration (Figures 2-16 and 2-17). The source of this is believed to be from runoff through methane-charged peat on land, since the highest concentrations are found in the surface waters of Herendeen Bay. It was originally thought that the biologically productive deep basin at the head of Herendeen Bay might be anoxic and therefore represent the major source of methane. However, direct measurements show the basin to be oxygenated throughout, even though the bottom is covered with organic-rich sediments (J. Cline, personal communication).

2.5 CIRCULATION AND MIXING IN PORT MOLLER

The physical processes dominant in Port Moller and Herendeen Bay are directly related to those on the adjacent continental shelf. Tidal currents are one of the dominant forcing mechanisms in the estuary. Winds associated with storms can produce storm surges and subtidal current variability. The wind forcing also produces secondary circulations (Ekman fluxes), which are important because they can bring deeper water masses onto the shelf during upwelling, and strengthen the coastal current during downwelling. The freshwater input to the Herendeen Bay fjord is confined primarily to the upper layer, and acts to isolate the deeper water from surface layer processes (heating and cooling) during the summer months. The interior deep basin water

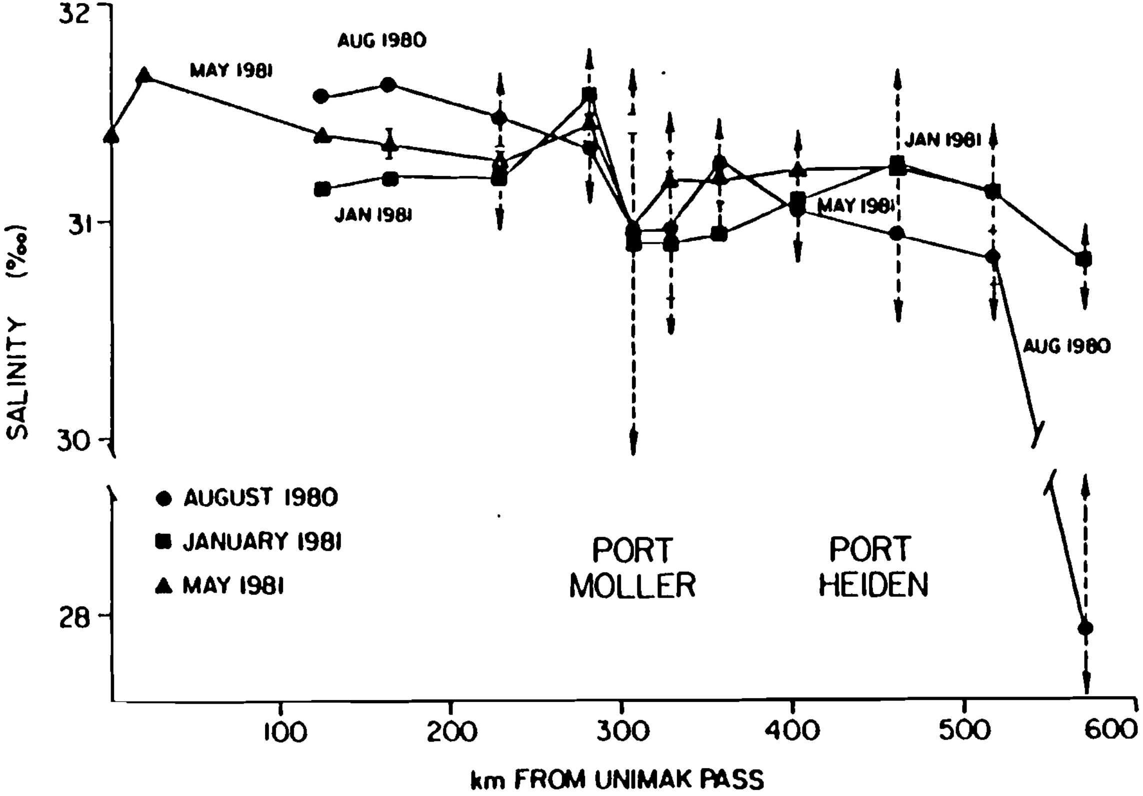


Figure 2-16. The average longitudinal distribution of salinity along the NAS coastal zone. Only staions at which the depth of water was less than 40 m were included in the analysis. The dashed arrows indicate the range of values about the mean. Note the large variations at the entrance to Port Moller (Cline et al., 1982).

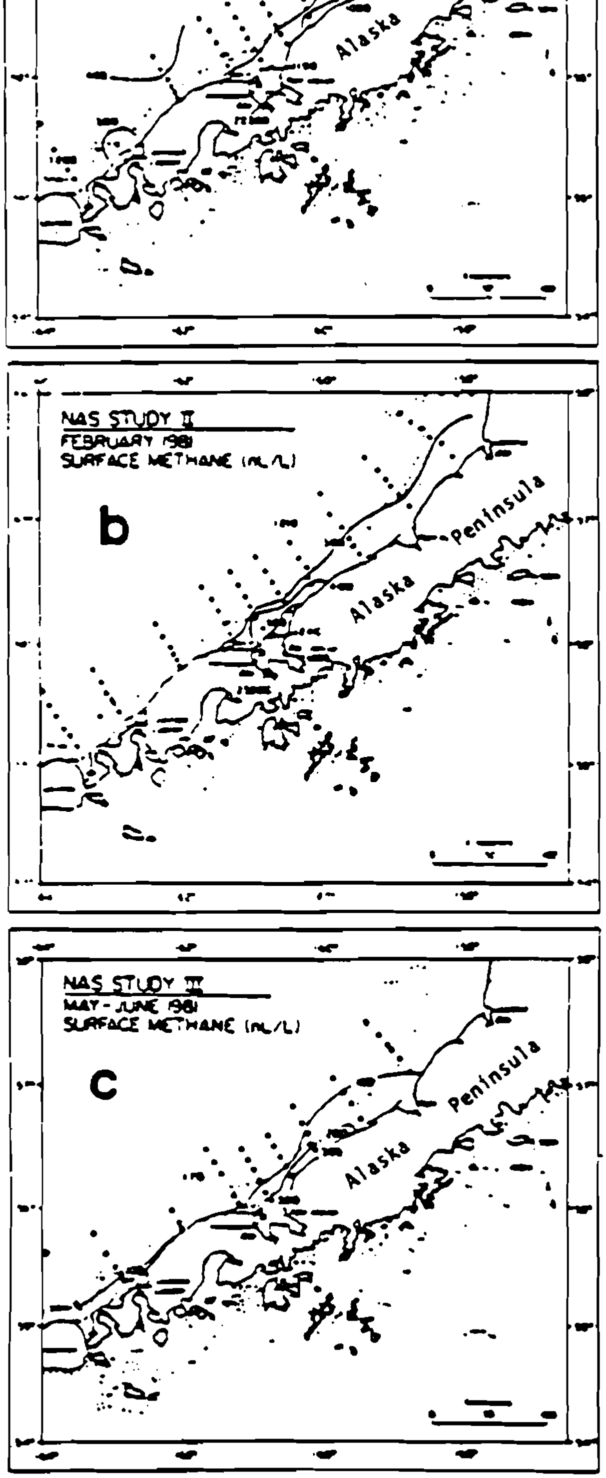


Figure 2-17. The distribution of methane at the surface along the NAS in (a) August 1980; (b) February 1981; and (c) May 1981. Concentrations are in nl/l (STP) (Cline et al., 1982).

then are modified by vertical diffusion produced by tidal mixing energy during the rest of the year. If this is the case, then the water should be relatively uniform with depth below the surface low-salinity layer. Although historical data within the Bay are sparse, the available information appears to confirm this. Table 2-3 shows an example of what the stratification was in this deep basin during May 1981 (Katz et al., 1982). There was a strong density gradient in the upper 30 m of the water column. This is attributed to extensive freshwater influx, since density at these low temperatures is primarily controlled by salinity. As the summer progresses, the stratification near the surface increases and that at depth decreases. The primary renewal of the deep water probably occurs in the winter by convective overturning.

2.6 RELATIONSHIP TO FISHERIES STUDIES

The presence of the large commercial fish, shellfish, bird, and marine mammal populations in the region of the North Aleutian Shelf (NAS) has been attributed to the abundance of food and suitable habitats. Although the bays and estuaries along the shelf may provide less than 15% of the total organic carbon budget of the entire NAS system, they function as nursery grounds to the larvae of several species of commercially important fish and shellfish (Pace, 1986). As such, both Pacific herring (*Clupea harengus pallasi*) and the blue king crab (*Paralithodes platypus*) spawn in the Port Moller/Nelson Lagoon complex, and are dependent on its habitats for successful stock recruitment (Figures 2-18 and 2-19; Barton et al., 1977; L. Inczes, personal communication).

Preliminary results from the 1990 Port Moller King Crab Study (S. Dinnel, personal communication) indicates this is an active spawning ground for both red and blue king crab. Fluctuations in the recruitment of herring stock are generally a consequence of egg and larval mortality (Lasker, 1985). Both food quality and quantity are determinants of growth and survival. In part, larval growth and survival may be dependent upon water column stratification, which is essential to the formation of dense patches of prey (Lasker, 1975; 1978). Other factors such as food quality and absence of

CRUISE NUMBER	LOCATION	INCLUSIVE DATES
RP-4-DI-81A-II	SOUTHEAST BERING SEA	11 MAY-04 JUN 1981

STATION	LATITUDE	LONGITUDE	DATE	TIME	GMT	BOTTOM DEPTH
PM-A	55 44.0N	160 41.5W	27 MAY	1810	+ 9	75

DEPTH	TEMPERATURE	SALINITY	SIGMA-T	METHANE	SOLUBILITY	C/C*
1	8.81	29.16	22.60	1866.0	63.54	29.36
20	6.94	30.31	23.76	87.7	66.03	1.32
30	5.04	30.62	24.22	97.8	69.18	1.41
40	3.83	30.72	24.42	85.7	71.39	1.20
50	1.44	30.86	24.72	91.5	76.15	1.20
70	1.08	30.93	24.79	316.0	76.89	4.10

STATION	LATITUDE	LONGITUDE	DATE	TIME	GMT	BOTTOM DEPTH
PM-B	55 46.8N	160 47.0W	27 MAY	1155	+ 9	30

DEPTH	TEMPERATURE	SALINITY	SIGMA-T	METHANE	SOLUBILITY	C/C*
1	8.18	29.72	23.13	6366.0	64.28	99.02
20	6.20	30.45	23.96	594.0	67.22	8.83

STATION	LATITUDE	LONGITUDE	DATE	TIME	GMT	BOTTOM DEPTH
PM-C	55 50.7N	160 47.4W	27 MAY	1755	+ 9	26

DEPTH	TEMPERATURE	SALINITY	SIGMA-T	METHANE	SOLUBILITY	C/C*
1	8.61	30.04	23.32	3731.0	63.47	58.77
10	8.24	30.08	23.40	3234.0	64.03	50.50

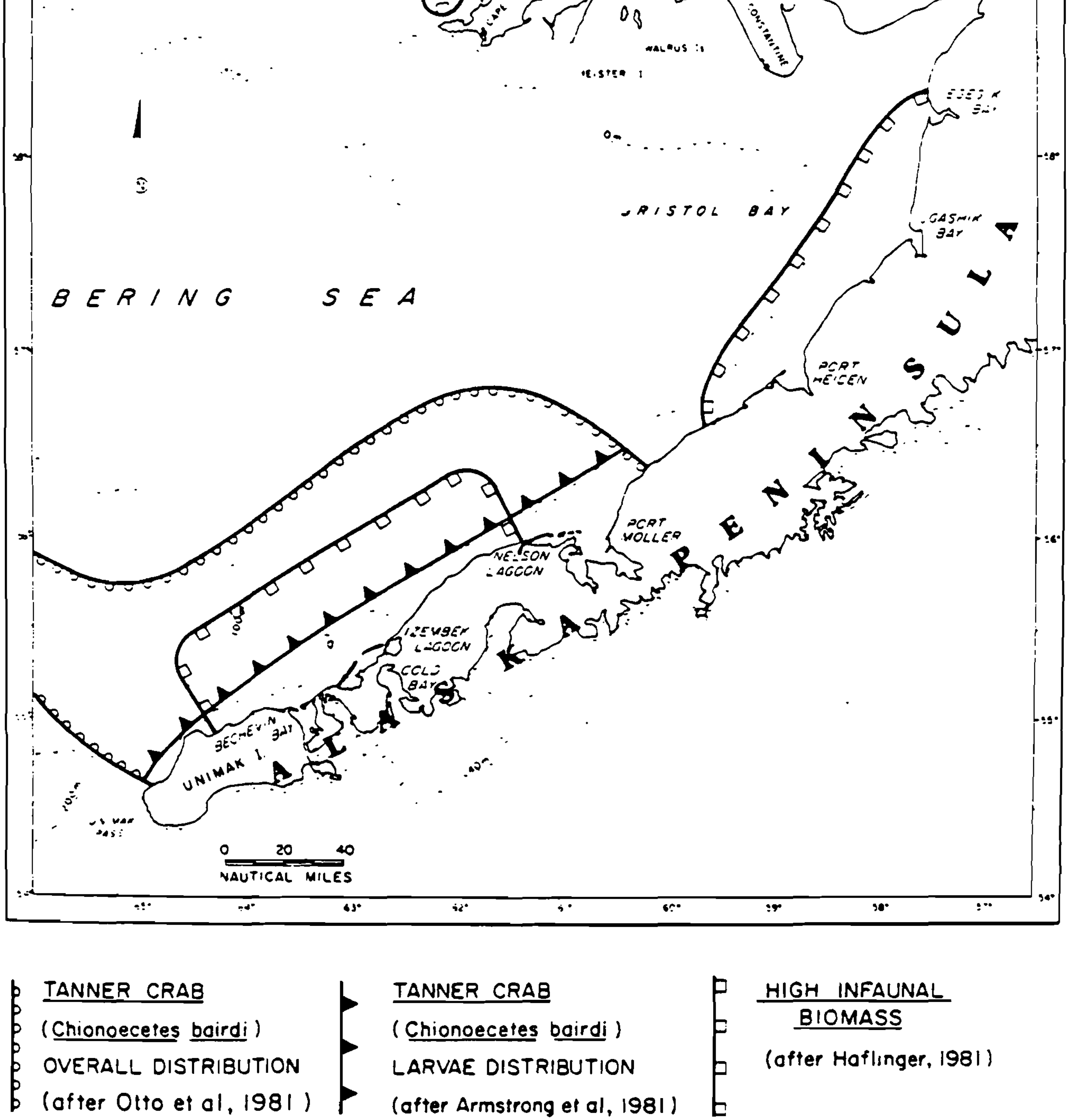


Figure 2-18. Distribution of Tanner crab and areas of high infaunal biomass in Bristol Bay (Pace, 1986).

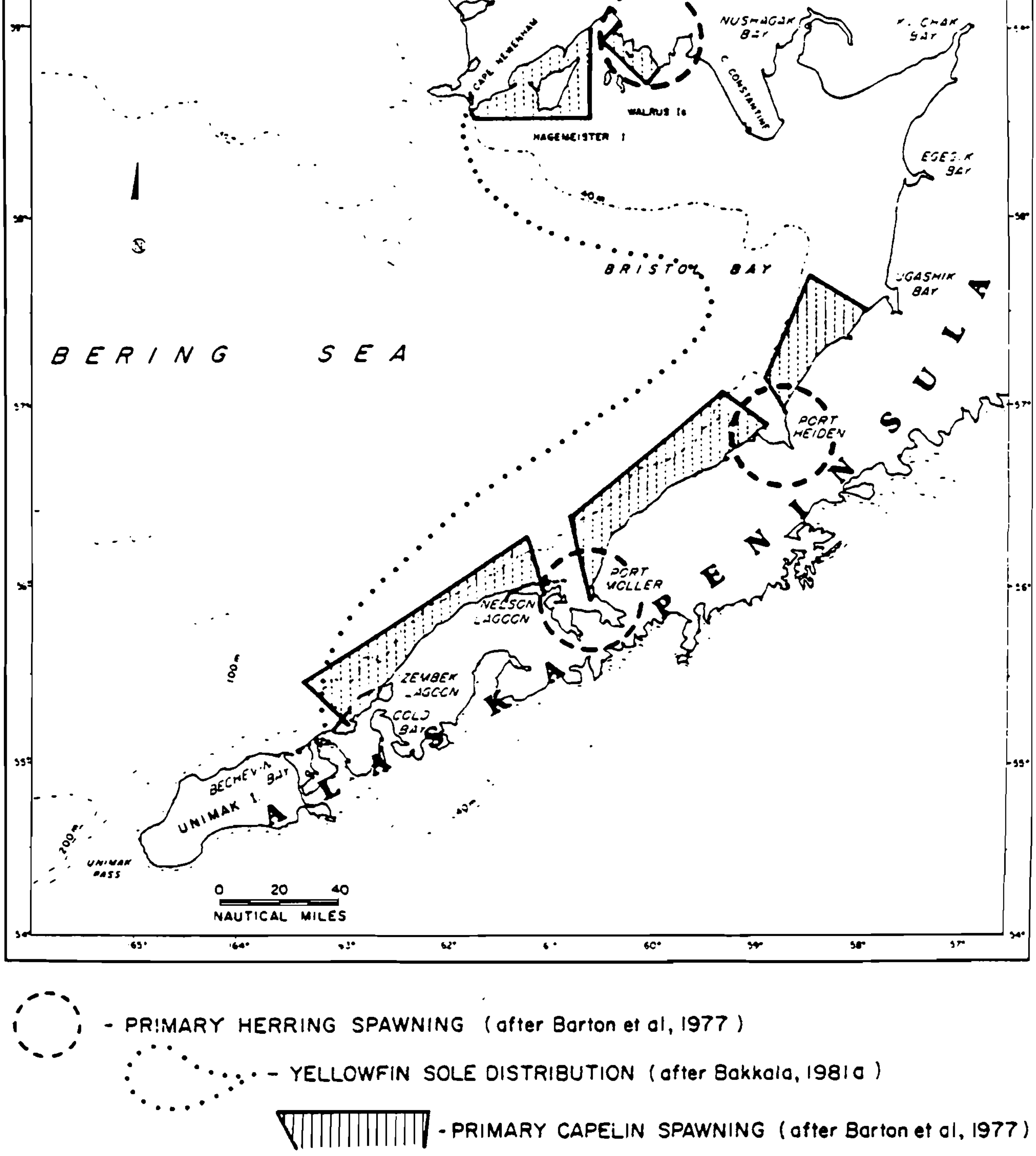


Figure 2-19. Distribution of important inshore fishes in Bristol Bay (Pace, 1986).

recruitment, NOAA/OCSEAP has funded a study, RU #695, to compare herring abundance, growth, and fitness with the abundance and availability of food in Auke Bay, Alaska.

Previous studies in Auke Bay have indicated that the success of fish stock recruitment depended on mild weather, an abundance of plankton, and a lack of severe storms. In the APPRISE program, light penetration was the limiting factor which regulated the rate of nitrate uptake, and thus phytoplankton productivity, during the spring bloom (Ziemann et al., 1988). Episodes of high light and stratified water column conditions presented the plankton populations with the optimum conditions for growth. However, when high winds caused mixing in the water column, and cloudy weather attenuated ambient light conditions, solar irradiance was decreased at depth and rates of plankton productivity fell. The adverse affects on the phytoplankton populations, in turn, decreased the availability of the zooplankton species to larval fish (Coyle and Paul, 1988). Thus, the climatic conditions, water column stratification, and mixing processes were among the major determinants to the stock recruitment.

Other studies in the APPRISE program indicated that the timing of the spring bloom and the species composition of the phytoplankton were critical to the growth and survival of the larval stages of the red king crab (*Paralithodes camschatica*). If a mismatch occurred between the hatching of the larvae and the availability of food, the year-class contribution to recruitment was threatened (Shirley and Shirley, 1988). In Auke Bay, where phytoplankton productivity was controlled by light, temperature shifts may have caused temporal asynchrony in both hatching of larval crabs and food availability. Species composition of phytoplankton was also critical, since early larval stages were unable to molt when fed monocultures of centric diatoms, but had the best growth rates when allowed to feed on water from the chlorophyll maximum depth in Auke Bay (Paul and Coyle, 1988). Thus, successful recruitment for red king crab was dependent on timing of the hatch and food availability.

at the head of Herendeen Bay (L. Incze, personal communication). It was doubtful that the population of red king crab utilized this habitat, since its largest spawning and larval settlement area lies along the shelf adjacent to the embayment (Haynes, 1974; Armstrong et al., 1981; Fukuhara, 1985). However, based on preliminary results from the 1990 Port Moller King Crab study, there is evidence that both red and blue king crab use Herendeen Bay as a spawning ground (S. Dinnel, personal communication).

The Port Moller/Herendeen Bay field program consisted of two meteorological stations and five moorings (eight current meters and two tide gauges) deployed from late May to early October 1989. Hydrographic cross- and along-channel sections of temperature, salinity, and velocity were also obtained during the deployment and recovery cruises. The final recovery occurred in October, after an initial attempt in September was aborted due to a series of vessel-related mechanical failures. A detailed sequence of events for each excursion is presented in Appendix A. The primary method of navigation used for all data collection related activities was Loran-C.

3.1 METEOROLOGICAL STATIONS AND MOORINGS

The Aanderaa meteorological stations were located at the tip of Harbor Point sand spit, marking the entrance to the eastern arm, and at Point Divide on the south shore of the channel leading into the western arm, Herendeen Bay (Figure 3-1). Both stations were designed to record wind speed and direction, as well as air temperature every hour. The instrument at Point Divide was also equipped with an atmospheric pressure sensor and an irradiance meter.

Station 1 was placed in the main channel connecting the estuary to the North Aleutian Shelf and consisted of two EG&G Acoustic Current Meters (ACMs) at 7.5 and 15 m, and an Aanderaa Water Level Recorder (WLR) on the bottom at 20 m. Station 2, with one ACM at 7.5 m, was in the channel off Harbor Point leading into the eastern arm. Station 3 was deployed in Hague Channel at the entrance to Herendeen Bay and had an ACM at 7.5 m and an Aanderaa Current Meter (RCM) at 15 m. During the predeployment velocity survey, currents greater than 125 cm/sec, the limit for these moorings' maximum allowable tilt, were encountered in the proposed locations for stations 2 and 3. These stations were moved slightly seaward to a wider section of the channel with lower velocities, to insure instrument tilts of less than 20 degrees and data integrity.

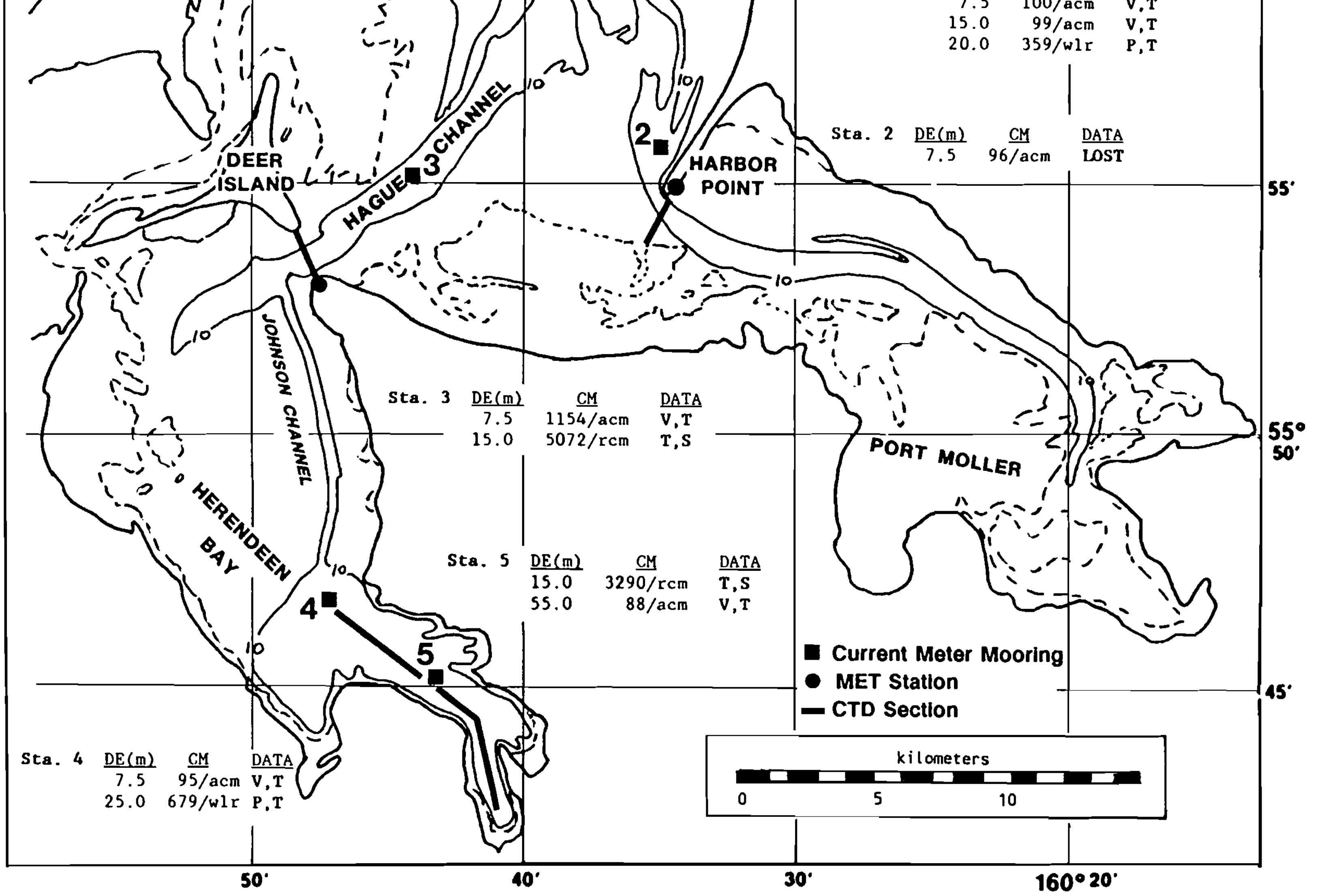


Figure 3-1. Map of Port Moller/Herendeen Bay Complex showing summer 1989 current meter, meteorological, and CTD station locations.

Station 5 was located in the deep hole (100 m) in the middle of Herendeen Bay, with one RCM at 15 m and an ACM at 55 m. These two stations were designed to monitor internal circulation and the seasonal progression of water property changes in Herendeen Bay, while stations 1, 2 and 3 were located to measure the exchange between the Port Moller/Herendeen Bay complex and the shelf. All current meters and tide gauges were equipped with temperature sensors and the two RCMs had conductivity sensors. The ACMs and Aanderaa instruments (RCMs and WLRs) recorded data every 20 and 30 minutes, respectively. The location and configuration of each instrument is shown in Figure 3-1 and listed in Table 3-1.

A number of the instruments deployed experienced technical difficulties. The meteorological station at Point Divide failed on 4 July, just 2 weeks after installation, while the Harbor Point system remained operational throughout the sampling period. Since the initial 2 weeks of data recorded by both meteorological stations is very similar (refer to Figure 4-4), the Harbor Point station is assumed to be representative of the winds in the outer harbor area for analysis purposes.

Mooring 1 was hit and moved on 13 July. The two current meters were recovered at this time by a fisherman, and the WLR, still operational, was retrieved later in the season by another fisherman. An offset of about 6 dbar was applied to the latter half of the WLR pressure record to compensate for the depth change experienced after the mooring was moved in July. Mooring 2, even after an extensive search, was never found. The RCM at station 3 had a damaged rotor and therefore only recorded temperature and salinity. The ACM at this station worked well for the first half of the deployment, and then the tape drive malfunctioned in late August. A similar problem was experienced by the ACM at station 4, which ceased to record readable data around mid-July. The RCM at station 5 had a fouled rotor and therefore only produced temperature and salinity measurements. The batteries on the Harbor Point meteorological station and the two RCMs ran out prior to the second recovery attempt in October due to the unexpected extended sampling period. The data return for each instrument during the deployment period is shown in Figure 3-2.

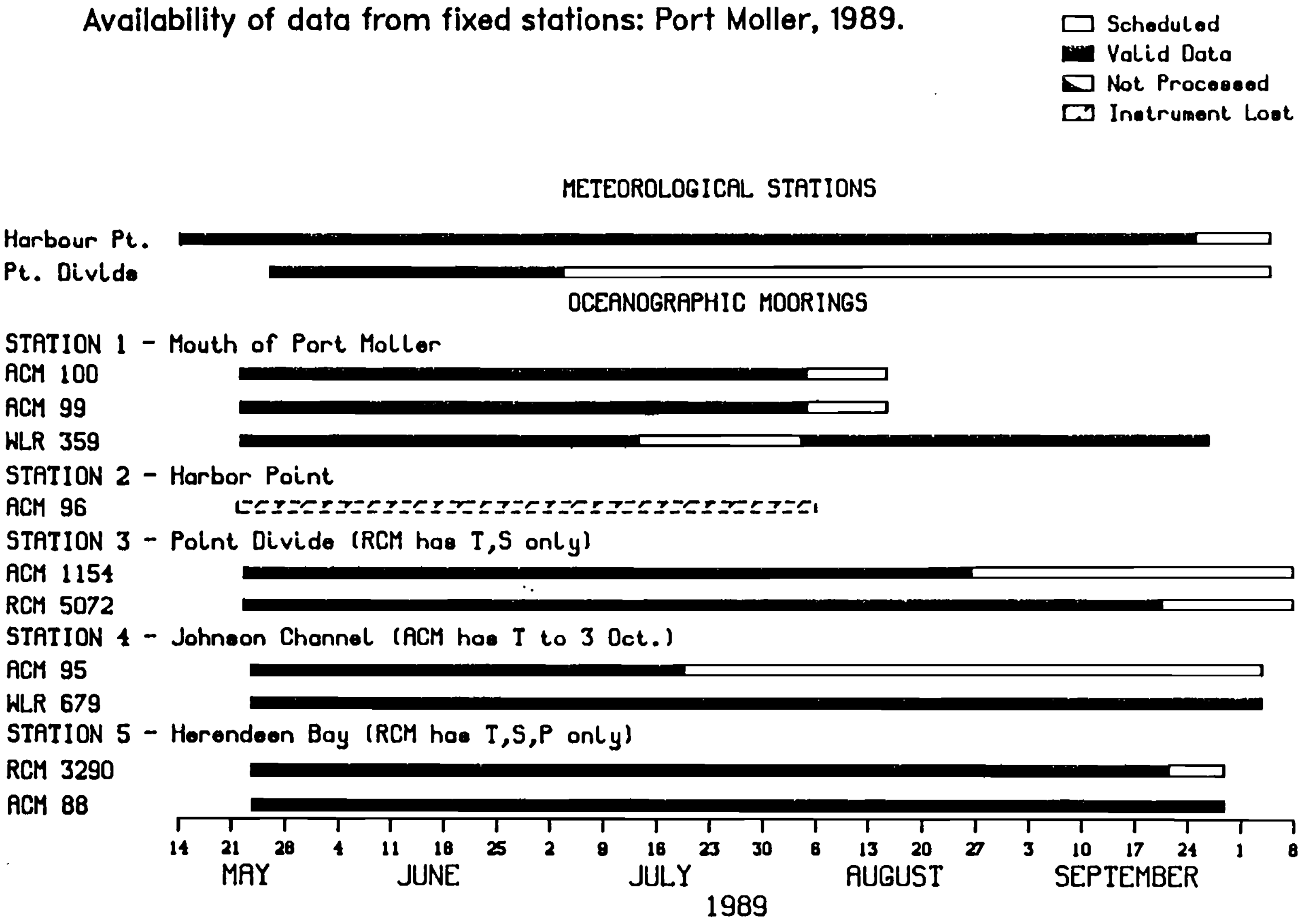


Figure 3-2. Bar chart shows percentage return on summer 1989 Port Moller time series data.

summer 1989).

May - September 1989 Port Moller Time Series Data

Sta. #	Location	Station Depth (m)	Latitude	Longitude	Instrument Depth/Hght	Instrument SN/Type	Data	Notes
1	Port Moller Mouth	20	56° 1.02' N	160° 38.52' W	7.5 15.0 20.0	100/ACM 99/ACM 359/WLR	V,T V,T P,T	Mooring dragged on 7/13/89, current meter recovered by fisherman, tape recorder malfunction, partial record, WLR recovered later by fisherman
2	Harbour Point Channel	25	55° 55.92' N	160° 34.86' W	7.5	96/ACM	-	Lost
3	Point Divide/ Hague Channel	24	55° 55.74' N	160° 43.56' W	7.5 15.0	1154/ACM 5072/RCM	V,T T,S	ACM - Tape recorder malfunction, partial record RCM - Rotor broken, battery ran out near end of deployment
4	Head of Johnson Channel	25	55° 46.86' N	160° 46.68' W	7.5 25.0	95/ACM 679/WLR	V,T P,T	ACM - Tape recorder malfunction, partial record
5	Herendeen Bay	93	55° 44.88' N	160° 42.18' W	15.0 55.0	3290/RCM 88/ACM	T,S,P V,T	RCM - Rotor fouled, battery ran out near end of deployment
M1	Point Divide	-	55° 53.0' N	160° 47.5' W	17.5	710/DL	W,P,T	Instrument failed on 7/4/89
M2	Harbour Point	-	55° 54.8' N	160° 34.8' W	9.0	712/DL	W,P,T	Battery ran out 1 week prior to recovery

equipped with pressure, temperature, and conductivity probes, were obtained in transects, across the main channel into the estuary complex, off Harbor Point, across Hague Channel, and in Herendeen Bay, during different phases of the tide to determine associated water property changes (see Figure 3-1). While profiling, ASCII data were collected every second on a laptop computer connected to the DRCM deck unit, which, in turn, received its signal via cable from the DRCM. Temperature/conductivity data were recorded continuously during the downcast. Current observations were obtained on the upcast by raising the instrument to a predetermined depth and holding it there for 2 minutes so that enough data could be recorded to determine a statistically significant vector velocity average.

Three profiling surveys of currents and temperature/salinity were conducted concurrent with mooring operations in May, September, and October. The most comprehensive water property survey, 57 profiles consisting of seven DRCM/CTD transects across the harbor entrance, one across the channel from Harbor Point, and three across Hague Channel, as well as numerous current meter calibration stations, was conducted during the deployment cruise in May. A contiguous series of six sections from 29 May at the estuary entrance provides an excellent example of observations portraying the evolution of water properties over one tidal cycle (see Appendix F).

Five profiles were obtained off Harbor Point as part of the aborted initial recovery attempt in September. Additional survey data, 18 profiles comprised of one section at the harbor entrance, two across Hague Channel, one in Herendeen Bay, and a number of calibration stations, were collected during the final recovery cruise in October. These fall profile transects allow for seasonal water property comparisons with the spring sections collected in May. The DRCM/CTD transect locations are plotted in Figure 3-1. Descriptions of each transect including tidal phase during occupation and individual station locations are provided in Tables 3-2 and 3-3. The profile data are provided as plots in Appendix E and as contoured sections in Appendix F.

are shown in Appendix F.

Port Moller Profiling Stations

DRCM profiling sections were run in four general areas during the deployment cruise and two recovery cruises:

PM - Five stations across the mouth of the estuary at ~55°59'N. Stations are numbered east to west from the Port Moller side over to mud flats.

HP - Four stations at Harbor Point from mud flats to the point at a heading of ~45°. Stations are numbered southwest to northeast.

HC - Three stations at Hague Channel/Pt. Divide across neck at a heading of ~135°. Stations are numbered northwest to southeast.

HB - Four stations in Herendeen Bay from current meter Station 4 up to Portage Creek. Stations are numbered in the sequence stated above.

CM - There are also a number of calibration and miscellaneous stations.

The naming convention for profiling files is as follows:

Station XX#*.DDD
XX = Section (PM, HP, HC, HB, and CM)
# = Section #
* = Station #
DDD = Date (month, day)

The following is a synopsis of station coverage and tide phase for each cruise:

MAY - DEPLOYMENT

	Station	ADT Time	Tide
PM	Port Moller Mouth (7 Sections)		
	STAPM1*.528	09:15-11:02	Ebb
	STAPM1*.529	05:54-07:50	Slack-Ebb
	STAPM2*.529	08:13-09:57	Ebb
	STAPM3*.529	10:57-12:37	Ebb-Slack
	STAPM4*.529	13:06-14:55	Flood
	STAPM5*.529	15:50-17:05	Flood
	STAPM6*.529	17:23-18:02	Flood
HP	Harbor Point (1 Section)		
	STAHP1*.525	14:05-15:15	Slack-Ebb

Port Moller Profiling Stations (Continued)

MAY - DEPLOYMENT (Continued)

HC Point Divide/Hague Channel (3 Sections)		
STAHC1*.525	16:25-17:06	Ebb
STAHC1*.526	09:20-09:55	Ebb-Slack
STAHC2*.526	13:07-13:45	Flood

SEPTEMBER - RECOVERY

Station	ADT Time	Tide
HP Harbor Point (1 Section)		
STAHP1*.93	11:18-12:44	Flood

OCTOBER - RECOVERY

Station	ADT Time	Tide
PM Port Moller (1 Section)		
STAPM*.105	12:41-14:12	Flood
HC Point Divide/Hague Channel (2 Sections)		
STAHC1*.105	15:03-15:54	Flood
STAHC1*.106	20:55-21:36	Ebb
HB Herendeen Bay (1 Section)		
STAHB1*.105	17:07-18:54	Ebb

NOTE: The time that appears in the header for each profile was logged by the computer as EDT (i.e., ADT + 4)

Moorings

May

Station	TD 1 (Y)	TD 2 (Z)	Latitude	Longitude	Depth (ft)
Port Moller					
1	33672.3	46339.9	55°59.52′	160°37.20′	66-72
2	33674.8	46343.2	55°59.16′	160°37.68′	56-60
3	33677.3	46352.6	55°59.40′	160°39.12′	43-54
4	33682.9	46367.1	55°59.34′	160°41.34′	42-48
5	33687.0	46377.0	55°59.16′	160°42.84′	30-35
Hague Channel					
1	33721.6	46414.1	55°53.94′	160°48.12′	28
2	33721.4	46412.4	55°53.82′	160°47.88′	75
3	33721.4	46411.1	55°53.70′	160°47.64′	38
Harbor Point					
1	33691.2	46335.3	55°54.36′	160°36.12′	15
2	33688.3	46331.7	55°54.78′	160°35.64′	58
3	33687.3	46330.8	55°54.90′	160°35.46′	192
4	33687.0	46330.0	55°54.96′	160°35.34′	140
Calibration Station					
1	33668.6	46347.4	56°01.08′	160°38.46′	80
2					
Test 21.519	33681.1	46326.2	55°56.04′	160°34.86′	68
Test 22.519	33687.1	46331.0	55°55.02′	160°35.52′	177
cm 2.525	33681.3	46326.4	55°56.04′	160°34.92′	76
3	33703.4	46384.0	55°55.74′	160°43.68′	92
4	33746.9	46407.8	55°46.86′	160°46.74′	87
5	33744.4	46380.9	55°44.88′	160°42.42′	300
Other					
HCIA.526	33723.6	46417.0	55°53.70′	160°48.60′	64

September

Harbor Point					
1	33691.1	46336.5	55°54.48′	160°36.30′	16
2	33688.6	46331.9	55°54.72′	160°35.64′	32
3	33687.7	46329.0	55°54.66′	160°35.16′	160
4	33688.3	46330.7	55°54.66′	160°35.46′	68
Calibration Station					
2	33681.4	46326.0	55°55.98′	160°34.86′	80

Moorings

October

Station	TD 1 (Y)	TD 2 (Z)	Latitude	Longitude	Depth (ft)
Port Moller					
1	33672.4	46340.0	55°59.46′	160°37.26′	69
2	33675.0	46343.0	55°59.10′	160°37.68′	60
3	33677.3	46352.6	55°59.40′	160°39.12′	55
4	33683.0	46367.0	55°59.28′	160°41.34′	50
5	33687.0	46377.0	55°59.22′	160°42.84′	45
Hague Channel					
1	33723.6	46417.0	55°53.70′	160°48.60′	22-37
2	33721.6	46414.7	55°54.00′	160°48.24′	22-25
3	33722.1	46413.5	55°53.76′	160°48.00′	86-96
4	33721.6	46411.1	55°53.70′	160°47.64′	30-36
Herendeen Bay					
1	33746.6	46407.9	55°46.92′	160°46.74′	98
2	33745.1	46394.1	55°46.02′	160°44.58′	184
3	33743.9	46379.8	55°44.94′	160°42.30′	310
4	33750.2	46375.2	55°42.84′	160°41.40′	170
Calibration Station					
3	33703.1	46383.1	55°55.74′	160°43.56′	90

both the temporal and spatial characteristics of the Port Moller/Herendeen Bay wind, current, and temperature/salinity fields. In addition to these *in situ* data, a variety of ancillary data were obtained to provide an overview and aid in the analysis process. Satellite imagery for the Port Moller area from May through early October were collected and processed by The Fairbanks Image Processing Facility, University of Alaska. The 12 clear images obtained during the 5-month deployment period appear in Appendix B. Regional historical climatic data (Appendix C) and daily synoptic weather maps (Appendix D) were supplied courtesy of the Arctic Environmental Data and Information Center (AEIDC) in Anchorage, Alaska.

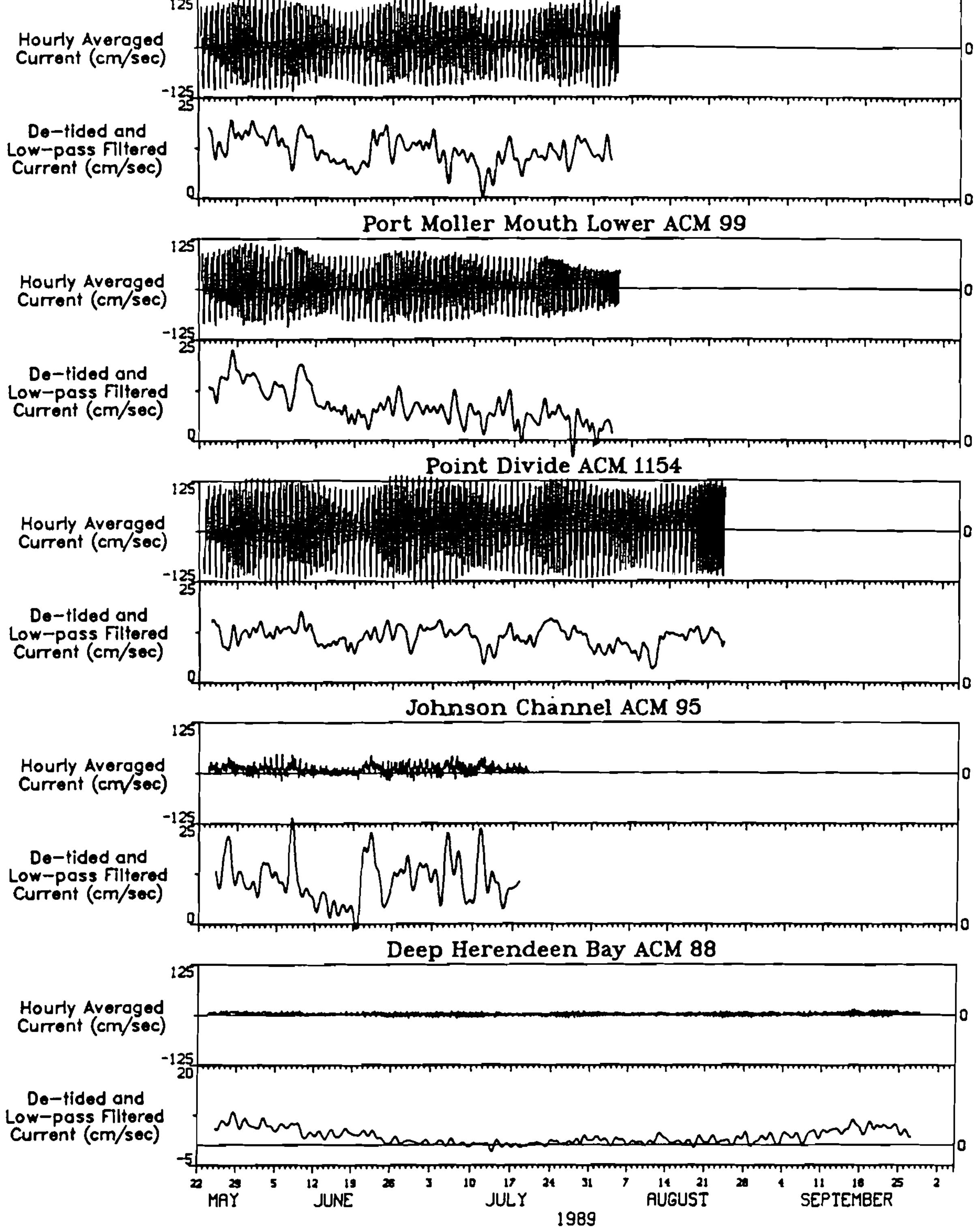
This chapter explores the relative importance of tidal and atmospheric forcing mechanisms on Port Moller circulation and water property distribution.

4.1 RELATION BETWEEN CURRENTS AND TIDES

All time series data (wind, current, pressure, temperature, and salinity) are edited and averaged into 1-hour intervals. Wind and current data are then decomposed into along- and cross-channel components for analysis. Figure 4-1 shows the along-channel hourly and detided, low-pass-filtered data for each current meter. The data were detided by using the method of Munk and Cartwright (1966) to calculate the predicted tidal currents and subtracting the resulting series from the observed current meter data. This time series was then low-pass filtered using a PL33 hour filter (Flagg, 1977). The along-channel direction used in the component calculation for each instrument is given in Table 4-1.

It is evident from Figure 4-1 that tidal forcing is the dominant factor affecting currents in this estuary. Along-channel tidal current speeds range up to 139 cm/sec, while the detided part of the current signal only reaches a maximum of around 25 cm/sec. Table 4-1 shows that the tidal currents are rectilinear in the along-channel direction and that ebb is stronger than flood, leading to a net outflow from the estuary onto the shelf. The highest speeds are found in the surface current meters at stations 1 and 3, indicating that the effect of tidal forcing diminishes as one heads into Herendeen Bay. Keep in mind that, due to mooring design constraints, station 3 was moved to a wider part of Hague Channel where the velocities are lower. If the station were located in the channel directly off of Point Divide, marking the entrance to Herendeen Bay, velocities would be even larger than those recorded here.

The tide has a range of approximately 3 m and is semidiurnal, with the largest tidal constituents being M_2, K_1, N_2, S_2 and O_1. See Table 4-2 for tidal constituent amplitude and phase information by current meter. Constituents were calculated using the method of Munk and Cartwright (1966) on the rotated hourly current meter data. The power spectral density plot in Figure 4-2 shows that the relative strength of the tidal signal, particularly


Port Moller Mouth Lower ACM 99

Point Divide ACM 1154

Johnson Channel ACM 95

Deep Herendeen Bay ACM 88

Figure 4-1. Along-channel currents in Port Moller from May - October 1989. The top tier for each instrument is the hourly averaged data and the lower tier represents detided, low-pass-filtered data (see Table 4-1 for along-channel direction.)

Current Statistics

Station Number	Instrument Number	Bathymetric Channel Orientation (°T)	Major Alongchannel Axis Orientation (°T)	Current Speed (cm/sec)			Alongchannel Current (cm/sec)				Cross-Channel Current (cm/sec)			
				Max	Min	Avg	Flood	Ebb	Avg	Std Dev	Max	Min	Avg	Std Dev
1	100	349	346	138	0.5	61	-110	136	12	67	17	-29	-4	7
1	99	349	348	116	0.5	50	-95	116	9	55	27	-25	-2	8
3	1154	49	49	139	0.7	71	-133	139	11	79	18	-14	2	4
4	95	298	300	50	0.4	16	-20	48	11	11	27	-22	8	6
5	88	298	293	15	0.1	4	-11	15	2	4	6	-5	0	1

Wind Statistics

Station	Orientation (°T)	Major Axis Orientation (°T)	Wind Speed (m/s)			Northward Component (m/s)				Eastward Component (m/s)			
			Max	Min	Avg	Max	Min	Avg	Std Dev	Max	Min	Avg	Std Dev
Harbor Point	0	305	25	1	9	19	-13	3	6	19	-23	-2	8
Point Divide	0	335	19	1	7	17	-15	1	6	12	-17	-1	5

Tidal Constituents

ACM 100

LINE	NODE FACTOR	EQ. TIDE	E-W AMPL.	E-W PHASE	N-S AMPL.	N-S PHASE	MAJ. AXIS	MIN. AXIS	MAJ. AXIS TO X AXIS	PHASE OF MAX. CURR.	ROT.
Q1	1.162	1.793	0.401	267.3	3.357	78.2	3.380	0.064	96.7	78.3	CCW
O1	1.162	9.365	0.242	278.5	14.293	90.7	14.295	0.033	91.0	90.7	CCW
M1	1.383	0.736	0.056	-2.6	1.218	105.1	1.218	0.053	90.8	105.2	CCW
K1	1.100	13.170	1.105	279.2	25.865	107.4	25.888	0.157	92.4	107.4	CW
J1	1.148	0.736	0.163	193.4	1.559	102.7	1.559	0.163	90.3	102.7	CW
MU2	0.969	0.232	1.115	121.4	8.473	285.4	8.541	0.304	-82.8	105.7	CCW
N2	0.969	1.456	2.759	114.0	22.714	273.7	22.861	0.951	-83.5	94.0	CCW
M2	0.969	7.605	3.484	152.5	82.741	317.7	82.810	0.886	-87.7	137.7	CCW
L2	0.741	0.215	0.117	227.3	2.203	308.5	2.203	0.115	-90.5	128.5	CCW
S2	1.000	3.538	0.862	332.7	16.540	85.5	16.544	0.795	91.2	85.5	CCW

ACM 99

LINE	NODE FACTOR	EQ. TIDE	E-W AMPL.	E-W PHASE	N-S AMPL.	N-S PHASE	MAJ. AXIS	MIN. AXIS	MAJ. AXIS TO X AXIS	PHASE OF MAX. CURR.	ROT.
Q1	1.162	1.793	0.645	233.6	2.764	83.2	2.821	0.312	101.6	81.9	CW
O1	1.162	9.365	1.545	217.1	11.667	91.3	11.703	1.249	94.5	90.8	CW
M1	1.383	0.736	0.036	266.1	0.965	105.3	0.966	0.012	92.0	105.3	CW
K1	1.100	13.170	1.339	299.1	21.187	107.5	21.228	0.269	93.5	107.5	CCW
J1	1.148	0.736	0.072	273.6	1.340	99.8	1.342	0.008	93.0	99.8	CW
MU2	0.969	0.232	1.164	130.3	6.819	288.6	6.905	0.424	-81.0	109.2	CCW
N2	0.969	1.456	1.524	175.4	17.251	280.0	17.256	1.475	-88.7	100.1	CCW
M2	0.969	7.605	5.125	227.2	66.242	314.8	66.242	5.120	-90.2	134.8	CCW
L2	0.741	0.215	0.185	298.3	1.453	300.0	1.464	0.005	-97.2	120.0	CCW
S2	1.000	3.538	2.444	102.6	12.987	82.2	13.188	0.838	80.0	82.9	CW

Tidal Constituents

ACM 1154

LINE	NODE FACTOR	EQ. TIDE	E-W AMPL.	E-W PHASE	N-S AMPL.	N-S PHASE	MAJ. AXIS	MIN. AXIS	MAJ. AXIS TO X AXIS	PHASE OF MAX. CURR.	ROT.
Q1	1.162	1.793	0.645	233.6	2.764	83.2	2.821	0.312	101.6	81.9	CW
O1	1.162	9.365	1.545	217.1	11.667	91.3	11.703	1.249	94.5	90.8	CW
M1	1.383	0.736	0.036	266.1	0.965	105.3	0.966	0.012	92.0	105.3	CW
K1	1.100	13.170	1.339	299.1	21.187	107.5	21.228	0.269	93.5	107.5	CCW
J1	1.148	0.736	0.072	273.6	1.340	99.8	1.342	0.008	93.0	99.8	CW
MU2	0.969	0.232	1.164	130.3	6.819	288.6	6.905	0.424	-81.0	109.2	CCW
N2	0.969	1.456	1.524	175.4	17.251	280.0	17.256	1.475	-88.7	100.1	CCW
M2	0.969	7.605	5.125	227.2	66.242	314.8	66.242	5.120	-90.2	134.8	CCW
L2	0.741	0.215	0.185	298.3	1.453	300.0	1.464	0.005	-97.2	120.0	CCW
S2	1.000	3.538	2.444	102.6	12.987	82.2	13.188	0.838	80.0	82.9	CW

ACM 95

LINE	NODE FACTOR	EQ. TIDE	E-W AMPL.	E-W PHASE	N-S AMPL.	N-S PHASE	MAJ. AXIS	MIN. AXIS	MAJ. AXIS TO X AXIS	PHASE OF MAX. CURR.	ROT.
Q1	1.162	1.793	0.407	42.3	0.460	271.6	0.559	0.254	-50.3	71.0	CW
O1	1.162	9.365	0.742	101.7	2.488	294.7	2.591	0.160	-73.7	113.7	CW
M1	1.390	0.736	0.104	139.9	0.163	301.0	0.191	0.029	-58.1	126.3	CCW
K1	1.100	13.170	1.756	154.3	1.934	-5.8	2.588	0.451	-48.3	165.4	CW
J1	1.148	0.736	0.139	201.4	0.304	28.5	0.334	0.016	114.4	27.3	CW
MU2	0.969	0.232	0.933	338.6	0.646	286.2	1.054	0.463	-151.6	145.3	CW
N2	0.969	1.456	1.488	343.1	2.089	230.7	2.211	1.300	-66.1	36.1	CW
M2	0.969	7.605	2.807	341.4	9.046	278.9	9.146	2.463	-98.8	101.3	CW
L2	0.731	0.215	0.115	196.7	0.362	257.3	0.367	0.099	-99.5	74.8	CCW
S2	1.000	3.538	0.435	45.0	4.127	47.9	4.150	0.022	84.0	47.9	CCW

ACM 88

LINE	NODE FACTOR	EQ. TIDE	E-W AMPL.	E-W PHASE	N-S AMPL.	N-S PHASE	MAJ. AXIS	MIN. AXIS	MAJ. AXIS TO X AXIS	PHASE OF MAX. CURR.	ROT.
Q1	1.160	1.793	0.007	13.2	0.097	250.3	0.098	0.006	-87.7	70.1	CW
O1	1.160	9.365	0.015	288.4	0.253	233.1	0.253	0.013	-92.0	53.2	CW
M1	1.356	0.736	0.002	186.9	0.018	278.4	0.018	0.002	-89.8	98.4	CCW
K1	1.099	13.170	0.047	135.5	0.742	270.6	0.743	0.033	-87.4	90.7	CCW
J1	1.146	0.736	0.003	85.2	0.068	241.0	0.068	0.001	-88.0	61.1	CCW
MU2	0.969	0.232	0.078	12.6	0.452	191.3	0.459	0.002	-80.2	11.3	CCW
N2	0.969	1.456	0.149	352.7	1.127	191.0	1.136	0.046	-82.8	10.7	CW
M2	0.969	7.605	0.368	70.0	4.006	256.9	4.022	0.044	-84.8	76.8	CW
L2	0.780	0.215	0.010	54.3	0.130	255.6	0.130	0.004	-85.8	75.5	CW
S2	1.000	3.538	0.085	234.7	0.753	54.8	0.758	0.000	96.4	54.8	CW

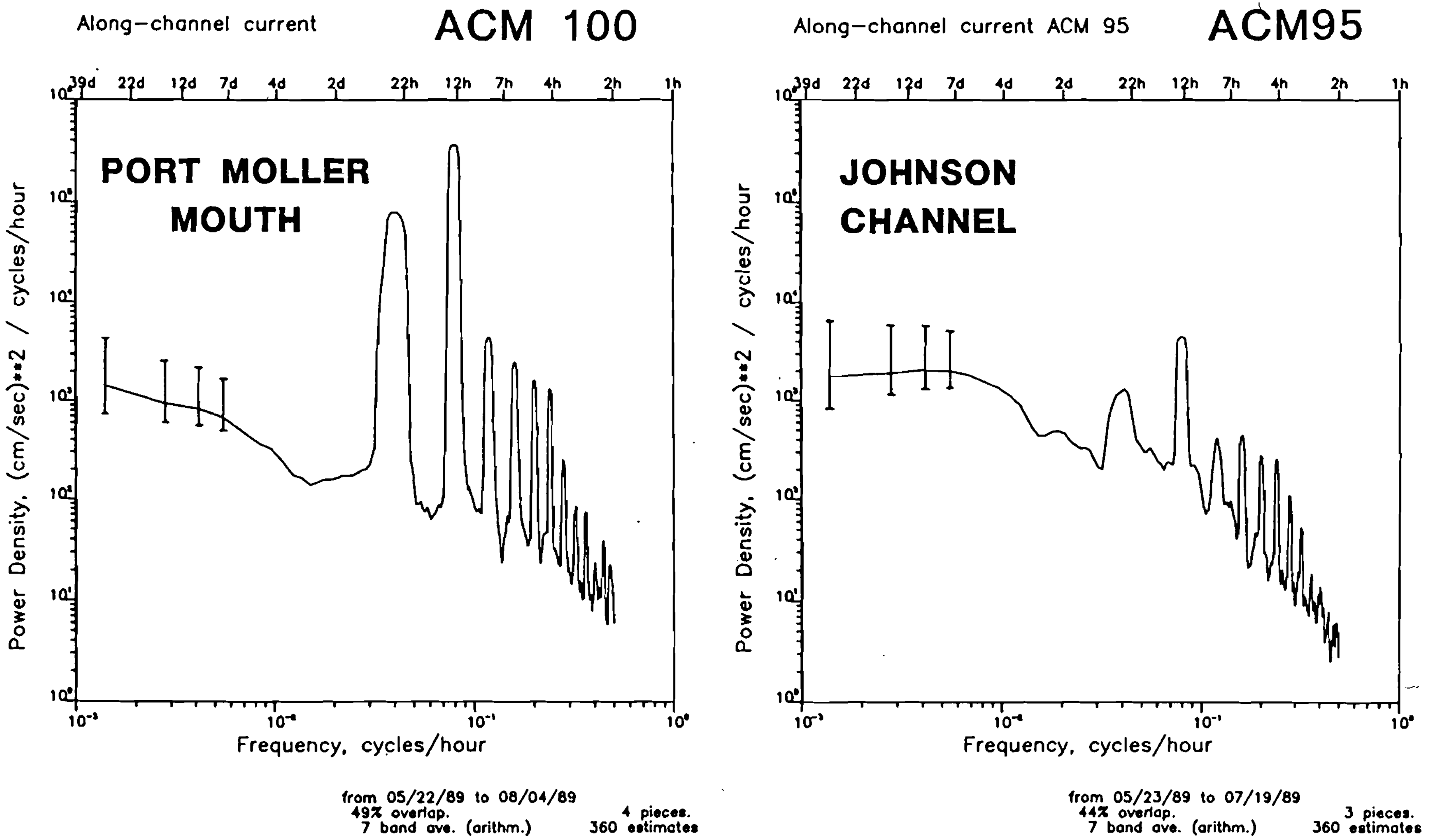


Figure 4-2. Power density spectra of along-channel currents near the entrance to the Harbor (ACM 100) and in Herendeen Bay (ACM 95) with 90% confidence limits superimposed.

estuary (ACM 100) are larger than those encountered in Herendeen Bay (ACM 95). These spectra were calculated using a Fast Fourier Transform on 30-day segments with a full cosine taper and approximately 50% overlap. The spectra were then plotted using a 7-band running average on a logarithmic scale with 90% confidence limits superimposed. The spectra for all current meters are contained in Appendix G.

The actual amounts of tidal energy associated with the velocity components at each current meter are given in Table 4-3. Again, one can see that the outer three current meters (100, 99, 1154) are predominantly influenced by tidal forcing, with over 90% of their along-channel component variance attributed to tidal effects. The along-channel tidal energy and residual, nontidal energy are approximately equal for the two instruments in Herendeen Bay (95 and 88), where the long, thin channel acts as a tidal damping mechanism. Only about 25% of the cross-channel current variation can be attributed to tidal forcing, with as little as a 5% tidal signal at ACM 88 in deep Herendeen Bay. Evidence of strong along-channel currents in the eastern arm, near where station 2 was lost, is provided by the velocity profiling surveys (see Harbor Point sections in Appendix F) and side-scan images of large sand waves along the bottom of the channel (Figure 4-3). These images were collected by EG&G as part of the King Crab Study in Port Moller during the summer of 1989.

4.2 THE RELATION BETWEEN CURRENT AND WIND

The next phase of the analysis is to remove the large tidal signal from the current time series data in order to examine the impact of other forcing mechanisms, such as wind, on the Port Moller circulation system. Figure 4-4 is a plot of detided, low-pass-filtered along-channel current velocity vectors at 6-hour intervals for each instrument, along with the two low-pass wind stress vector records obtained from the meteorological stations at Harbor Point and Point Divide. The Harbor Point winds will be used for the remainder of the analysis and assumed to be representative of the winds in the outer estuary, since it was operational throughout the deployment period and the initial data recorded simultaneously by the two stations appear similar. Wind stress was calculated using the algorithm of Blanton et al. (1989). Wind

	Variance (cm/sec)^2				
	Total	Tidal		Residual	
Alongchannel					
ACM 100	4507.5	4305.5	95.5%	202.0	4.5%
ACM 99	3019.2	2772.9	91.8%	246.3	8.2%
ACM 1154	6206.7	5634.7	90.8%	572.0	9.2%
ACM 95	114.7	50.6	44.0%	64.1	56.0%
ACM 88	17.1	8.9	52.0%	8.2	48.0%
Cross Channel					
ACM 100	43.0	10.9	25.0%	31.6	75.0%
ACM 99	65.2	20.0	31.0%	45.2	69.0%
ACM 1154	14.6	3.5	24.0%	11.1	76.0%
ACM 95	40.5	9.6	24.0%	30.9	76.0%
ACM 88	2.2	0.1	5.0%	2.1	95.0%

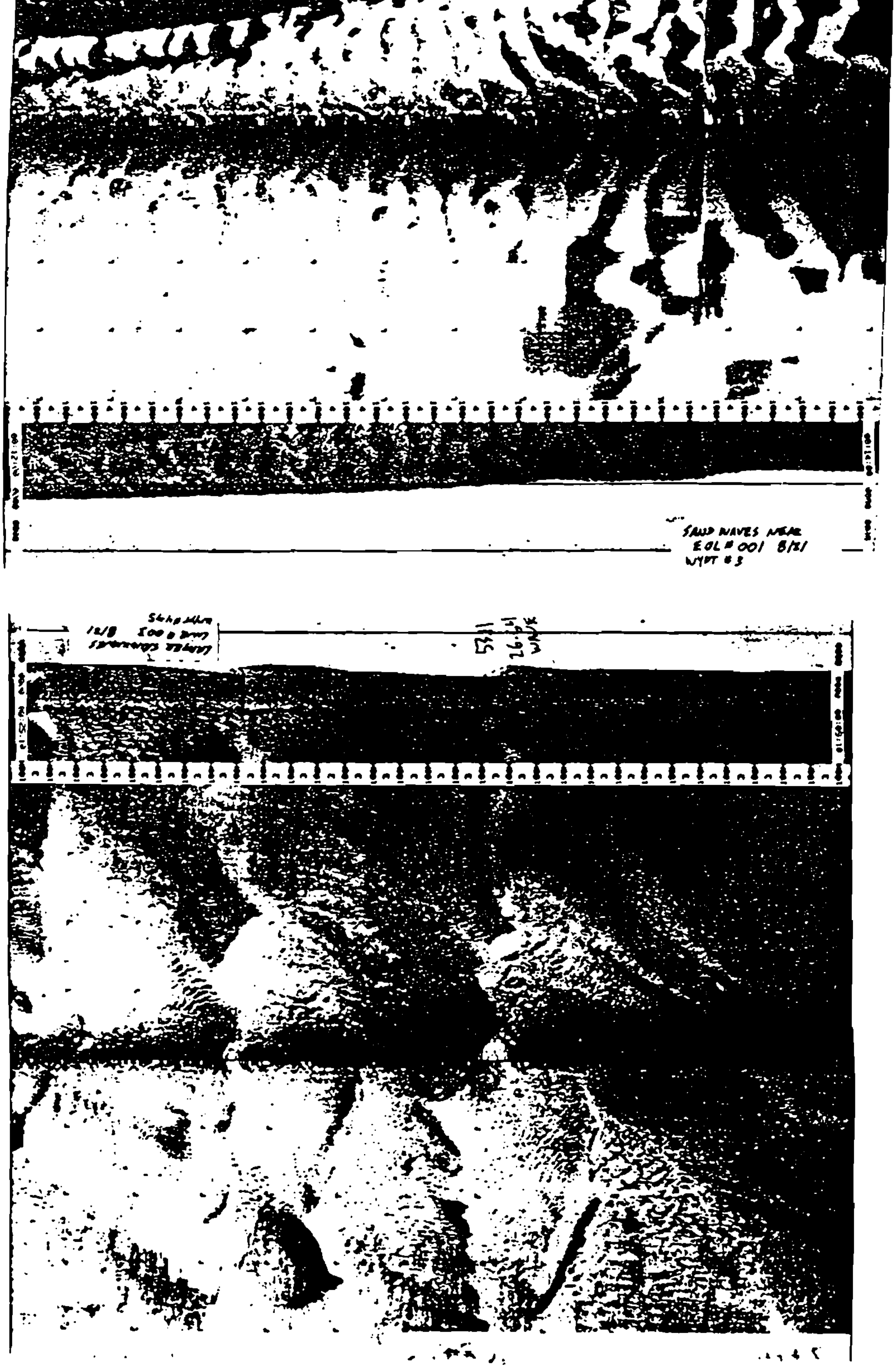


Figure 4-3. Side-scan images of large sandwaves in the eastern arm of Port Moller Estuary.

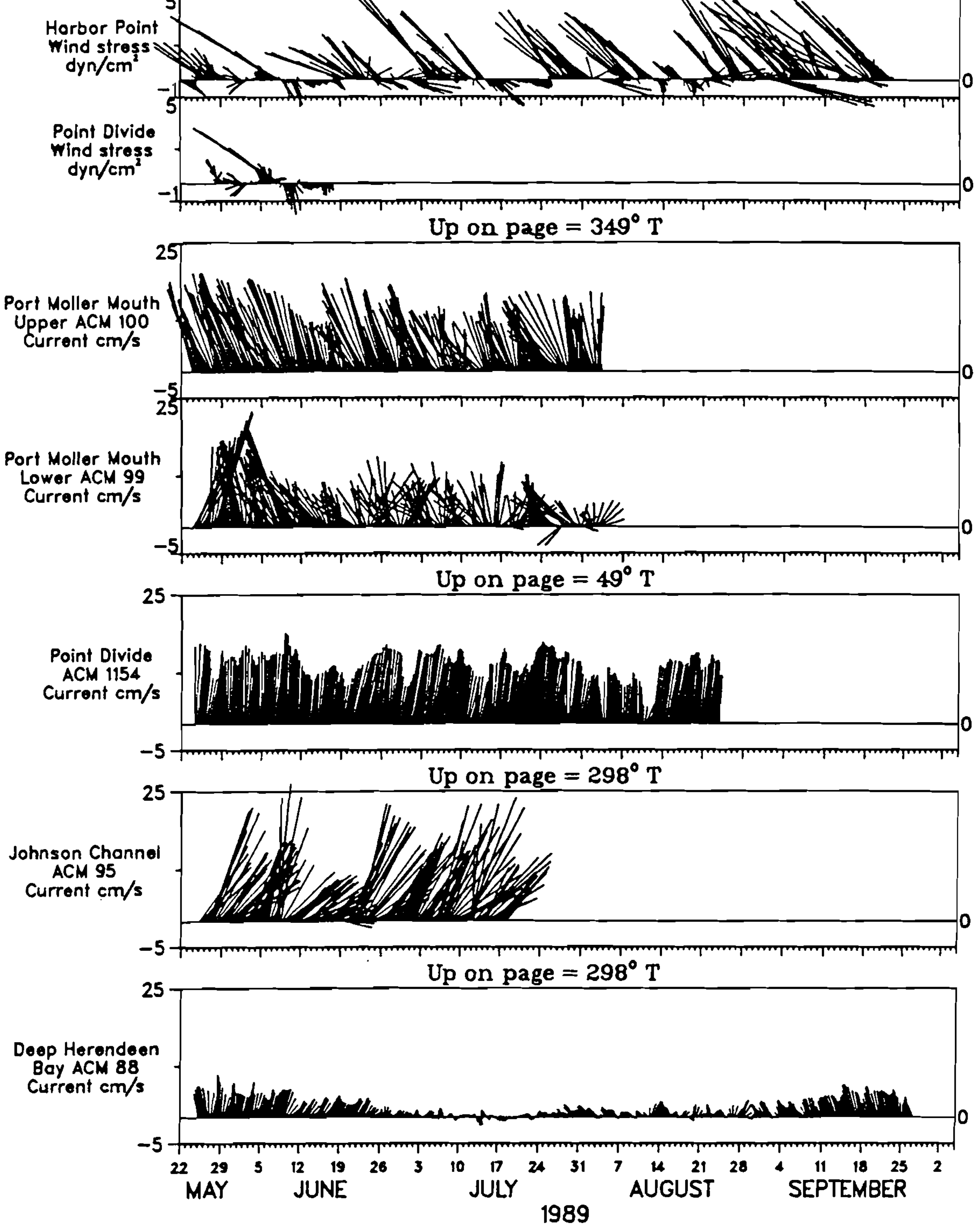


Figure 4-4. Low-pass-filtered wind stress vectors convention (toward) and detided, low-pass-filtered current velocity vectors plotted at 6-hour intervals. Wind vectors are relative to 0°T and the current vectors are relative to the along-channel axis indicated by the angle label on top of each tier.

convention of wind direction "blowing toward."

The maximum wind speeds observed at Harbor Point were 25 m/s with an average of 9 m/s toward the northwest (see Table 4-1). This is twice the climatic average of 4.5 m/s reported by Brower et al. (1988). Winds tended to be either from the southeast or northwest, with southeasterly (from the southeast) winds dominating. This rectilinear wind pattern can be attributed to the mountainous topography in this area. The eastern arm of the estuary trends southeast to northwest, and is surrounded by mountains which funnel the winds in one of these two directions depending on the large-scale wind patterns.

Low-passed components of the Harbor Point wind stress and detided, low-passed currents are plotted in Figure 4-5. From the wind stress time series, it is possible to pick out individual atmospheric events and correlate them with the regional synoptic pressure and wind fields to determine the cause of these events and see if any consistent pattern emerges. The record is dominated by southeasterly winds (from the southeast) with a few reversals from the northwest interspersed. There appear to be two relatively calm periods around 9-19 June and 17-24 July 1989, and a period of increased storm activity starting on 21 August 1989. Examples of the weather systems associated with these events are described in the following paragraph and presented as synoptic maps in Appendix D.

The southeasterly winds, predominant at Port Moller, result from a variety of regional weather patterns. The passage of a low to the south of the Alaska Peninsula on 8 June 1989 and to the north of the peninsula on 5 July 1989 both produced southeasterly winds at Port Moller. Examples of weather systems which result in winds from the northwest are given in Appendix D for the 29 June and 2 August 1989 reversal events. It appears that periods of strong northwesterly winds are associated with lows which track along the peninsula from west to east and stall to the east-southeast of Port Moller. This is the expected wind pattern from the trailing edge of a low pressure system. The 1-5 September 1989 sequence of back-to-back southeastward and northwestward wind events is given in Appendix D to illustrate the abruptness of the reversals. A 10-day segment (15-25 September) during the active storm period at the end of the time series

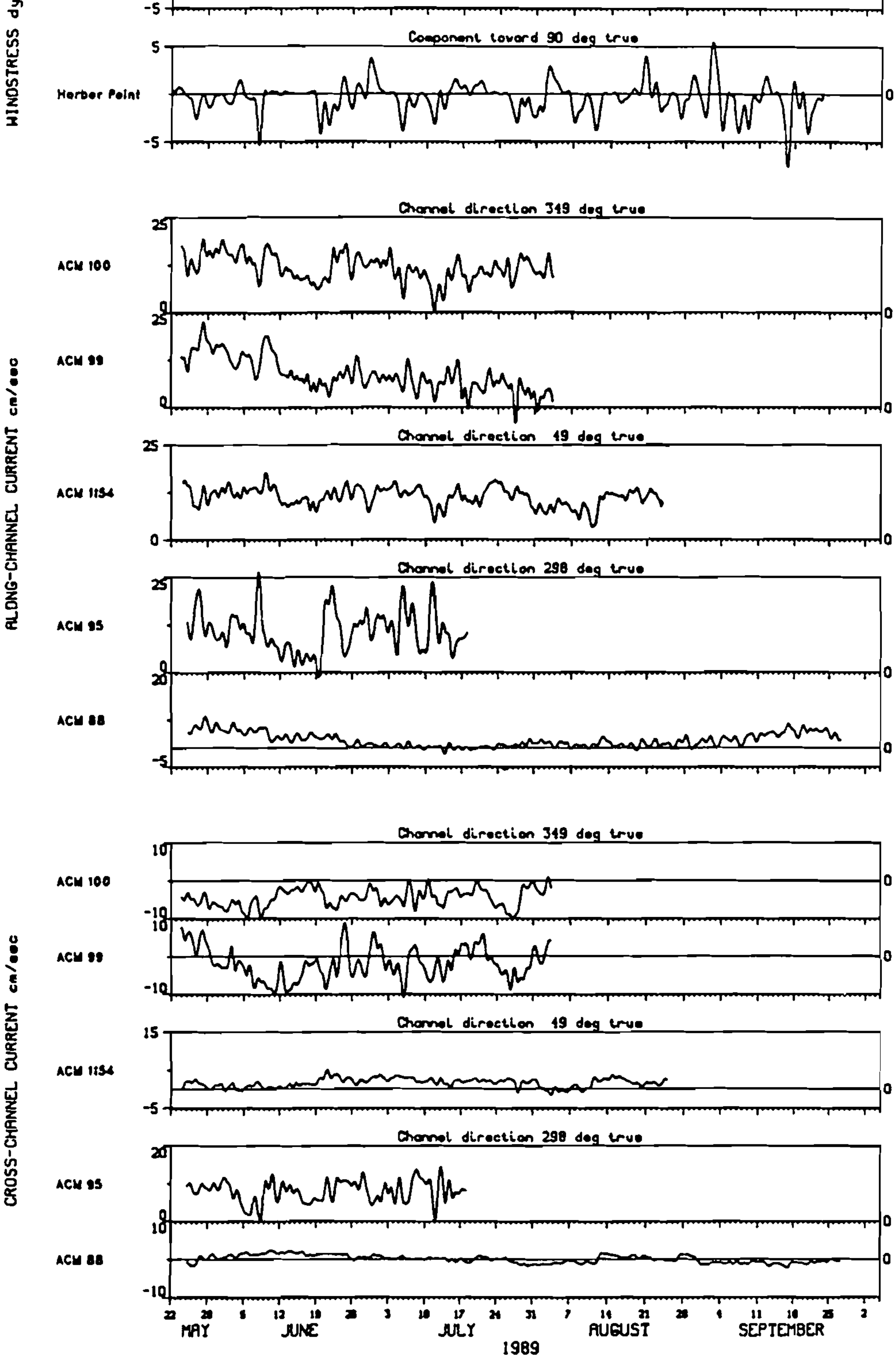


Figure 4-5. Along- and cross-channel components of low-pass-filtered wind (convention toward) data and detided, low-pass-filtered current data from Port Moller (summer, 1989). The along-channel axis is indicated at the top of each tier.

which storms track over this region in the late summer season. The track of these storms, from the southwest to Bristol Bay, as seen in the late September example, is consistent with Overland's (1981) observations for this area. The number of lows per month, an average of ten for 1989 in this region with four to five of these storms per month impacting Port Moller directly, is also comparable to Overland's (1981) data (Figure 4-6).

But what is the impact of wind on Port Moller currents? Referring to Figure 4-4, the average near-surface, along-channel current is out of the estuary at about 11 cm/sec. This flow rate is determined by the amount of water entering the drainage basin for this embayment and will be discussed in a following section. Even though all instruments show outward flow, their records are slightly different in magnitude and variability. The most consistent flow pattern is at station 3, where the bathymetry and current are most tightly constrained. The upper current meter at station 1, near the Port Moller entrance, and station 4, in Herendeen Bay, both show comparable speeds with greater variability than station 3. The lower ACM (99) at station 1, appears to have a velocity signal that slowly degrades with time, indicating a possible fouling problem. Results from this meter should be viewed with caution. ACM 88, located at a depth of 55 m in deep Herendeen Bay, recorded an average current of 2 cm/sec outward with a decrease in velocity during the summer months.

Figure 4-5 portrays both along- and cross-channel components of low-pass-filtered and detided currents and winds (also refer to Table 4-1). Again, one can see that there is an average outflow along-channel and that the average and range in speed of the events in the cross-channel direction is less than those associated with along-channel flow. The average cross-channel flow patterns, although they appear less coherent, are related to the instrument's location in the channel, with the average cross-channel flow being in the direction opposite to the nearest channel wall.

Superimposed on this general pattern of outward flow are a number of events that appear to be wind related. Overlaying the time series of northward component of the wind at Harbor Point with the along-channel component of the near-surface current meter (ACM100 - station 1) at the entrance to the estuary, we find that not to be the case (Figure 4-7).

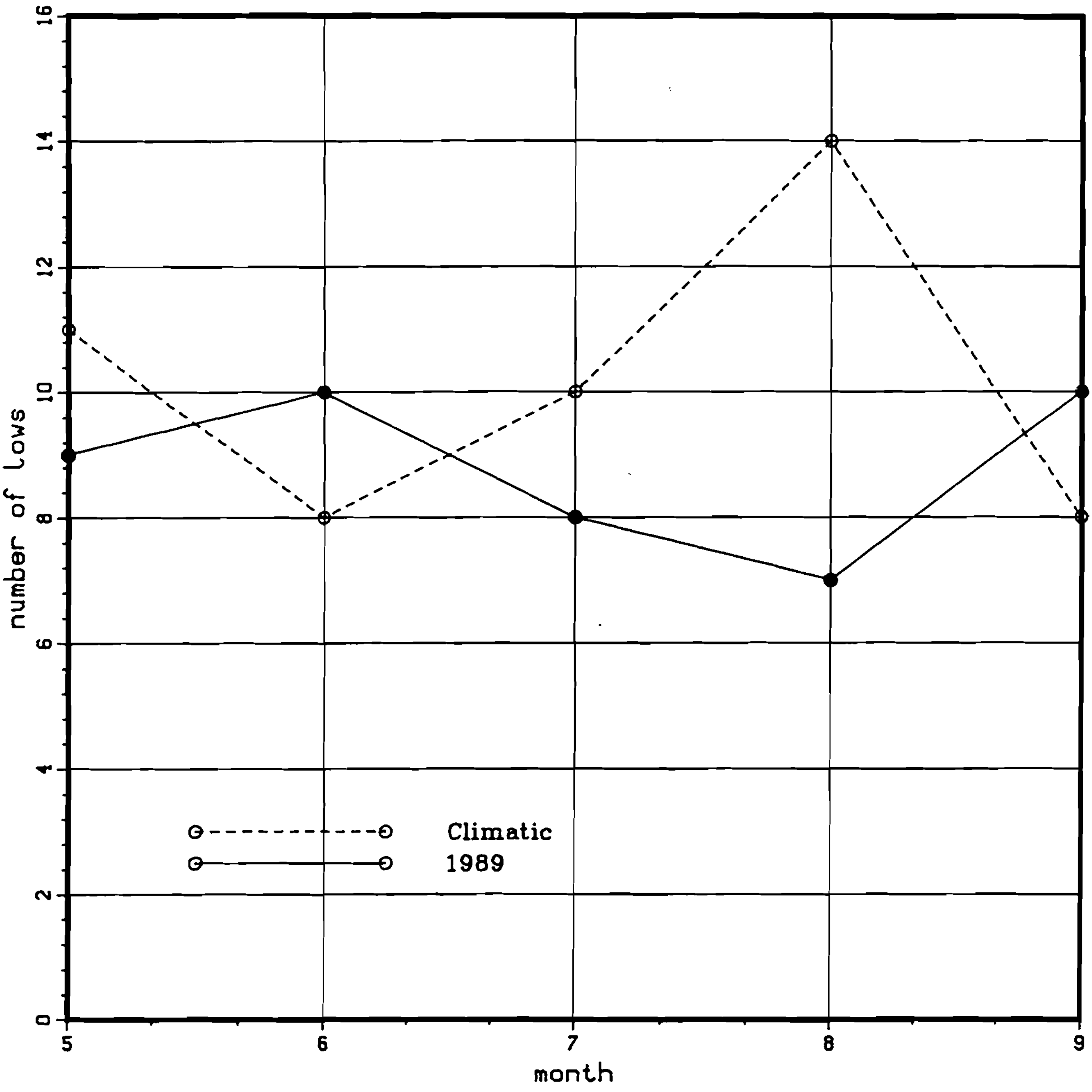


Figure 4-6. Climatic number of lows in the area 50°-70°N, 160°-180°W, from Overland (1981) and number of lows in 1989 for the area 50°-70°N, 130°-180°W.

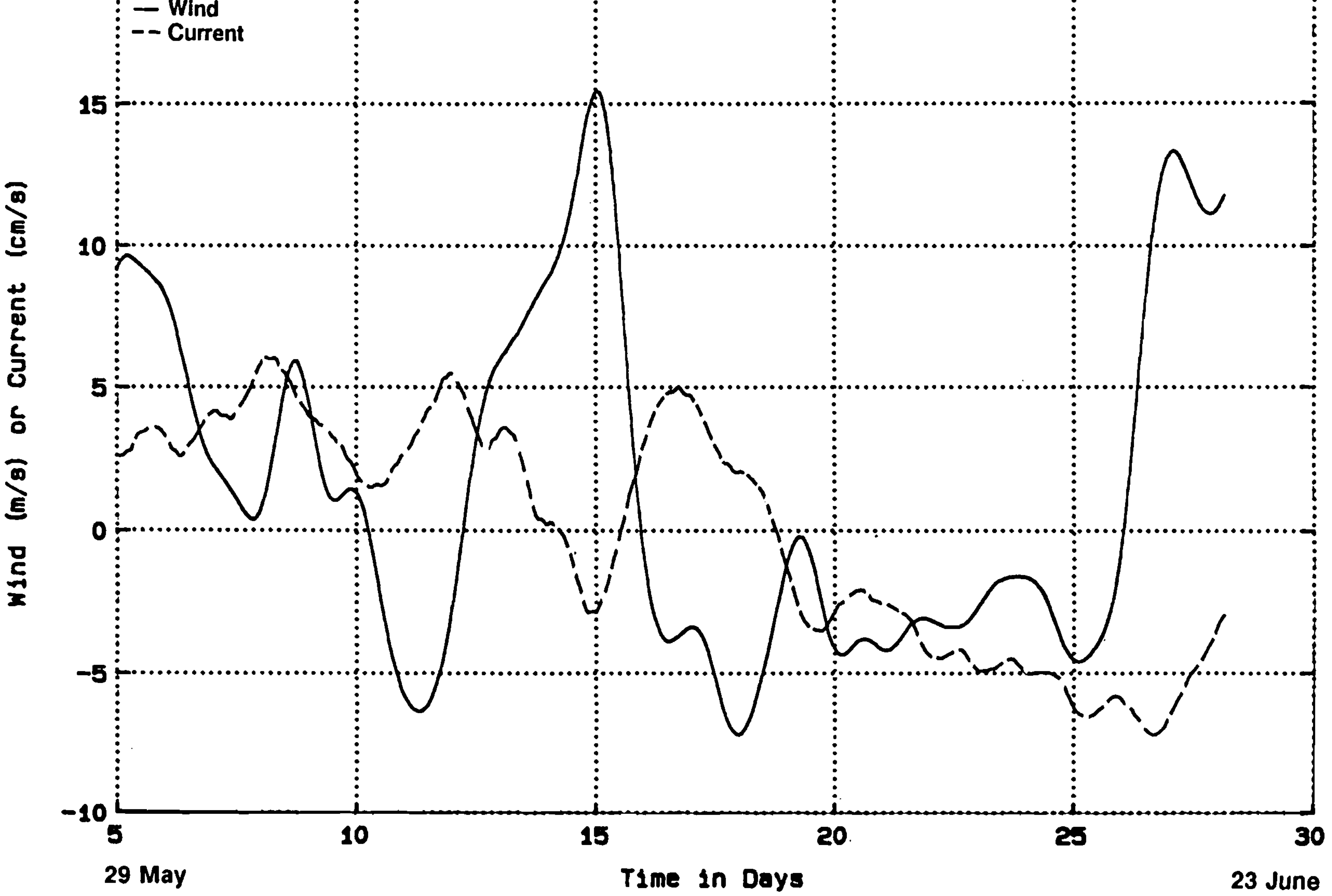


Figure 4-7. Low-pass-filtered northward component of Harbor Point wind (solid line) and detided, low-pass-filtered near-surface, along-channel (349°T) current at the Harbor entrance (dashed line) are plotted from 29 May-23 June 1989.

find that although the wind and current are significantly coherent in the 1-7 day band, they are 180° out of phase (Appendix H). The same pattern is observed between the wind and the near-surface current at station 3 (1154) off Point Divide, also in the outer harbor area. The only near-surface current meter that has a stable phase with respect to the local wind is ACM 95 at station 4 in Herendeen Bay, but its coherence in the 1-7 day band is low. There must be something happening on the shelf that is overriding the effect of local winds on currents in the outer harbor.

We hypothesized that when the regional wind pattern is blowing from the southwest quadrant, a downwelling condition is set up along the North Aleutian coast, causing onshore flow. However, due to the orientation of the topography surrounding the Port Moller/Herendeen Bay complex, the winds are funneled from the south/southeast to the northwest. This results in currents into the estuary during periods when the wind is blowing outward.

To test this hypothesis, we plotted (Figure 4-8) the pressure difference between the low-pass-filtered WLR pressure data at the entrance and comparable data from the WLR in Herendeen Bay (station 1 - station 4) to see if we were actually getting an increase in pressure at the entrance associated with the remote wind field. It appears from the correlation between these two data sets that this is, indeed, the case. In periods where there is no strong northward local wind, the pressure differential tends to be negative, or toward the shelf. During periods of strong northward local winds, but regionally downwelling-favorable winds and associated onshore flow, the WLR pressure near the entrance increases, causing a reversal in the outer to inner estuary pressure gradient. So the result is that the currents in the outer part of the estuary are dominated by tidal and remote atmospheric forcing, while the near-surface currents in Herendeen Bay are more a function of local, topographically steered winds.

4.3 WATER PROPERTY DISTRIBUTIONS

The moored instruments also recorded temperature and salinity, resulting in time series of water properties at set locations in the estuary. These measurements were supplemented by profiling surveys of velocity, temperature, and salinity that provide sections of spatial water property information, both

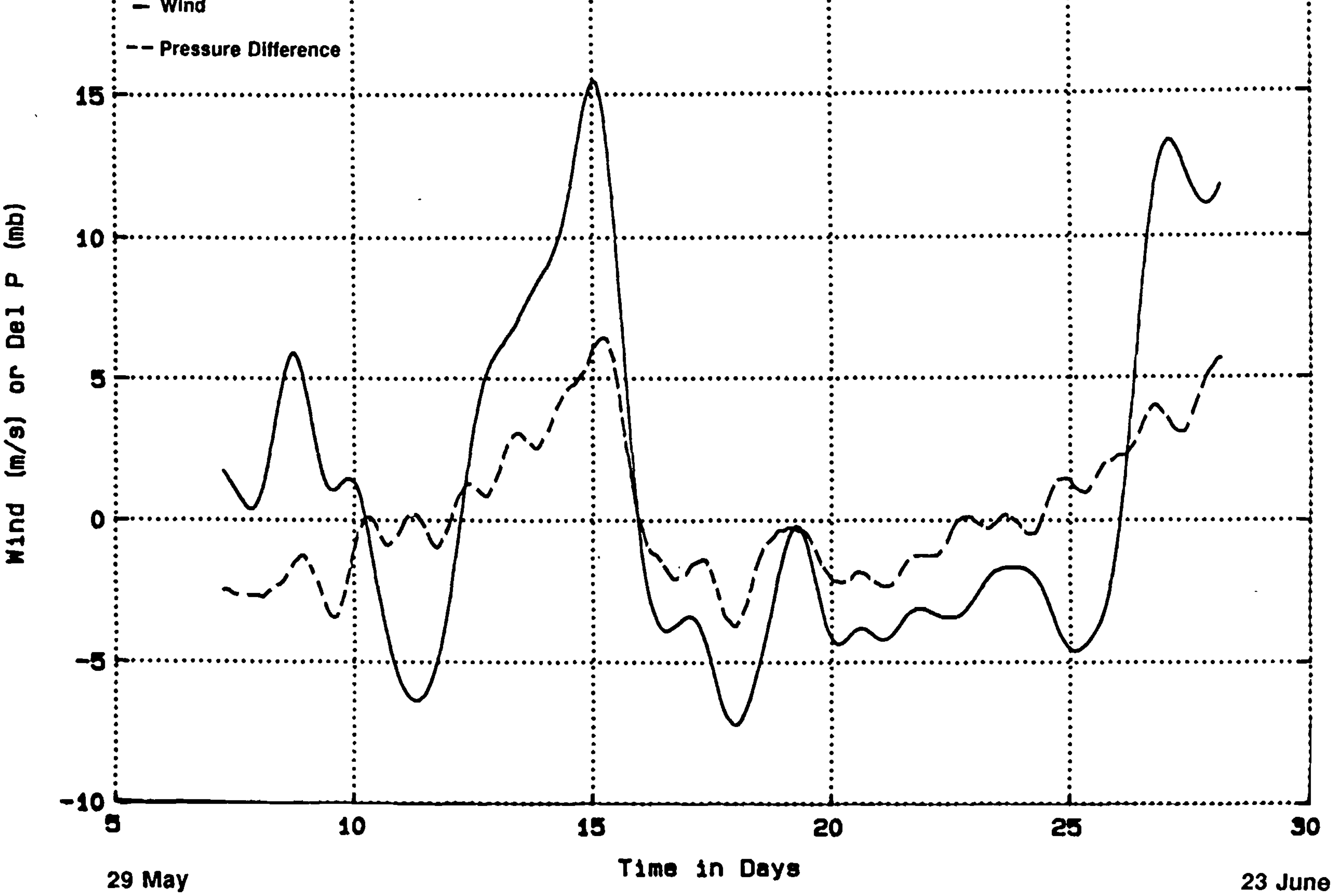


Figure 4-8. Low-pass-filtered northwind component of Harbor Point wind (solid line) and the low-pass-filtered pressure differential (station 1 - station 4) between WLRs at the harbor entrance (station 1) and in Herendeen Bay (station 4) are plotted from 29 May to 23 June 1989.

combination of these two types of data allows us to evaluate, at least to the first order, the temporal and spatial variability of temperature and salinity in the estuary.

Figure 4-9 shows the low-pass-filtered temperature and salinity time series for all the instruments. The maximum temperature, about 13°C for most current meters, occurs around 18 August 1989, just prior to a period of enhanced storm activity which led to increased mixing and lower temperatures. Most of the instruments started the deployment at a minimum temperature of around 4°C. ACM 88, at 55 m in Herendeen Bay, continues to rise throughout the deployment period from 1.5°C to 7.65°C. Salinity at both stations 1 and 3 decreases over the summer season. The salinity at station 3 (5072), 15 m, began the deployment with maximum values of about 31.02 psu and ended on 14 July 1989 with values on the order of 30.00 psu. The 5072 salinity time series continues beyond this date, but values are suspect due to sensor fouling. Station 5 RCM started with a value of 29.25 psu, decreased to about 27 psu by 14 August, and ended with a value of 23.4 psu by 18 September 1989. Temperature and salinity measurements from the deployment and recovery surveys in May and October at these locations appear as profiles in Appendix E and are consistent with these values.

Horizontal Gradients

Time series of horizontal gradients between current meters at the same depth level, from the mouth of Port Moller to Herendeen Bay, are plotted in Figure 4-10. The Port Moller to Johnson Channel time series represents the temperature gradient at 7.5 m over a distance of 20 km. The maximum measured temperature and salinity differences between the inner and outer harbor, of 3°C and 2.5 psu, respectively, occur at 15 m between stations 3 (5072) and 5 (3290) separated by 15 km. The largest change in gradient, 4.5°C in temperature and 1 psu in salinity, was recorded between these two stations during the period 19 June through 1 July 1989. Prior to this event, temperature in the outer estuary was about 2°C higher than in Herendeen Bay. The temperature differential following this event oscillates around zero, with about a 10-day periodicity. Information concerning the salinity gradient is not available after 14 July 1989.

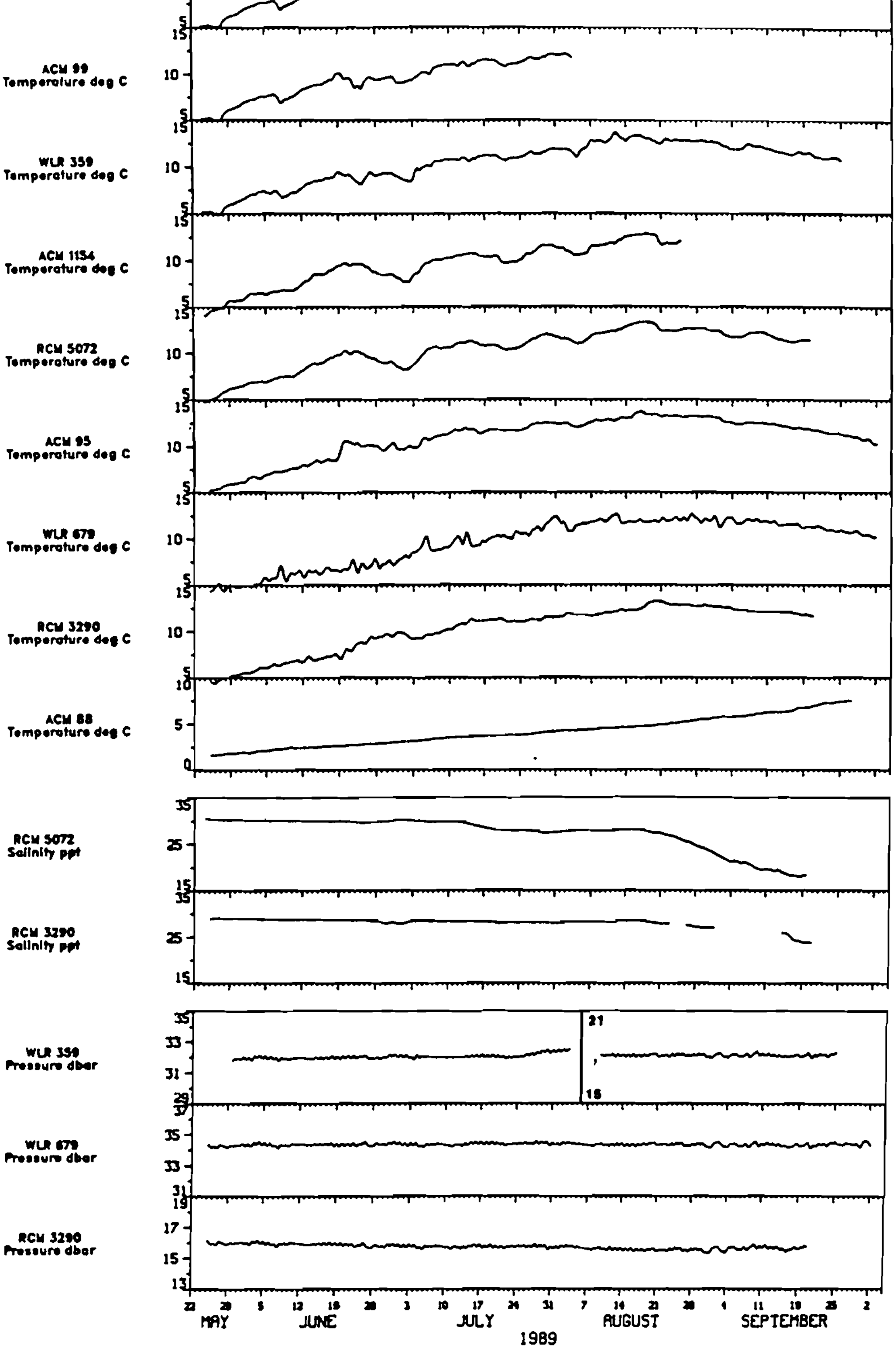


Figure 4-9. Low-pass-filtered temperature, salinity, and pressure records from all instruments deployed in Port Moller during the summer of 1989.

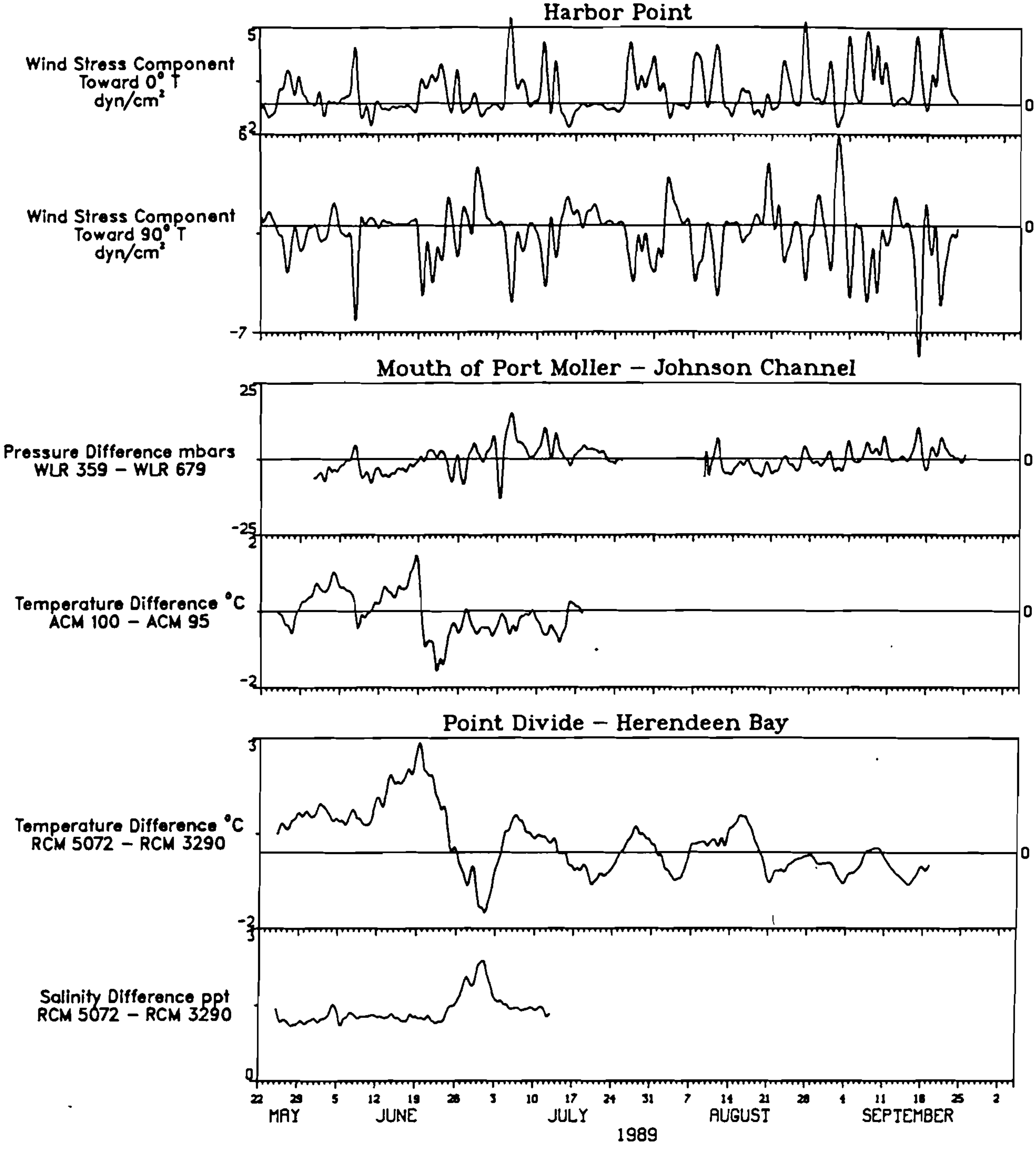


Figure 4-10. Horizontal temperature, pressure, and salinity differentials between instruments at similar depths from near the harbor entrance to inner Herendeen Bay. Wind stress from Harbor Point is also plotted for reference.

following an unusually light period of winds. It appears that during the calm period, the shallower, outer harbor heated up and stratified more rapidly than the inner bay, causing a positive increase in the temperature differential. After a strong front came through on 19 June, the shallow, outer harbor water was mixed from top to bottom incorporating colder, saltier water from the shelf, while Herendeen Bay, due to its location and depth, experienced less wind induced mixing. This resulted in an outer to inner harbor temperature gradient decrease and salinity gradient increase (Figure 4-10).

Satellites, when not obstructed by clouds, have the advantage of viewing the entire study area at once. Twelve AVHRR satellite images of Port Moller were collected during the deployment period to provide an overview of the seasonal surface thermal structure. Absolute temperature values for these images (Appendix B) should be viewed with caution as no atmospheric or time of day corrections have been applied to the thermal data and no reliable *in situ* observations were available for calibration. However, temperature gradients provided by these images should be comparable to near-surface water temperature measurements. Satellite observations indicate the surface temperature differential between points at station 1 and station 5 to be between 1 and 3°C, which is consistent with the current meter observations.

Since water properties, like currents, are strongly influenced by tidal energy, it is difficult to compare inner to outer harbor temperature and salinity gradients using the profile data since it could not be collected simultaneously. However, comparisons can be made of data taken within a few days of each other during the same phase of the tide. Table 4-4 shows the approximate horizontal gradients from the outer to inner harbor, a distance of about 25 km, as measured by survey data. The differentials are calculated using the average values of temperature and salinity from the 29 May (Section 2) and 5 October 1989 Port Moller sections compared with data from station 5 in Herendeen Bay (see Appendices E and F). All but the Herendeen Bay October data were collected during ebb tide. One can see that Herendeen Bay experiences a greater change in temperature and salinity over time and as the season progresses, the horizontal temperature differential from the inner

Large-Scale Horizontal Gradients

	Location	May	October	Δ Time (October-May)
Temperature (°C)	Port Moller Entrance	5.85	9.20	3.35
	Herendeen Bay	4.82	9.82	5.00
ΔT	25,000 m	1.03	-0.62	
Salinity (psu)	Port Moller Entrance	30.20	29.95	-0.25
	Herendeen Bay	28.75	27.29	-1.46
ΔS	25,000 m	1.45	2.66	
Density (σT)	Port Moller Entrance	23.75	23.15	-0.60
	Herendeen Bay	22.75	20.97	-1.78
Δρ	25,000 m	1.00	2.18	

Vertical Gradients at Station 5 in Herendeen Bay

	Depth (m)	May	October	Δ Time (October - May)
Temperature (°C)	15	4.82	9.82	5.00
	55	2.40	8.31	5.91
ΔT	40 m	2.42	1.51	
Salinity (psu)	15	28.75	27.29	-1.46
	55	29.27	28.94	-0.43
ΔS	40 m	-0.62	-1.65	
Density (σT)	15	22.75	20.97	-1.78
	55	23.36	22.46	-0.90
Δρ	40 m	-0.61	-1.49	

months.

Using the transects from Port Moller Entrance (Appendix F) to examine horizontal gradients on a smaller scale, in May we find a maximum temperature differential across the 6 km wide section of 1.2°C at the beginning of Ebb (29 May, Section 1) and a maximum salinity gradient of 1.2 psu across the same section at the beginning of Flood (29 May, Section 4). This result indicates that the temperature signal, strongest during flood, is dominated by cold, shelf water, while the salinity signal originates in the inner bays with fresh water runoff and is most prevalent during ebb. The 5 October Port Moller section portrays a relatively homogeneous temperature distribution (0.5°C gradient), with a larger cross-channel salinity gradient of 1.8 psu, than was observed in May. This is consistent with the larger-scale seasonal horizontal gradient pattern of decreasing temperature and increasing salinity gradients, observed from the inner to outer estuary. The magnitudes of the maximum large-scale/along-channel and small-scale/cross-channel temperature and salinity gradients encountered, 0.2°C/km, 0.17 psu/km, and 0.2°C/km, 0.2 psu/km, respectively, are also comparable.

