MARINE ENVIRONMENTAL CONDITIONS IN THE EASTERN NORTH PACIFIC OCEAN January 1978 - March 1979

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LARGE-SCALE MARINE CLIMATIC CONDITIONS

Atmospheric Circulation

Wagner (1979) described the atmospheric circulation and weather over North America during 1978. The winter 1977-78 and the first part of the winter 1978-79 continued a pattern of atmospheric circulation begun in 1976-77 in which a strong ridge of atmospheric pressure formed along the west coast with a trough downstream over the central or eastern United States (Fig. 1). This circulation continued the pattern of winter 1976-77, with mild temperatures and abundant precipitation in Alaska areas with cold, snowy weather to the east. During winter 1977-78 temperatures along the California coast were near or above normal and precipitation was abundant as the ridge allowed storms to move in from the southwest. During December 1978 and January 1979 the ridge formed again but was shifted to the west several hundred kilometers off the coast and extended northwards over Alaska. This allowed some northerly flow over the west coast, bringing below normal temperatures, especially over the southern part of California. By February 1979 the ridge shifted farther west and became an "omega type" blocking ridge over the Bering Strait (Dickson 1979). This led to the formation of a trough near the west coast which brought above normal precipitation to much of the coast.

Surface Pressure

Maps of the distribution of surface barometric pressure are available routinely from many agencies (see, for example, those published in Fishing Information); for brevity they are not reproduced here. These maps show the Aleutian low pressure system centered near the Aleutian Islands in winter with resultant westerly winds over much of the North Pacific. In spring and summer the low fills and weakens and the North Pacific high-pressure system expands from off California so that by August the high dominates the circulation of the northeastern Pacific. In fall the high-pressure cell contracts and the Aleutian low deepens and resumes its normal winter position over the Aleutians.

This annual pattern of pressure distribution occurred in 1978 and early 1979 with several variations. In early 1978 strong westerly winds occurred over much of the northeastern Pacific and apparently caused strengthened flow of the California Current. In September 1978 an isolated low-pressure system occurred in the Gulf of Alaska.

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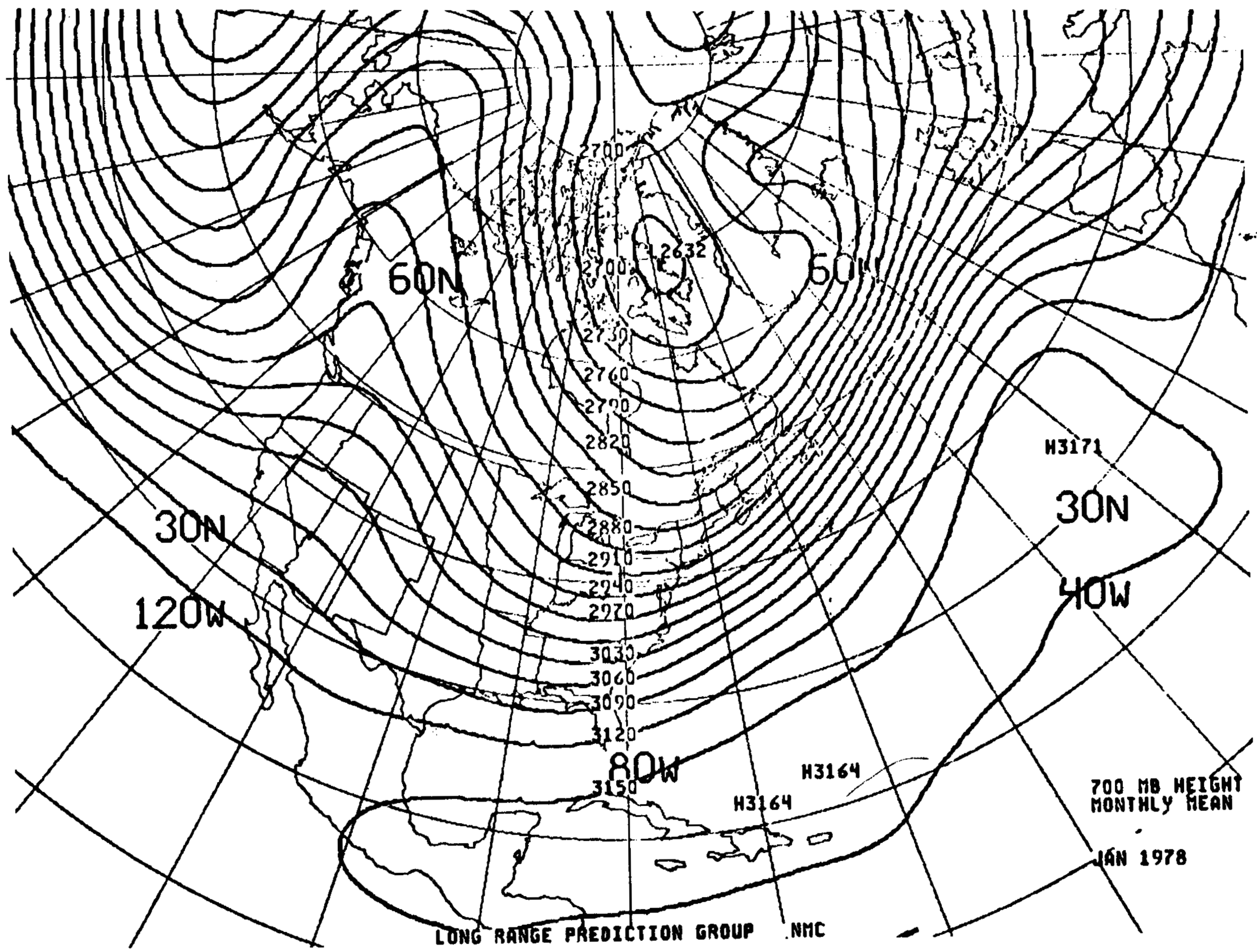
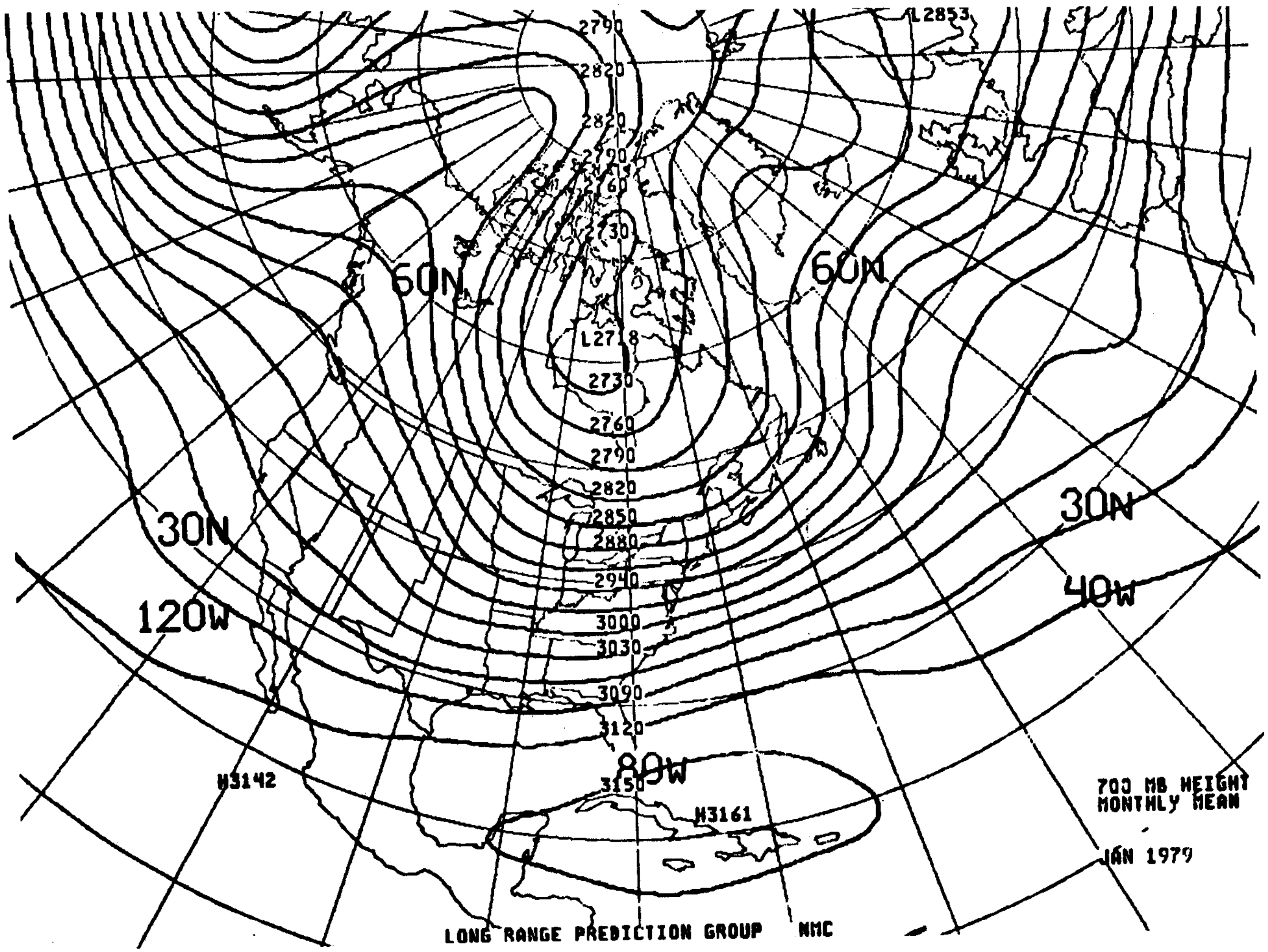