The temperature encountered at any one location (obtained from current meter data) has a maximum tidal range of 2.5°C, with a decreasing differential as the season progresses. Referring once again to the Port Moller section series from 29 May 1989, we see a maximum temperature and salinity differential, over one tidal cycle, 1.9°C and 0.7 psu on the western side, respectively, and a 1.1°C and 0.9 psu change on the eastern side of the harbor entrance. The spatial distributions of these temperature and salinity changes with time are suggestive of shelf inflow on the west and outflow on the east side of the entrance to Port Moller. Profiling velocity measurements indicate that this is indeed the case, but that the magnitude of the velocity on the eastern side of the entrance appears to be greater. So the tidal range in temperature is comparable to the horizontal differences encountered in the estuary, while the tidal salinity range is less than horizontal gradient observations in the estuary.

vertical stratification in the sections at the entrance to Port Moller, in Hague Channel and off Harbor Point (Appendix F). The only location that exhibits any significant vertical variation in water properties is Herendeen Bay, where the water is deeper and tidal mixing is limited. Evidence for this is given in Figure 4-11, where the vertical temperature difference from the near-surface to deep current meters at stations 1 and 5 were calculated. Station 1 indicates a small, increasing vertical temperature gradient as the season progresses. Station 5, with the deep current meter at 55 m, shows thermal stratification slowly increasing from a 2°C differential to 8°C from May to August 1989, and a more rapid decline back to around 2°C again in October. Notice that temperature increases until about 18 August 1989, the point at which storm activity and, hence, mixing and cooling increase. Figure 4-12 shows profiles of temperature, salinity and density at station 5 in Herendeen Bay from May and October with the depths of the two current meters superimposed for reference. One can see that temperature increases throughout the water column, while the temperature profile shape and gradient remains approximately the same. Salinity decreases throughout the water column, but much more so near the surface, resulting in an increased salinity gradient from May to October. So it is primarily the freshwater input at the surface over the summer that contributes to the increased stratification seen in the density profile from October.

Actual temperature and salinity values and their associated vertical gradients and change with season are listed in Table 4-4. Using an average water column increase of 5.45°C/127 days results in a heating rate of 0.043°C/day. This value is greater than that which can be attributed to just diffusion processes, indicating that some type of mechanical mixing must be occurring in Herendeen Bay. The decrease in salinity over the water column (about 1 psu) is representative of a substantial influx of freshwater into Herendeen Bay over the summer season.

Water Budget

The volume of freshwater inflow was calculated three different ways, in order to obtain the best estimate of water residence time and flushing rate possible for the Herendeen Basin. The first method is based on calculating

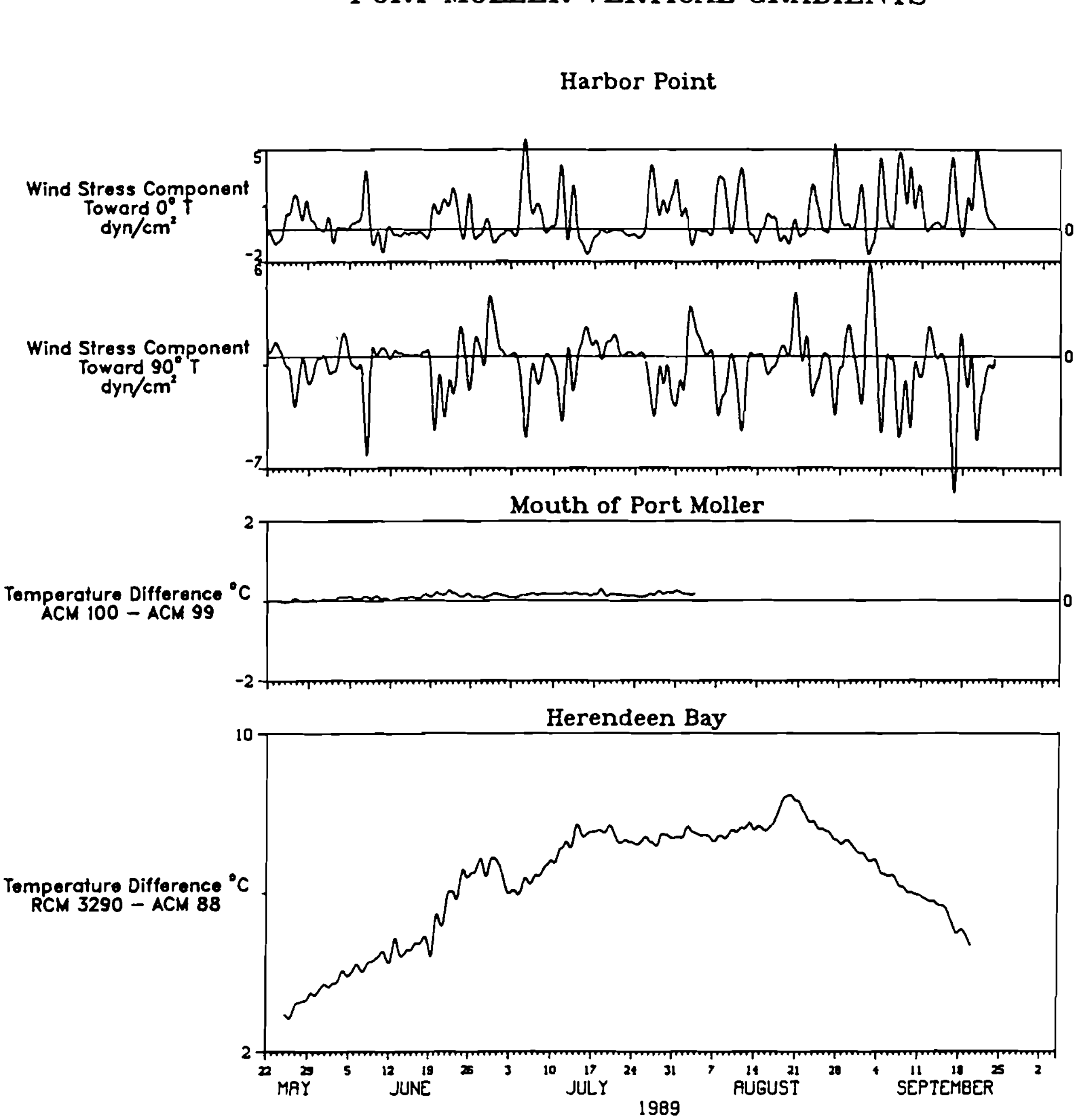


Figure 4-11. Vertical temperature gradients at station 1 in the harbor entrance and in deep Herendeen Bay are plotted along with the Harbor Point wind stress for reference.

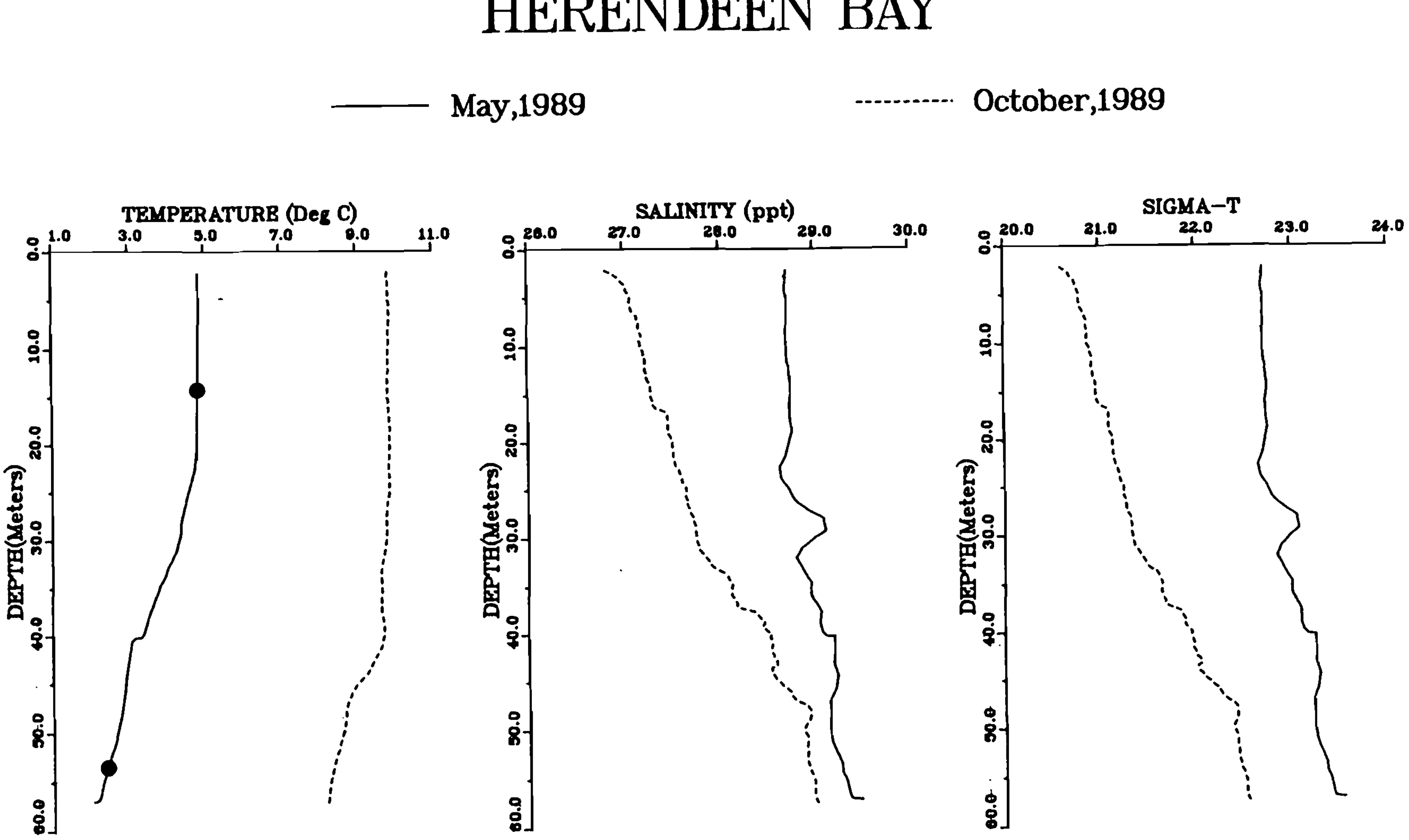


Figure 4-12. Temperature, salinity, and density profiles in deep Herendeen Bay from May and October 1989.

some of the streams were gauged, but none of these data are available in this area for 1989. However, climatic data from Port Moller are available for the period 1959-1969, and climatic data from the same period, as well as 1989, are available for Cold Bay, which is 75 miles southwest of Port Moller on the peninsula (see Appendix C). The Port Moller and Cold Bay 1959-1969 climatic mean precipitation records are plotted versus month in Figure 4-13. If a relationship between these two records can be established, a 1989 precipitation record for Port Moller can be estimated.

It appears from Figure 4-13 that the two stations are reasonably well correlated during the winter months (December through May), but Port Moller peaks in August as opposed to September for Cold Bay. The peak and total rainfall also tend to be higher at Port Moller than at Cold Bay. The 1959-1969 mean yearly rainfall totals at these sites are 94.61 and 79.74 cm, respectively. It can be seen, when plotting these two records relative to each other (Figure 4-14), that there is no obvious correlation between them for the record as a whole, but a relatively good linear correlation can be made for the 6 winter months. Now if we assume that the ratio of total rainfall between the two sites remains the same, we can get the total rainfall for 1989 at Port Moller. If we also assume that the ratio of the two main peaks in the two records remains the same, and occurs in the same month as that indicated by climatic measurements, we can estimate the amount of rainfall in August 1989 at Port Moller. Next, we can calculate the rainfall for each of the winter months at Port Moller using the linear relation derived in Figure 4-14. That leaves 5 months of precipitation unaccounted for. The rainfall in the remaining 5 months is constrained by the total amount of rainfall and can be estimated if one assumes a curve shape similar to the climatic data.

The result of this exercise, estimated precipitation at Port Moller for 1989, is plotted in Figure 4-15 along with the Cold Bay data from that year. The total rainfall estimated for 1989 at Port Moller is 109 cm, which is consistent with climatology. Based on this estimate and the drainage basin area (776 km^2), calculated using a digitizer and topographic maps, the total

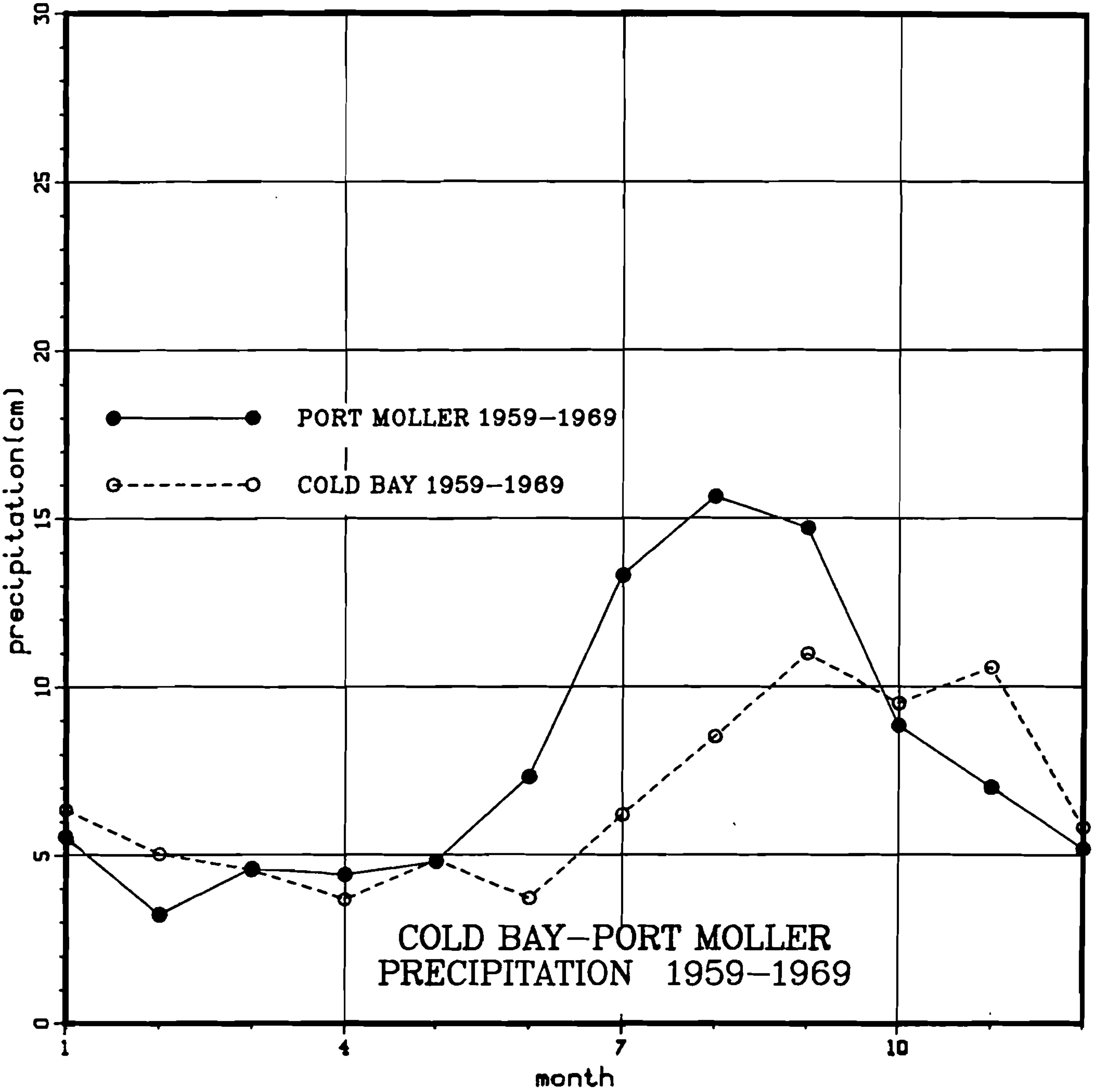


Figure 4-13. The 1959-1969 climatic mean monthly precipitation (cm) for Cold Bay and Port Moller.

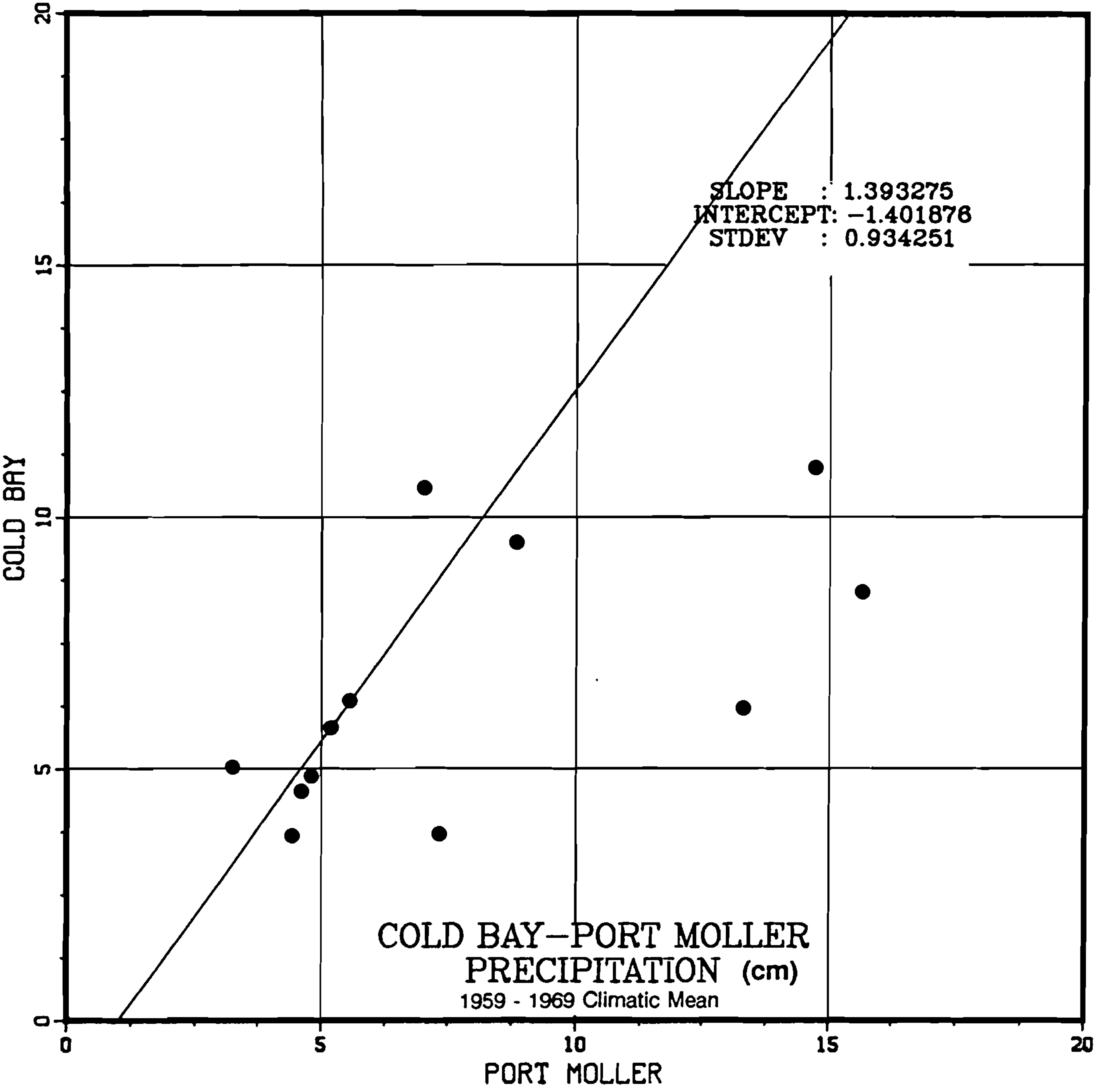


Figure 4-14. The 1959-1969 climatic mean monthly precipitation (cm) of Cold Bay plotted against Port Moller. The linear regression is fit to the six points on the lower left side of the plot, which represent the months of December through May.

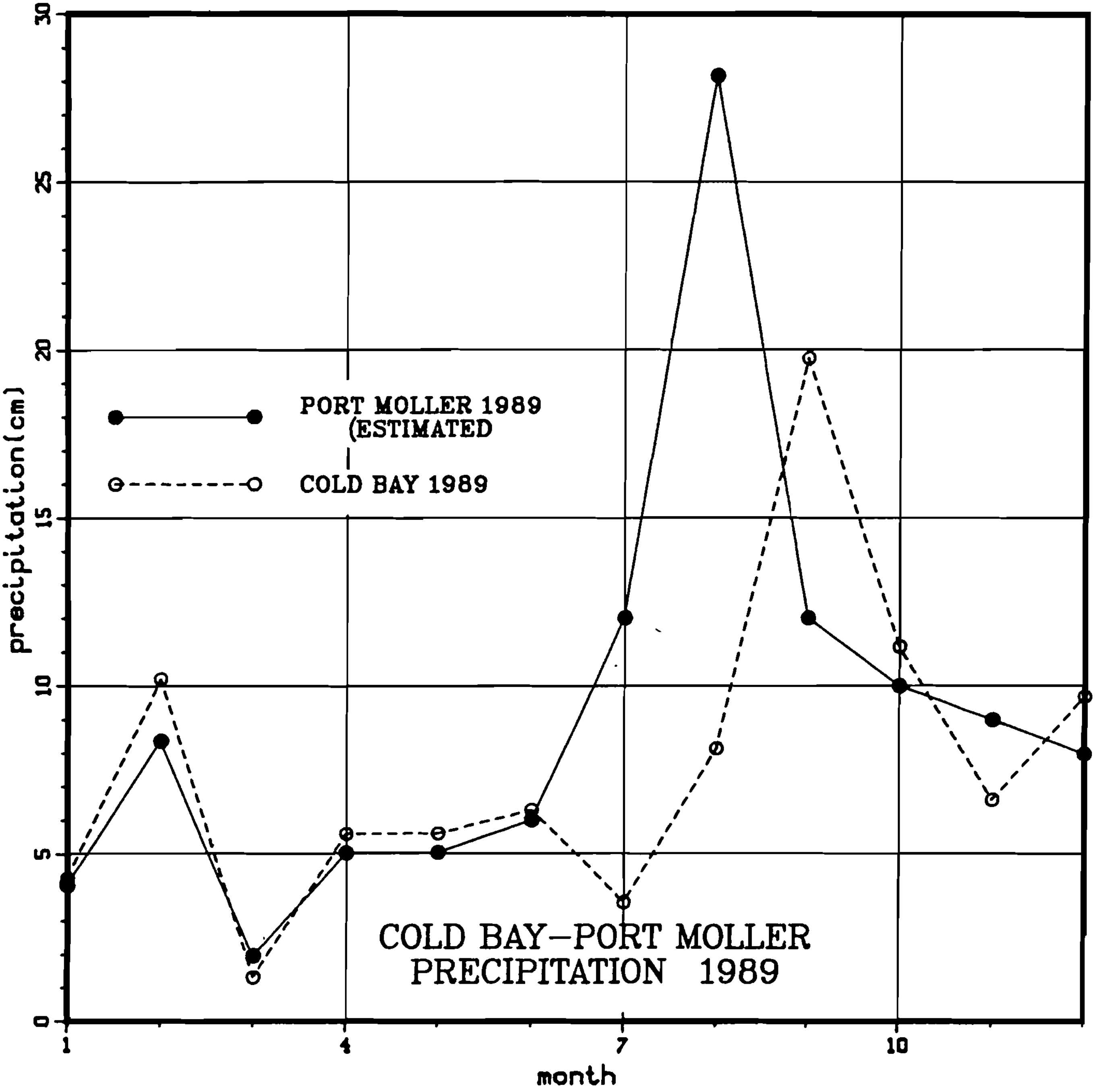


Figure 4-15. The 1989 monthly precipitation (cm) for Cold Bay (solid line) and the predicted 1989 monthly precipitation (cm) for Port Moller (dashed line).

Evaporation for this area is estimated to be on the order of 2mm/day (Griffiths and Driscoll, 1982). If we multiply this by the surface area of Herendeen Bay (251 km^2 and the number of days in the 4-month sampling period (122), we obtain the total amount of fresh water lost, $0.6x10^8$ m^3. Therefore, the total freshwater input to the system over this time period is $P-E = 4.3x10^8$ m^3.

A check on this value can be done by using the difference between the average water column salinity in May to October and calculating how much fresh water is necessary to reduce the salinity of the entire basin by this amount. Table 4-4 shows that the salinity dropped an average of 1 psu across the entire water column in the basin for this period. Calculating the volume of the basin, at mid-tide, from the bathymetry chart with a digitizer, yields $2.3x10^9$ m^3. Therefore the amount of fresh water necessary to decrease the salinity of this body of water 1 psu, assuming steady state, is $1x10^8$ m^3. This value is lower than that predicted by the rainfall estimate, but given the set of assumptions, the fact that they are the same order of magnitude is encouraging.

A third way to estimate the volume input to the basin is to determine the outflow and assume steady state. Since we have the average velocity out of the embayment entrance from current meter measurements (11 cm/sec) and can determine the cross-sectional area of the channel at this point (25,000 m^2) an estimate of the volume transport over the 4-month period can be made. An average velocity of 1.1 cm/sec, representative of the whole section, was used in the calculation, since the measured value of 11 cm/sec is assumed to be the channel maximum. The area times the flow rate yields a transport of 138 m^3/sec out of the estuary, which converts to a total outflow volume of $14x10^8$ m^3 for the 4-month period. This value is almost three times as large as that estimated by the rainfall technique and an order of magnitude larger than that calculated using the observed seasonal salinity differential. The calculated values used in the comparison between these three input volume determination techniques are listed in Table 4-5.

In evaluating which of these values is closest to reality, one must take into account a number of factors. First of all, if we convert these volumes

Measurement Type	Total Volume ($\times 10^8$ m^3)	Volume Transport		Flowrate		ΔS	Residence Time (yr)
		($\times 10^6$ m^3/day)	(m^3/sec)	(m/day)	(cm/sec)	($^{o}/_{oo}$)	
P-E	4	4	41	280	0.32	5	1.5
Currents	14	12	138	950	1.10	18	0.5
Δ Salinity	1	1	8	52	0.06	1	7.5

estimate and the channel velocity measurement techniques. These salinity differences seem high, especially since the survey measurements from May to October generally confirm the 1 psu salinity differential. There are a couple of explanations for this. One is that a lower average salinity occurred earlier in the season, say in August and we are not measuring the maximum differential from May, in which case salinity may in fact have experienced a greater decrease than 1 psu, although 18 psu seems a little high. The other may be that there is some average flow of saline water back into the basin deep in the channel, which, if unaccounted for, makes our average observed salinity differential estimates too low and our velocity measurements too high, because it eliminates the one source, steady state assumption.

The relative error associated with each of the measurements used in the water budget calculation are estimated to be on the order of:

Area ±10%

P-E ±20%

Salinity ±5%

Velocity ±100%

The error associated with area is due to the accumulated errors of delineating the drainage basin by marking the maps and digitizing. P-E errors are associated with the lack of direct Port Moller climatic information as discussed above. Salinity is as good as the measurements, both moored and profiling. Velocity exhibits the largest error because we are looking at a nontidal constant outflow through Point Divide of 1-10 cm/sec, upon which is superimposed a tidal signal of 50-150 cm/sec, resulting in a large relative error and uncertainty. One can see from this analysis that the estimates obtained for the simple, steady-state water budget calculation represents a very rough idea of residence time in the estuary, with velocities being the greatest source of error.

The input volume that is most conceivable based on all the information provided is probably somewhere between the salinity differential and rainfall estimates of 1-4x10^8 m^3. The volume input resulting from the velocity-based calculation yields a volume which represents about half the water in the entire basin and there is no evidence to support this large an input. As overestimated the precipitation influx. If we take a value of 2.0×10^8 m^3, mid-range between these two 4-month volume estimates, and calculate a residence time for the basin, we get something on the order of 3 years.

Since deep Herendeen Bay water is most likely renewed episodically by either convective overturn within the bay during winter, or like southeast Alaska fjords, by the occurrence of denser water at sill depth during some part of the year, the 3-year residence time predicted with the box model appears to be an overestimate. Note that tidal flushing of the inner bay is impeded by the long, thin channel connecting it to the outer harbor, and therefore a standard tidal prism flushing model does not apply.

Even though the steady-state water budget calculation results in a suspect residence time, it provides insight into the size and relative importance of the various factors contributing to fluxes into and out of Herendeen Bay.

The primary forcing mechanism governing the circulation in the Port Moller/Herendeen Bay complex is the tide, which results in currents of over 140 cm/sec and vertically well-mixed water in the main channels of the outer estuary. Tidal effects are substantially reduced in Herendeen Bay. Superimposed on the tidal current oscillation is an average estuary outflow of 11 cm/sec. Similar velocities and flow patterns were observed on the shelf near the mouth of Port Moller by Kinder and Schumacher (1981). Non-tidal currents near the entrance to the estuary are dominated by shelf effects, such as onshore flow caused by downwelling conditions set up by regional alongshore winds. The local winds are out of the southeast at an average of about 9 m/s, the result of topographic steering of regional wind fields generated by passing lows. In summary, the circulation in the Port Moller/Herendeen Bay estuary is dominated by tidal and remote atmospheric forcing in the outer harbor and by local, topographically steered winds in Herendeen Bay.

Due to tidal mixing, horizontal water property gradients are stronger than vertical gradients in the main channels of the outer harbor. The magnitude of the along- and cross-channel horizontal gradients of temperature and salinity in the estuary are comparable. Stronger vertical gradients and stratification exist in Herendeen Bay where tidal fluctuations are limited and there is a substantial freshwater influx. For these reasons, during the 1989 summer season Herendeen Bay experienced a greater change in temperature and salinity over time as compared to the outer estuary. As the season progresses, temperature in Herendeen Bay increases at an average rate of 0.043°C/day and salinity decreases at a rate of 7.87×10^{-3} psu/day, while the horizontal temperature differential from the inner to outer estuary decreases and the salinity gradient increases. Volume transport calculations, based on rainfall estimates, observed salinity changes and velocity measurements, predict a residence time on the order of 3 years for Herendeen Bay.

These physical parameters may have a substantial impact on the biological systems in the estuary. The combination of a deep basin sheltered from large tidal effects and atmospheric events with a high freshwater influx leads to a stratified water column, which is one of the critical factors conducive to enhanced biological activity.

General recommendations for future work in the Port Moller area include: use of a larger, more reliable boat for the deployment and recovery of current meters and data collection in general; more measurements in the eastern arm; a rain gauge and meteorological station in central Herendeen Bay; stream gauges; a temperature and conductivity chain in Herendeen Bay; O_2 measurements, especially in Herendeen Bay; a set of profiling time series at various locations; and, if possible, deployment of a suite of current meters and tide gauges, similar to those used for this study, over the winter season.

Winter profiling of temperature, salinity and oxygen, as well as year-round monitoring, would provide information on the mechanism and frequency of Herendeen Bay deepwater renewal. Determining how and when this process occurs is critical to understanding the biological environment of Herendeen Bay and its susceptibility to human intervention.

Overall, the summer 1989 physical oceanography program was successful in providing a first order description of the processes affecting the circulation and water property distribution in the Port Moller/Herendeen Bay estuary and laying the foundation for concurrent and future biological, chemical and physical oceanographic studies in this area.

Armstrong, D., L. Incze, L. Armstrong, D. Wencker, and B. Dumbauld. 1981. Distribution and abundance of decapod crustacean larvae in the S.E. Bering Sea with emphasis on commercial species. Environmental Assessment Alaska Continental Shelf. Annual Rep. (1981) 2:365-596.

Baker, E.T. 1981. North Aleutian Shelf transport experiment. Annual Reports of Principal Investigators for the Year Ending March 1981. Vol. VI, OCSEAP/NOAA, Boulder, CO. pp. 329-389.

Bakkala, R.G. and G.B. Smith. 1978. Demersal Fish Resources of the Eastern Bering Sea: Spring 1976. NOAA/NMFS/NWAFC Processed Rept., Seattle, Wash., 234 pp., Data Appendices, 534 pp.

Barton, L.H., I.M. Warner, and P. Shafford. 1977. Herring spawning surveys - southeastern Bering Sea. Environmental assessment of the Alaska Continental Shelf. NOAA, OCSEAP Final Rep. 7:1-112.

Bax, N.J. 1985. Simulations of the Effects of Potential Oil Spill Scanarios on Juvenile and Adult Sockeye Salmon (*Oncorhynchus nerka*) Migrating Through Bristol Bay, Alaska; NWAFC Processed Report 85-03. In: Outer Continental Shelf Environmental Assessment Program, Final Reports of Principal Investigators 36 Part 1: 455-595

Bax, N.J. 1987. Effects of a tanker accident and an oil blowout in Bristol Bay, Alaska, on returning adult sockeye salmon (*Oncorhynchus nerka*) - a simulation study.

Blanton, J.O., J.A. Amft, D.K. Lee, and A. Riordan. 1989. Wind Stress and Heat Fluxes Observed During Winter and Spring 1986. In: Journal of Geophysical Research, Vol. 94, No. C8, pp. 10,686-10,698.

Brower, W.A., R.G. Baldwin, C.N. Williams, Jr., J.L. Wise, and L.D. Leslie. 1988. Climatic Atlas of the Outer Continental Shelf Waters and Coastal Regions of Alaska. U.S. Department of Commerce, NOAA, OCSEAP, 519 pp.

Cline, J.D., K. Kelly-Hansen, and C.N. Katz. 1982. The Production and Dispersion of Dissolved Methane in the Southeastern Bering Sea. Final Report, OCSEAP, pp. 309-417.

Coachman, L.K. 1986. Circulation, water masses, and fluxes on the southeastern Bering Sea shelf. Continental Shelf Res., Vol. 5, Nos. 1/2, pp. 23-108. Pergamon Press, Ltd., Great Britain.

Coachman, L.K. and R.L. Charnell. 1977. Finestructure in outer Bristol Bay, Alaska. Deep Sea Res., 24:869-889.

Coachman, L.K. and J.J. Walsh. 1981. A diffusion model of cross-shelf exchange of nutrients in the southeastern Bering Sea. Deep Sea Res., 28A(8):819-846.

Annual Report, SFOS APP87-100. School of Fisheries and Ocean Sciences, University of Alaska, Fairbanks, pp. 195-253.

Dodimead, A.J, F. Favorite, and T. Hirano. 1963. Review of oceanography of the subarctic Pacific region. In: Salmon of the North Pacific Ocean, Bulletin. International North Pacific Fisheries Commission, 13, 195 pp.

Feely, R.A., G.J. Massoth, A.J. Paulson, M.F. Lamb, and E.A. Martin. 1981. Distribution and elemental composition of suspended matter in Alaskan coastal waters. NOAA Technical Memo ERL-PMEL-27. Pacific Marine Environmental Laboratory, Seattle. 119 pp.

Flagg, C.N. 1977. The kinematics and dynamics of the New England continental shelf and shelf/slope front. Ph.D. Thesis, Department of Meteorology, MIT, Cambridge, MA and Woods Hole Oceanographic Institution, Woods Hole, MA.

Fukuhara, F.M. 1985. Northwest and Alaska fisheries center processed report 85-11: Biology and fishery of southeastern Bering Sea red king crab (*Paralithodes camtschatica*, Tilesius). U.S. Dep. Commer., NOAA, OCSEAP Final Rep. 36 Part 2 (1986): 801-982.

Gamble, J.C., P. MacLachlan, N.T. Nicholl, and I.G. Baxter. 1981. Growth and feeding of Atlantic herring larvae reared in large plastic enclosures. Rapp. Reun. Cons. Int. Explor. Mer. 178:121-134.

Griffiths, J.F. and D.M. Driscoll. 1982. Survey of Climatology. Charles E. Merrill Publishing Company, 358 pp.

Haynes, E.B. 1974. Distribution and relative abundance of larvae of king crab, *Paralithodes camschatica*, in the Southeastern Bering Sea, 1969-1970. Fish. Bull. 72:804-812.

Johnson, W.R. and C.L. Greengrove. 1990. Circulation in the Port Moller/Herendeen Bay Estuary, Alaska. EOS, 71(2), p. 122.

Katz, C.N., J.D. Cline, and K. Kelly-Hansen. 1982. Dissolved Methane Concentration in the Southeast Bering Sea, 1980 and 1981. NOAA Data Report ERL PMEL-6. Pacific Marine Laboratory, Seattle. 194 pp.

Kinder, T.H. and J.D. Schumacher. 1981a. Hydrographic Structure over the Continental Shelf of the Southeastern Bering Sea. In: The Eastern Bering Sea Shelf: Oceanography and Resources, Hood, D.W. and J.A. Calder (eds.), Vol. I, pp. 31-52.

Kinder, T.H. and J.D. Schumacher. 1981b. Circulation over the Continental Shelf of the Southeastern Bering Sea. In: The Eastern Bering Sea Shelf: Oceanography and Resources, Hood, D.W. and J.A. Calder (eds.), Vol. I, pp. 53-75.

1985. Northwest and Alaska Fisheries Center Processed Report 85-19: Evaluation of the effects of oil development on the commercial fisheries in the Eastern Bering Sea. U.S. Dept. Commer., NOAA, OCSEAP Final Rep. 36 Part 1 (1986):1-48.

Laevastu, T. and F.M. Fukuhara. 1985. Northwest and Alaska Fisheries Central Processed Report 85-01; Oil on the bottom of the sea - a simulation study of oil sedimentation and its effects on the Bristol Bay ecosystem. U.S. Dept. Commer., NOAA, OCSEAP Final Rep. 36 Part 1 (1986):395-454.

Lasker, R. 1985. What limits clupeoid production? *Can. J. Fish. Aquat. Sci.* 42:31-38.

Lasker, R. 1978. The relationship between oceanographic conditions and larval anchovy food in the California Current: identification of factors contributing to recruitment. *Rapp. Reun. Cons. Int. Explor. Mer.* 173:212-230.

Lasker, R. 1975. Field criteria for survival of anchovy larvae: the relation between inshore chlorophyll maximum layers and successful first feeding. *Fish. Bull.*, U.S. 73:453-462.

LGL, Inc. 1987. Environmental Characterization and Biological Utilization of the North Aleutian Shelf Nearshore Zone, Final Report. Prepared for NOS/OMA/OAD, Alaska Office. July.

Marlow, M., et al. 1980. "Resource Report for Proposed OCS Lease Sale No. 75. Northern Aleutian Shelf, Bering Sea, Alaska," Open-File Report. Menlo Park, CA, U.S. Dept. of the Interior, Geological Survey.

Munk, W.H. and D.E. Cartwright. 1966. Tidal Spectroscopy and Prediction. *Phil. Trans. Royal Soc. London*, Series A, No. 1105, Vol. 259, pp. 533-581. May.

Niebauer, H.J. 1981. Recent Fluctuations in Sea Ice Distribution in the Eastern Bering Sea. *In*: The Eastern Bering Sea Shelf: Oceanography and Resources, Hood, D.W. and J.A. Calder (eds.), Vol. I, pp. 133-140.

Overland, J.E. 1981. Marine Climatology of the Bering Sea. *In*: The Eastern Bering Sea Shelf: Oceanography and Resources, Hood, D.W. and J.A. Calder (eds.), Vol. I, pp. 15-22.

Overland, J.E., C.H. Pease, 1982. A Model of the Atmospheric Boundary Layer Over the Marginal Ice Zone: *J. Geophys. Res.*, 88(C5): 2836-2840.

Pace, S.D. 1986. Environmental Characterization of the North Aleutian Shelf Nearshore Region: Characterization, Processes, and Vulnerability to Development. U.S. Dept. Commer., NOAA, OCSEAP Final Report 38 (1985):1-473.

Report, SFOS APP87-100. School of Fisheries and Ocean Sciences, University of Alaska, Fairbanks, pp. 385-404.

Pearson, C.A., H.O. Mofjeld, and R.B. Tripp. 1981. Tides of the Eastern Bering Sea shelf. *In*: The Eastern Bering Sea Shelf: Oceanography and Resources. D.W. Hood and J.A. Calder (eds.). Vol. I:111-130. NOAA, distrib. by Univ. Washington Press, Seattle, WA.

Roden, G.T. 1967. On river discharge into the northeastern Pacific Ocean and the Bering Sea. *J. Geophys. Res.* 72(22):5613-5629.

Royer, T.C. 1975. Seasonal variations of waters in the northern Gulf of Alaska. *Deep Sea Res.* 22(6): p 403-416

Sambrotto, R.N. 1983. Nitrogen Utilization during Spring Phytoplankton bloom development in the southeast Bering Sea. Ph.D. dissertation, University of Alaska, Fairbanks, 274 pp.

Schnack, D. 1981. Studies on the mortality of Pacific herring larvae during their early development, using *in situ* containers. *Rapp. Reun. Cons. Int. Explor. Mer.* 178:135-142.

Schumacher, J.D. and T.H. Kinder. 1983. Low-frequency current regimes over the Bering Sea shelf. *J. Phys. Oceanogr.* 13(4):607-623.

Schumacher, J.D. and P.D. Moen. 1983. Circulation and Hydrography of the Unimak Pass and the Shelf Waters North of the Alaska Peninsula. NOAA Technical Memorandum ERL PMEL-47. Pacific Marine Laboratory, Seattle. 75 pp.

Schumacher, J.D., T.H. Kinder, D.J. Pashinski, and R.L. Charnell. 1979. A structural front over the continental shelf of the eastern Bering Sea. *J. Phys. Oceanogr.* 9:79-87.

Sharma, G.D. 1974. Contemporary depositional environment of the eastern Bering Sea. *In*: Oceanography of the Bering Sea, D.W. Hood and E.J. Kelley (eds.). Occ. Pub. No. 2. Inst. Mar. Sci., Univ. Alaska, Fairbanks. pp. 517-552.

Shirley, T.C. and S.M. Shirley. 1988. Seasonal abundance of red king crab larvae in Auke Bay, 1986. *In*: Vol. I. APPRISE Annual Report, SFOS APP87-100. School of Fisheries and Ocean Sciences, University of Alaska, Juneau, pp. 363-382.

Stringer, W.J., 1981. Interaction of Bering Sea and Norton Sound Pack Ice; Submitted to Arctic and Alpine Research, 16 pp.

Sverdrup, H.U., M.W. Johnson, and R.H. Fleming. 1942. The Oceans. Prentice-Hall, Inc., Englewood Cliffs, NJ, 1087 pp.

Res., Vol. 76, No. 32. pp. 8021-8041.

U.S. Department of Commerce. 1988. United States Coast Pilot 9; Pacific and Arctic Coasts. 328 pp.

U.S. Department of the Interior, Minerals Management Service, Alaska Outer Continental Shelf Region. 1985. Draft Environmental Impact Statement North Aleutian Basin Sale 92.

Ziemann, D.A., L. Conquest, P. Bienfang, and J. Kanda. 1988. Patterns of primary production and sedimentation during the 1987 spring bloom in Auke Bay, Alaska. In: Vol. I. APPRISE Annual Report, SFOS APP87-100. School of Fisheries and Ocean Sciences, University of Alaska, Fairbanks, pp. 29-194.

APPENDIX A

PORT MOLLER 1989
FIELD LOGS

PORT MOLLER
MAY 1989 DEPLOYMENT

11 May

0800 Arrived at the EG&G facility and picked up Direct Reading Current Meter (DRCM) system.

0900 Arrived NOAA/OCSEAP and picked up Mr. J. Dermody.

0945 Arrived Anchorage Airport (ANC) and checked extra baggage on Reeve Air Aleutian (RAA).

1045 Departed ANC for Cold Bay.

1250 Arrived Cold Bay and transferred equipment to Peninsula Air.

1900 Departed Cold Bay for Port Moller.

1930 Arrived Port Moller and checked into Peter Pan Seafood (PPSF) facility.

2130 Located all of the equipment except the weather stations, two floats and the generator in storage at PPSF.

12 May

0700 Rain with winds from the southwest 10-15 knots.

0800 Began assembling and locating gear. PPSF will not be able to launch the Munson for a day because the doors to the shed where the lift is stored need modification. Mr. Dexter Lowell, resident manager at PPSF, indicated that the lift would be ready in a day or two.

0900 Began cutting the anchor stock, while John offloaded the three-wheeler.

1330 Began transfer of oceanographic equipment to lab space in living quarters. Continued to fabricate anchors.

1500 Completed cutting of anchor stock, and continued transferring equipment to temporary electronics lab.

1700 Completed equipment transfer.

arrangements to have the generator shipped to PPSF via Peninsula at the first opportunity.

13 May

0700 Snow fall during the evening: winds calm.

0800 Uncrated weather stations and repacked one station for immediate deployment at Harbor Point.

1230 Departed PPSF with John for Harbor Point on NOAA three-wheeler and Dexter's personal three-wheeler. The distance overland is approximately 8 miles over roads and beach terrain.

1400 Assembled Aanderaa weather station at Harbor Point and prepared to erect the mast and 10-meter tower.

1500 Lost one of the anchors which inadvertently pulled out of the beach root mass. As a result, the tower fell and the speed sensor cups were shattered on impact. Repacked station sensors and returned to PPSF to assess further damage.

1600 Arrived at PPSF and contacted Anchorage with request for sensor replacements. Tested all sensors a PPSF. All were functional except for the speed sensor.

15 May

0700 More snow fall during the night: winds 15-20 knots southwest, 29.89 inches Hg.

0900 Began Aanderaa Water Level Recorder (WLR) and Recording Current Meter (RCM) checkouts and mobilization.

1200 Completed checkouts and initiated recording sequences for two WLR-5 and two RCM-4 instruments.

1300 Departed for Harbor Point to install Aanderaa weather station. John's borrowed three-wheeler threw a link in the drive chain. Pushed the three-wheeler up on the beach and rode piggyback to the station site.

1330 Arrived Harbor Point with new wind speed sensor.

Air Temperature, SN #24 on Channel 5
Air Temperature, SN #25 on Channel 8

1500 Initiated logging weather data on Recorder SN #712
Wind: 20-25 knots at 285 degrees magnetic
Pressure: 30.00 inches Hg
Air Temperature: 4.5 degrees C

1515 Crossarm orientation is 350.5 degrees magnetic. Magnetic variation is 17.5 degrees EAST (USGS).

1600 Departed Harbor Point and recovered stricken three-wheeler after getting replacement link at PPSF.

1700 Arrived PPSF in time for dinner.

1830 Tested damaged crossarm successfully.

15 May

0700 Snow covers ground: freezing temperatures. Winds 20 knots northwest. Barometric pressure rising to 30.35 inches Hg.

0800 Contacted L. Jarvela and discussed priorities. The boat lift is not operational because the hydraulics need to be repaired.

0930 Began mobilization of EG&G Acoustic Current Meters (ACM).

1130 Made jig for ACM tests and cut mooring chain to lengths.

1330 Made battery pack for extra ACM.

1500 Spliced terminations in 5/8-inch poly groundline.

2000 M. Avakian arrived with the rest of the electronic test gear and replacement wind sensor.

16 May

0700 Cloudy: winds 15 knots northeast. Pressure rising at 30.65 inches Hg.

0800 Began to check out ACMs (6) and releases (3), while John continued to work on the Munson.

0900 Programmed EG&G BACs unit 8011 to command the Oceano releases.

battery is dead, and the unit's display is nonfunctional.

1930 Munson is lifted into the water; continued to check out the ACMs. ACM #96 is nonfunctional. Traced problem to an unsoldered wire from one of the acoustic transducers. EG&G Ocean Products appeared not to have run a final test on this equipment, since the problem would have rendered the units during a "Zero Test" nonfunctional. Repaired problem and continued with the checkout.

2100 Completed mobilization and recording initialization of all ACMs.

2130 Test ran the Munson. Engine cuts out at high speed. Should check filters and lines, and order a replacement Loran unit in the morning. The vessel is not ready for mooring or profiling operations. Suggested that the boat be fueled.

17 May

0700 Rain: wind 5-10 knots southwest. Pressure falling to 30.14 inches Hg.

0800 Vessel hydraulics not working: Briggs & Stratton engine needs attention, DRCM spool needs modification and spool valve needs replumbing. Suggested fueling the boat.

0930 Changed fuel in B&S engine and changed mixture adjustment. Modified DRCM spool and installed capstan on forward spooling motor to aid in anchor recoveries.

1630 Completed modifications to hydraulics system by adding 5 gallons of oil to reservoir.

1800 Mobilized DRCM system on boat.

18 May

0700 Clear: wind 5 knots from the northwest. Pressure steady at 30.15 inches Hg.

0800 Suggested that the boat be fueled; attempted to fuel the boat. Dumped 60 gallons of gasoline below the deck of the wheelhouse due to unattached fill hose in the cabin.

decks. Removed all of the gas by hand pump, and discovered uninsulated bare ignition wires exposed in the bilge. The tanks have no inspection plates and no working fuel gauges and the filling system is not to code: the rubber hose is exposed to the interior of the cabin and is attached with two hose clamps. The overflow goes into the bilge that is vented only inside the cabin. This was probably the source of gas fumes in the previous years, and we were all exceedingly lucky that an explosion did not occur when the crew smoked. John was warned about smoking.

1600 Received replacement Loran unit and installed it.

1630 Fueled boat after applying a temporary fix to the filling system.

<u>19 May</u>

0700 Calm: pressure 30.60 inches Hg.

0800 Discovered clogged fuel line and blew it out with compressed air.

0930 Departed for Harbor Point to test DRCM system.

0935 Port engine will not stay at cruising RPMs: dies immediately after boat begins planing. Limped on one engine to Harbor Point. Seas calm.

1000 Arrived at proposed current meter location at Harbor Point and conducted successful test of DRCM.

1135 Returned to PPSF on one engine.

1300 Attempted to trouble shoot port engine. Lowest starboard plug is not firing. John got the mechanic at PPSF to look at and clean the carburetor, but this lead to no improvement in the engine's performance.

1730 John called for the spare engines from Anchorage. They will be sent tomorrow at 1000 hours on a Northern Air Cargo flag stop.

<u>20 May</u>

0700 Deteriorating: winds 35 knots southwest. Pressure falling to 30.15 inches Hg. Northern Air Cargo will not come today.

0930 Organized staging area and mooring supplies.

1430 Removed port engine from boat during low tide.

1600 Changed hydraulic spooler valve plumbing to accommodate smoother DRCM operations.

1800 Completed plumbing change and stripped port engine of cowling and wheel.

21 May

0700 Calm: pressure rising at 30.60 inches Hg.

0800 Discovered the NOAA tide gauge installation at Port Moller and viewed the official weather station. We will not use the data from this weather station as originally proposed because the wind sensors are improperly mounted. The wind sensors are mounted on a crossarm 1-2 feet above a large wooden water tower on the PPSF dock. The tower is the lowest structure on the dock, and is in the lee of winds from any direction, except the southwest. Additionally, during a strong wind from the southwest, the direction sensor wondered aimlessly in the turbulence created by the dock structures and did not indicate the direction of the wind.

1230 Met the NAC flag stop flight with the new engines for the boat.

1400 Installed new port engine.

1900 Tested engines which ran fine on the unloaded boat.

22 May

0700 Winds 5 knots northwest: pressure falling to 30.45 inches Hg.

0800 Loaded mooring station #1 on Munson.

0850 Departed PPSF for offshore mooring site. Starboard engine will not run at higher cruising RPMs. Continued to offshore site in calm seas at 8-10 knots.

entrance to Port Moller.

1030 Anchored and assembled mooring and anchors.

1120 Initiated deployment of mooring.

1200 Deployment complete, and successfully interrogated and disabled the acoustic release.

1220 Departed for PPFS dock.

1300 Arrived PPFS dock and consulted with mechanic about starboard engine.

1330 Mark found a jelly-like substance in the bottom of the oil supply system which causes the supply line to clog. Changed both containers.

1530 Loaded mooring station #3 on the Munson.

1755 Departed PPSF for Hague Channel mooring site.

1830 Completed initial survey and began mooring deployment.

2016 Completed deployment, and successfully interrogated and disabled release.

2100 Arrived PPFS dock with working engines since replacing the oil supply tanks.

23 May

0700 Winds 20 knots northwest: snowing with pressure falling to 30.18 inches Hg.

0800 Loaded Munson with moorings for stations 4 and 5.

0930 Departed for Herendeen Bay.

1130 Arrived Herendeen Bay through Johnson Channel and began DRCM survey in the bay.

1530 Began mooring deployment at station 4 in the sill area of Herendeen Bay.

1640 Completed deployment at station 4.

1900 Initiated mooring deployment at station 5 in Herendeen Bay.

2130 Returned to PPSF.

24 May

0700 Calm: pressure 30.15 inches Hg.

1200 Loaded Aanderaa weather station on Munson for Point Divide.

1400 Arrived Point Divide, and assembled weather station.

1517 Installed the following sensors on the crossarm:
Wind Speed SN #433 Channels 2 and 3
Wind Direction SN #708 Channel 4
Air Temperature SN #301 Channel 5
Air Temperature SN #--- Channel 8
Barometric Pressure SN #512607 Channel 9
Solar Irradiance SN #93 Channel 11

1530 Aanderaa tower failed during installation, damaging the wind sensor (cups broke). One of the lengths of the tower did not seat properly.

1700 Successfully erected tower, but did not activate logger. Returned to PPSF.

25 May

0700 Calm: pressure steady at 30.14 inches Hg.

0800 Fueled boat and repaired wind speed sensor cups.

1230 Departed for Harbor Point to initiate DRCM survey.

1400 Began DRCM profiling series.

1530 Completed DRCM profiling at Harbor Point. Departed for Hague Channel/Point Divide.

1630 Initiated DRCM profiling in Point Divide channel.

1720 Completed profiling, and return to PPSF.

26 May

0700 Clear: winds 0-5 knots northeast. Pressure 29.77 inches Hg.

1000 Completed profiling, and reinstalled wind sensor at Point Divide weather station.

1100 Tested weather system and installed crossarm at 12-degree magnetic orientation. Elevation of station is 25 feet to the bottom of the base of the station above sea level.

1130 Winds are 5-10 knots, 70 degrees magnetic, air temperature is 8 degrees C. Pressure is 29.78 inches Hg.

1200 Initiated logging sequence on weather station.

1240 Resumed DRCM profiling at Point Divide.

1420 Completed profiling and returned to PPSF.

1500 Refueled Munson, and stored gear in sea van.

<u>27 May</u>

0700 Winds 30-35 knots northeast: pressure falling to 29.44 inches Hg.

0800 Weathered out for the day. Completed notice to fishermen of mooring locations and arranged with PPSF to circulate it to all fishermen and tenders.

0900 Moved all equipment from warehouse staging area to sea van storage.

1200 Winds 35 knots northeast.

<u>28 May</u>

0700 Clear: winds 5-7 knots northeast: pressure 29.96 inches Hg.

0800 Began DRCM profiling operations at Port Moller entrance.

1200 Ended profiling operations. Winds increased to 25 knots southwest, and too rough to continue.

<u>29 May</u>

0500 Calm: pressure 29.70 inches Hg.

0530 Departed for Port Moller entrance.

1100 Resumed profiling at entrance.

1850 Completed profiling operations and returned to PPSF for demobilization.

1930 Munson is lifted out of water and blocked on deck.

<u>30 May</u>

0800 Continued to demobilize boat and pack equipment for shipment.

1415 Departed PPSF for Cold Bay.

1630 Departed Cold Bay for Anchorage.

1800 Arrived ANC.

PORT MOLLER
SEPTEMBER AND OCTOBER 1989
RECOVERY

Trip Report for the Field Recovery of Oceanographic Equipment at Port Moller, Alaska, 1989

8/31/89 <u>Initial Recovery Effort</u>

1020 Departed Anchorage (ANC) for Cold Bay (CDB) on Reeve Aleutian Airlines (RAA) flight #1085.

1200 Arrived CDB and departed on Kenai Air for Port Moller.

1400 Arrived Peter Pan Sea Food PPSF at Port Moller.

1500 Winds 30 kts SE, weather day. Boat will need to be demobilized from the crab work.

1900 Copied all previous files.

9/1/89

0700 Winds 5-10 kts NE, rain 29.16"Hg.

0800 Began demobilizing side scan winch and cleaned boat.

1000 Completed patching holes in deck left by side scan demobilization.

1100 Completed removal of side scan winch, and changed zooplankton net spool with DRMC spool and cable.

1200 Completed loading generator and iron davit.

1300 Reorganize seavan contents and transferred ACM II SN#2483 to lab space for demobilization.

9/2/89

0700 Winds 20-25 kts NE, rain, 29.88" Hg.

0800 Fueled vessel and mobilized DRCM system.

1000 Completed DRCM mobilization and checkout.

1100 Attempted to leave PPSF for work site at Harbor Point, but hydraulic system not working and the starboard engine will not start on the Munson. J. Dermody consulted with the PPSF mechanic on water in carburetors and fuel tanks.

1130 Demobilized ACM SN#100 successfully.

1830 Departed for Harbor Point on ATVs to check out weather station.

2130 Returned from Harbor Point. Instrument checked out successfully.

9/3/89

0700 Winds calm, 30.20"Hg.

0800 Delayed departure to Harbor Point, because Munson was not functioning.

0900 Departed for Harbor Point with one engine functioning in calm seas.

1000 Began DRCM profile at C-2 for intercalibration purposes.

1120 Began sampling 4 DRCM stations at Harbor Point.

1300 Completed flood stage current sampling at Harbor Point.

1330 Successfully recovered anchor in 2 knots of current by hand after the hydraulic system failed. The pony engine powering the hydraulics lost its lubricating oil after a modification made of galvanized pipe failed. No harm was done to the engine, since the leak was quickly discovered.

1400 Returned to PPSF on one engine as winds increased from the SE to 20 kts. Additional work was discontinued due to failure of the vessel systems.

9/4/89

0700 Winds 20 kts SE, 29.55"Hg.

1000 Hauled boat and began to replace starboard engine with new OMC.

1900 Completed installation of replacement OMC engine.

9/5/89

0700 Winds 10 kts SE, 30.18"Hg.

0800 Removed sheared pipe threads from hydraulic pony engine and replaced lost oil from sump. Tested engine successfully.

1000 Soldered connections to hydraulic lift on new OMC, and briefly test-fired engine.

1230 Launched boat.

1330 Could not start new engine. Began troubleshooting engine ignition system.

1600 Discovered open circuit in ignition key and switch. Pat Harman arrived and took over the repair operation of the vessel.

1900 Engine ignition repaired.

9/6/89

0700 Calm seas! Winds 0-2 kts, variable.

0800 Attempted to resume sampling efforts, but neither engines will start.

0930 New engine will not start because the pistons smashed the bottom of the spark plugs. There are no more spare engines to replace the defects.

1000 Winds increased rapidly to 15 kts SE.

1100 Consulted with NOAA/OCSEAP Anchorage office about possible local boat charters. Continued gathering information on available boats and costs.

9/7/89

0700 Winds 30-35 kts SE.

0930 Met with John Woods, skipper of the STORMBIRD, about possible charter.

1230 Met with Peter Kust, owner and skipper of the KISCO about possible charter.

1420 Departed PPSF on Kenai Air for CDB.

1630 Departed CDB for ANC on RAA.

1900 Arrived ANC.

9/27/89 Second Recovery Effort

1020 Departed Anchorage (ANC) for Cold Bay (CDB) on Reeve Aleutian Airlines (RAA) flight #1085.

1330 Arrived CDB and made arrangements to fly to Peter Pan Sea Foods (PPSF) on Kenai Air.

1430 Departed CDB for PPSF.

1530 Arrived PPSF and mobilized DAWN TREADER for recovery of C-2 mooring by dragging.

1830 Departed PPSF for C-2 and began dragging operations.

2030 Returned to PPSF without recovering mooring.

9/28/89

0700 Winds light 2-4 kts from the NW.

0900 Departed PPSF for C-2.

0930 Arrived C-2 and remarked deployment location and dragged area for mooring without success.

1030 Departed for C-3 mooring site.

1050 Arrived C-3 mooring site and interrogated Oceano release #74 successfully. Attempted to fire release repeatedly without success. Release replied with 10 pings/cycle @ 1 ping/4 seconds. Attempted to range to release with EG&G 8011 BACS unit without success. The release does not appear to be equipped for ranging operations.

1230 Departed for C-5.

1530 Arrived C-5 and began successful recovery with EG&G BACS and Oceano #86 release.

1555 Interrogated and fired release. Release responded with 10 pings/cycle @ 1 ping/4 seconds.

1600 Began recovery operations. Mooring line was fouled around spindle assembly of Aanderaa RCM-4 vane.

1630 Completed recovery of C-5 during engine failure of the vessel.

1700 Began CTD profile at C-5 and noted anoxic sediments in conductivity cell on recovery of the Sea-Bird instrument.

1800 Anchored near Old Bluff Point to repair electrical system of the vessels engine. Fuel solenoid wiring failed.

9/29/89

0730 Winds variable 2-3 kts.

0800 Departed anchorage for C-4 mooring site, and began dragging operations for recovery. Bottom is composed of Eel Grass and dark anoxic mud.

1420 Completed a CTD cast at C-4 with the Sea-Bird instrument. Departed site without recovering mooring.

1530 Arrived C-3 site and interrogated release. Attempted to fire release without success.

1630 Began dragging operations at C-3. Bottom is composed of cobbles and worm tubes.

1830 Abandoned dragging operations, and returned to PPSF for repairs to vessel steering system.

1930 Replaced ruptured hydraulic line in steering system, and began making telephone calls to ship EG&G magnetometer to PPSF for survey of the 3 mooring sites; C-2, C-3 and C-4.

9/30/89

0700 Winds; 50 kts SE.

0930 Departed PPSF for Harbor Point.

1200 Made arrangements for transfer of equipment from CDB to PPSF with Kanai Air.

1430 Magnetometer arrived from CDB on Kenai Air.

1630 DAWN TREADER arrived from Harbor Point in following seas and 30 kts SE winds. Moored to dock for the night.

10/1/89

0730 Winds; 30 kts West. Occasional rain.

1030 Arranged to rent PPSF aluminum skiff for further recovery attempts. Winds predicted to switch to the SE within 24 hours.

1130 Attempted to move to Hague Channel for magnetic search of C-3 mooring, but high seas in channel prevented transit to site. Returned to PPSF dock. Moored to dock for the night.

10/2/89

0730 Winds 3-5 kts SE. Departed for Hague Channel mooring site, C-3.

0830 Conducted magnetometer survey of the immediate area and found a possible target 100 feet SW of C-3 deployment coordinates.

1030 Departed for Johnson Channel mooring site, C-4.

1130 Conducted magnetometer search for mooring and found possible target 200 feet NE of original C-4 deployment coordinates.

1330 Departed C-4 site for Harbor Point mooring site, C-2.

1500 Conducted magnetometer search for C-2 mooring, but could not distinguish signal from strong background noise and broad magnetic anomaly at the original deployment site.

1630 Moored vessel behind Harbor Point. Winds 35-40 kts SE.

10/3/89

0730 Winds 15 kts SW. Departed Harbor Point for PPSF.

0800 Arrived PPSF and arranged to rent skiff from same for recovery operations of C-4 and C-3.

1100 Departed PPSF with skiff in tow for Johnson Channel mooring site, C-4.

1230 Arrived C-4 and began dragging operations with skiff and DAWN TREADER.

1315 Snagged target on second attempt. Several juvenile crabs were recovered on the groundline.

1330 Buoy on surface.

1400 Recovery operation of C-4 complete. Mooring instruments were heavily fouled with marine growth. Dragline was heavily fouled and appeared to have been floating in the water column.

1430 Departed for C-3 station in Hague Channel.

1515 Arrived Hague Channel and began dragging operations.

1600 Swamped skiff by inadvertently towing it backwards while positioning DAWN TREADER for second pass. Began recovery operations of skiff after landing A.Parkin on vessel.

1700 Completed recovery of skiff and all equipment excluding a single oar, and returned to PPSF to haul skiff. Offloaded heavy mooring equipment and returned to C-3 for marker floats and anchor.

1900 Returned to PPSF for the evening. All freight arrived at PPSF from CDB via Kenia Air.

10/4/89

0730 Winds 10 kts SE.

0830 Cleaned outboard engine on skiff and attempted to start without success. Began offloading mooring instruments from vessel for clean up and demobilization.

1000 Began cleaning and packing equipment.

1300 Completed cleaning mooring instruments, and began demobilization procedures for data recovery.

1430 Completed demobilization of ACMs from C-4 and C-5 and Aanderaa WLR-5 from C-4.

1530 Departed PPSF for Harbor Point.

1615 Arrived Harbor Point and began demobilization of weather station. Battery appears to have run down due to the unanticipated lengthened deployment period.

1715 Departed Harbor Point for Point Divide.

1900 Arrived Point Divide and began demobilization of weather station. Battery no longer providing sufficient power for normal functioning of station.

2015 Departed Point Divide for PPSF.

2130 Arrived PPSF. Winds 20 kts SE.

10/5/89

0730 Winds 15 kts SE.

0830 Delivered outboard engine to mechanic for cleaning, and began mobilizing vessel for DRCM survey.

1100 Completed repair of engine, and tested without success. Problem appears to be water in the carburetor bowl. Completed mobilization of DRCM system.

1130 Departed PPSF and began flood series of transect measurements across the entrance to Port Moller.

1300 Departed Port Moller entrance in route to Hague Channel transect stations.

1500 Departed Hague Channel transect for Herendeen Bay transect.

1900 Completed Herendeen Bay transect on Ebb tide and departed for Hague Channel to complete ebb flow measurements.

2100 Completed Hague Channel measurements in route for calibration comparison with the C-3 mooring in Hague Channel.

2215 Departed C-3 site for PPSF.

2330 Arrived PPSF.

10/6/89

0730 Winds 10 kts SW. Rain.

0800 Packed equipment for shipment to Anchorage via Naknek and King Salmon on the DAWN TREADER.

1030 Depart for Harbor Point to complete DRCM profiling operations.

1212 Began flood tide profiling at Harbor Point. Cable failure in the system prevented the completion of the DRCM task.

1225 Completed CTD measurement at Harbor Point with the SeaBird backup instrument, and departed for Port Moller Bay.

1330 Completed second CTD profile 2 miles south of Harbor Point.

1350 Completed third CTD profile 4 miles south of Harbor Point. Departed for Hague Channel to drag for C-3 with the vessel TAZIMNA.

1645 Arrived at C-3 in heavy seas. Departed for PPSF.

1730 Arrived PPSF and made arrangements for possible dragging operations on the next AM tide with the TAZIMNA.

1930 Packed equipment for departure. Searched the entire area for a missing ORE 28" float. Beach crew loaded the buoy belonging to PMEL onto the STORMBIRD. However, it was not unloaded in Seward by the crew.

10/7/89

0730 Winds 10-15 kts NW. Rain.

0830 Packed remaining equipment and prepared for departure for C-3.

0930 Departed for C-3.

1015 Arrived C-3, and attempted simple drag without the second vessel. No success.

1130 Began dragging operations with F/V TAZIMNA for the mooring, and succeeded on the second attempt.

1345 Completed recovery of C-3 mooring. TAZIMNA departed.

1400 Departed for PPSF.

1500 Arrived PPSF, and offloaded equipment in preparation for demobilization.

1600 Demobilized ACM and RCM-4 successfully, and packed for transport.

1800 Loaded DAWN TREADER with equipment and fuel. Readied for early vessel departure.

10/8/89

0100 Winds 10-15 kts SW. Rain. Vessel DAWN TREADER departs PPSF for Naknek with A. Parkin as crew with F. Dyson, skipper.

0730 Winds 20 kts SW.

0830 Cleaned out seavan, organized remaining crates and spools, and secured seavan for winter.

1330 Settled final accounts with PPSF, and made arrangements to depart for ANC on Kenai Air and RAA on Monday.

10/9/89

1230 Departed PPSF on Kenai Air for CDB.

1400 Arrived CDB after subduing drunk cannery worker on flight. Cannery worker arrested in CDB by Alaska State Trooper.

1700 Departed for ANC on RAA.

1930 Arrived ANC. End of study!

APPENDIX B

SATELLITE INVENTORY AND SELECTED SLIDES

Date	Time (ADT)	Orbit	NOAA Sat. No.
May 8	15:57	03195	11
May 11	05:26	03231	11
June 10	15:18	03660	11
June 12	15:08	03674	11
June 17	15:48	03759	11
July 2	10:44	14490	10
July 25	10:32	14817	10
July 26	05:48	04303	11
August 5	15:44	04450	11
August 6	11:05	14988	10
August 6	15:34	04464	11
August 26	05:27	04740	11

5							
6	Pink	133-134	4.3 to 4.8	Tan	18-20	Brown	14
7							
8	Tan	135	3.8	Sand	21-23	Sand	15
9							
10	Sand	136	3.3	Yellow	24-25	Yellow	16-18
11							
12	Medgreen	137	2.8	Ltgreen		Ltgreen	
13							
14	Dkblue	138-139	2.3 to 1.7				
15							
16	Ltblue	140-142	1.2 to 0.2				
17							
18	White	143	-0.3				

5							
6	Pink	136	3.3	Tan		Brown	
7							
8	Tan	137	2.8	Sand		Sand	
9							
10	Sand	138	2.3	Yellow		Yellow	
11							
12	Medgreen	139	1.7	Ltgreen		Ltgreen	
13							
14	Dkblue	140	1.2				
15							
16	Ltblue	141	0.7				
17							
18	White	143	-0.3				

5							
6	Pink	127-128	7.5 to 8.0	Tan		Brown	16
7							
8	Tan	129	7	Sand		Sand	17
9							
10	Sand	130	6.6	Yellow		Yellow	18-19
11							
12	Medgreen	131	6.1	Ltgreen		Ltgreen	
13							
14	Dkblue	132	5.6				
15							
16	Ltblue	133	5.1				
17							
18	White	134-135	4.1 to 4.6				

5							
6	Pink	125-126	8.5 to 9.0	Tan	18	Brown	15-16
7							
8	Tan	127-128	7.5 to 8.0	Sand	19-20	Sand	17-18
9							
10	Sand	129	7	Yellow	21-24	Yellow	19-20
11							
12	Medgreen	130	6.6	Ltgreen		Ltgreen	
13							
14	Dkblue	131	6.1				
15							
16	Ltblue	132	5.6				
17							
18	White	133	4.6 to 5.1				
19							
20		134					

5							
6	Pink	121-123	10.7-9.8	Tan	12	Brown	16
7							
8	Tan	124	9.3	Sand	13-15	Sand	17
9							
10	Sand	125	8.8	Yellow	16-19	Yellow	18
11							
12	Medgreen	126	8.3	Ltgreen	20-30	Ltgreen	19
13			8.8				
14	Dkblue	127	7.8				
15							
16	Ltblue	128	7.3				
17							
18	White	129-132	6.9-3.4				

4	Red	111-113	7.9 to 8.7	Black		Black
5						
6	Pink	114-115	7.0 to 7.4	Tan		Brown
7						
8	Tan	116	6.5	Sand		Sand
9						
10	Sand	117	6.1	Yellow		Yellow
11						
12	Medgreen	118	5.6	Ltgreen		Ltgreen
13						
14	Dkblue	119	5.2			
15						
16	Ltblue	120	4.7			
17						
18	Ltgreen					

4	Red	99-100	13.2 to 13.7	Black		Black	
5							
6	Pink	101-102	12.4 to 12.8	Tan		Brown	
7							
8	Tan	103-104	11.6 to 12.0	Sand		Sand	
9							
10	Sand	105-106	10.7 to 11.1	Yellow		Yellow	
11							
12	Medgreen	107-108	9.9 to 10.3	Ltgreen		Ltgreen	
13							
14	Dkblue	109	9.4				
15							
16	Ltblue	110	9				
17							
18	Ltgreen						

5							
6	Pink	119	11.6	Tan		Brown	
7							
8	Tan	120	11.1	Sand		Sand	
9							
10	Sand	121	10.7	Yellow		Yellow	
11							
12	Medgreen	122	10.2	Ltgreen		Ltgreen	
13							
14	Dkblue	123	9.7				
15							
16	Ltblue	124	9.2				
17							
18	Ltgreen	125	8.8				

5							
6	Pink	122	10.1	Tan	16	Brown	13
7							
8	Tan	123	9.6	Sand	17	Sand	14
9							
10	Sand	124	9.2	Yellow	18-20	Yellow	15-19
11							
12	Medgreen	125-126	8.2 to 8.7	Ltgreen		Ltgreen	
13							
14	Dkblue	127	7.7				
15							
16	Ltblue	128	7.2				
17							
18	Ltgreen	129	6.7				
19							
20	White	130	6.3				

4	Red	103-104	12.2 to 12.6	Black	13	Black	10 - 11
5							
6	Pink	105	11.7	Tan	14	Brown	12
7							
8	Tan	106	11.3	Sand	15	Sand	13-14
9							
10	Sand	107	10.9	Yellow		Yellow	15-18
11							
12	Medgreen	108	10.4	Ltgreen		Ltgreen	
13							
14	Dkblue	109	10				
15							
16	Ltblue	110	9.6				
17							
18	Ltgreen						

4	Red	114-116	12.9 to 13.8	Black	15-15	Black	12
5							
6	Pink	117	12.5	Tan	16	Brown	13
7							
8	Tan	118-119	11.5 to 12.0	Sand	17	Sand	14
9							
10	Sand	120	11.1	Yellow	18-19	Yellow	15-17
11							
12	Medgreen	121	10.6	Ltgreen		Ltgreen	
13							
14	Dkblue	122	10.1				
15							
16	Ltblue	123	9.6				
17							
18	Ltgreen	124	9.2				
19							
20	White	130	6.3				

4	Red	120	11.1	Black		Black	11 - 12
5							
6	Pink	121	10.7	Tan		Brown	13-14
7							
8	Tan	122	10.2	Sand		Sand	15-17
9							
10	Sand	123	9.7	Yellow		Yellow	18-21
11							
12	Medgreen	124	9.3	Ltgreen		Ltgreen	22-26
13							
14	Dkblue						28-30
15							
16	Ltblue				Night time image		
17							
18	Ltgreen						
19							
20	White						

4	P3	55 deg 56 min 160 deg 43 min	#3	
5	P4	56 deg 7 min 160 deg 45 min	SHELF	
6				
7		May 8, 1989 Orbit 03195	DN	Temp C
8	P1		136	3.3
9	P2		135	3.8
10	P3		135	3.8
11	P4		137	2.8
12		May 11, 1989 Orbit 03231		
13	P1		136	3.3
14	P2		142	0.2
15	P3		139	1.7
16	P4		139	1.7
17		June 10, 1989 Orbit 03660		
18	P1		131	6.1
19	P2		132	5.6
20	P3		128	7.5
21	P4		134	4.6
22		June 12, 1989 Orbit 03674		
23	P1		128	7.5
24	P2		125	9
25	P3		133	5.1
26	P4		130	6.6
27		June 17, 1989 Orbit 03759		
28	P1		124	9.3
29	P2		126	8.3
30	P3		124	9.3
31	P4		124	8.3
32		July 2, 1989 Orbit 14490		
33	P1		117	6.1
34	P2		110	9.2
35	P3		117	6.1
36	P4		119	5.2
37		July 25, 1989 Orbit 14817		
38	P1		107	10.7
39	P2		104	11.6
40	P3		111	8.6
41	P4		108	9.9
42		July 26, 1989 Orbit 04303		
43	P1		122	10.2
44	P2		121	10.7
45	P3		122	10.2
46	P4		125	8.8
47				
48				

52	P3		128	7.2
53	P4		125	8.7
54		August 6, 1989 Orbit 14988		
55	P1		107	10.9
56	P2		106	11.3
57	P3		107	10.9
58	P4		108	10.4
59		August 6, 1989 Orbit 04464		
60	P1		143	-6.1
61	P2		155	-12.5
62	P3		155	-12.5
63	P4		155	-12.5
64		August 26, 1989 Orbit 04740		
65	P1		121	10.7
66	P2		123	9.7
67	P3		121	10.7
68	P4		121	10.7

APPENDIX C

SELECTED CLIMATOLOGICAL DATA

25625 PORT MOLLER ALASKA AFS 59-69
STATION STATION NAME YEARS

	AMOUNTS (INCHES)													PERCENT OF DAYS WITH MEASURABLE AMTS	TOTAL NO. OF OBS.	MONTHLY AMOUNTS (INCHES)		
PRECIP.	NONE	TRACE	.01	.02-.05	.06-.10	.11-.25	.26-.50	.51-1.00	1.01-2.50	2.51-5.00	5.01-10.00	10.01-20.00	OVER 20.00					
SNOWFALL	NONE	TRACE	0.1-0.4	0.5-1.4	1.5-2.4	2.5-3.4	3.5-4.4	4.5-6.4	6.5-10.4	10.5-15.4	15.5-25.4	25.5-50.4	OVER 50.4					
SNOW-DEPTH	NONE	TRACE	1	2	3	4-6	7-12	13-24	25-36	37-48	49-60	61-120	OVER 120			MEAN	GREATEST	LEAST
JAN	28.1	20.7	6.4	13.7	10.9	12.9	5.2	1.6	.4					51.2	248	2.18	2.58	.56
FEB	32.8	21.7	7.2	11.6	12.6	11.1	2.0	1.0						45.5	198	1.27	2.13	.62
MAR	31.7	18.8	9.1	14.0	7.5	12.9	6.2	.3						49.5	186	1.81	2.50	.98
APR	25.0	24.6	5.9	12.1	12.9	13.7	5.0	.8	.4					50.4	240	1.74	3.26	.66
MAY	29.8	20.6	6.0	17.7	9.7	9.3	5.4	1.7	.4					49.6	248	1.89	2.60	.32
JUN	22.4	21.7	2.9	15.8	9.6	11.7	6.3	3.3	1.3					53.9	240	2.88	6.10	1.29
JUL	29.0	17.3	3.6	12.9	9.0	11.3	11.7	4.4	4.0	.4				53.6	248	5.24	8.98	2.47
AUG	14.8	11.7	5.3	17.6	7.7	17.1	12.0	7.7	4.5	.3				73.2	310	6.16	10.44	3.46
SEP	13.3	16.7	4.2	11.7	11.7	17.9	12.1	10.0	2.9					70.0	240	5.79	8.60	2.44
OCT	11.3	18.7	5.0	18.5	14.1	21.4	7.4	2.0	1.6					70.0	248	3.48	5.72	2.24
NOV	19.0	20.0	2.4	20.0	14.8	15.2	6.2	1.4	1.0					61.0	210	2.76	7.08	1.24
DEC	25.8	20.8	7.6	16.6	8.6	14.7	4.3	1.9	.4					53.4	279	2.04	3.20	1.47
ANNUAL	23.7	19.3	5.4	15.1	10.5	14.0	7.0	2.9	1.3	.1				56.8	2945	37.24	☒	☒

#1961	1.93	.62	72	78	[illegible]	[illegible]							
1962	2.53	1.53	2.10	0.76	2.37	0.12	3.41	1.98	3.84	4.16	2.57	1.02	26.39
1963	4.91	0.43	3.02	1.66	1.32	1.06	4.29	2.69	3.61	3.03	1.45	2.01	29.48
1964	1.33	1.75	1.32	0.21	1.15	1.85	1.74	3.56	5.25	3.33	3.71	1.31	26.51
1965	1.21	2.78	3.05	0.83	2.66	2.54	1.20	1.57	9.79	2.75	2.55	1.77	32.70
1966	2.21	1.59	1.40	1.31	2.49	0.79	4.63	3.73	4.28	2.96	2.80	2.09	30.28
1967	1.60	2.56	2.54	3.06	0.62	2.48	2.89	4.72	2.91	2.71	7.40	4.49	38.00
1968	2.77	1.29	1.21	1.37	1.30	0.84	0.99	3.53	2.55	8.02	3.32	1.17	28.36
1969	3.75	2.33	1.92	1.09	3.44	2.52	2.01	5.02	5.18	3.90	2.97	2.33	36.46
1970	2.11	4.15	3.32	3.83	2.06	2.99	3.86	3.82	5.62	5.82	2.89	5.94	46.41
1971	1.34	2.17	0.59	0.43	3.75	6.67	2.27	2.76	3.86	3.28	5.11	4.87	37.10
1972	4.08	1.09	0.41	3.09	2.06	2.91	1.82	3.84	1.30	3.91	6.96	6.49	37.96
1973	1.97	1.60	1.87	1.30	1.06	0.78	1.31	2.16	3.07	4.80	2.45	2.67	25.04
1974	2.96	2.72	0.72	1.69	3.12	0.92	1.93	2.63	2.55	2.15	3.78	1.73	26.90
1975	3.12	4.93	2.85	2.53	0.88	3.03	2.55	1.10	4.23	3.18	1.15	5.03	34.58
1976	1.88	2.88	3.76	2.09	0.94	2.69	1.92	2.01	2.38	5.63	2.51	2.89	31.58
1977	4.82	2.36	4.70	2.38	1.71	1.14	2.89	3.32	2.63	5.12	6.85	3.55	41.47
1978	3.70	1.74	2.22	5.42	3.63	2.84	5.67	2.88	3.82	7.67	6.67	6.89	53.15
1979	4.10	0.78	4.65	6.55	4.92	1.98	2.02	5.33	5.31	7.14	7.57	2.21	52.56
1980	3.51	1.69	3.52	1.71	4.22	3.67	2.68	3.95	5.23	4.42	2.88	2.24	39.72
1981	2.34	4.45	2.34	1.30	3.09	1.75	2.64	5.73	2.25	6.51	3.11	3.16	38.67
1982	5.41	1.13	3.45	1.33	4.13	2.93	6.13	2.17	6.44	2.41	5.12	3.10	43.75
1983	1.58	0.66	0.88	3.53	1.59	1.31	2.71	4.06	4.41	4.82	5.69	7.31	38.55
1984	2.30	2.82	1.56	1.79	1.20	1.45	1.77	1.48	2.87	3.64	7.61	3.19	31.68
1985	3.29	2.42	2.85	1.01	2.45	2.19	2.27	5.47	7.14	6.59	7.72	4.95	48.35
1986	2.05	2.23	0.55	1.12	2.02	1.91	2.48	2.63	7.37	3.03	5.08	4.94	35.41
1987	3.17	3.15	3.18	1.94	1.52	4.00	1.80	2.56	4.25	5.60	3.17	3.69	38.03
1988	3.70	2.91	0.89	1.81	2.70	1.69	1.12	3.03	3.90	3.28	3.97	6.37	35.37
1989	1.68	4.02	0.52	2.20	2.21	2.46	1.40	3.20	7.77	4.39	2.60	3.83	36.28
Record Mean	2.73	2.57	2.04	1.86	2.26	2.18	2.36	3.61	4.06	4.49	4.39	3.31	35.85

See Reference Notes on Page 6B.

AVERAGE TEMPERATURE (deg. F)

COLD BAY. ALASKA

YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	ANNUAL
1960	32.0	30.0	25.9	25.8	39.6	44.4	51.6	51.2	47.2	40.7	32.8	33.3	37.9
#1961	31.0	23.3	25.1	33.1	41.4	45.2	49.6	50.5	48.0	38.8	35.5	26.3	37.3
1962	22.7	33.2	31.2	31.9	38.2	44.6	51.4	52.1	46.8	39.6	35.8	29.3	38.1
1963	34.1	29.1	34.4	32.9	40.8	45.9	50.6	50.6	48.5	38.1	28.4	31.8	38.8
1964	30.0	26.2	29.3	32.7	38.1	46.4	47.8	48.6	47.1	39.7	32.9	30.3	37.4
1965	27.3	24.7	35.6	35.2	36.3	44.4	48.7	50.3	48.9	36.7	36.0	28.5	37.7
1966	32.8	31.7	21.4	34.4	37.4	44.2	48.6	49.1	44.6	33.9	32.3	27.7	36.5
1967	26.5	28.5	34.5	38.2	41.5	46.8	52.9	51.3	46.3	38.2	38.0	30.4	39.5
1968	28.3	24.0	30.4	34.2	42.7	45.4	52.9	52.0	46.8	38.9	36.0	30.9	38.6
1969	31.8	28.0	32.5	34.5	41.7	46.9	53.2	53.4	50.2	42.9	33.5	31.3	40.0
1970	22.4	28.1	31.8	31.8	40.8	47.8	51.3	50.2	46.9	40.0	37.6	30.5	38.3
1971	22.1	26.0	20.2	28.0	34.3	40.5	47.8	48.5	44.5	38.7	32.4	32.4	34.6
1972	27.2	21.4	16.3	29.5	38.6	41.6	48.6	50.0	47.9	39.8	34.3	30.4	35.5
1973	22.9	30.6	29.0	31.5	36.0	42.5	47.5	50.0	46.4	38.5	37.5	30.1	36.9
1974	29.7	19.0	28.9	32.2	41.4	45.8	49.9	53.2	49.2	40.4	34.2	27.5	37.6
1975	24.4	23.7	26.8	32.0	38.4	46.2	50.5	52.5	46.4	39.3	30.1	27.9	36.5
1976	25.5	23.9	22.0	27.2	36.6	44.6	49.7	50.8	45.3	39.1	30.5	28.2	35.3
1977	35.3	33.5	30.7	31.3	39.3	49.6	54.0	53.6	50.1	38.9	31.2	29.4	39.8
1978	33.4	28.4	30.8	37.9	40.5	47.0	49.6	54.3	48.8	40.1	38.1	35.2	40.3
1979	35.1	28.4	35.4	40.8	43.4	50.6	52.3	51.9	49.0	41.9	35.0	26.7	40.9
1980	23.5	25.4	33.7	35.6	41.4	45.9	52.9	51.5	48.1	40.3	36.4	32.1	38.9
1981	30.9	29.4	35.9	38.4	44.8	47.6	52.9	52.2	48.1	40.8	33.8	30.7	40.5
1982	29.8	27.1	33.9	32.1	38.0	45.0	46.8	50.2	45.1	37.5	35.3	30.5	37.6
1983	24.6	31.5	33.5	36.8	41.7	48.4	51.6	52.2	47.3	39.7	34.6	37.5	40.0
1984	31.2	18.7	33.7	31.6	38.0	47.0	49.7	54.7	49.7	40.8	37.0	37.3	39.1
1985	36.1	27.9	30.1	26.8	38.3	42.5	50.6	50.8	49.5	39.6	38.9	35.6	38.9
1986	24.4	28.4	27.0	32.2	38.0	44.7	51.7	51.2	49.8	42.2	37.0	34.4	38.4
1987	30.5	31.2	33.6	34.2	38.8	44.5	50.9	52.8	46.9	41.0	30.0	28.3	38.6
1988	31.2	30.2	26.1	31.1	40.3	46.0	51.0	51.1	46.9	40.5	32.5	30.9	38.2
1989	22.3	35.0	31.5	34.3	40.6	46.0	50.9	53.3	49.8	42.3	32.1	31.3	39.1
Record Mean	28.4	27.9	29.1	32.9	39.5	45.4	50.2	51.4	47.4	39.8	34.3	30.1	38.0
Max	32.8	32.5	34.0	37.5	44.2	50.0	54.6	55.6	51.8	44.4	38.7	34.5	42.5
Min	23.9	23.3	24.3	28.3	34.7	40.8	45.7	47.2	42.9	35.1	29.9	25.8	33.5

See Reference Notes on Page 6B.

1960	3.75	2.42	0.65	1.52	2.10	1.66	1.39	4.30	2.92	4.10	8.94	4.75	38.50
#1961	1.93	1.62	1.72	1.78	0.95	0.12	1.08	3.50	1.93	1.88	4.11	2.79	23.41
1962	2.53	1.53	2.10	0.76	2.37	0.12	3.41	1.98	3.84	4.16	2.57	1.02	26.39
1963	4.91	0.43	3.02	1.66	1.32	1.06	4.28	2.69	3.61	3.03	1.46	2.01	29.48
1964	1.33	1.75	1.32	0.21	1.15	1.85	1.74	3.56	5.25	3.33	3.71	1.31	26.51
1965	1.21	2.78	3.05	0.83	2.66	2.54	1.20	1.57	9.79	2.75	2.55	1.77	32.70
1966	2.21	1.59	1.40	1.31	2.49	0.79	4.63	3.73	4.29	2.96	2.80	2.09	30.28
1967	1.60	2.58	2.54	3.06	0.62	2.48	2.89	4.72	2.91	2.71	7.40	4.49	38.00
1968	2.77	1.29	1.21	1.37	1.30	0.84	0.99	3.53	2.55	8.02	3.32	1.17	28.36
1969	3.75	2.33	1.92	1.09	3.44	2.52	2.01	5.02	5.18	3.90	2.97	2.33	36.46
1970	2.11	4.15	3.32	3.83	2.06	2.99	3.86	3.82	5.62	5.82	2.89	5.94	46.41
1971	1.34	2.17	0.59	0.43	3.75	6.67	2.27	2.76	3.86	3.28	5.11	4.87	37.10
1972	4.08	1.09	0.41	3.09	2.06	2.91	1.82	3.84	1.30	3.91	6.96	6.49	37.96
1973	1.97	1.60	1.87	1.30	1.06	0.78	1.31	2.16	3.07	4.80	2.45	2.67	25.04
1974	2.96	2.72	0.72	1.69	3.12	0.92	1.93	2.63	2.55	2.15	3.78	1.73	26.90
1975	3.12	4.93	2.85	2.53	0.88	3.03	2.55	1.10	4.23	3.18	1.15	5.03	34.58
1976	1.88	2.88	3.76	2.09	0.94	2.69	1.92	2.01	2.38	5.63	2.51	2.89	31.58
1977	4.82	2.36	4.70	2.38	1.71	1.14	2.89	3.32	2.63	5.12	6.85	3.55	41.47
1978	3.70	1.74	2.22	5.42	3.63	2.84	5.67	2.88	3.82	7.67	6.67	6.89	53.15
1979	4.10	0.78	4.65	6.55	4.92	1.98	2.02	5.33	5.31	7.14	7.57	2.21	52.56
1980	3.51	1.69	3.52	1.71	4.22	3.67	2.68	3.95	5.23	4.42	2.88	2.24	39.72
1981	2.34	4.45	2.34	1.30	3.09	1.75	2.64	5.73	2.25	6.51	3.11	3.16	38.67
1982	5.41	1.13	3.45	1.33	4.13	2.93	6.13	2.17	6.44	2.41	5.12	3.10	43.75
1983	1.58	0.66	0.88	3.53	1.59	1.31	2.71	4.06	4.41	4.82	5.69	7.31	38.55
1984	2.30	2.82	1.56	1.79	1.20	1.45	1.77	1.48	2.87	3.64	7.61	3.19	31.68
1985	3.29	2.42	2.85	1.01	2.45	2.19	2.27	5.47	7.14	6.59	7.72	4.95	48.35
1986	2.05	2.23	0.55	1.12	2.02	1.91	2.48	2.63	7.37	3.03	5.08	4.94	35.41
1987	3.17	3.15	3.18	1.94	1.52	4.00	1.80	2.56	4.25	5.60	3.17	3.69	38.03
1988	3.70	2.91	0.99	1.81	2.70	1.69	1.12	3.03	3.90	3.28	3.97	6.37	35.37
Record Mean	2.76	2.54	2.08	1.85	2.26	2.17	2.38	3.62	3.97	4.49	4.44	3.30	35.84

See Reference Notes on Page 6B.

AVERAGE TEMPERATURE (deg. F)

COLD BAY, ALASKA

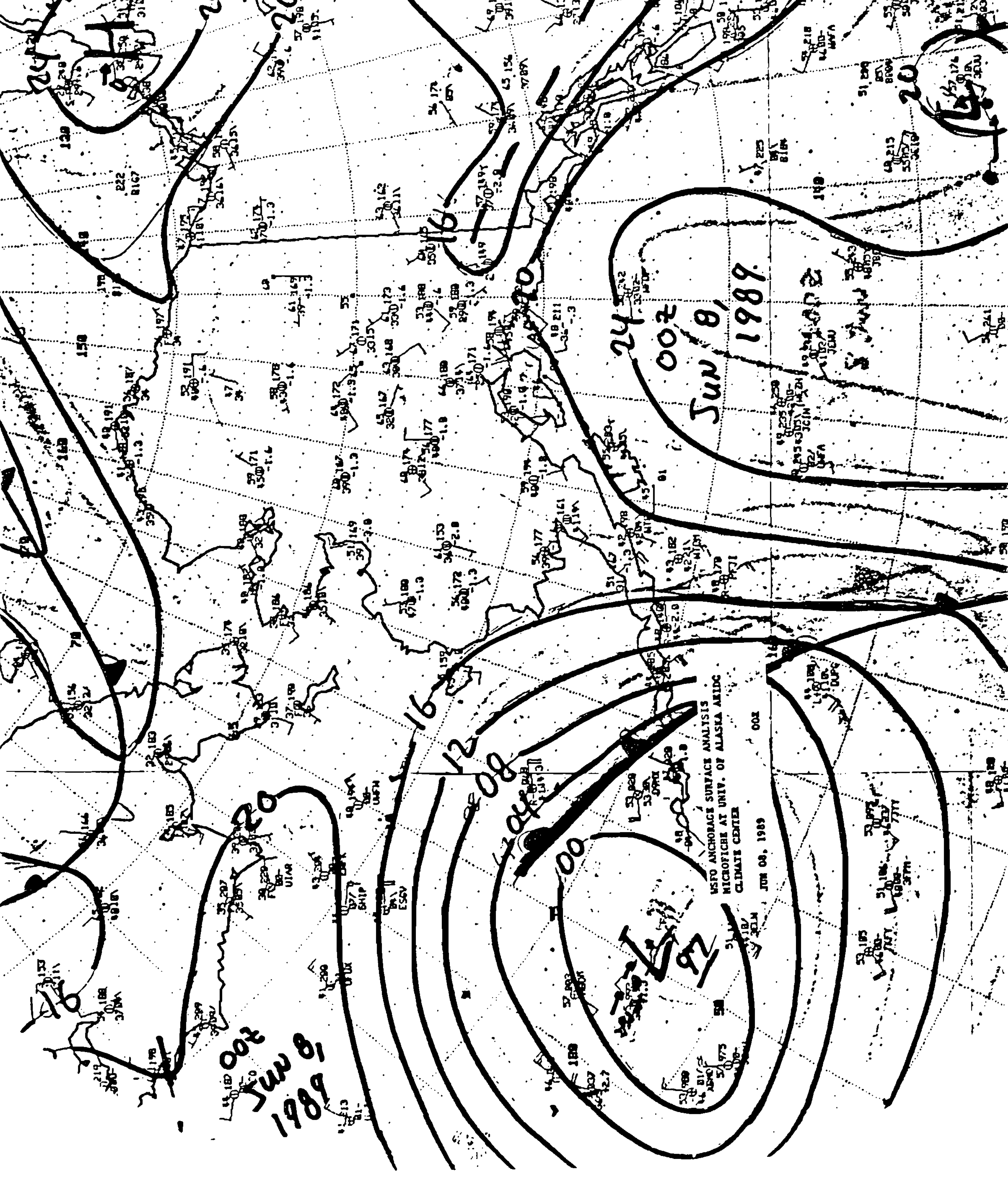
YEAR	JAN	FEB	MAR	APR	MAY	JUNE	JULY	AUG	SEP	OCT	NOV	DEC	ANNUAL
1959	28.8	32.5	19.4	31.1	40.9	43.2	47.7	51.6	47.5	41.5	36.2	25.9	37.2
1960	32.0	30.0	25.9	25.8	39.6	44.4	51.6	51.2	47.2	40.7	32.8	33.3	37.9
#1961	31.0	23.3	25.1	33.1	41.4	45.2	49.6	50.5	48.0	38.8	35.5	26.3	37.3
1962	22.7	33.2	31.2	31.9	38.2	44.6	51.4	52.1	46.8	39.6	35.8	29.3	38.1
1963	34.1	29.1	34.4	32.9	40.8	45.9	50.6	50.6	48.5	38.1	28.4	31.8	38.8
1964	30.0	26.2	29.3	32.7	38.1	46.4	47.8	48.6	47.1	39.7	32.9	30.3	37.4
1965	27.3	24.7	35.6	35.2	36.3	44.4	48.7	50.3	48.9	36.7	36.0	28.5	37.7
1966	32.8	31.7	21.4	34.4	37.4	44.2	48.6	49.1	44.6	33.9	32.3	27.7	36.5
1967	26.5	28.5	34.5	38.2	41.5	46.8	52.9	51.3	46.3	38.2	38.0	30.4	39.5
1968	28.3	24.0	30.4	34.2	42.7	45.4	52.9	52.0	46.8	38.9	36.0	30.9	38.6
1969	31.8	28.0	32.5	34.5	41.7	46.9	53.2	53.4	50.2	42.9	33.5	31.3	40.0
1970	22.4	28.1	31.8	31.8	40.8	47.8	51.3	50.2	46.9	40.0	37.6	30.5	38.3
1971	22.1	26.0	20.2	28.0	34.3	40.5	47.8	48.5	44.5	38.7	32.4	32.4	34.6
1972	27.2	21.4	16.3	29.5	38.6	41.5	48.6	50.0	47.9	39.8	34.3	30.4	35.5
1973	22.9	30.6	29.0	31.5	36.0	42.5	47.5	50.0	46.4	38.5	37.5	30.1	36.9
1974	29.7	19.0	28.9	32.2	41.4	45.8	49.9	53.2	49.2	40.4	34.2	27.5	37.6
1975	24.4	23.7	26.8	32.0	38.4	46.2	50.5	52.5	46.4	39.3	30.1	27.9	36.5
1976	25.5	23.9	22.0	27.2	36.6	44.6	49.7	50.8	45.3	39.1	30.5	28.2	35.3
1977	35.3	33.5	30.7	31.3	39.3	49.6	54.0	53.6	50.1	38.9	31.2	29.4	39.8
1978	33.4	28.4	30.8	37.9	40.5	47.0	49.6	54.3	48.8	40.1	38.1	35.2	40.3
1979	35.1	28.4	35.4	40.8	43.4	50.6	52.3	51.9	49.0	41.9	35.0	26.7	40.9
1980	23.5	25.4	33.7	35.6	41.4	45.9	52.9	51.5	48.1	40.3	36.4	32.1	38.9
1981	30.9	29.4	35.9	38.4	44.8	47.6	52.9	52.2	48.1	40.8	33.8	30.7	40.5
1982	29.8	27.1	33.9	32.1	38.0	45.0	46.8	50.2	45.1	37.5	35.3	30.5	37.6
1983	24.6	31.5	33.5	36.8	41.7	48.4	51.6	52.2	47.3	39.7	34.6	37.5	40.0
1984	31.2	18.7	33.7	31.6	38.0	47.0	49.7	54.7	49.7	40.8	37.0	37.3	39.1
1985	36.1	27.9	30.1	26.8	38.3	42.5	50.6	50.8	49.5	39.6	38.9	35.6	38.9
1986	24.4	28.4	27.0	32.2	38.0	44.7	51.7	51.2	49.8	42.2	37.0	34.4	38.4
1987	30.5	31.2	33.6	34.2	38.8	44.5	50.9	52.8	46.9	41.0	30.0	28.3	38.6
1988	31.2	30.2	26.1	31.1	40.3	46.0	51.0	51.1	46.9	40.5	32.5	30.9	38.2
Record Mean	28.5	27.8	29.1	32.9	39.4	45.4	50.1	51.4	47.3	39.7	34.3	30.1	38.0
Max	32.9	32.4	34.0	37.5	44.2	50.0	54.5	55.6	51.7	44.3	38.7	34.5	42.5
Min	24.1	23.1	24.3	28.2	34.6	40.8	45.7	47.2	42.9	35.1	29.9	25.7	33.5

See Reference Notes on Page 6B.