Figure 1.--Height of the 700 mb pressure surface (meters) in January 1978 (upper) and January 1979 (lower). From 30°-60°N the upper level winds flow generally west to east (midlatitude westerlies) parallel to the contour lines, carrying with them to some extent the air mass conditions of temperature and humidity of upstream areas. The closer the spacing of the contour lines, the steeper the height gradient of the pressure surface, and the



faster the wind speeds; thus the farther downstream the upstream air mass characteristics may be carried. In general, under a pressure surface ridge or area of divergence of the contour lines, weather is fair, warm, and dry; under a trough or area of convergence of the contour lines, weather is likely to be cloudy, cold, wet, and stormy. Charts supplied by the Long Range Prediction Group, NWS, Washington, DC 20233.

In January 1979 an intense Aleutian low was present over the central Aleutians, while the North Pacific high was shifted to the west of its normal position, thus causing strong southwesterly winds in the region between it and the low. In February the low split into an eastern and western portion with the eastern portion centered over the Gulf of Alaska near southeastern Alaska.

Wind-Driven Transport

The oceanic surface layer transport due to surface wind stress is estimated monthly by calculations of wind-driven (Ekman) transport using monthly mean fields of surface barometric pressure. These data are summarized as vectors of transport by month at selected points in the northeast Pacific.[3] Figure 2 shows monthly vectors of computed transport for the 15 months January 1978-March 1979, while Figure 3 shows the long-term monthly mean vectors (January-March repeated).

During late 1977 and early 1978 there was stronger than normal northeastward Ekman transport in the Gulf of Alaska (57°N, 140°W) and northeastward rather than the normal southeastward flow at 50°N, 133°W. This northeastward transport moved water towards the shore, which resulted in downwelling along the coast of southeastern Alaska and British Columbia and caused a strengthening of the northerly flow along the coast. Biological implications included a massive intrusion of salps into the area. Strong northward transport occurred at 57°N, 170°W in the Bering Sea.

At the two locations, 39°N, 149°W and 27°N, 140°W, there was unusually strong southeastward transport in January-February 1978, and at 27°N, 140°W, the transport was also southeastward rather than the normal northward flow. These transports resulted from the strong atmospheric circulation over the eastern North Pacific during winter 1977-78.

Transports during spring and summer 1978 were near normal values with the exception of strong offshore transport off California (39°N, 128°W) during May-July.