APPENDIX D

SELECTED SYNOPTIC WEATHER MAPS

8-11 June 1989



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MICROFICHE AT UNIV. OF ALASKA AEIDC
CLIMATE CENTER

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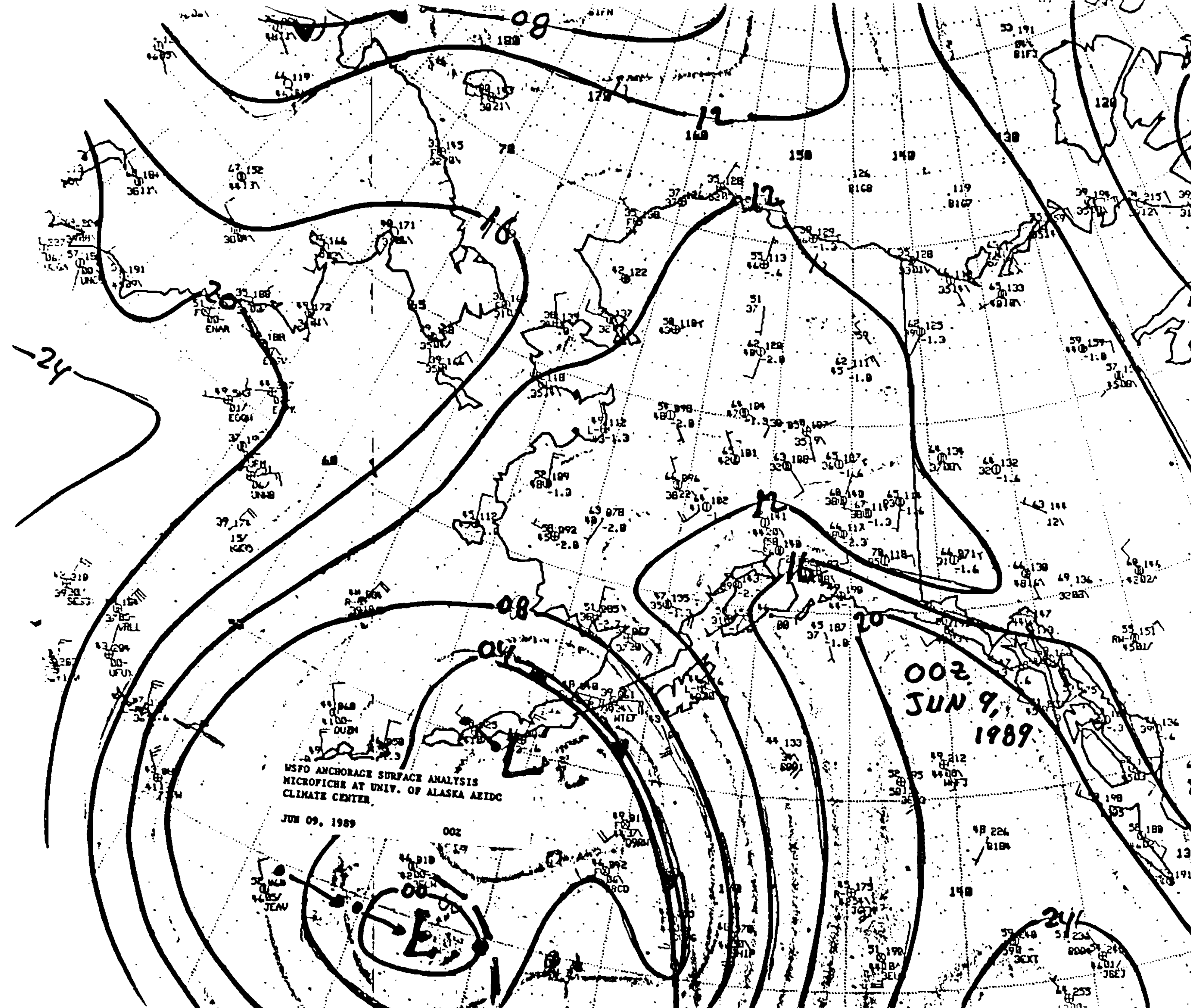
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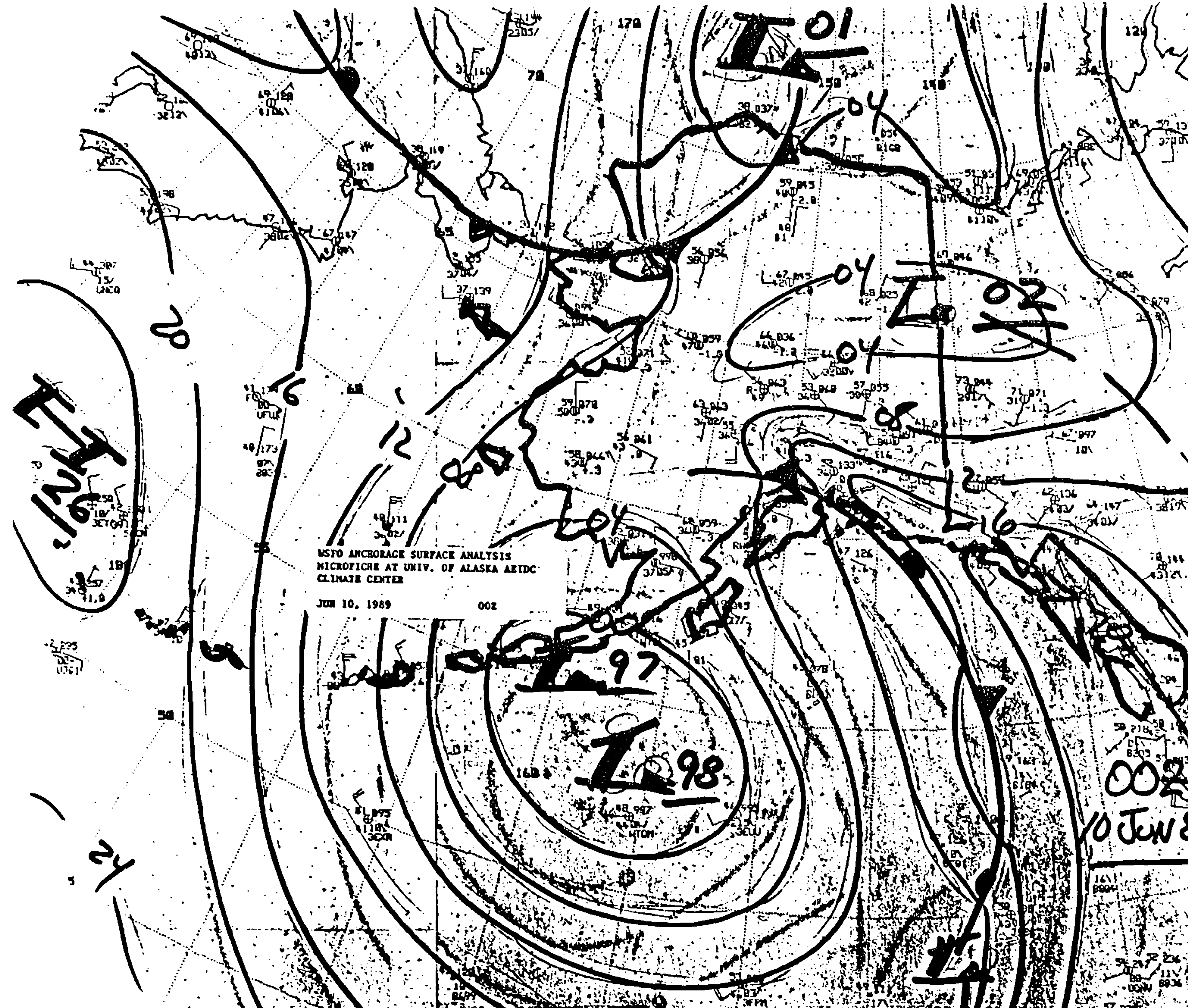

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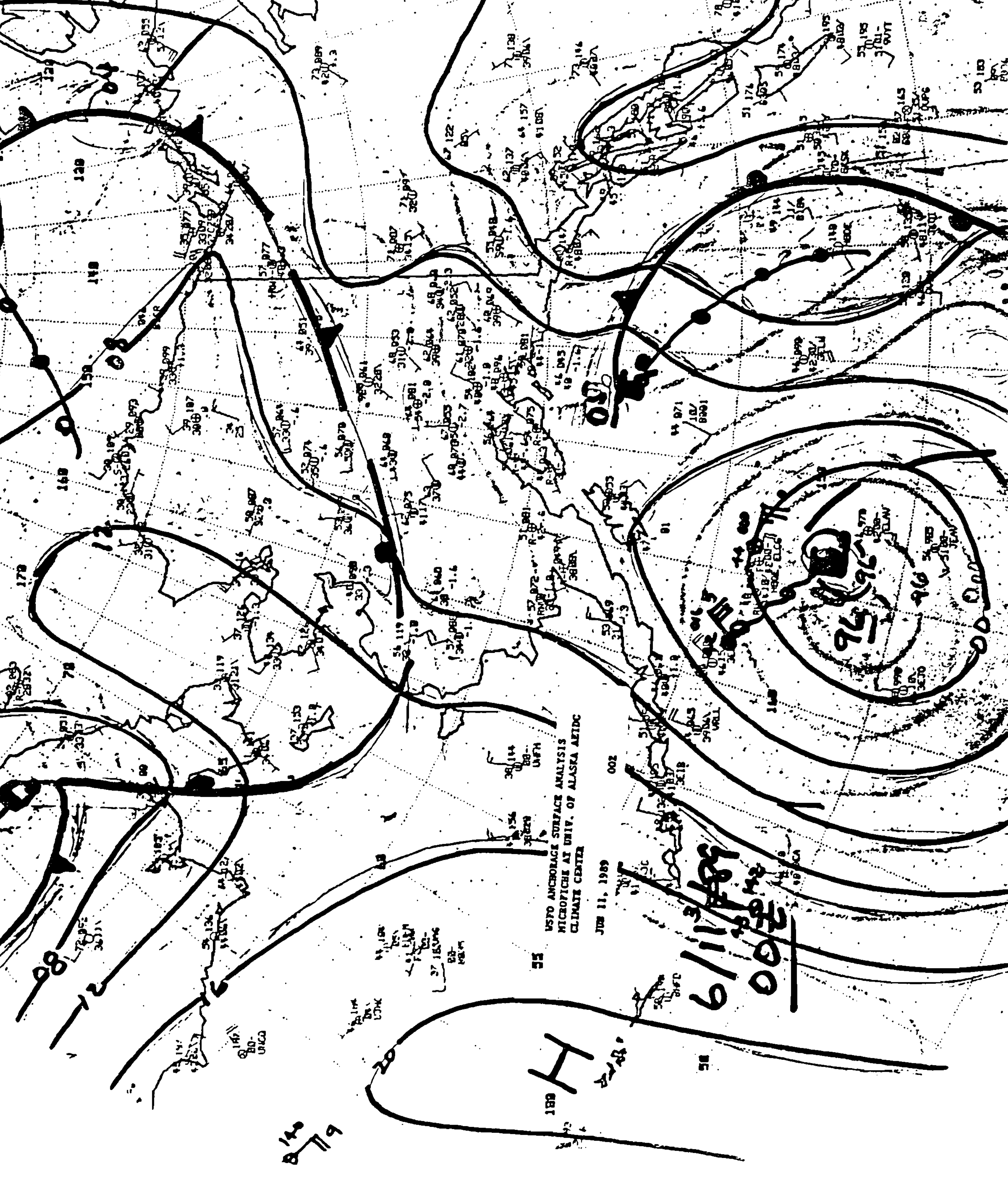

USFO ANCHORAGE SURFACE ANALYSIS
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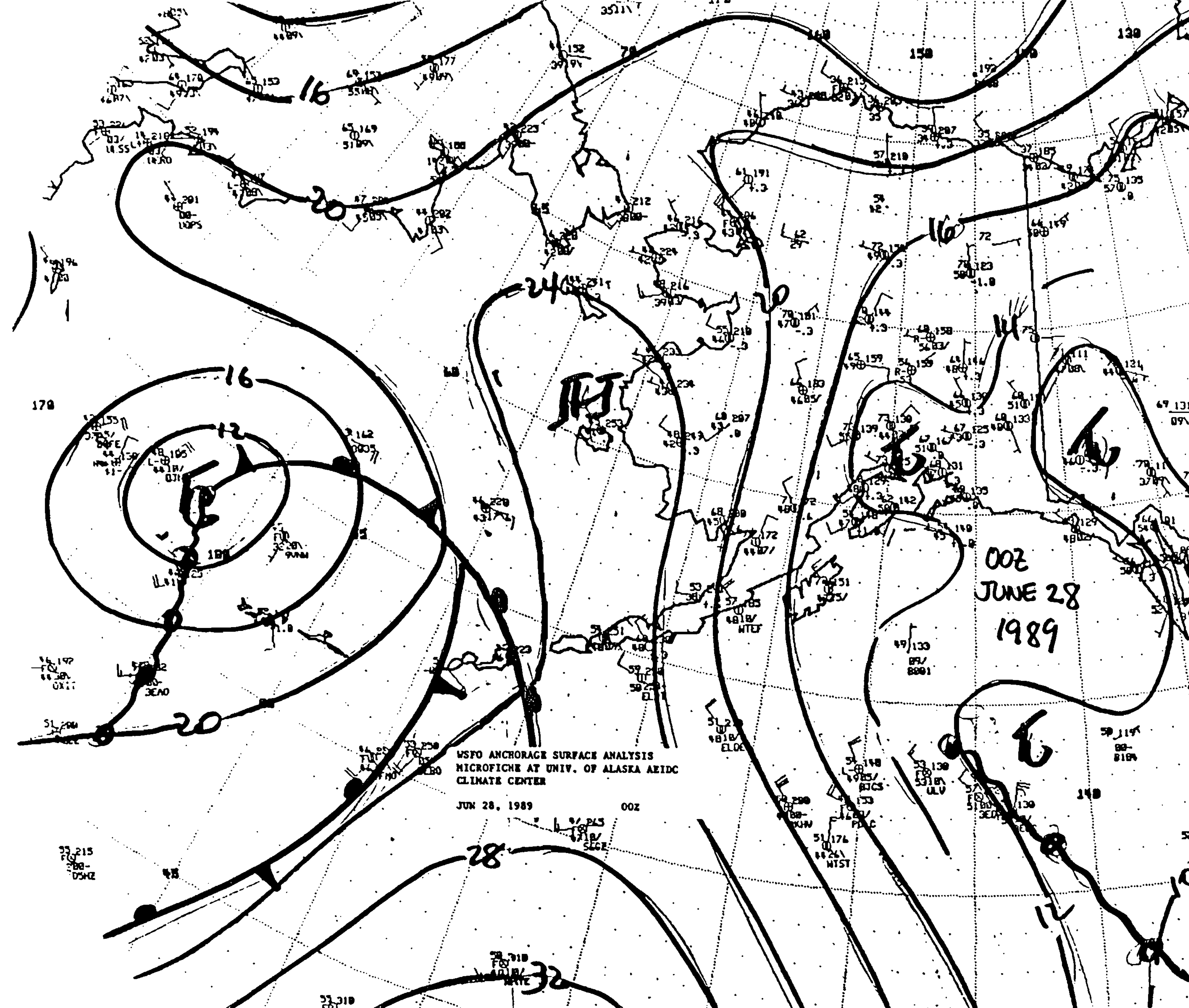
28-30 June 1989



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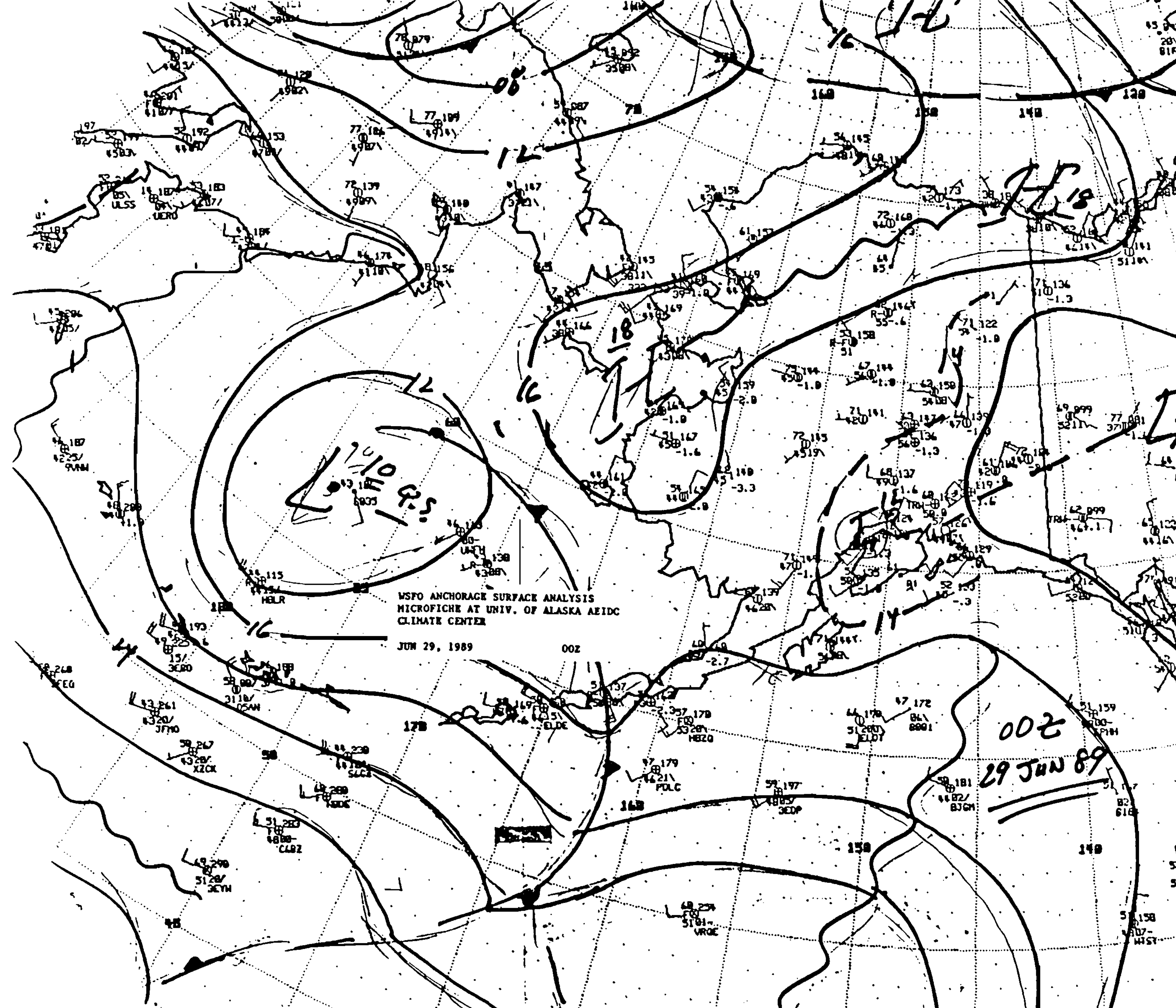

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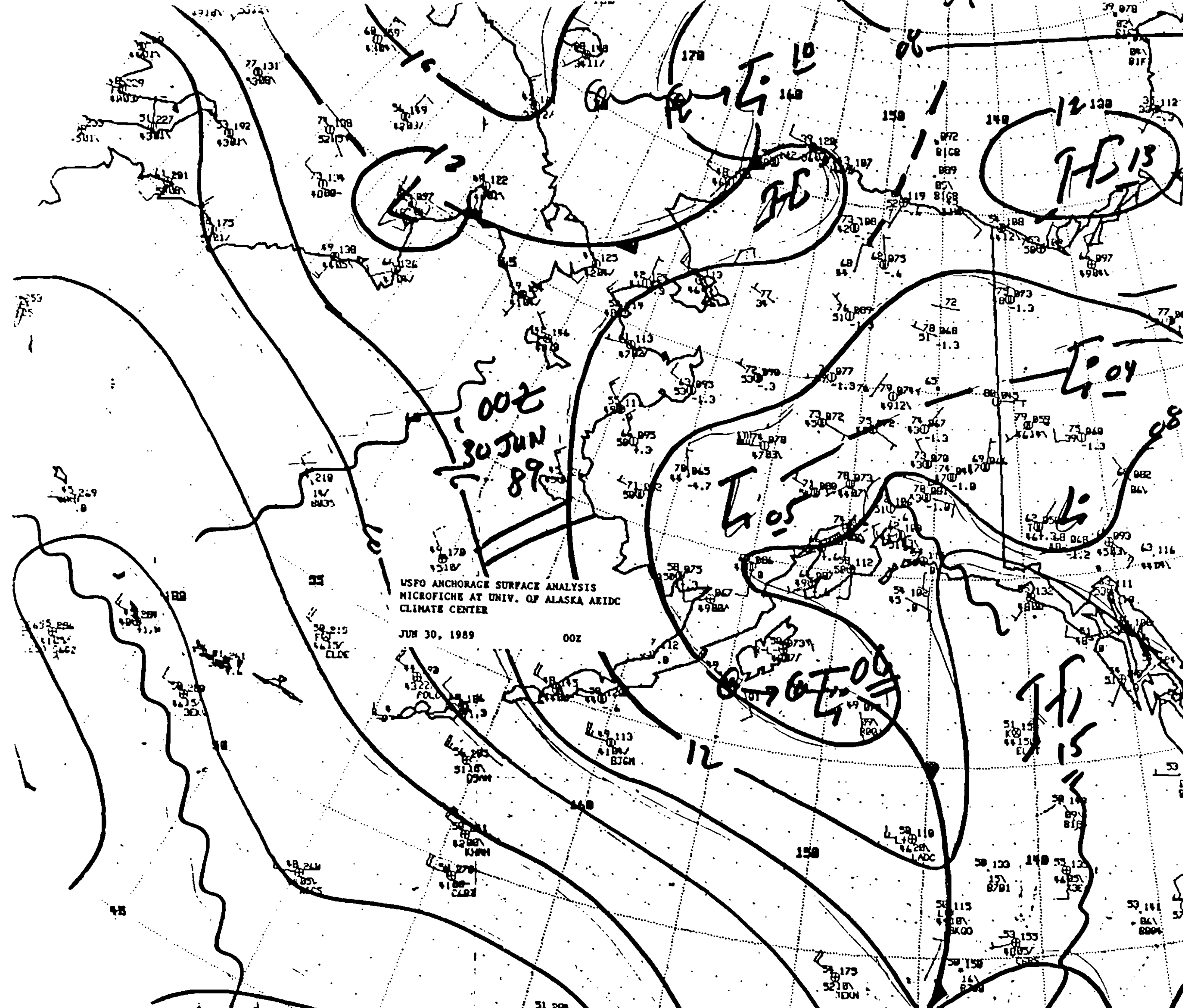

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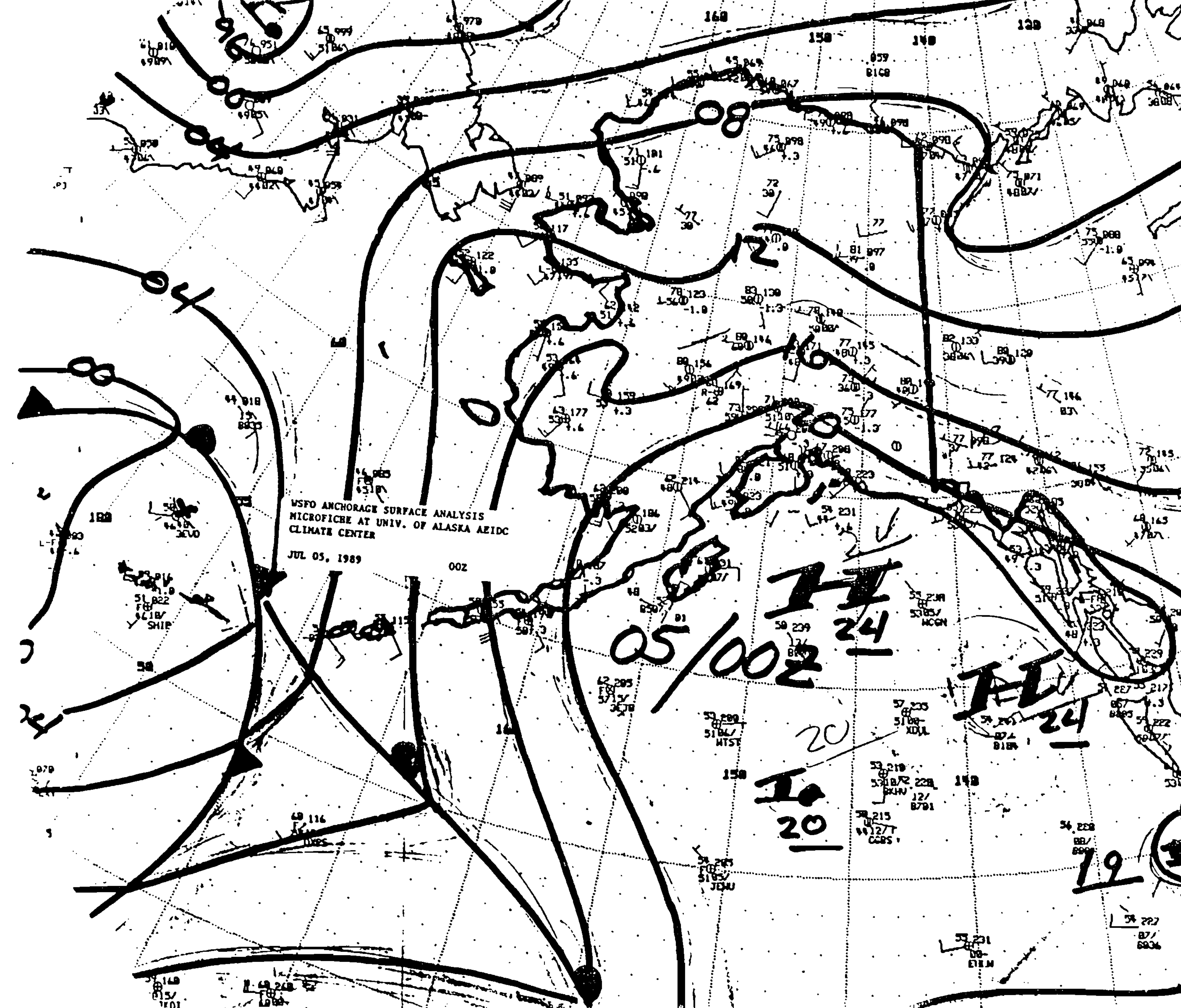

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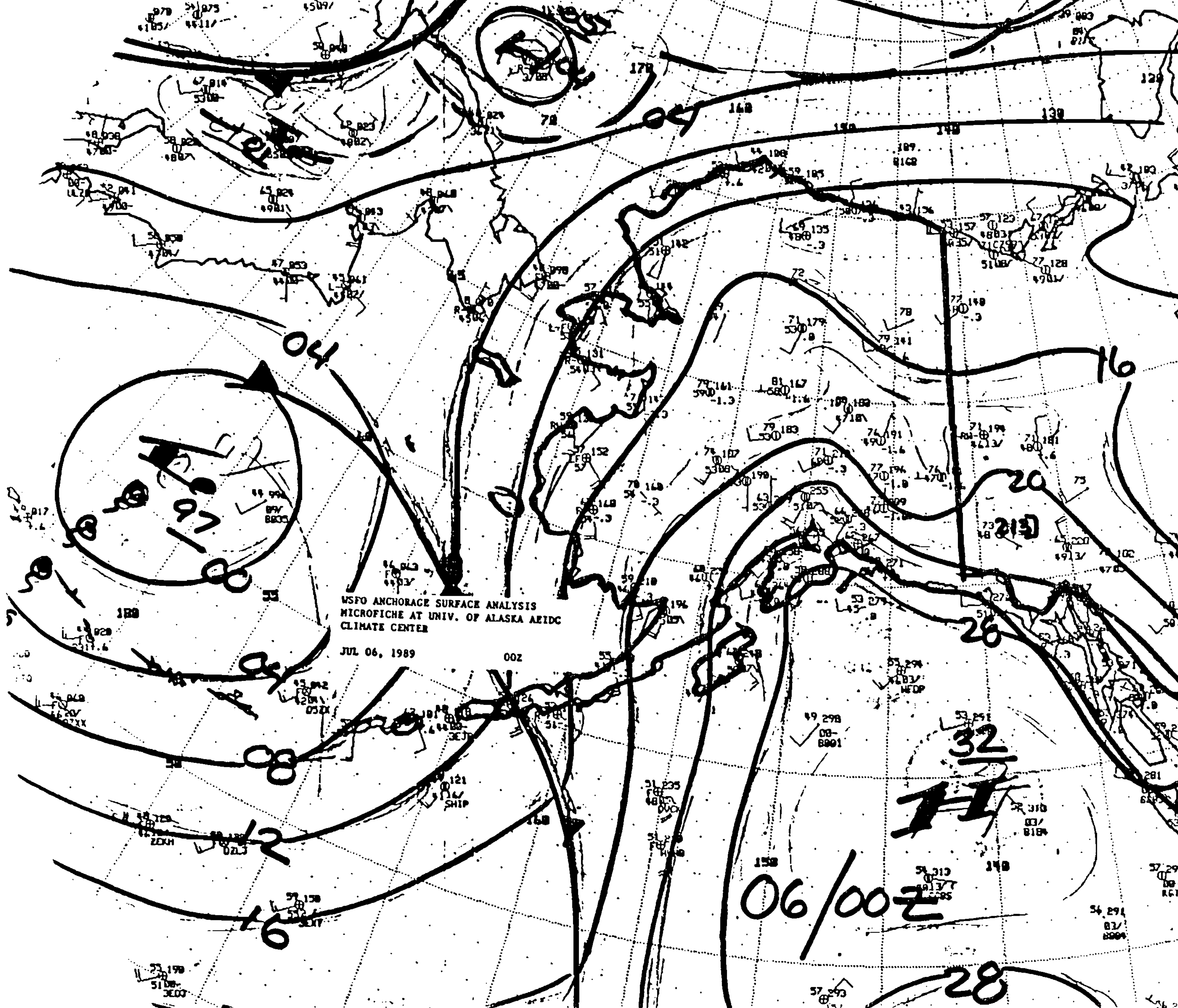

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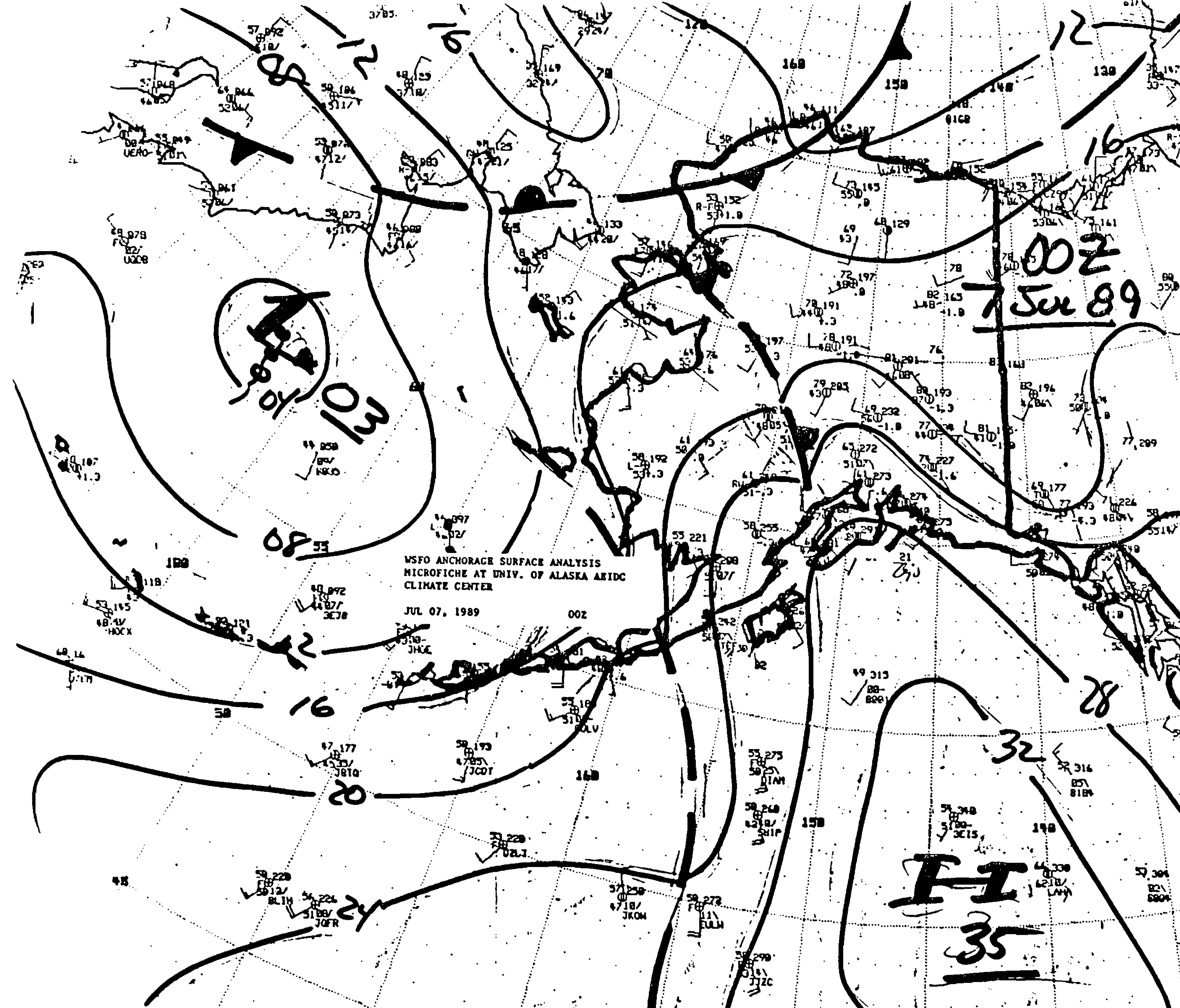

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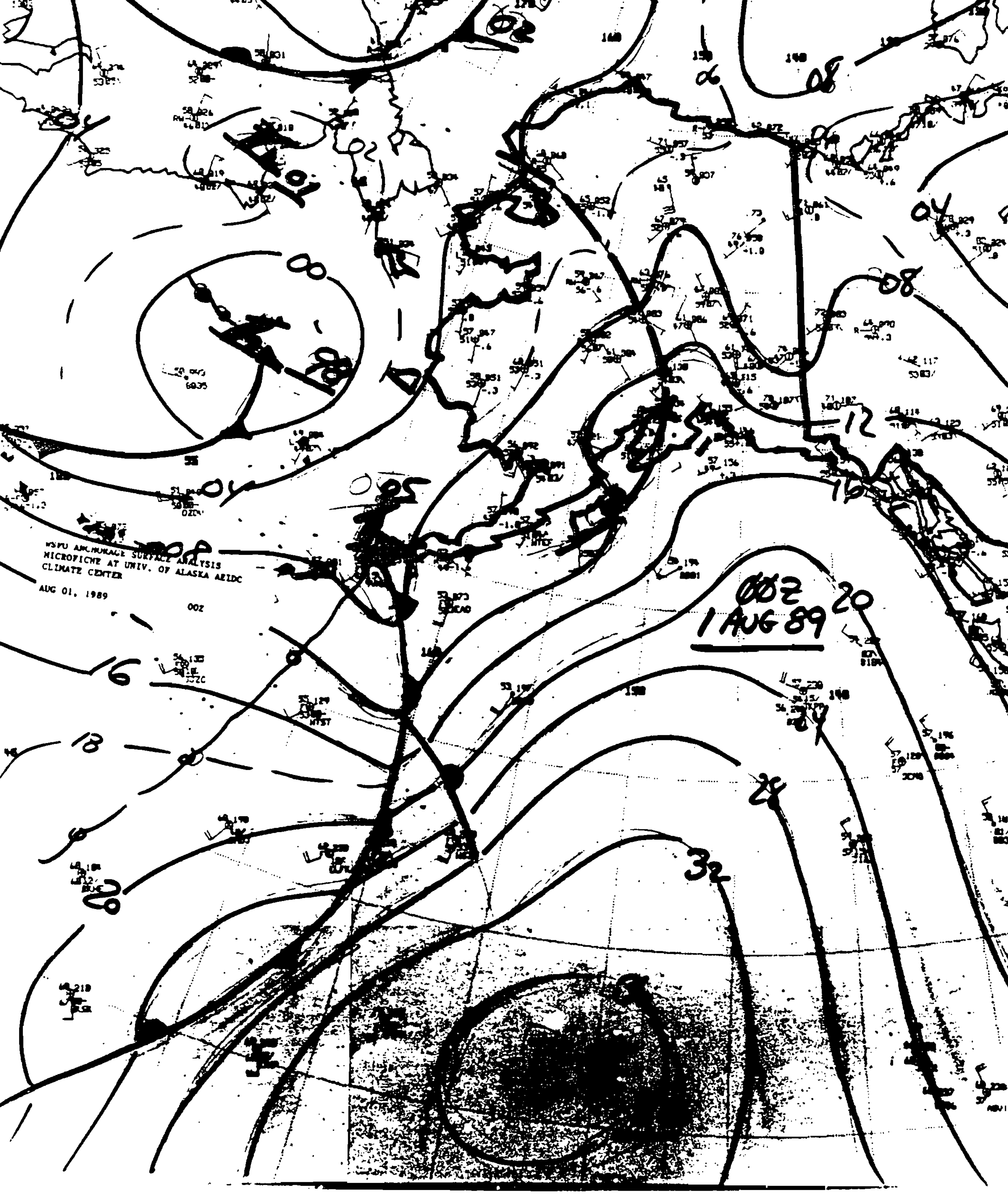

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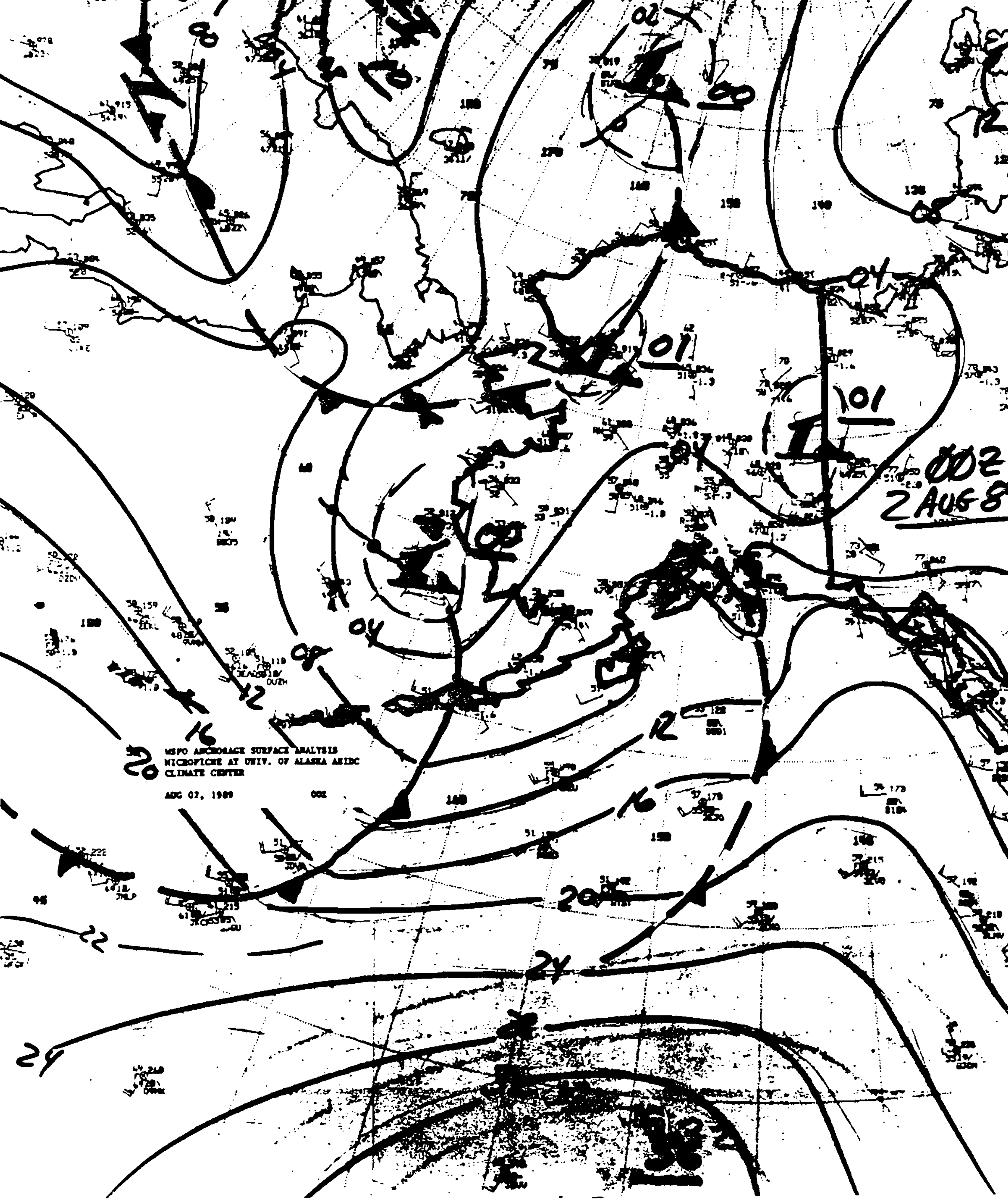

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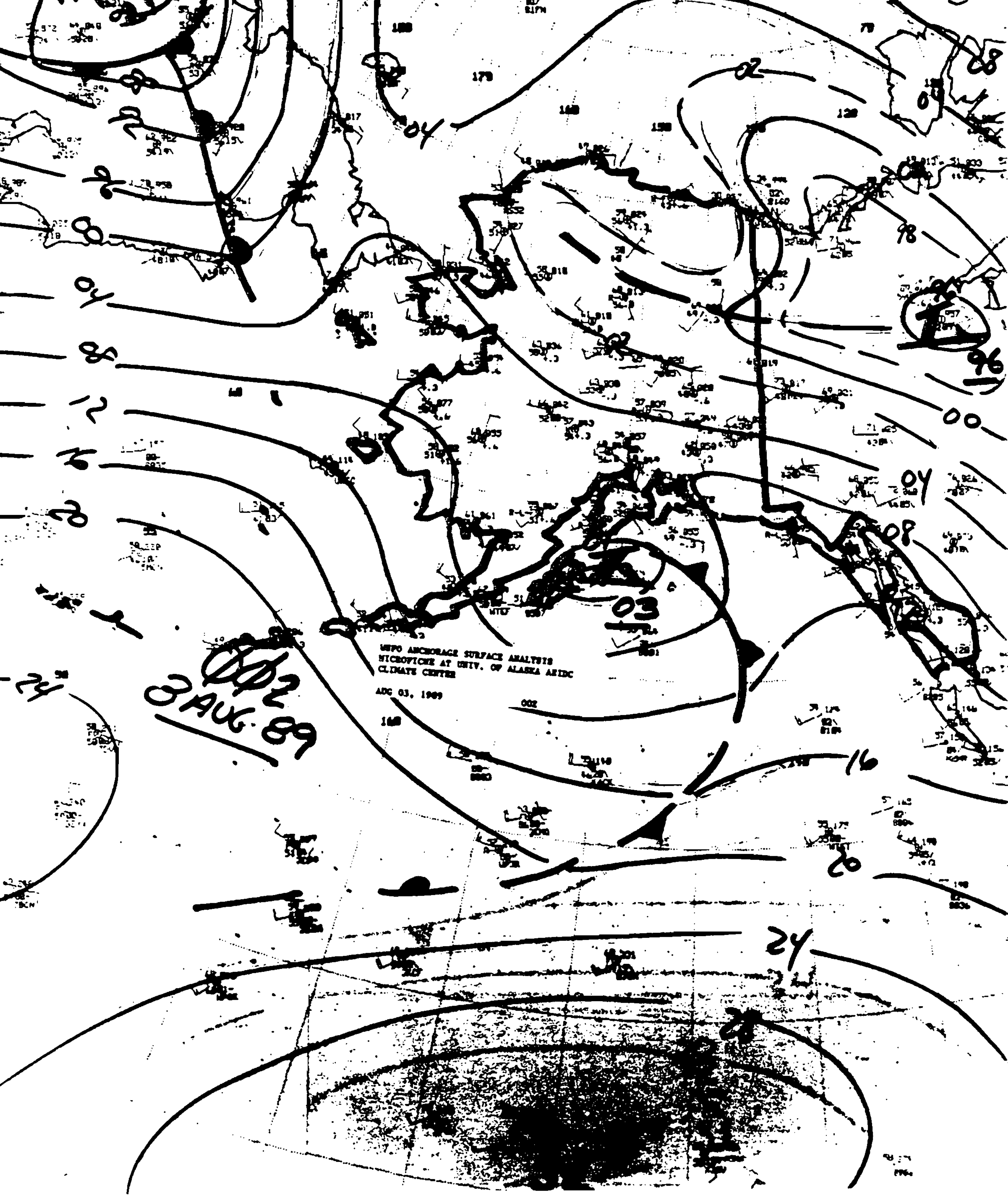

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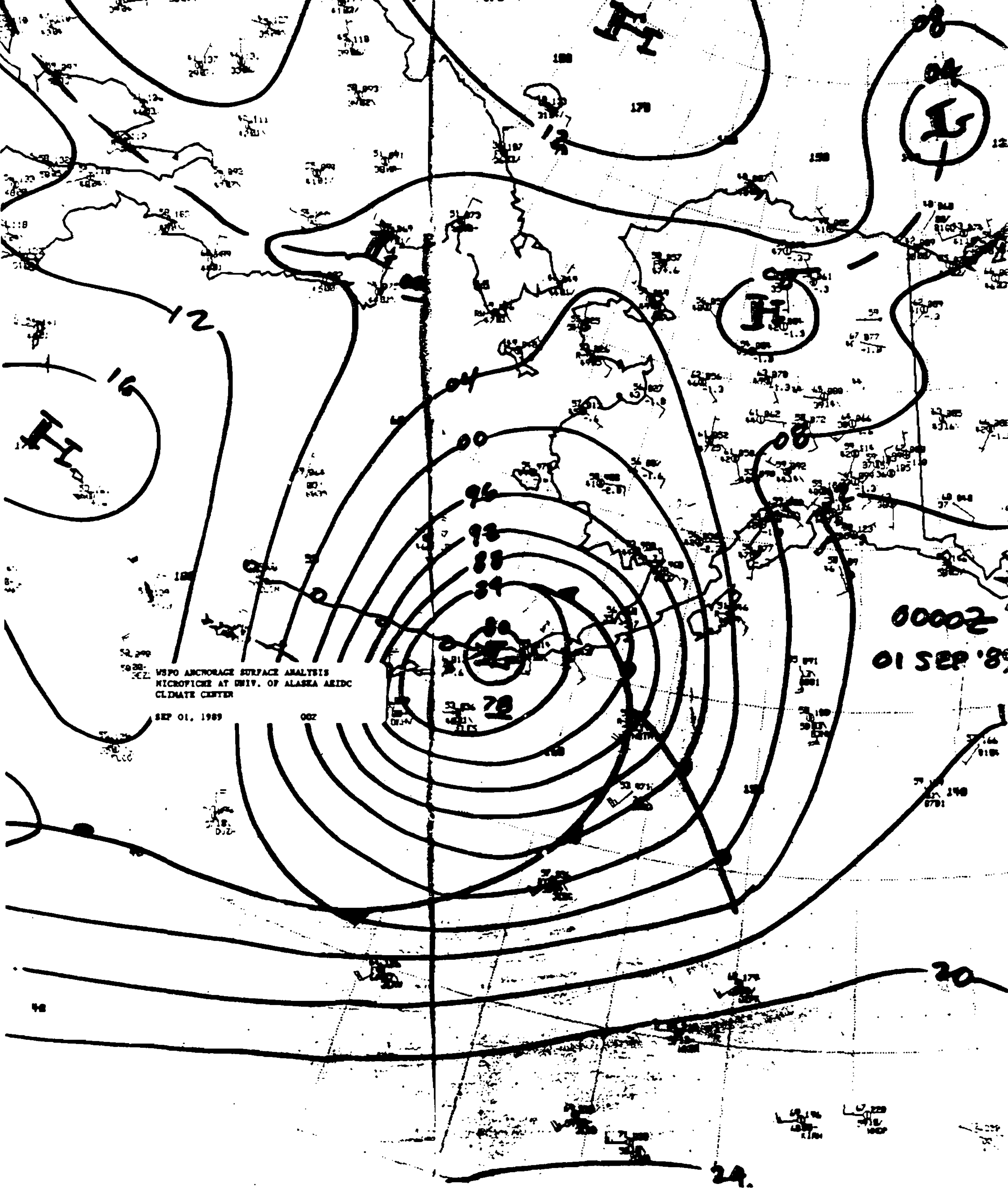

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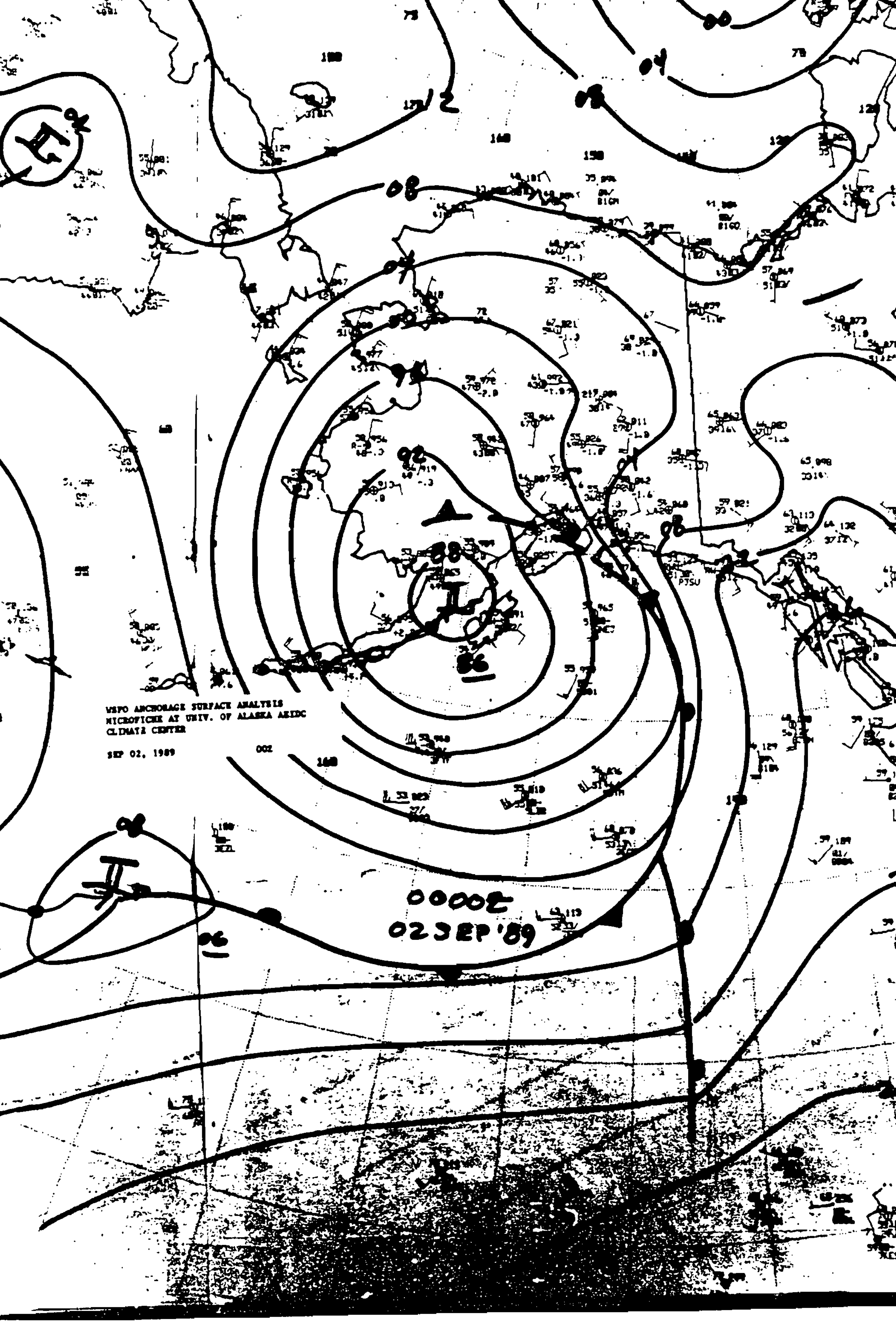

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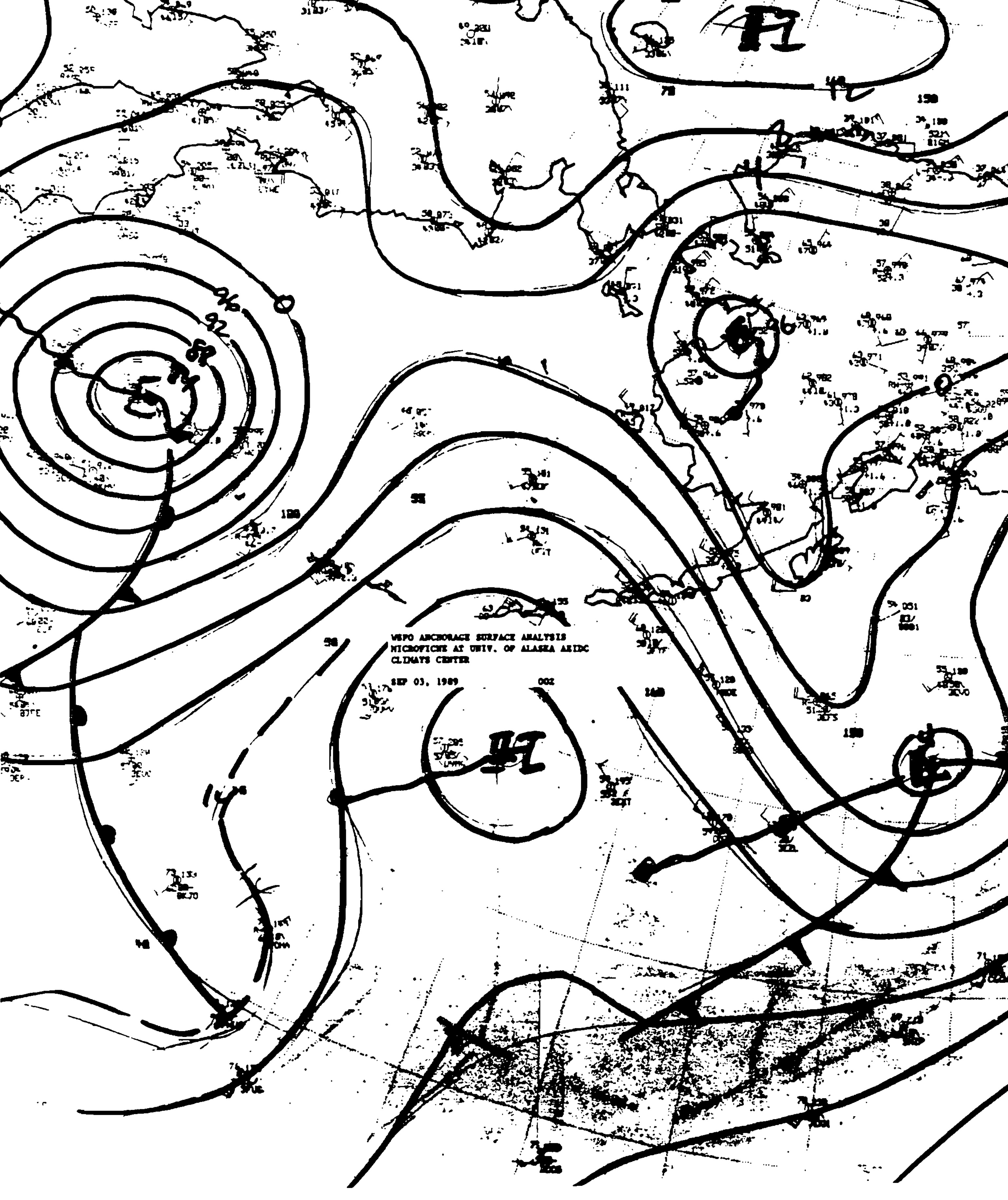

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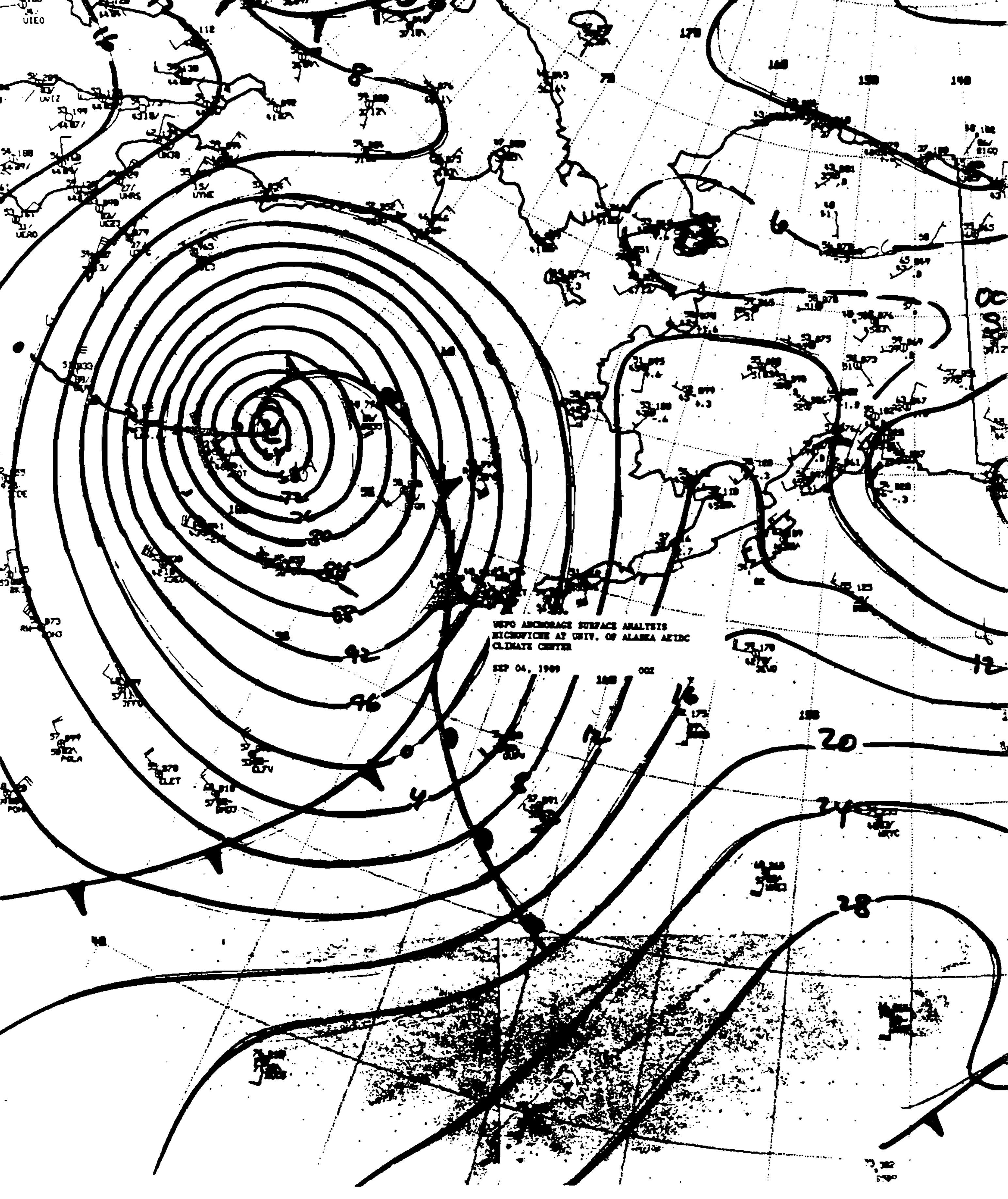

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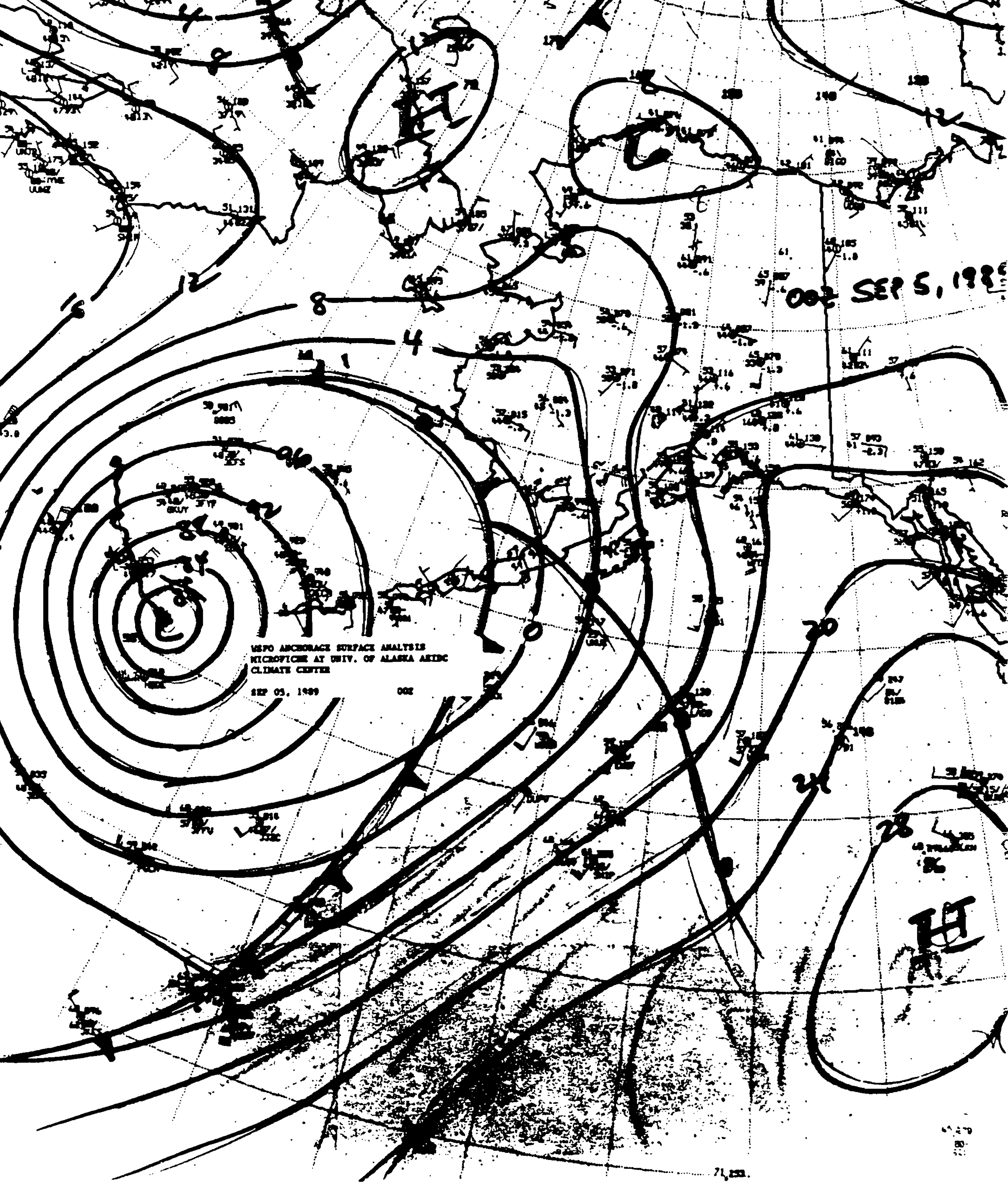
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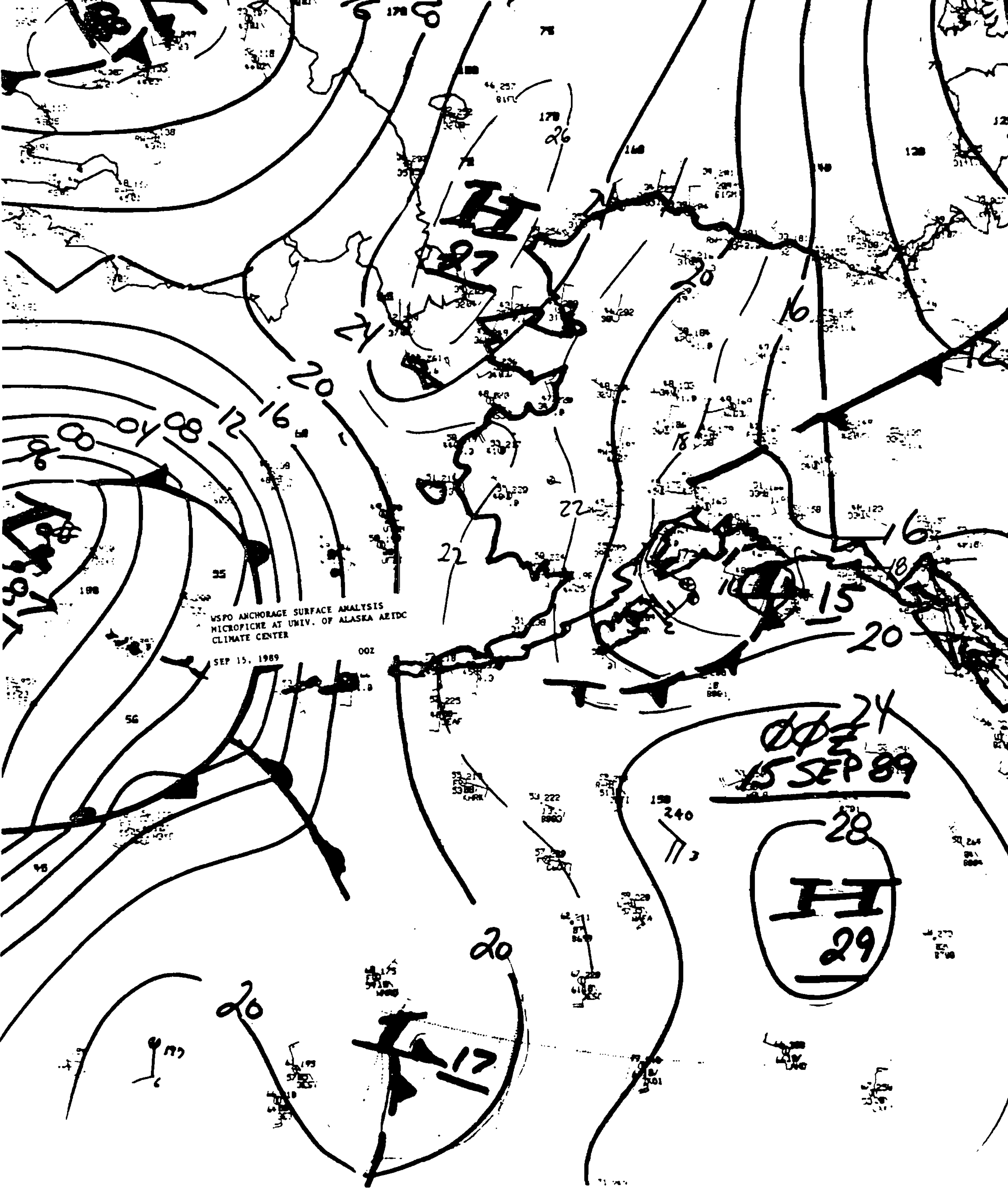

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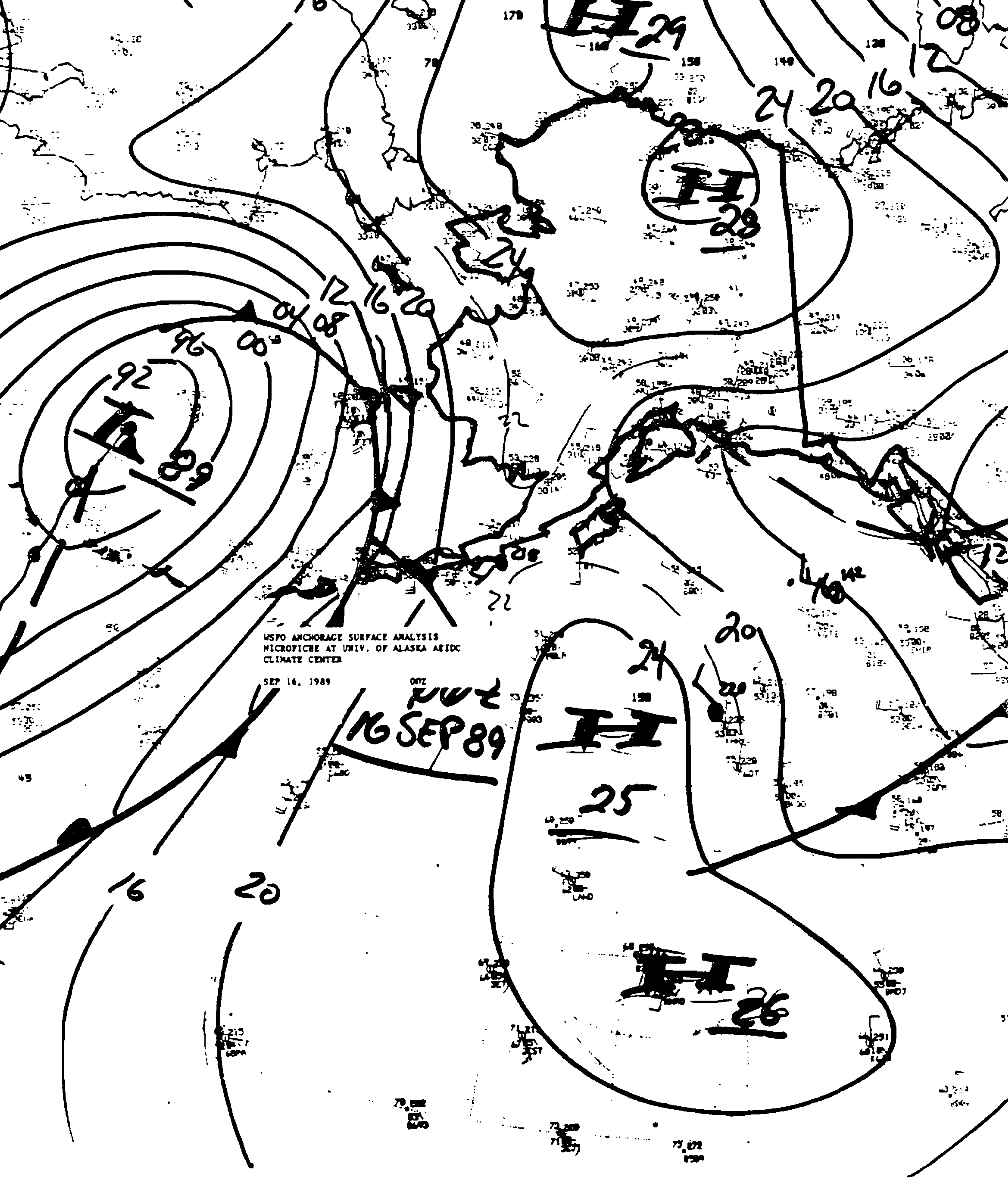

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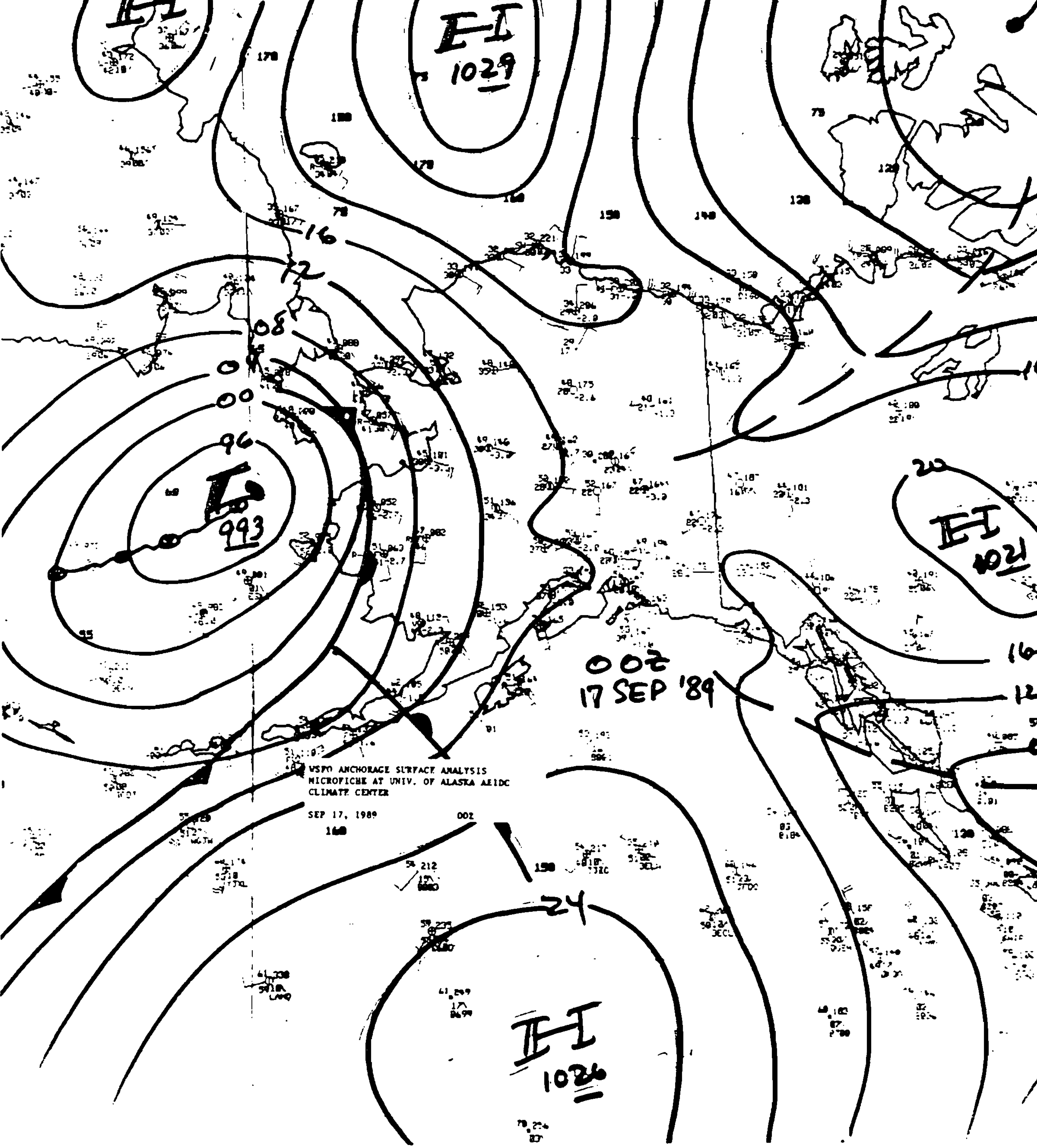

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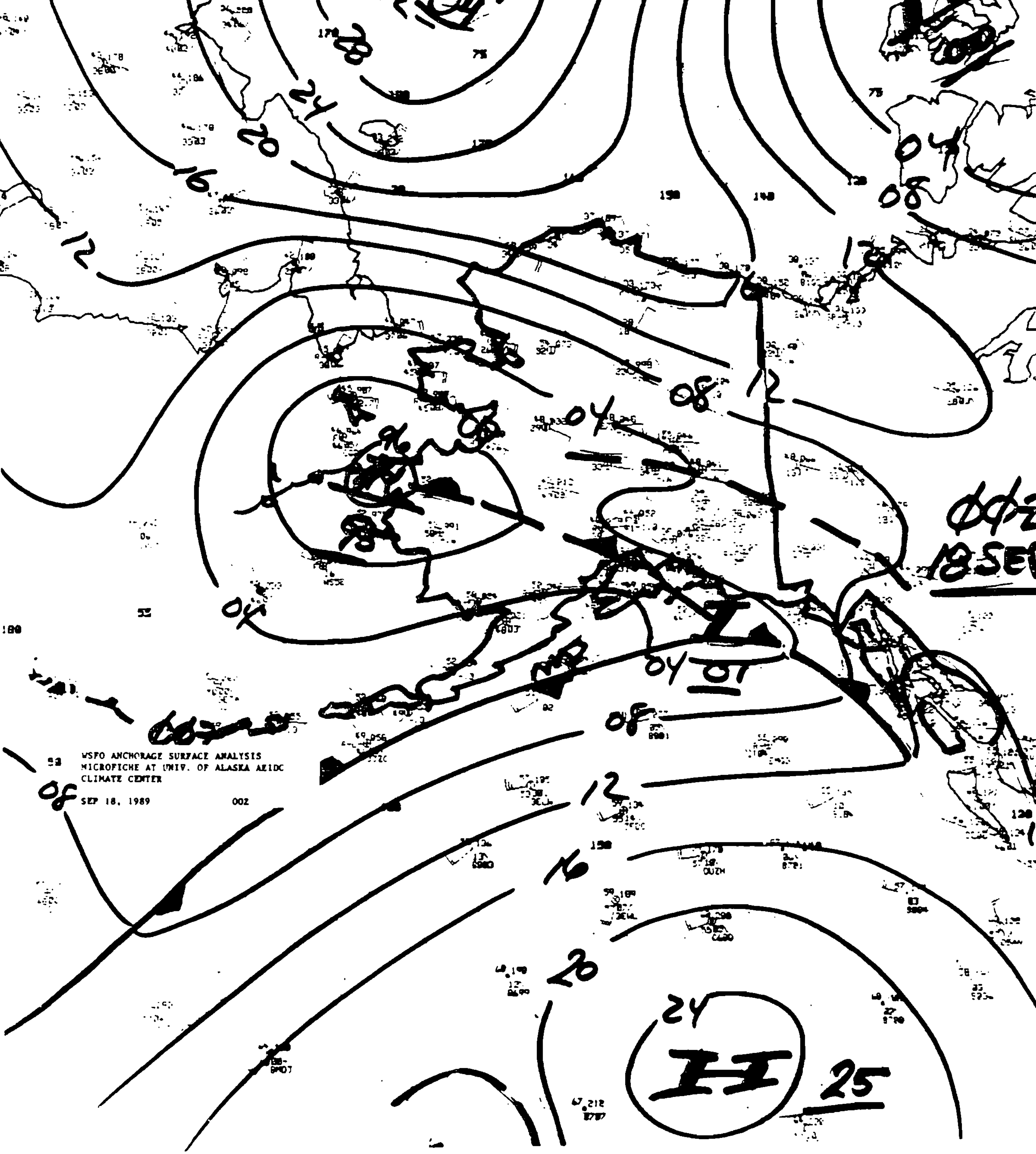

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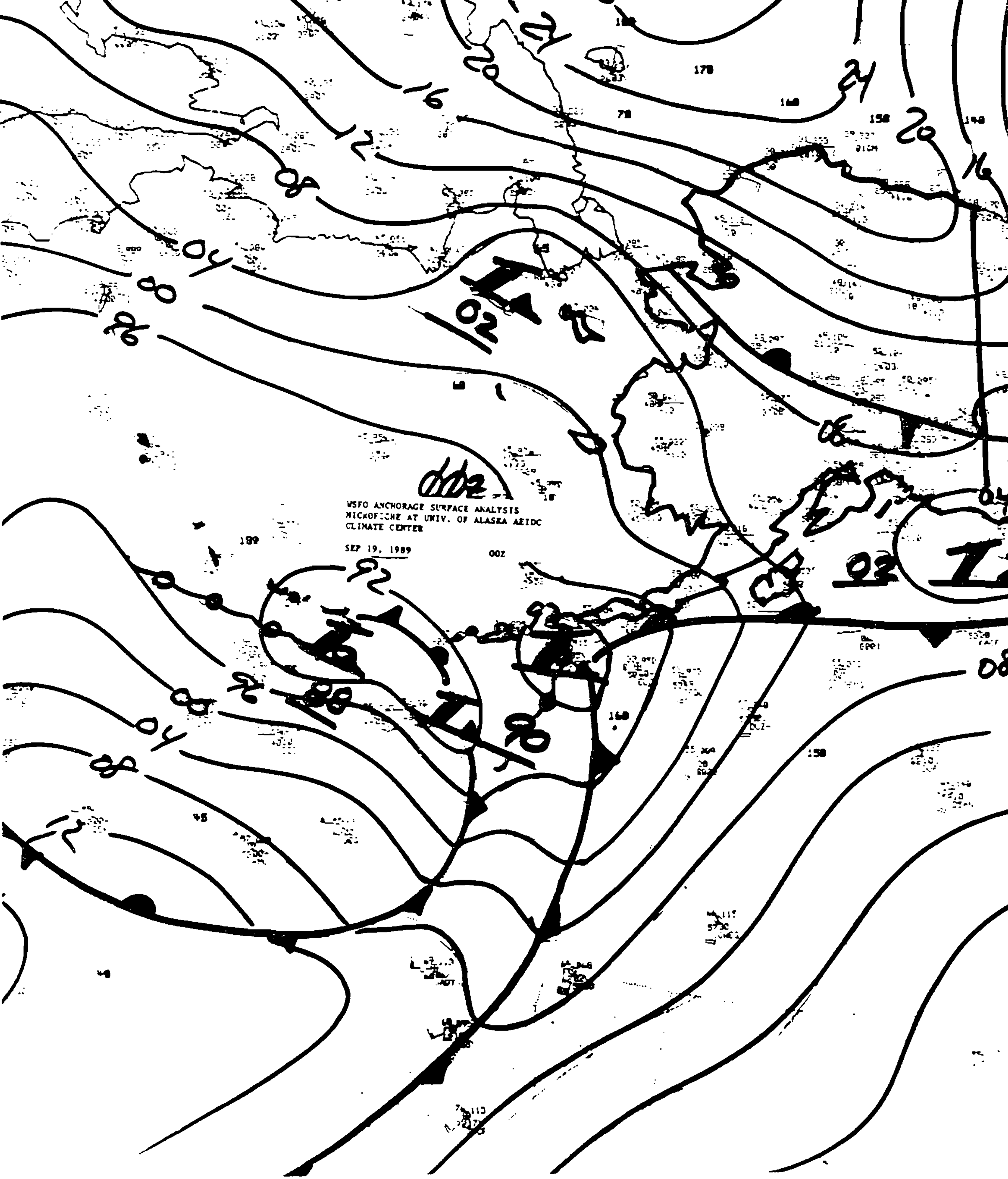

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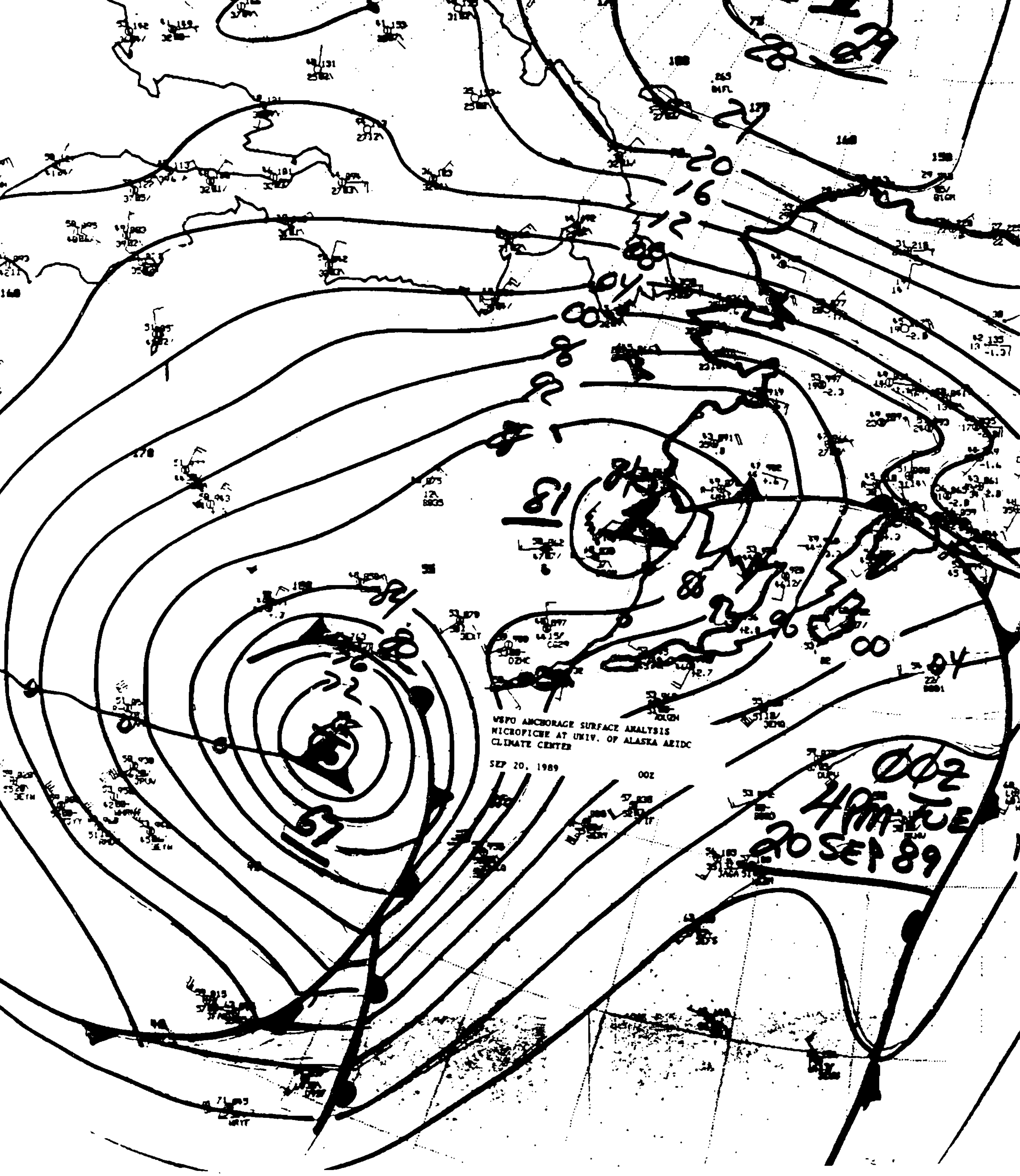

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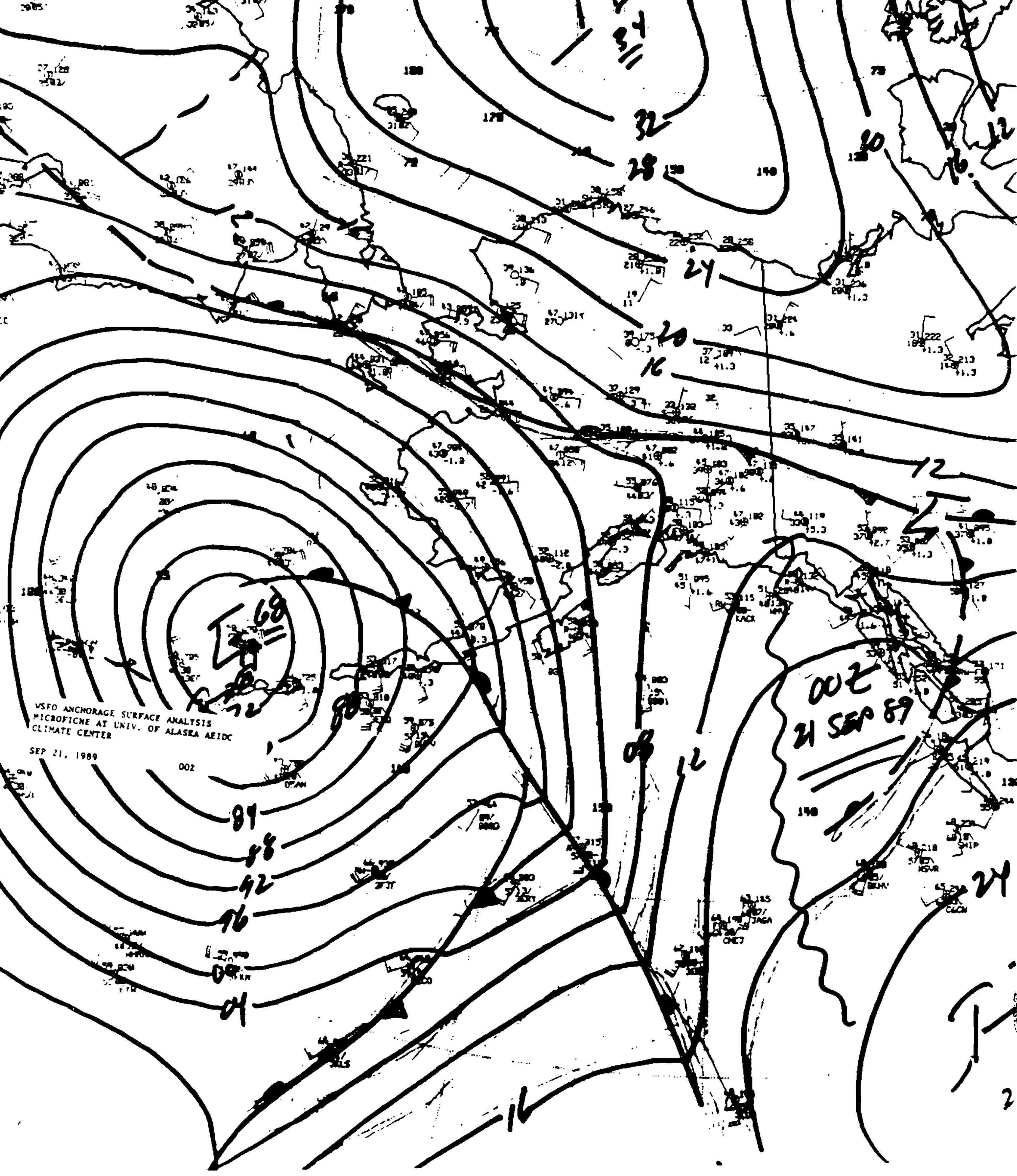

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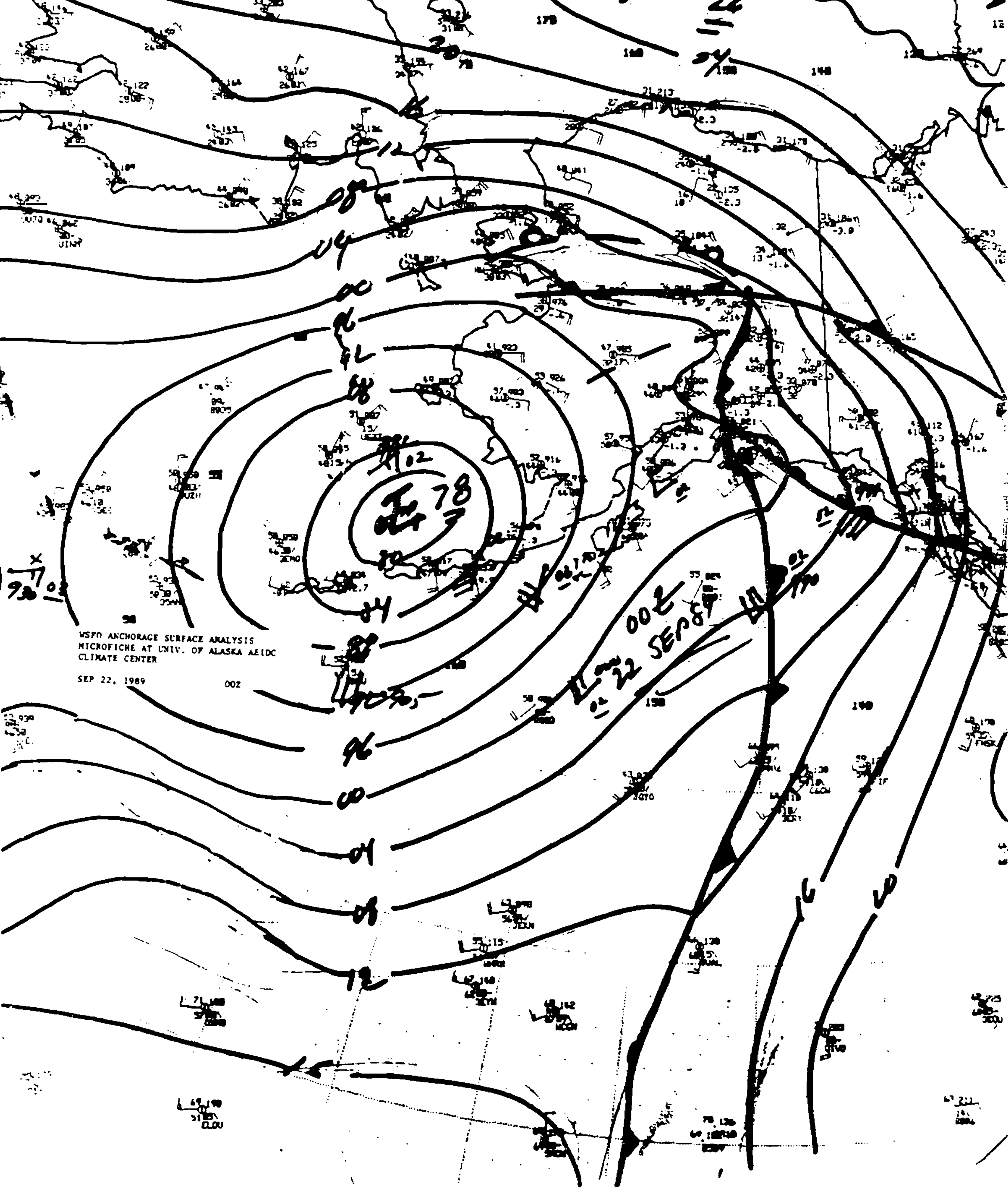

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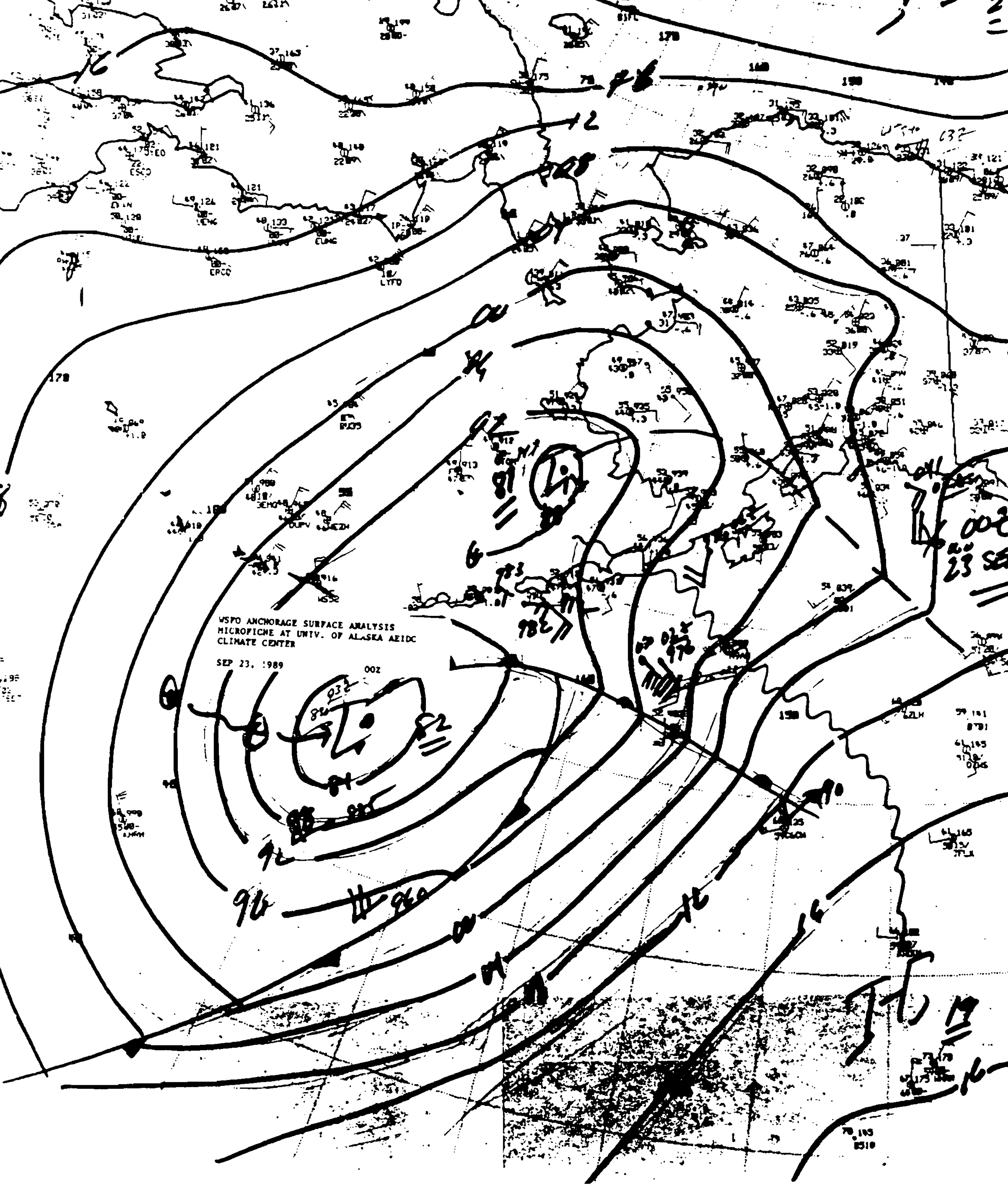
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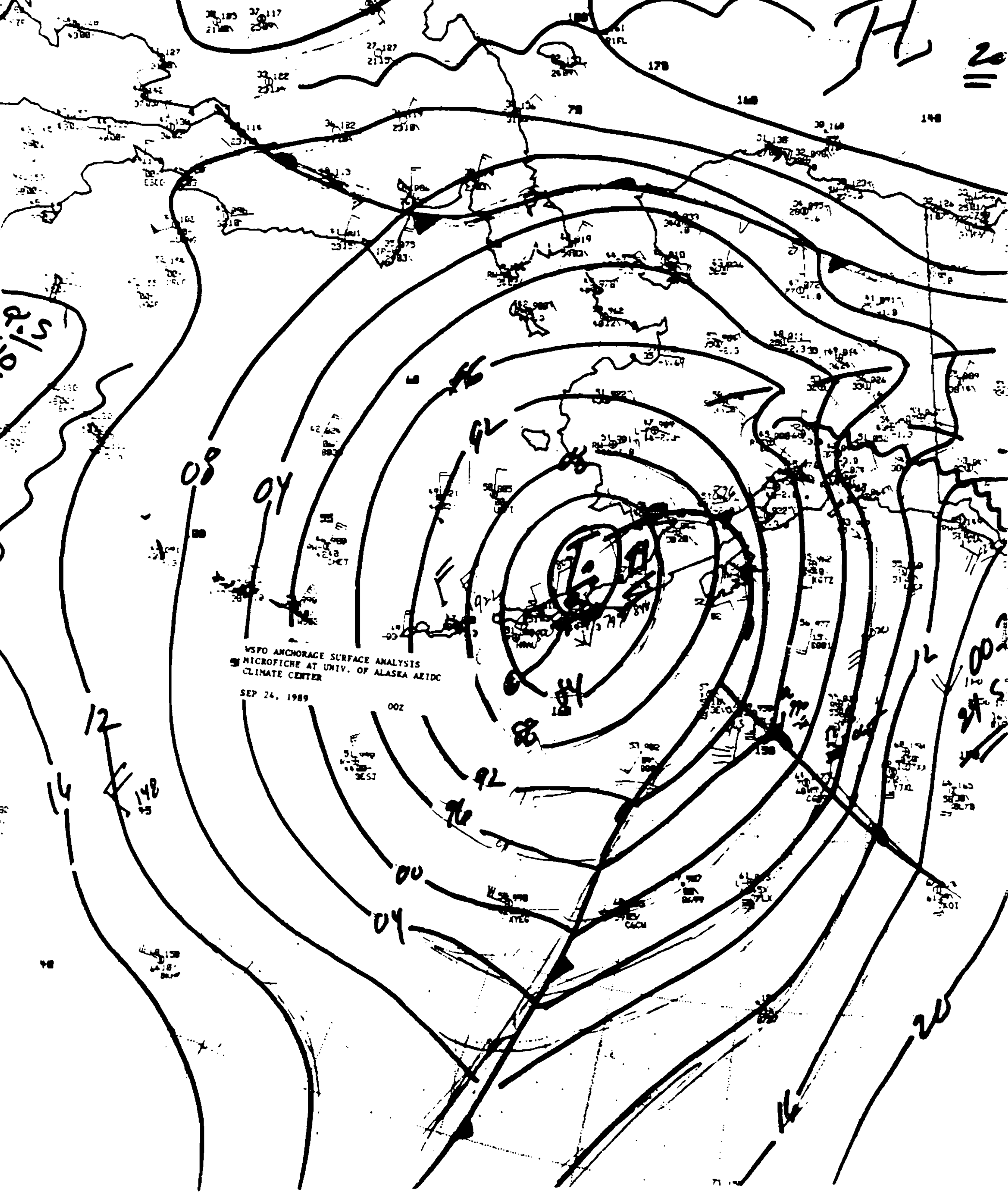

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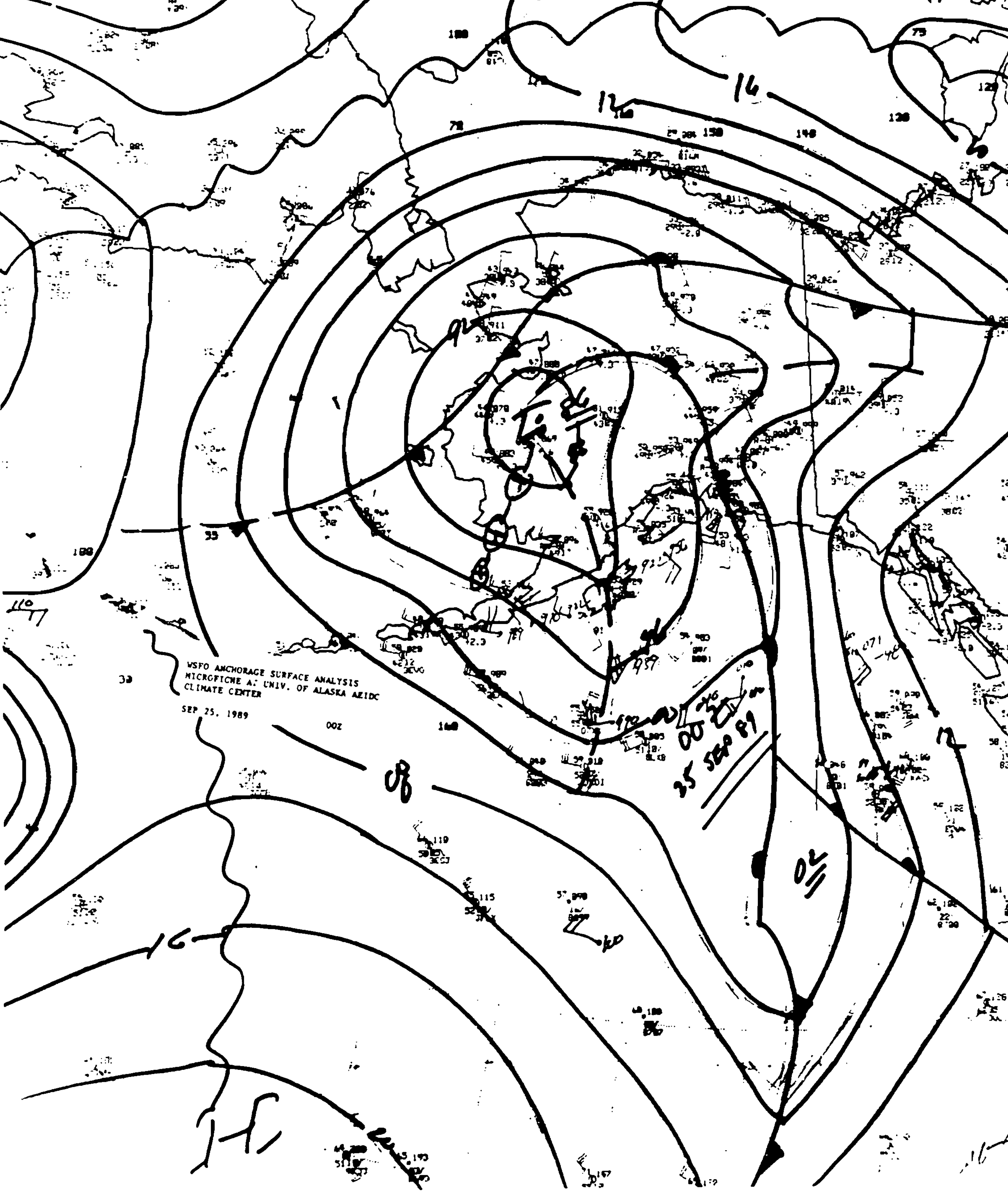
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APPENDIX E

PORT MOLLER
1989 DRCM/CTD PROFILES

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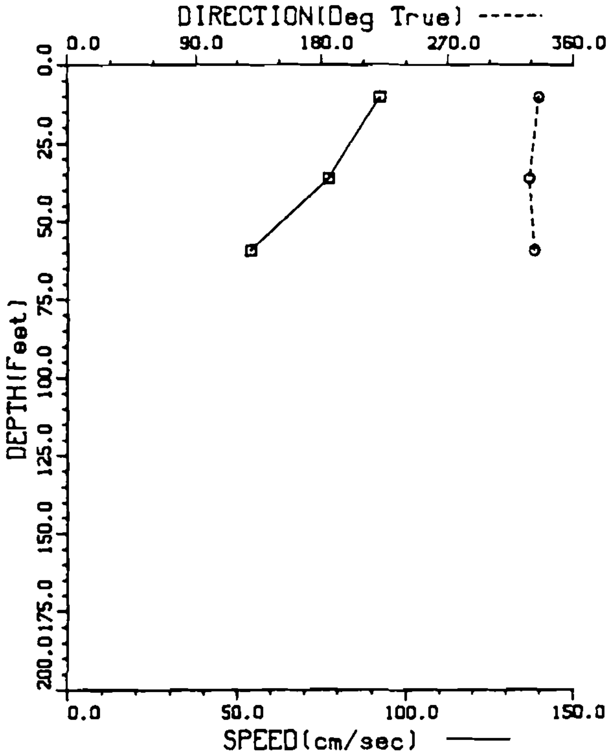

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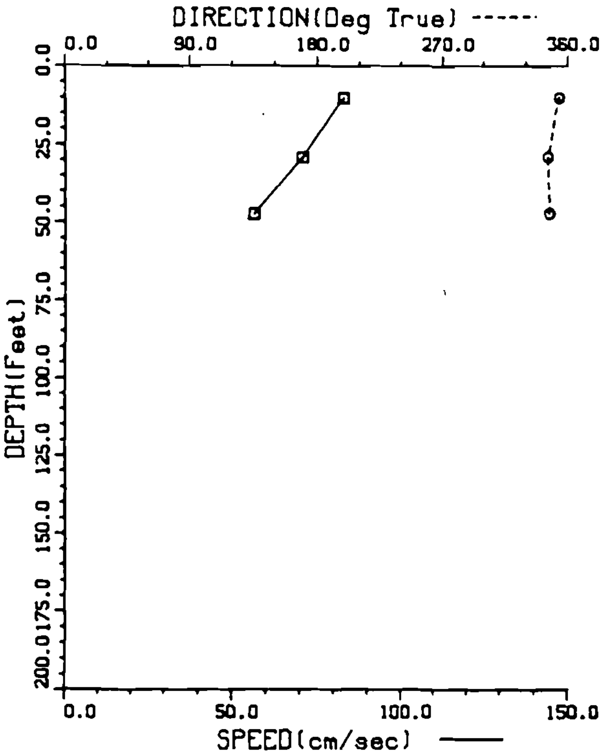

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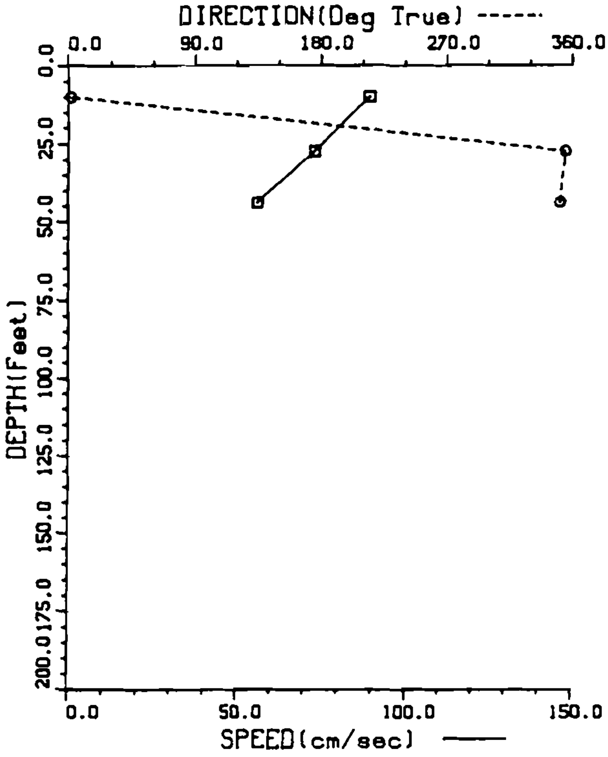

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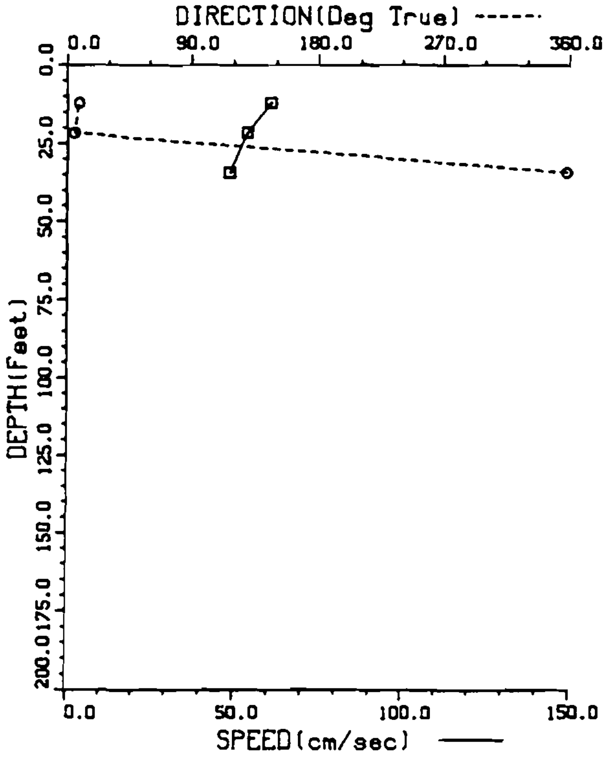

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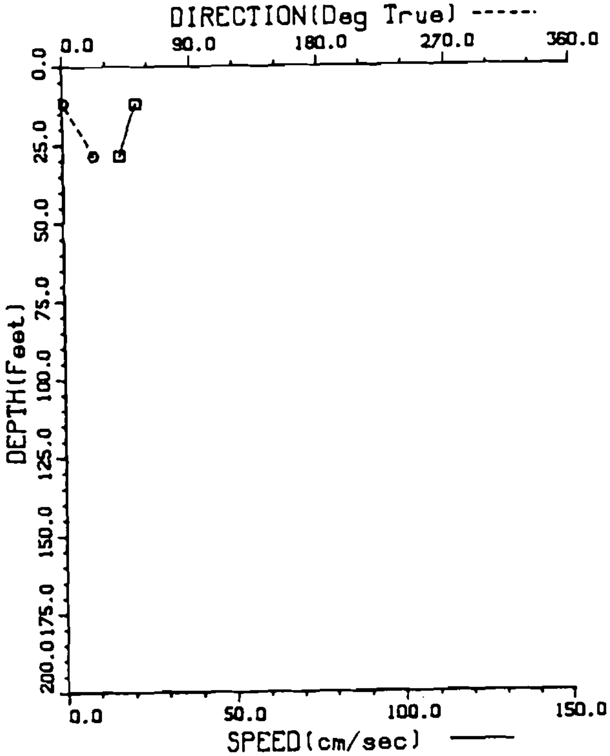

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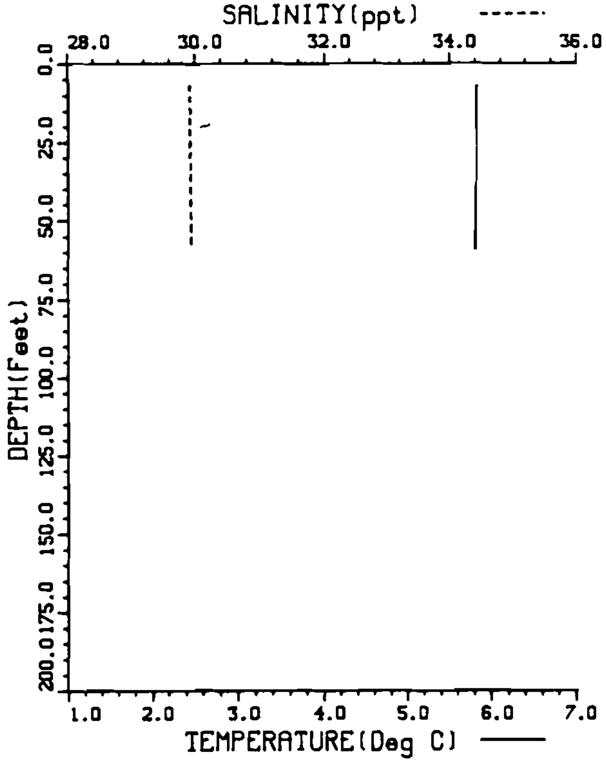

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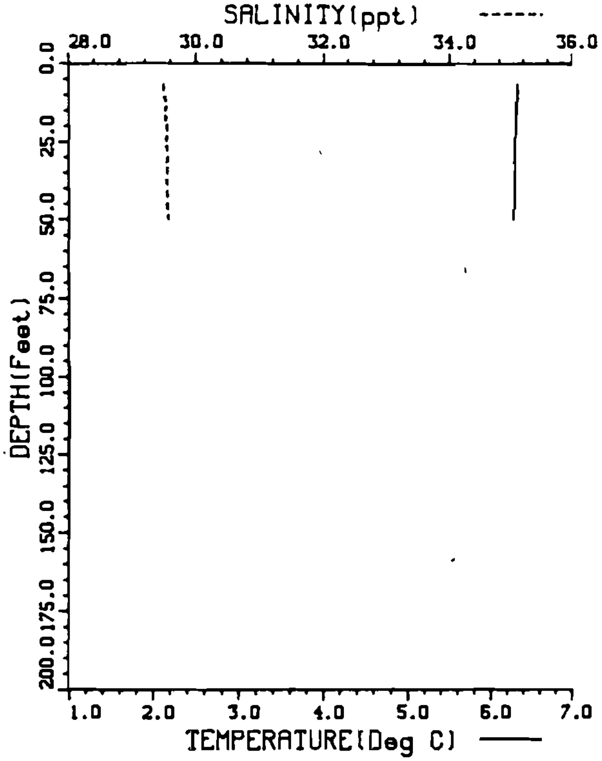

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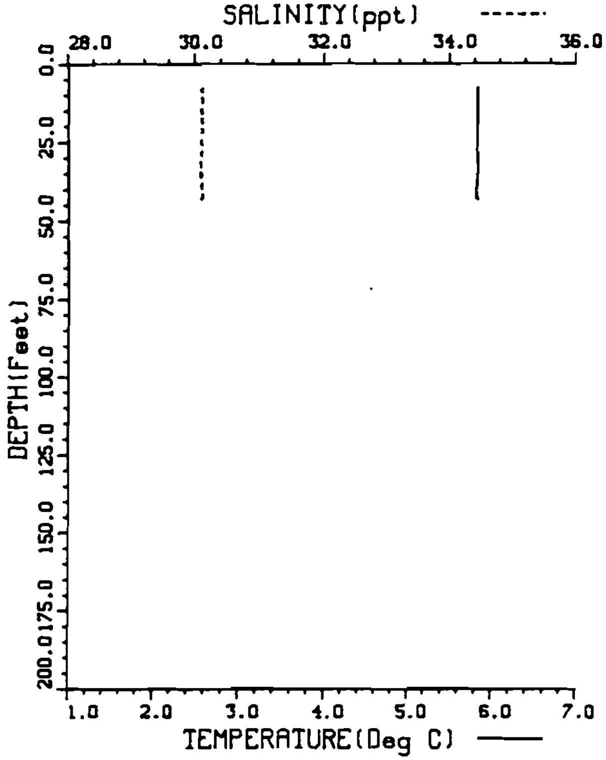
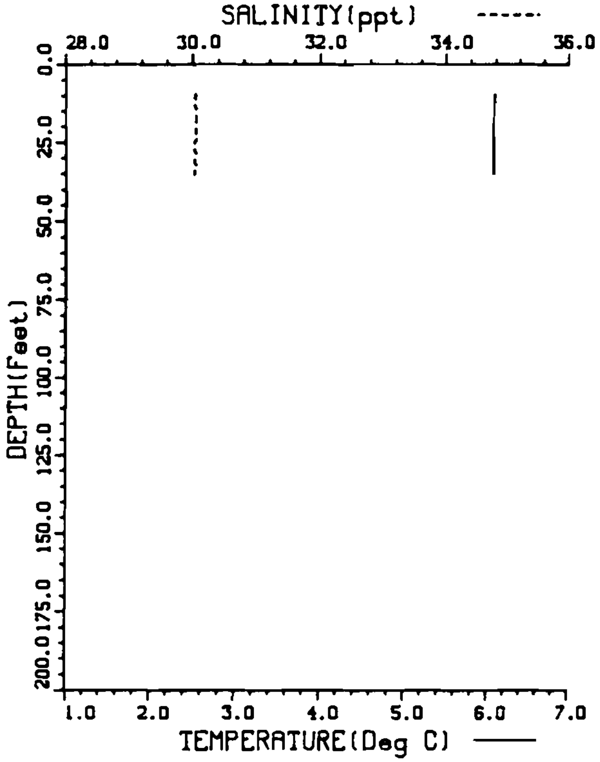
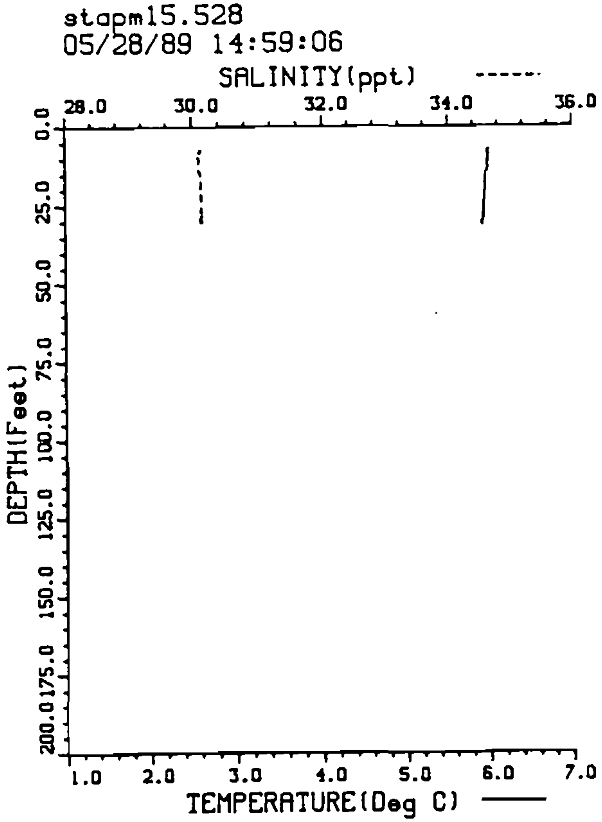
05/28/89 13:56:42



stapm14.528
05/28/89 14:33:18




stapm15.528
05/28/89 14:59:06
SALINITY(ppt)
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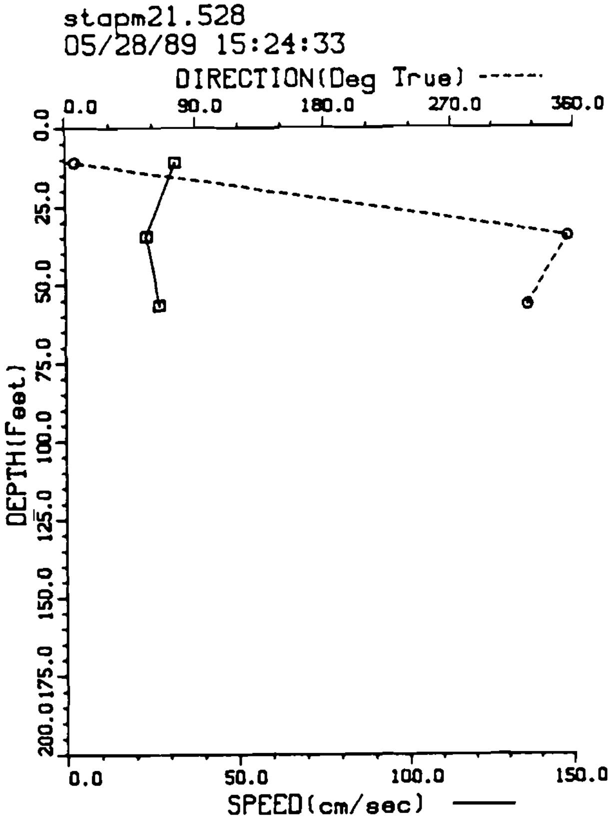
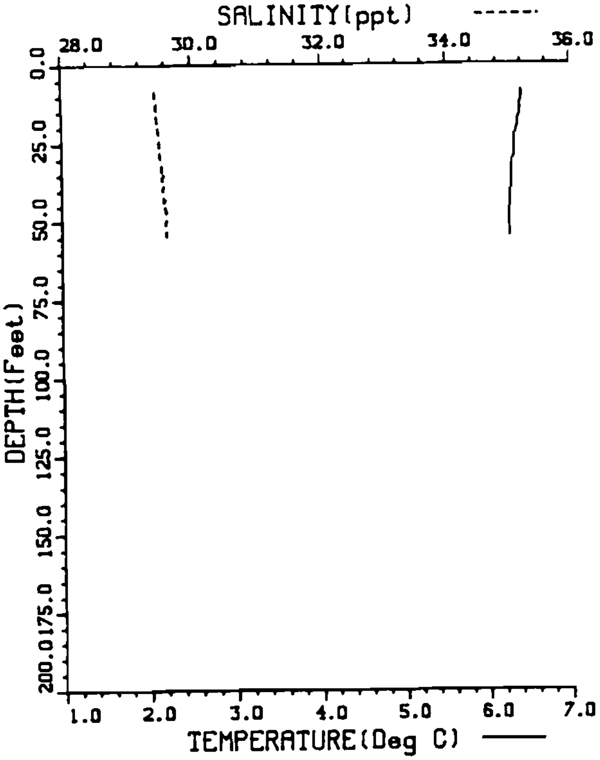
30.0
32.0
34.0
36.0
DEPTH(Feet)
0.0
25.0
50.0
75.0
100.0
125.0
150.0
175.0
200.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
TEMPERATURE(Deg C)

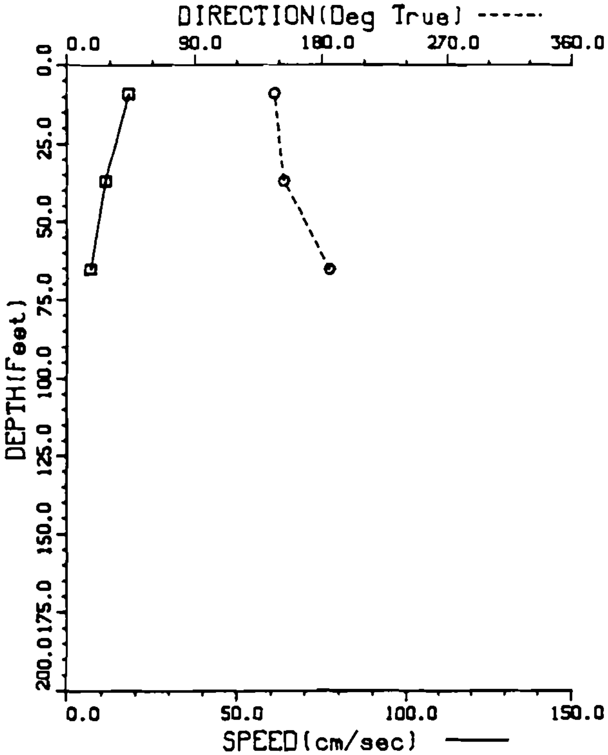
Port Moller 2 – May 28



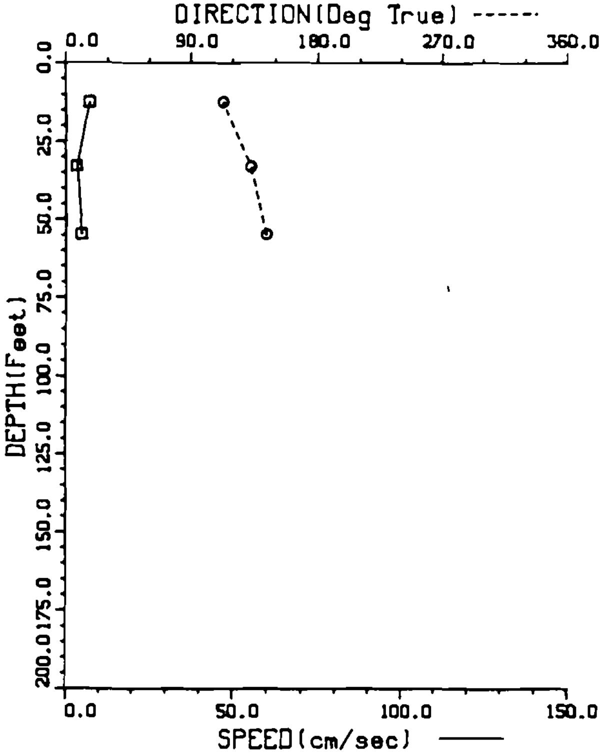
stapm21.528
05/28/89 15:24:33



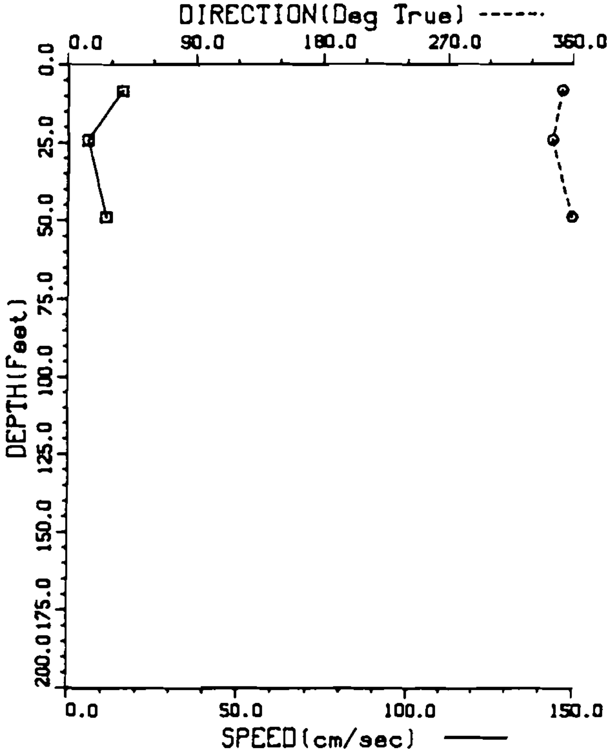
stapm11.529
05/29/89 05:50:46



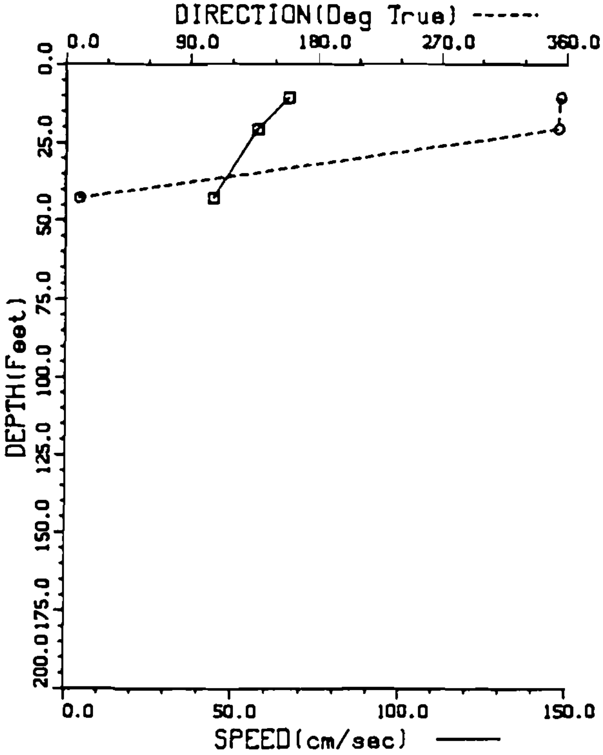
stapm12.529
05/29/89 05:50:46



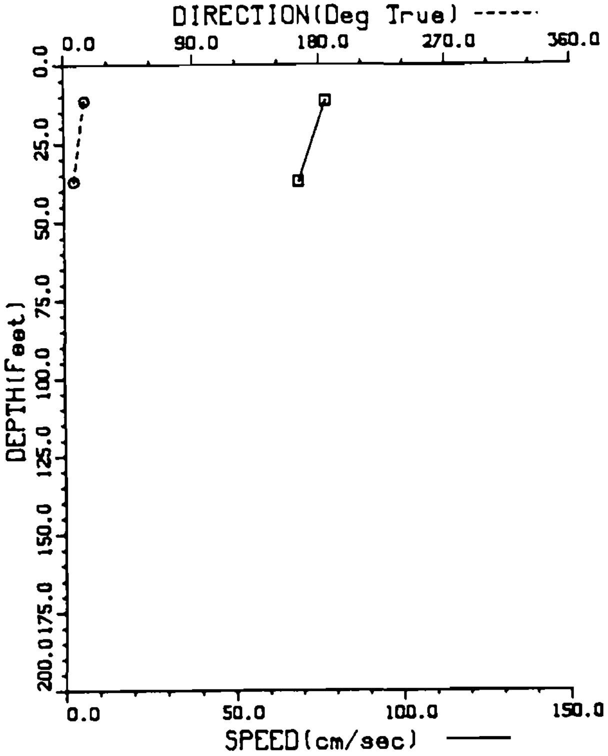
stapm13.529
05/29/89 05:50:46



stapm14.529
05/29/89 05:50:46

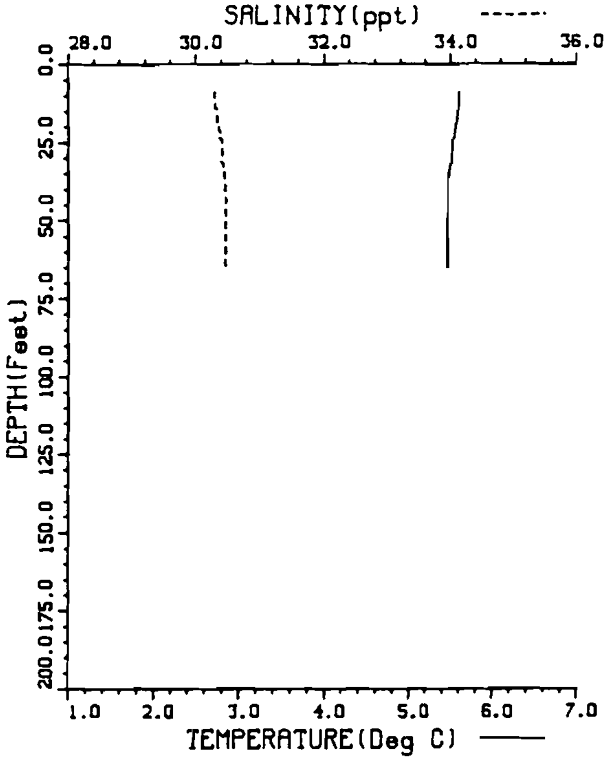


stopm15.529
05/29/89 05:50:46

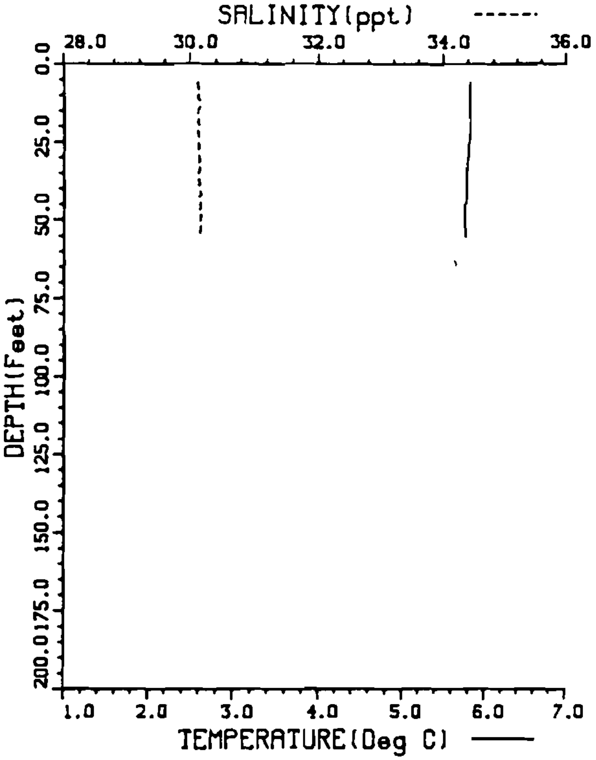


Port Moller I - May 29

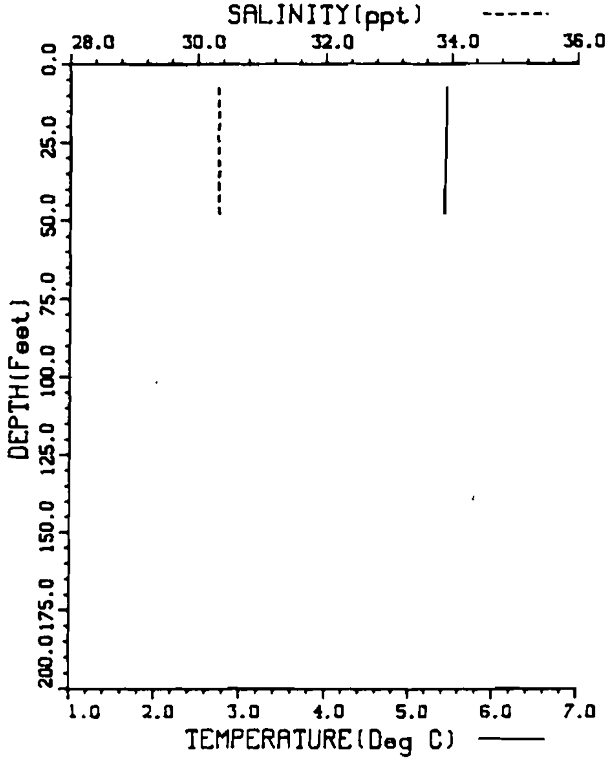
stapm11.529
05/29/89 05:50:46



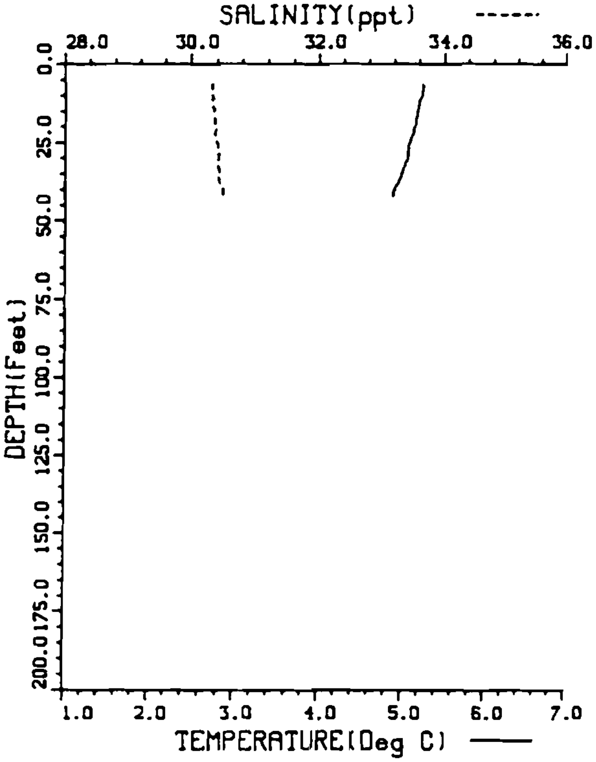
stapm12.529
05/29/89 05:50:46



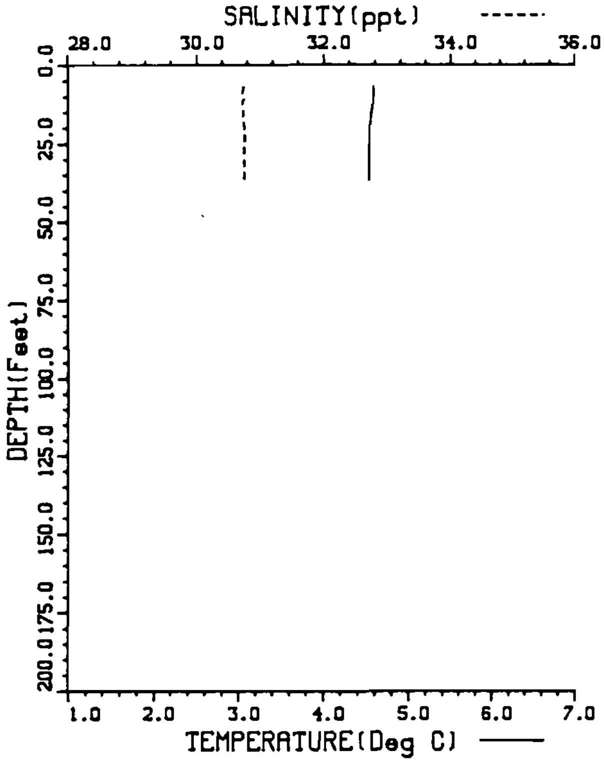
stapm13.529
05/29/89 05:50:46

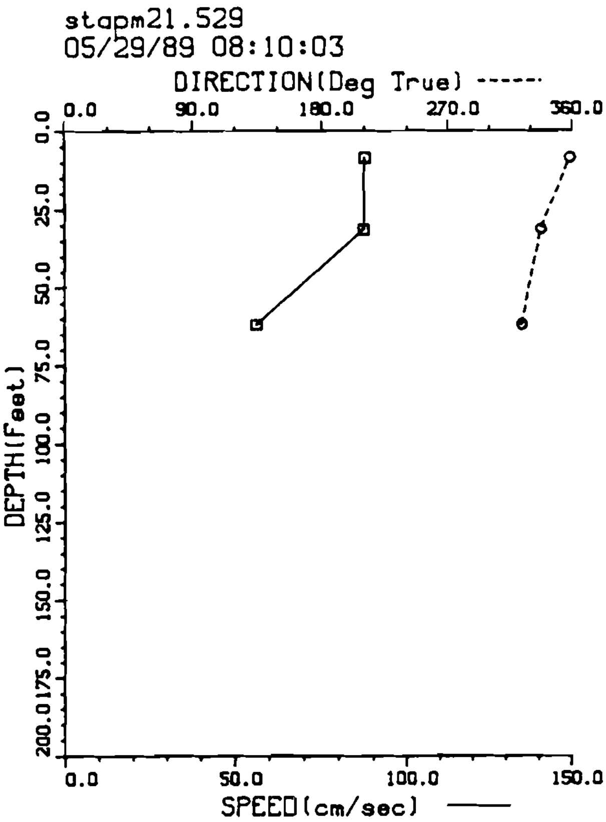


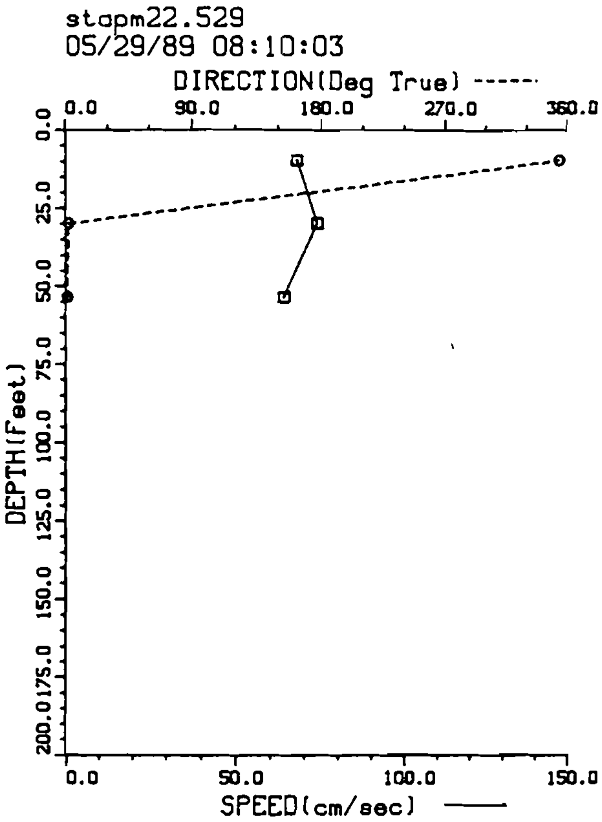
stapm14.529
05/29/89 05:50:46

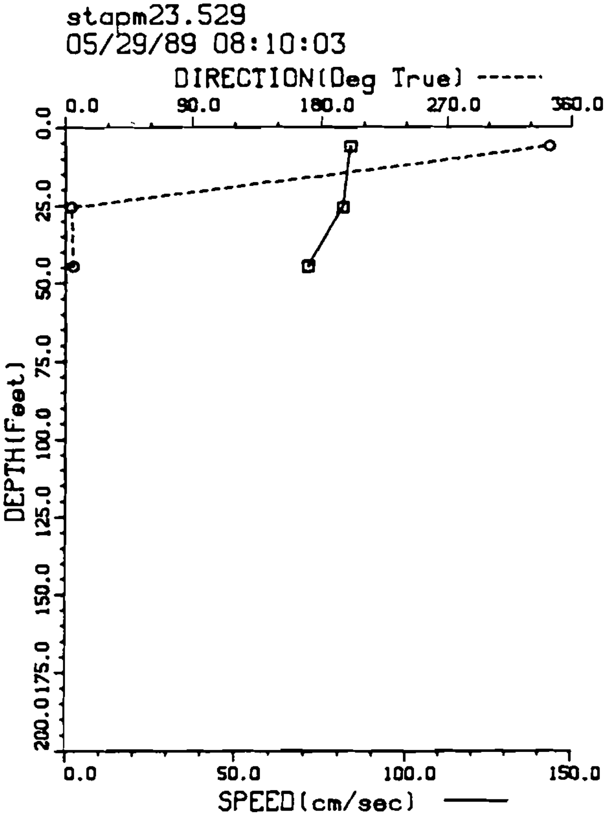


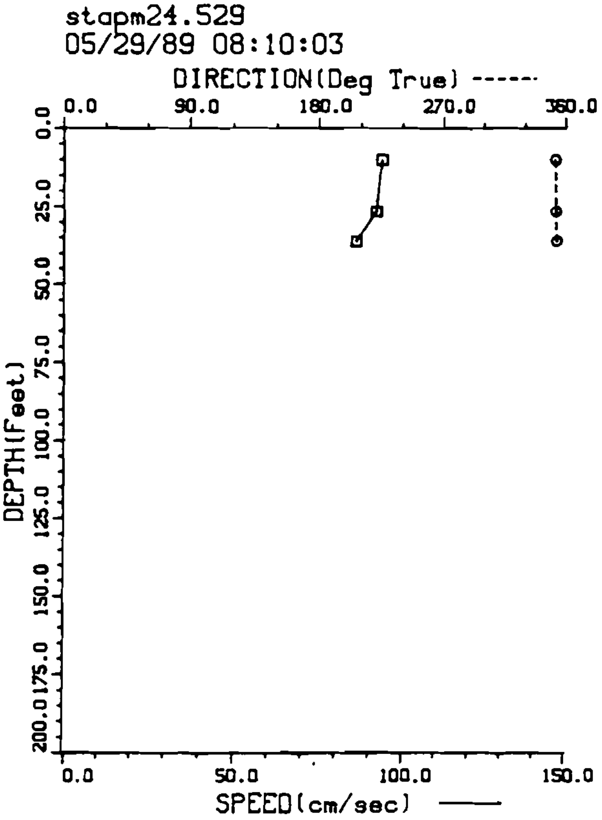
stapm15.529
05/29/89 05:50:46

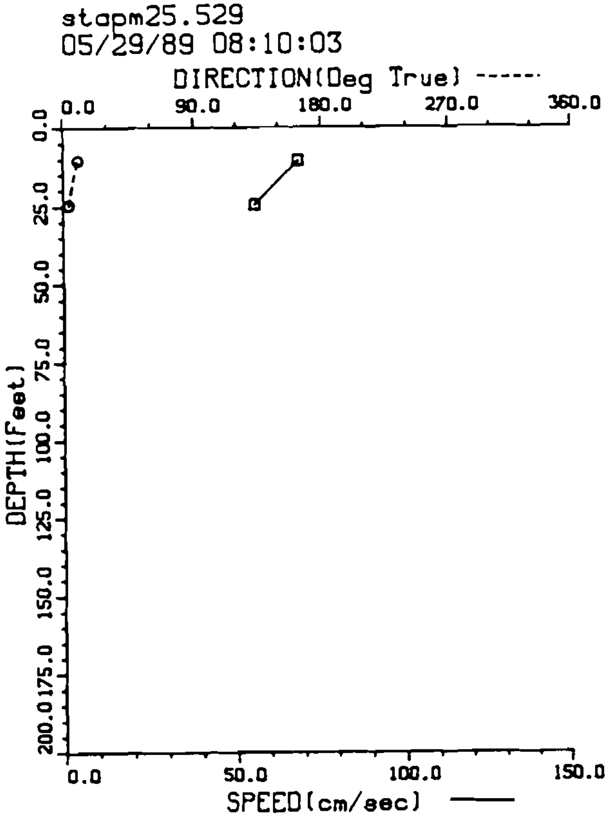



stopm21.529
05/29/89 08:10:03
DIRECTION(Deg True) ------
0.0
90.0
180.0
270.0
360.0
DEPTH(Feet)
0.0
25.0
50.0
75.0
100.0
125.0
150.0
175.0
200.0
0.0
50.0
100.0
150.0
SPEED(cm/sec) ——


stopm22.529
05/29/89 08:10:03
DIRECTION(Deg True) ------
0.0
90.0
180.0
270.0
360.0
DEPTH(Feet)
0.0
25.0
50.0
75.0
100.0
125.0
150.0
175.0
200.0
0.0
50.0
100.0
150.0
SPEED(cm/sec) ——

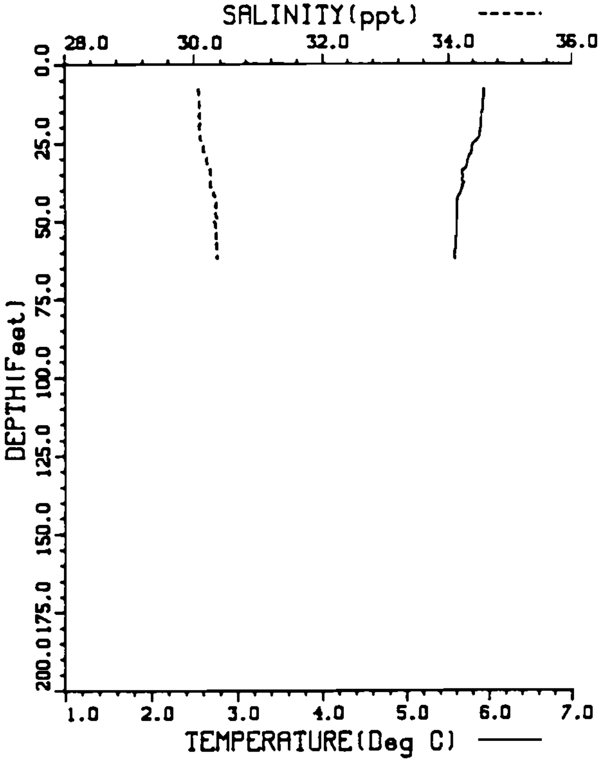

stopm23.529
05/29/89 08:10:03
DIRECTION(Deg True) ------
0.0
90.0
180.0
270.0
360.0
DEPTH(Feet)
0.0
25.0
50.0
75.0
100.0
125.0
150.0
175.0
200.0
0.0
50.0
100.0
150.0
SPEED(cm/sec) ——


stopm24.529
05/29/89 08:10:03
DIRECTION(Deg True) ------
0.0
90.0
180.0
270.0
360.0
DEPTH(Feet)
0.0
25.0
50.0
75.0
100.0
125.0
150.0
175.0
200.0
0.0
50.0
100.0
150.0
SPEED(cm/sec) ——

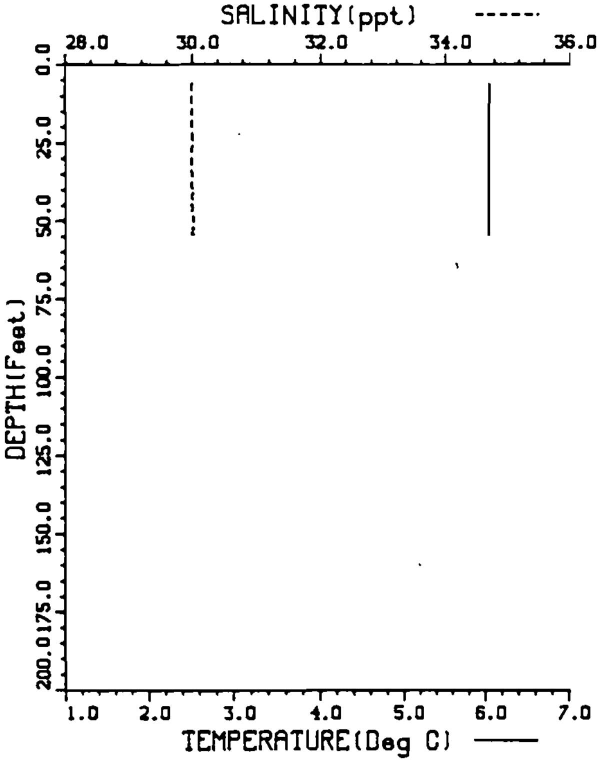

stapm25.529
05/29/89 08:10:03
DIRECTION(Deg True) ------
0.0
90.0
180.0
270.0
360.0
DEPTH(Feet)
0.0
25.0
50.0
75.0
100.0
125.0
150.0
175.0
200.0
0.0
50.0
100.0
150.0
SPEED(cm/sec) ——

Port Moller 2

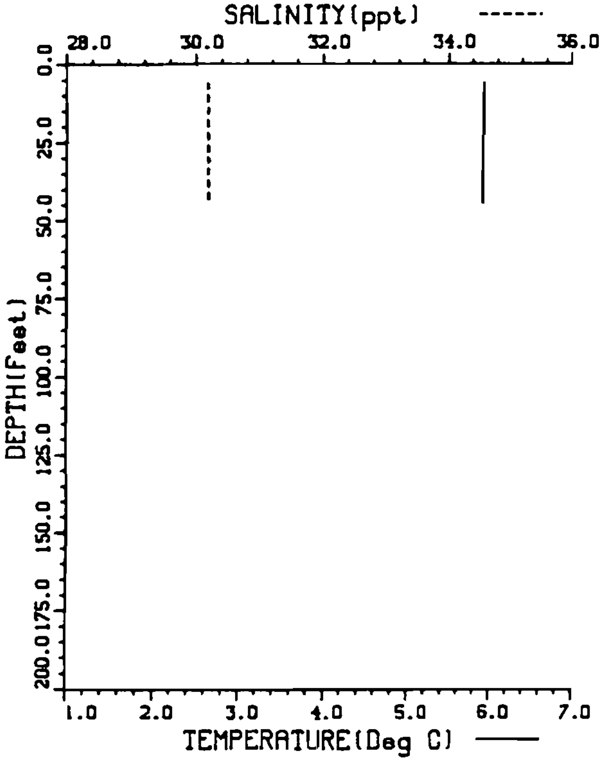
stapm21.529
05/29/89 08:10:03



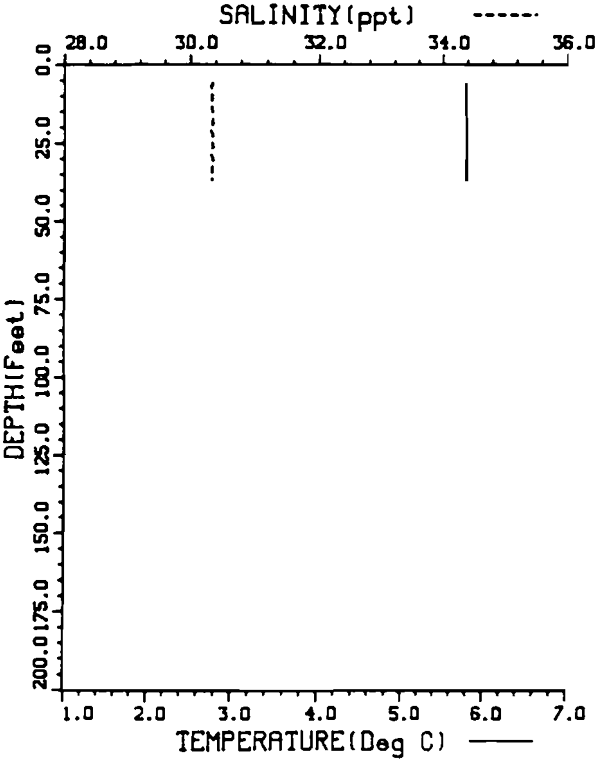
stapm22.529
05/29/89 08:10:03



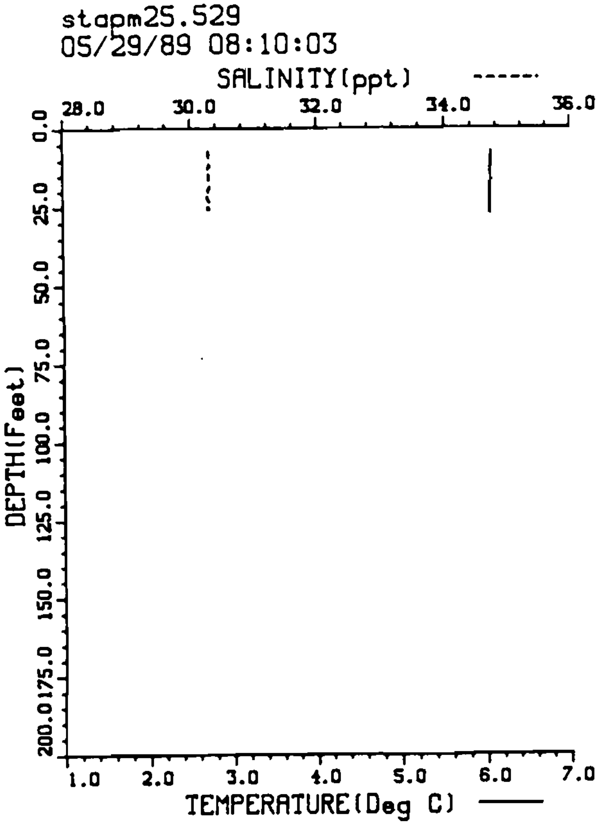
stapm23.529
05/29/89 08:10:03



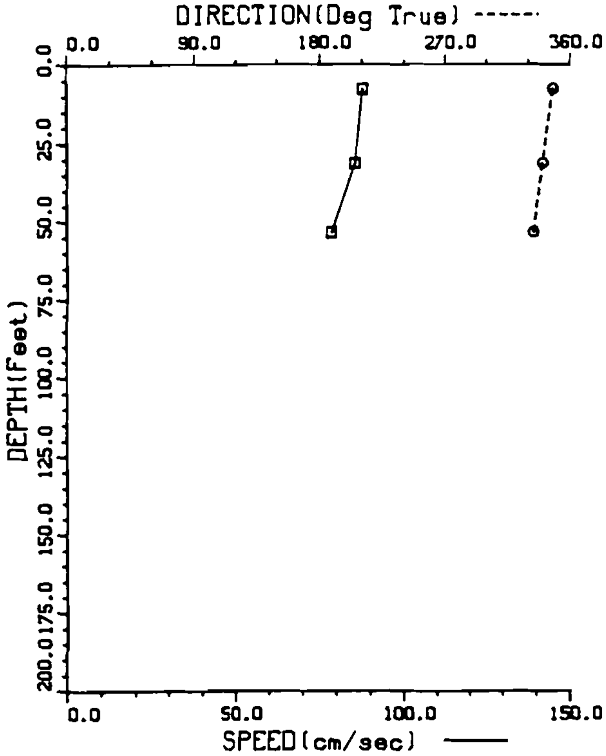
stapm24.529
05/29/89 08:10:03



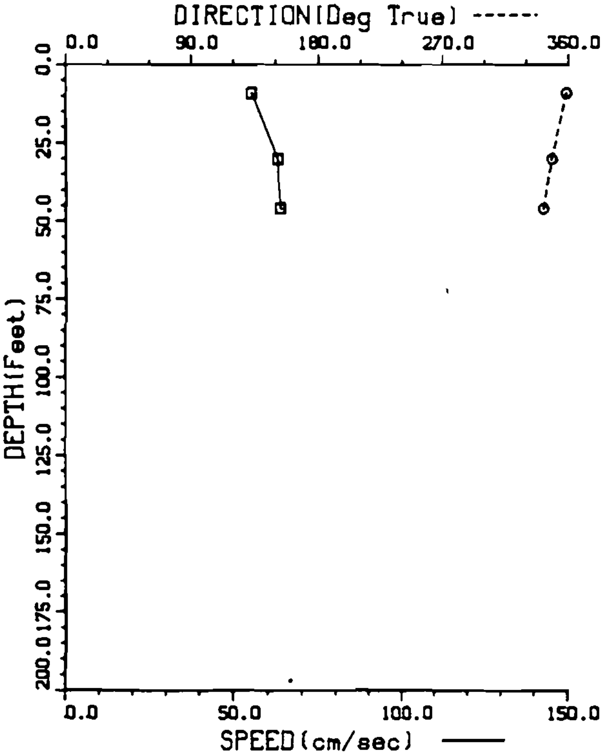
Port Moller 2



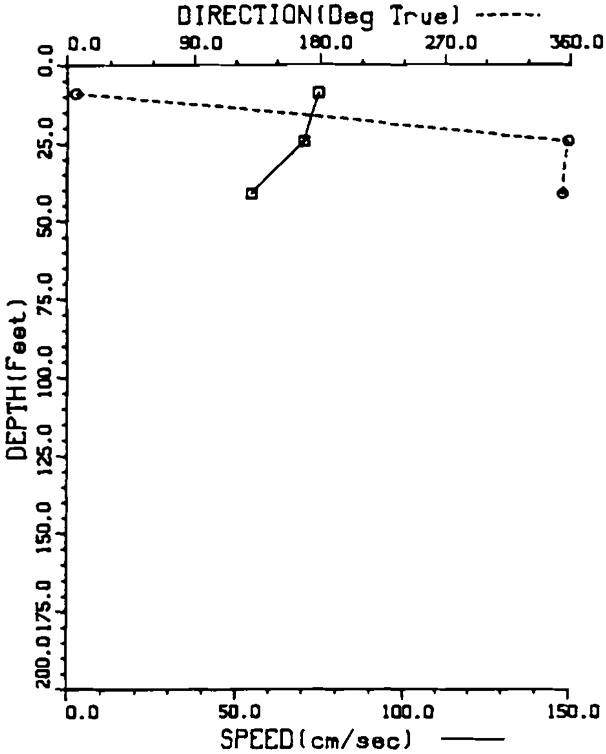
stapm31.529
05/29/89 14:50:18



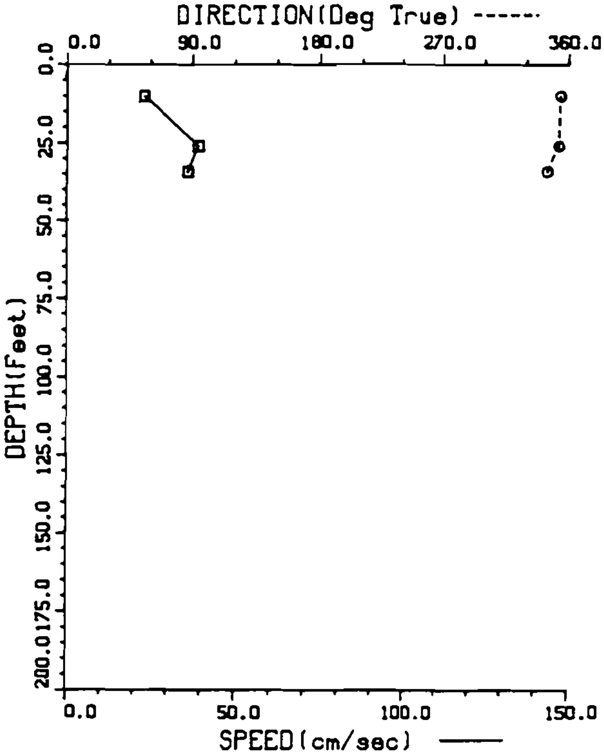
stapm32.529
05/29/89 14:50:18



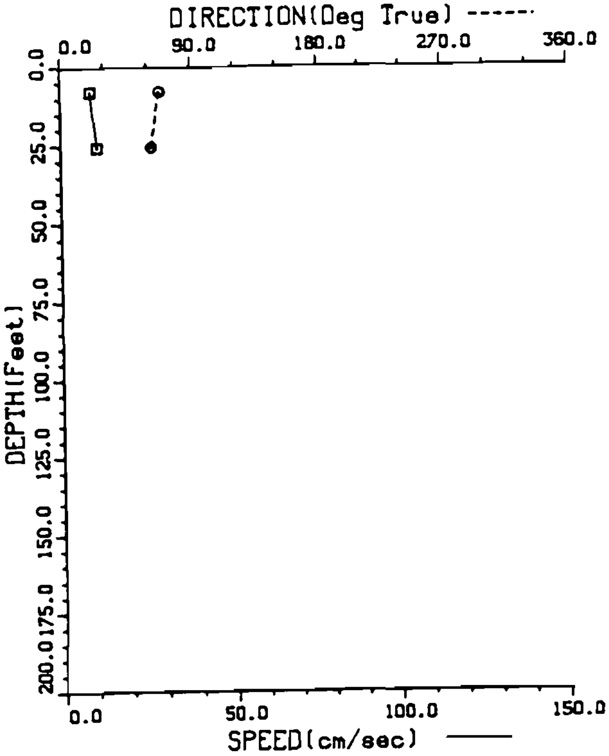
stapm33.529
05/29/89 14:50:18



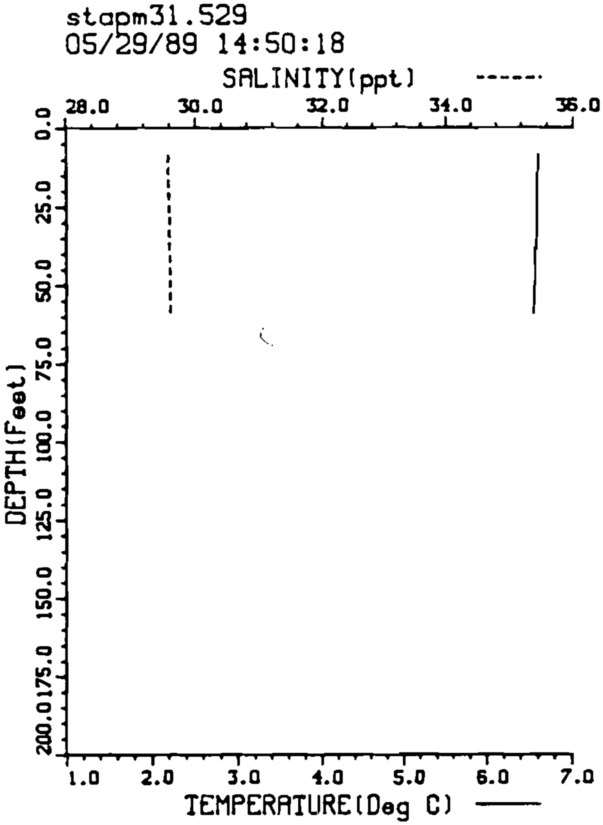
stapm34.529
05/29/89 14:50:18

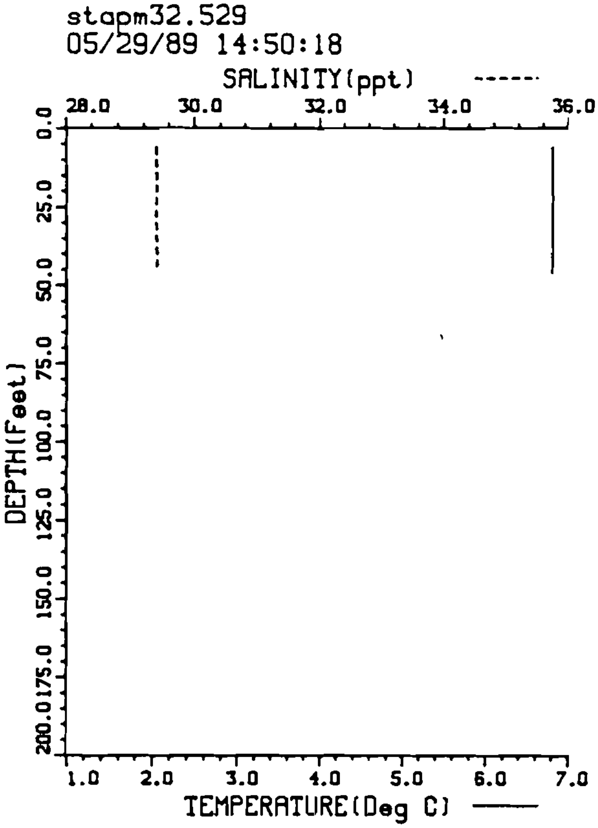


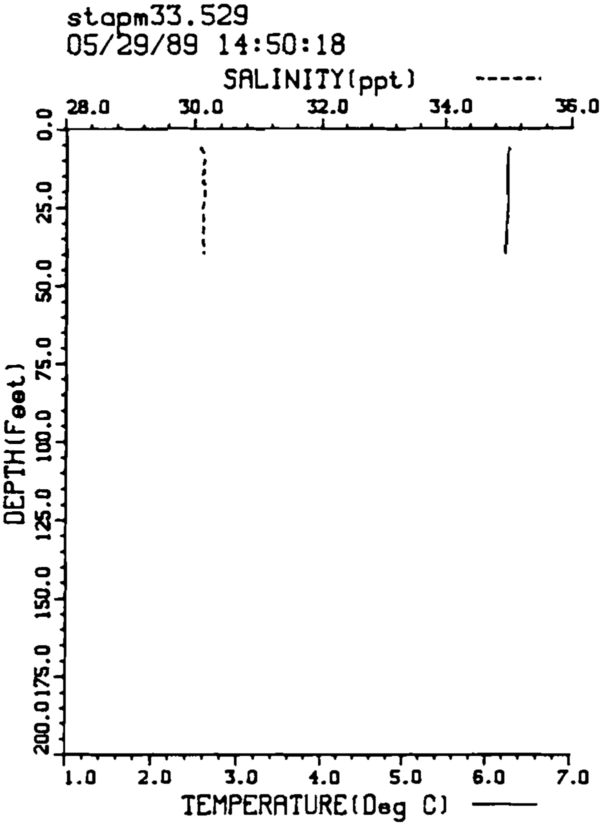
stapm35.529
05/29/89 14:50:18

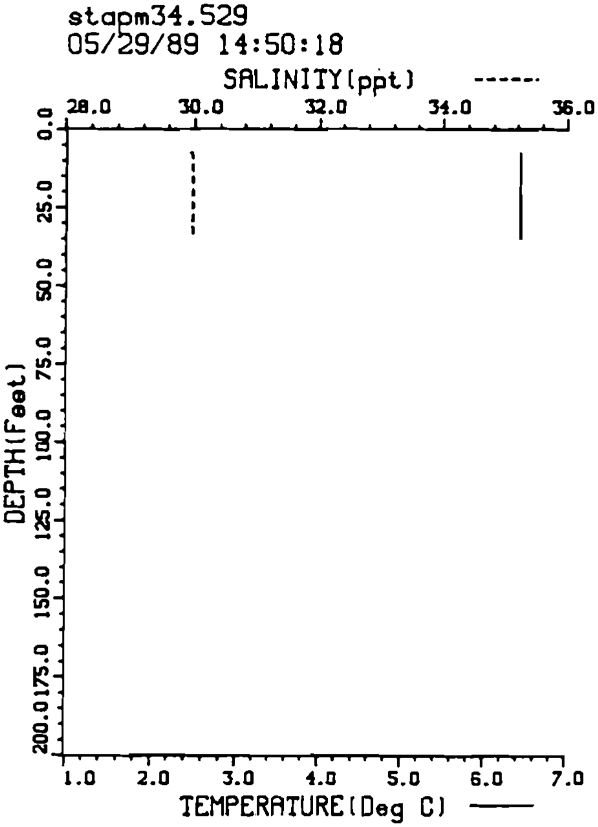


Port Moller 3

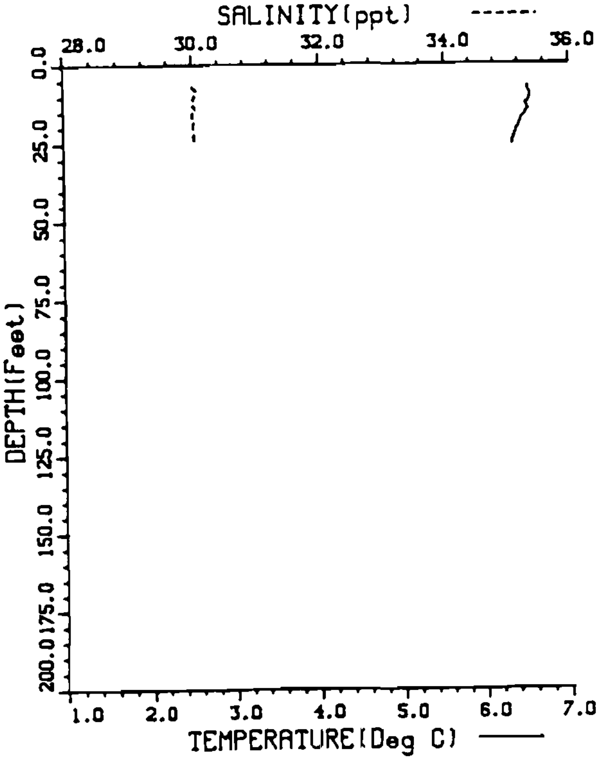




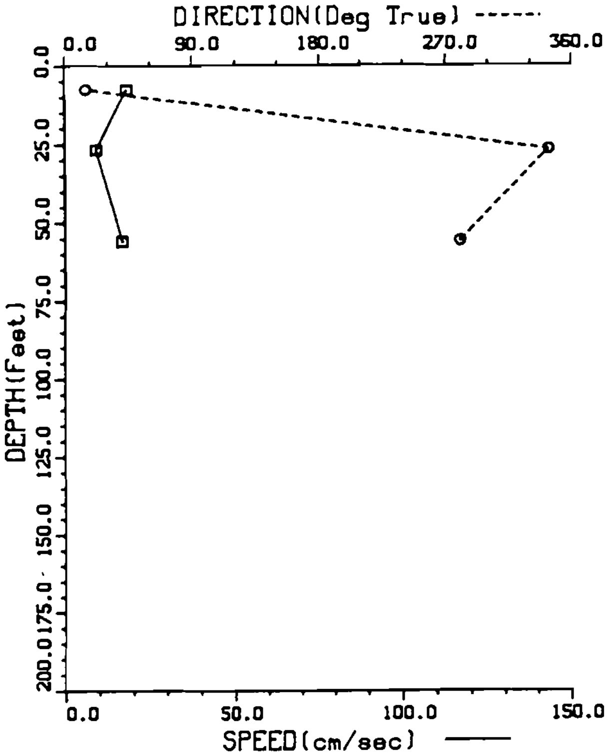




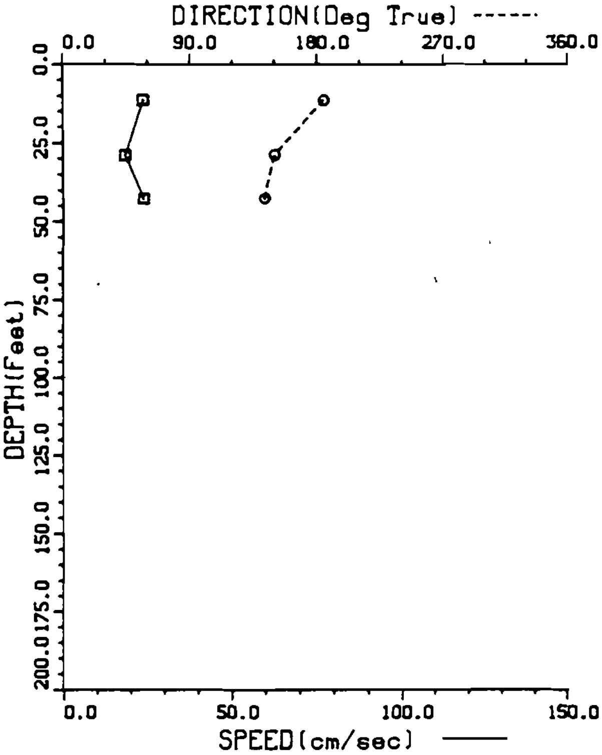
stapm35.529
05/29/89 14:50:18



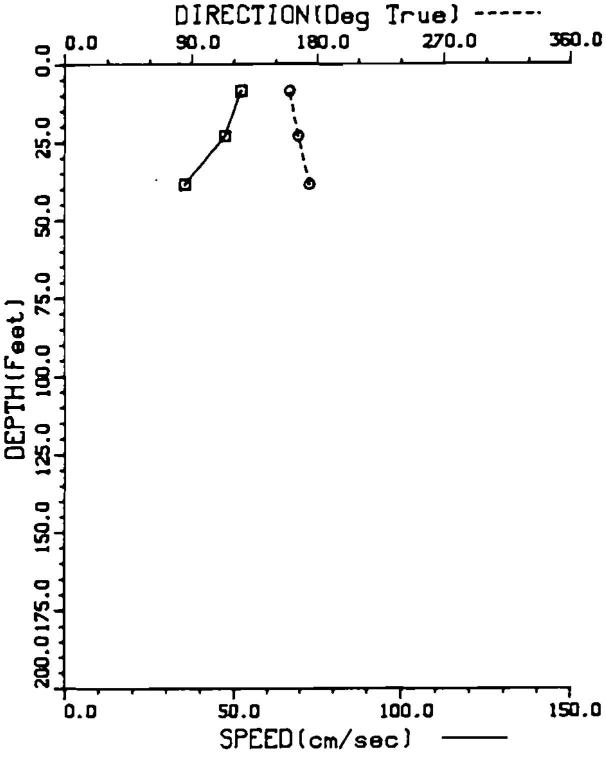
stapm41.529
05/29/89 17:01:41



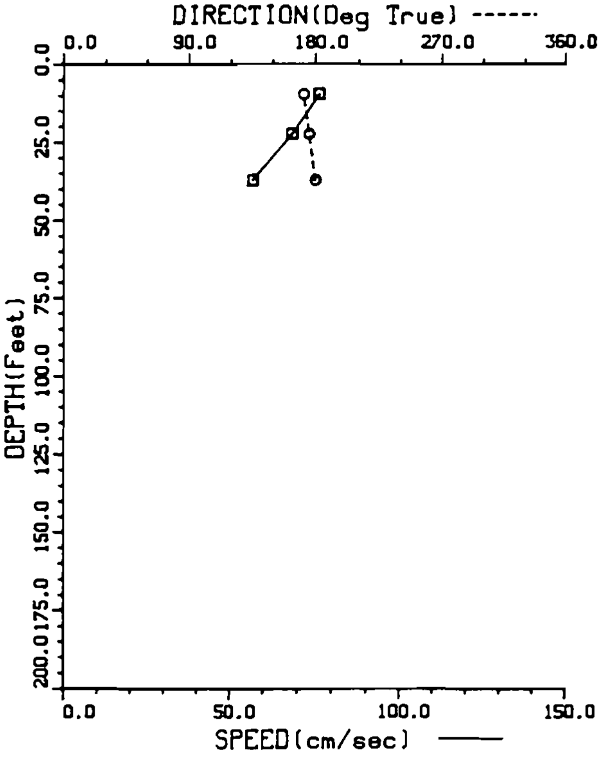
stapm42.529
05/29/89 17:01:41



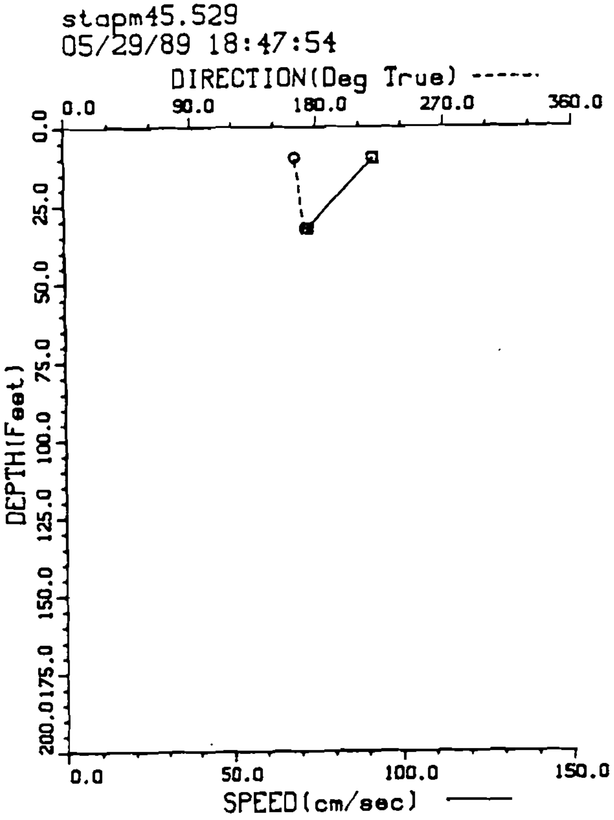
stapm43.529
05/29/89 17:01:41

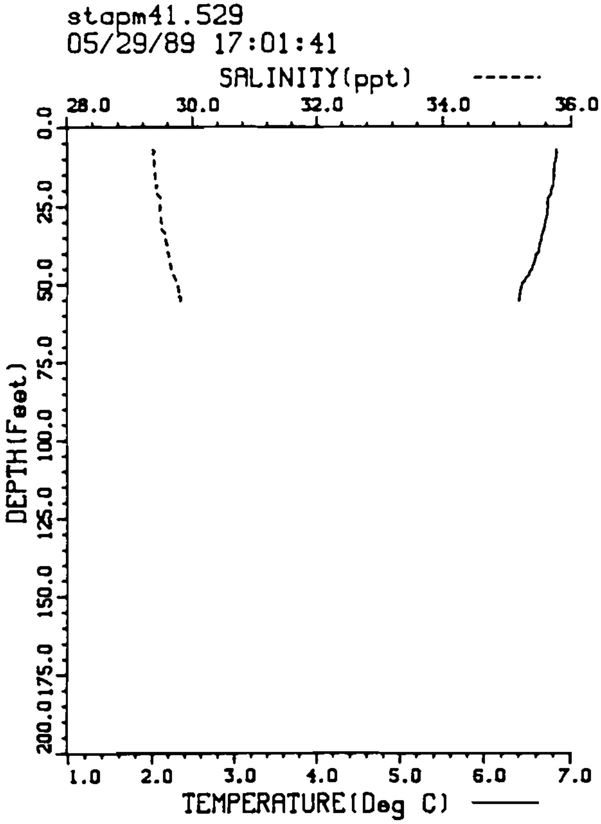


stapm44.529
05/29/89 17:01:41



Port Moller 4




stapm41.529
05/29/89 17:01:41
SALINITY(ppt) ------
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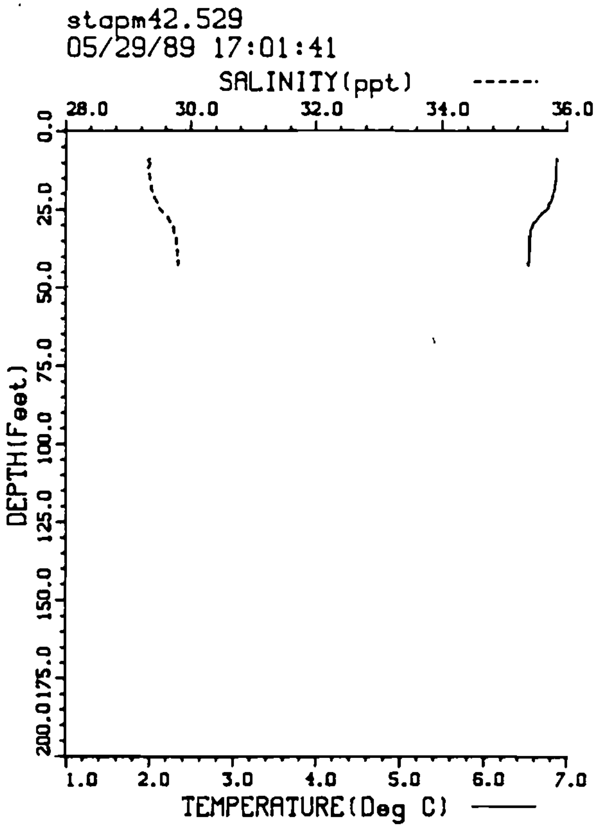
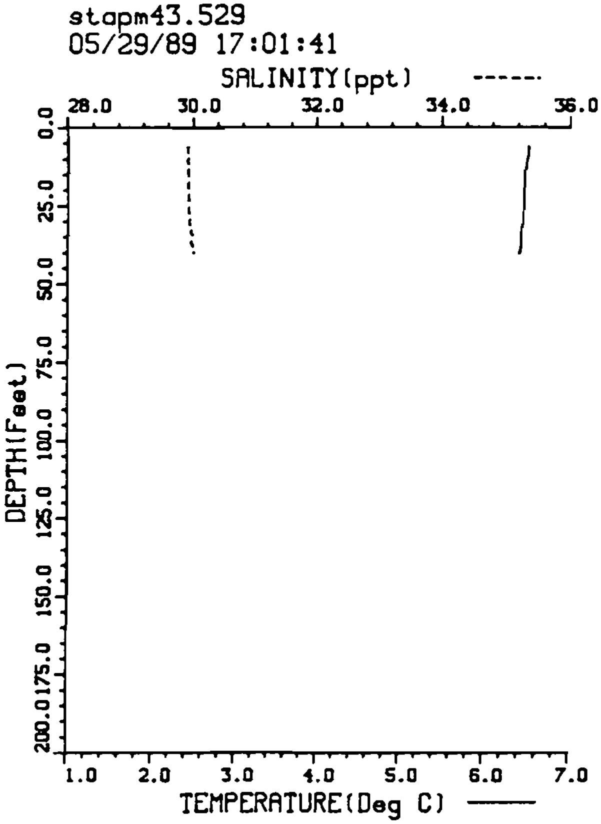
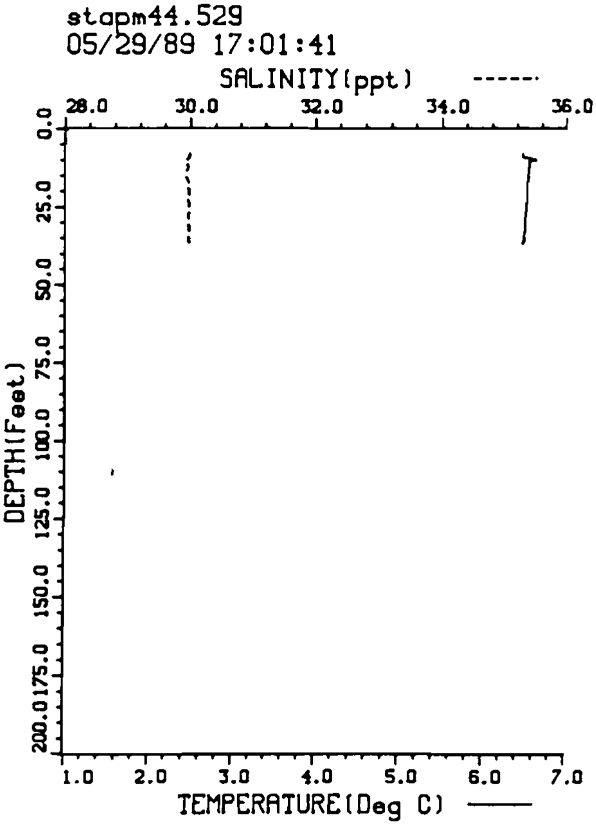
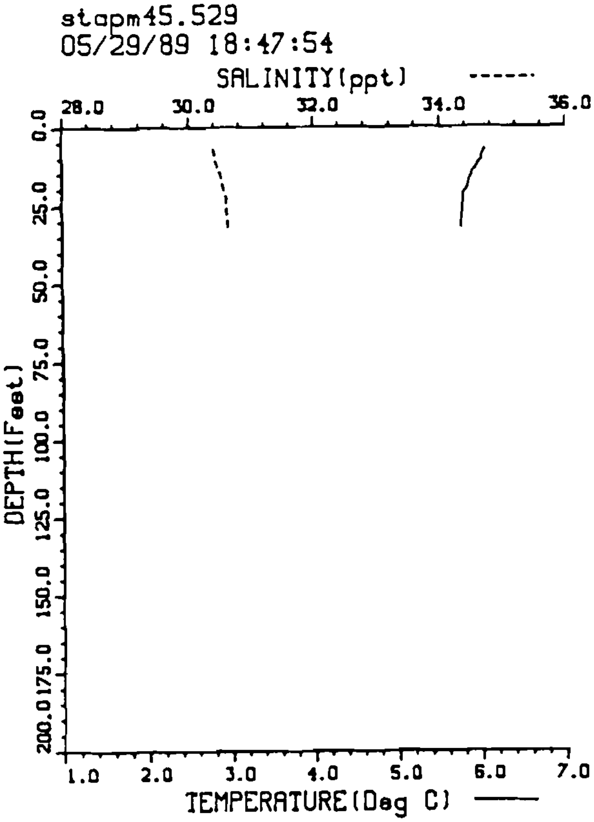
30.0
32.0
34.0
36.0
DEPTH(Feet)
0.0
25.0
50.0
75.0
100.0
125.0
150.0
175.0
200.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
TEMPERATURE(Deg C) ——

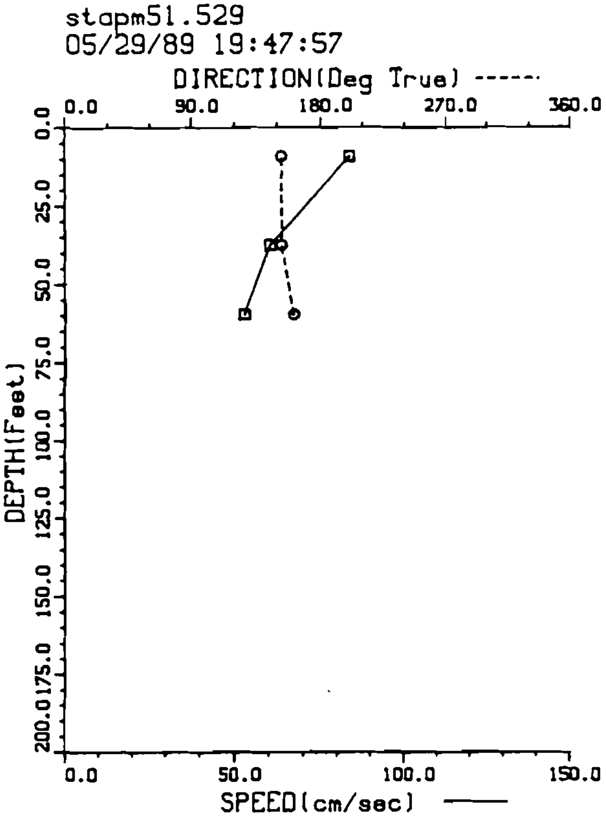

stapm42.529
05/29/89 17:01:41
SALINITY(ppt) ------
28.0
30.0
32.0
34.0
36.0
DEPTH(Feet)
0.0
25.0
50.0
75.0
100.0
125.0
150.0
175.0
200.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
TEMPERATURE(Deg C) ——

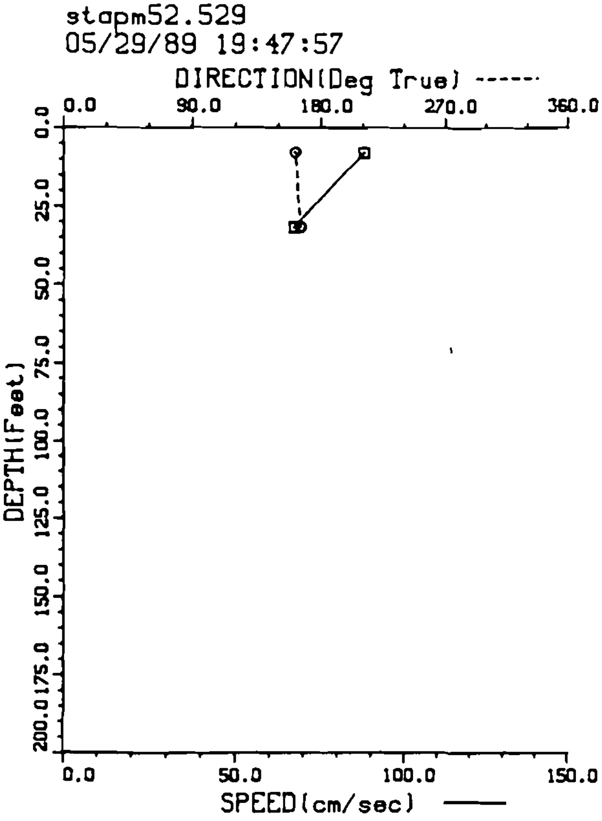

stapm43.529
05/29/89 17:01:41
SALINITY(ppt) ------
28.0
30.0
32.0
34.0
36.0
DEPTH(Feet)
0.0
25.0
50.0
75.0
100.0
125.0
150.0
175.0
200.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
TEMPERATURE(Deg C) ——

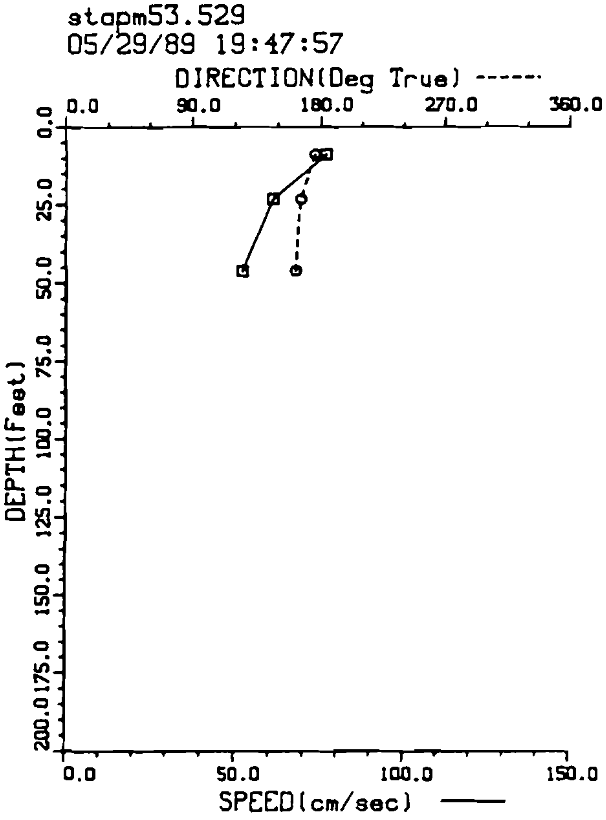

stapm44.529
05/29/89 17:01:41
SALINITY(ppt) ------
28.0
30.0
32.0
34.0
36.0
DEPTH(Feet)
0.0
25.0
50.0
75.0
100.0
125.0
150.0
175.0
200.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
TEMPERATURE(Deg C) ——

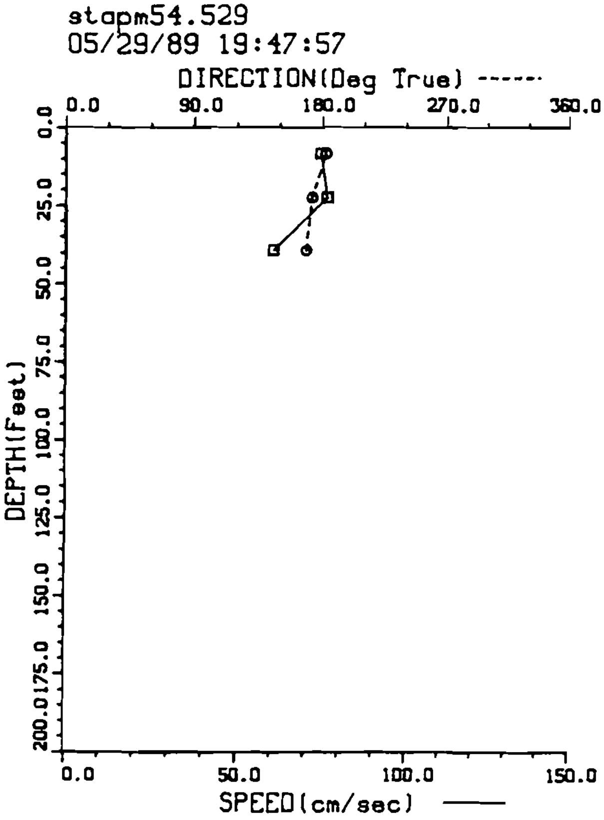
Port Moller 4



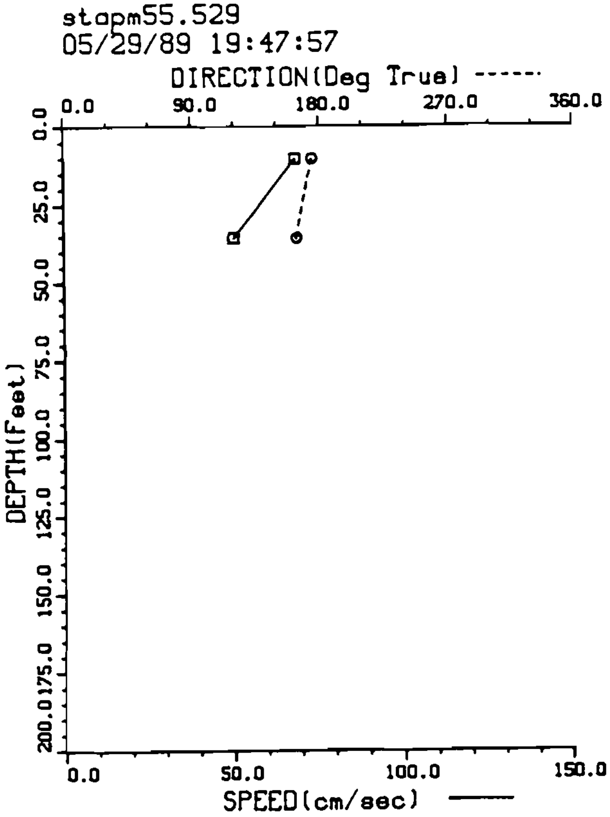

stapm51.529
05/29/89 19:47:57
DIRECTION(Deg True) ------
0.0
90.0
180.0
270.0
360.0
DEPTH(Feet)
0.0
25.0
50.0
75.0
100.0
125.0
150.0
175.0
200.0
0.0
50.0
100.0
150.0
SPEED(cm/sec) ——


stapm52.529
05/29/89 19:47:57
DIRECTION(Deg True) ------
0.0
90.0
180.0
270.0
360.0
DEPTH(Feet)
0.0
25.0
50.0
75.0
100.0
125.0
150.0
175.0
200.0
0.0
50.0
100.0
150.0
SPEED(cm/sec) ——

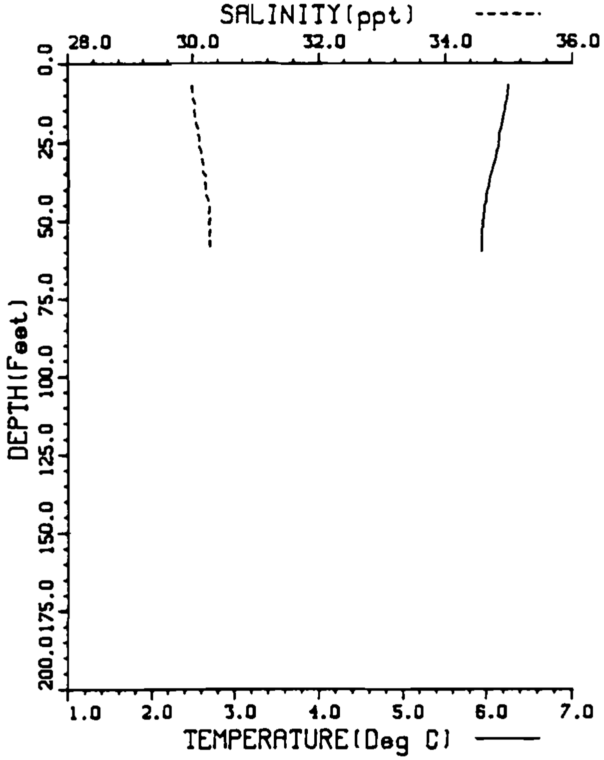

stapm53.529
05/29/89 19:47:57
DIRECTION(Deg True) ------
0.0
90.0
180.0
270.0
360.0
DEPTH(Feet)
0.0
25.0
50.0
75.0
100.0
125.0
150.0
175.0
200.0
0.0
50.0
100.0
150.0
SPEED(cm/sec) ——


stapm54.529
05/29/89 19:47:57
DIRECTION(Deg True) ------
0.0
90.0
180.0
270.0
360.0
DEPTH(Feet)
0.0
25.0
50.0
75.0
100.0
125.0
150.0
175.0
200.0
0.0
50.0
100.0
150.0
SPEED(cm/sec) ——

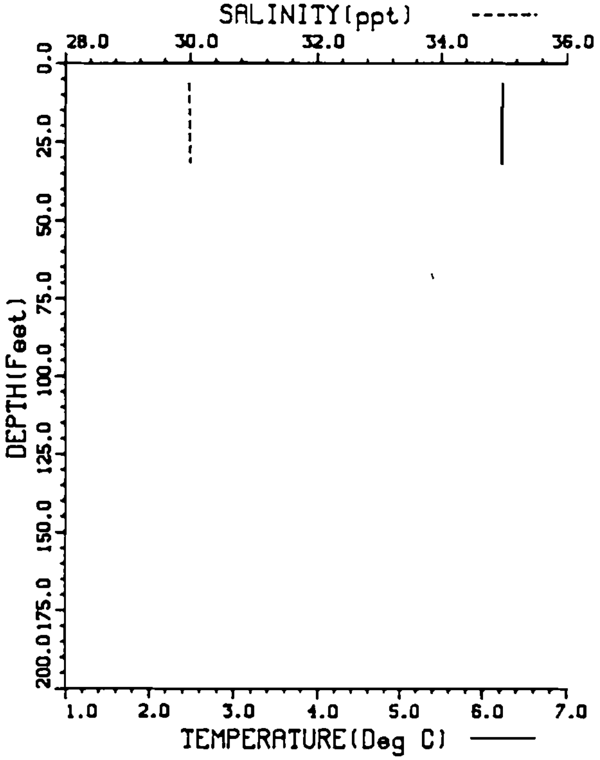
Port Moller 5



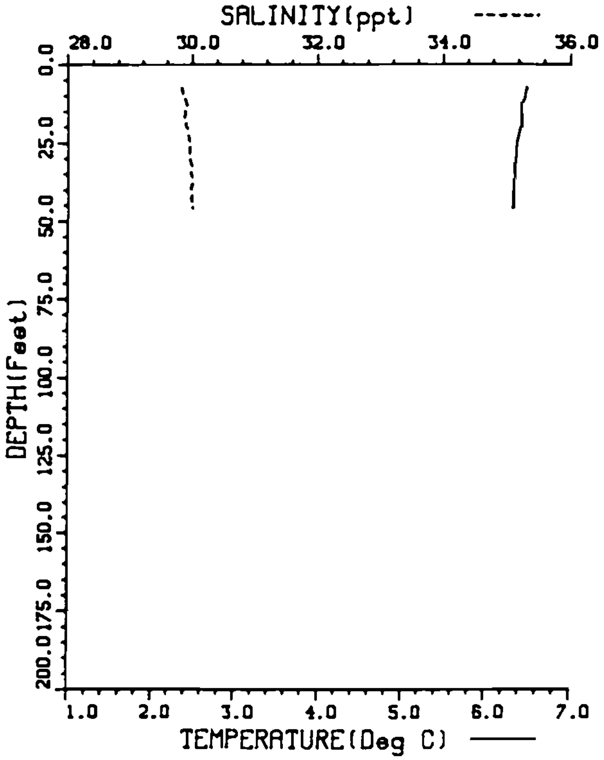
stapm51.529
05/29/89 19:47:57



stapm52.529
05/29/89 19:47:57



stapm53.529
05/29/89 19:47:57



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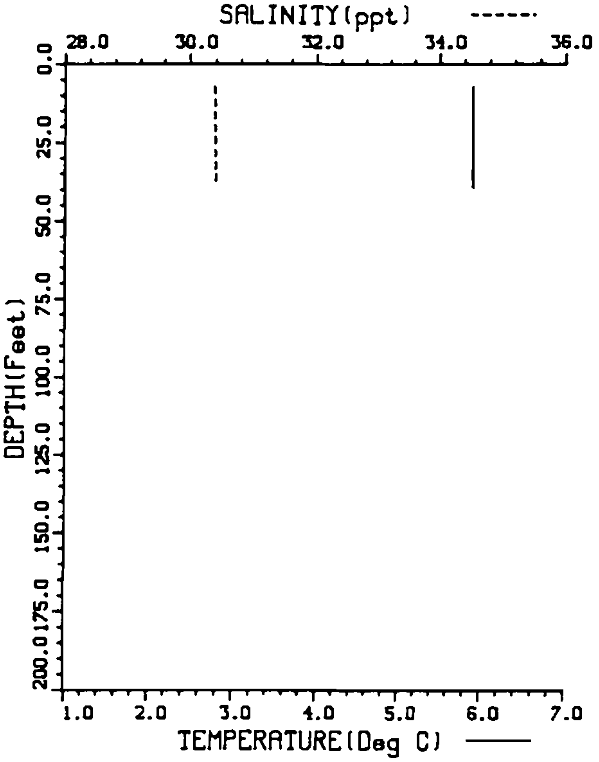
05/29/89 19:47:57



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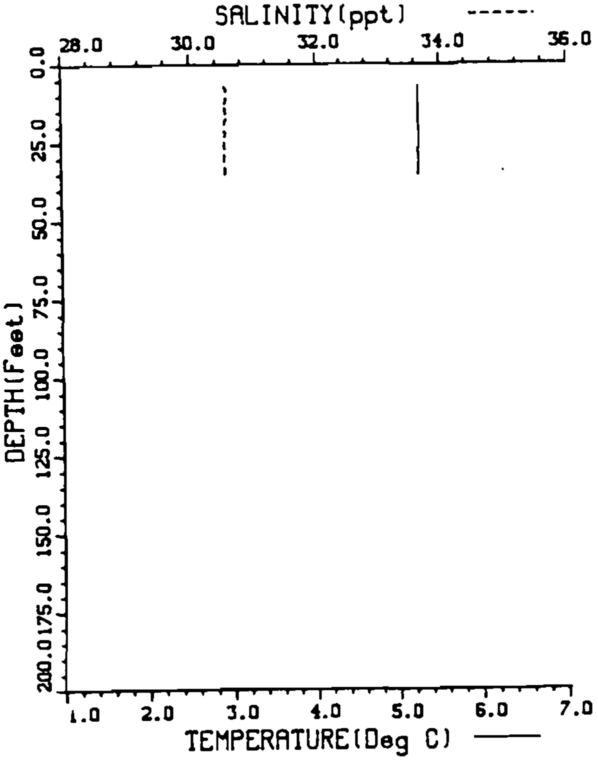
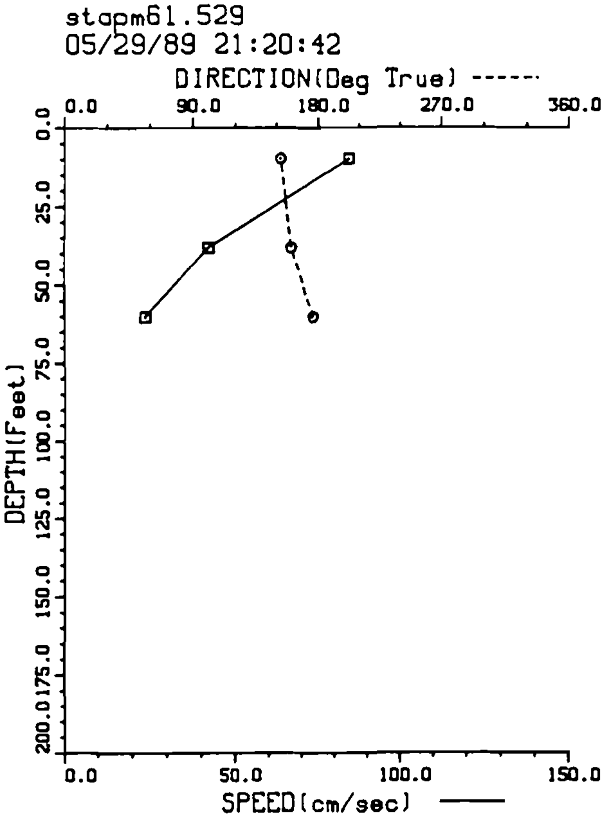
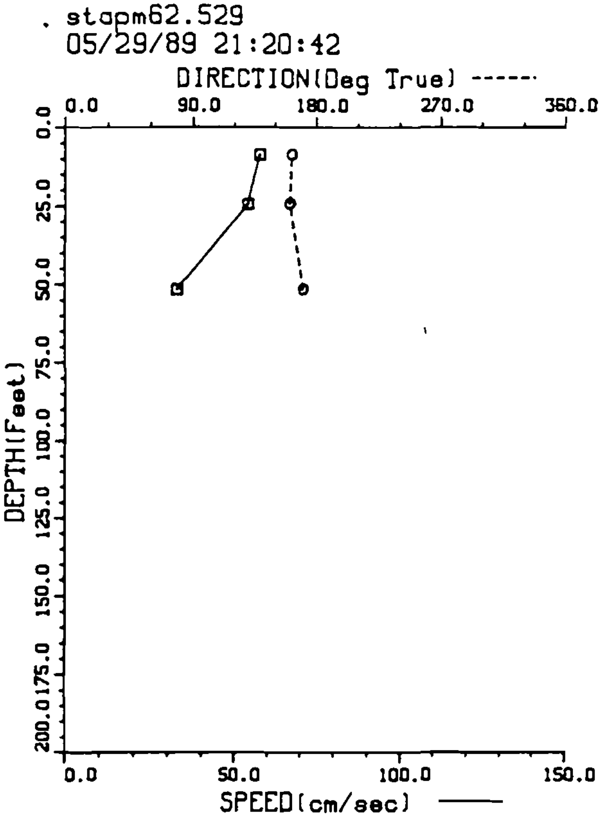
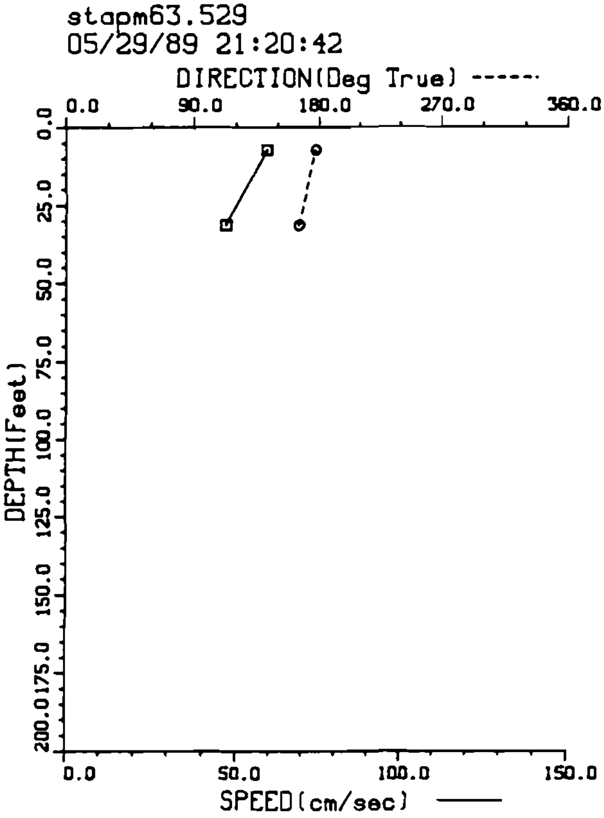
05/29/89 19:47:57



Port Moller 6

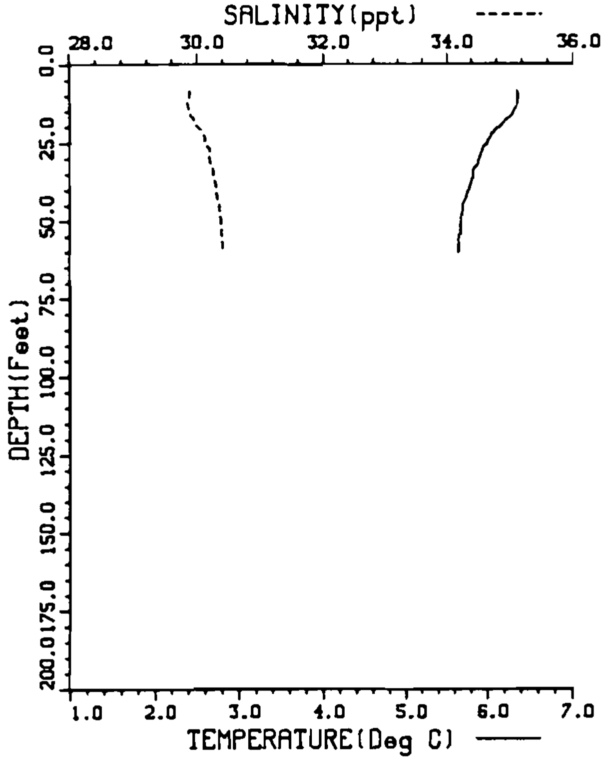






Port Moller 6

stapm61.529
05/29/89 21:20:42



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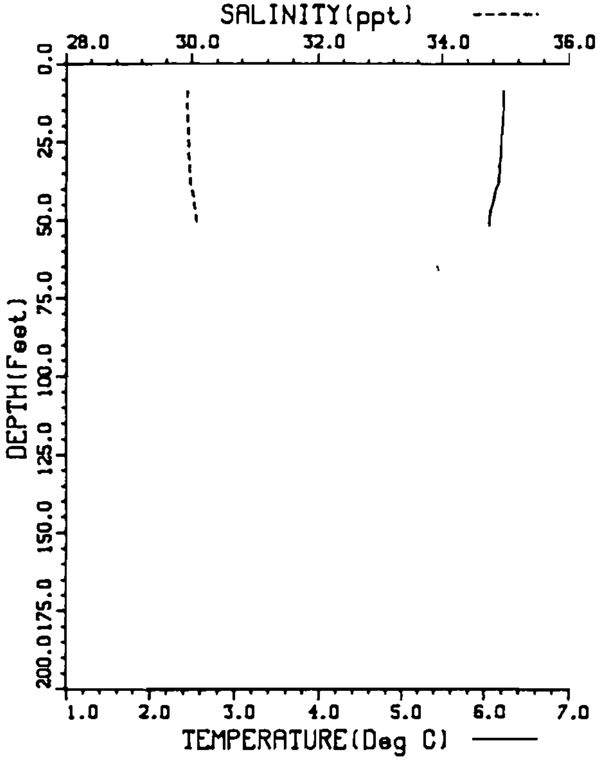
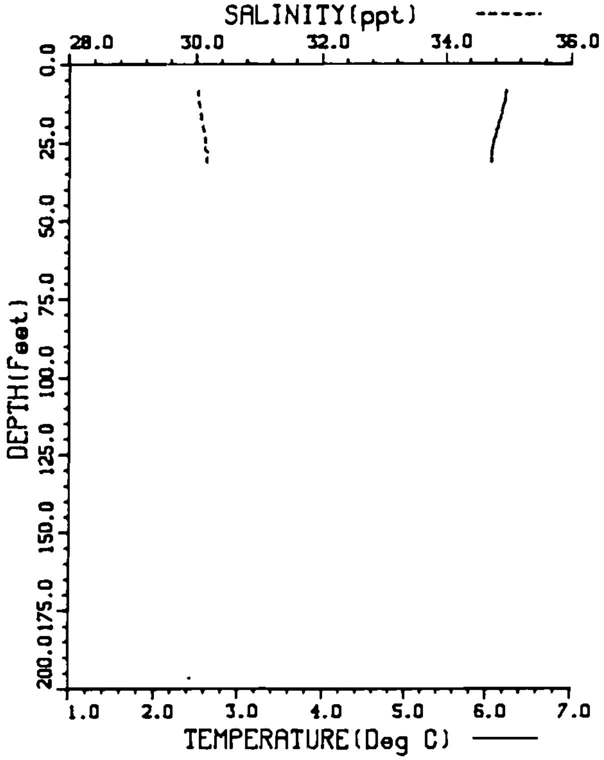
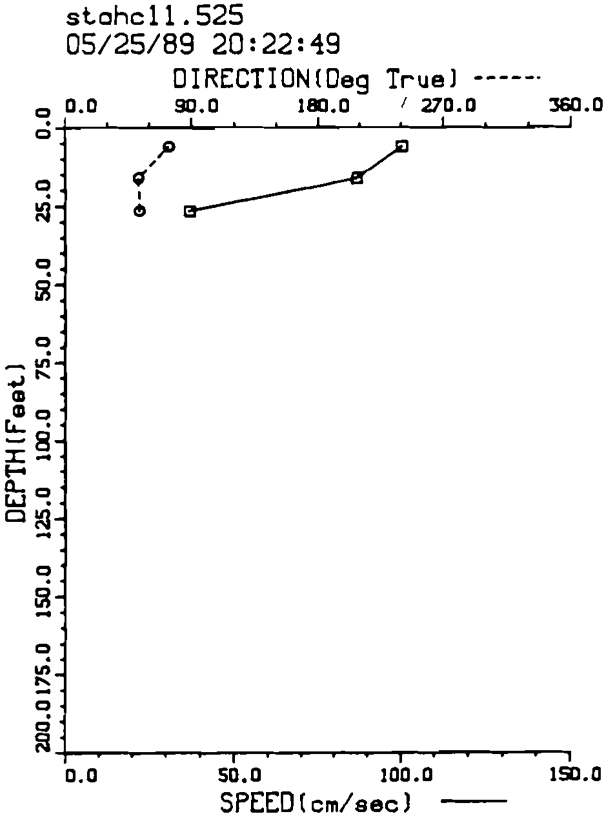
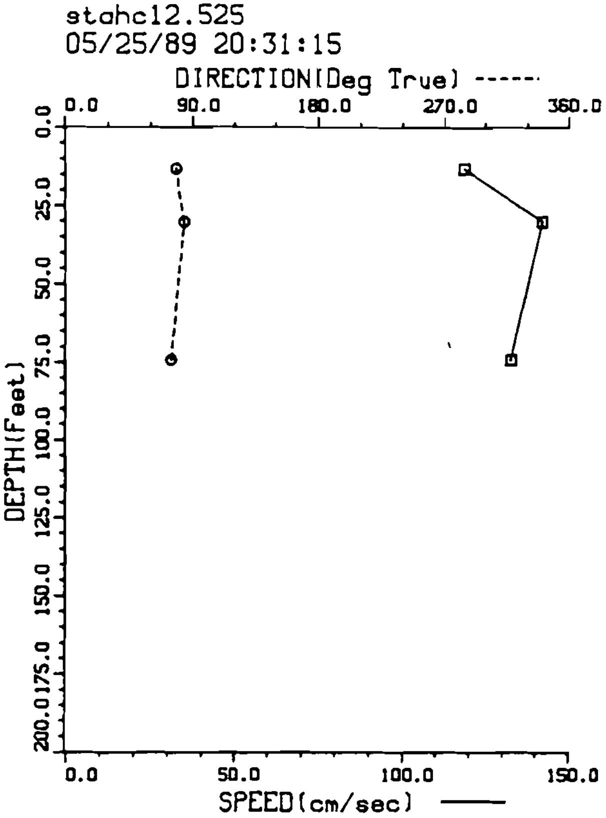