During winter 1978-79 several large anomalous transports occurred. In the Gulf of Alaska (57°N, 140°W) transport was southeastward in early winter rather than in the usual northeastward direction. Very strong northward transport occurred at 57°N, 140°W in February 1979. South of Kodiak (50°N, 153°W) strong southeastward transport occurred in October and December. Off California (39°N, 128°W) there was strong southeastward transport in February 1979.

Upwelling

Bakun (1973) computed an index of coastal upwelling using the component of Ekman transport normal to the coastline at 15 locations along the west coast from the Gulf of Alaska to Baja California. Historical values of upwelling index are presented in Figure 4 for the period of record, 1946 to the present, as anomalies from the long-term mean of the reference period 1948-67. This period is used for various other data sets in this report and also is used as a reference period by Fishing Information. Positive values of the index represent upwelling, and negative values represent downwelling.

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[3] A. Bakun, Pacific Environmental Group, NMFS, Monterey, CA 93940. Values are computed on a grid of 3 degrees of latitude and longitude from data of Fleet Numerical Oceanobraphy Center, Monterey, CA 93940.

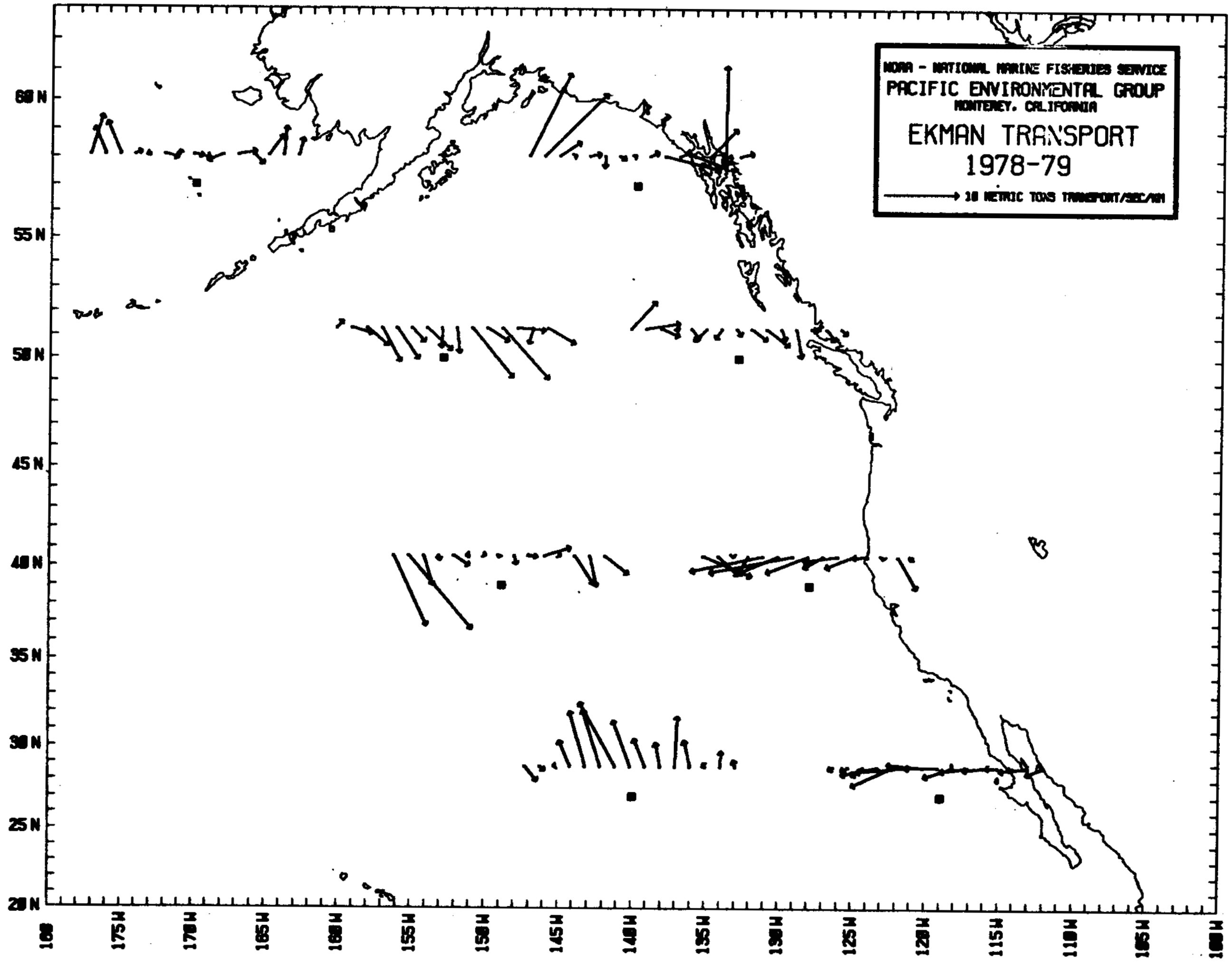

Figure 2.--Vectors of monthly mean Ekman transport for 15 months during January 1978-March 1979 for selected points in the eastern North Pacific, computed over a 3-degree area of latitude and longitude. Points are shown as black squares. Data from A. Bakun, Pacific Environmental Group, NMFS, Monterey, CA 93940.