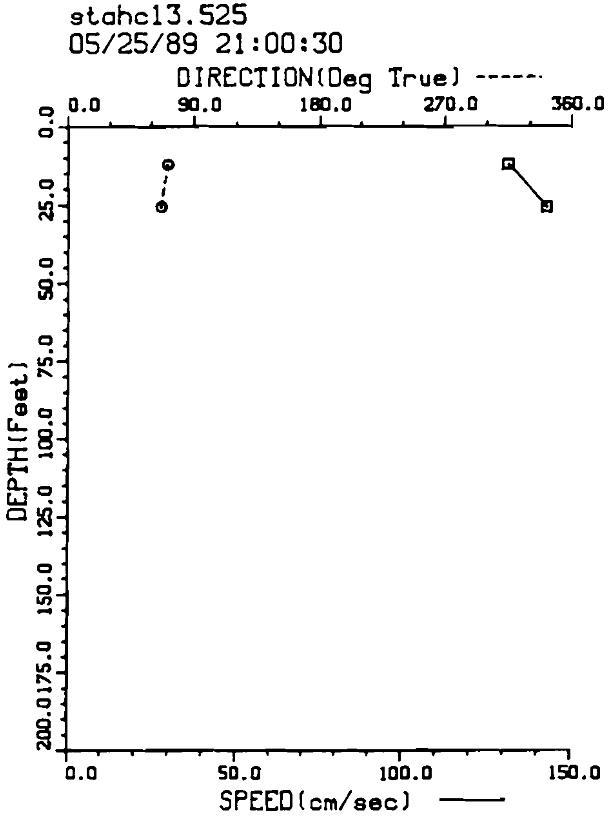
stapm63.529
05/29/89 21:20:42



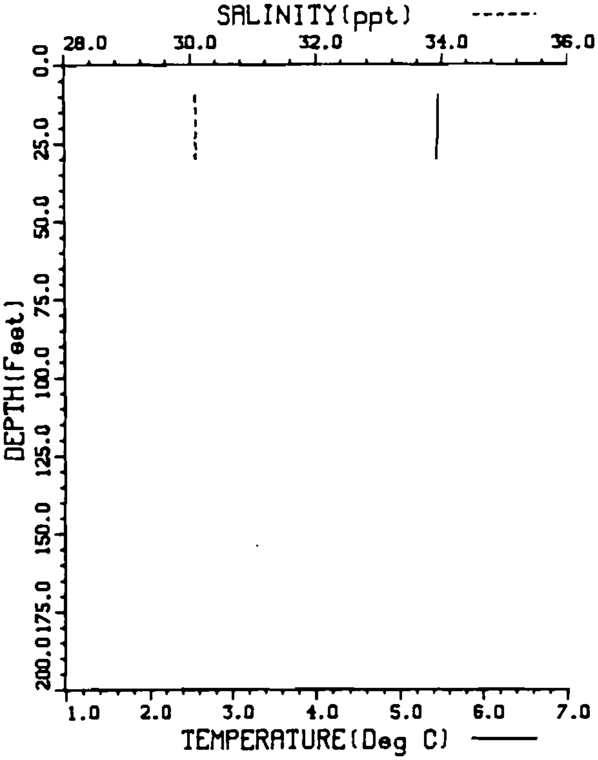
Hague Channel 1 - May 25







stahc11.525
05/25/89 20:22:49



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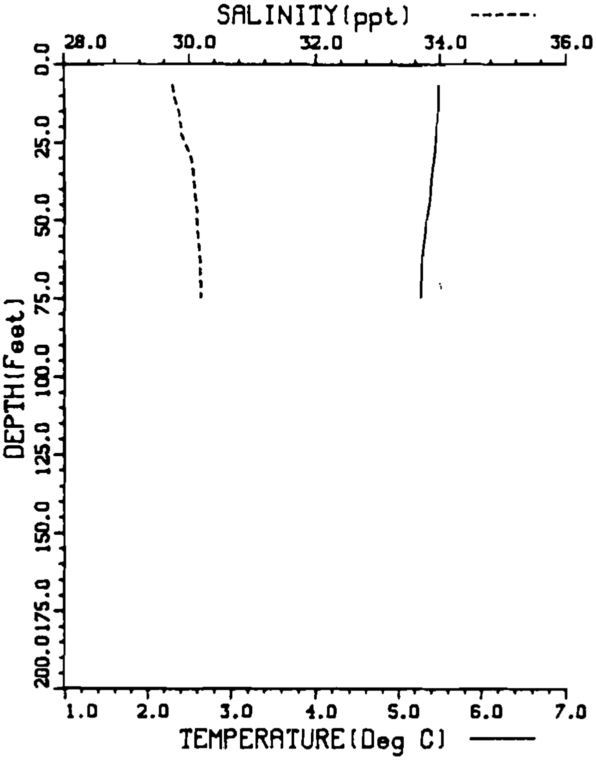
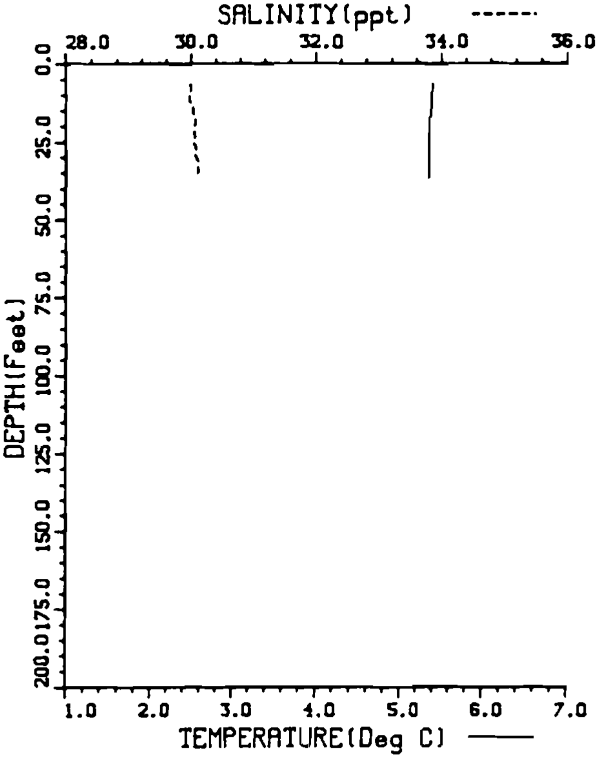
05/25/89 20:31:15

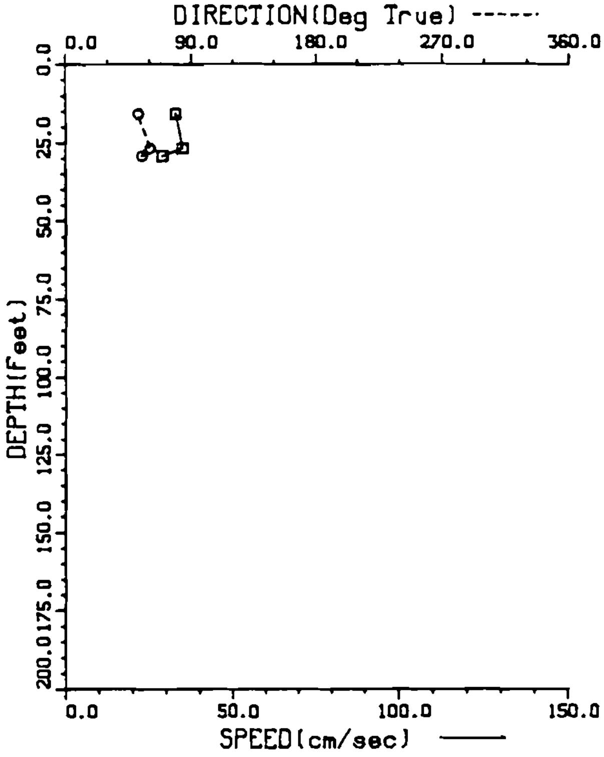


stahc13.525
05/25/89 21:00:30

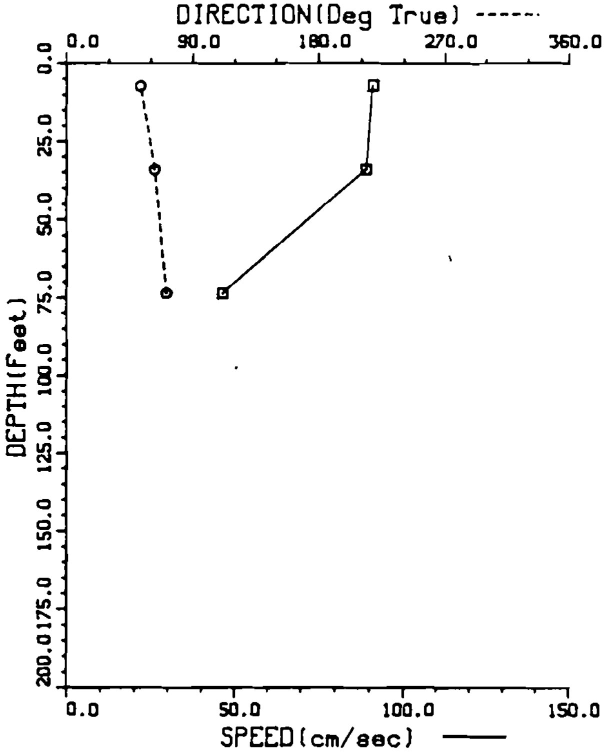


Hague Channel 1 – May 26

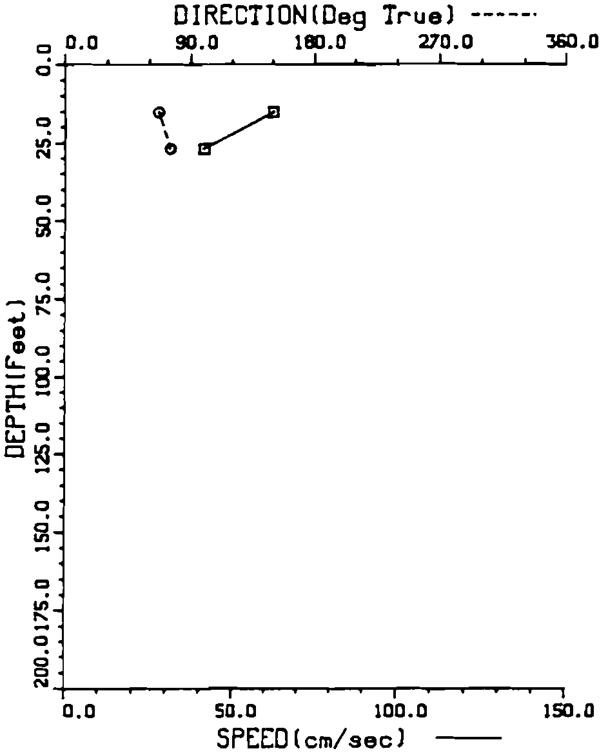
stahcl1.526
05/26/89 13:46:03



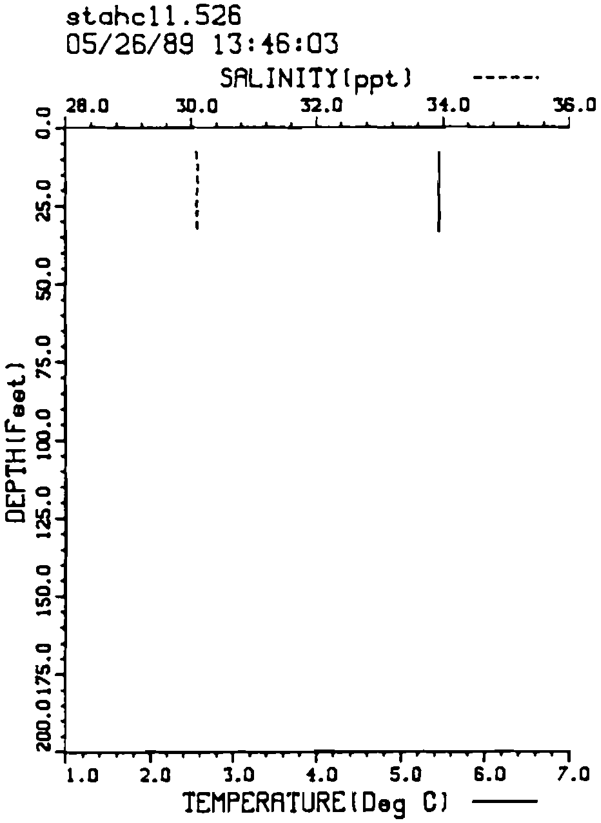
stahcl2.526
05/26/89 13:27:41

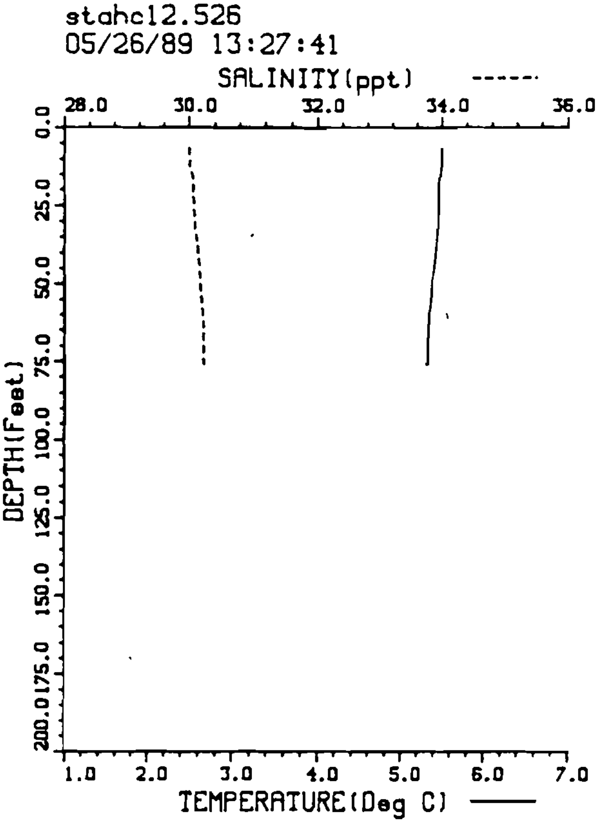


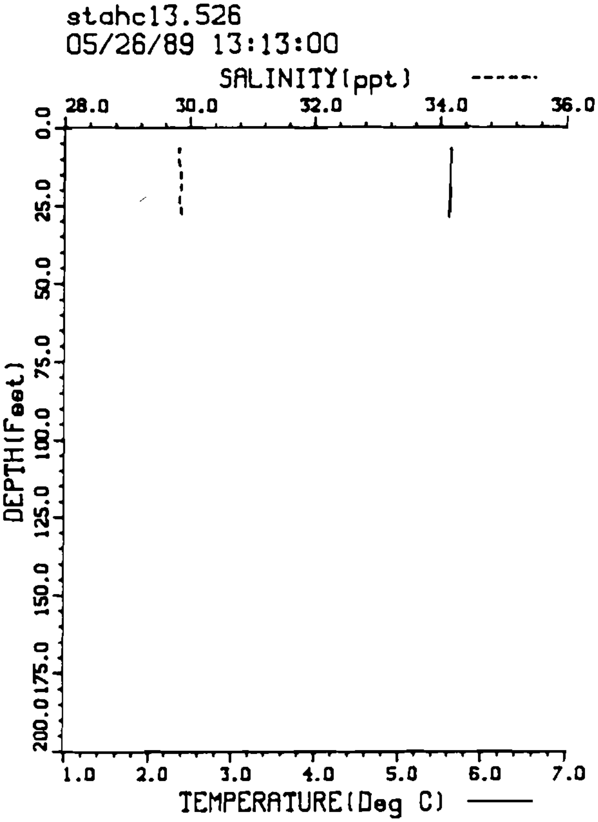
stahcl3.526
05/26/89 13:13:00



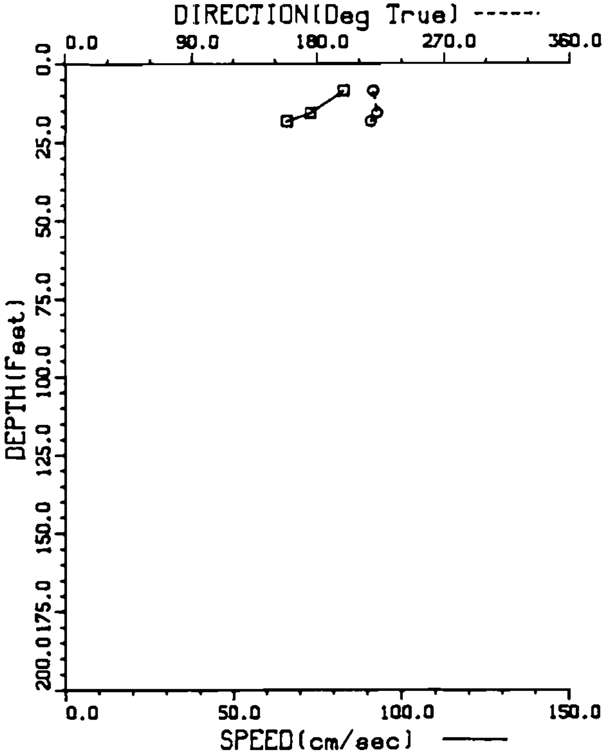
Hague Channel 1 – May 26



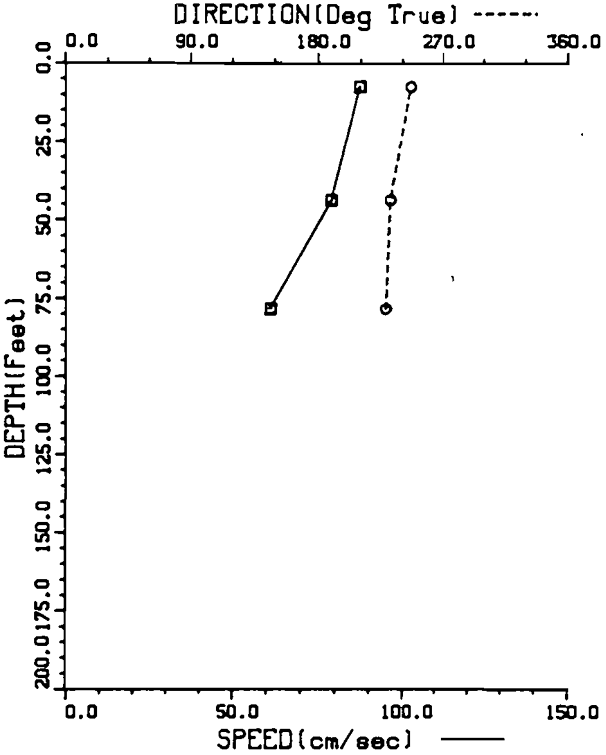




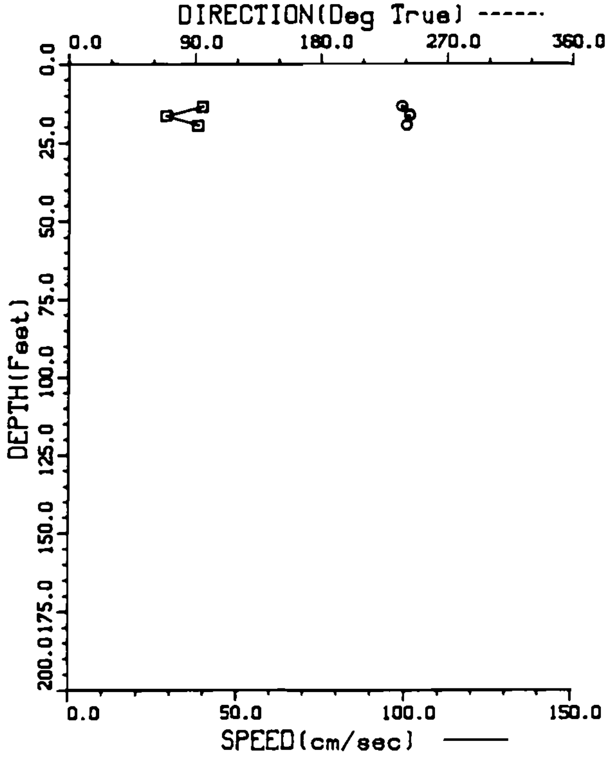
stahc21.526
05/26/89 17:04:44



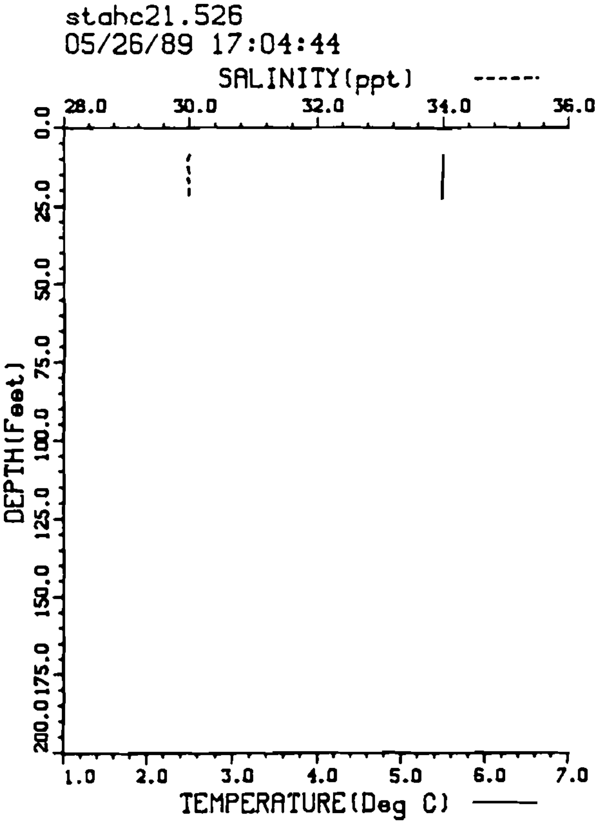
stahc22.526
05/26/89 17:21:26



stahc23.526
05/26/89 17:41:37



Hague Channel 2



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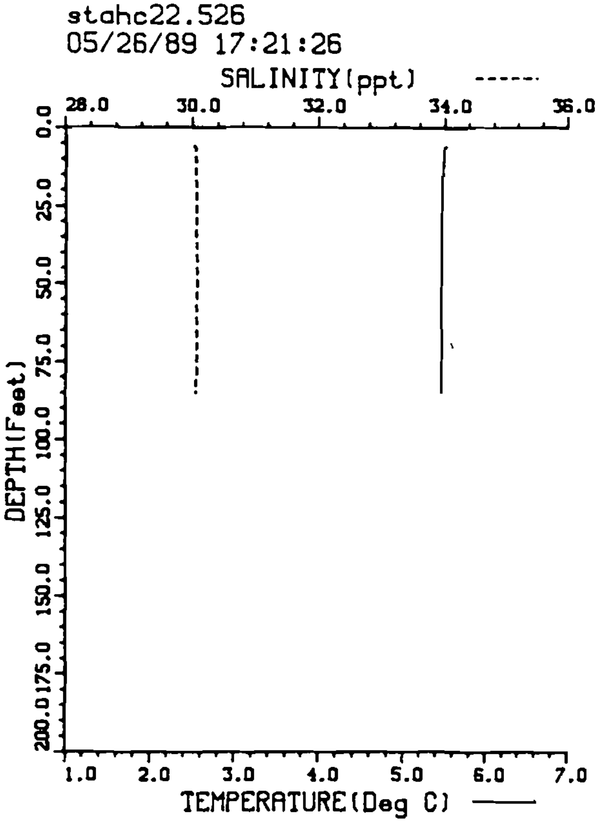
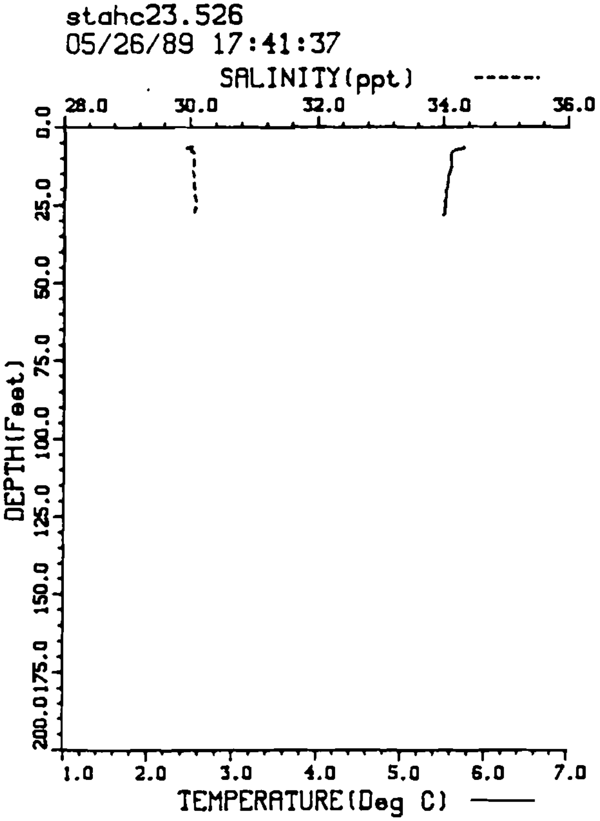
05/26/89 17:04:44

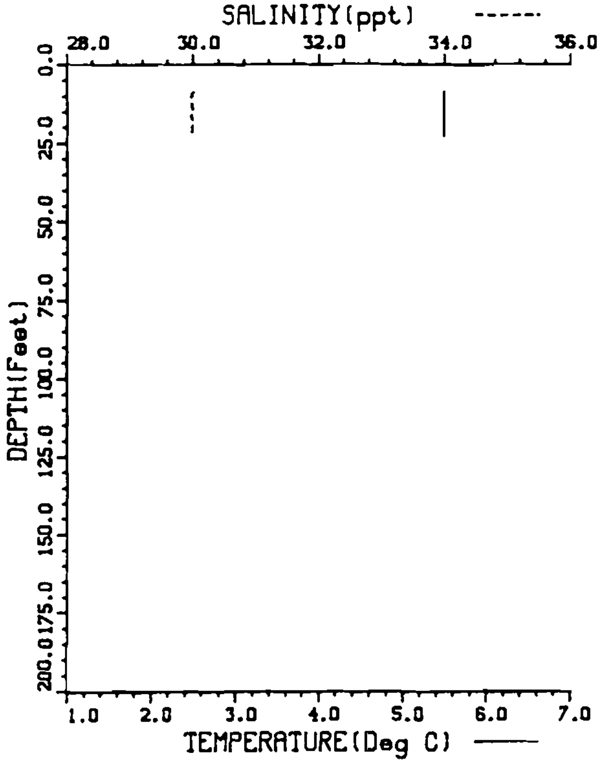


stahc22.526
05/26/89 17:21:26



stahc23.526
05/26/89 17:41:37

stahc21.526
05/26/89 17:04:44



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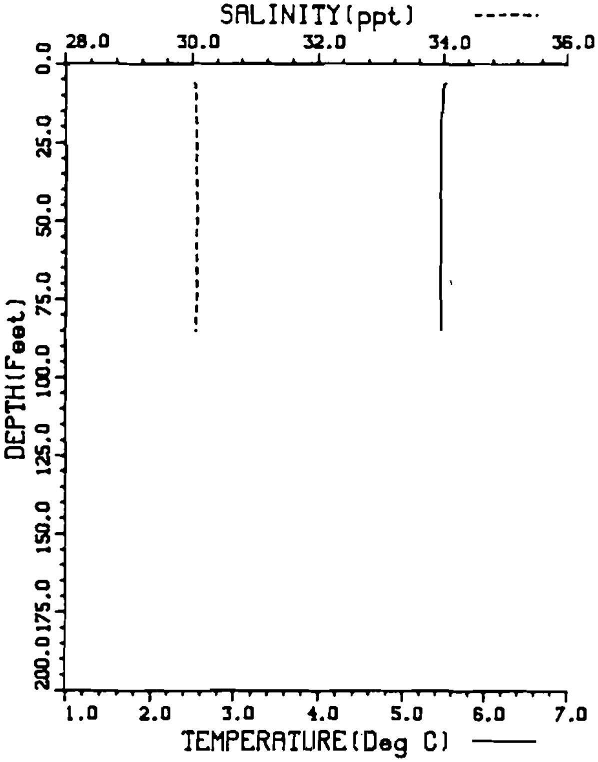

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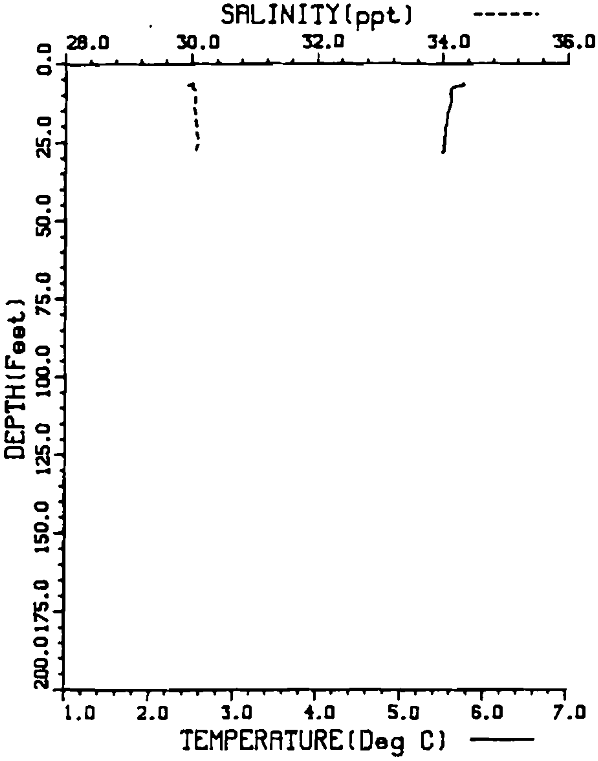
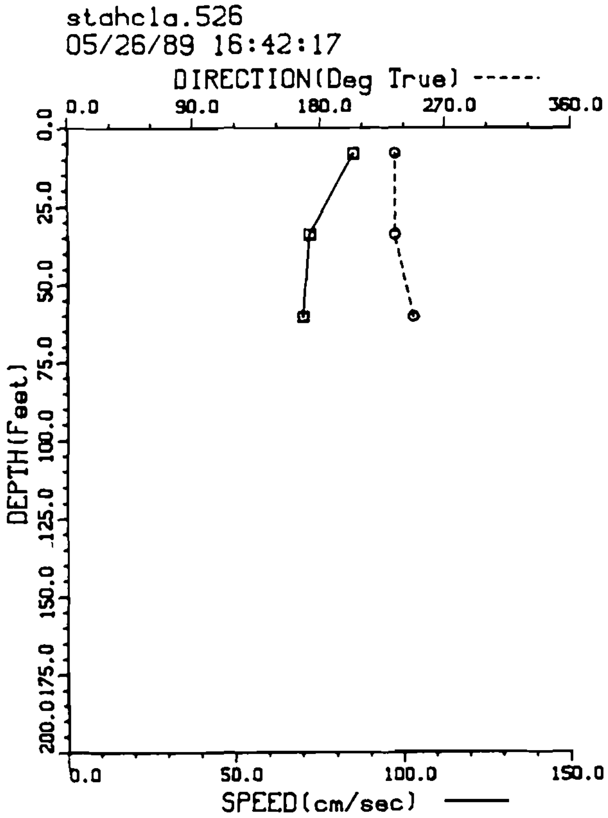
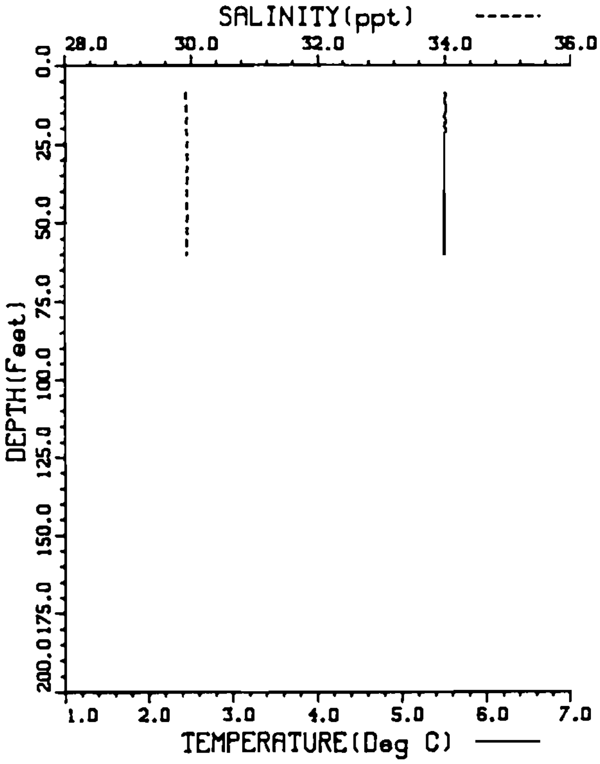


Hague Channel 1 - May 26

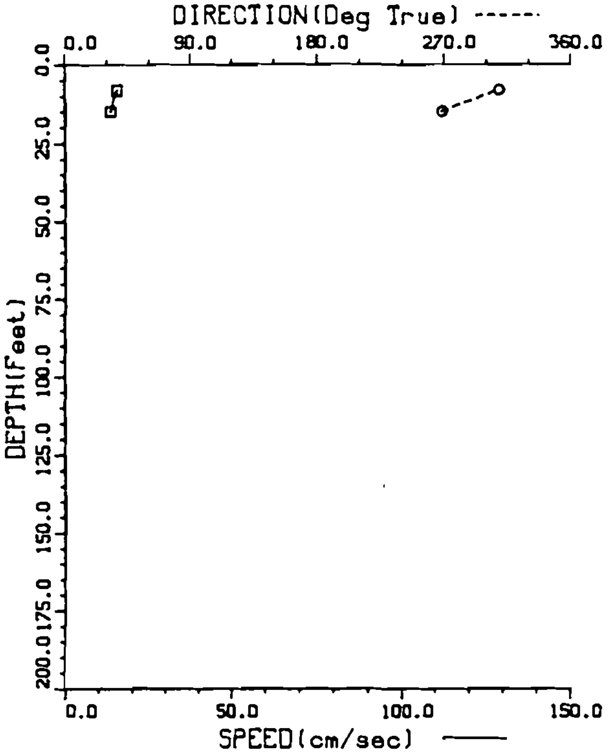


stahcla.526
05/26/89 16:42:17

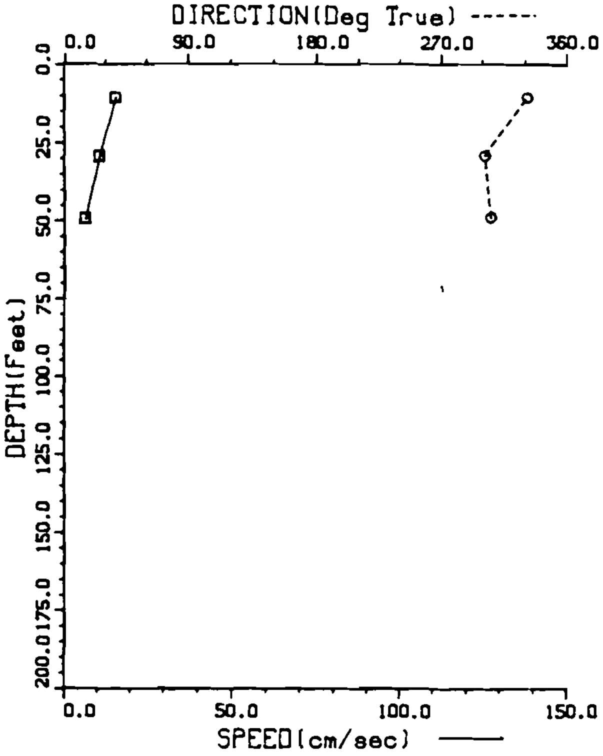


Harbor Point

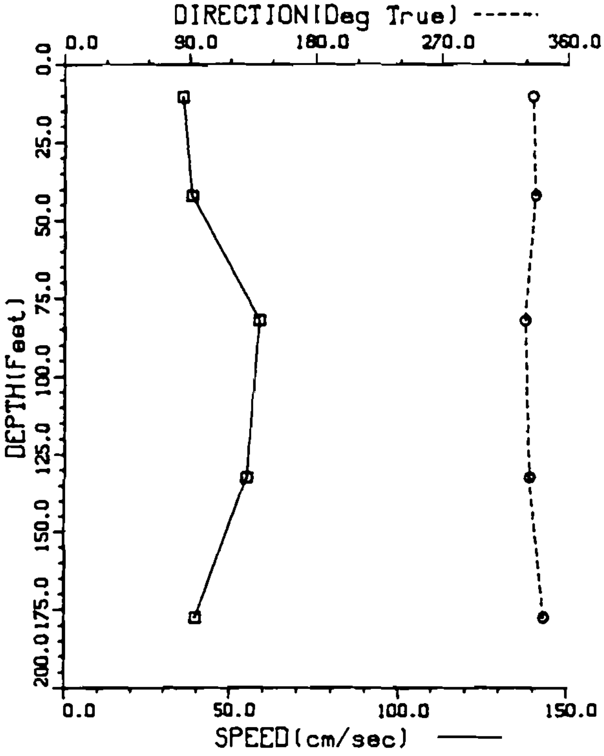
stahp11.525
05/25/89 18:03:12



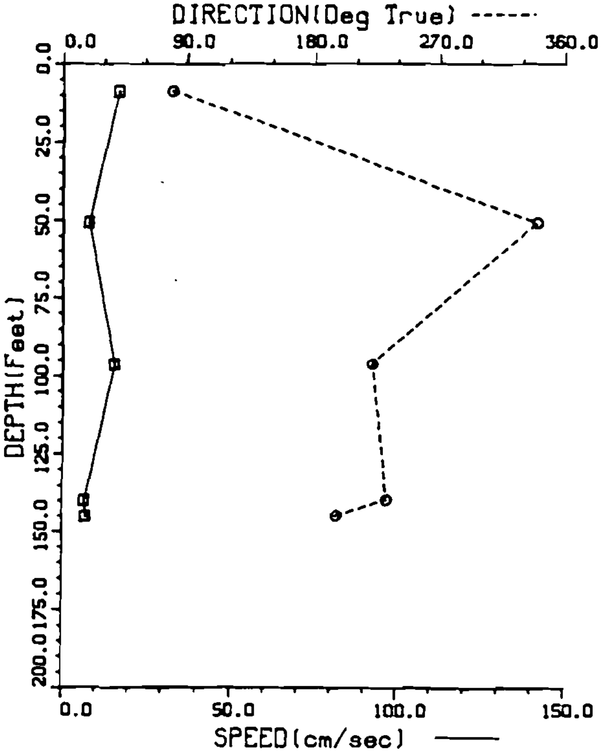
stahp12.525
05/25/89 18:15:03



stahp13.525
05/25/89 18:40:08

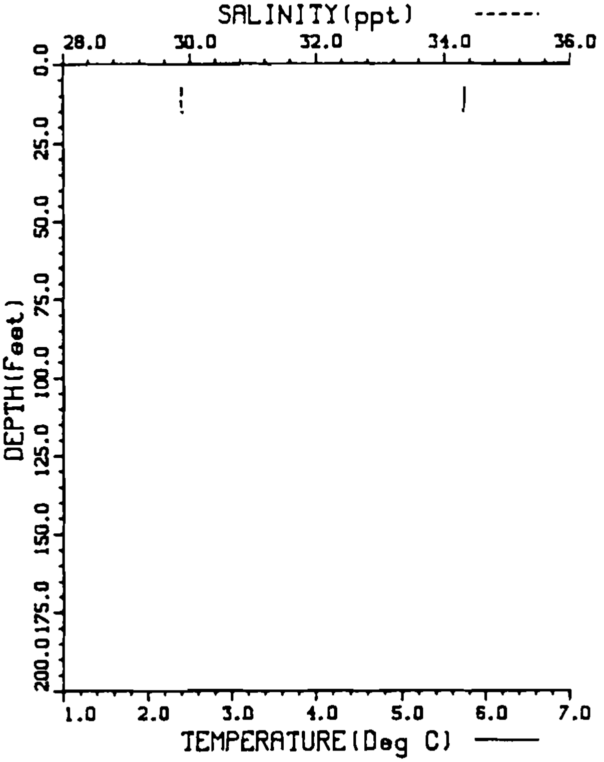


stahp14.525
05/25/89 19:11:35

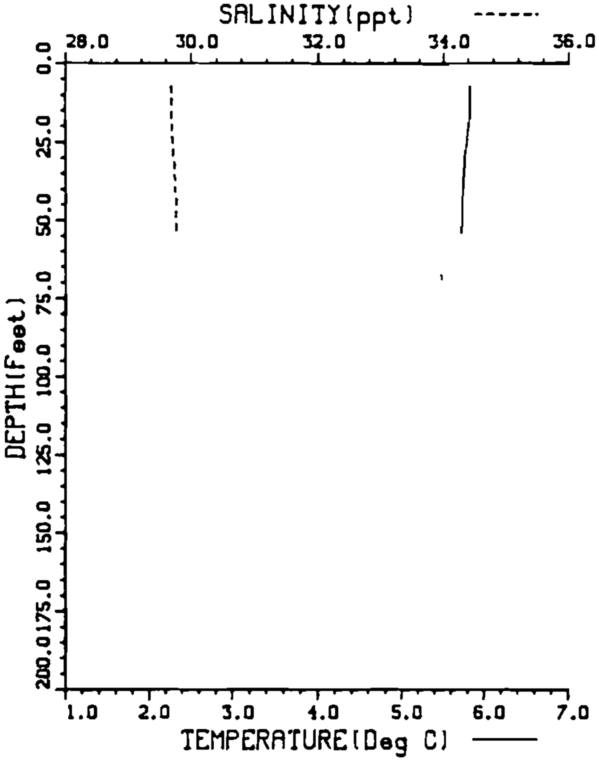


Harbor Point

stahp11.525
05/25/89 18:03:12



stahp12.525
05/25/89 18:15:03



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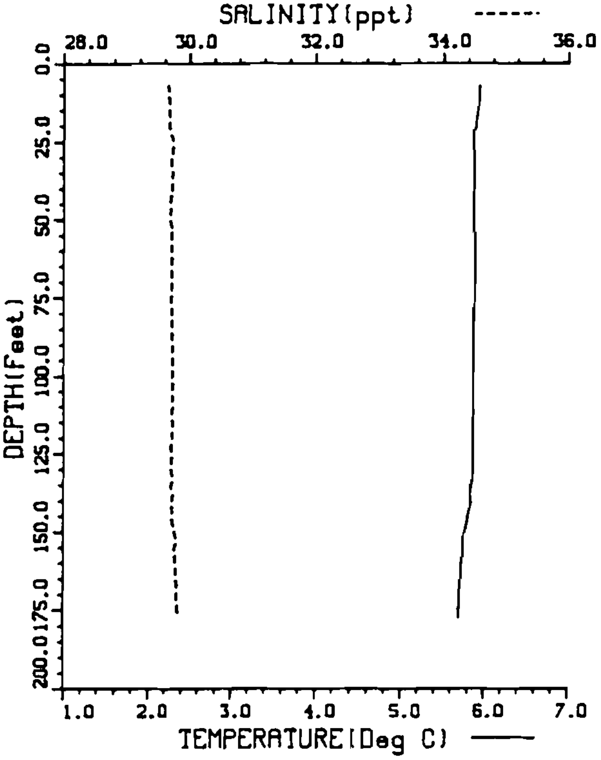

stahp14.525
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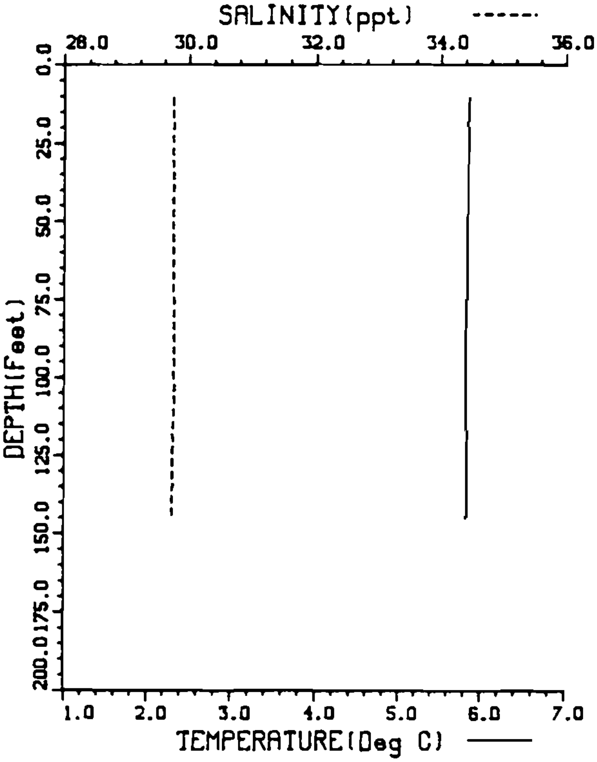
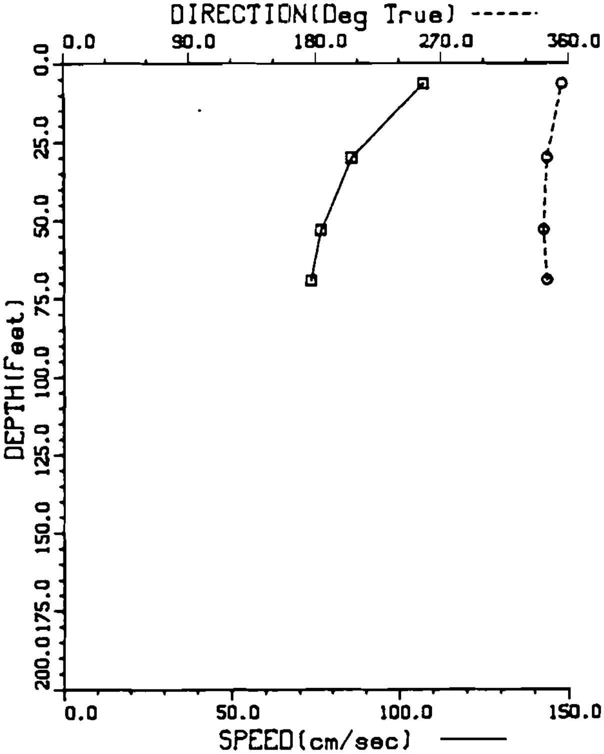
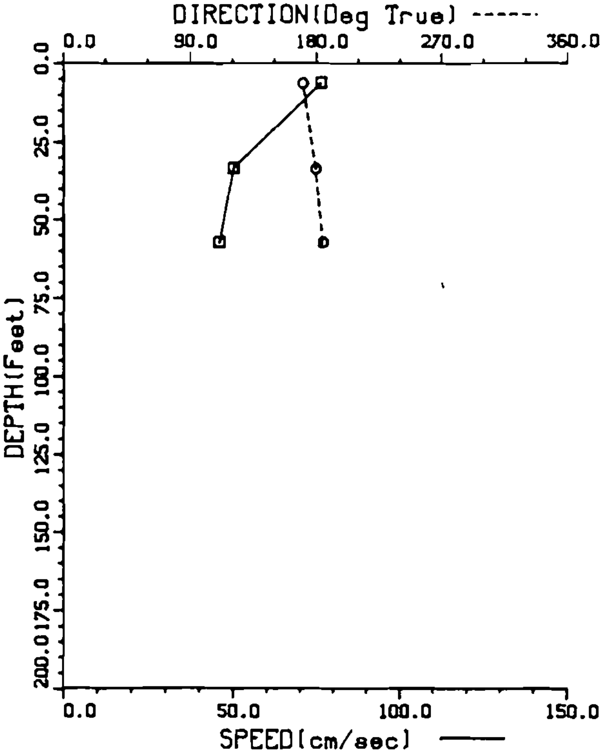


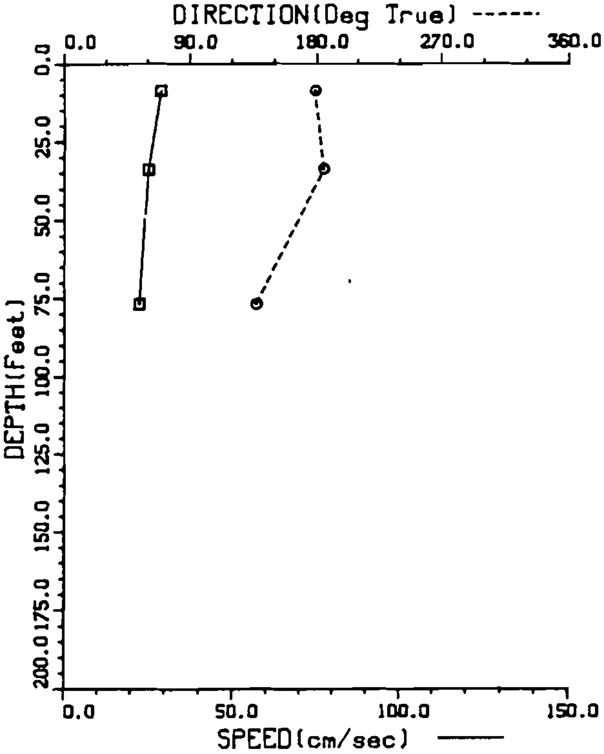
stacml.528
05/28/89 12:39:17



stacml.529
05/29/89 19:14:53

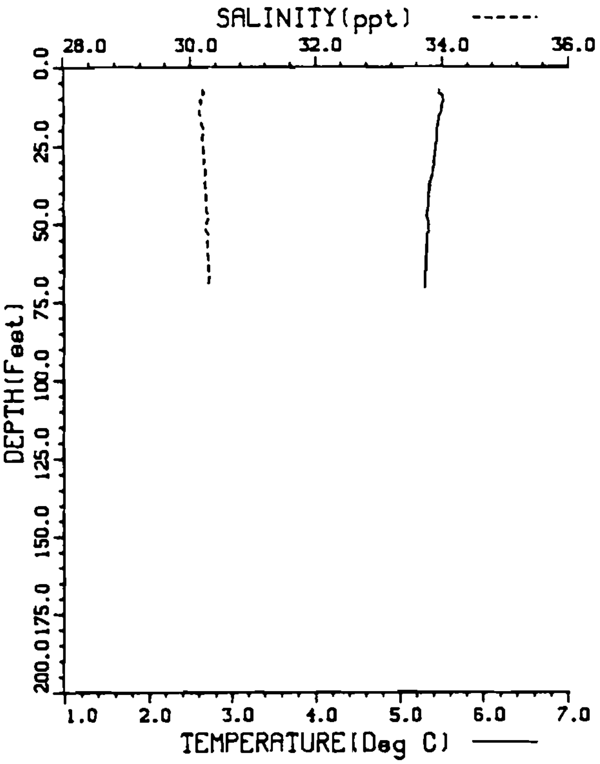


stacmla.529
05/29/89 22:16:00



Mooring 1

stacml.528
05/28/89 12:39:17



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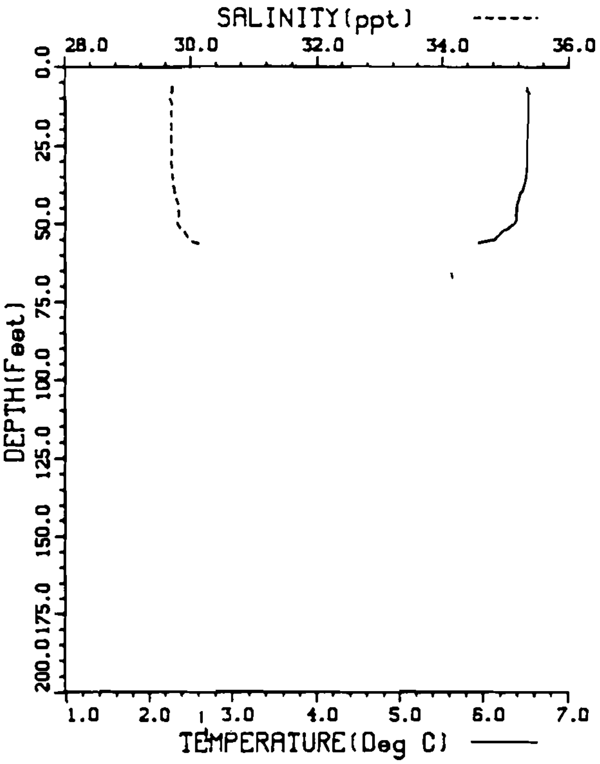

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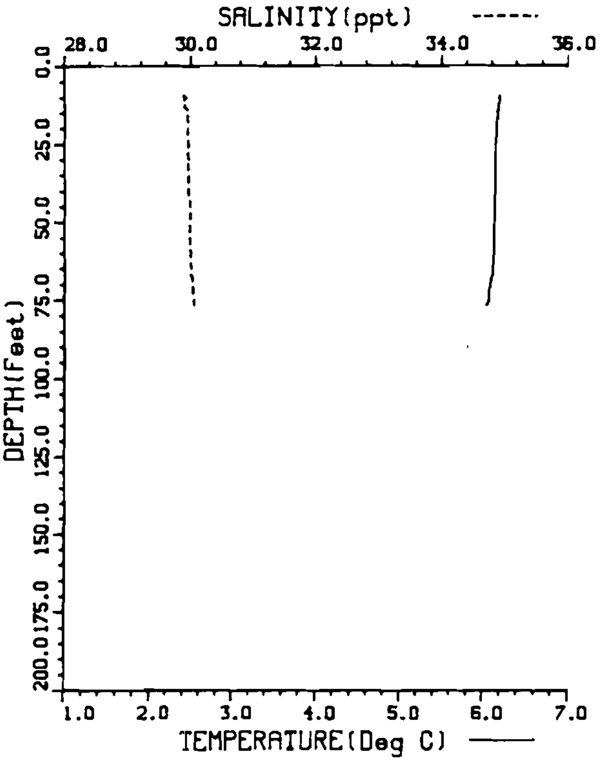
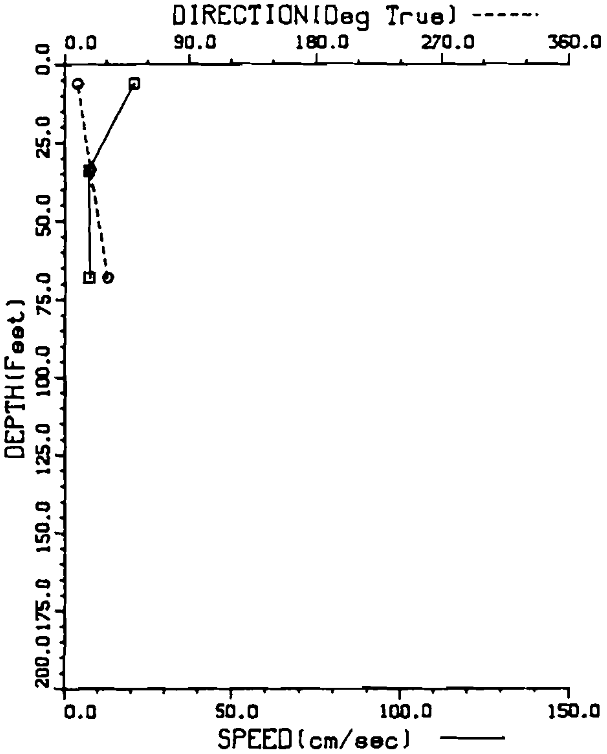
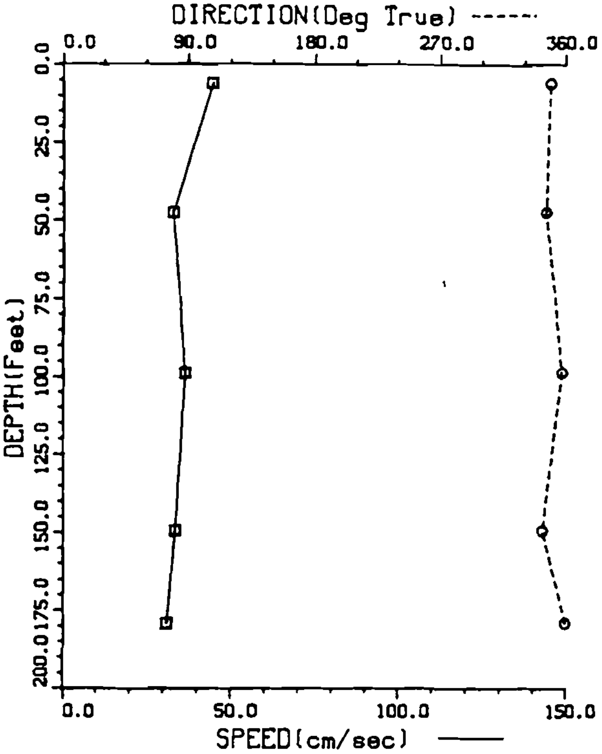


Mooring

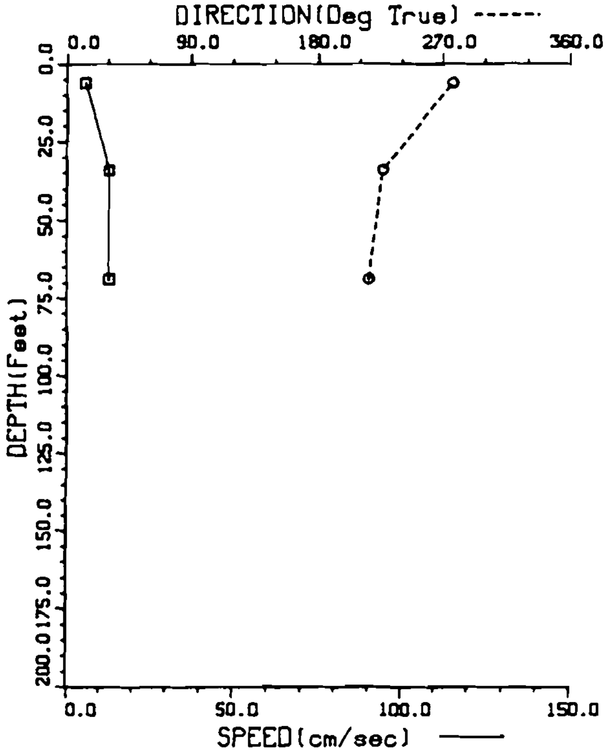
statest21.519
05/19/89 14:15:10



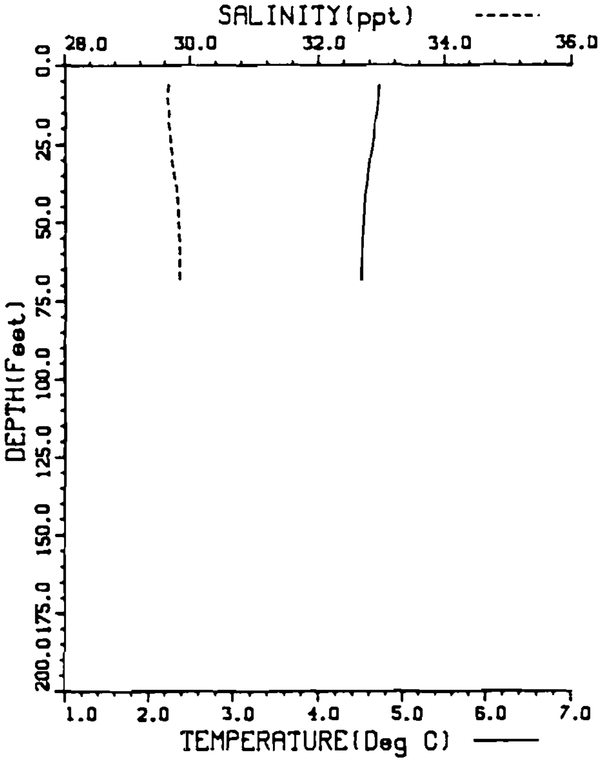
statest22.519
05/19/89 15:03:31



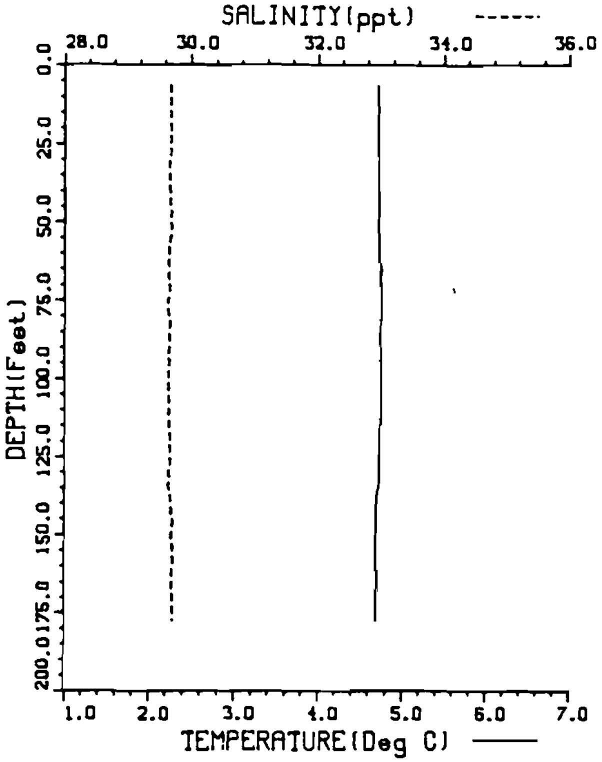
stacm2.525
05/25/89 17:18:28



statest21.519
05/19/89 14:15:10



statest22.519
05/19/89 15:03:31



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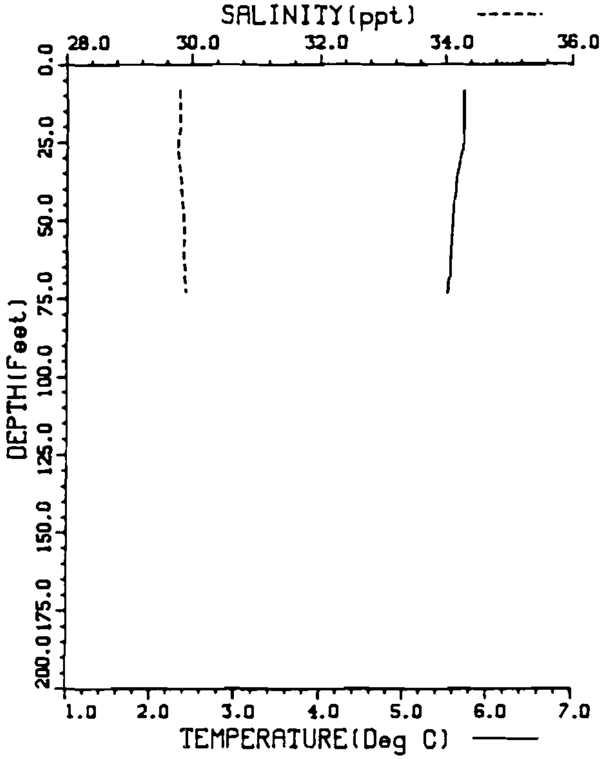
05/25/89 17:18:28



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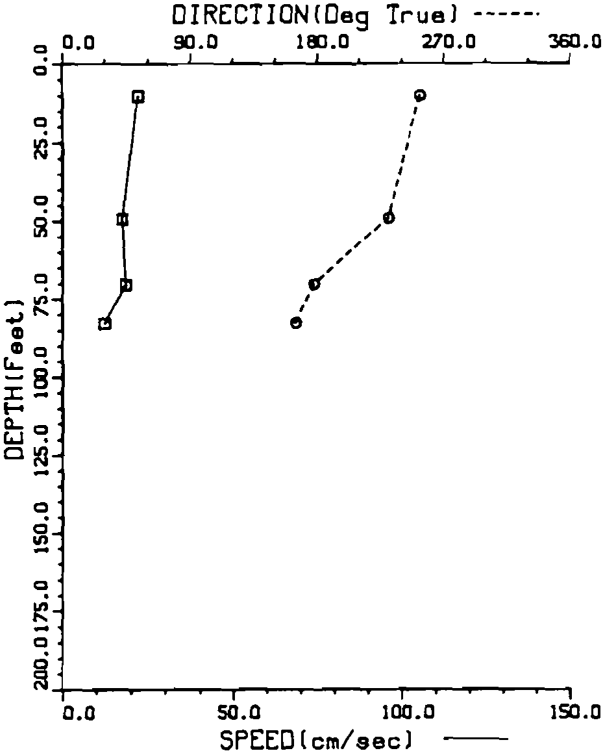
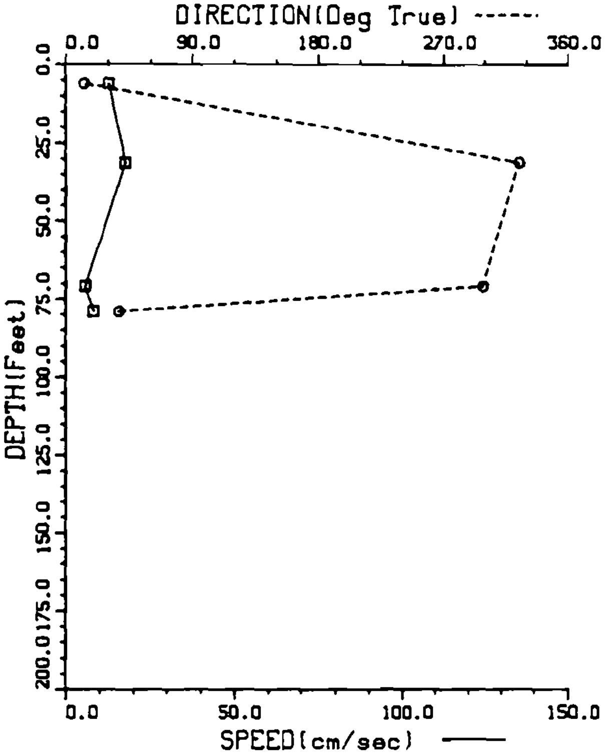
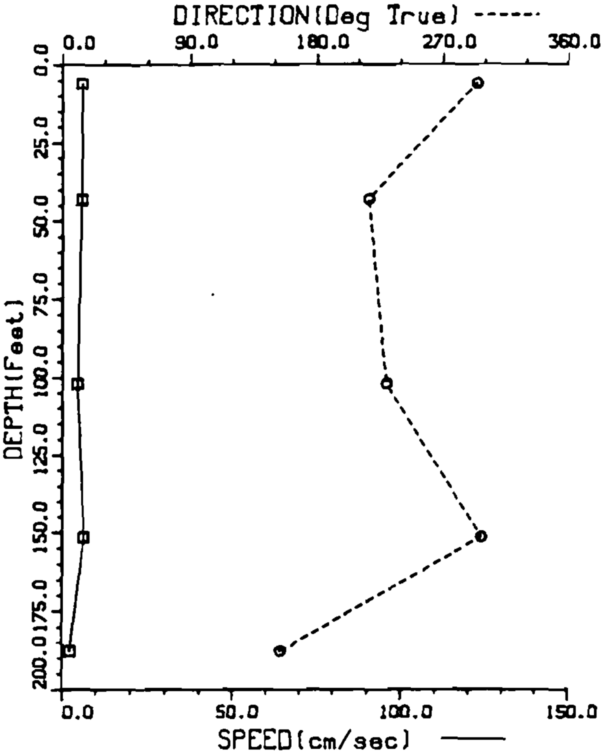
05/26/89 18:11:10



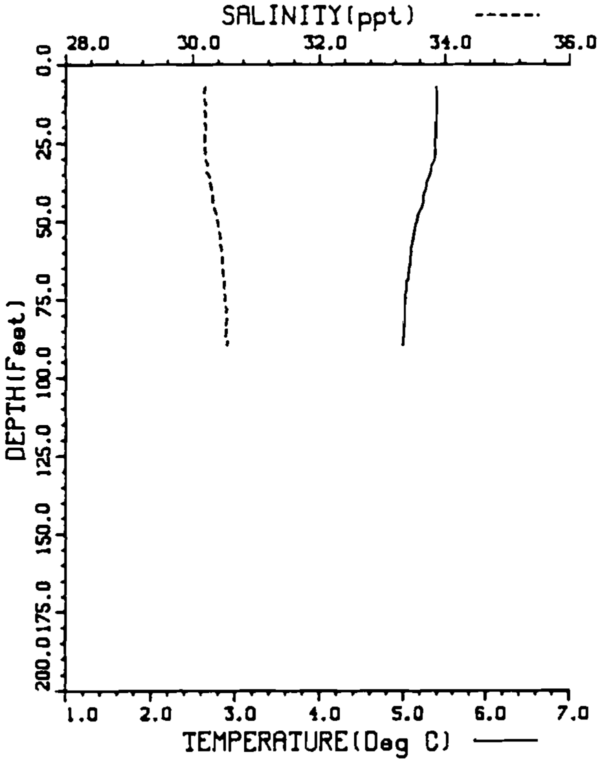
stacm4.523
05/23/89 18:26:29



stacm5.523
05/23/89 21:38:34



stacm3.526
05/26/89 18:11:10



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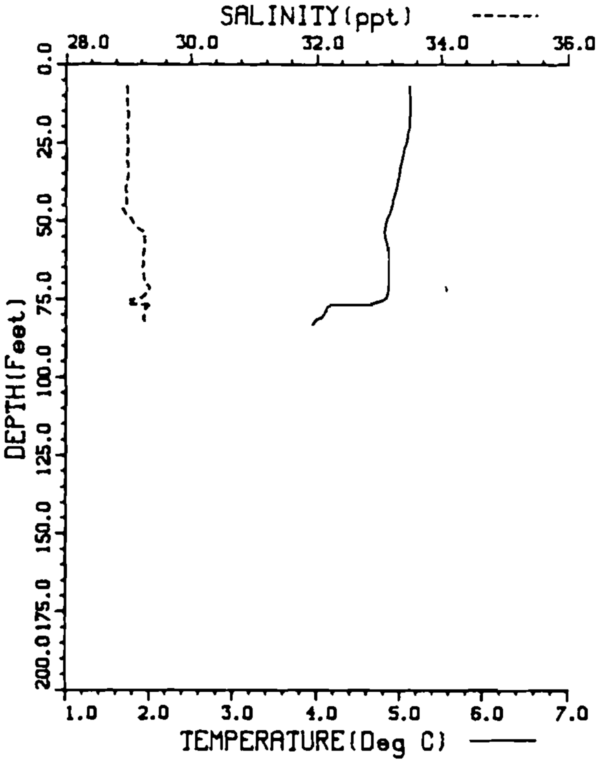
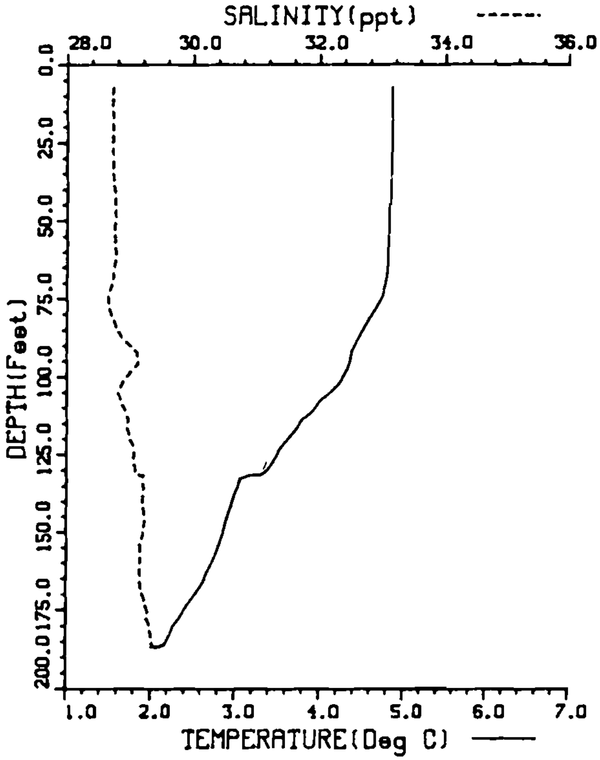
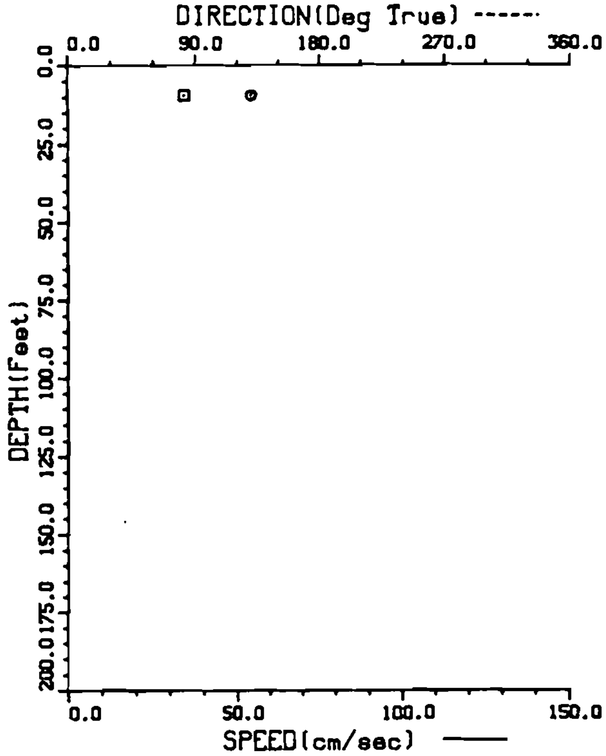


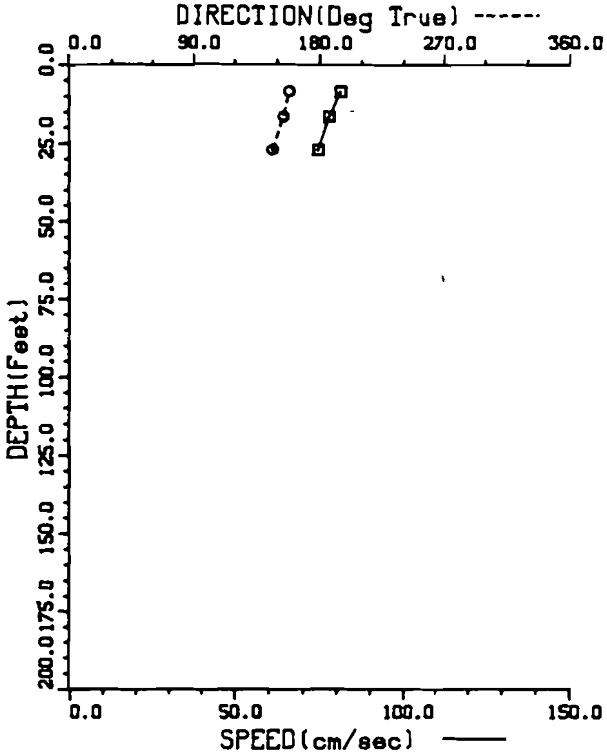
stacm5.523
05/23/89 21:38:34



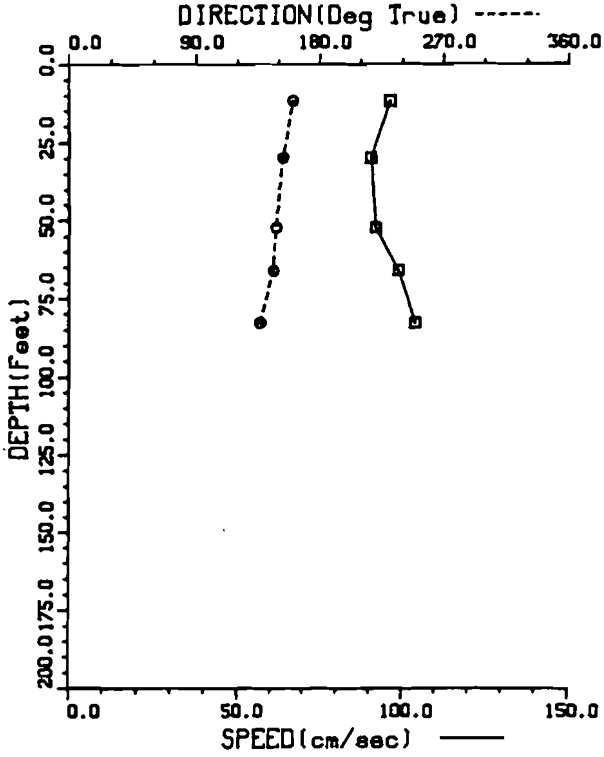
stahp1.93
09/03/89 15:13:40



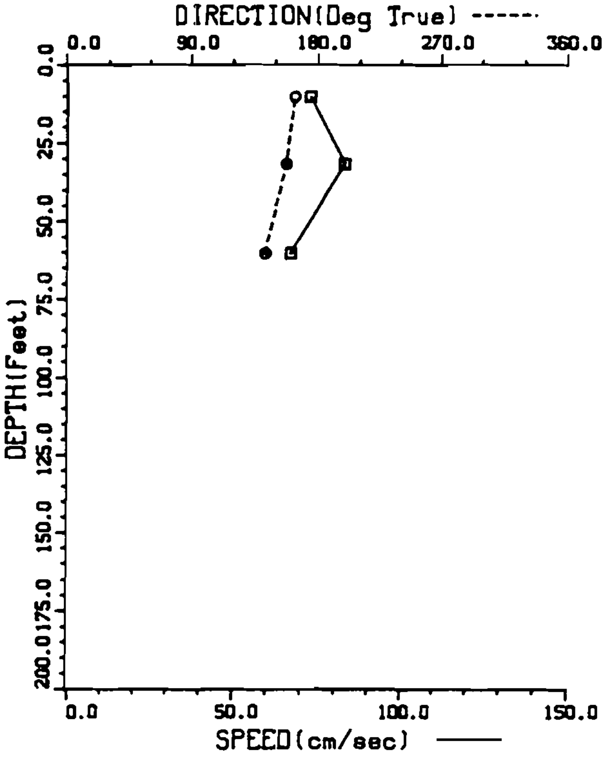
stahp2.93
09/03/89 15:37:02



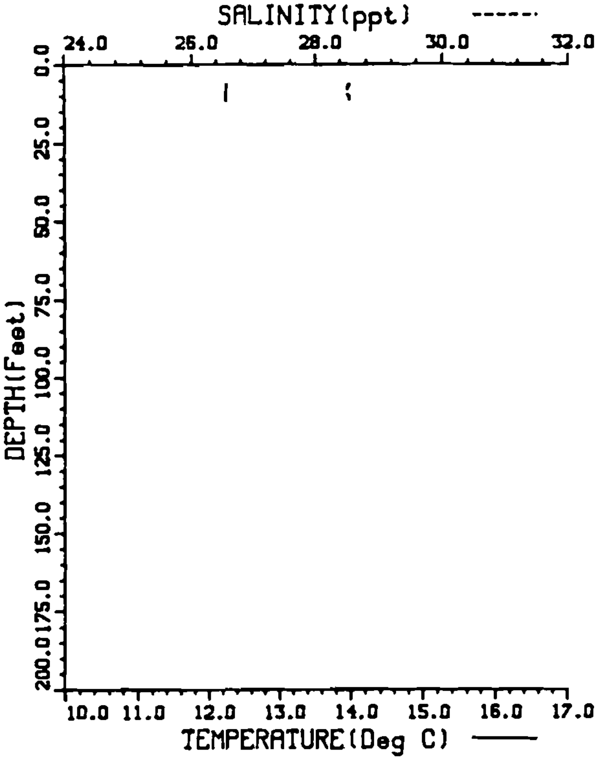
stahp3.93
09/03/89 16:02:21



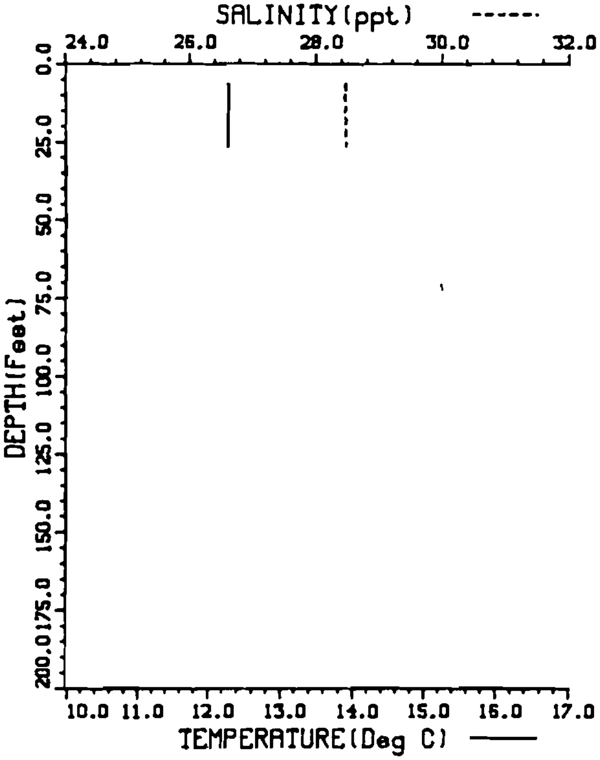
stahp4.93
09/03/89 16:39:40



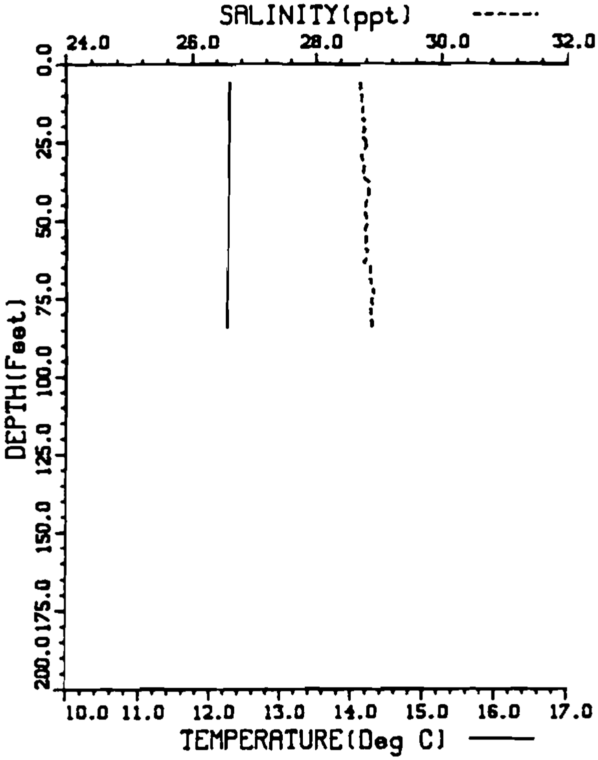
stahp1.93
09/03/89 15:13:40



stahp2.93
09/03/89 15:37:02



stahp3.93
09/03/89 16:02:21



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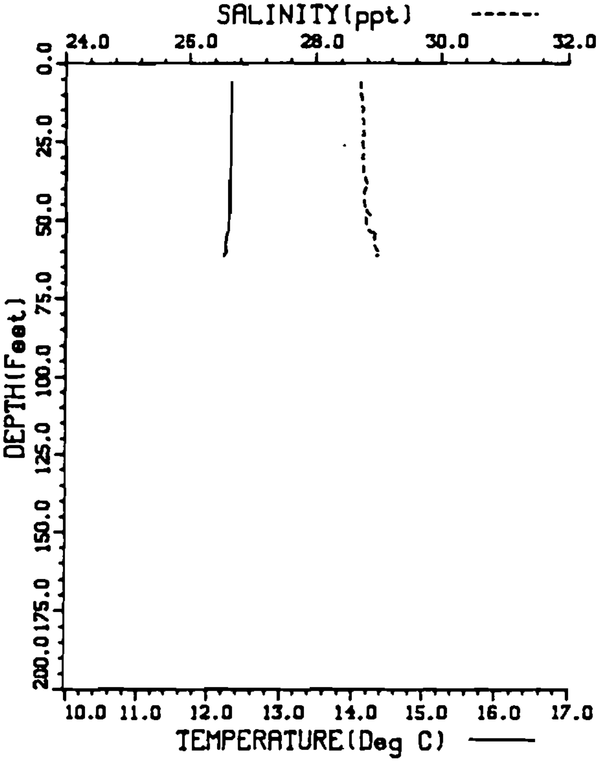
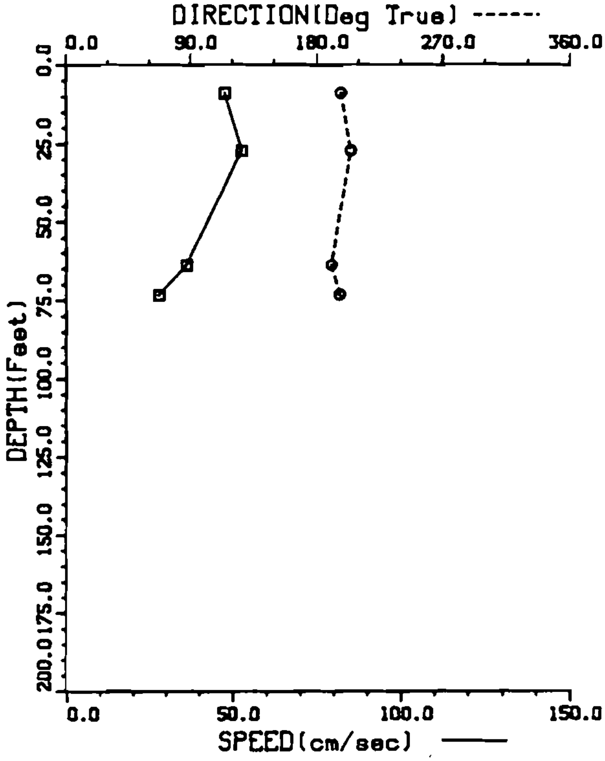
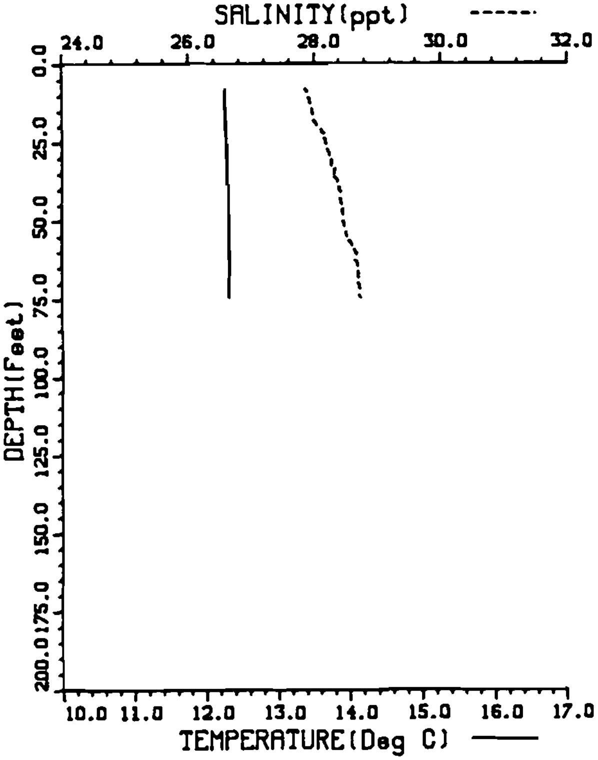
09/03/89 16:39:40



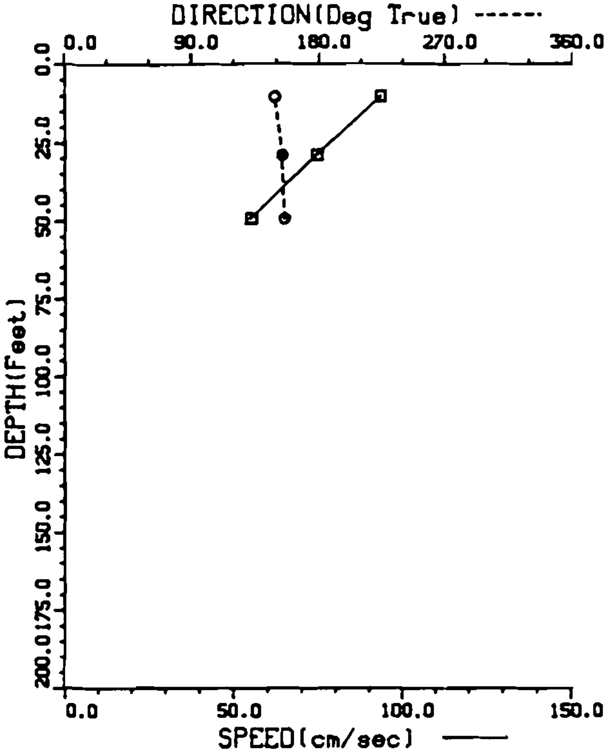
09/03/89 14:18:07



stacm2.93
09/03/89 14:18:07



stapm1.105
10/05/89 16:32:59



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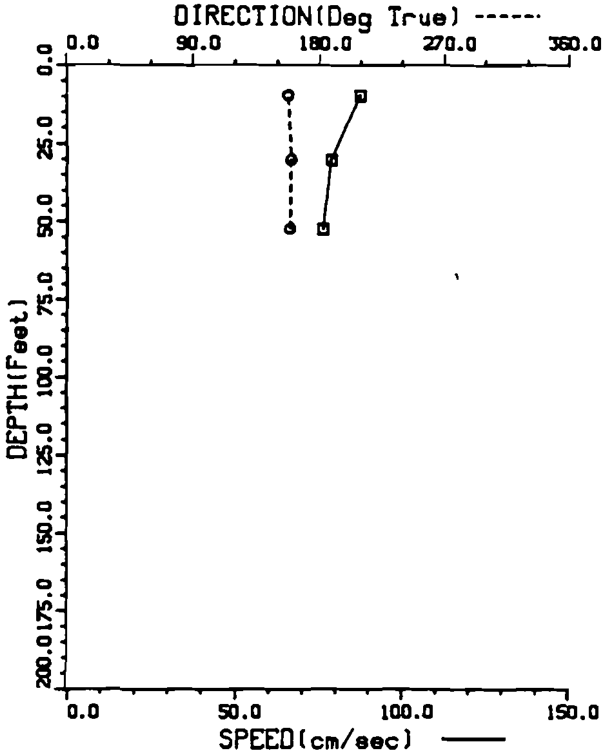
10/05/89 16:47:27



stapm3.105
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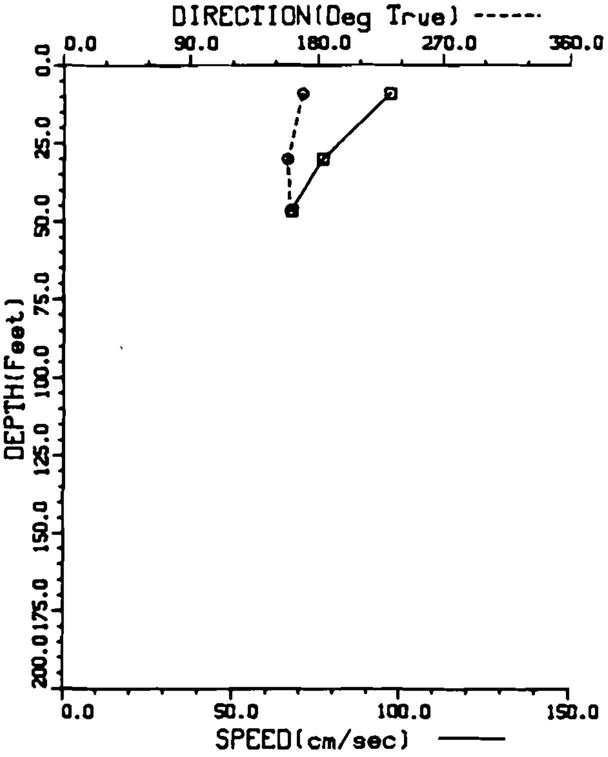

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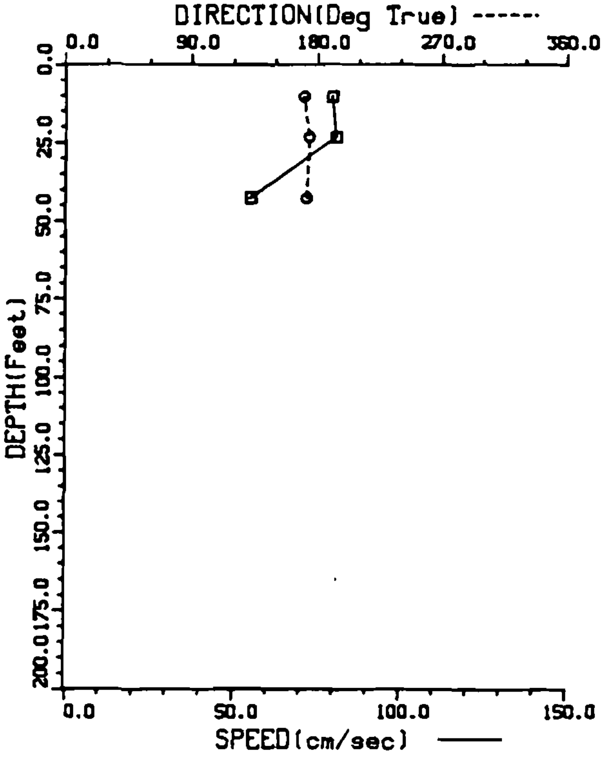
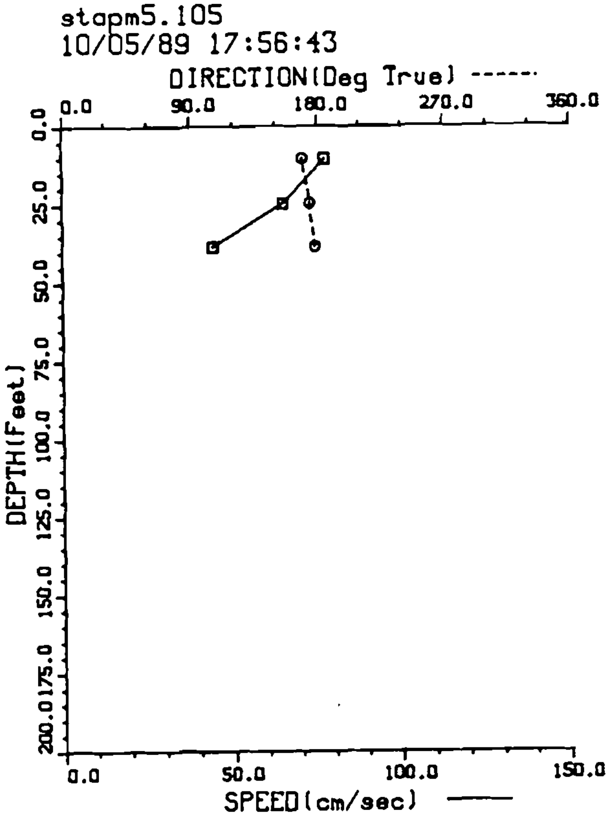
10/05/89 17:34:30



Mouth of pere



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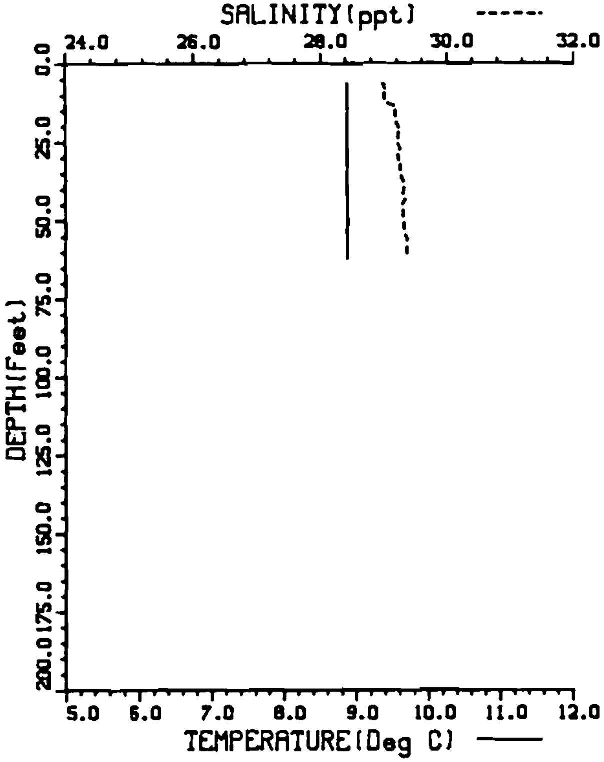

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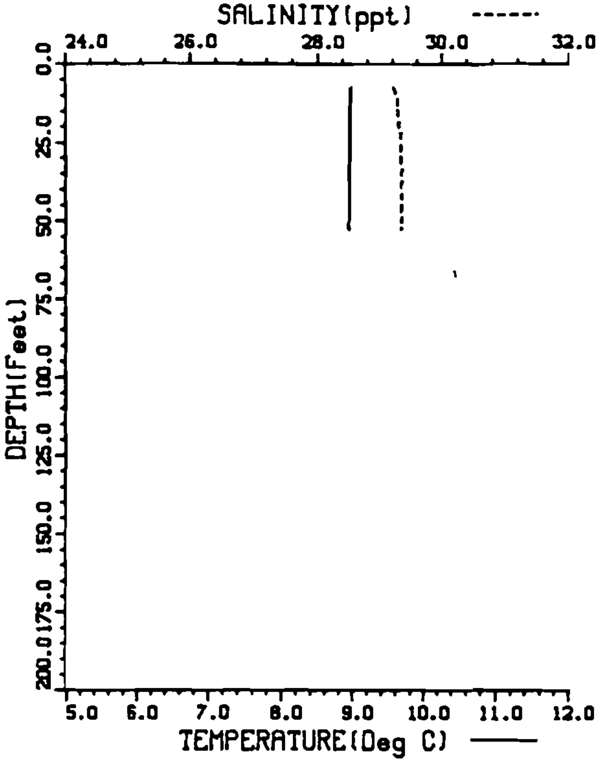

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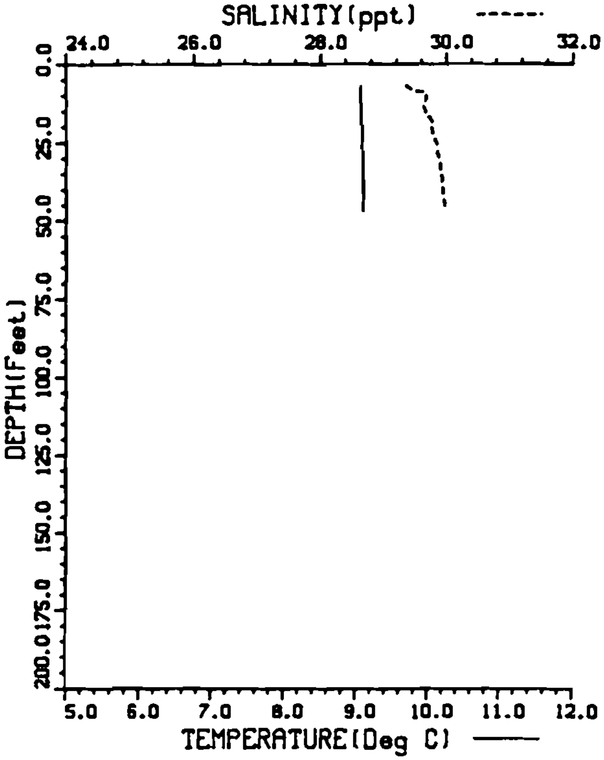
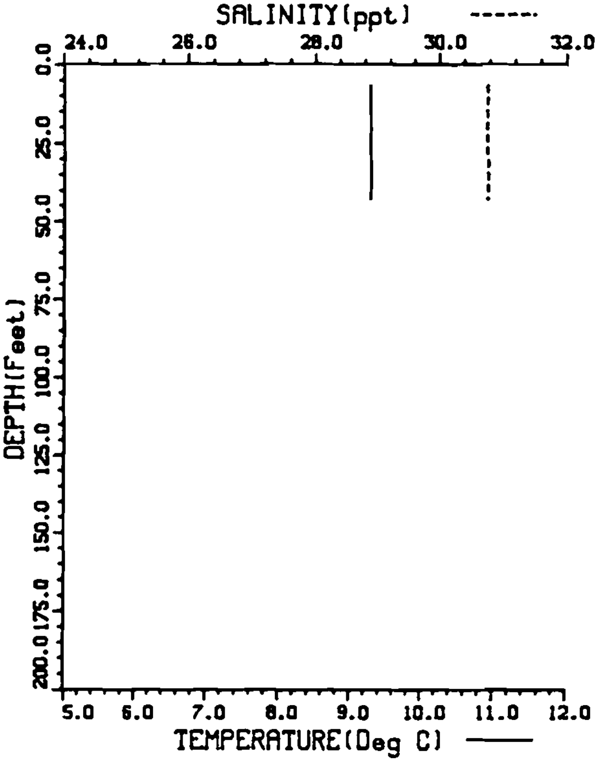


stapm4.105
10/05/89 17:34:30



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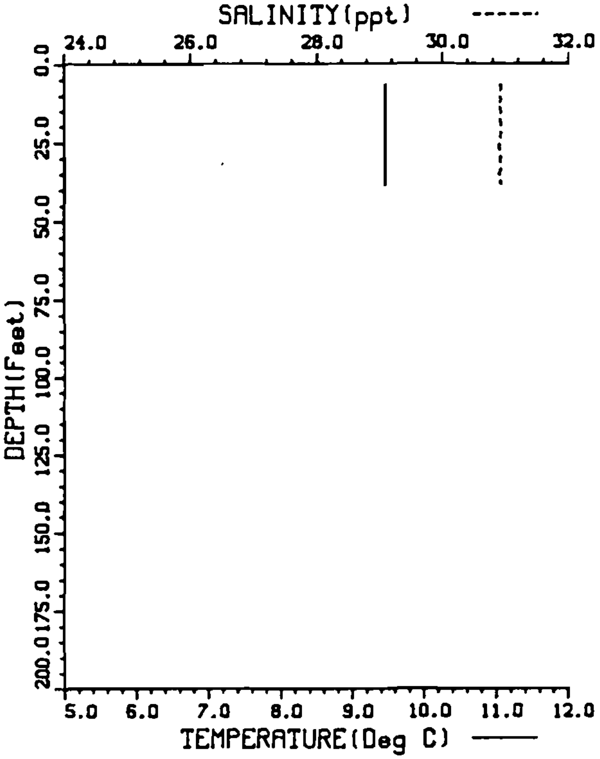

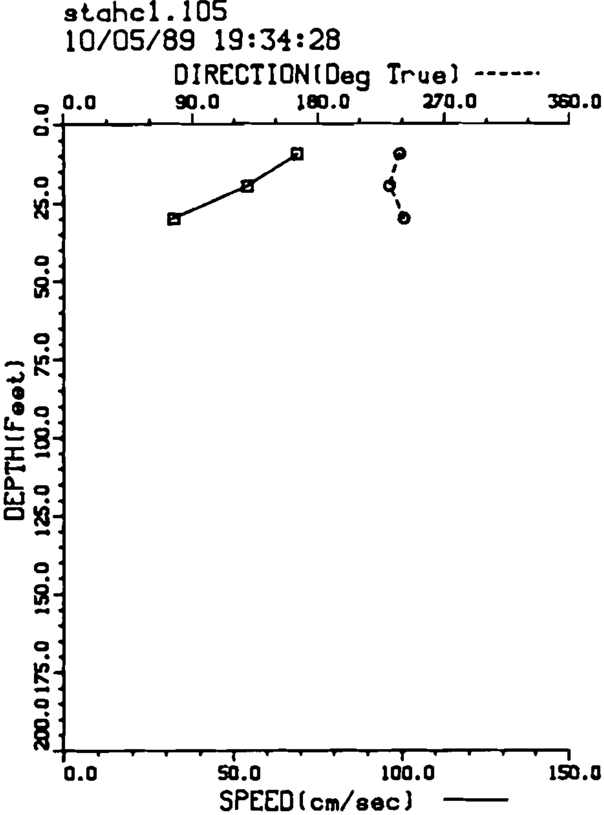
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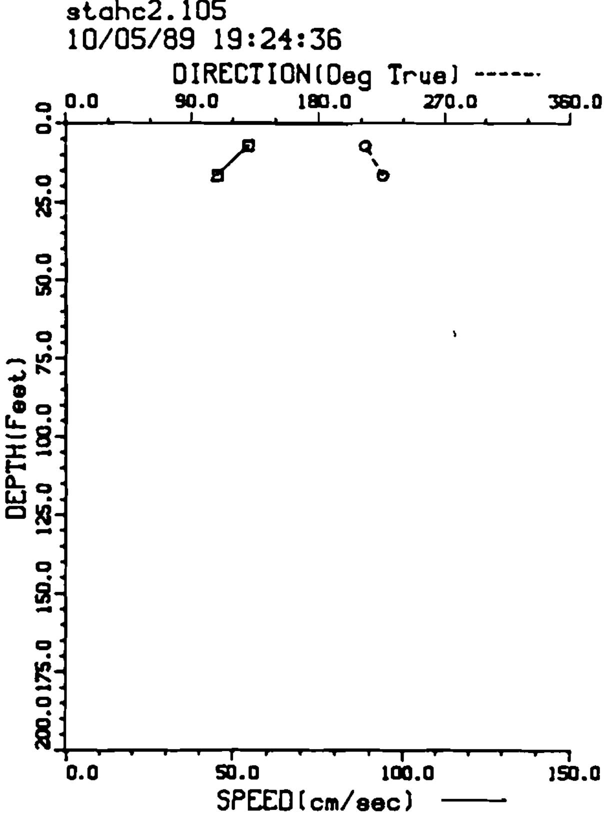
10/05/89 19:34:28
DIRECTION(Deg True)
0.0
90.0
180.0
270.0
360.0
DEPTH(Feet)
0.0
25.0
50.0
75.0
100.0
125.0
150.0
175.0
200.0
0.0
50.0
100.0
150.0
SPEED(cm/sec)


stahc2.105
10/05/89 19:24:36
DIRECTION(Deg True)
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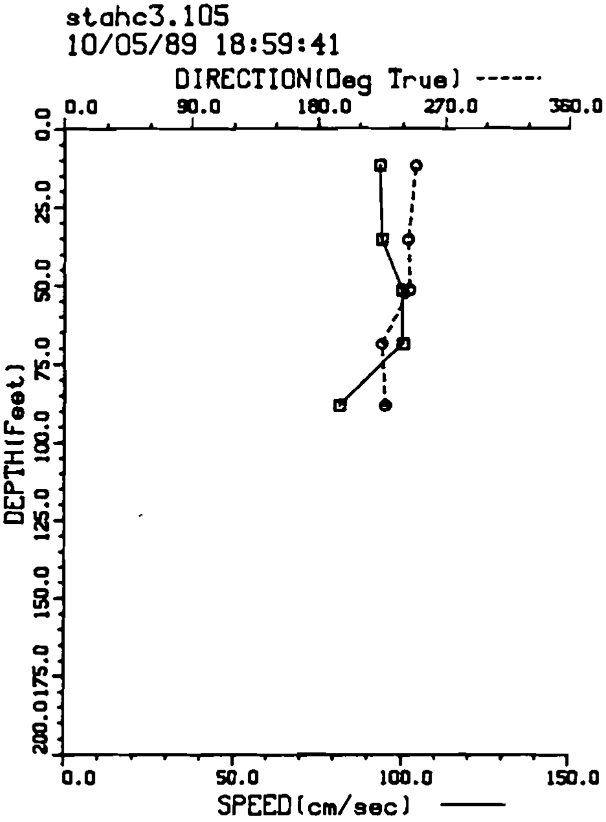
90.0
180.0
270.0
360.0
DEPTH(Feet)
0.0
25.0
50.0
75.0
100.0
125.0
150.0
175.0
200.0
0.0
50.0
100.0
150.0
SPEED(cm/sec)


stahc3.105
10/05/89 18:59:41
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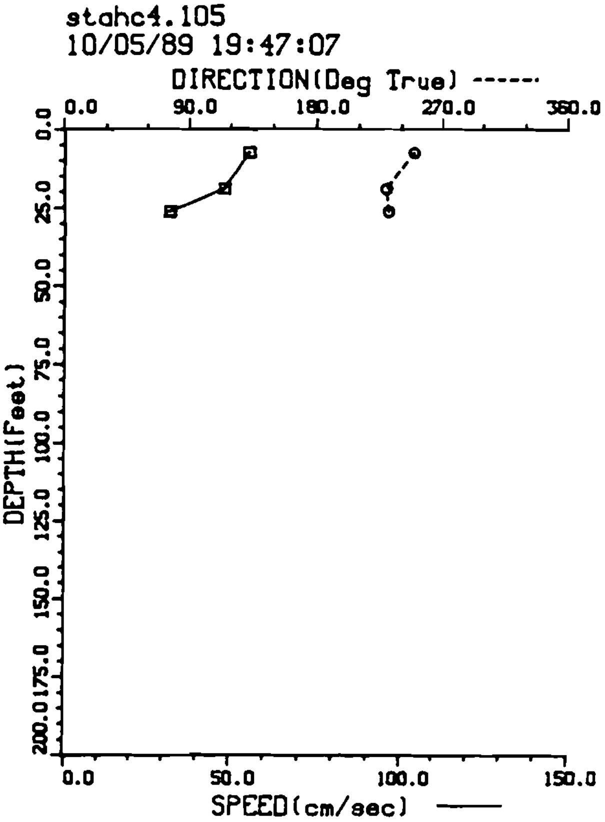
90.0
180.0
270.0
360.0
DEPTH(Feet)
0.0
25.0
50.0
75.0
100.0
125.0
150.0
175.0
200.0
0.0
50.0
100.0
150.0
SPEED(cm/sec)


stahc4.105
10/05/89 19:47:07
DIRECTION(Deg True)
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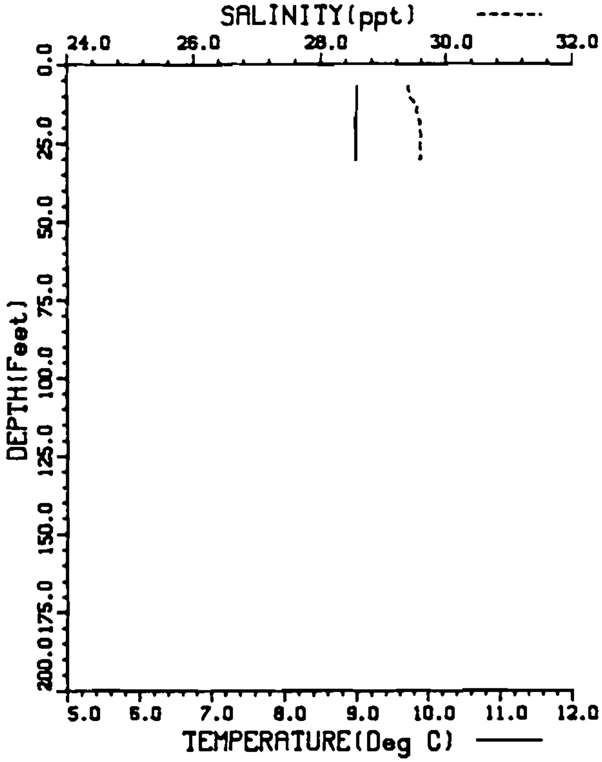
90.0
180.0
270.0
360.0
DEPTH(Feet)
0.0
25.0
50.0
75.0
100.0
125.0
150.0
175.0
200.0
0.0
50.0
100.0
150.0
SPEED(cm/sec)

stahc1.105
10/05/89 19:34:28



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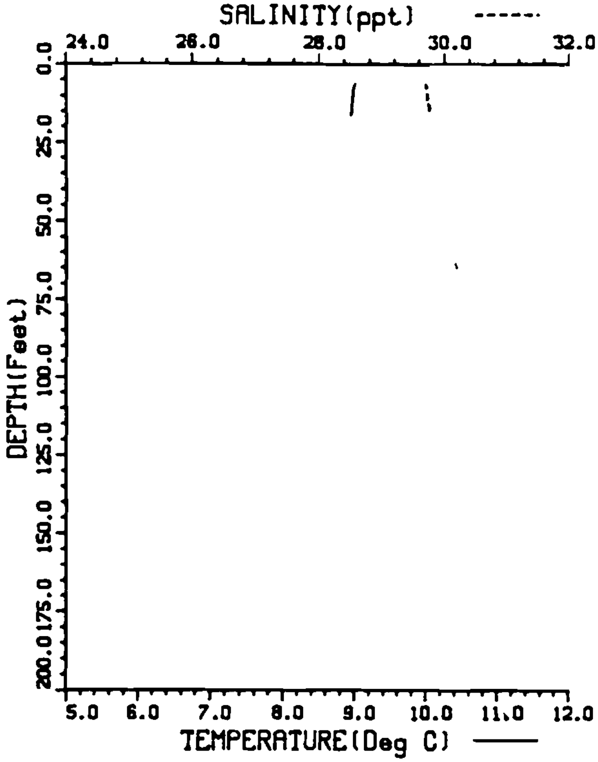

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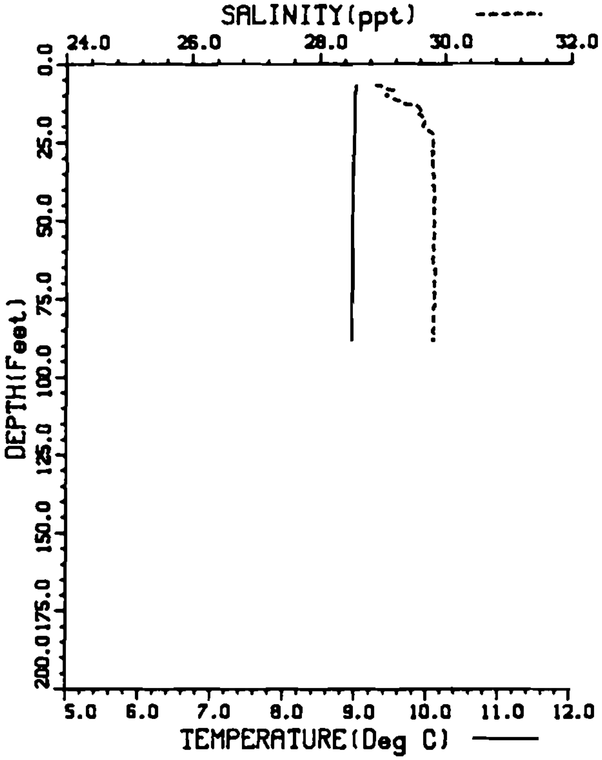

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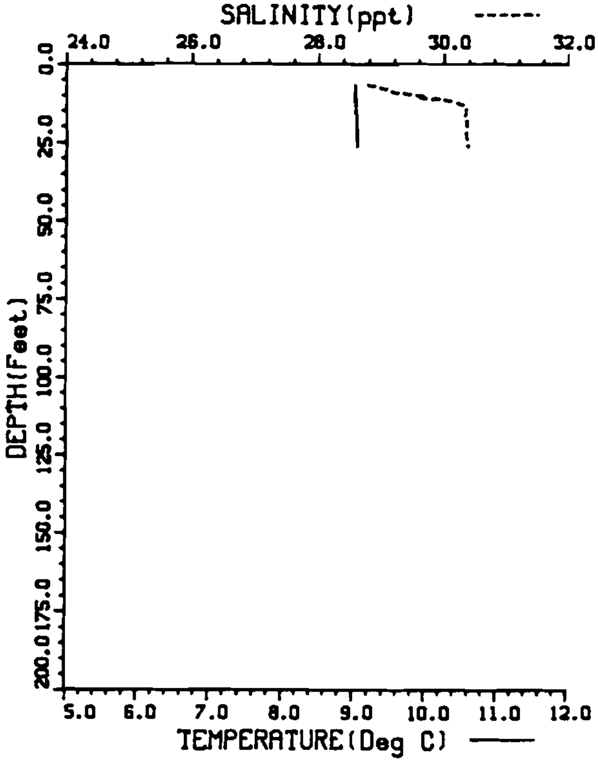

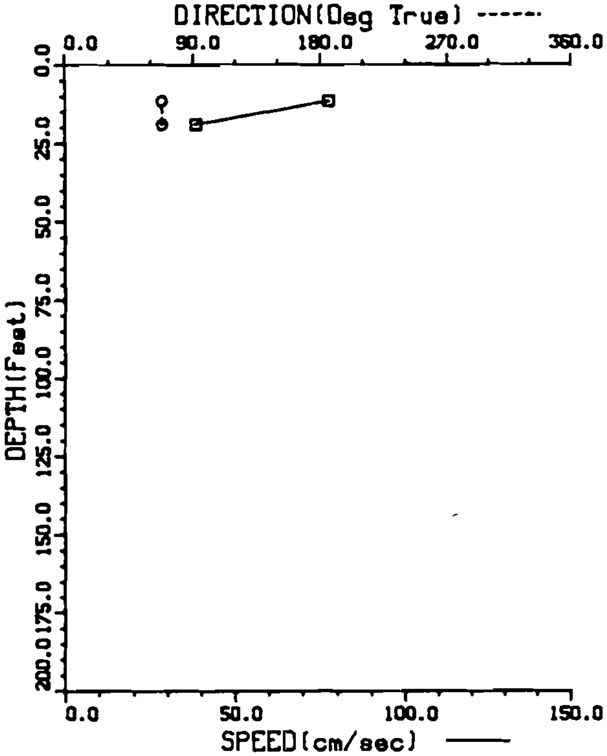

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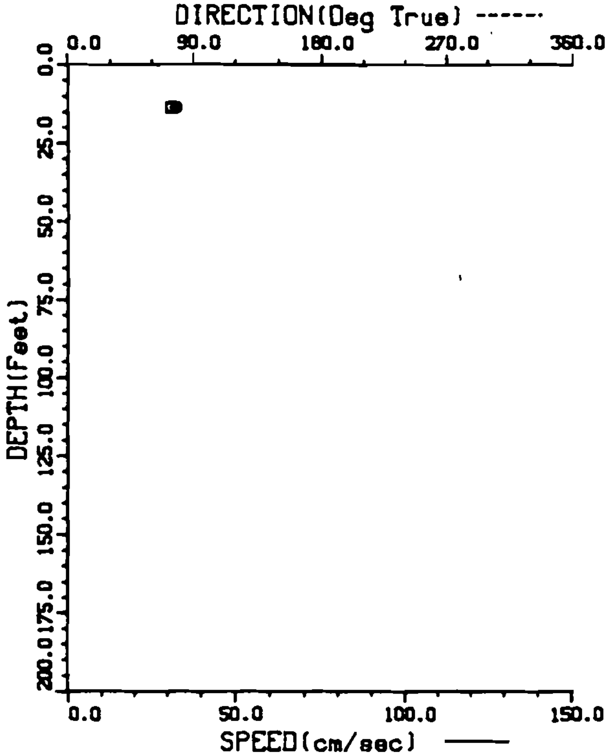

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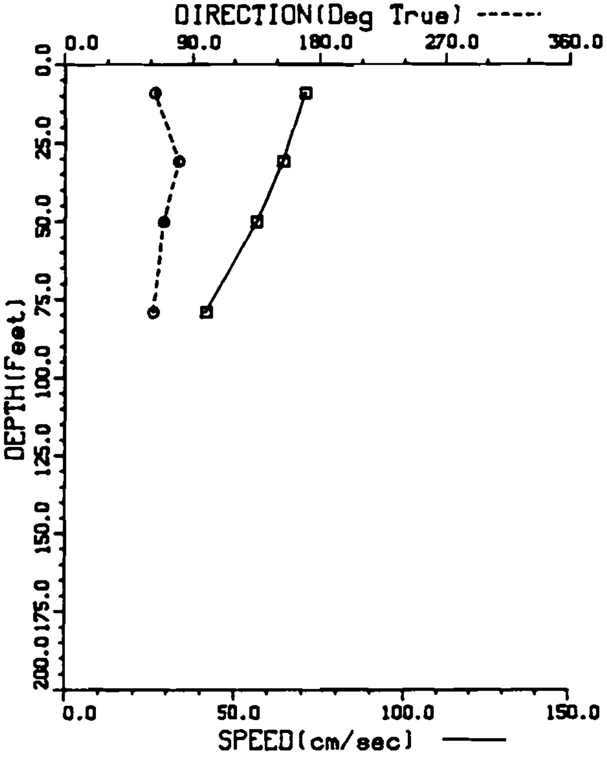

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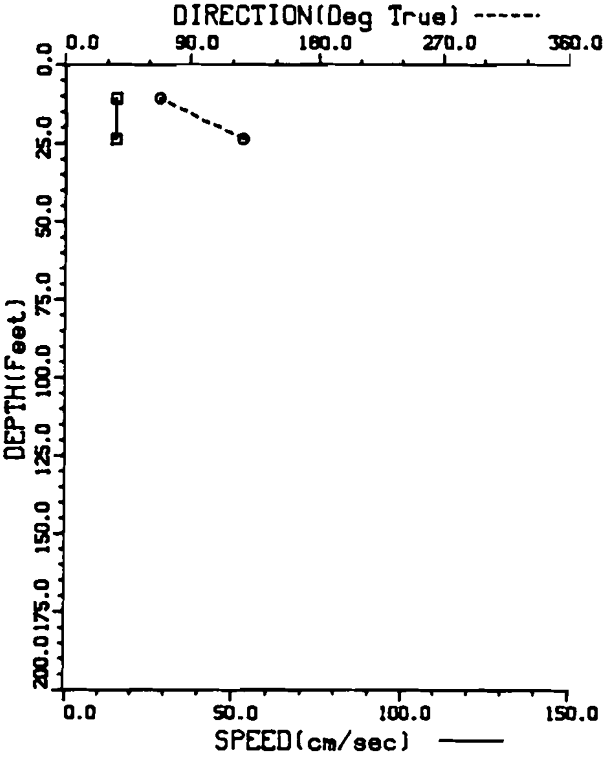

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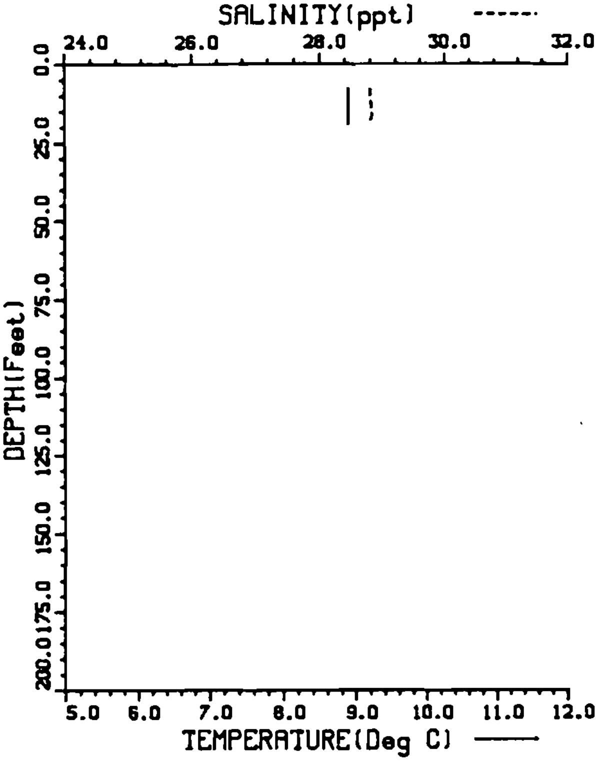

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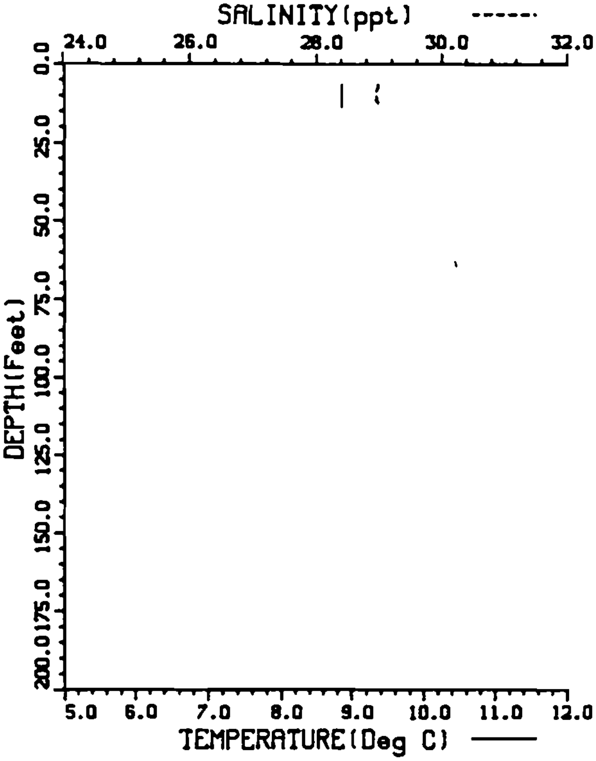
10/06/89 00:53:07



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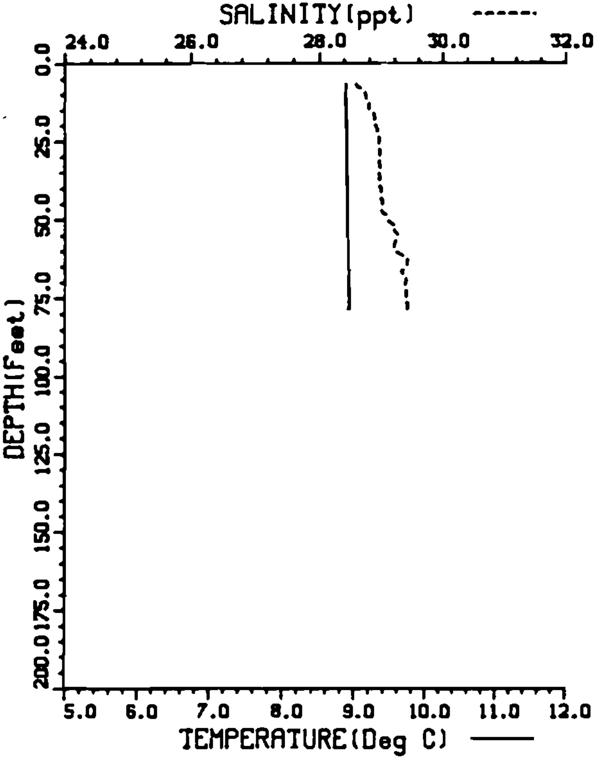
10/06/89 01:12:50



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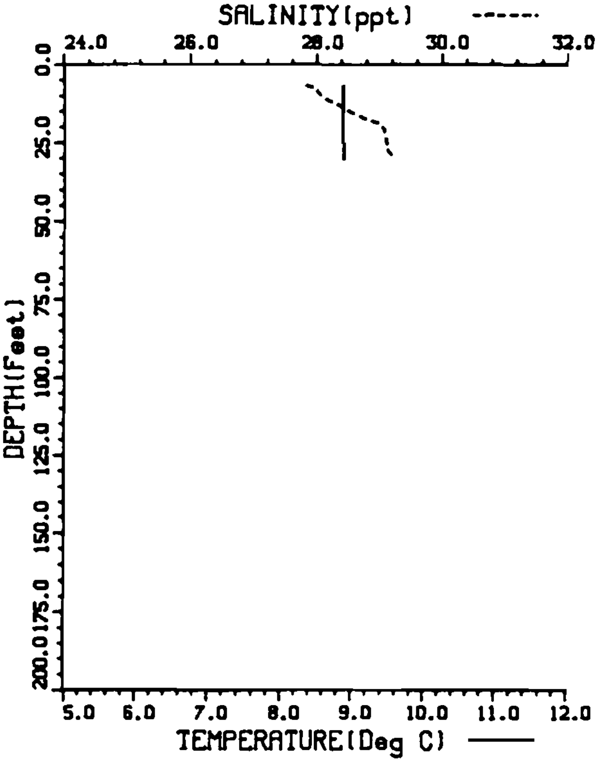

Herendeen Bay

stahb1.105
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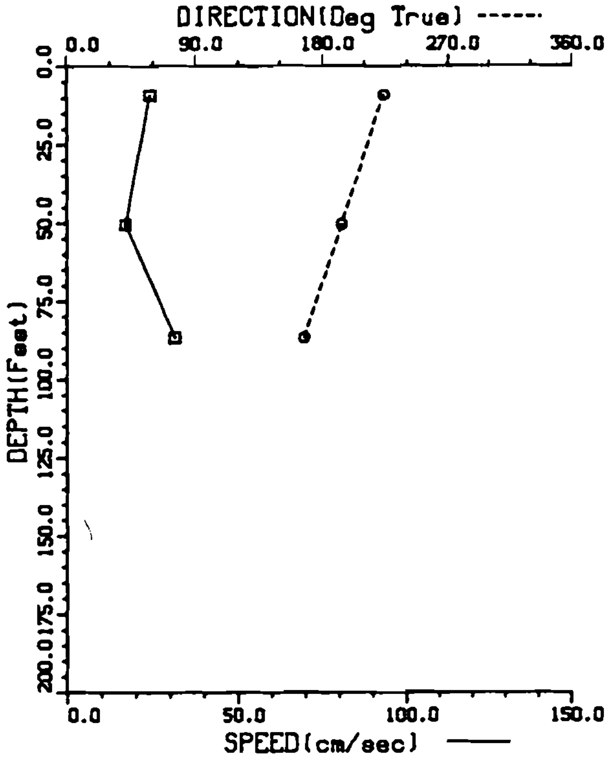

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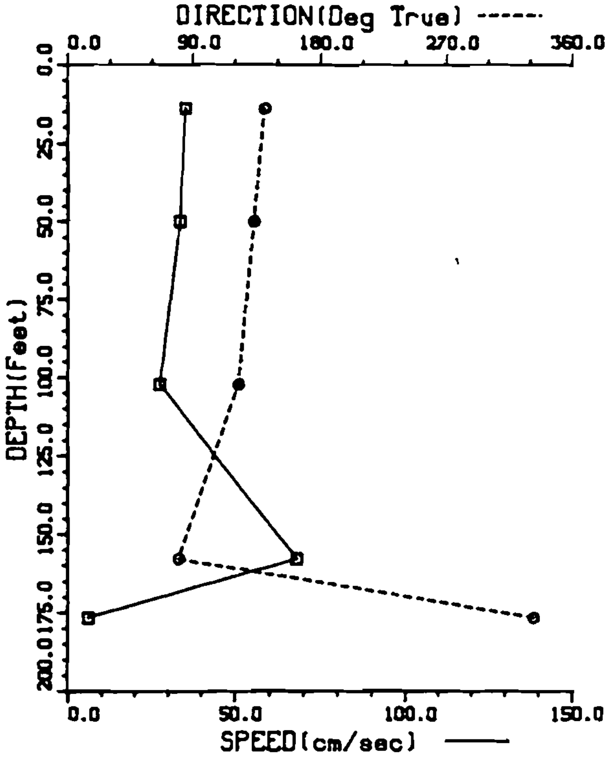
10/05/89 21:11:26



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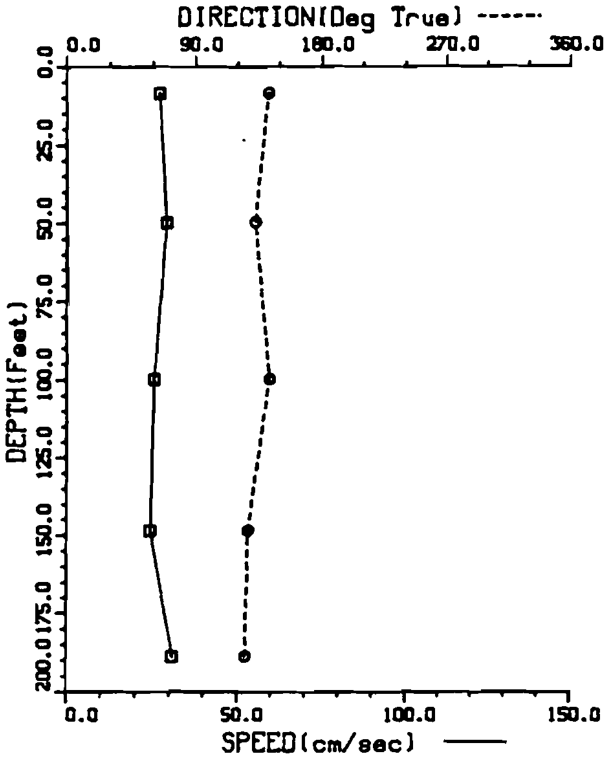

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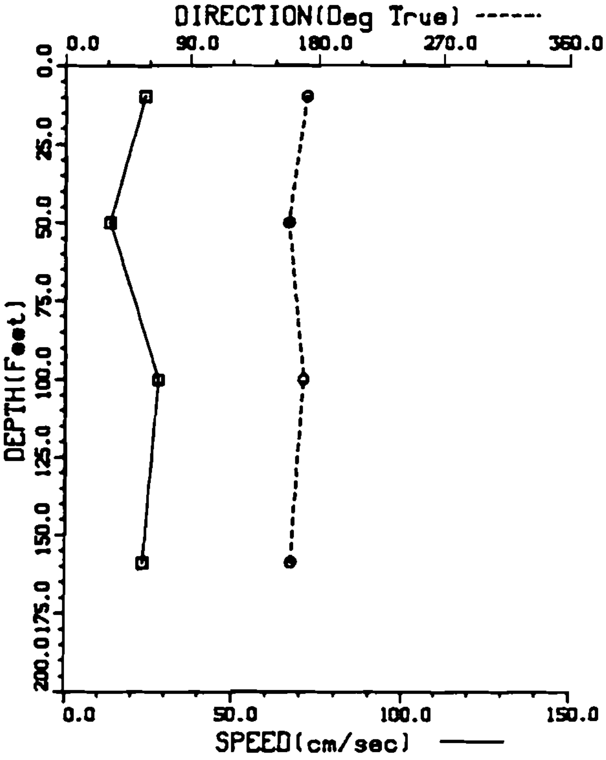

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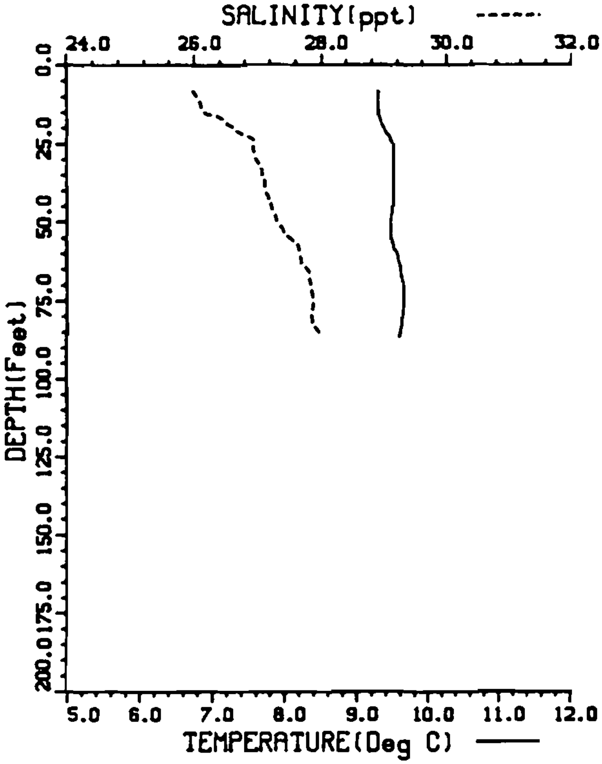

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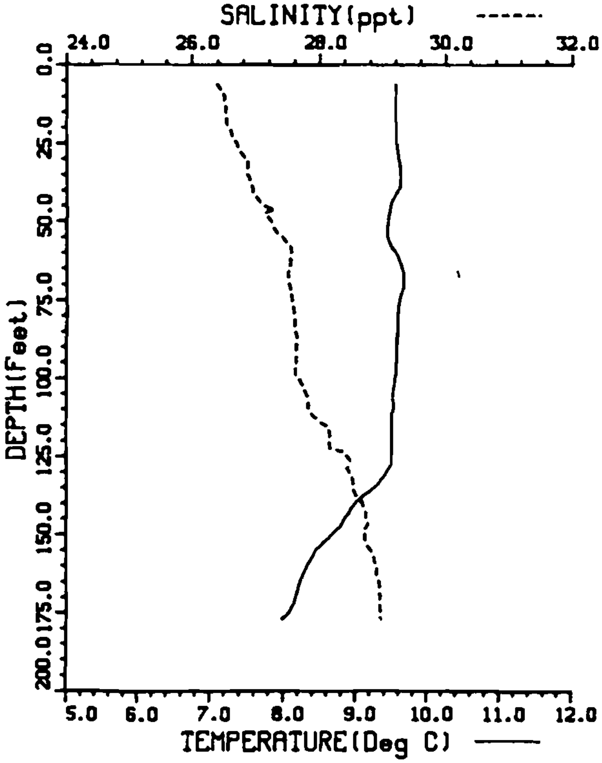

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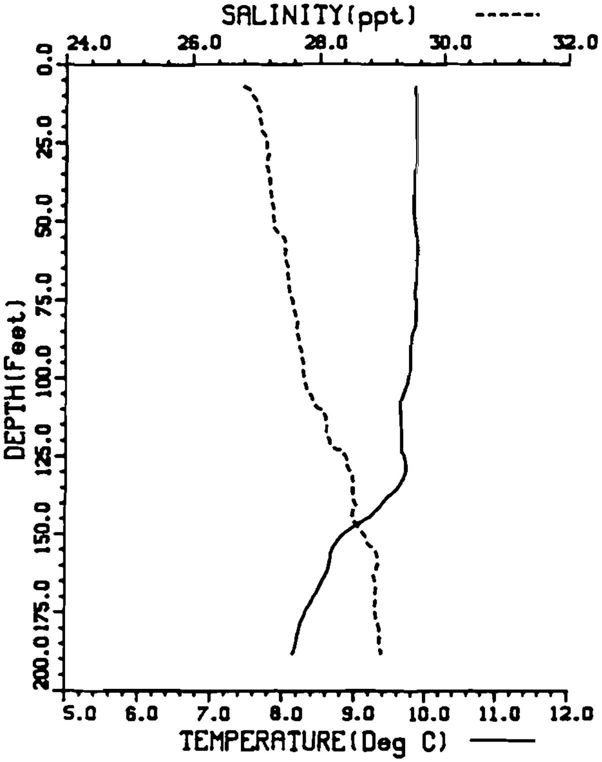

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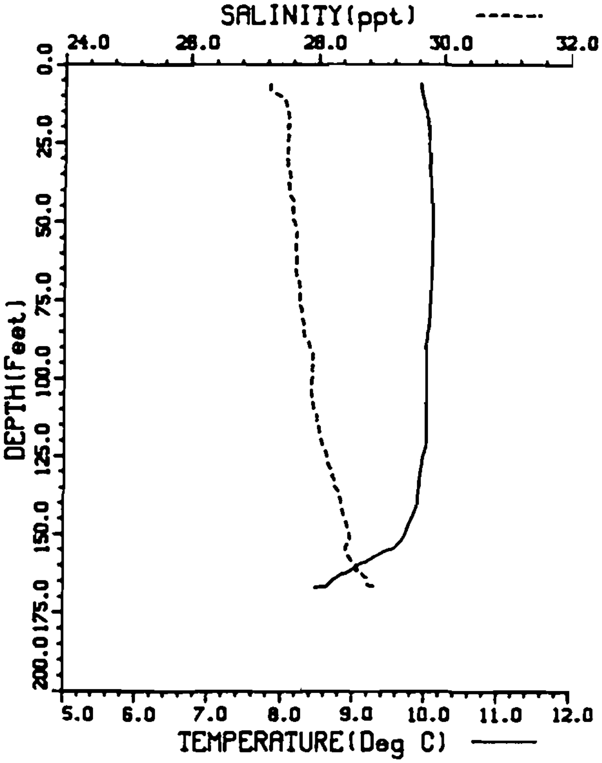
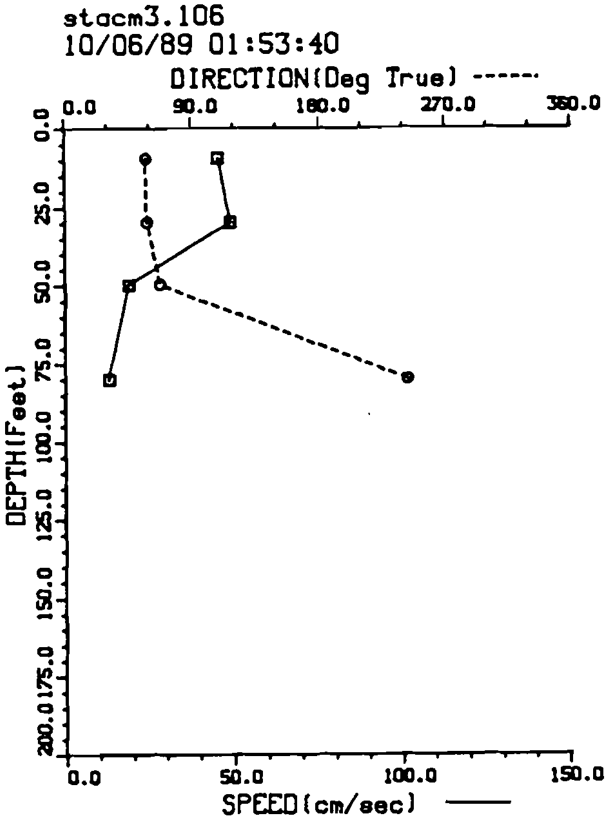


Point Divide



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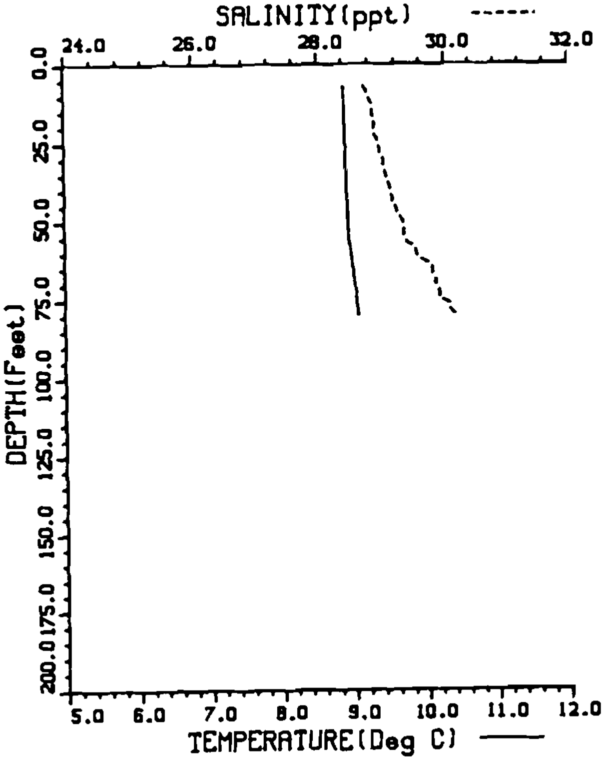
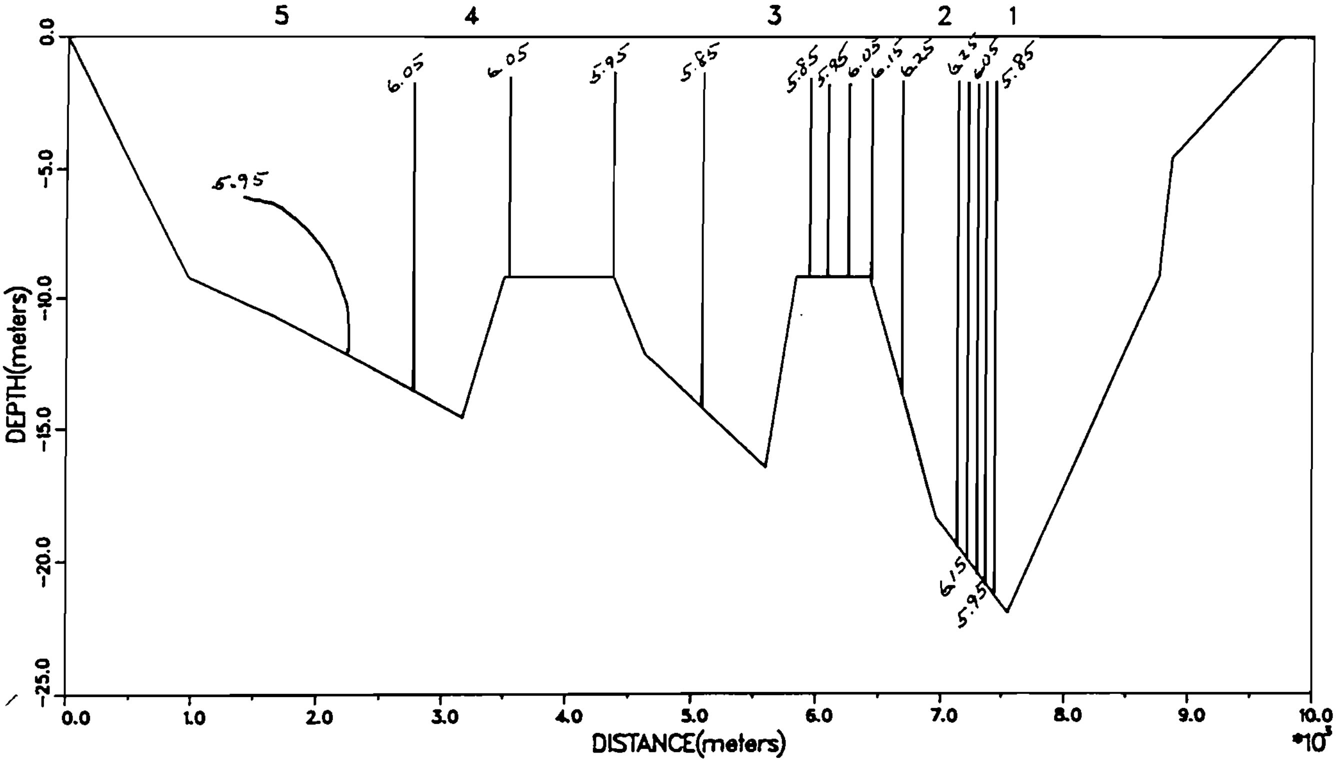


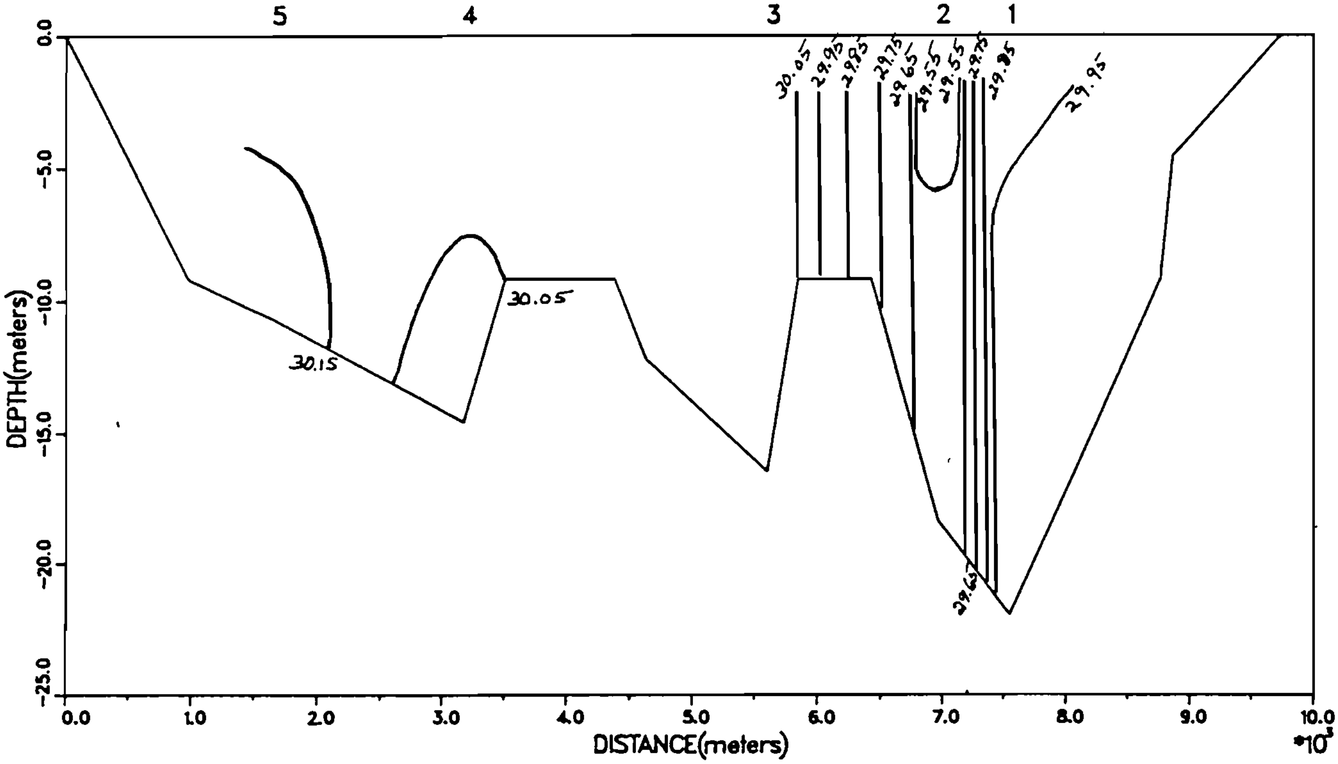
APPENDIX F

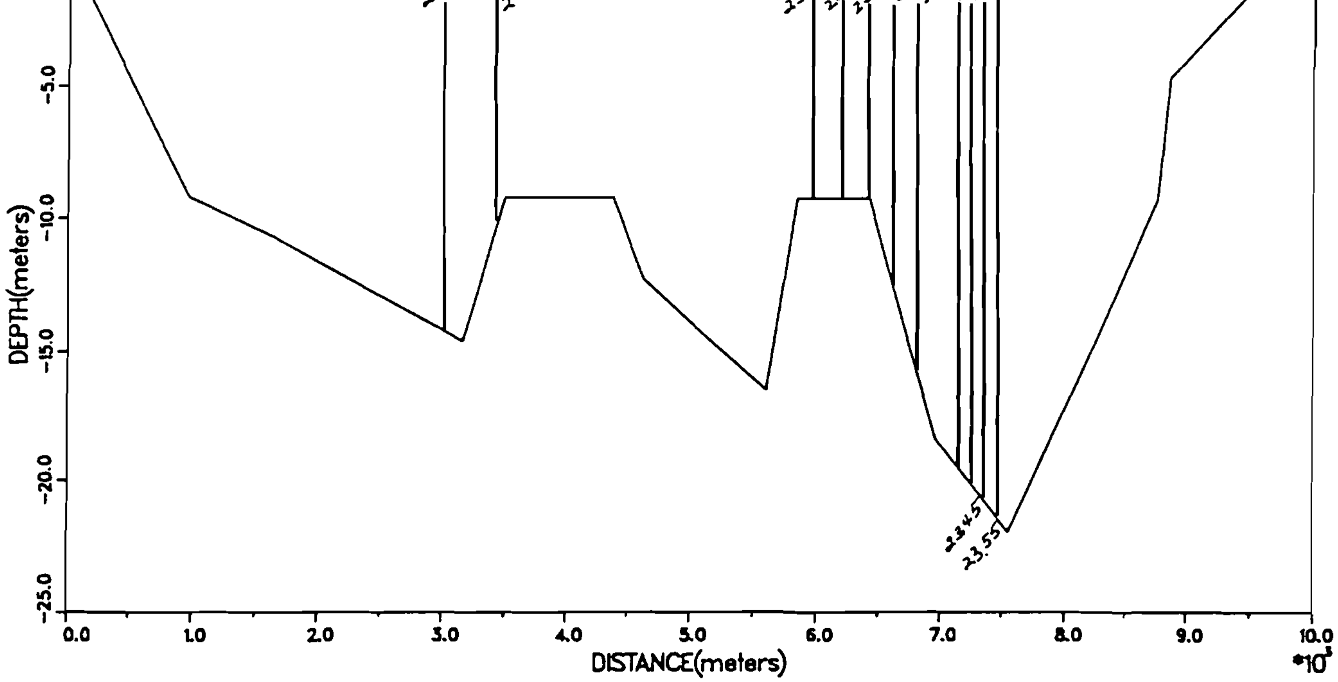
PORT MOLLER
1989 WATER PROPERTY SECTIONS

The scales between sections from different locations differs because of the disparity in channel depths. The contours for all the sections, except the October Hague Channel transects, have the following property intervals: temperature .1°C, salinity .1 psu, density .1, velocity 25 cm/sec. The October Hague Channel section, owing to its large range in water characteristics in a narrow channel, is contoured in increments of .1°C for temperature, .25 psu for salinity, .25 for density, and 25 cm/sec for velocity.

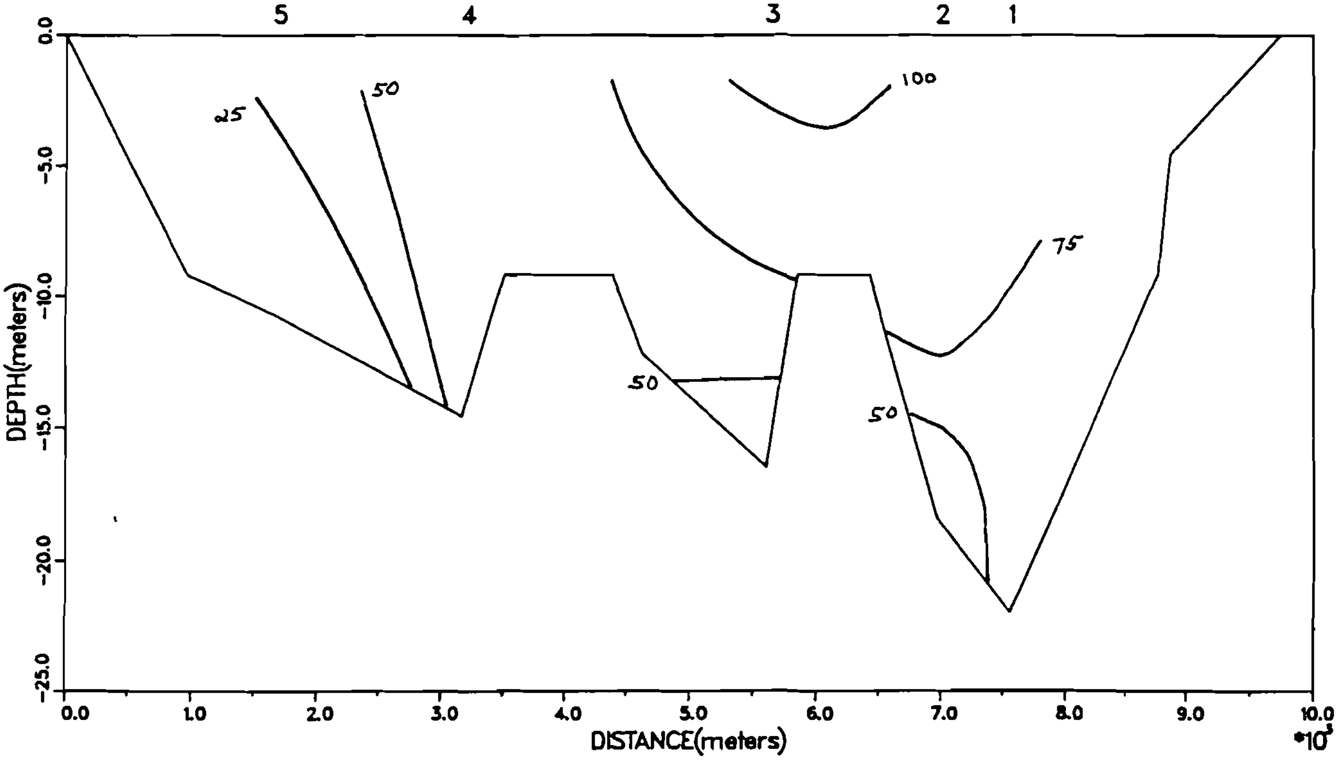


Salinity (psu)

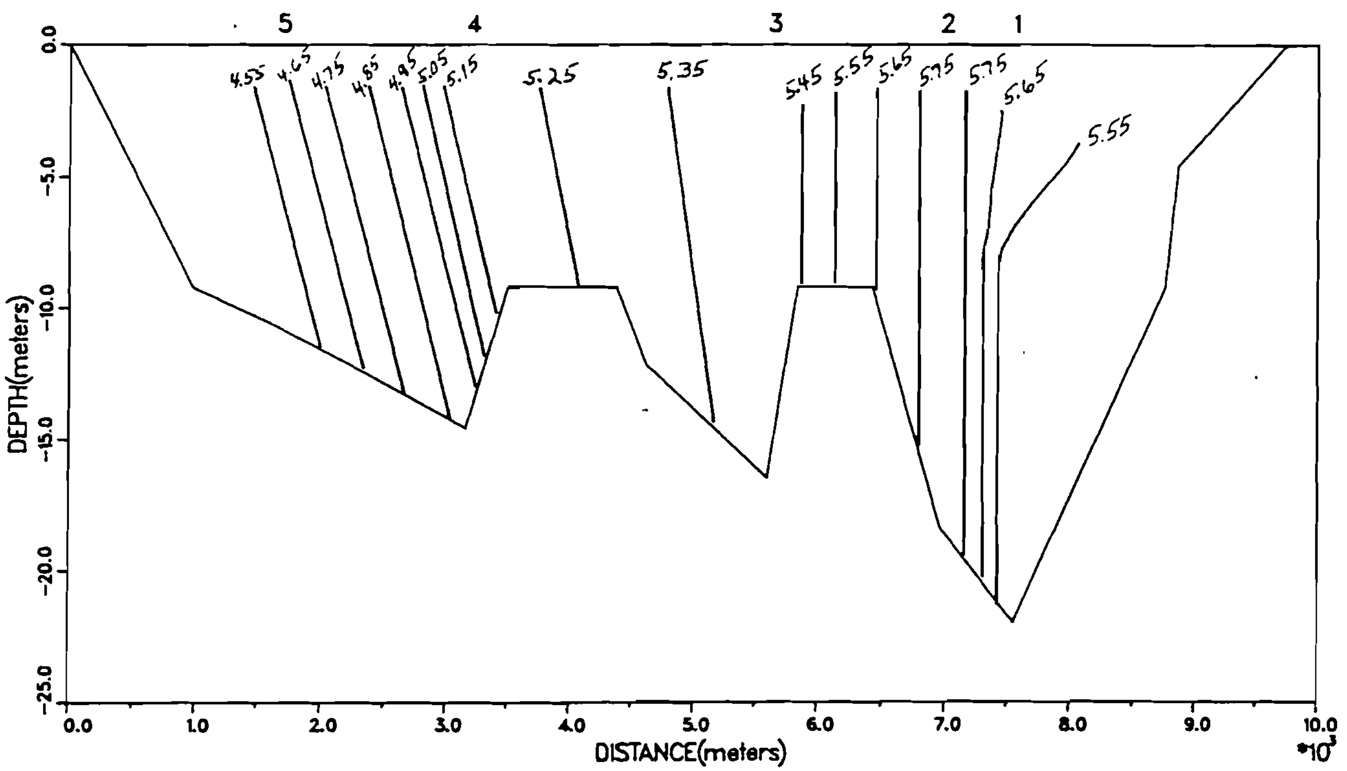




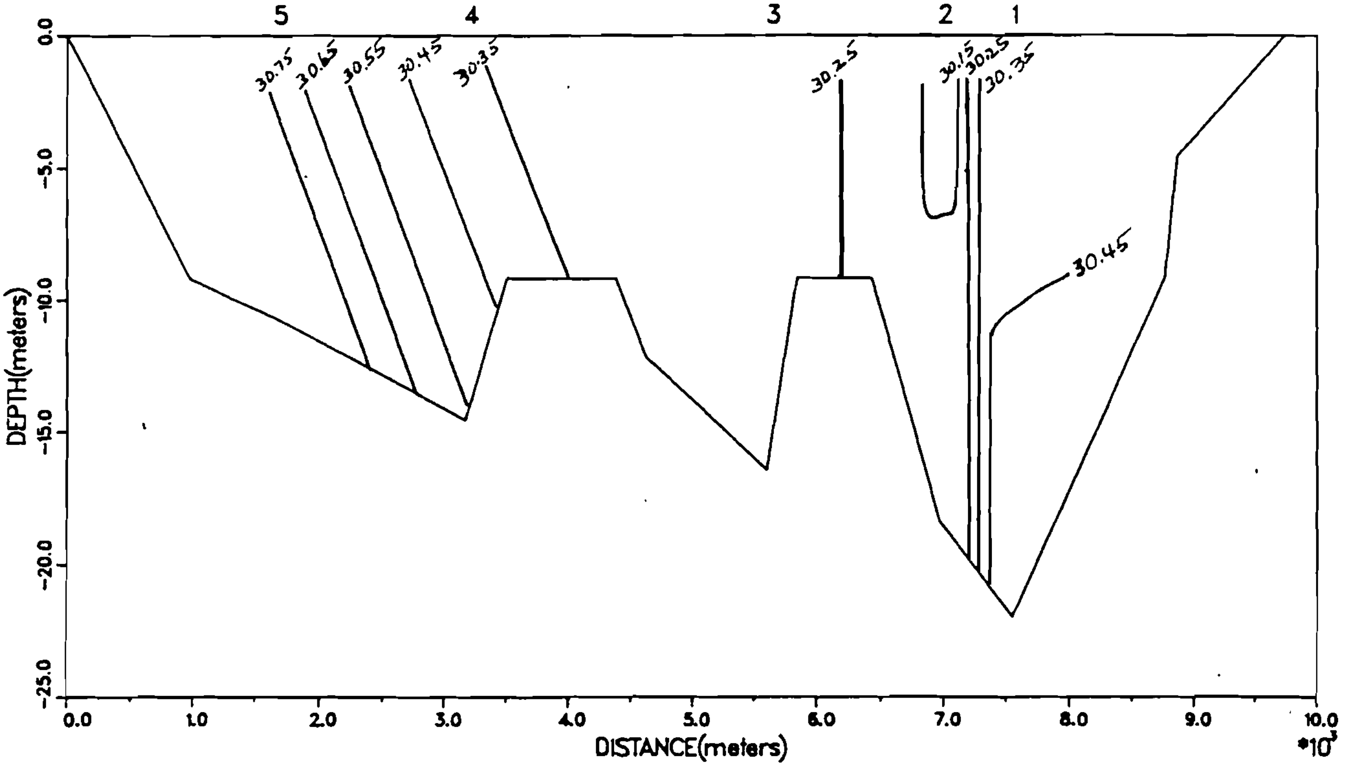
Along channel flow (cm/sec)



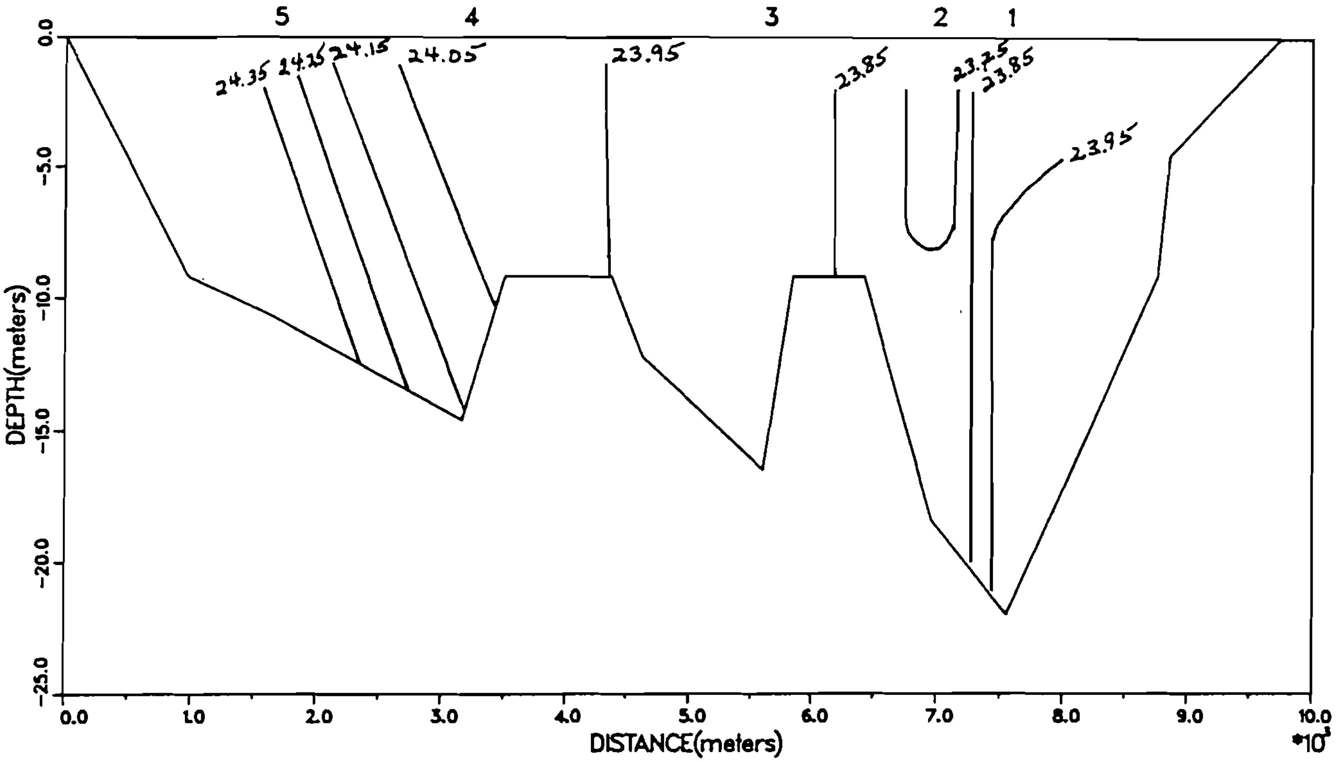
Temperature (deg C)



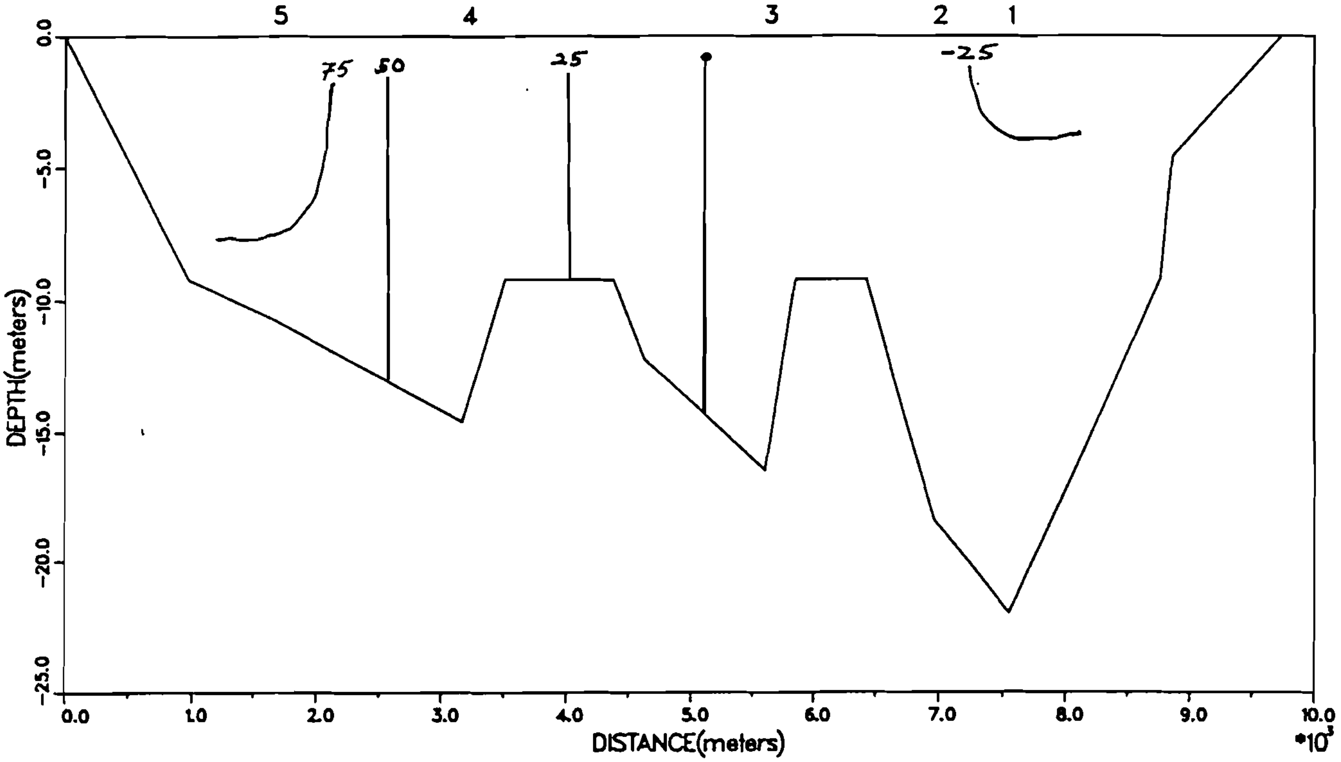
Salinity (psu)



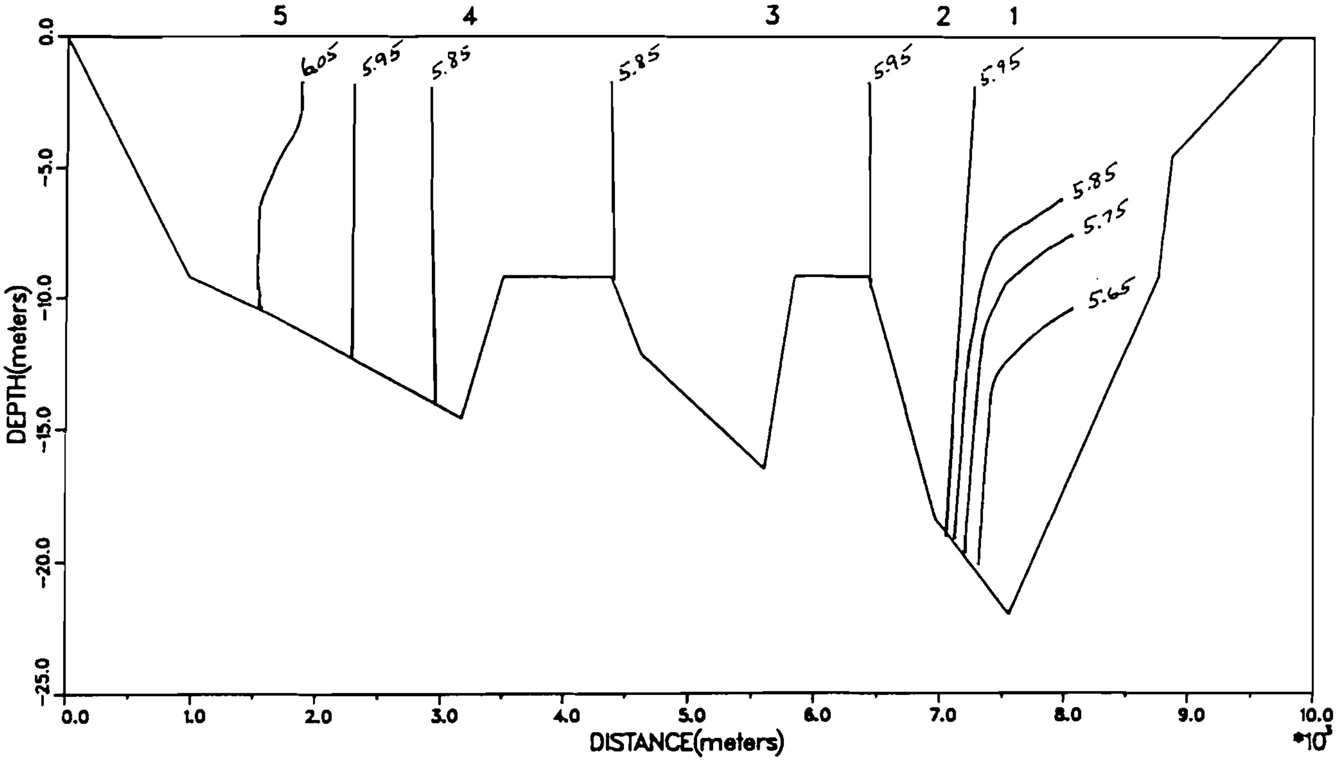
Sigma T



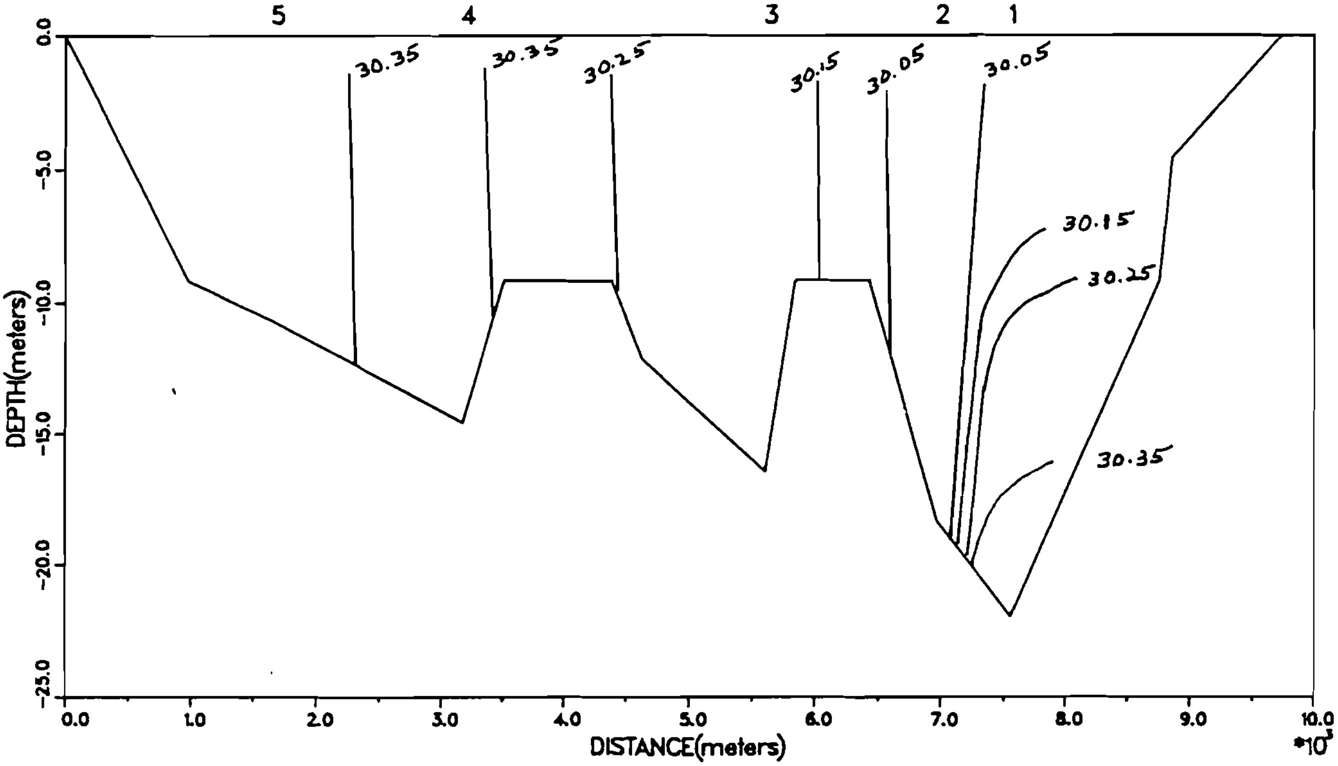
Along channel flow (cm/sec)

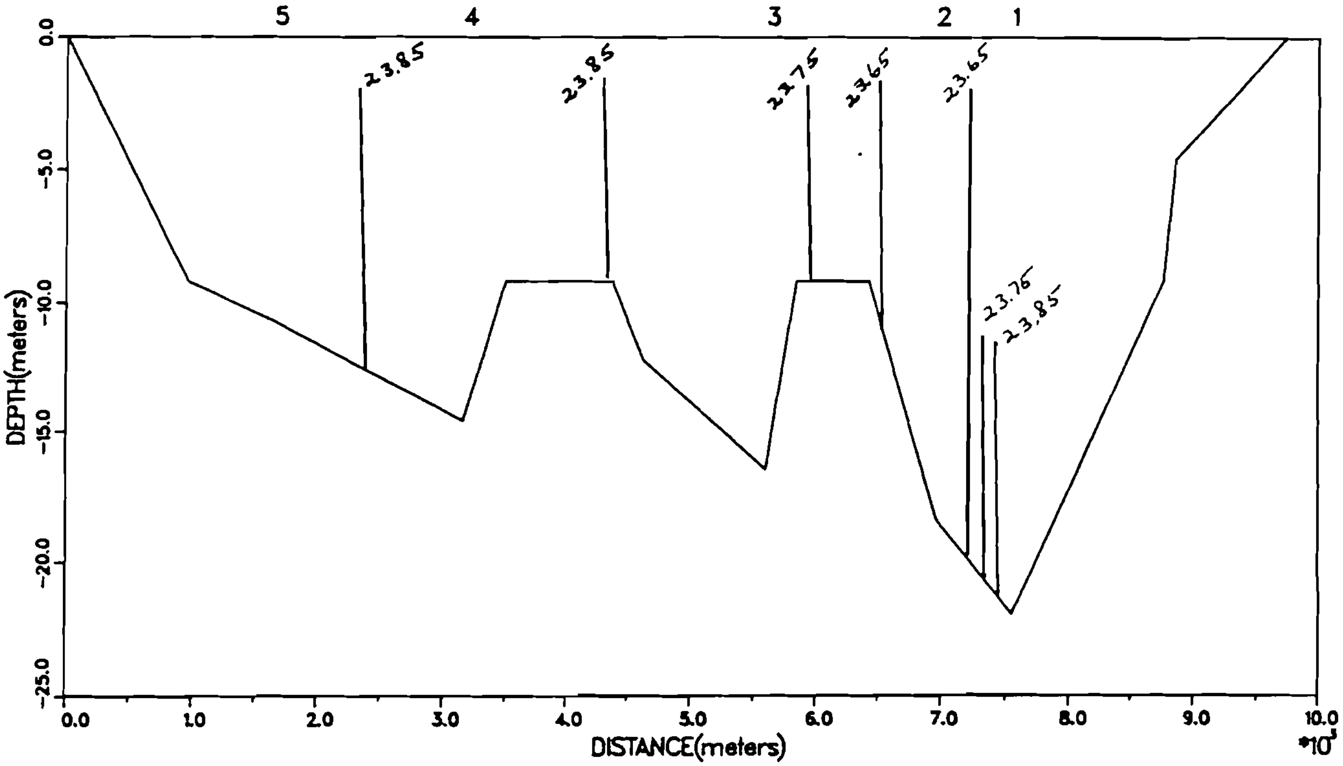


Temperature (deg C)

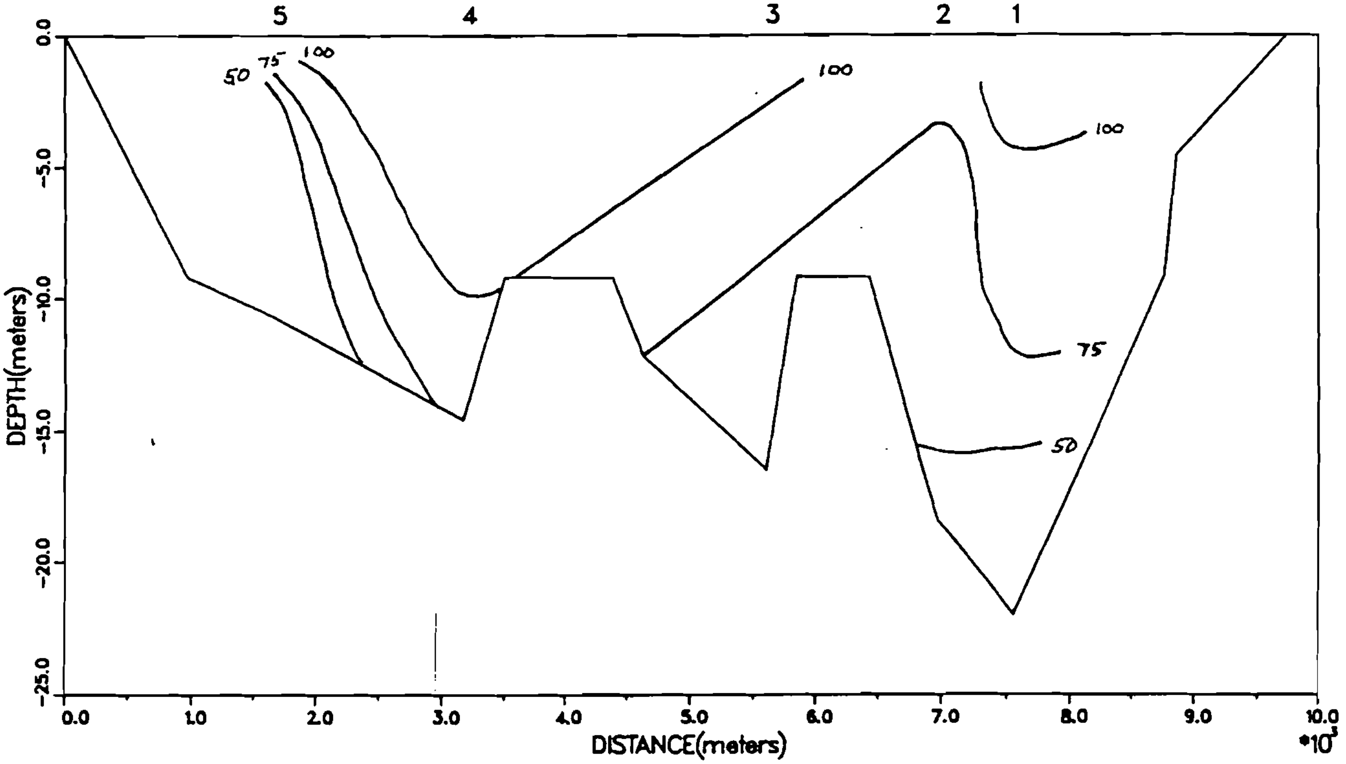


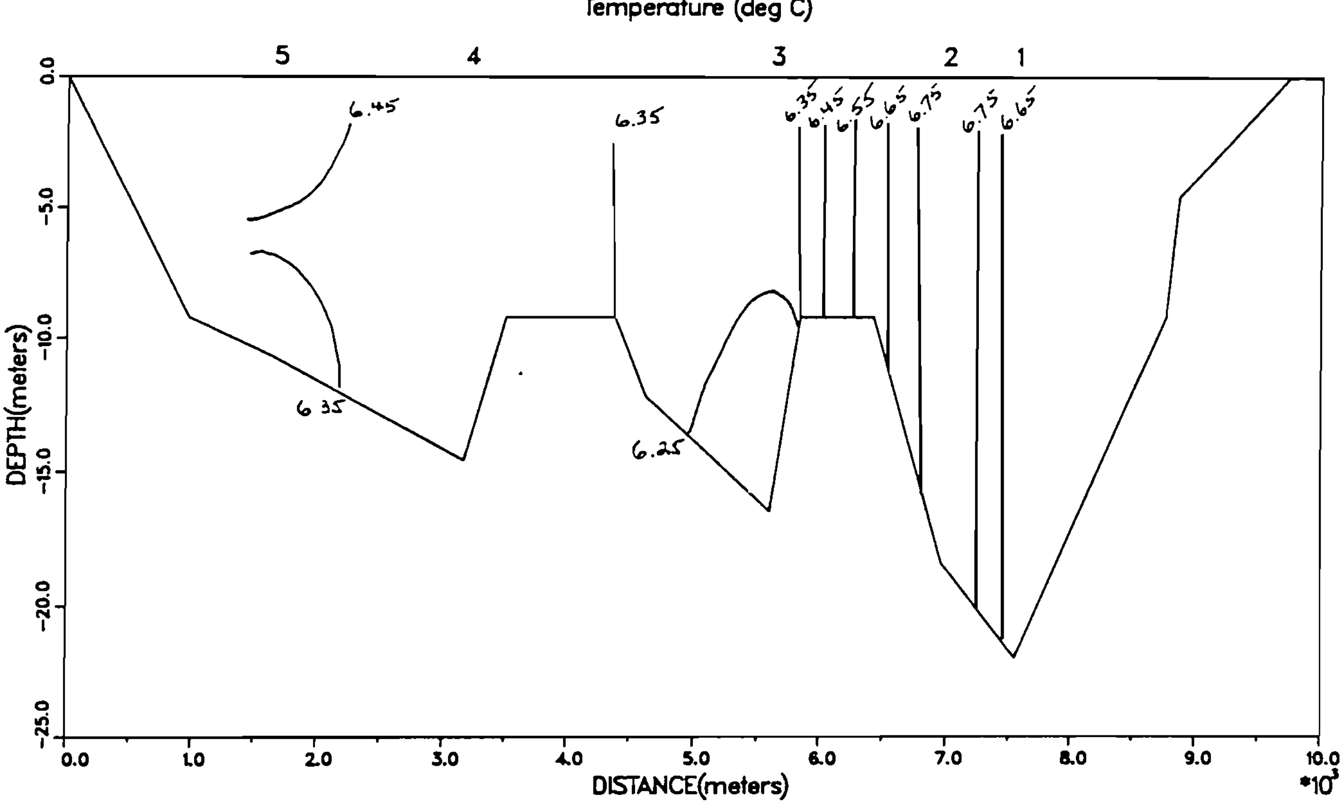
Salinity (psu)

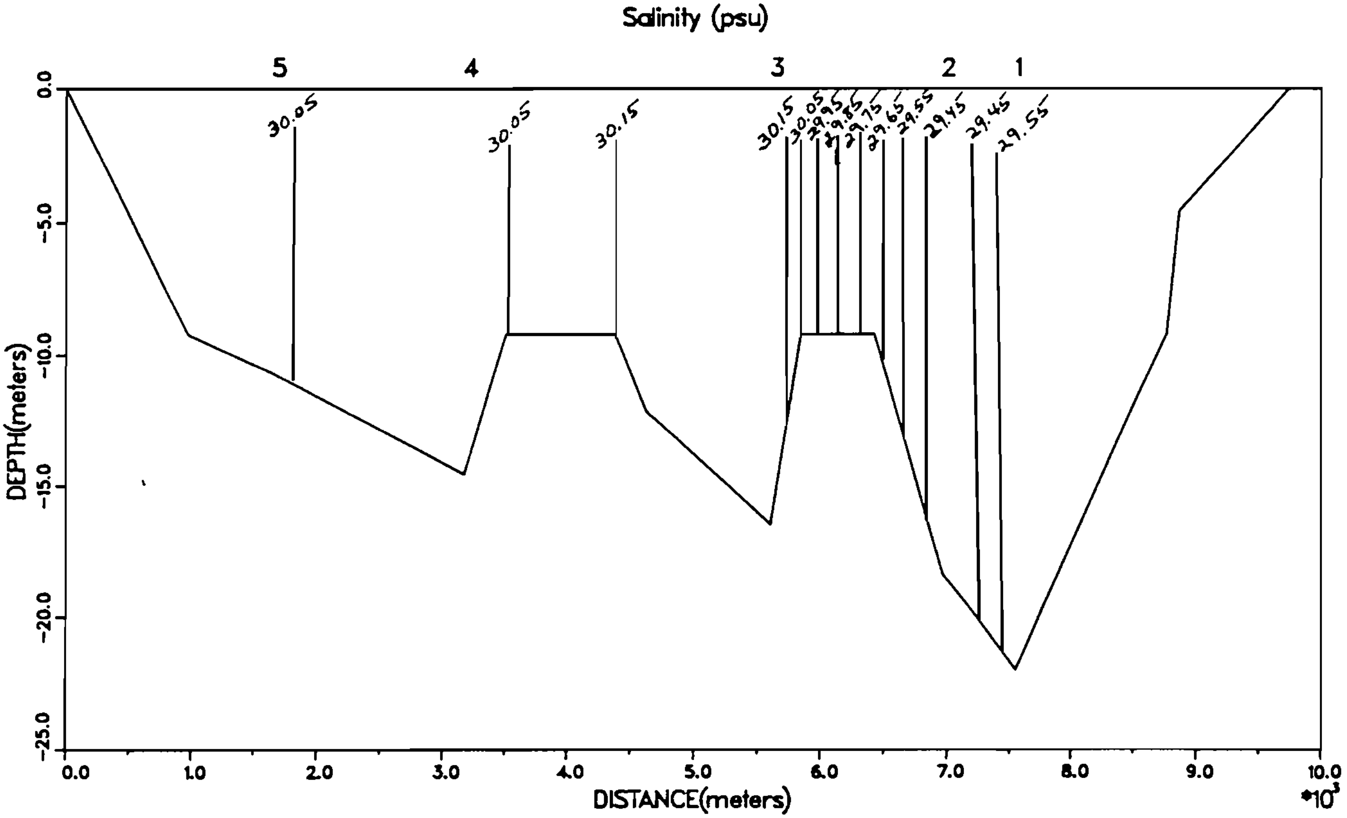


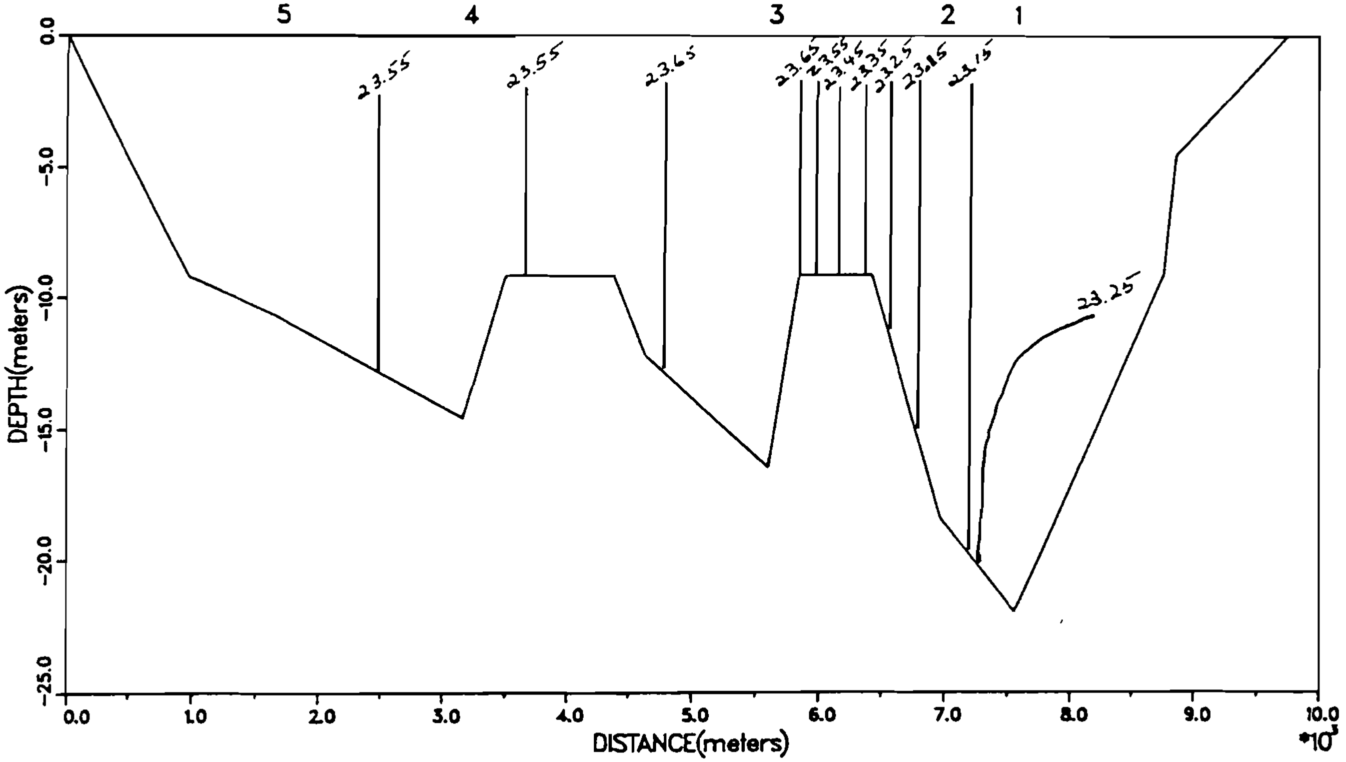


Along channel flow (cm/sec)

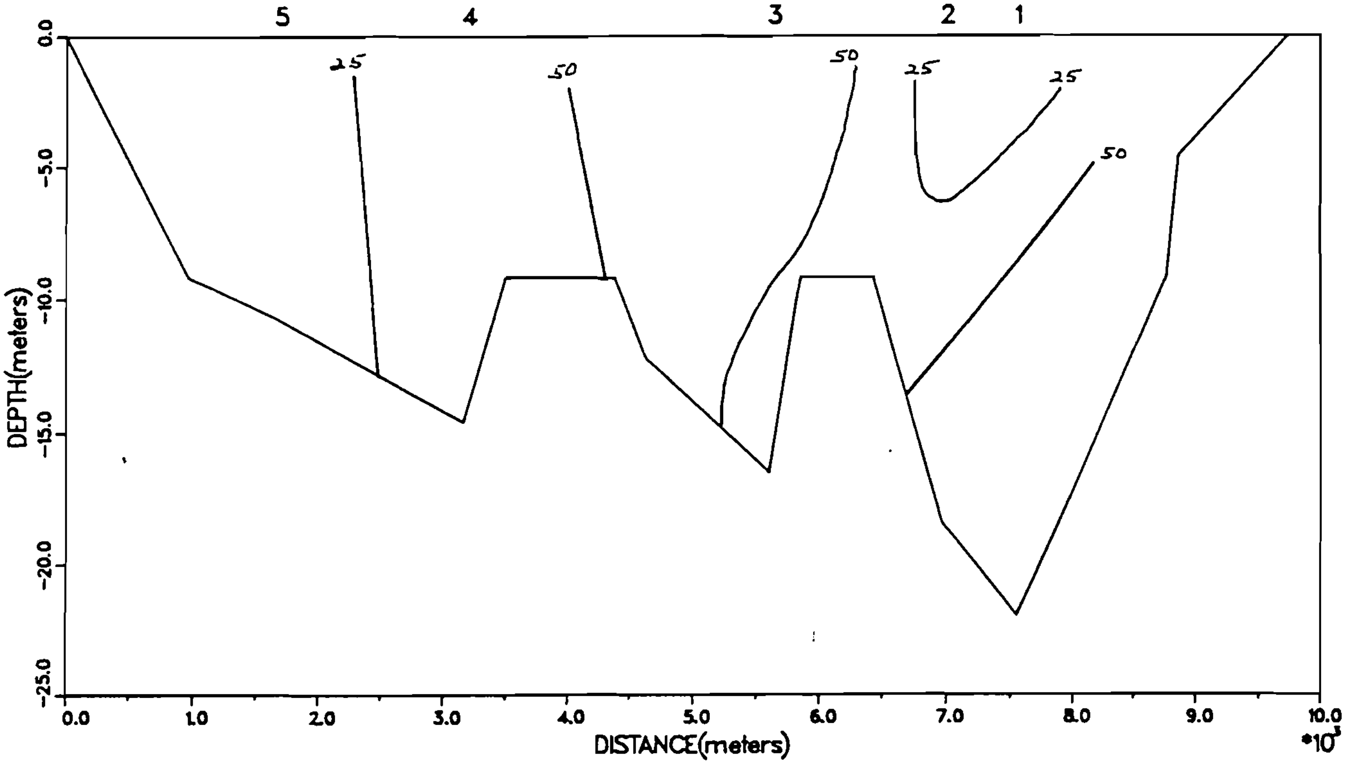



Temperature (deg C)


Salinity (psu)

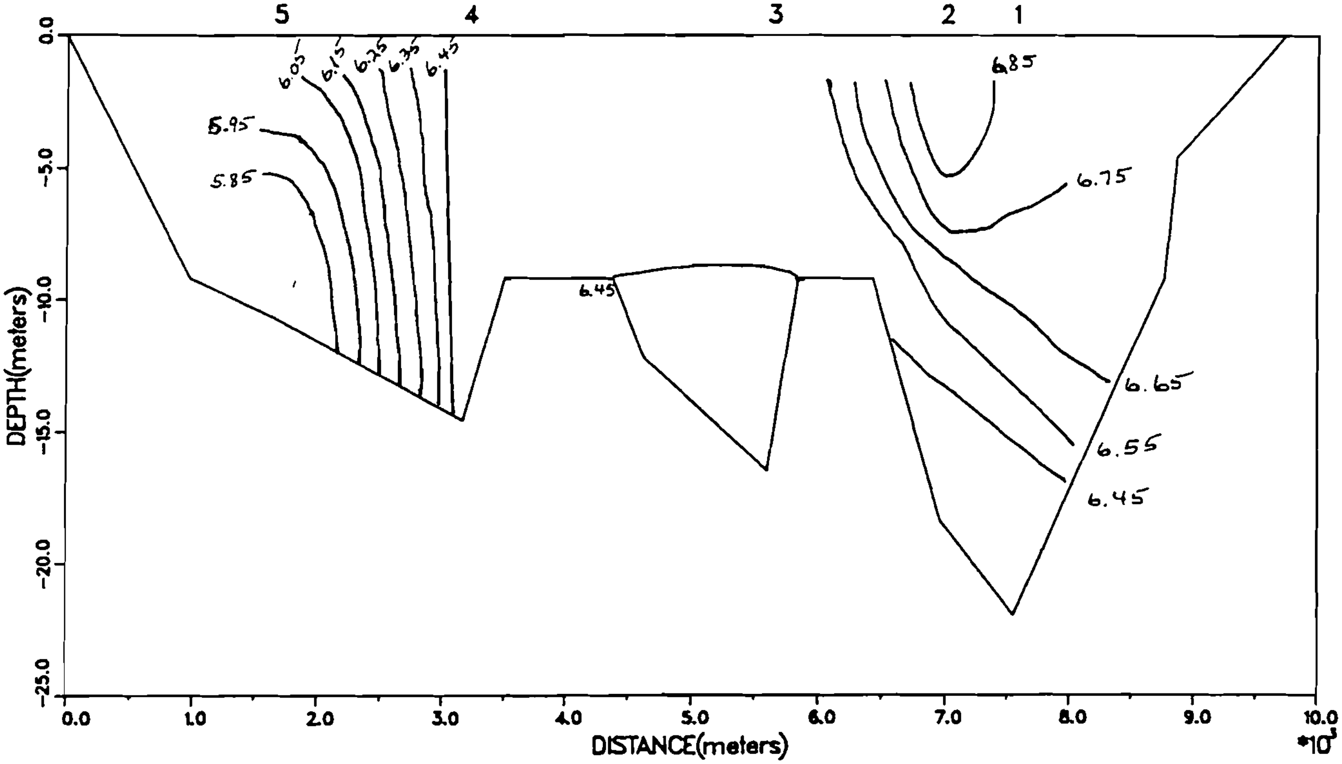


Along channel flow (cm/sec)

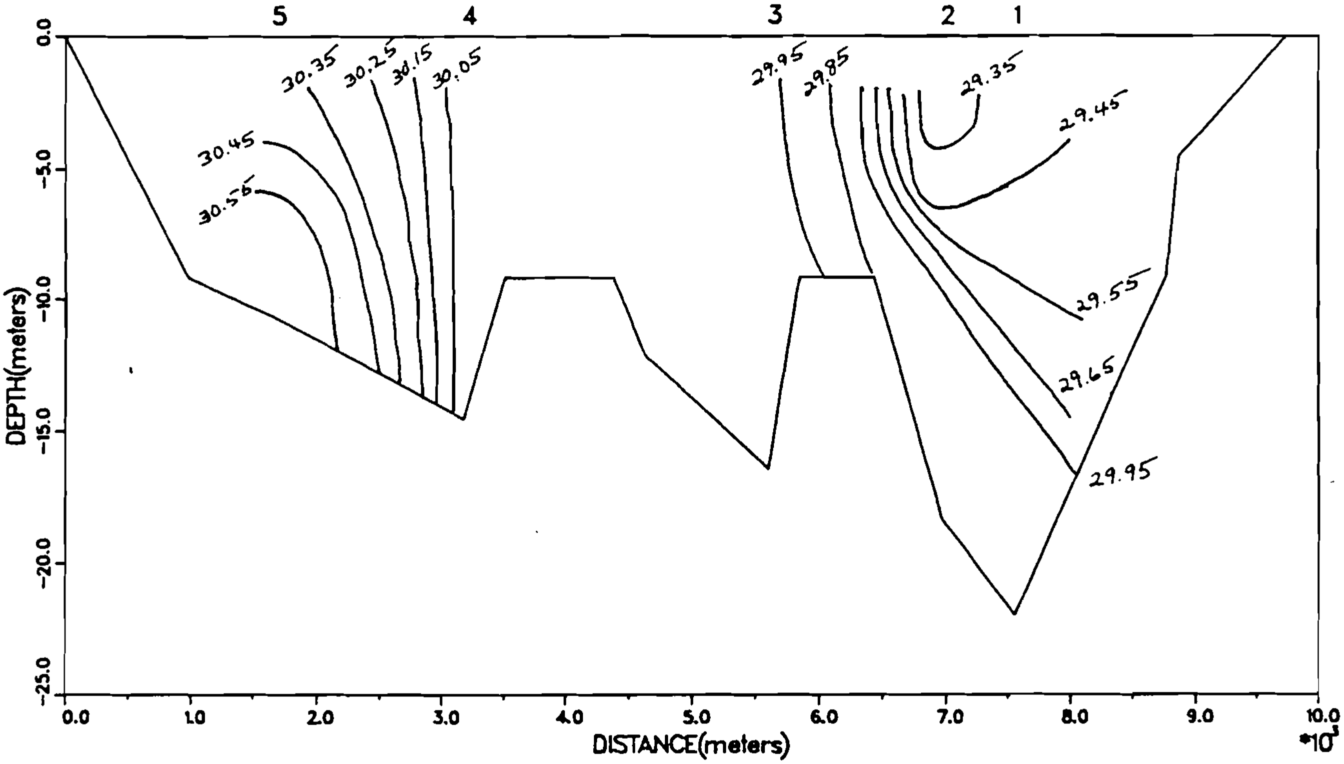


NO. 4

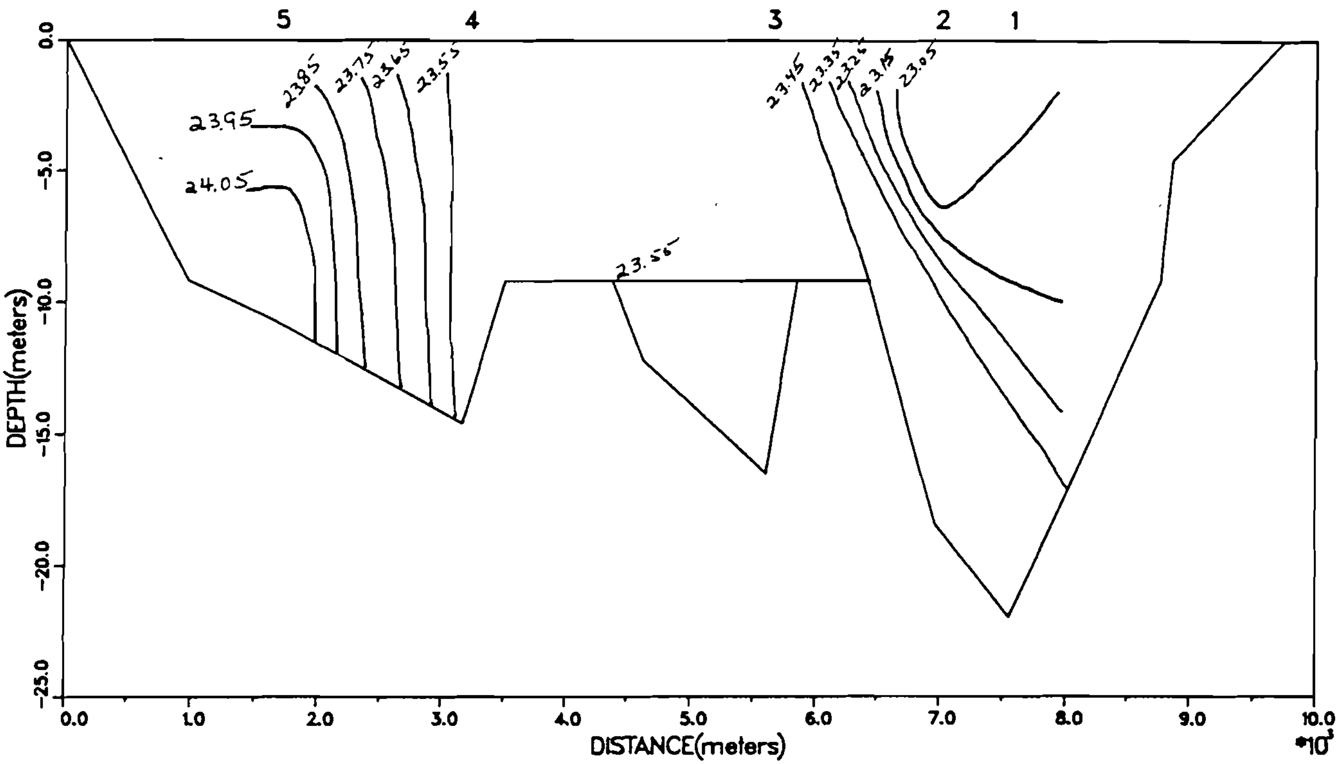
Temperature (deg C)



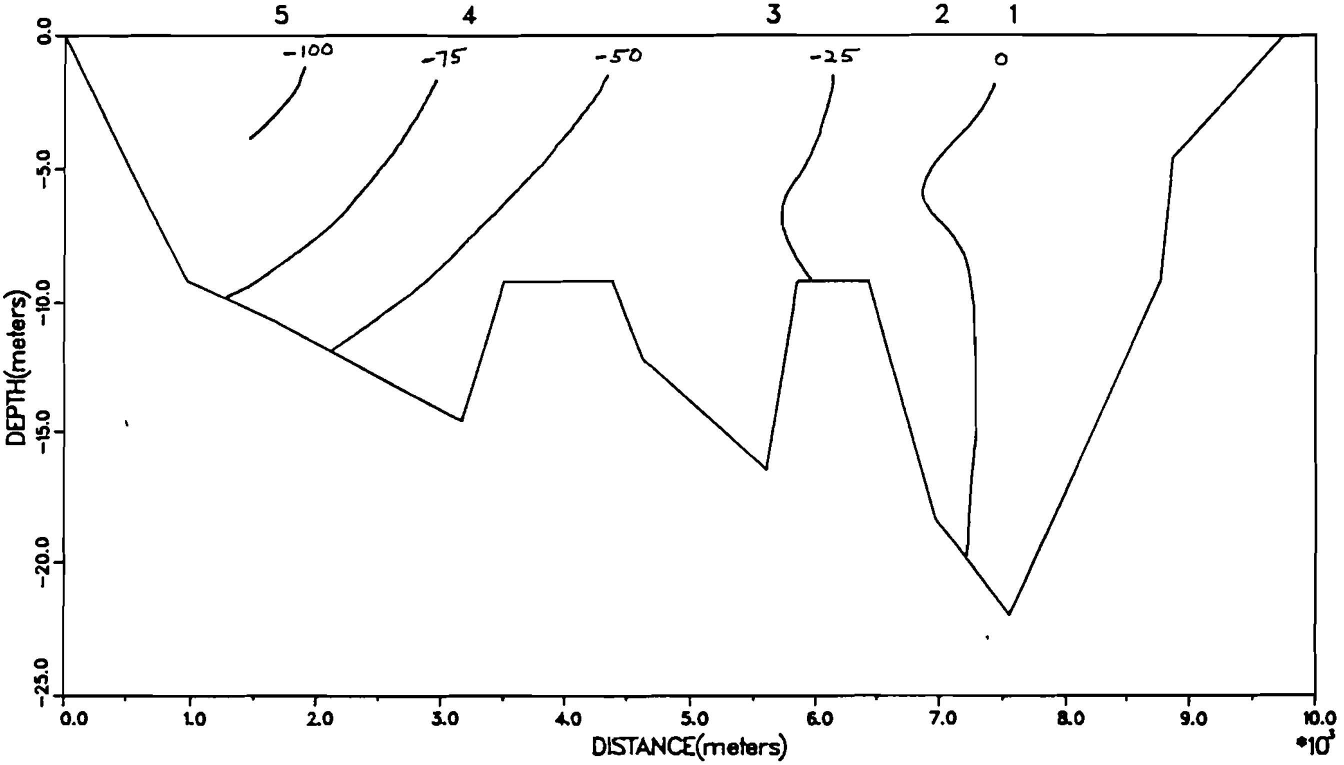
Salinity (psu)