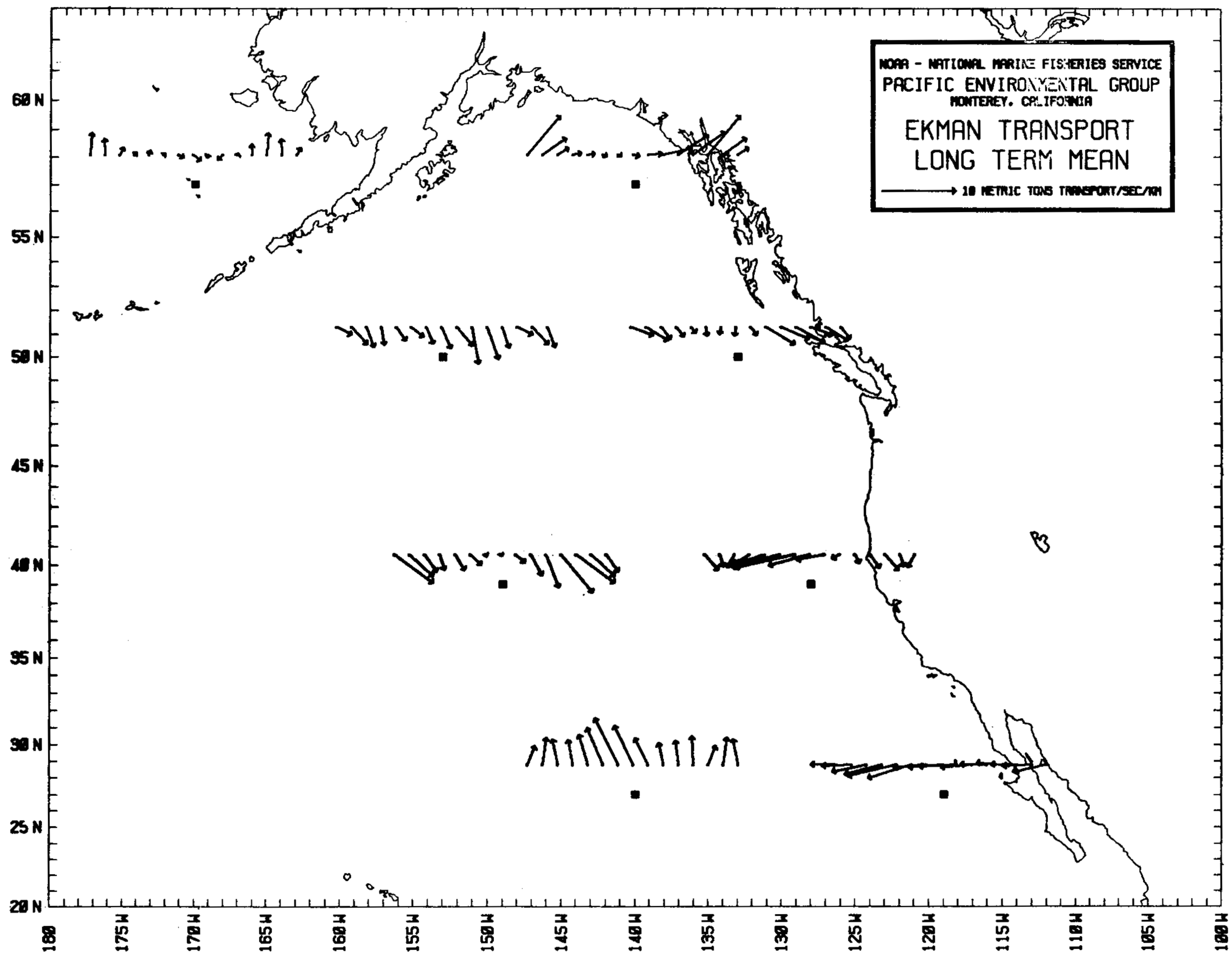

Figure 3.--Long-term mean monthly Ekman transport for 15 months (January-March repeated) for the reference period 1948-67 for selected points in the eastern North Pacific, computed over a 3-degree area of latitude and longitude. Points are shown as black squares. Data from A. Bakun, Pacific Environmental Group, NMFS, Monterey, CA 93940.