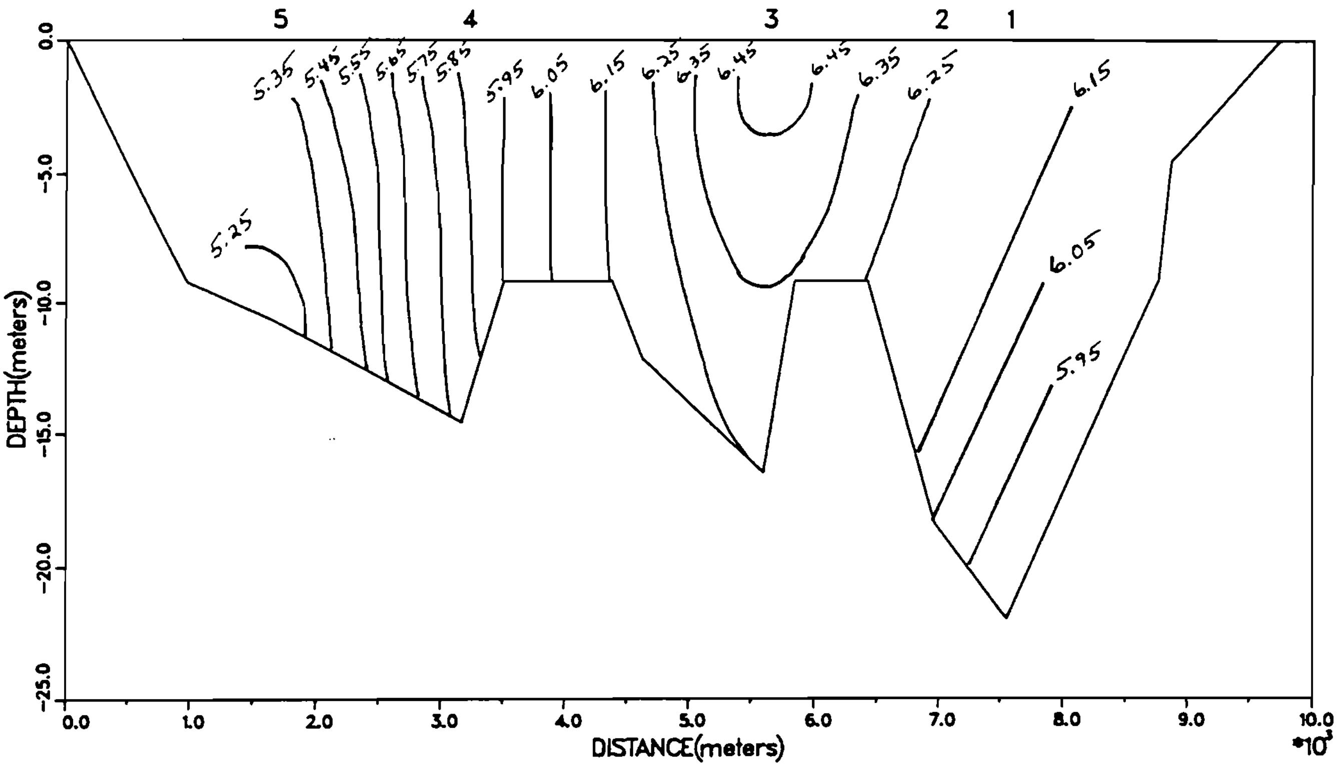


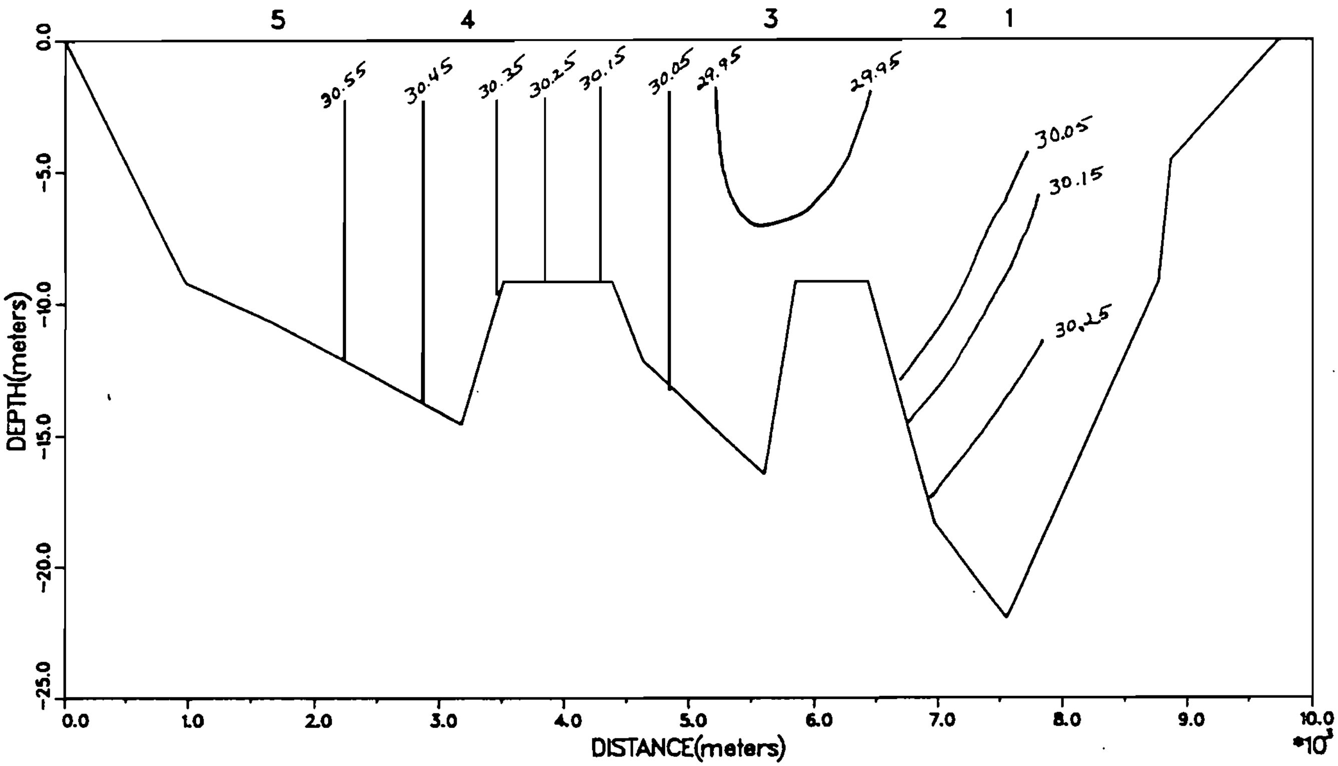
Sigma T

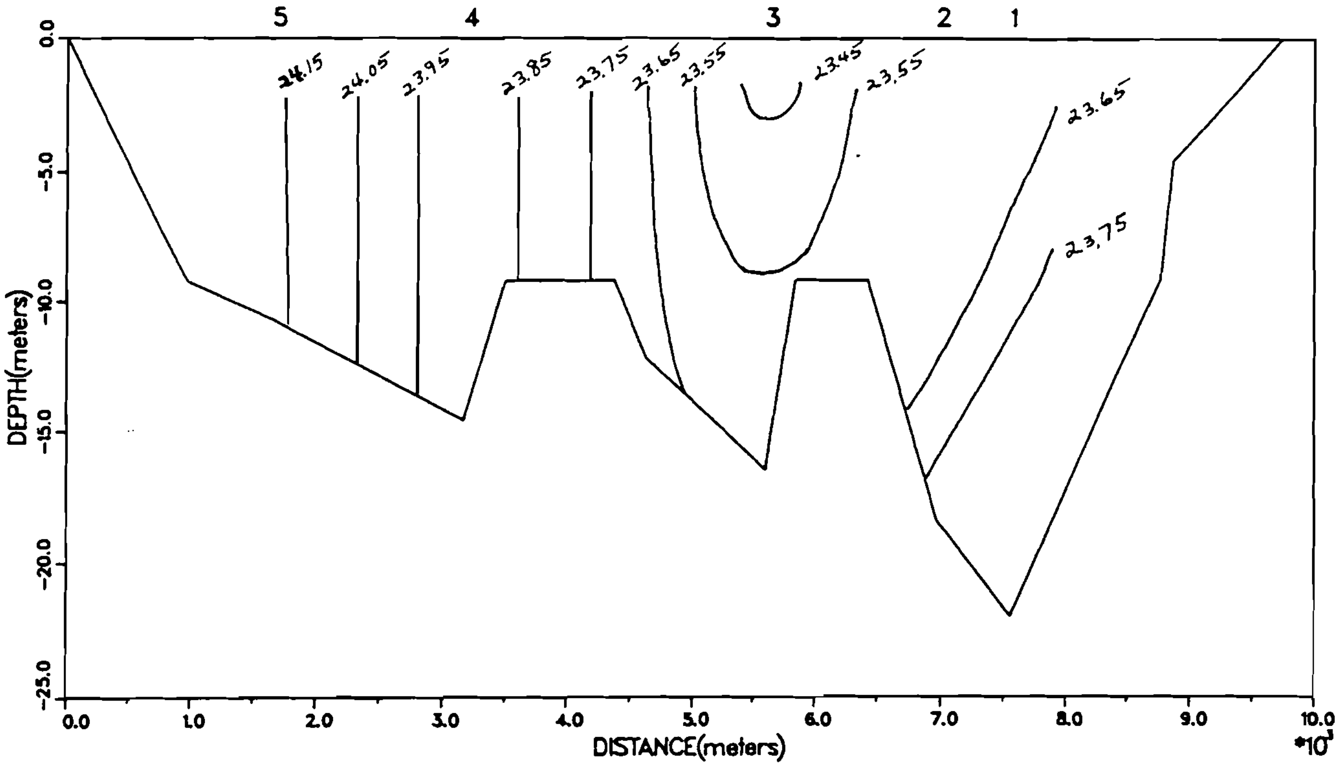


Along channel flow (cm/sec)

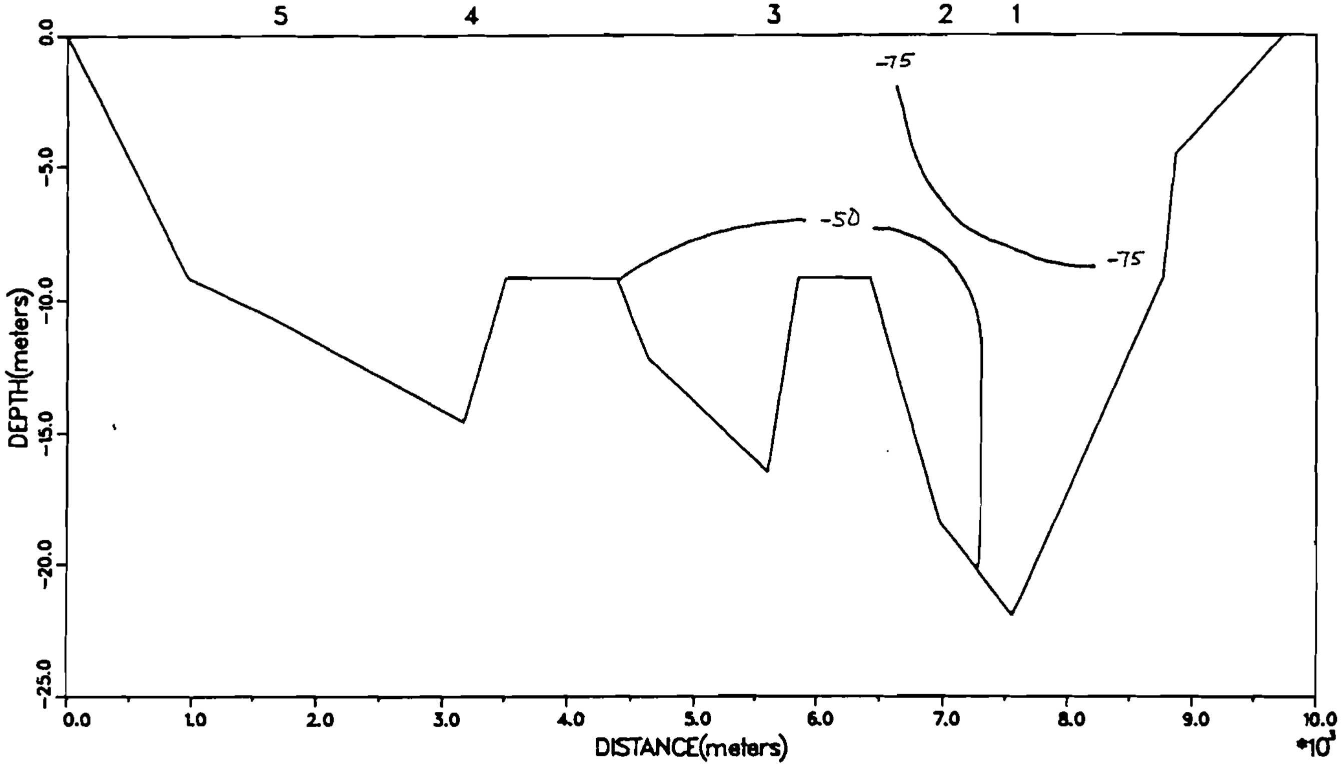



Temperature (deg C)


Salinity (psu)

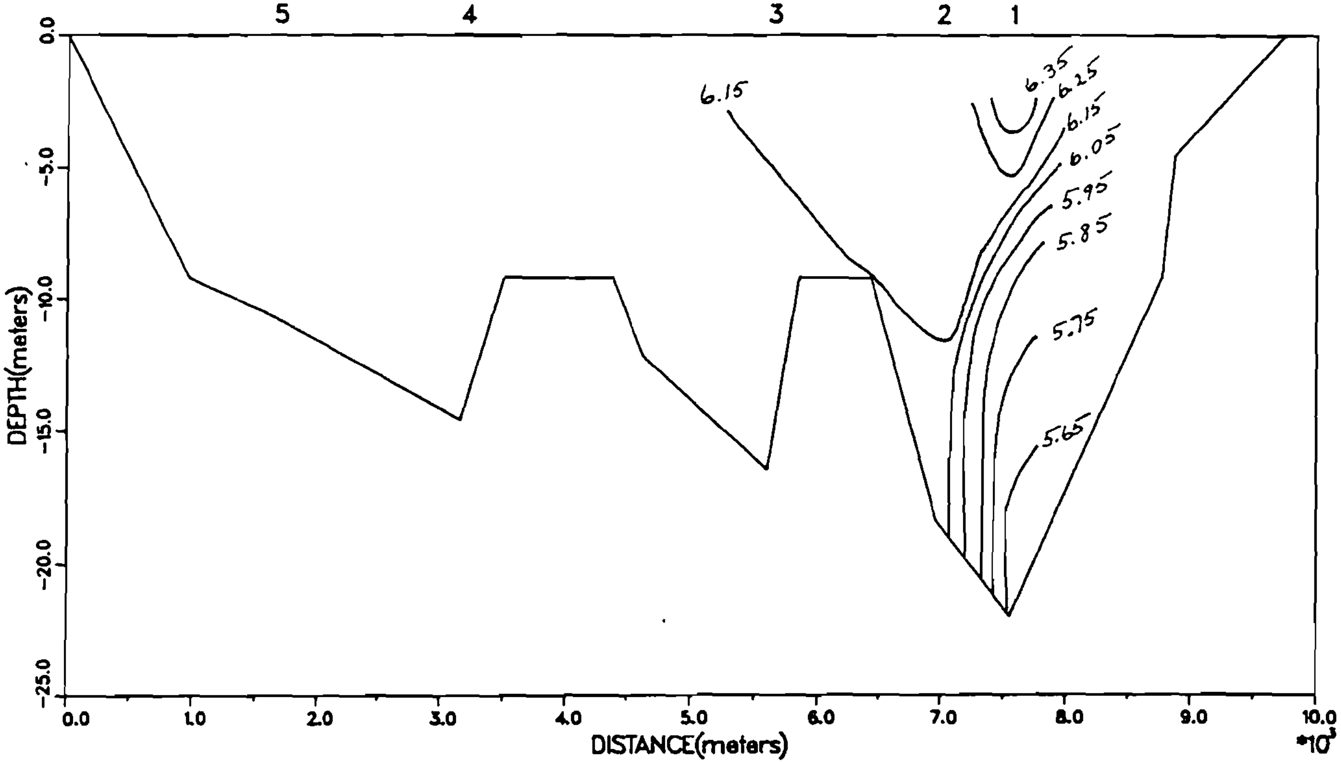


Sigma T

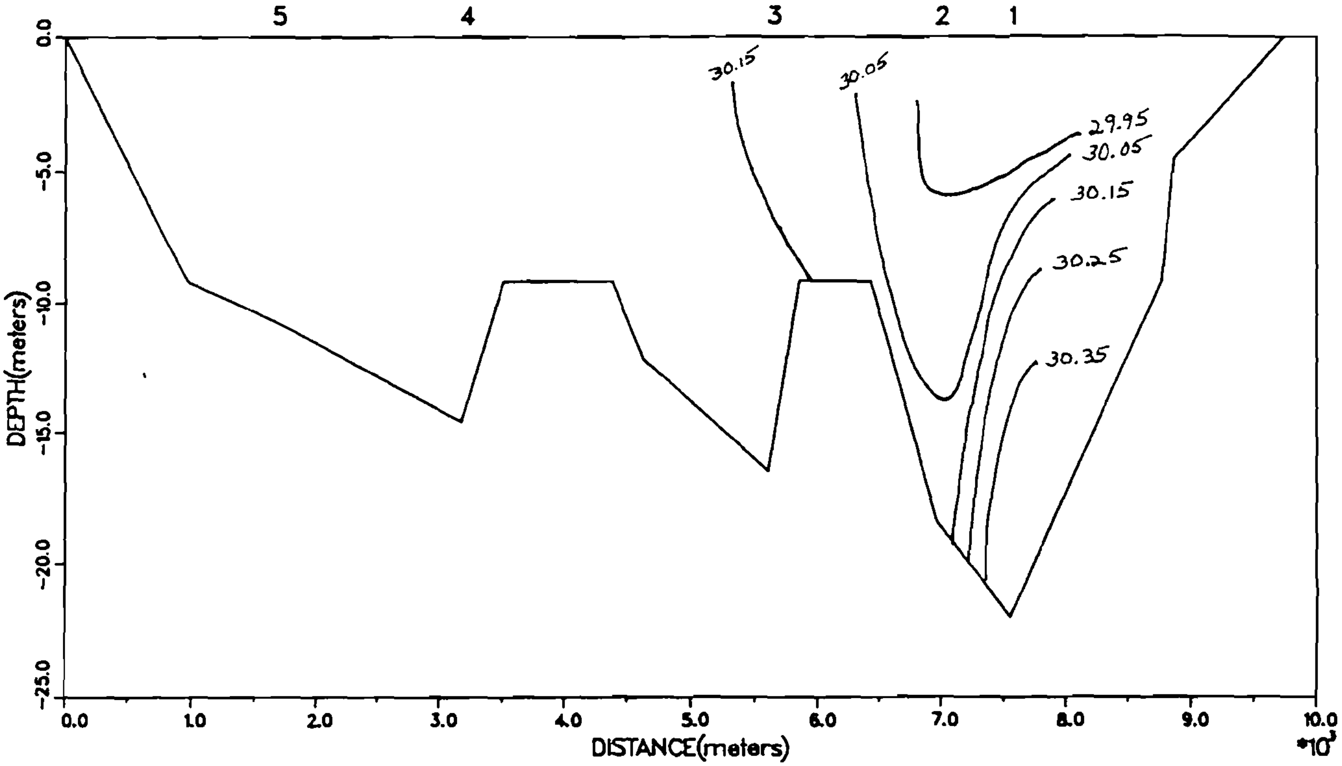


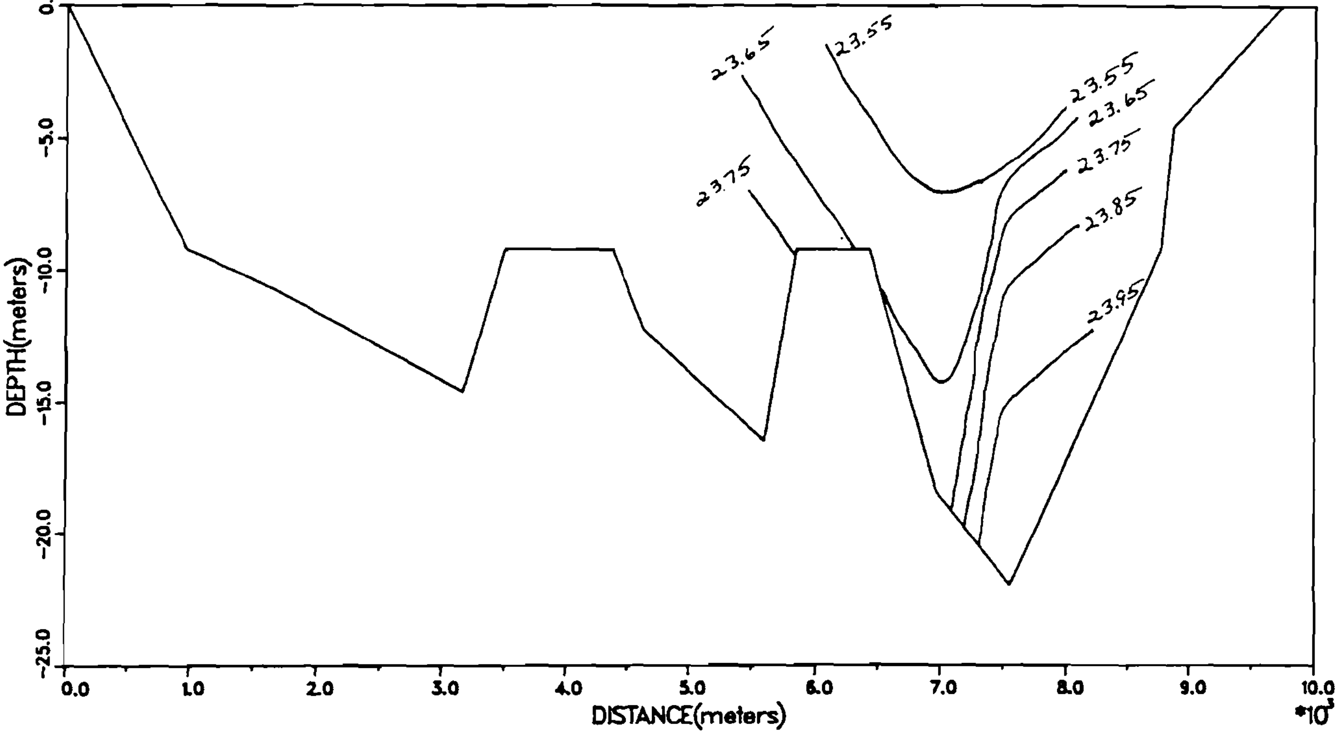
Along channel flow (cm/sec)

Temperature (deg C)

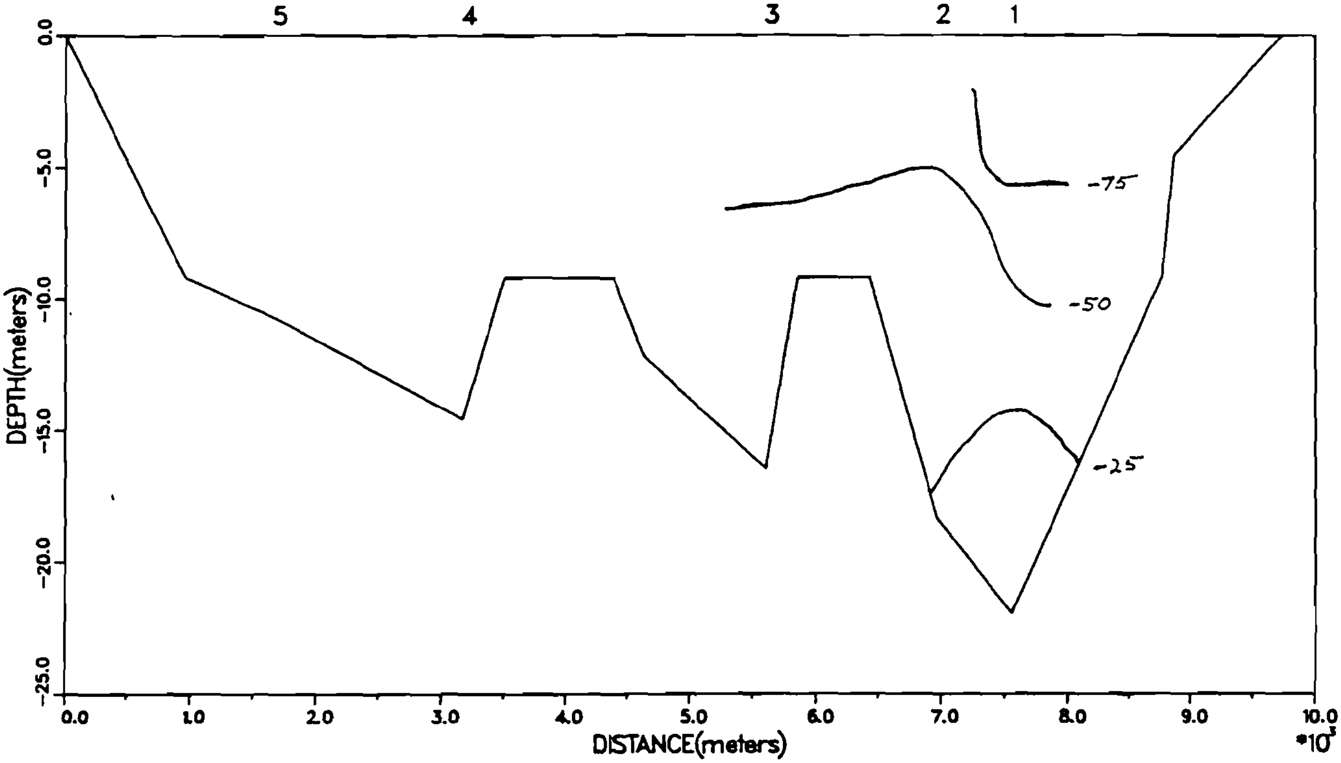


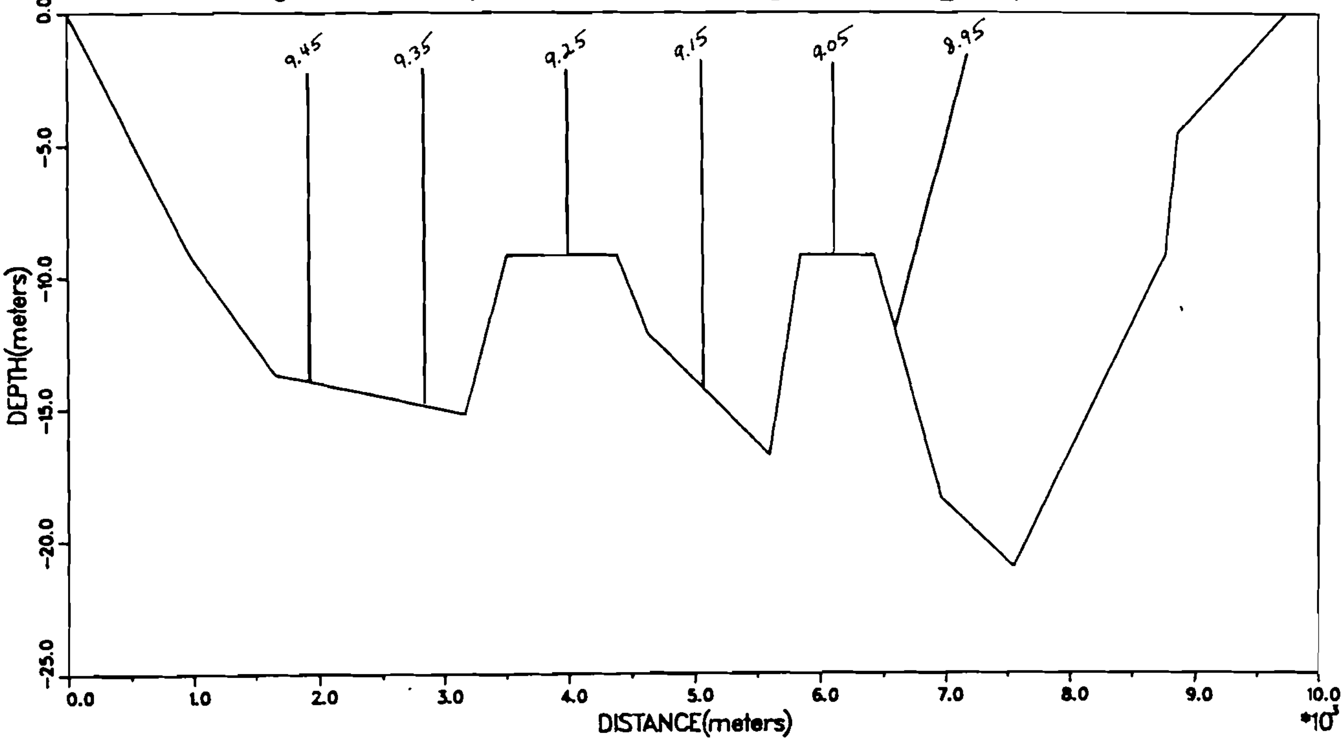
Salinity (psu)



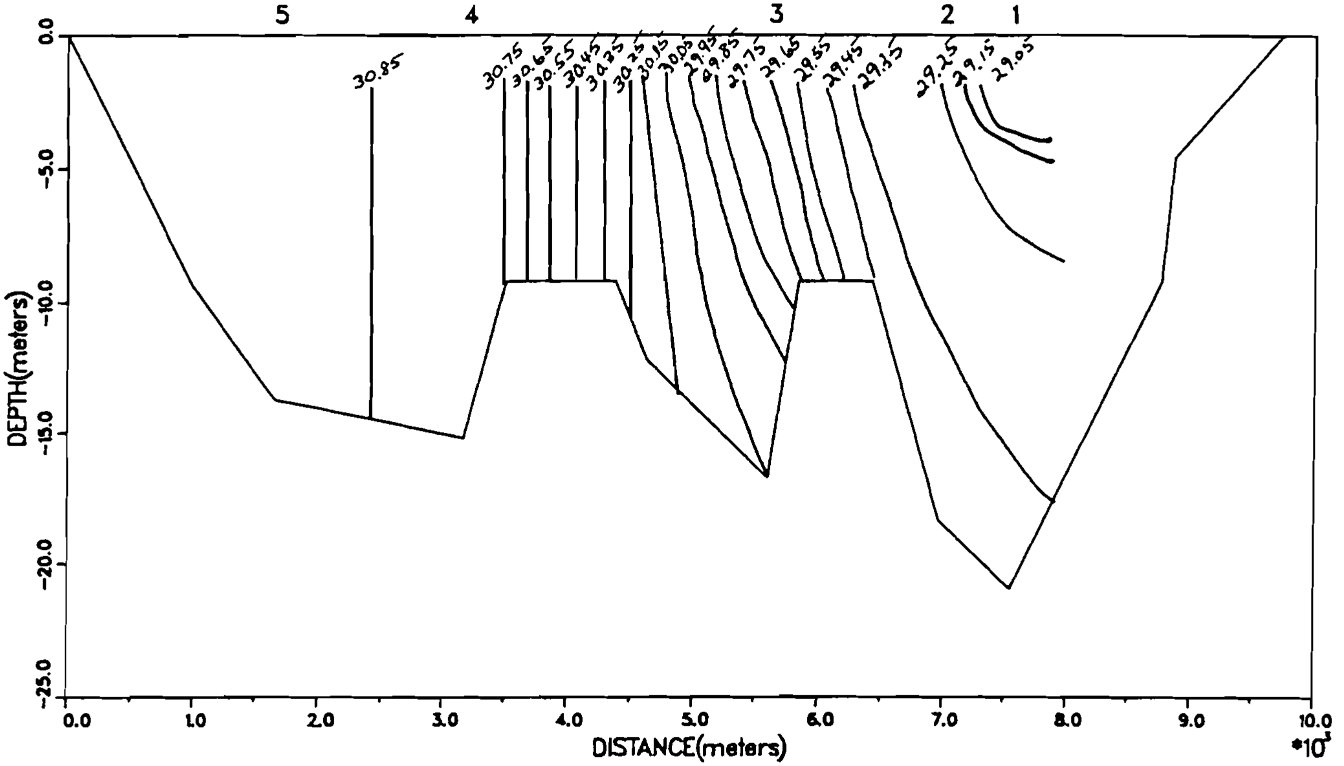


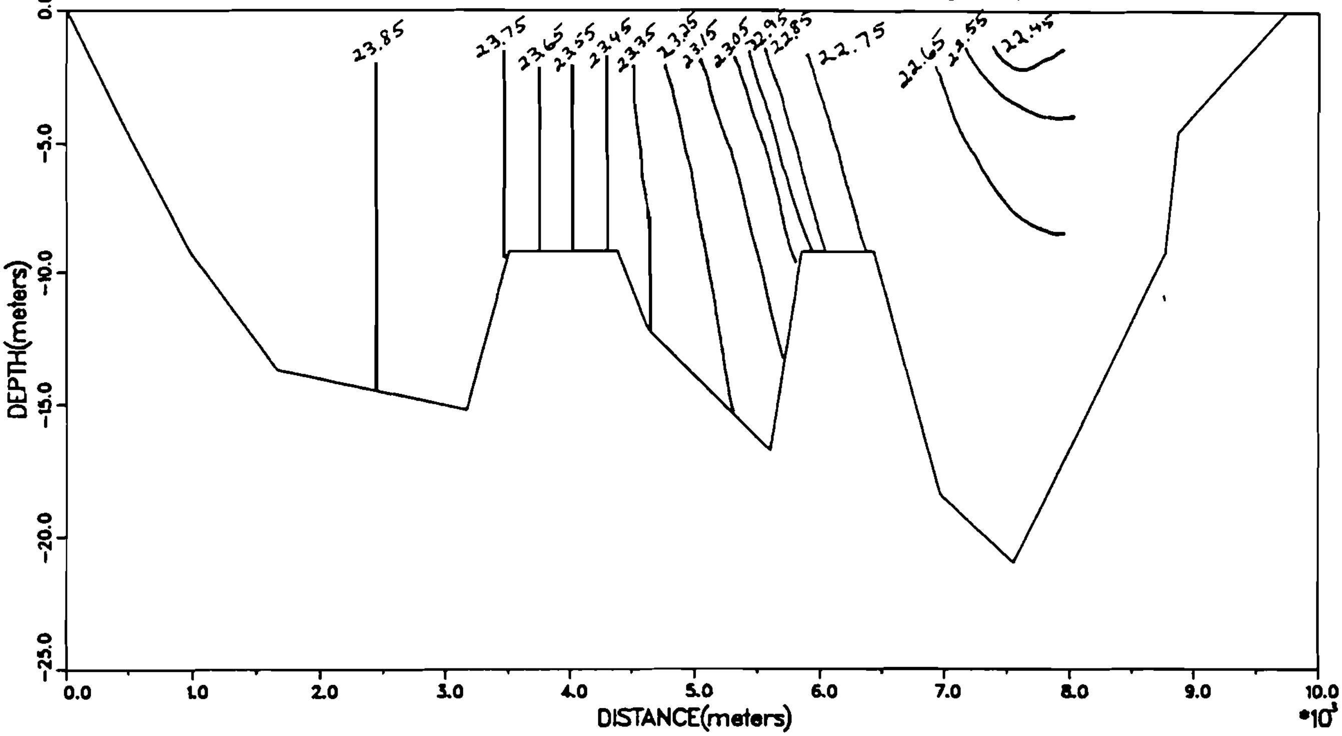
Along channel flow (cm/sec)



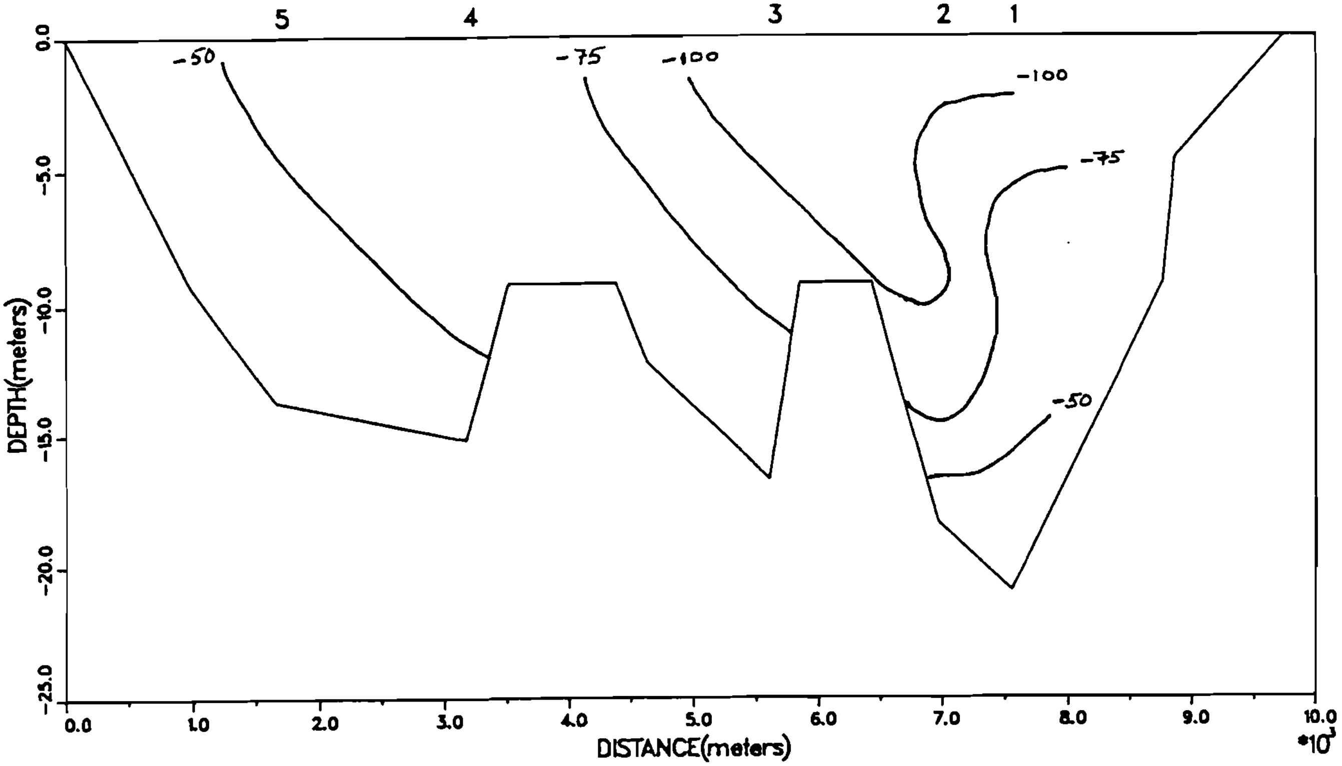


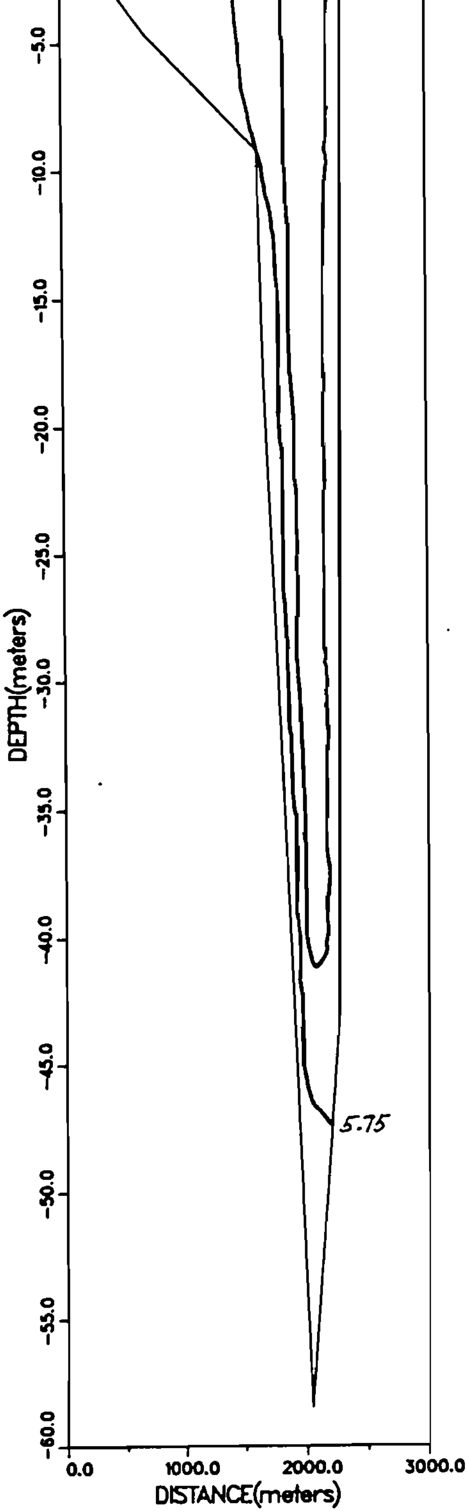
Salinity (psu)

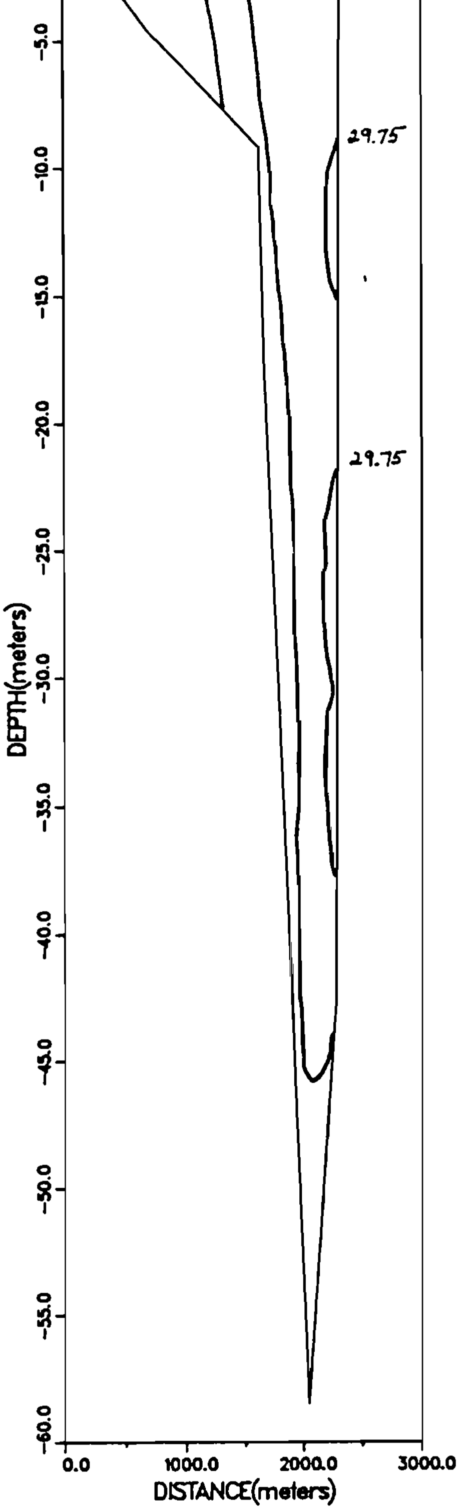


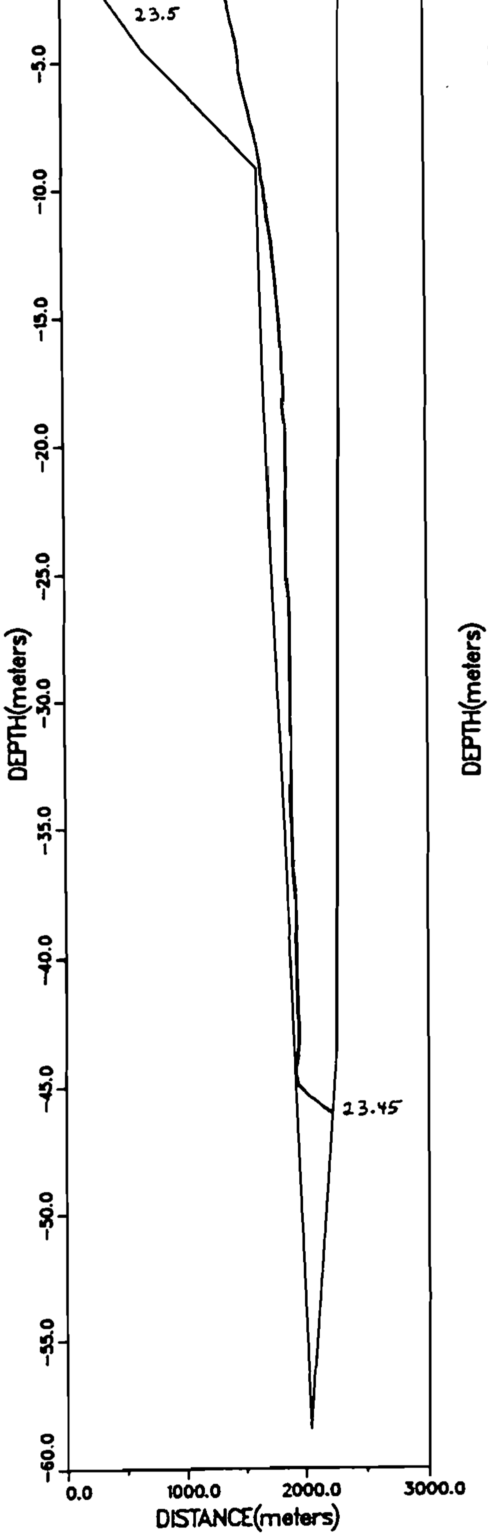


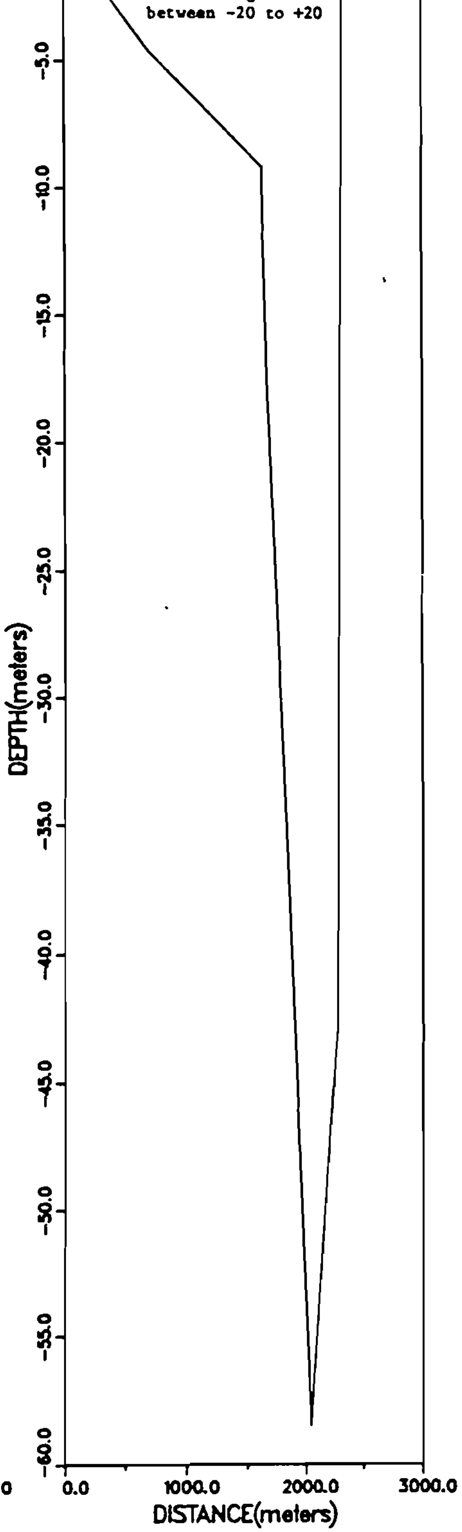
Along channel flow (cm/sec)

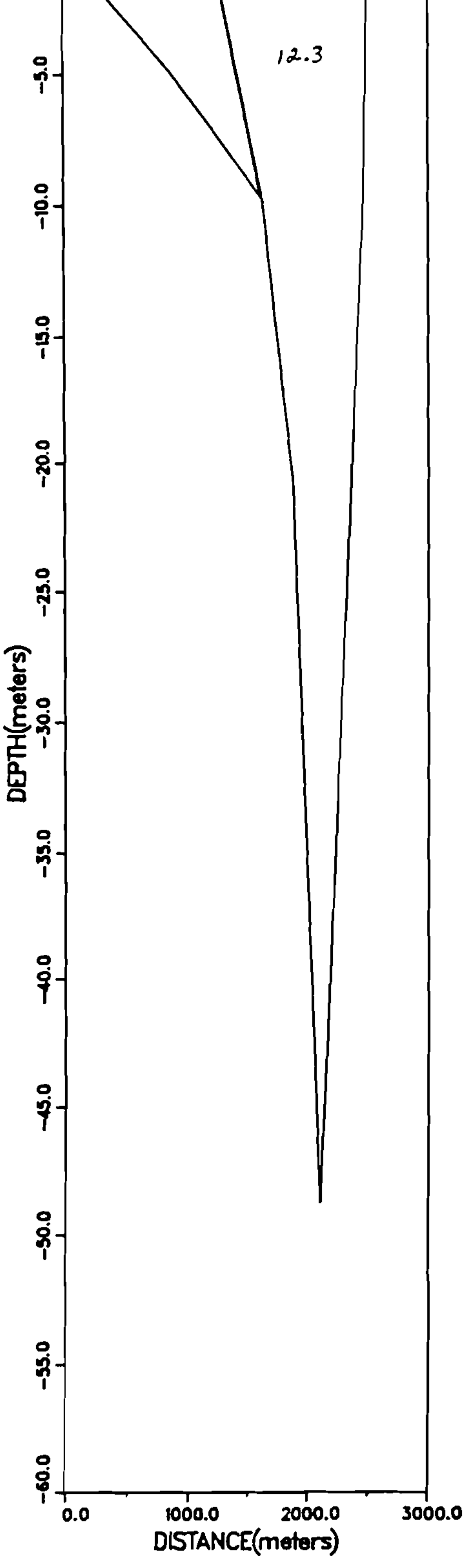


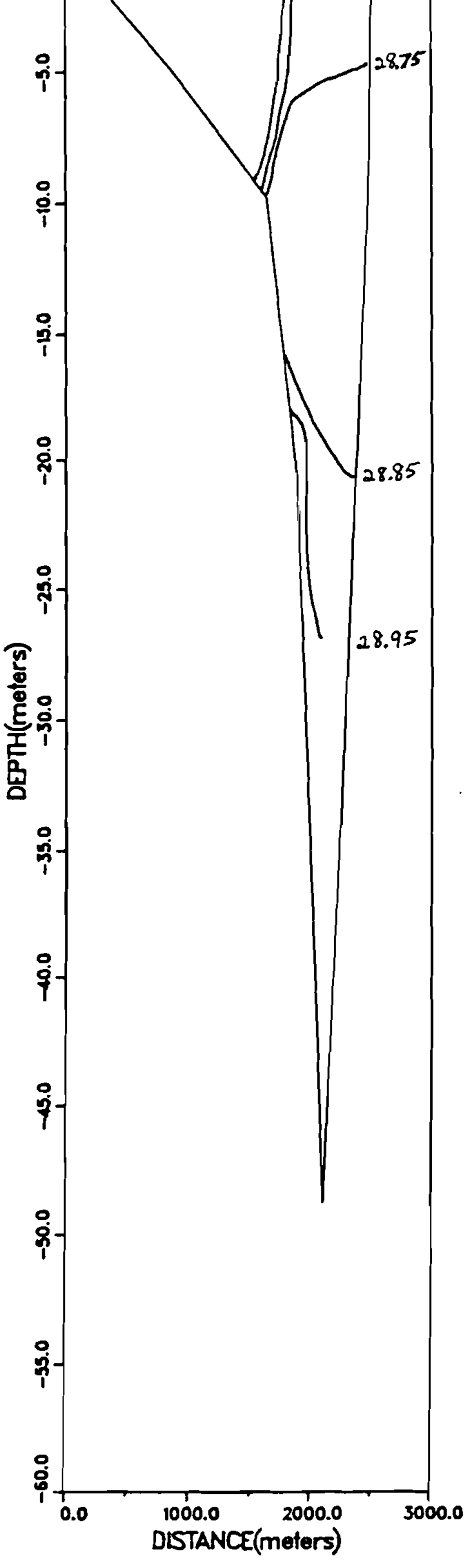

DEPTH(meters)
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
-40.0
-45.0
-50.0
-55.0
-60.0
5.75
0.0
1000.0
2000.0
3000.0
DISTANCE(meters)

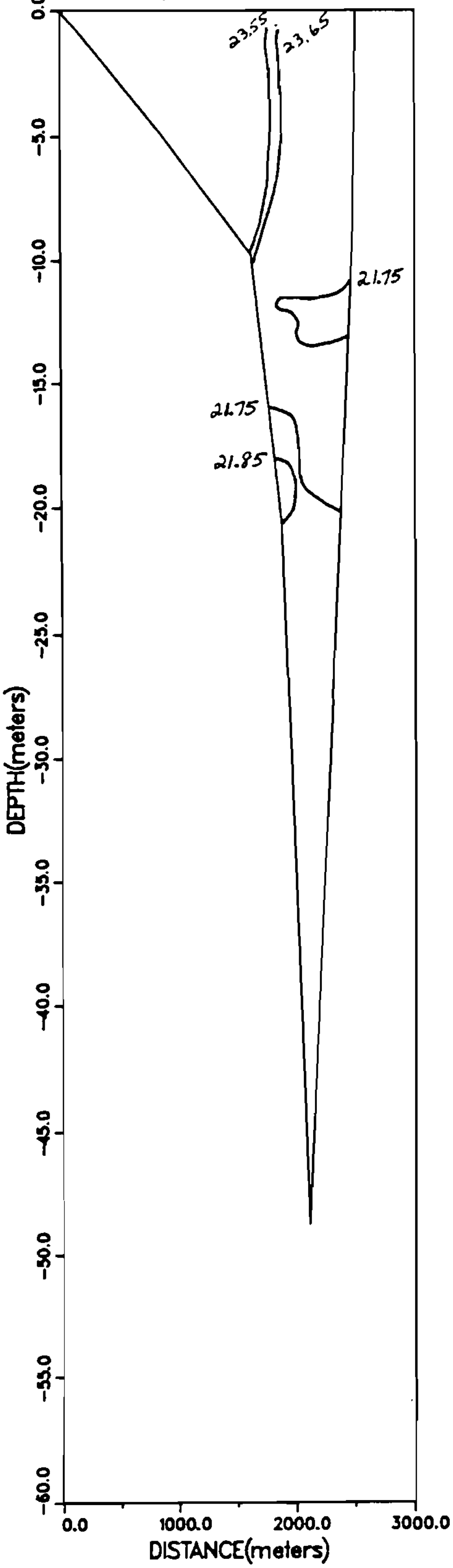

DEPTH(meters)
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
-40.0
-45.0
-50.0
-55.0
-60.0
29.75
29.75
0.0
1000.0
2000.0
3000.0
DISTANCE(meters)


23.5
23.45
DEPTH(meters)
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
-40.0
-45.0
-50.0
-55.0
-60.0
0.0
1000.0
2000.0
3000.0
DISTANCE(meters)

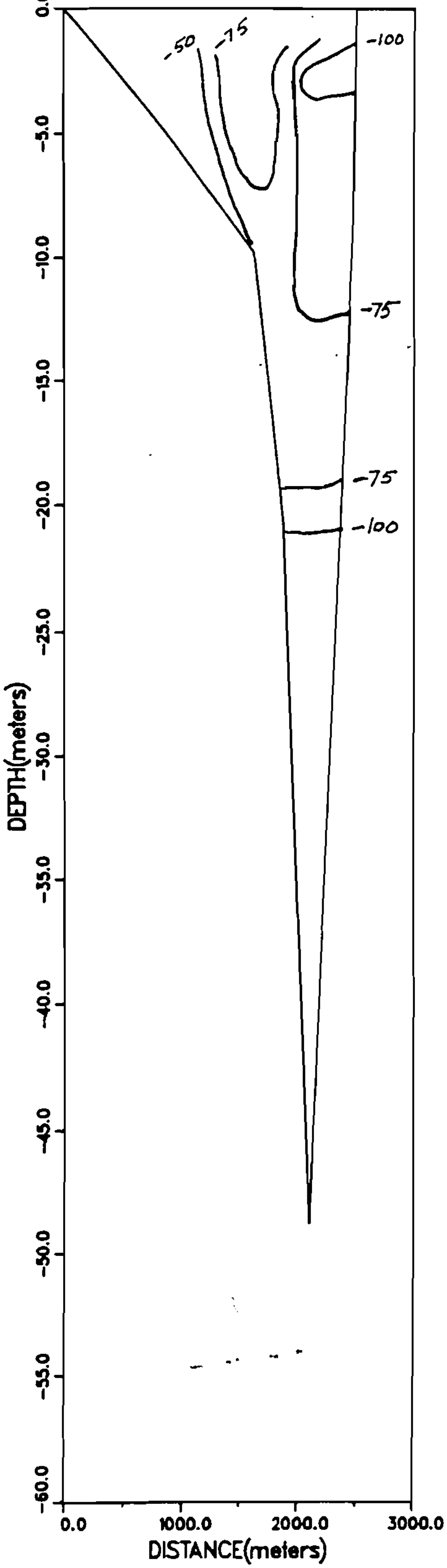

between -20 to +20
DEPTH(meters)
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
-40.0
-45.0
-50.0
-55.0
-60.0
0.0
1000.0
2000.0
3000.0
DISTANCE(meters)


12.3
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
-40.0
-45.0
-50.0
-55.0
-60.0
DEPTH(meters)
0.0
1000.0
2000.0
3000.0
DISTANCE(meters)

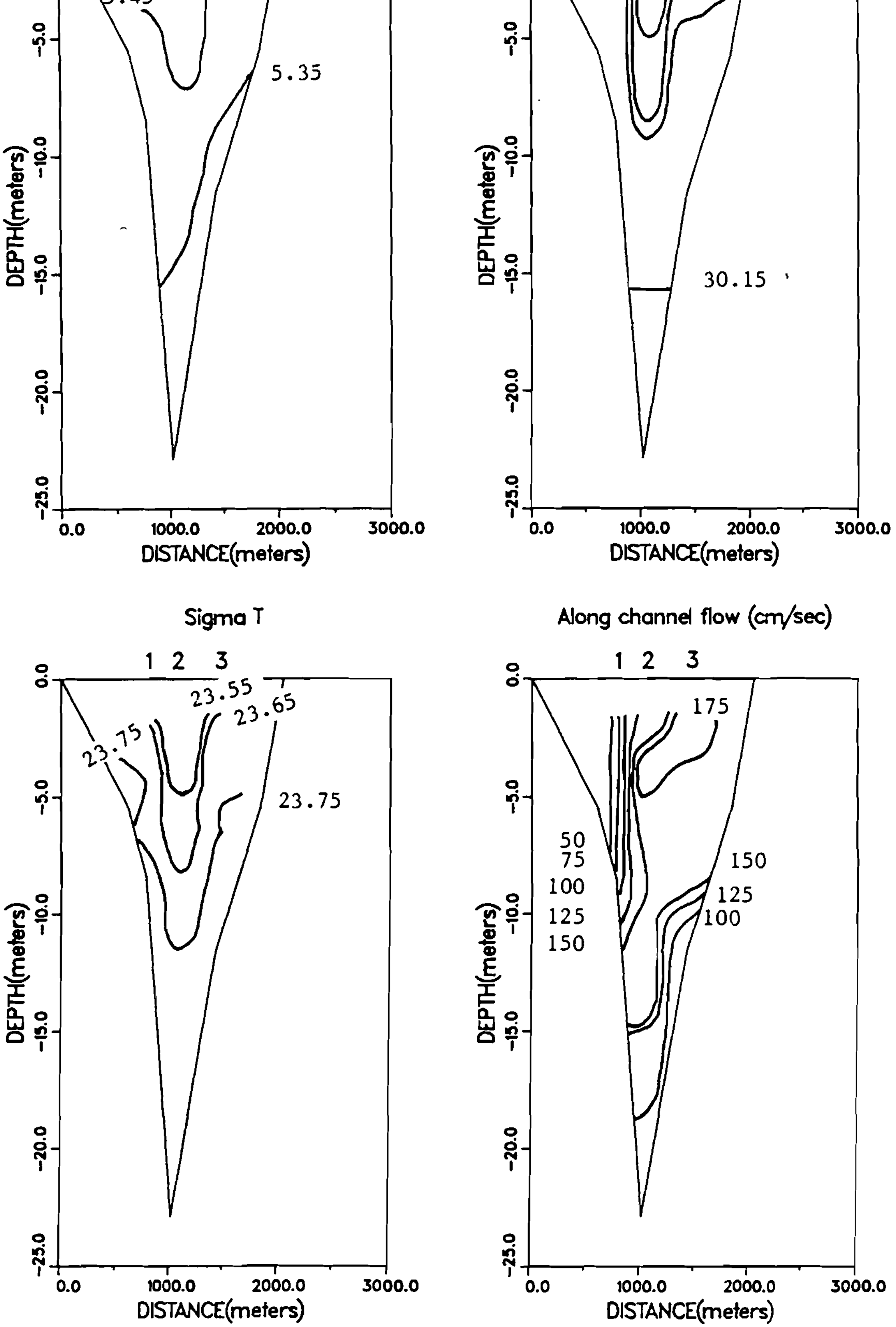

28.75
28.85
28.95
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
-40.0
-45.0
-50.0
-55.0
-60.0
DEPTH(meters)
0.0
1000.0
2000.0
3000.0
DISTANCE(meters)

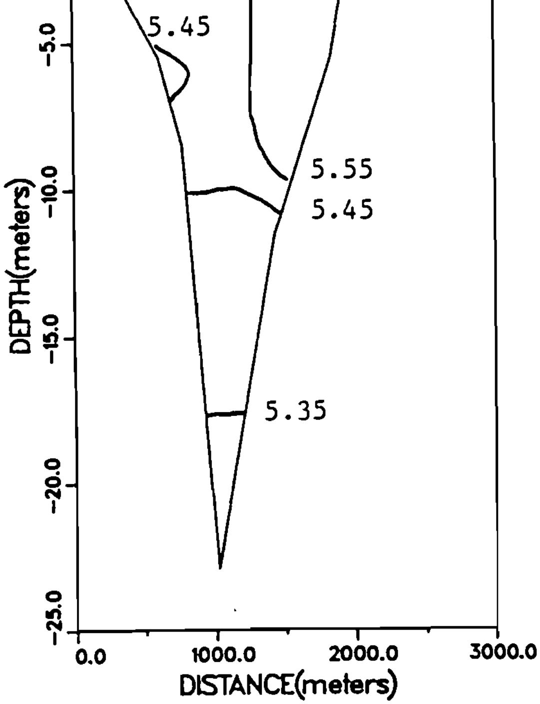


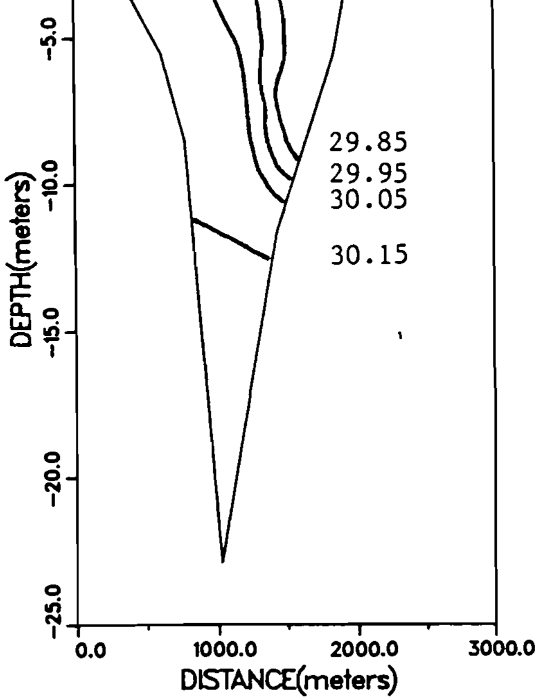
23.55
23.65
21.75
21.75
21.85
DEPTH(meters)
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
-40.0
-45.0
-50.0
-55.0
-60.0
0.0
1000.0
2000.0
3000.0
DISTANCE(meters)



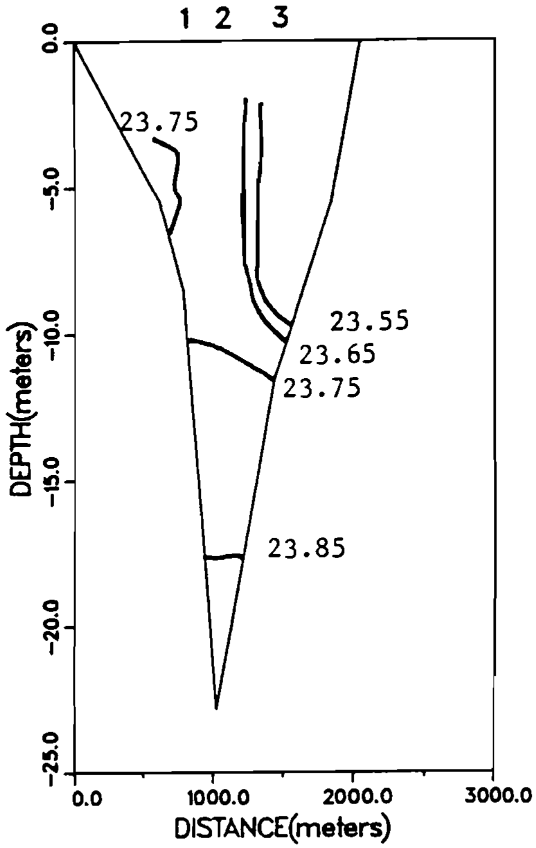
-50
-75
-100
-75
-75
-100
DEPTH(meters)
0.0
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
-40.0
-45.0
-50.0
-55.0
-60.0
0.0
1000.0
2000.0
3000.0
DISTANCE(meters)


5.35
DEPTH(meters)
-5.0
-10.0
-15.0
-20.0
-25.0
0.0
1000.0
2000.0
3000.0
DISTANCE(meters)
30.15
Sigma T
1 2 3
23.55
23.65
23.75
23.75
Along channel flow (cm/sec)
175
50
75
100
125
150
150
125
100

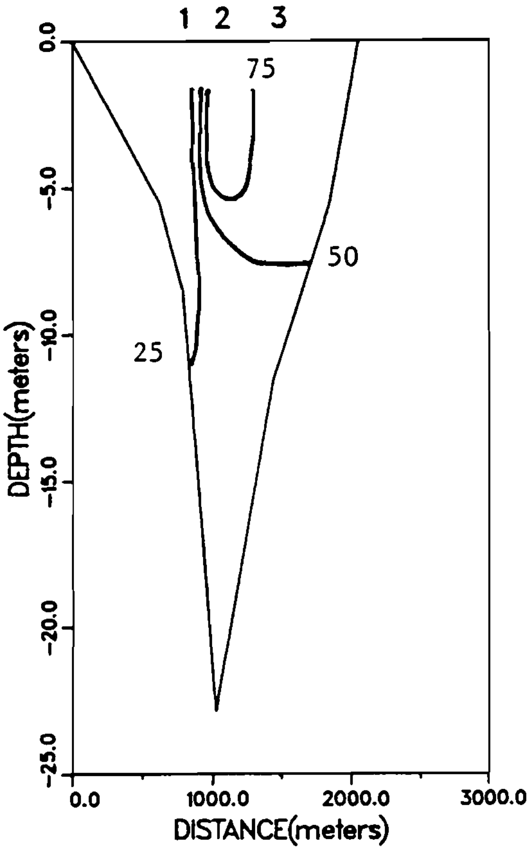


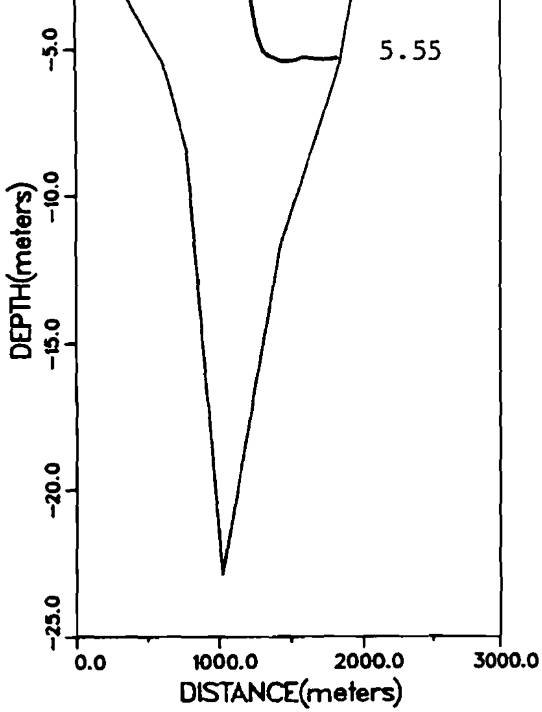


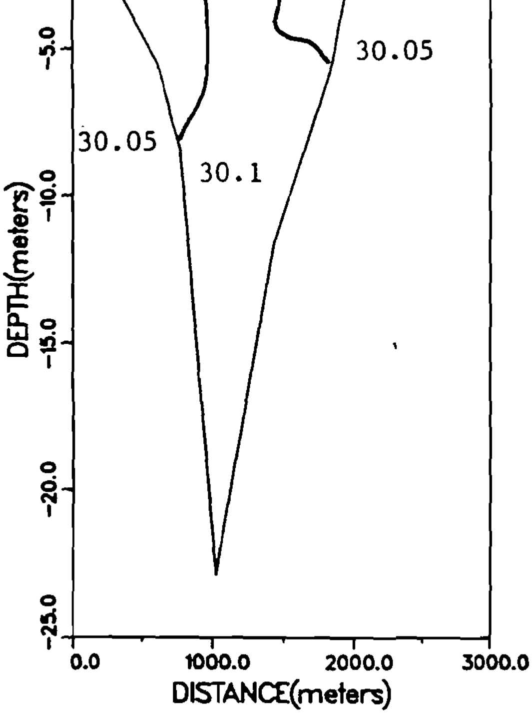
Sigma T

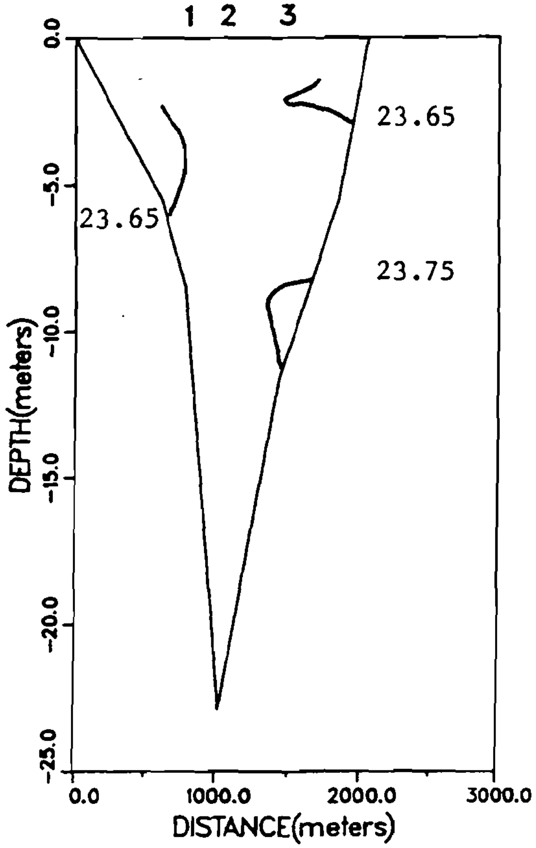


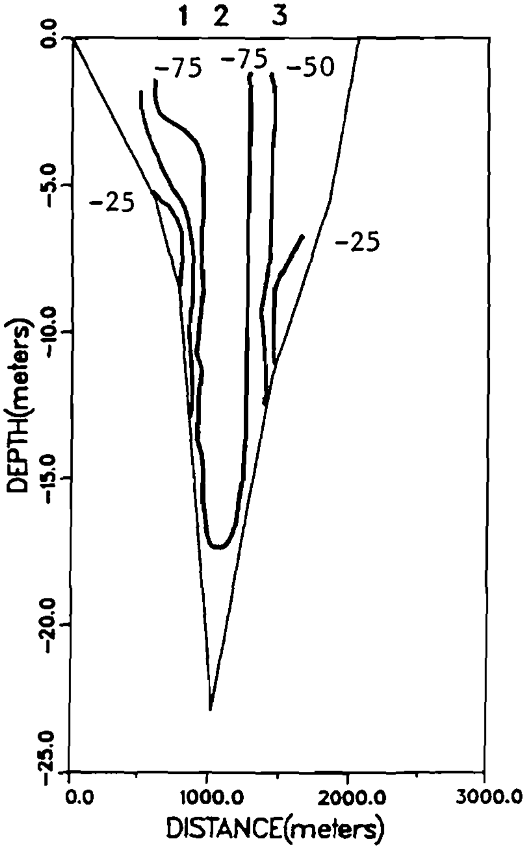
Along channel flow (cm/sec)

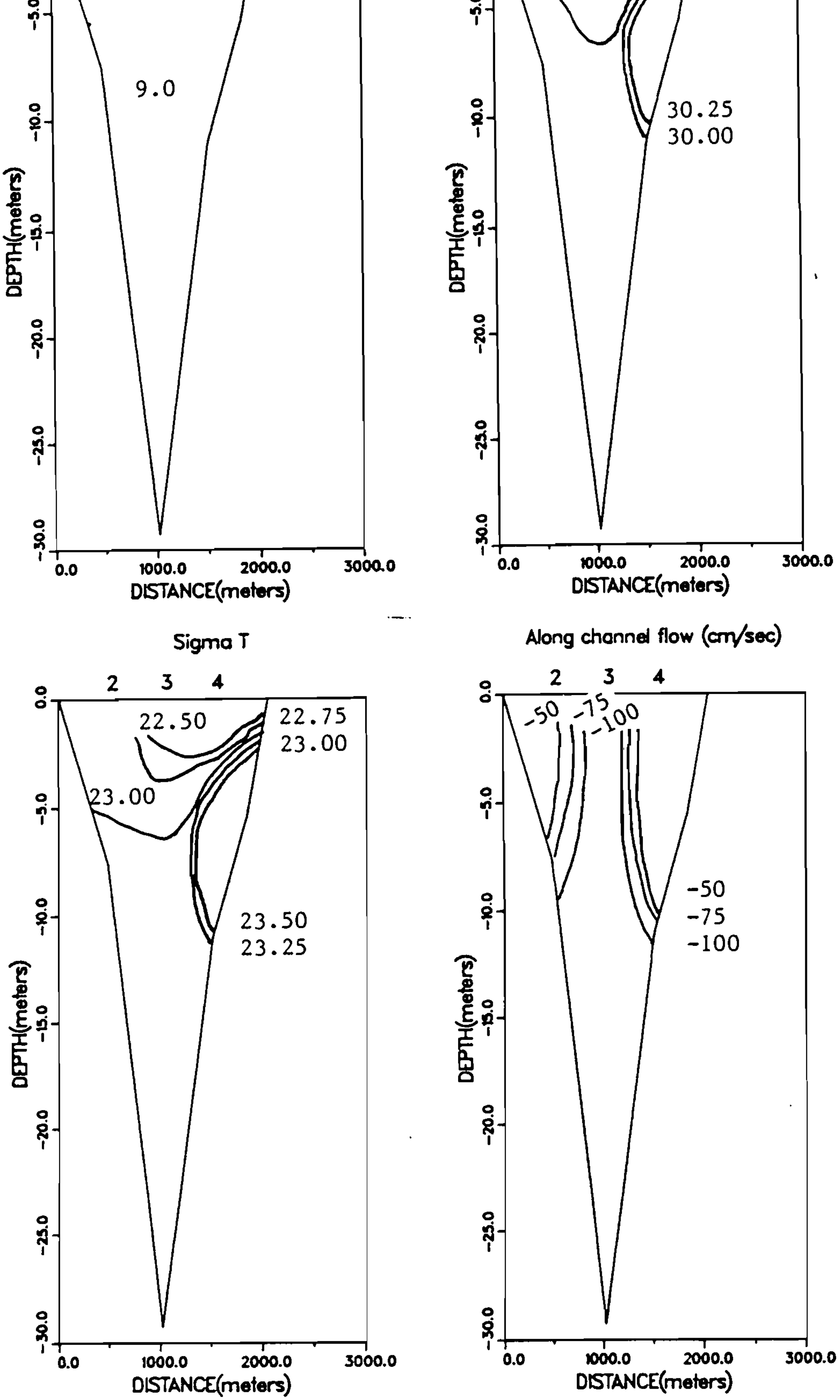






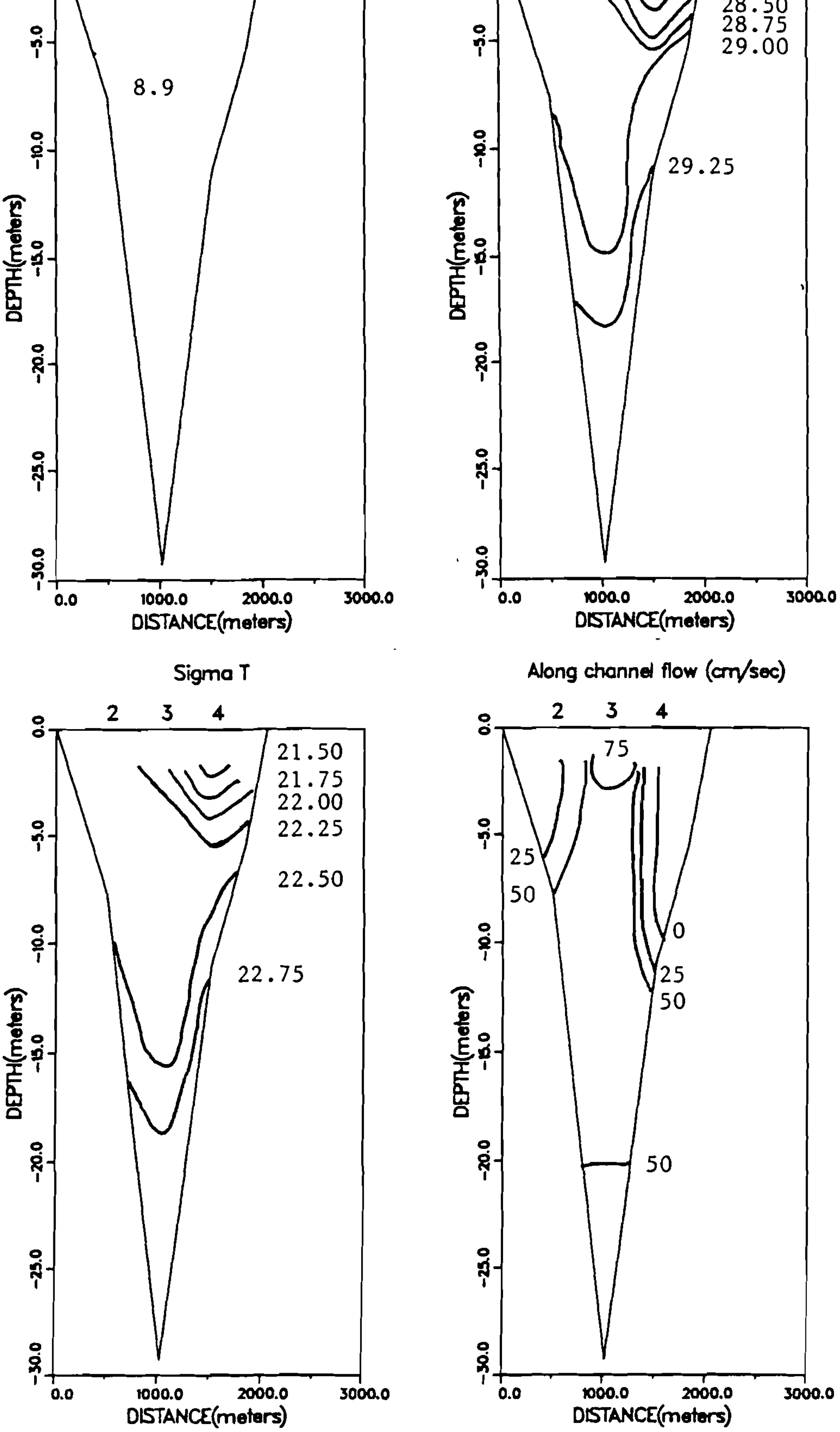

Sigma T

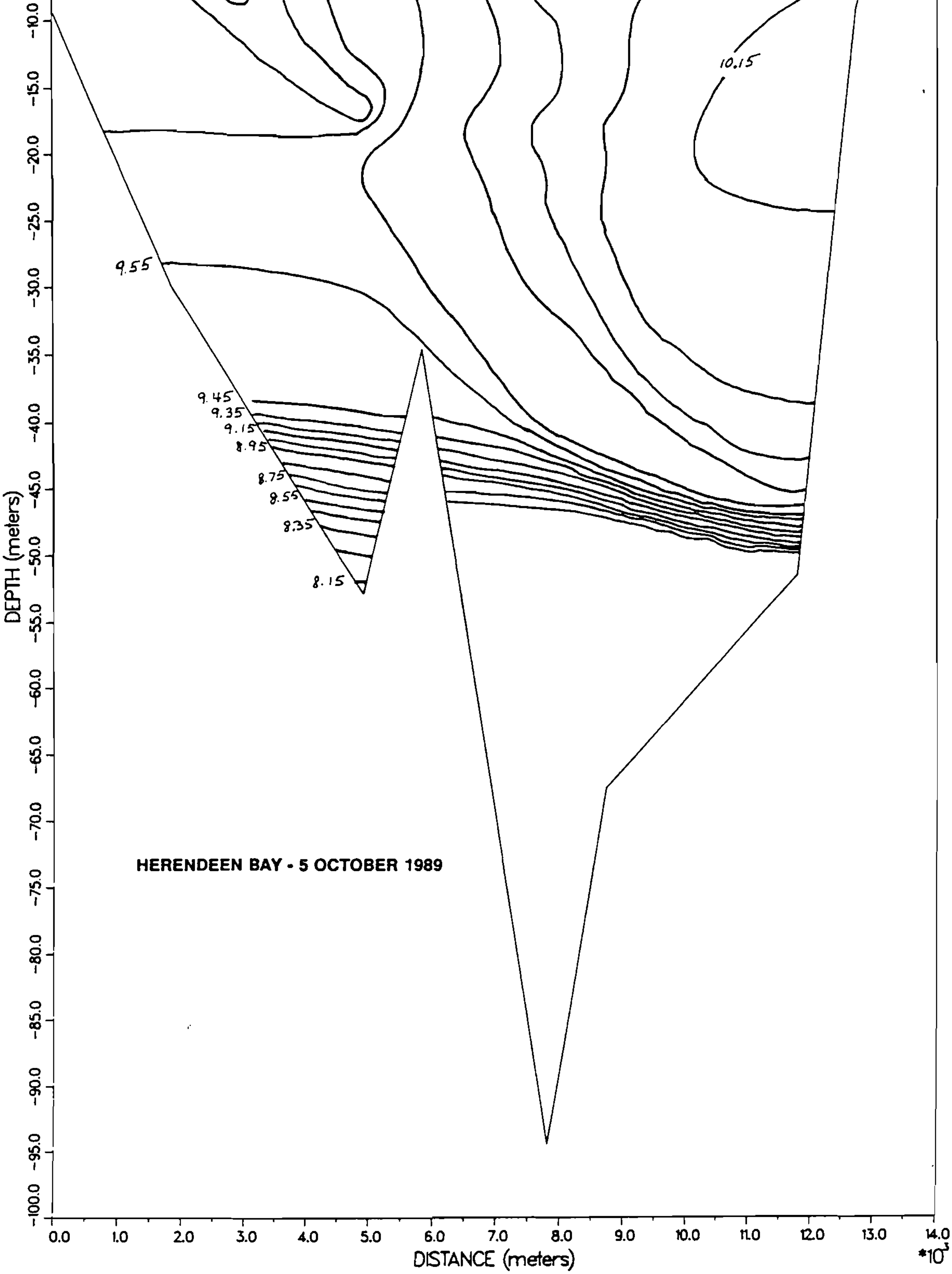

Along channel flow (cm/sec)

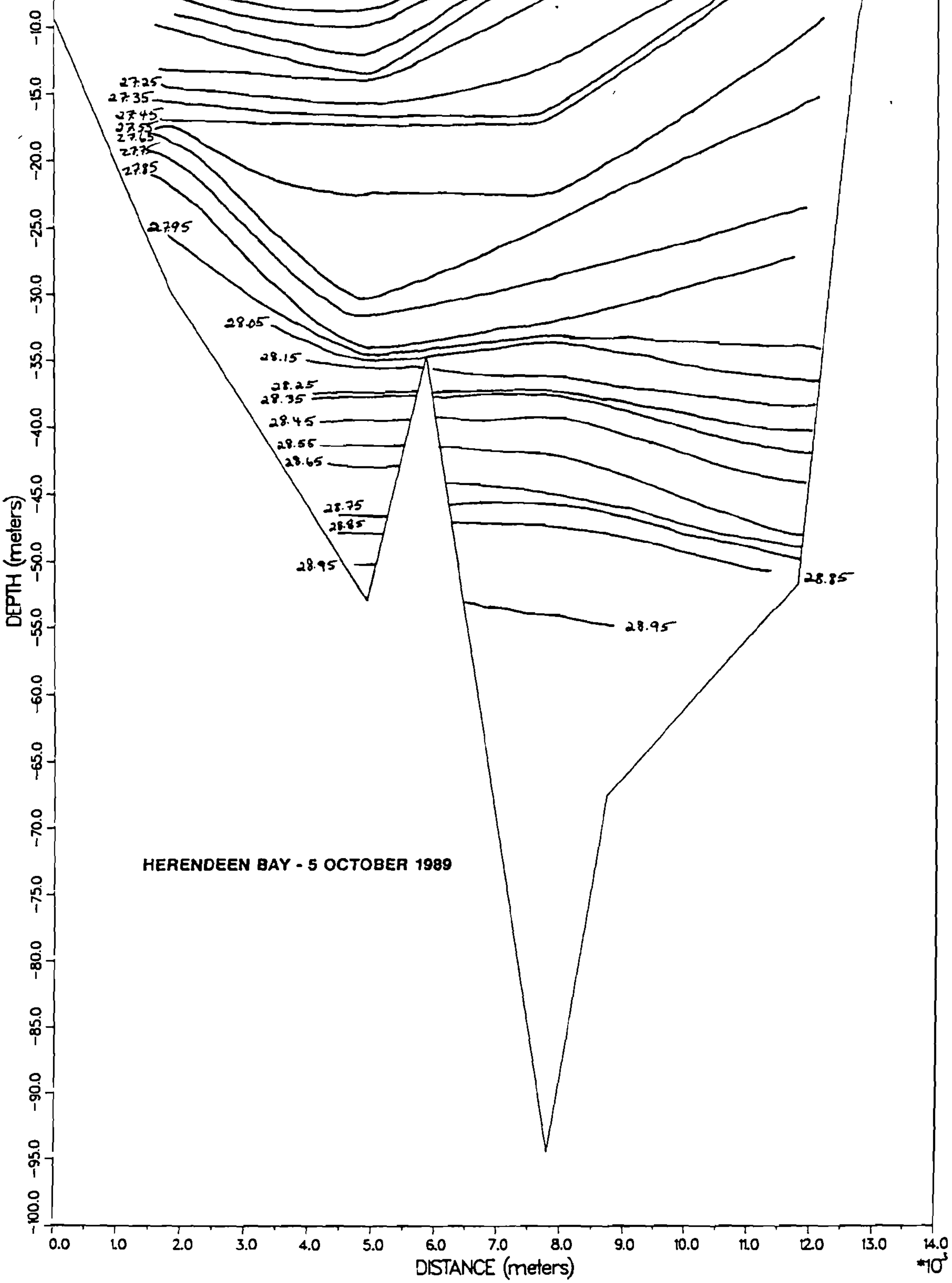


Sigma T

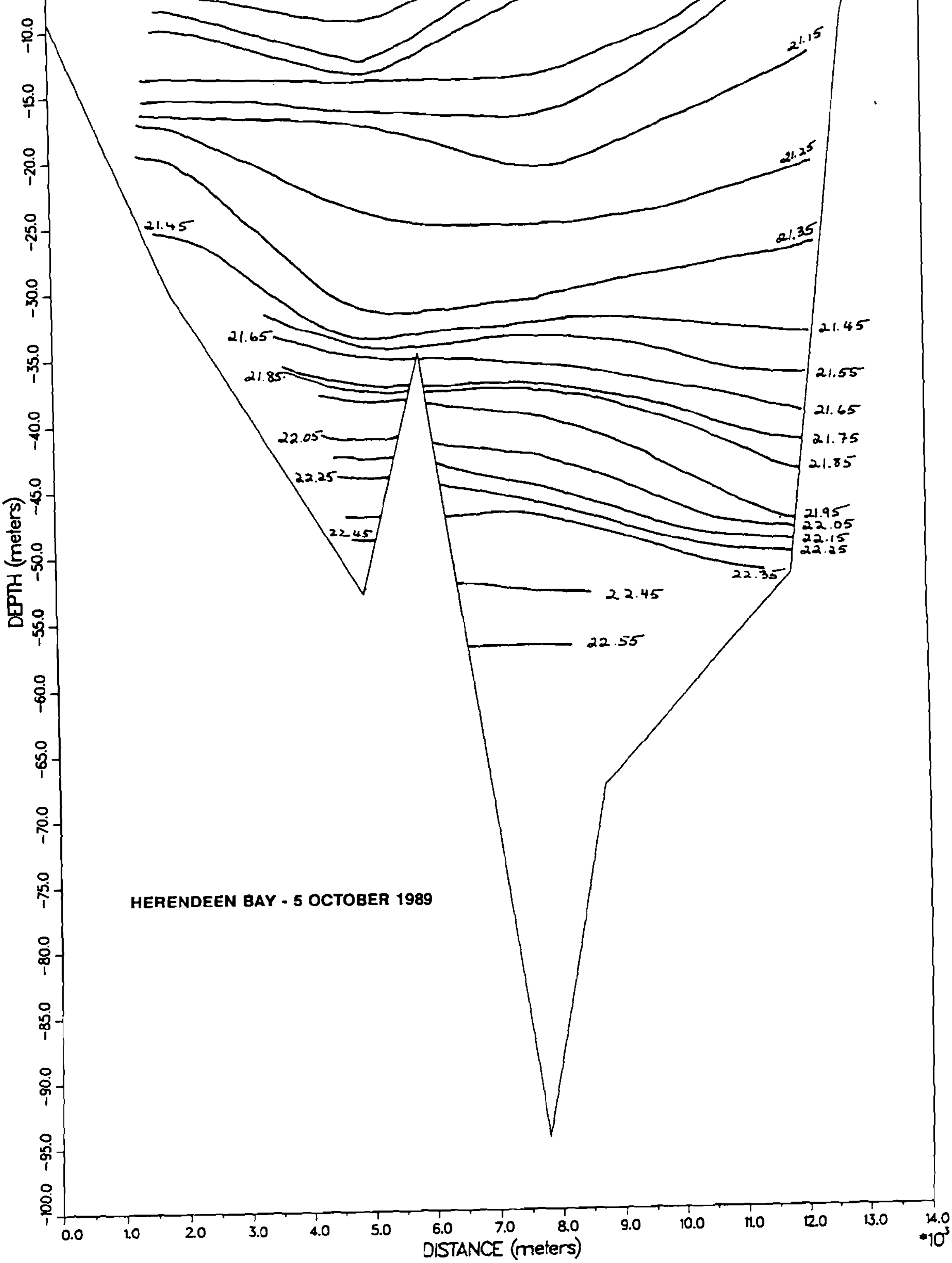
Along channel flow (cm/sec)

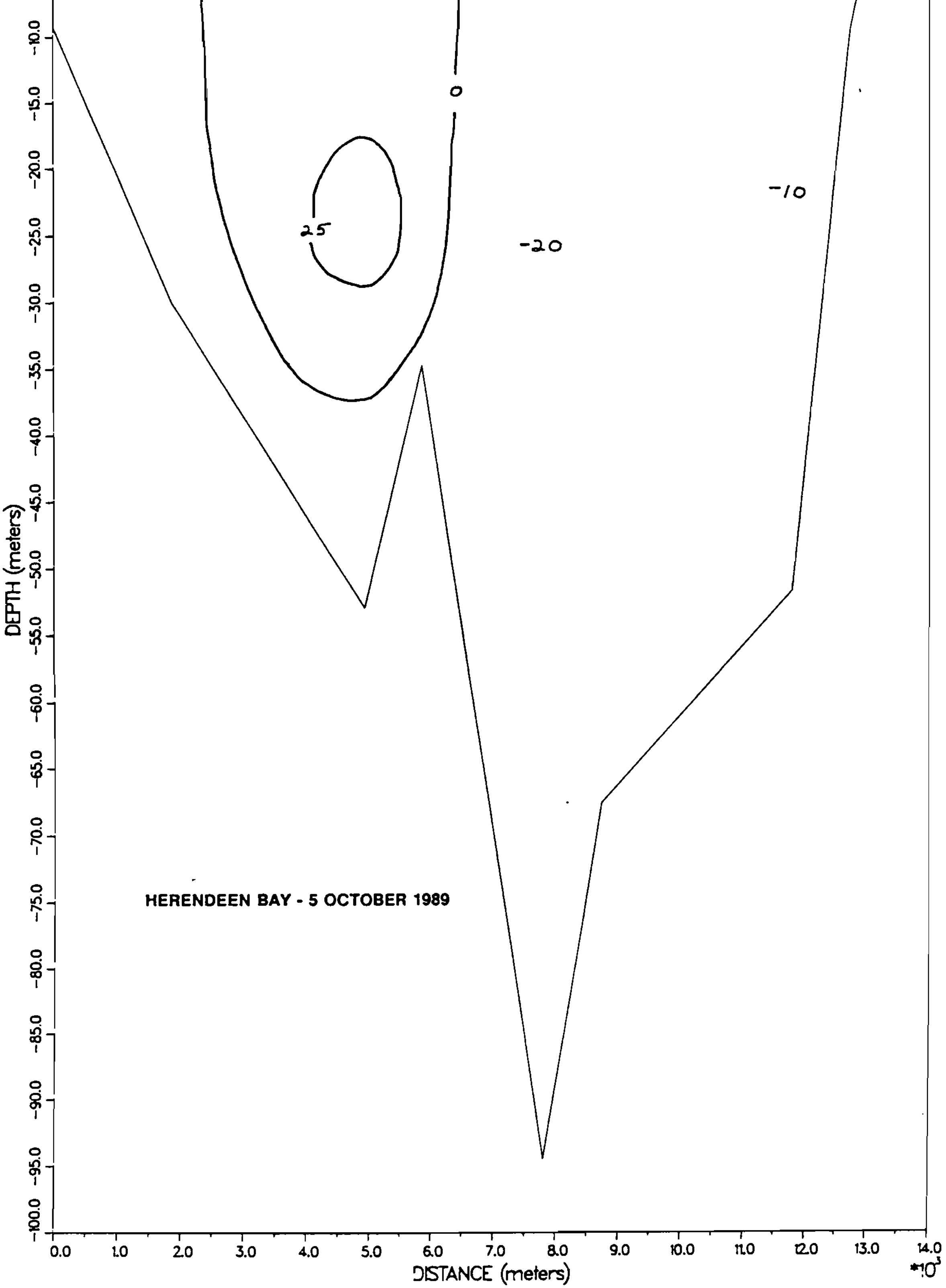

8.9
28.50
28.75
29.00
29.25
DEPTH(meters)
DISTANCE(meters)
-5.0
-10.0
-15.0
-20.0
-25.0
-30.0
0.0
1000.0
2000.0
3000.0
Sigma T
2
3
4
21.50
21.75
22.00
22.25
22.50
22.75
Along channel flow (cm/sec)
75
25
50
0
25
50
50


10.15
9.55
9.45
9.35
9.15
8.95
8.75
8.55
8.35
8.15
HERENDEEN BAY - 5 OCTOBER 1989
DEPTH (meters)
-10.0
-15.0
-20.0
-25.0
-30.0
-35.0
-40.0
-45.0
-50.0
-55.0
-60.0
-65.0
-70.0
-75.0
-80.0
-85.0
-90.0
-95.0
-100.0
0.0
1.0
2.0
3.0
4.0
5.0
6.0
7.0
8.0
9.0
10.0
11.0
12.0
13.0
14.0
DISTANCE (meters)
*10³

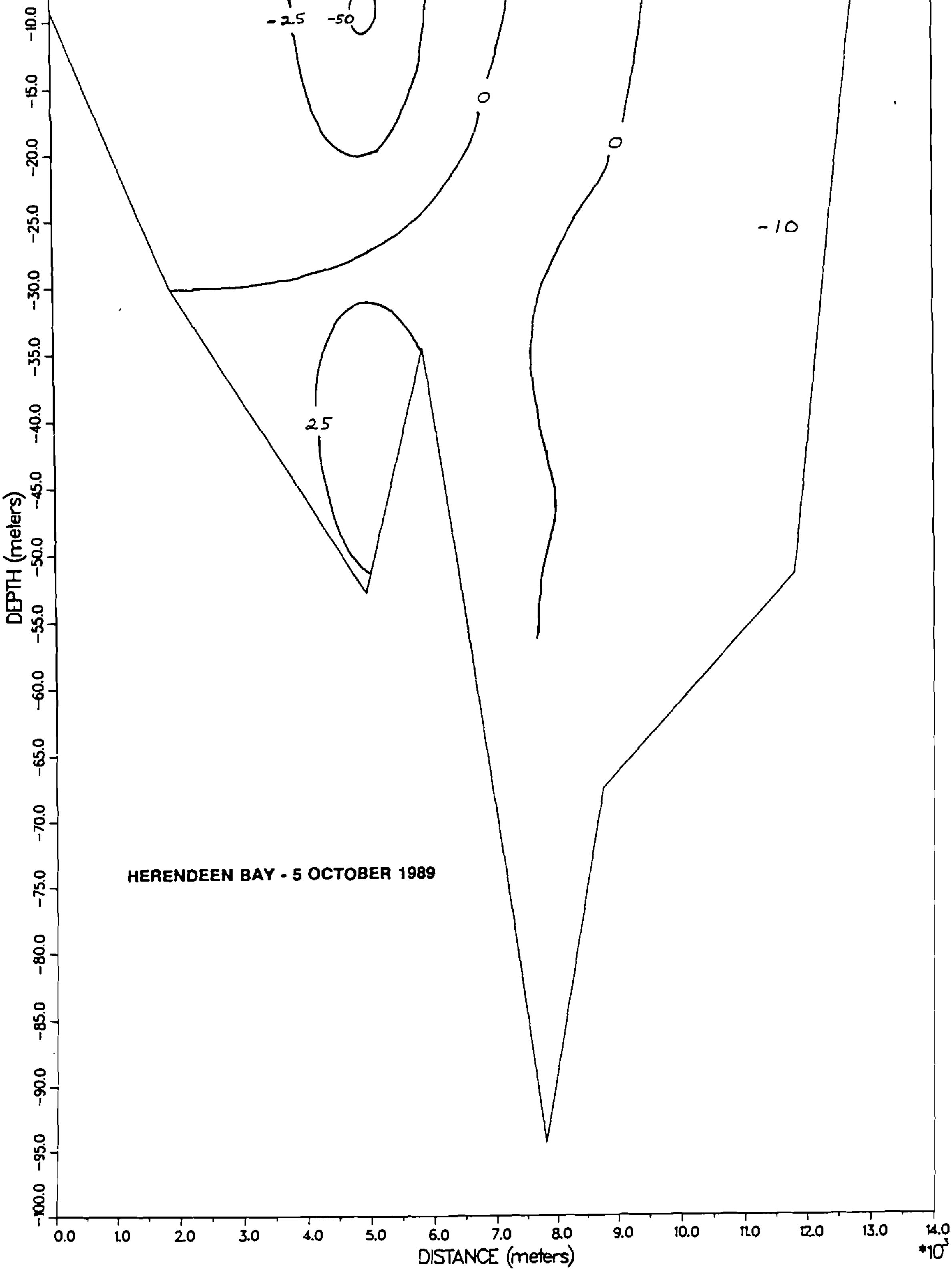


HERENDEEN BAY - 5 OCTOBER 1989


HERENDEEN BAY - 5 OCTOBER 1989



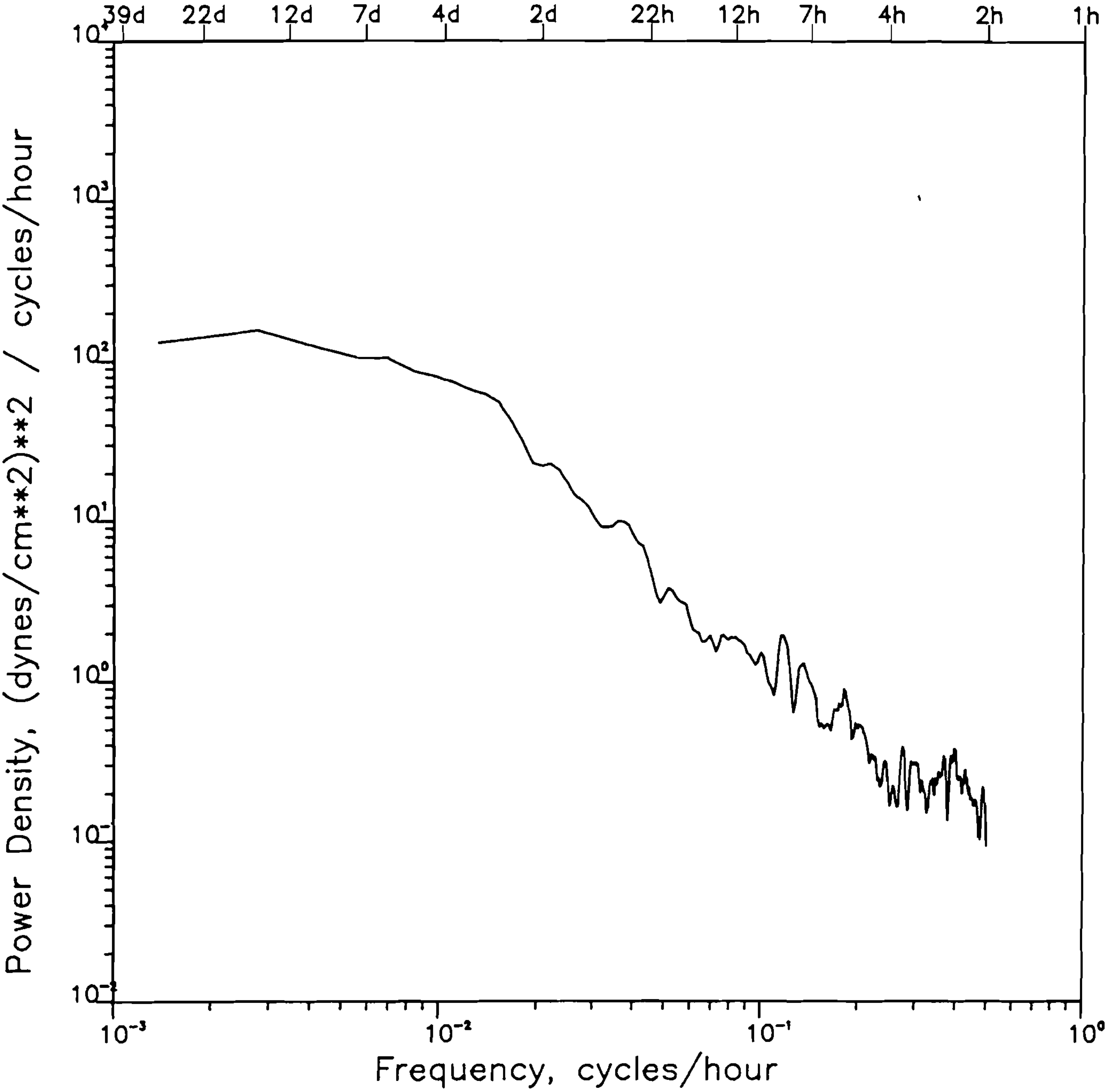
HERENDEEN BAY - 5 OCTOBER 1989



HERENDEEN BAY - 5 OCTOBER 1989

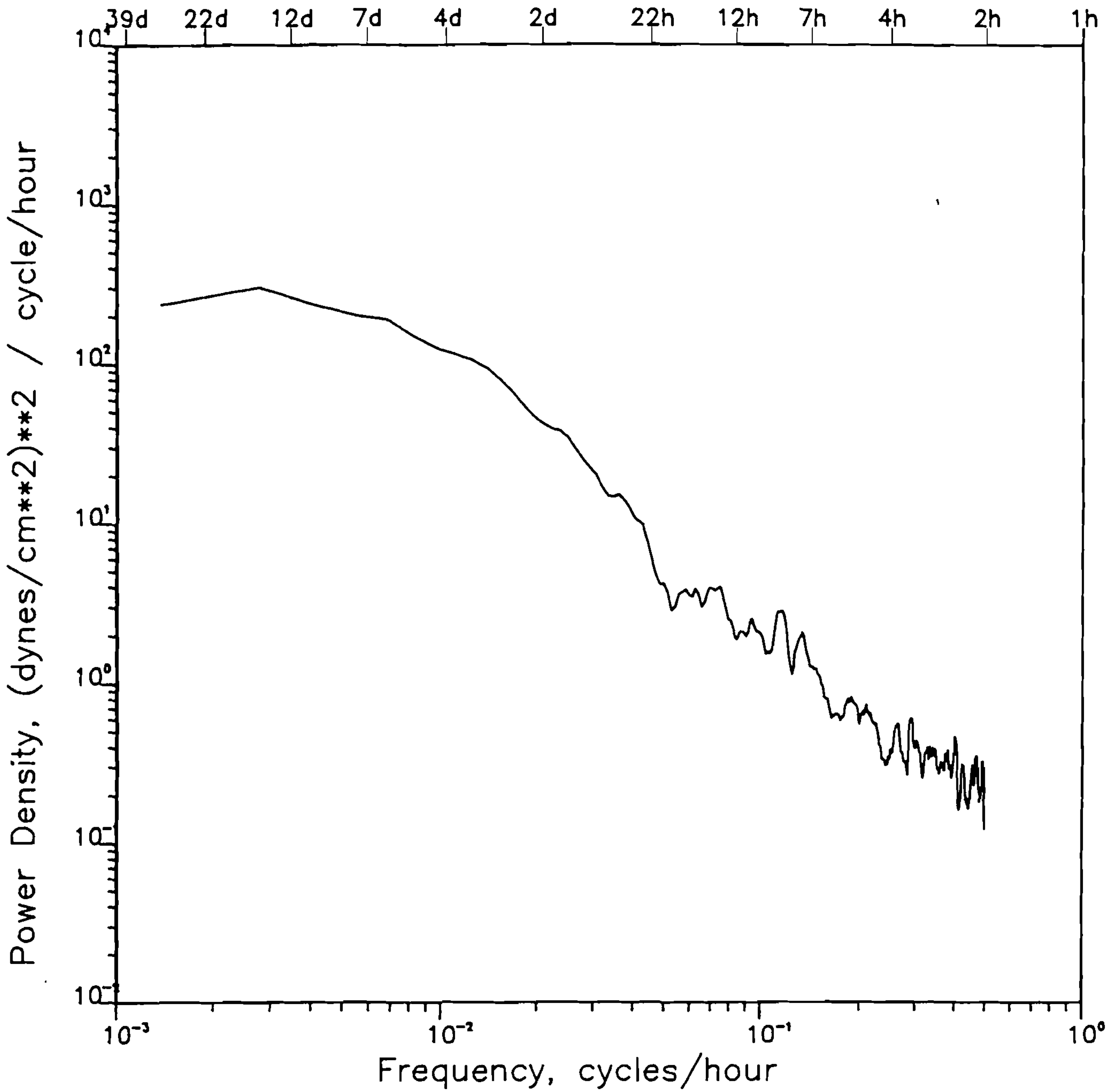
APPENDIX G

PORT MOLLER
1989 SPECTRAL PLOTS

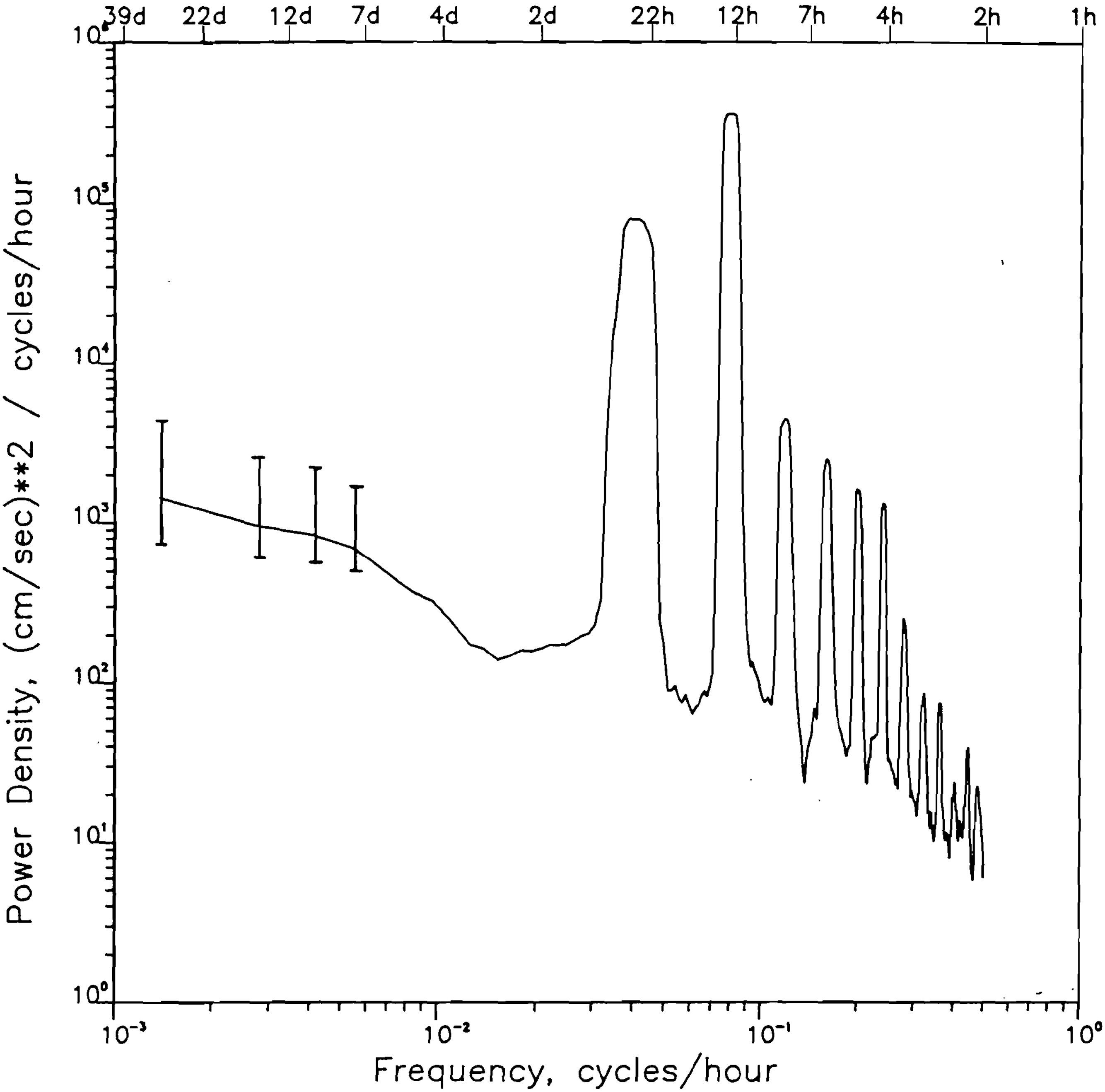


from 05/23/89 to 09/28/89
50% overlap. 7 pieces.
7 band ave. (arithm.) 360 estimates

Harbor Pt Windstress (east component)



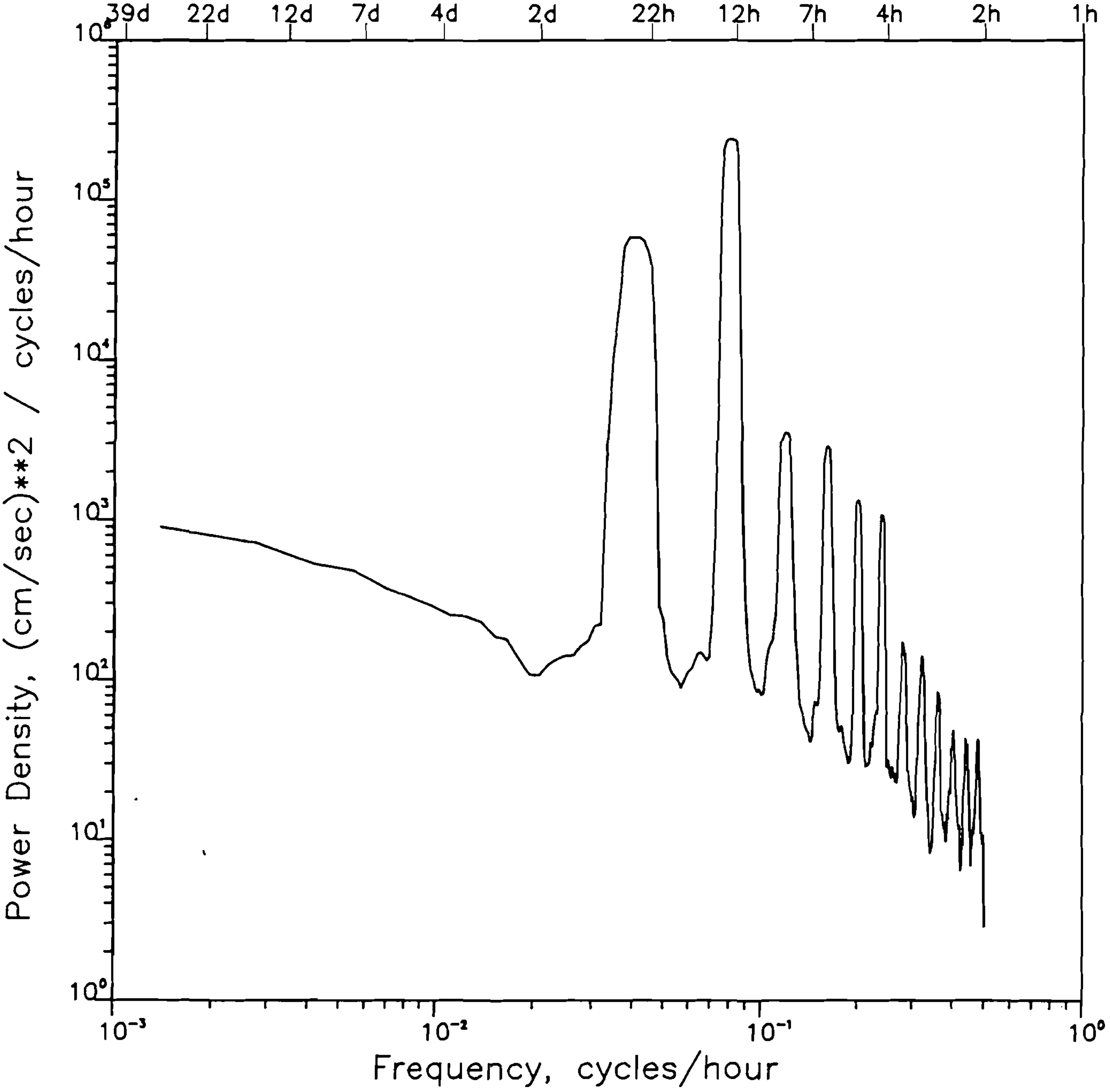
from 05/23/89 to 09/28/89
50% overlap. 7 pieces.
7 band ave. (arithm.) 360 estimates



from 05/22/89 to 08/04/89
49% overlap.
7 band ave. (arithm.)

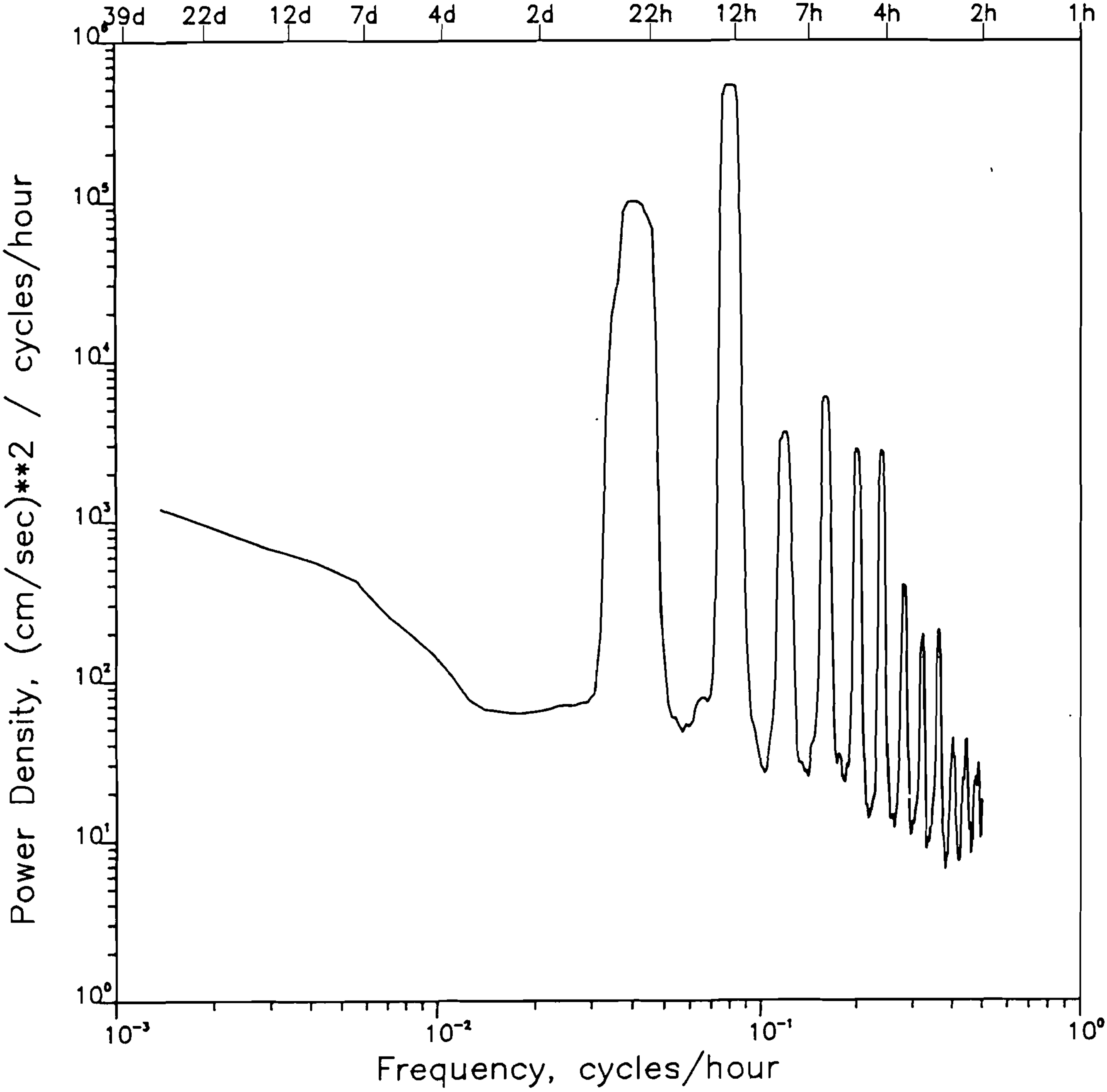
4 pieces.
360 estimates

Along-channel current ACM 99



from 05/22/89 to 08/04/89
49% overlap. 4 pieces.
7 band ave. (arithm.) 360 estimates

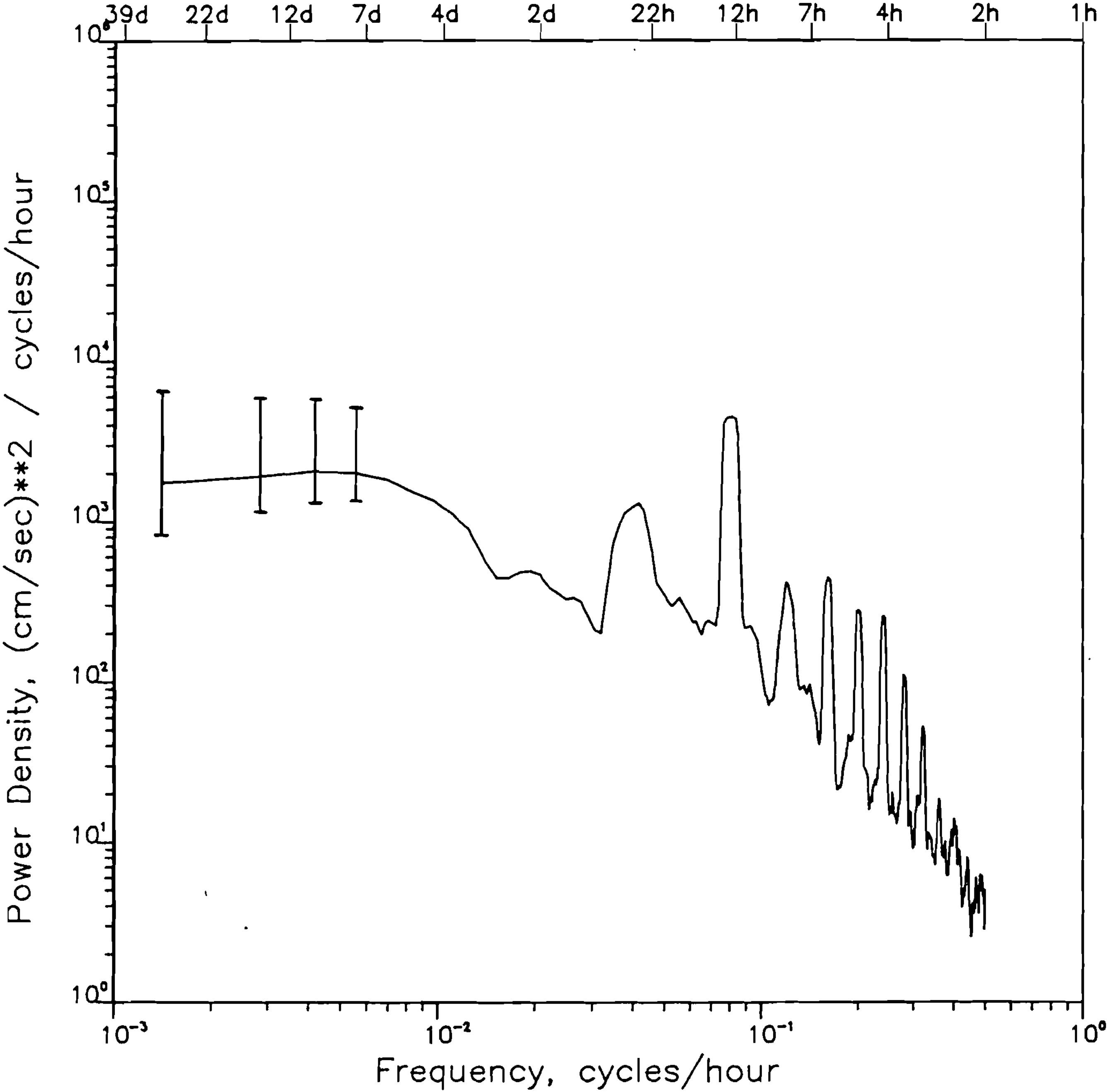
Along-channel current ACM 1154



from 05/22/89 to 08/26/89
50% overlap.
7 band ave. (arithm.)

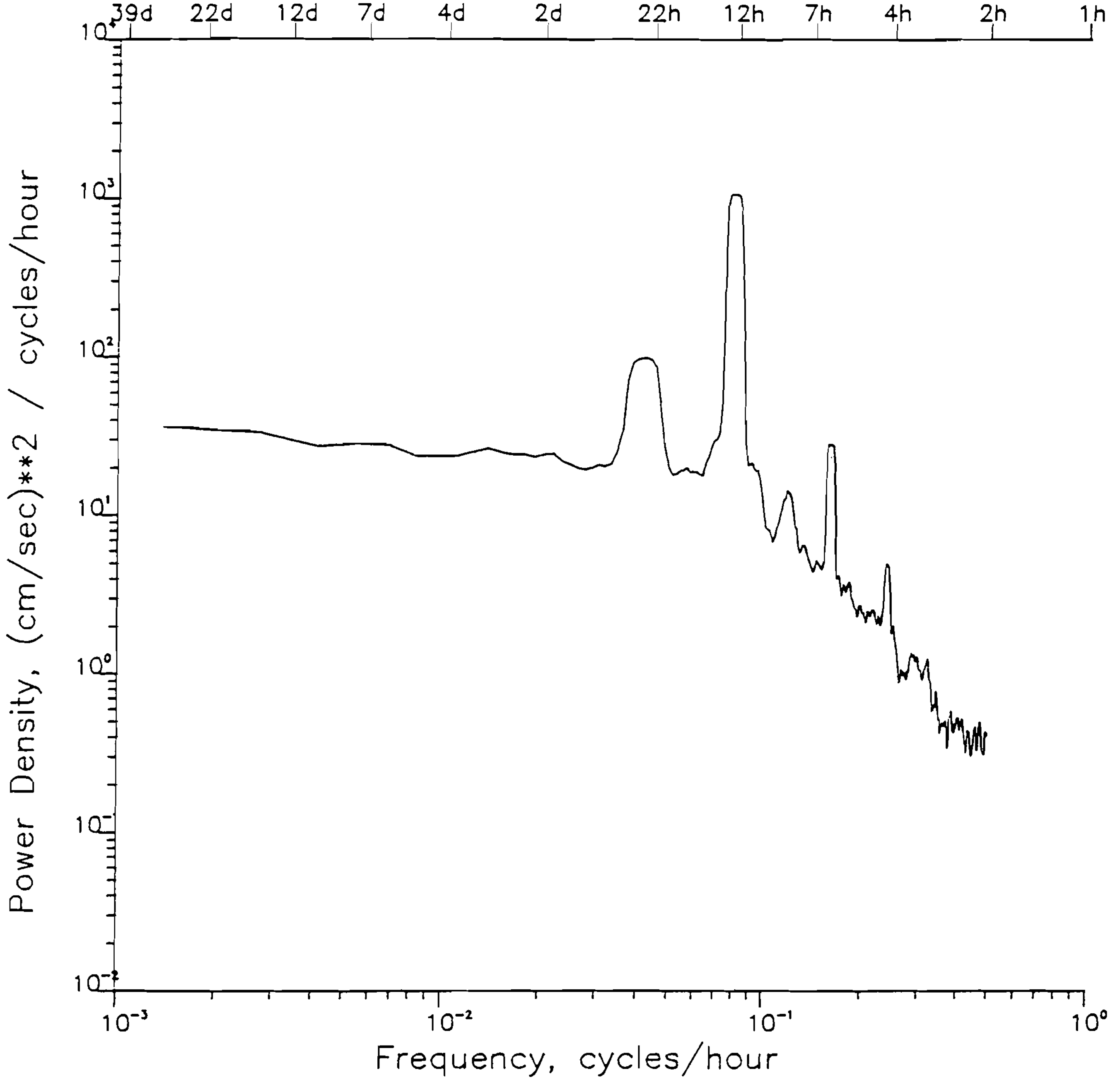
5 pieces.
360 estimates

Along-channel current ACM 95

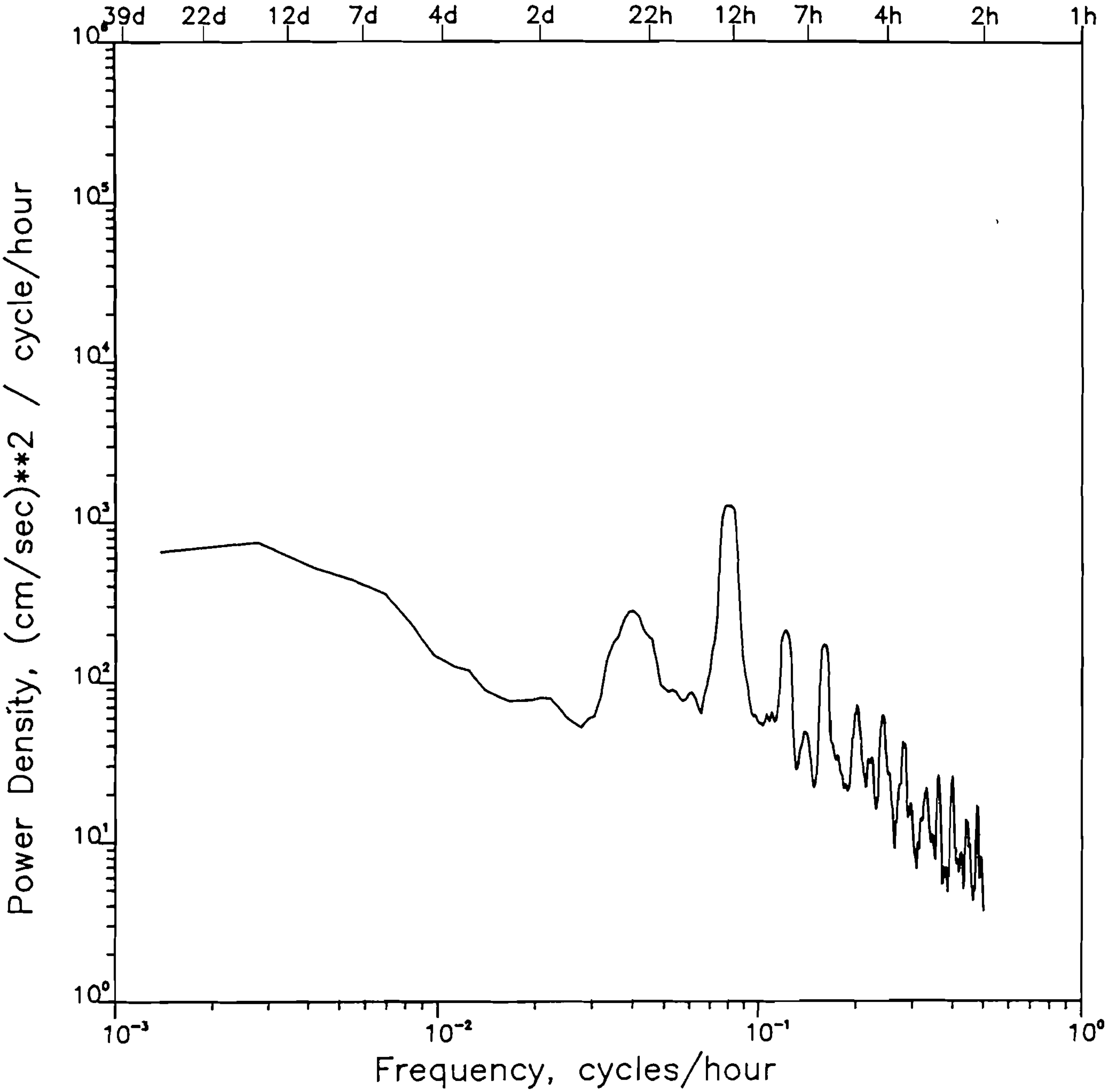


from 05/23/89 to 07/19/89
44% overlap. 3 pieces.
7 band ave. (arithm.) 360 estimates

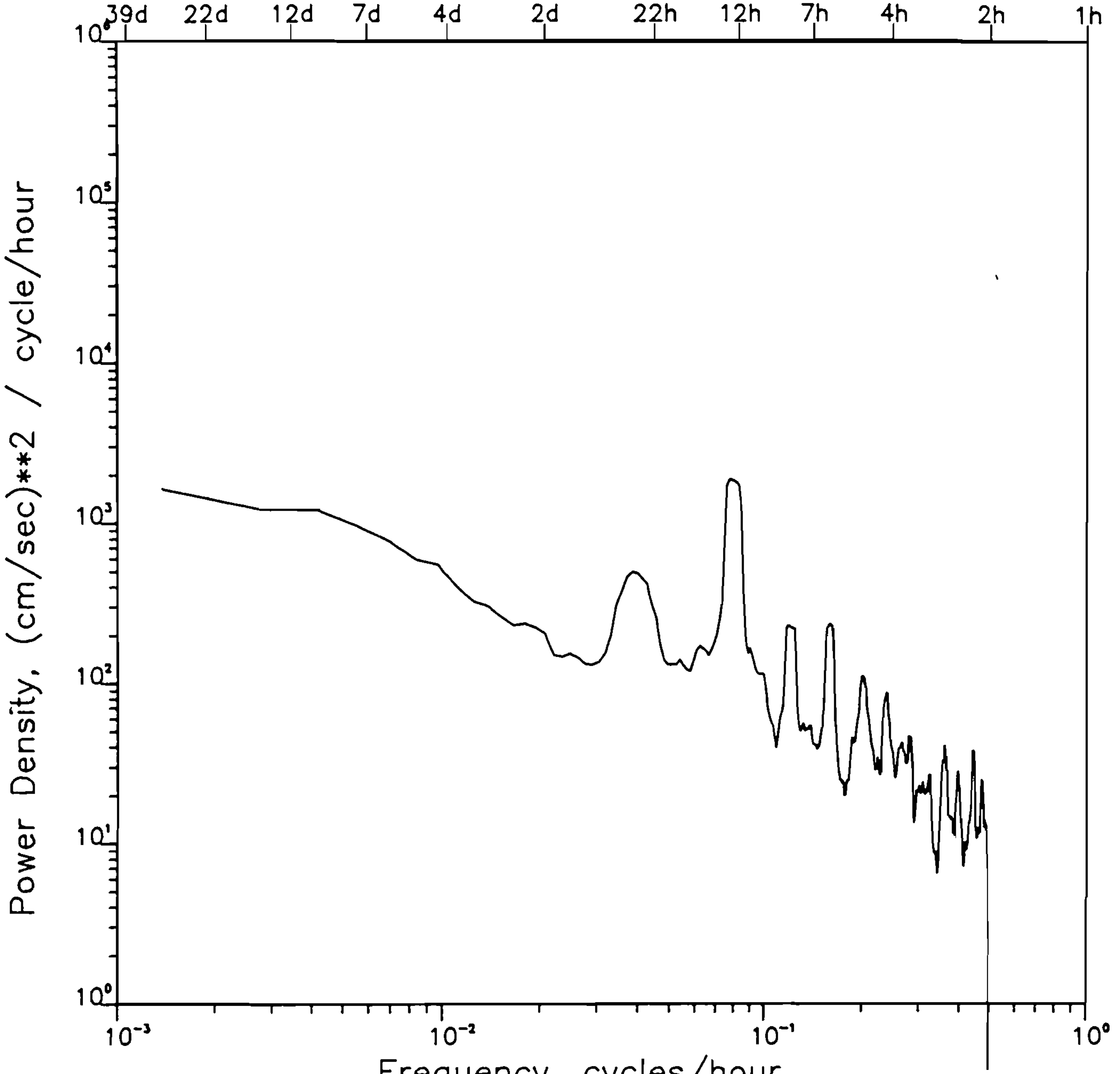
Along−channel current ACM 88



from 05/23/89 to 09/28/89
50% overlap. 7 pieces.
7 band ave. (arithm.) 360 estimates

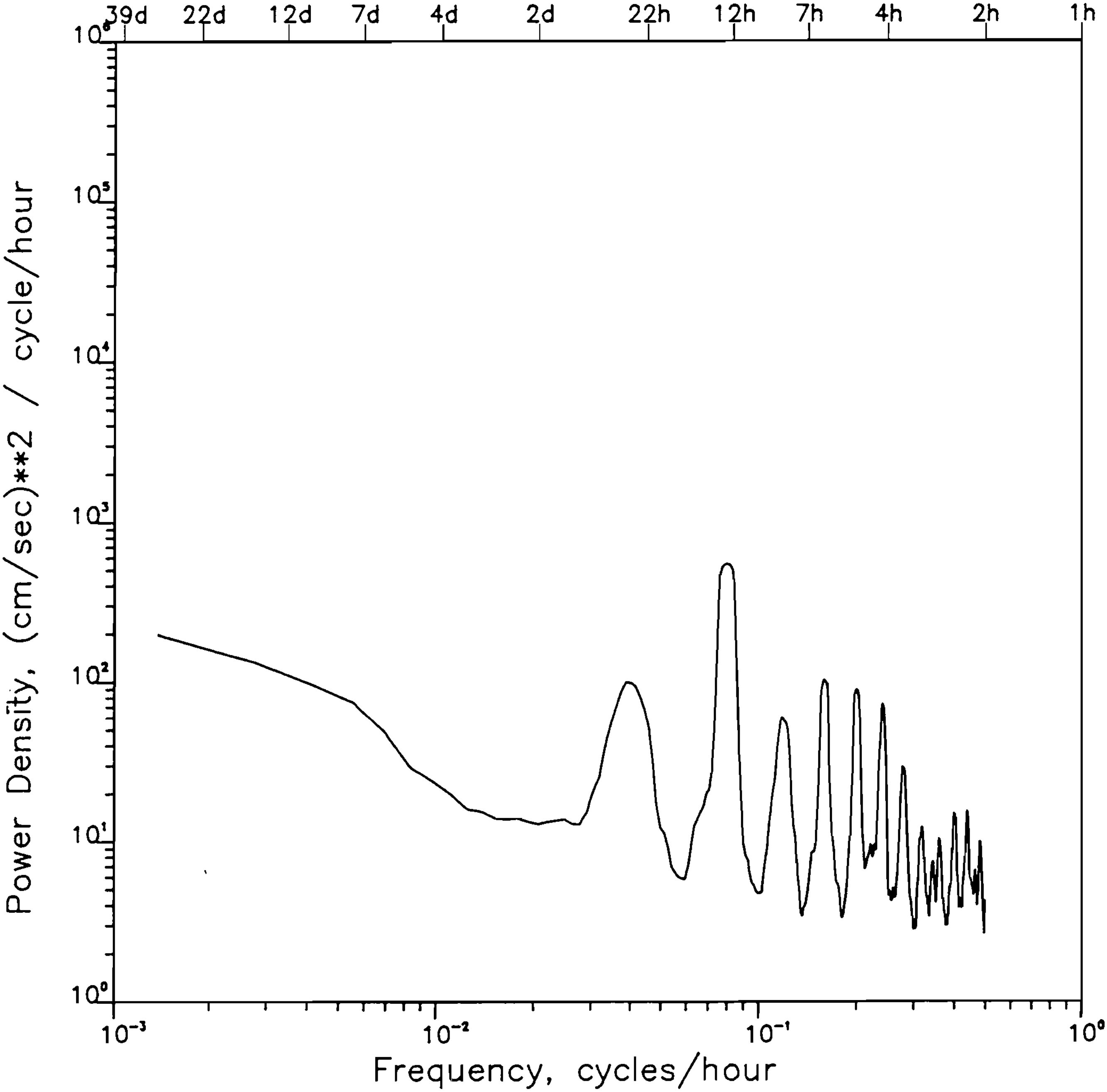


from 05/22/89 to 08/04/89
49% overlap. 4 pieces.
7 band ave. (arithm.) 360 estimates

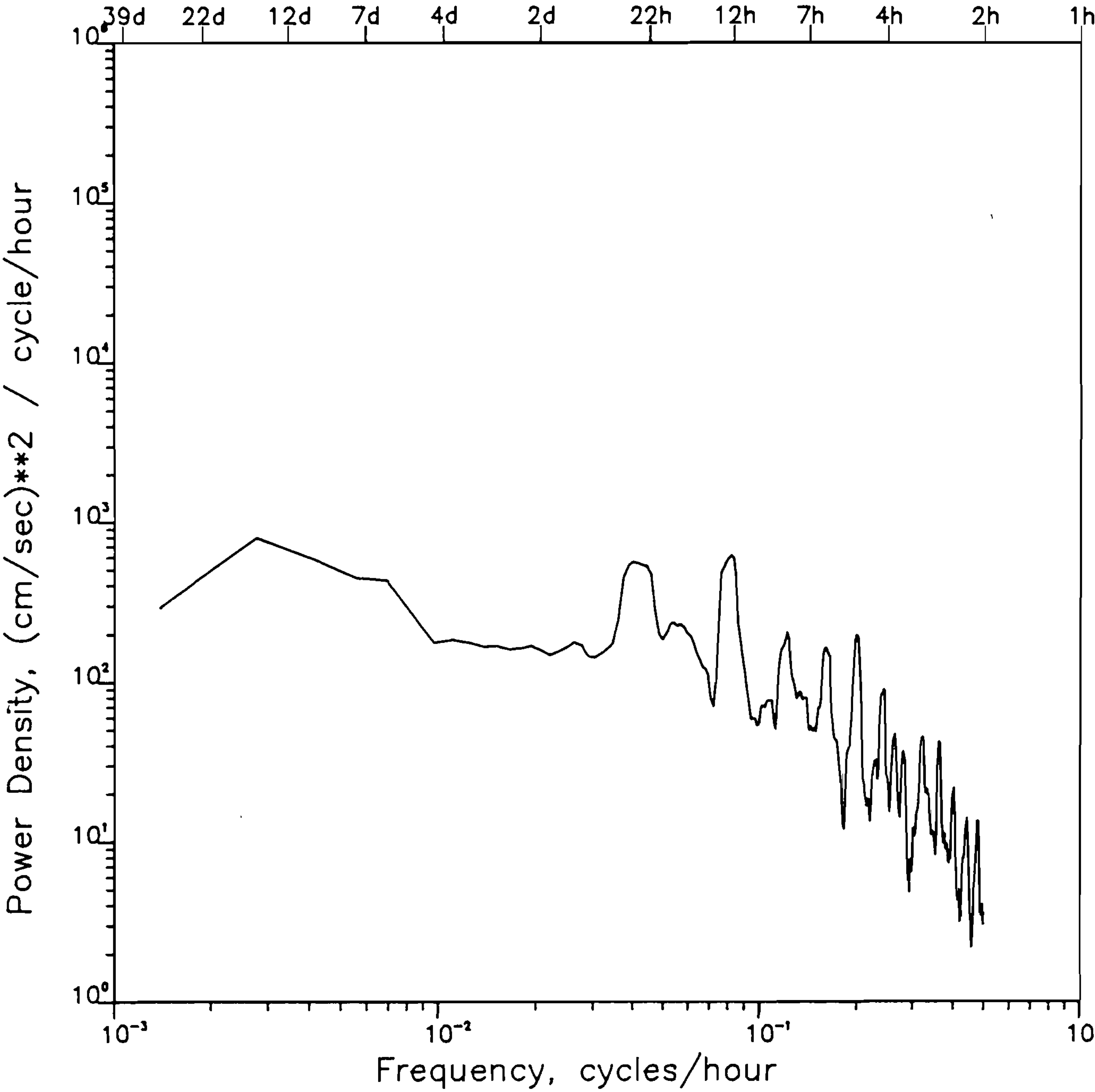


from 05/22/89 to 08/04/89
49% overlap. 4 pieces.
7 band ave. (arithm.) 360 estimates

Cross-channel current ACM 1154

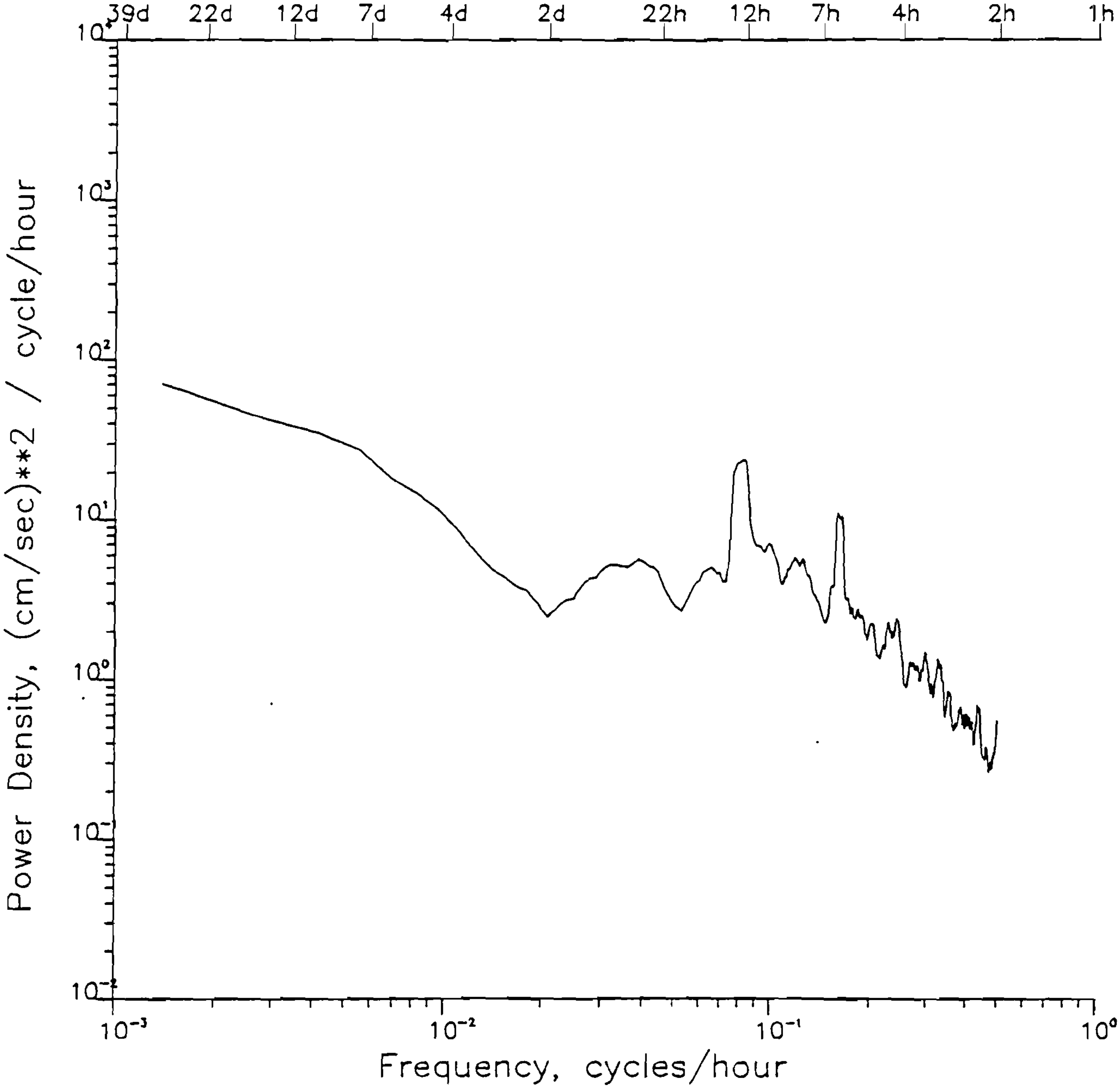


from 05/22/89 to 08/26/89
50% overlap. 5 pieces.
7 band ave. (arithm.) 360 estimates



from 05/23/89 to 07/19/89
44% overlap. 3 pieces.
7 band ave. (arithm.) 360 estimates

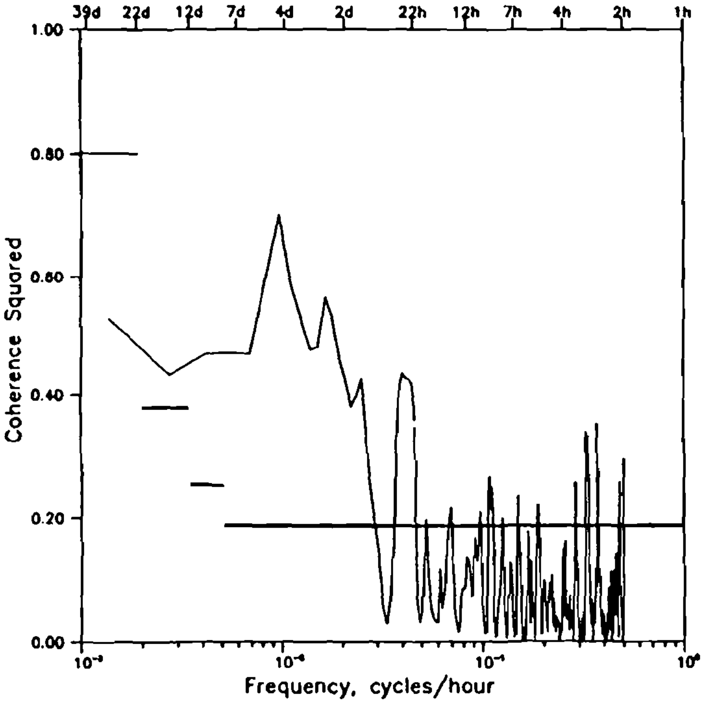
Cross-channel current ACM 8



from 05/23/89 to 09/28/89
50% overlap. 7 pieces.
7 band ave. (arithm.) 360 estimates

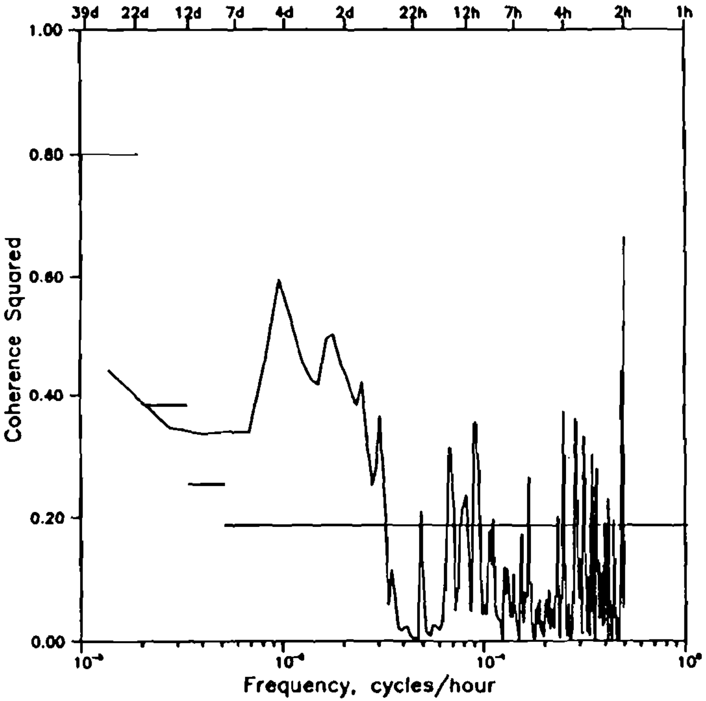
APPENDIX H

PORT MOLLER
1989 COHERENCE AND PHASE PLOTS



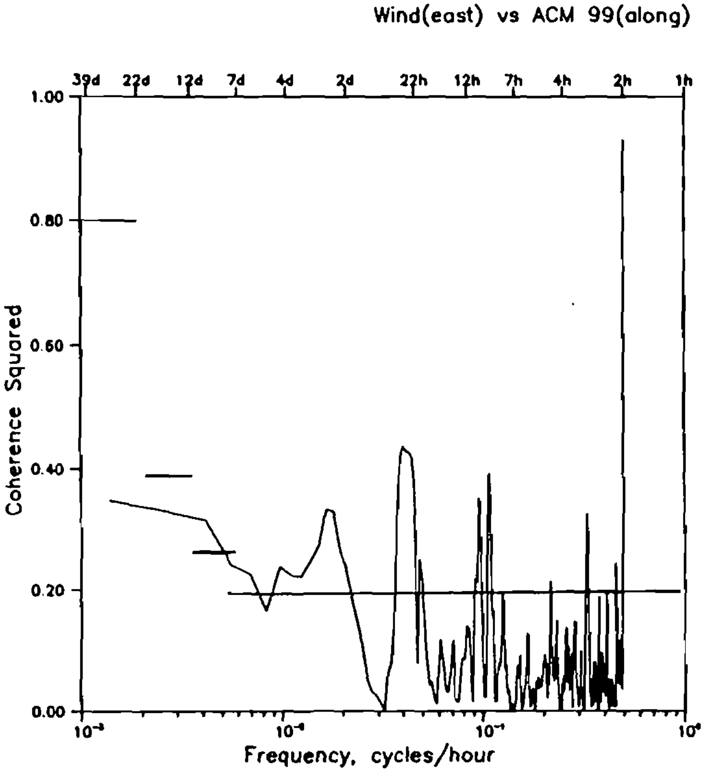
Wind(east) vs ACM 100(along)

from 05/22/89 to 08/04/89
50% overlap. 3 pieces.
7 band ave. (arithm.) 360 estimates

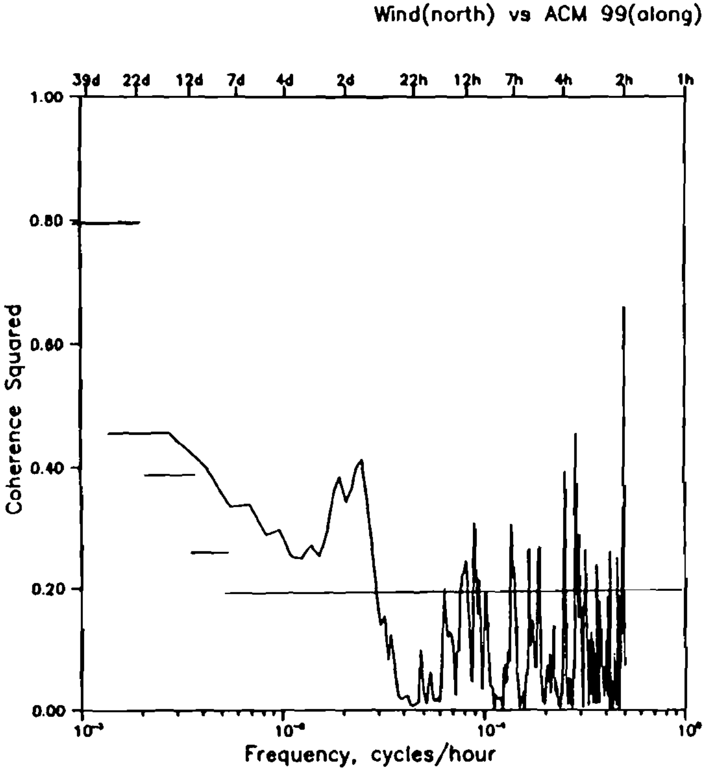


Wind(north) vs ACM 100(along)

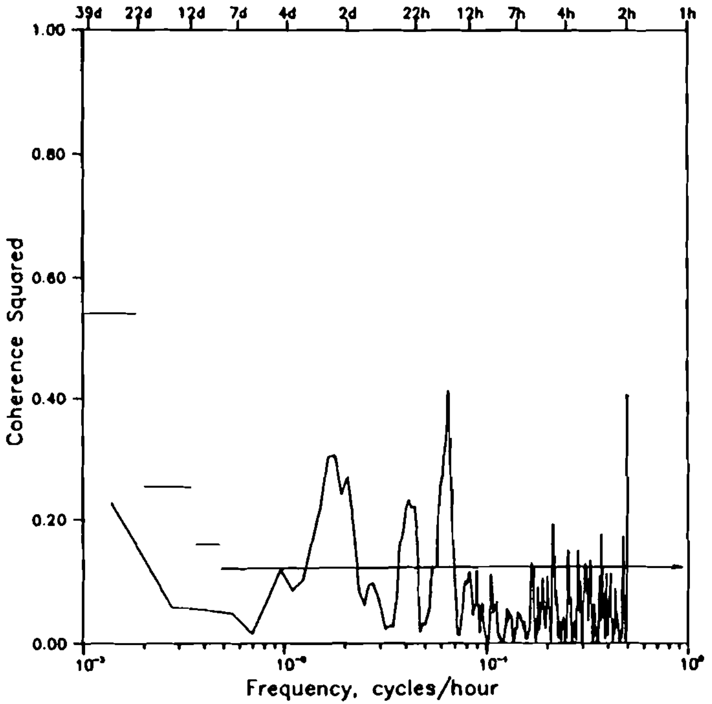
from 05/22/89 to 08/04/89
50% overlap. 3 pieces.
7 band ave. (arithm.) 360 estimates


Wind(east) vs ACM 99(along)

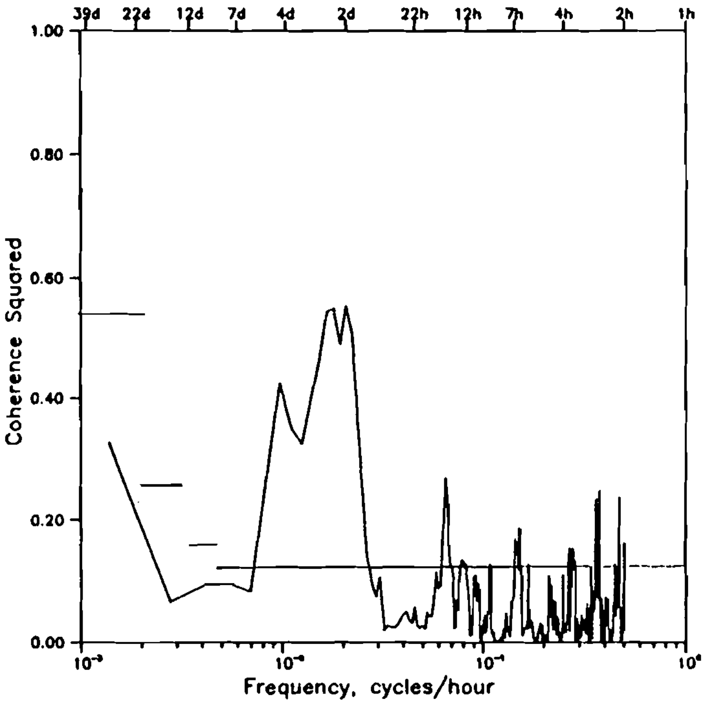
from 05/22/89 to 08/04/89
50% overlap. 3 pieces.
7 band ave. (arithm.) 360 estimates


Wind(north) vs ACM 99(along)

from 05/22/89 to 08/04/89
50% overlap. 3 pieces.
7 band ave. (arithm.) 360 estimates

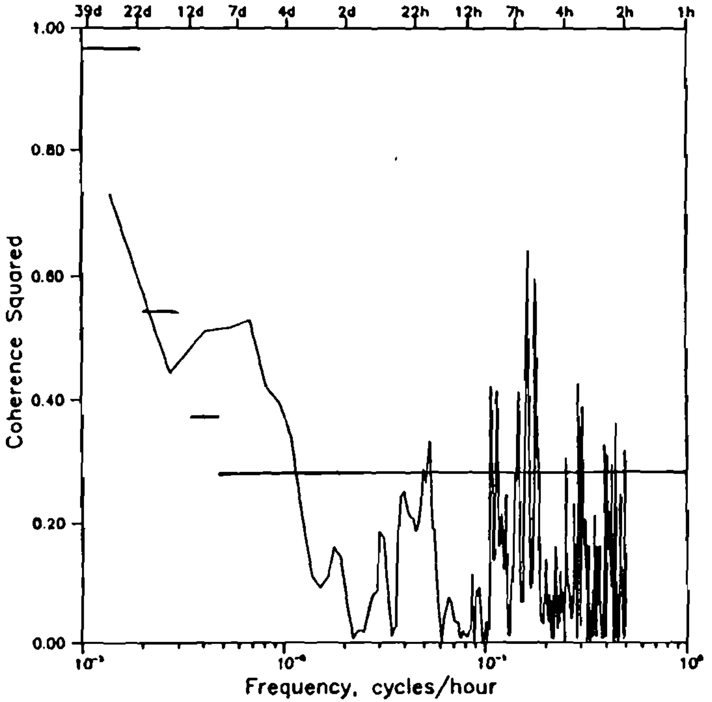

Wind(east) vs ACM 1154(along)

from 05/22/89 to 08/28/89
50% overlap. 5 pieces.
7 band ave. (arithm.) 360 estimates


Wind(north) vs ACM 1154(along)

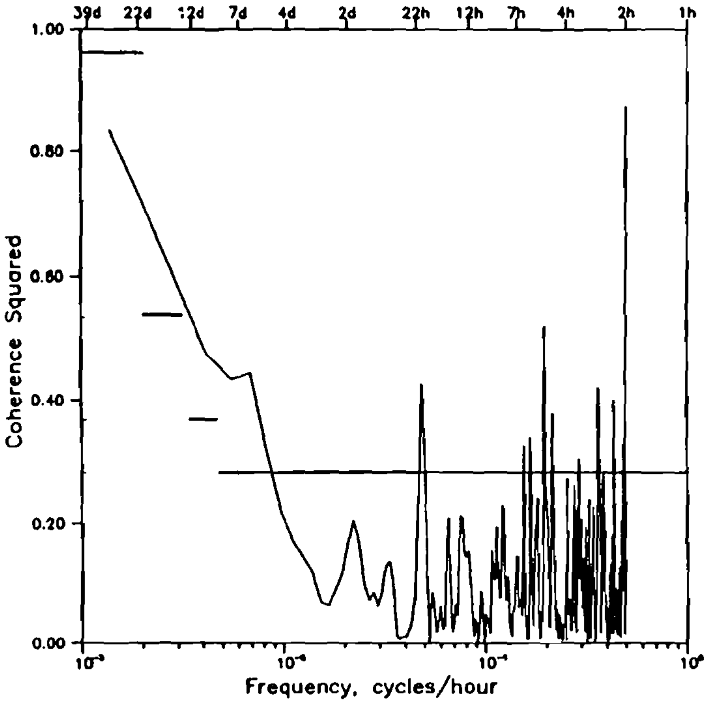
from 05/22/89 to 08/26/89
50% overlap. 5 pieces.
7 band ave. (arithm.) 360 estimates

Wind(east) vs ACM 95(along)



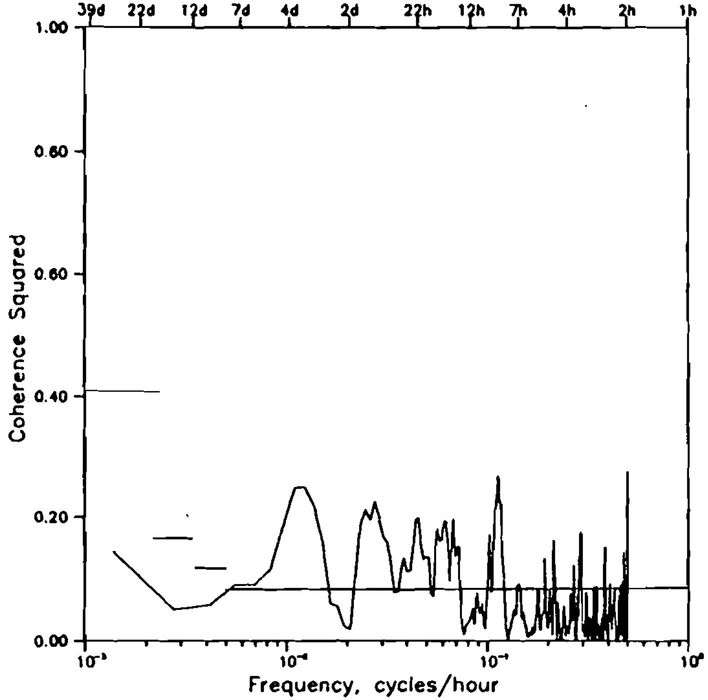
from 05/23/89 to 07/19/89
50% overlap. 2 pieces.
7 band ave. (arithm.) 360 estimates

Wind(north) vs ACM 95(along)



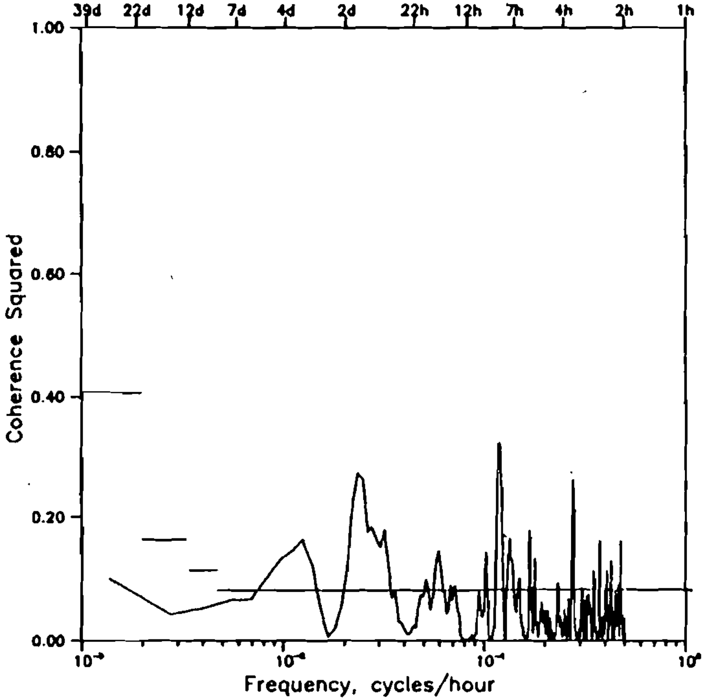
from 05/23/89 to 07/19/89
50% overlap. 2 pieces.
7 band ave. (arithm.) 360 estimates

Wind(east) vs ACM 88(along)



from 05/23/89 to 09/28/89
50% overlap. 7 pieces.
7 band ave. (arithm.) 360 estimates

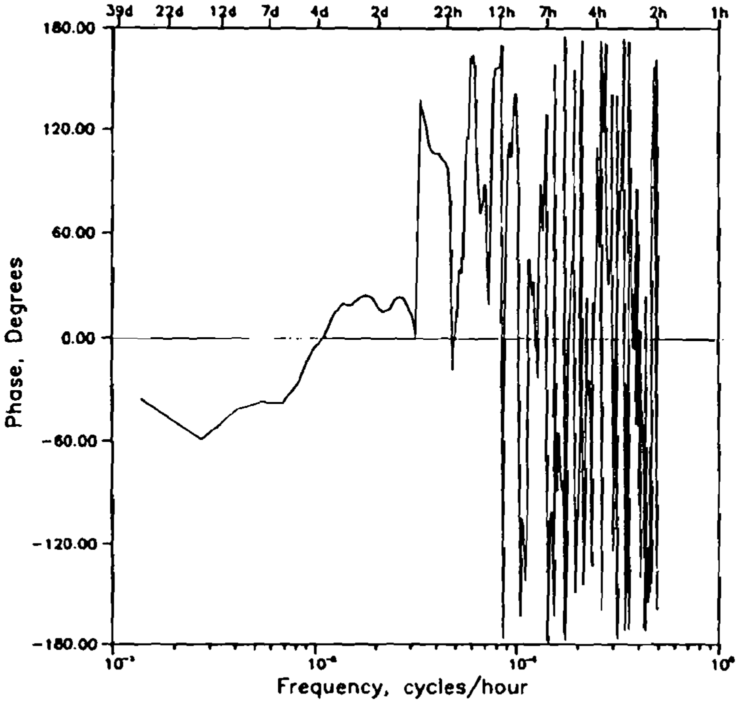
Wind(north) vs ACM 88(along)



from 05/23/89 to 09/28/89
50% overlap. 7 pieces.
7 band ave. (arithm.) 360 estimates

Wind(east) vs ACM 100(along)

PHASE POSITIVE FOR X LEADING Y

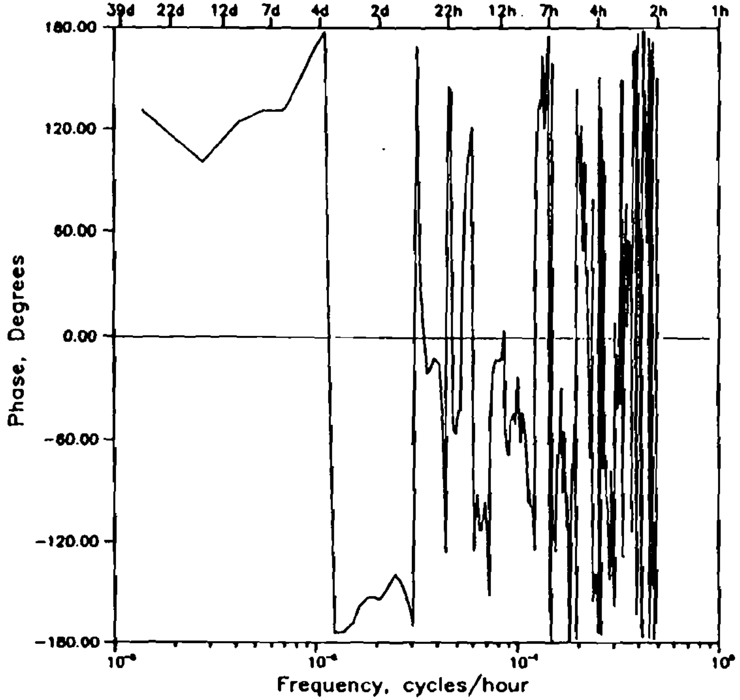


from 05/22/89 to 08/04/89
50% overlap.
7 band ave. (arithm.)

3 pieces.
360 estimates

Wind(north) vs ACM 100(along)

PHASE POSITIVE FOR X LEADING Y

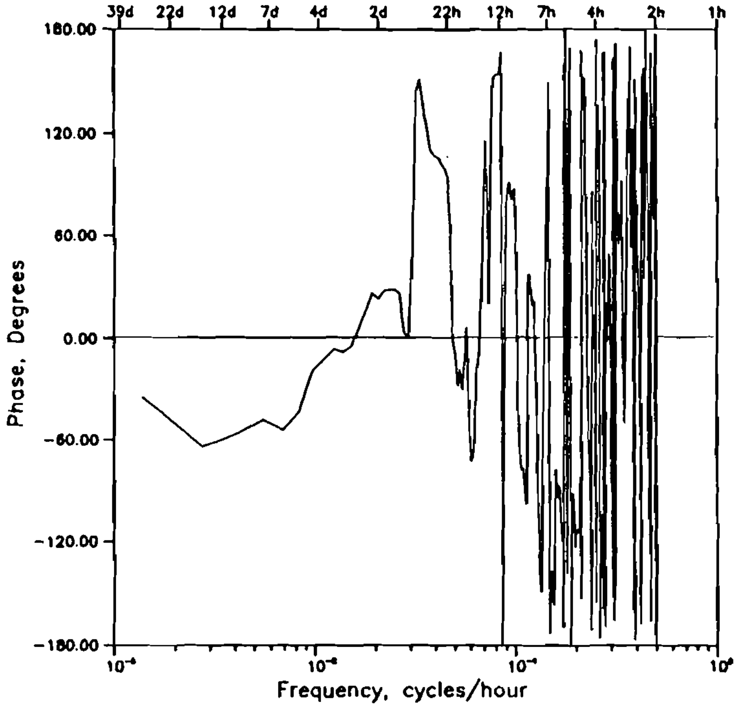


from 05/22/89 to 08/04/89
50% overlap.
7 band ave. (arithm.)

3 pieces.
360 estimates

Wind(east) vs ACM 99(along)

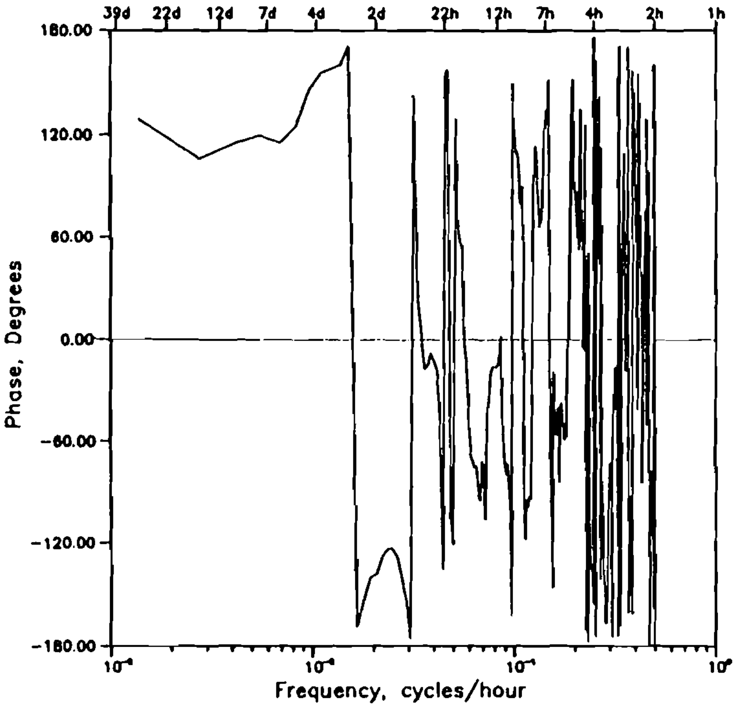
PHASE POSITIVE FOR X LEADING Y



from 05/22/89 to 08/04/89
50% overlap. 3 pieces.
7 band ave. (arithm.) 360 estimates

Wind(north) vs ACM 99(along)

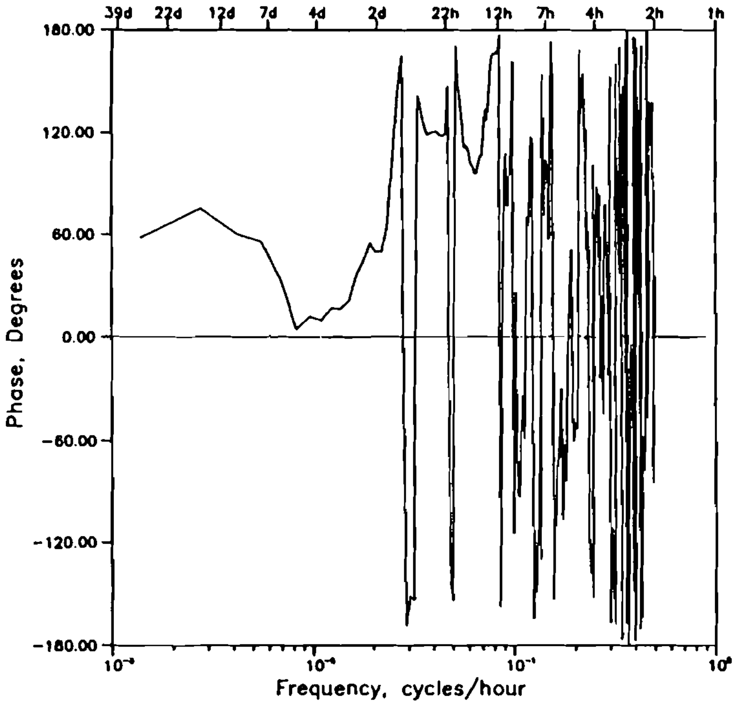
PHASE POSITIVE FOR X LEADING Y



from 05/22/89 to 08/04/89
50% overlap. 3 pieces.
7 band ave. (arithm.) 360 estimates

Wind(east) vs ACM 1154(along)

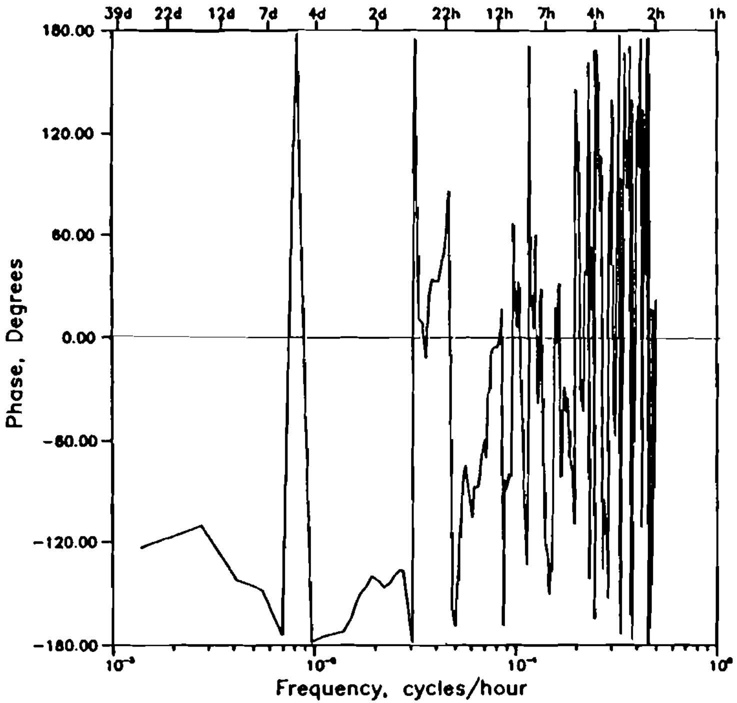
PHASE POSITIVE FOR X LEADING Y



from 05/22/89 to 08/26/89
50% overlap. 5 pieces.
7 band ave. (arithm.) 360 estimates

Wind(north) vs ACM 1154(along)

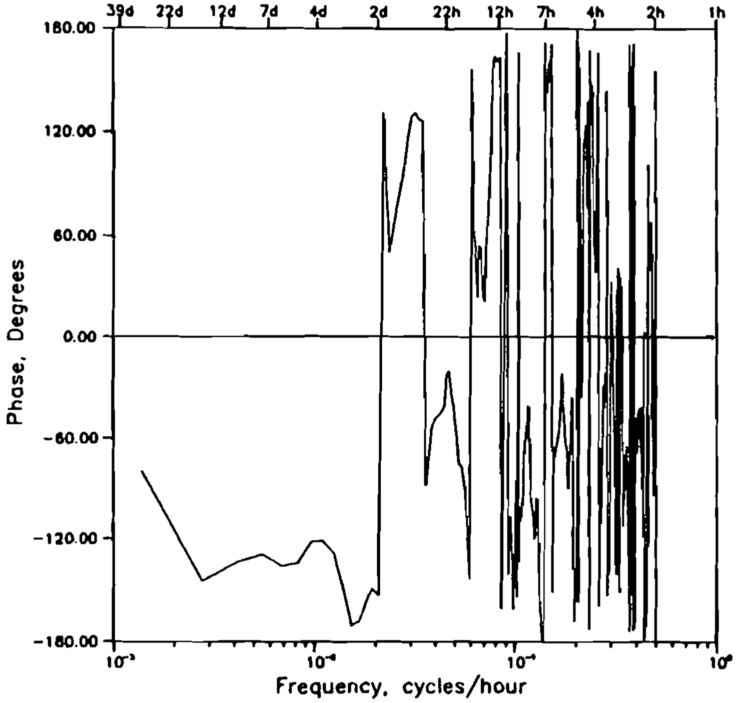
PHASE POSITIVE FOR X LEADING Y



from 05/22/89 to 08/26/89
50% overlap. 5 pieces.
7 band ave. (arithm.) 360 estimates

Wind(east) vs ACM 95(along)

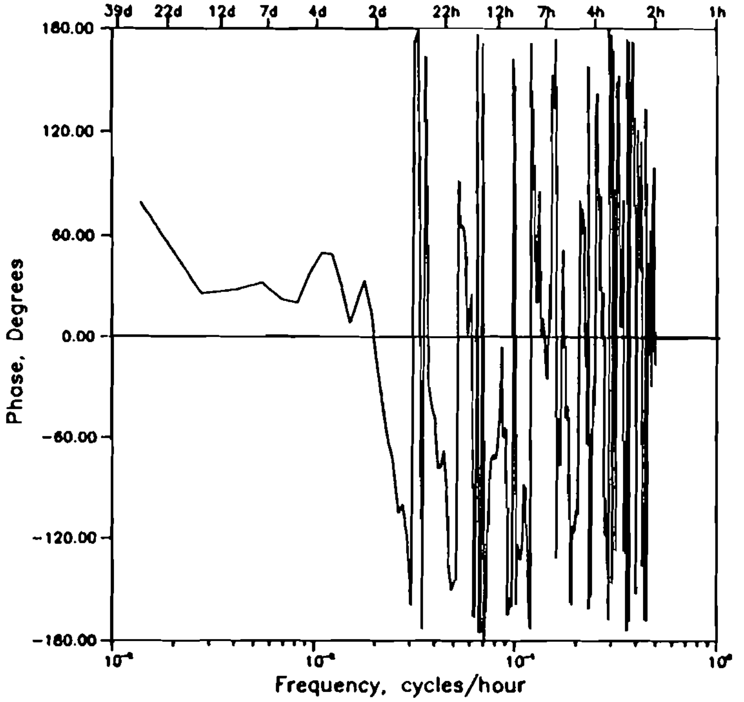
PHASE POSITIVE FOR X LEADING Y



from 05/23/89 to 07/19/89
50% overlap.
7 band ave. (arithm.)
2 pieces.
360 estimates

Wind(north) vs ACM 95(along)

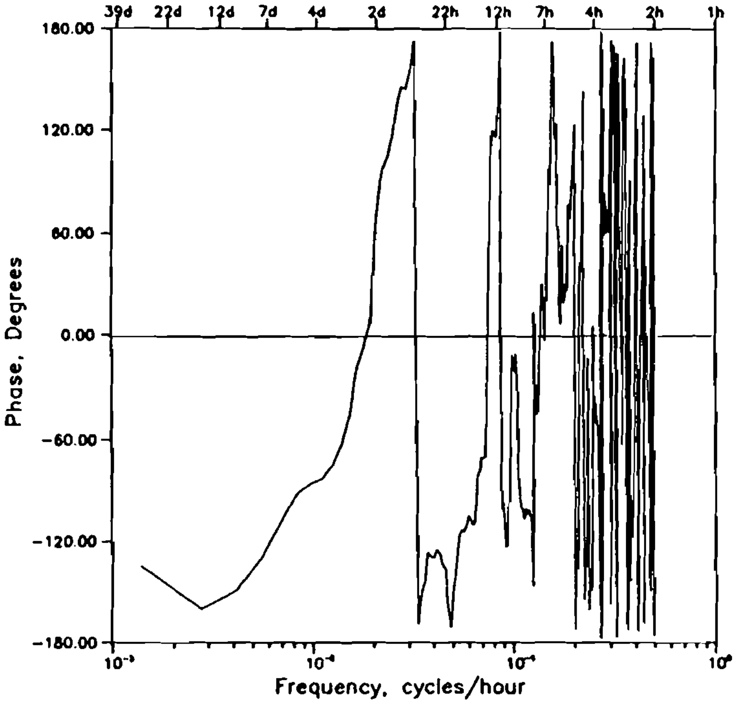
PHASE POSITIVE FOR X LEADING Y



from 05/23/89 to 07/19/89
50% overlap.
7 band ave. (arithm.)
2 pieces.
360 estimates

Wind(east) vs ACM 88(along)

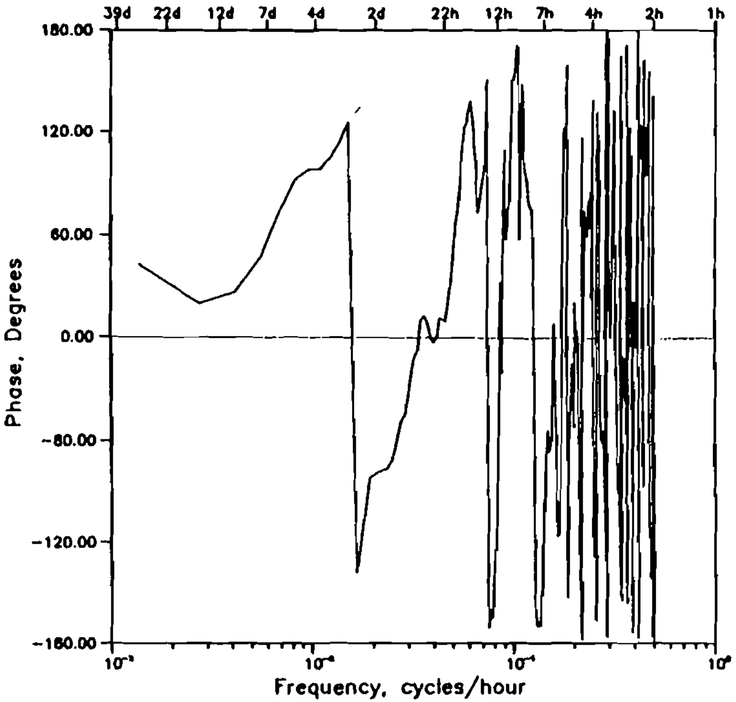
PHASE POSITIVE FOR X LEADING Y



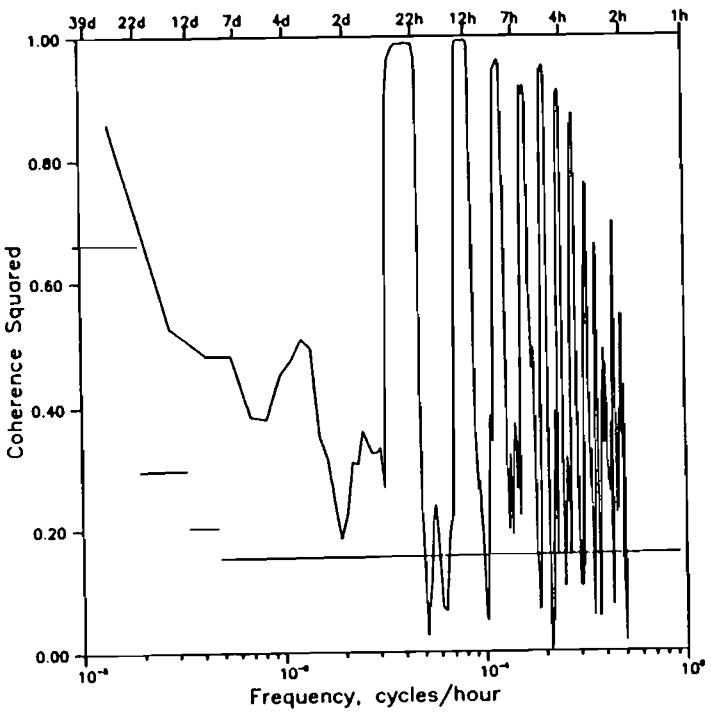
from 05/23/89 to 09/28/89
50% overlap. 7 pieces.
7 band ave. (arithm.) 360 estimates

Wind(north) vs ACM 88(along)

PHASE POSITIVE FOR X LEADING Y

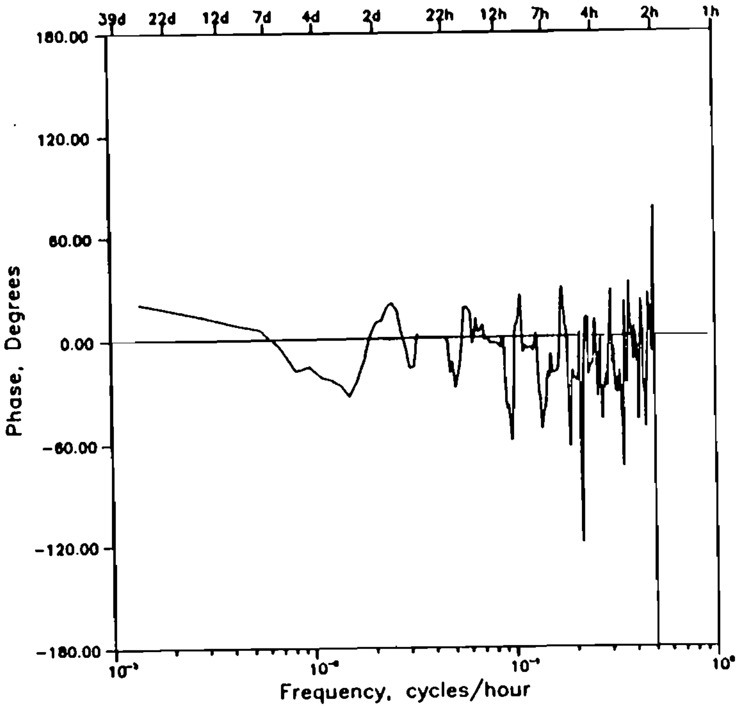


from 05/23/89 to 09/28/89
50% overlap. 7 pieces.
7 band ave. (arithm.) 360 estimates



ACM 100 vs ACM 99 (along)

from 05/22/89 to 08/04/89
49% overlap.
7 band ave. (arithm.)
4 pieces.
360 estimates

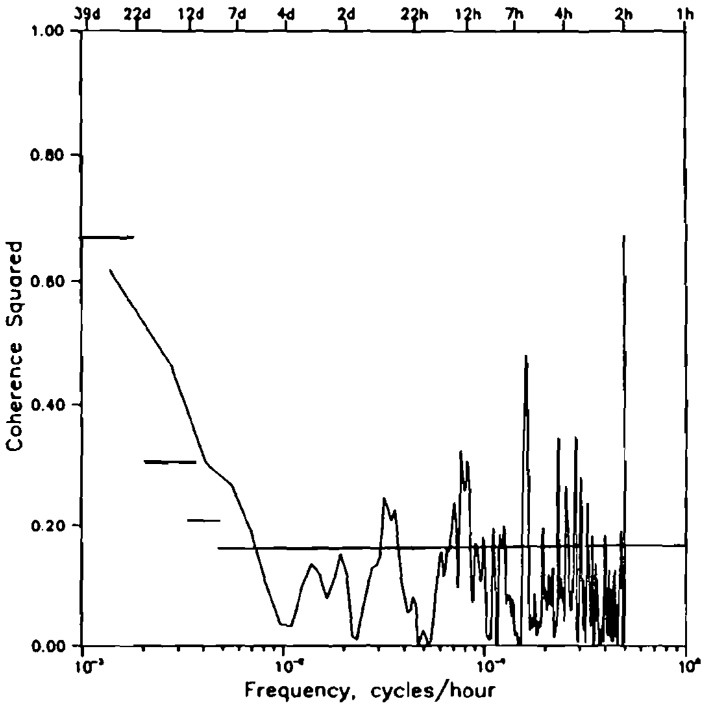


ACM 100 vs ACM 99 (along)

PHASE POSITIVE FOR X LEADING Y

from 05/22/89 to 08/04/89
49% overlap.
7 band ave. (arithm.)
4 pieces.
360 estimates

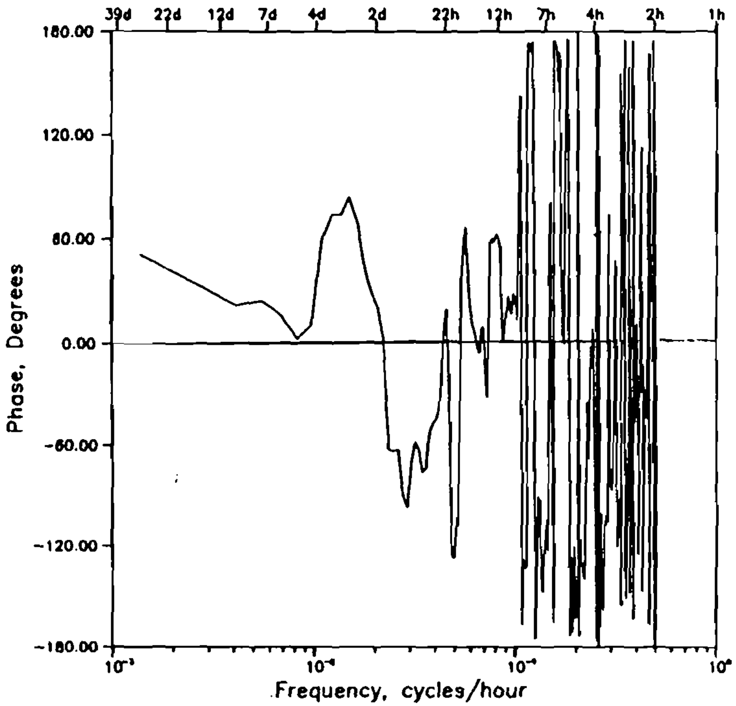
ACM 100 vs ACM 99 (cross)



from 05/22/89 to 08/04/89
49% overlap. 4 pieces.
7 band ave. (arithm.) 360 estimates

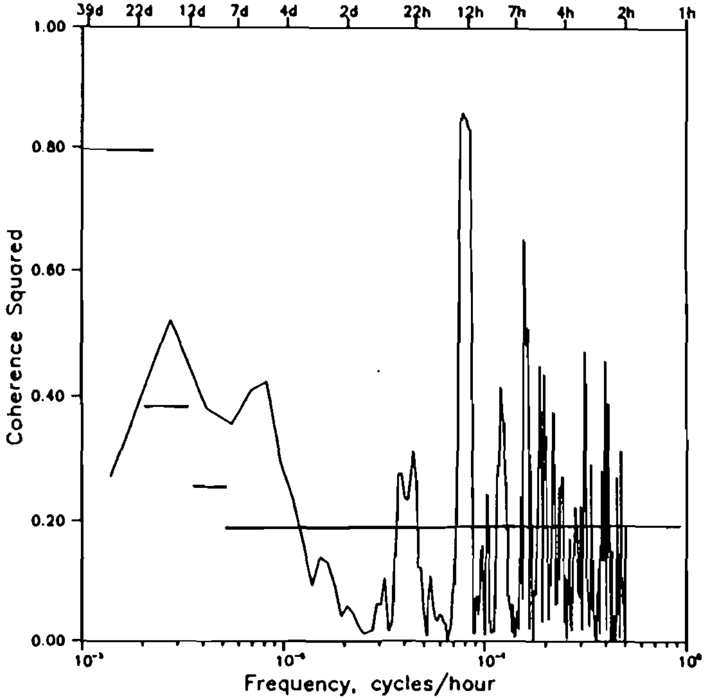
ACM 100 vs ACM 99 (cross)

PHASE POSITIVE FOR X LEADING Y



from 05/22/89 to 08/04/89
49% overlap. 4 pieces.
7 band ave. (arithm.) 360 estimates

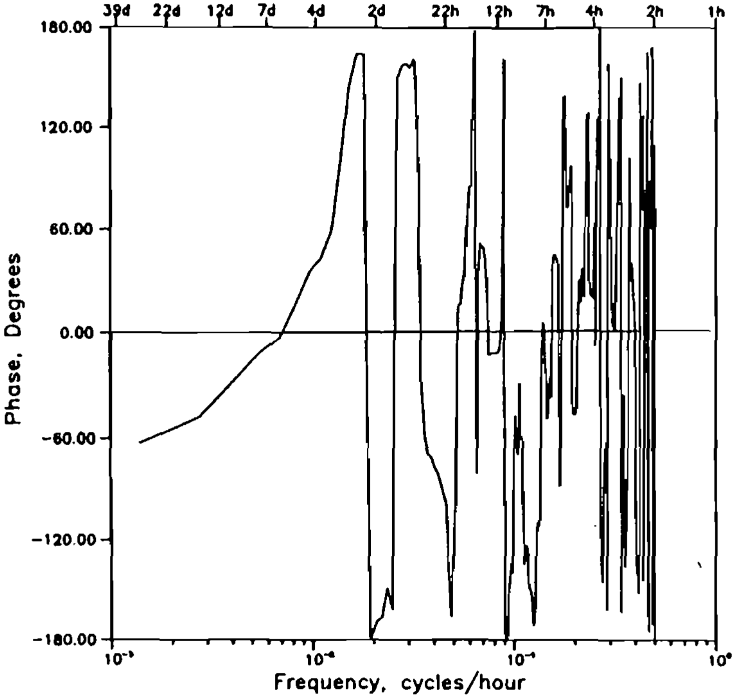
ACM 95 vs ACM 88 (along)



from 05/23/89 to 07/19/89
44% overlap. 3 pieces.
7 band ave. (arithm.) 360 estimates

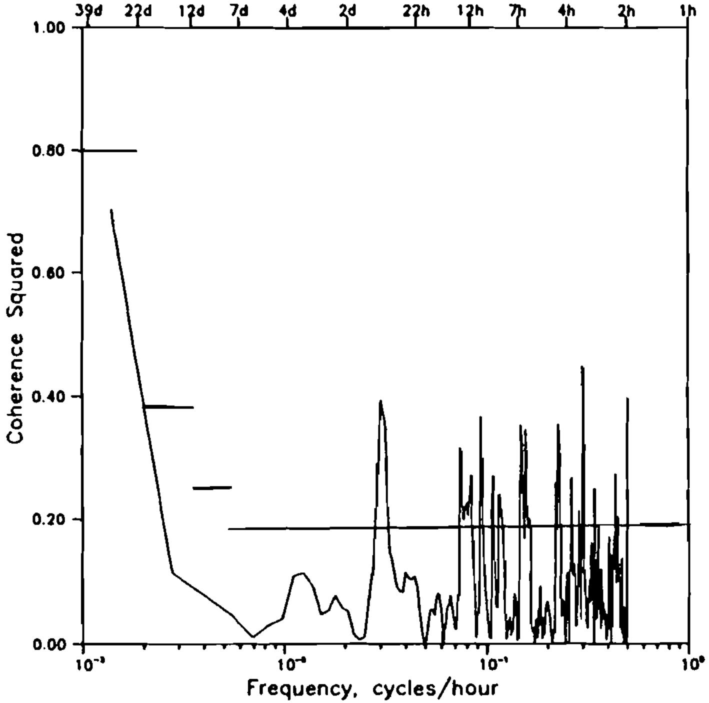
ACM 95 vs ACM 88 (along)

PHASE POSITIVE FOR X LEADING Y



from 05/23/89 to 07/19/89
44% overlap. 3 pieces.
7 band ave. (arithm.) 360 estimates

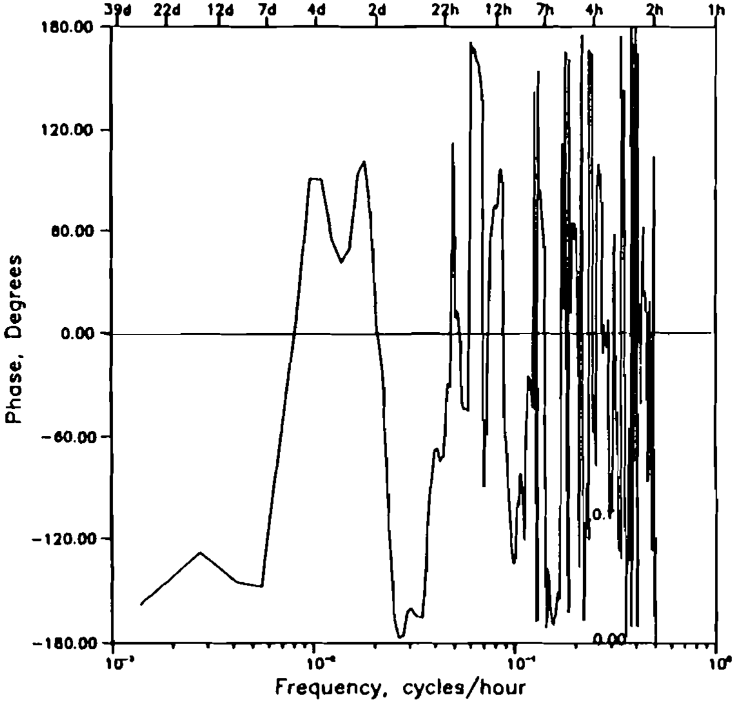
ACM 95 vs ACM 88 (cross)



from 05/23/89 to 07/19/89
44% overlap.
7 band ave. (arithm.)
3 pieces.
360 estimates

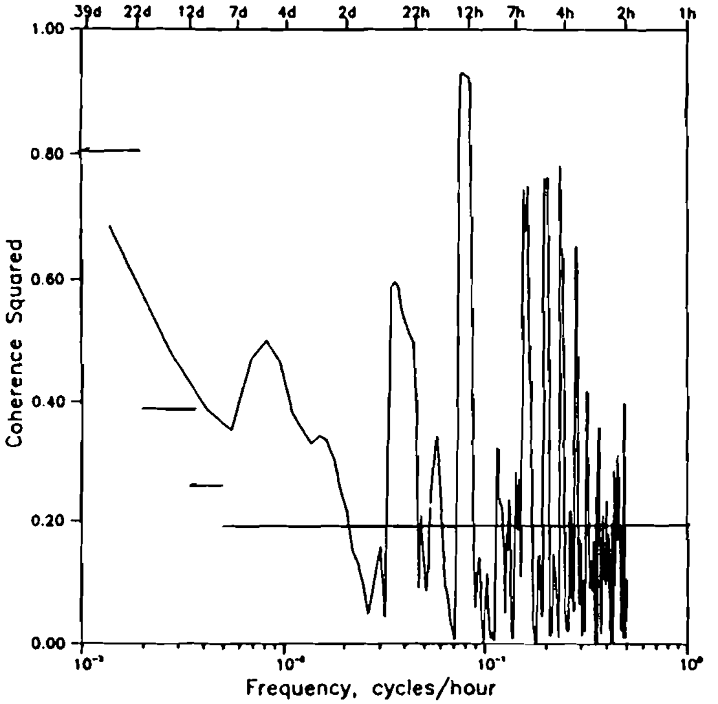
ACM 95 vs ACM 88 (cross)

PHASE POSITIVE FOR X LEADING Y



from 05/23/89 to 07/19/89
44% overlap.
7 band ave. (arithm.)
3 pieces.
360 estimates

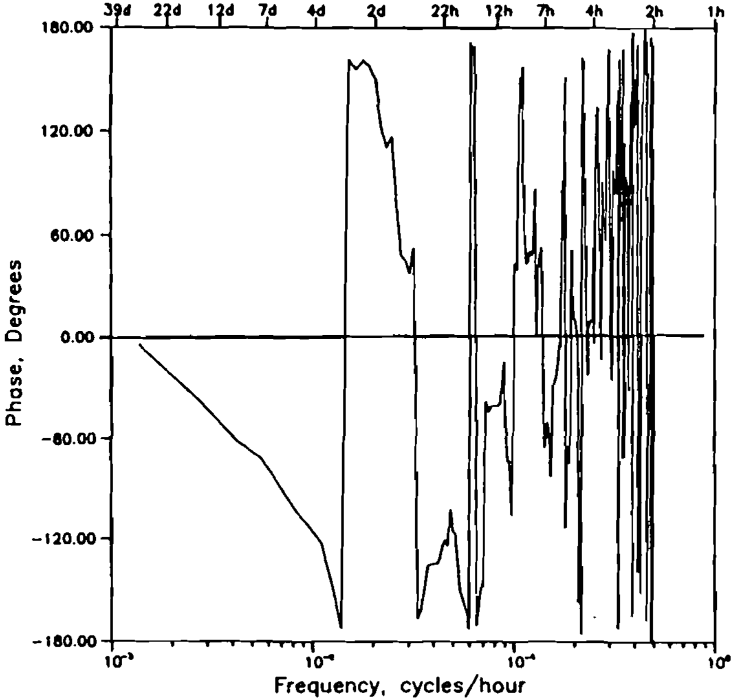
ACM 100 vs ACM 95 (along)



from 05/23/89 to 08/04/89
43% overlap. 3 pieces.
7 band ave. (arithm.) 360 estimates

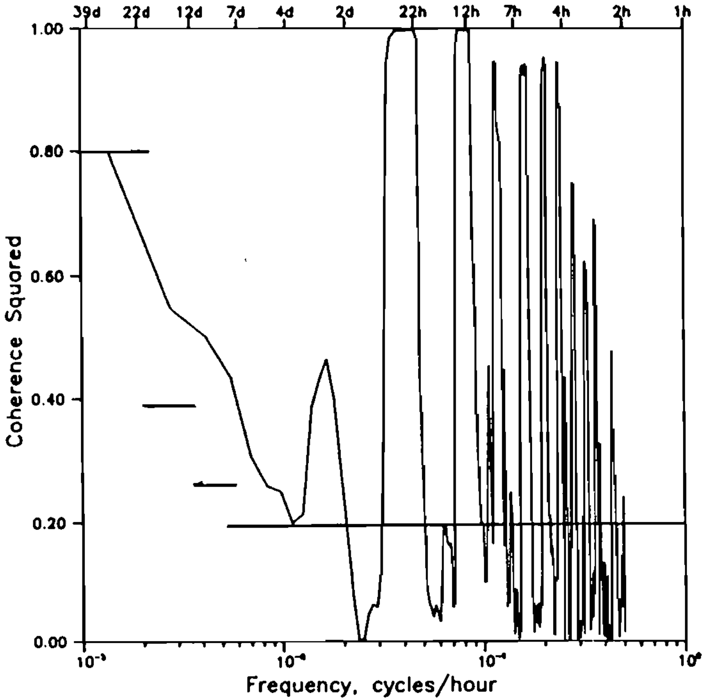
ACM 100 vs ACM 95 (along)

PHASE POSITIVE FOR X LEADING Y



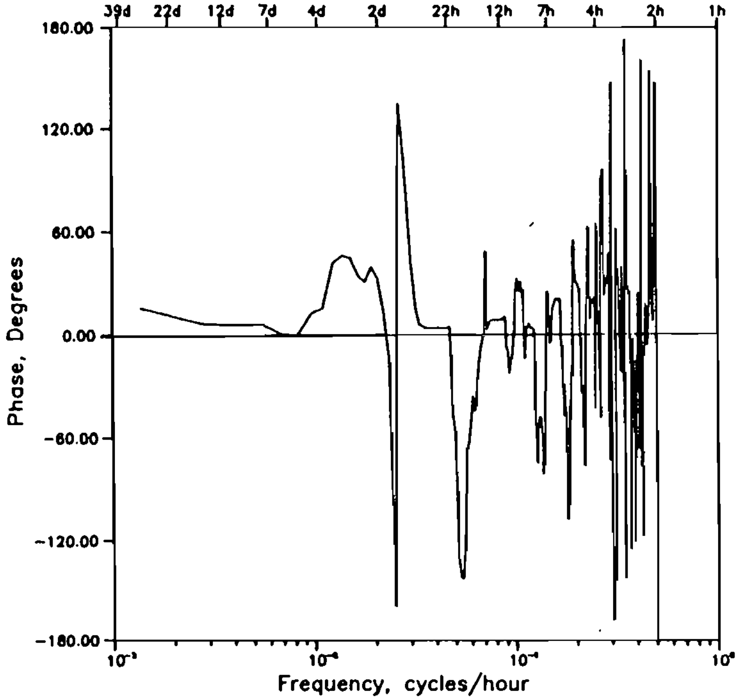
from 05/23/89 to 08/04/89
43% overlap. 3 pieces.
7 band ave. (arithm.) 360 estimates

ACM 100 vs ACM 1154 (along)



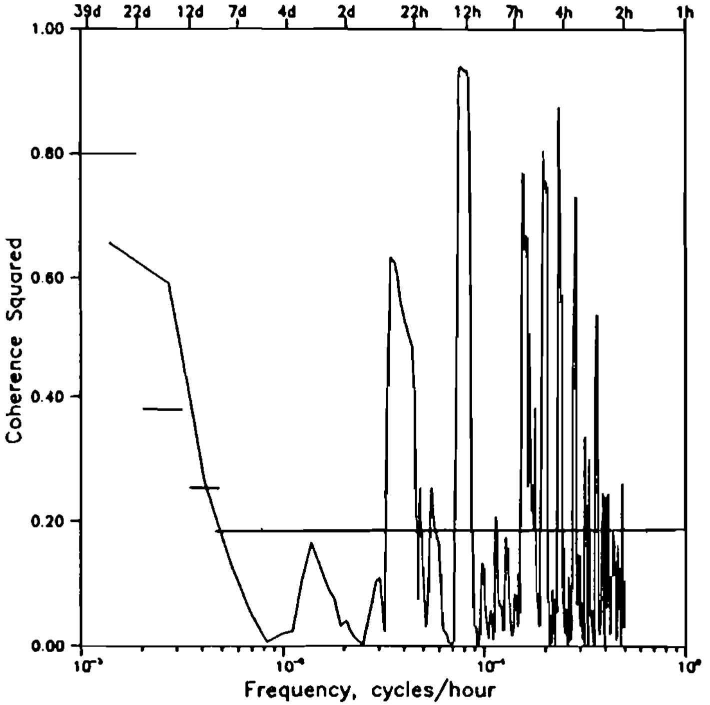
from 05/22/89 to 08/04/89
49% overlap.
7 band ave. (arithm.)
3 pieces.
360 estimates

ACM 100 vs ACM 1154 (along)
PHASE POSITIVE FOR X LEADING Y



from 05/22/89 to 08/04/89
49% overlap.
7 band ave. (arithm.)
3 pieces.
360 estimates

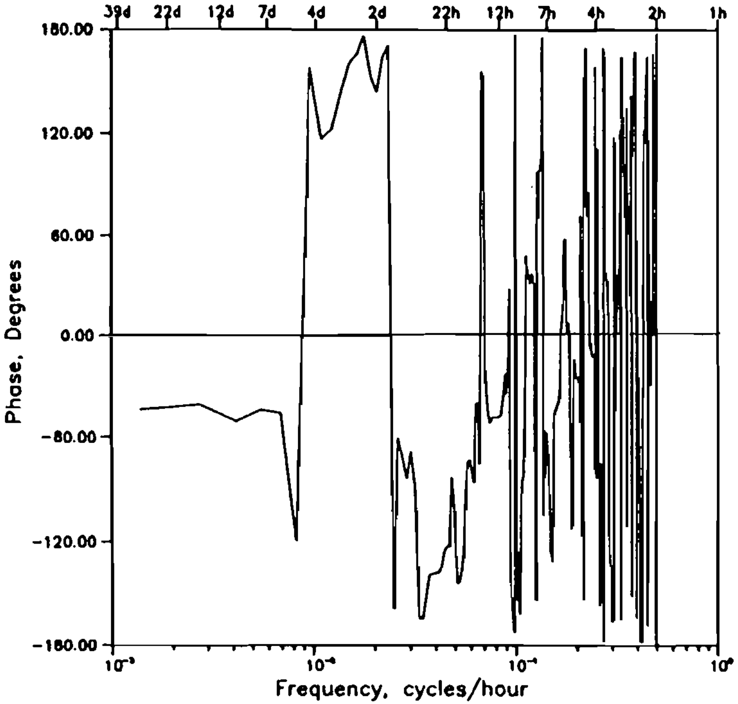
ACM 1154 vs ACM 95 (along)



from 05/23/89 to 07/19/89
44% overlap.
7 band ave. (arithm.)
3 pieces.
360 estimates

ACM 1154 vs ACM 95 (along)

PHASE POSITIVE FOR X LEADING Y



from 05/23/89 to 07/19/89
44% overlap.
7 band ave. (arithm.)
3 pieces.
360 estimates