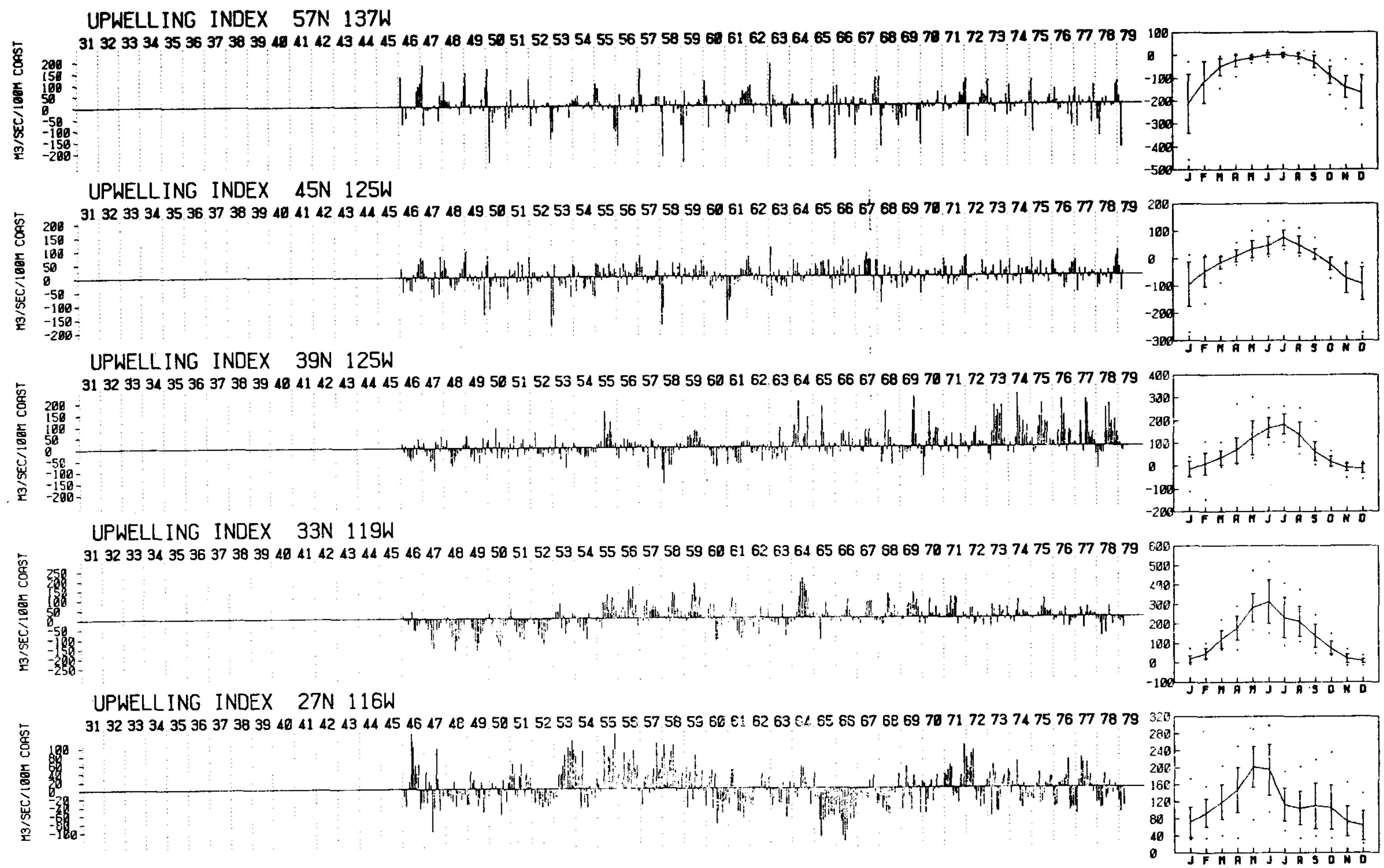

Figure 4.--Time series for 1931-79 of anomaly of upwelling index in cubic meters of water per second per 100 meters length of coastline from the long-term mean reference period 1948-67. Data from A. Bakun, Pacific Environmental Group, NMFS, Monterey, CA 93940. Small boxes on the right-hand side of this and other time series plots show the annual cycle with the range and standard deviation of interannual variations during the reference period.

The area of maximum upwelling along the west coast is centered near 39°N, 125°W (Bakun et al. 1974), although numeric values of the upwelling index are higher off southern California due to an effect of coastal mountains (Bakun 1973). For the sixth year in a row, upwelling at 39°N, 125°W was generally above normal during 1978. In early 1979 upwelling indices at 39°N, 125°W were near normal.

Farther south at 33°N, 119°W, upwelling indices have been near normal in recent years, whereas at 27°N, 116°W, values have been generally below normal. North of 39°N upwelling is less important and downwelling in winter becomes dominant. At 45°N, 125°W and 57°N, 137°W upwelling indices in recent years have been variable, but near normal values.

Details of the variations of upwelling indices in 1978 and early 1979 at all 15 locations along the coast are presented in Figure 5. The data are presented as percentiles of occurrence of values of upwelling index at that location over the period of record (1946 to date). By taking percentiles of the values, the data are normalized and can be intercompared. Low percentiles indicate increased downwelling or decreased upwelling while high percentiles indicate increased upwelling or decreased downwelling.

Although upwelling indices were generally high during 1978, at 39°N, 125°W during January-March they were below normal and were unusually low from 30° to 36°N. Extreme low index values occurred at 36°N, 122°W in January and from 30°N to 36°N in March. This was a case of predominant onshore transport and downwelling during a period of light or southerly winds associated with a persistent high-pressure system and drought conditions then occurring over California. The onshore transport apparently concentrated fish larvae near shore, as will be mentioned later.

During May-July upwelling conditions returned to more normal ranges. Upwelling was stronger than normal north of 51°N in June and north of 39°N in July. Weak upwelling occurred from 42°-54°N in August and September. Upwelling indices then returned to abnormally high values in October-December north of 36°N. Intense upwelling conditions in Gulf of Alaska waters may have resulted in anomalous offshore transports of fish larvae. During December 1978 and early 1979 onshore transport again occurred off central and southern California. This was a similar occurrence to that in early 1978, but was much less extreme.

Extremely high upwelling indices were calculated at 21°N, 107°W throughout the period. Similar high values occurred during 1977. Because the high values occurred only at the one location, 21°N, 107°W, and not to the north, the data appear questionable; the cause is not known, but it may be due to a change in analysis procedures of the surface pressure observations.

Sea Level

Long historical records of tide height are available for many tide gage stations along the coast. Tide height is primarily affected by astronomical factors, but also by oceanographic and meteorological factors including variations in speed of alongshore currents (Reid and Mantyla 1976). Most of the tidal effects are relatively short-term and can be averaged out by making monthly means of the hourly tide height observations. Meteorological and long-term (nodal) tide effects can be compensated for, and thus tide height or sea-level data can be used to infer changes in ocean circulation.

Bretschneider and McLain (1979) presented monthly mean sea-level data for a series of stations along the west coast of North and South America from the Aleutian Islands to Chile. They showed that anomalies of monthly mean

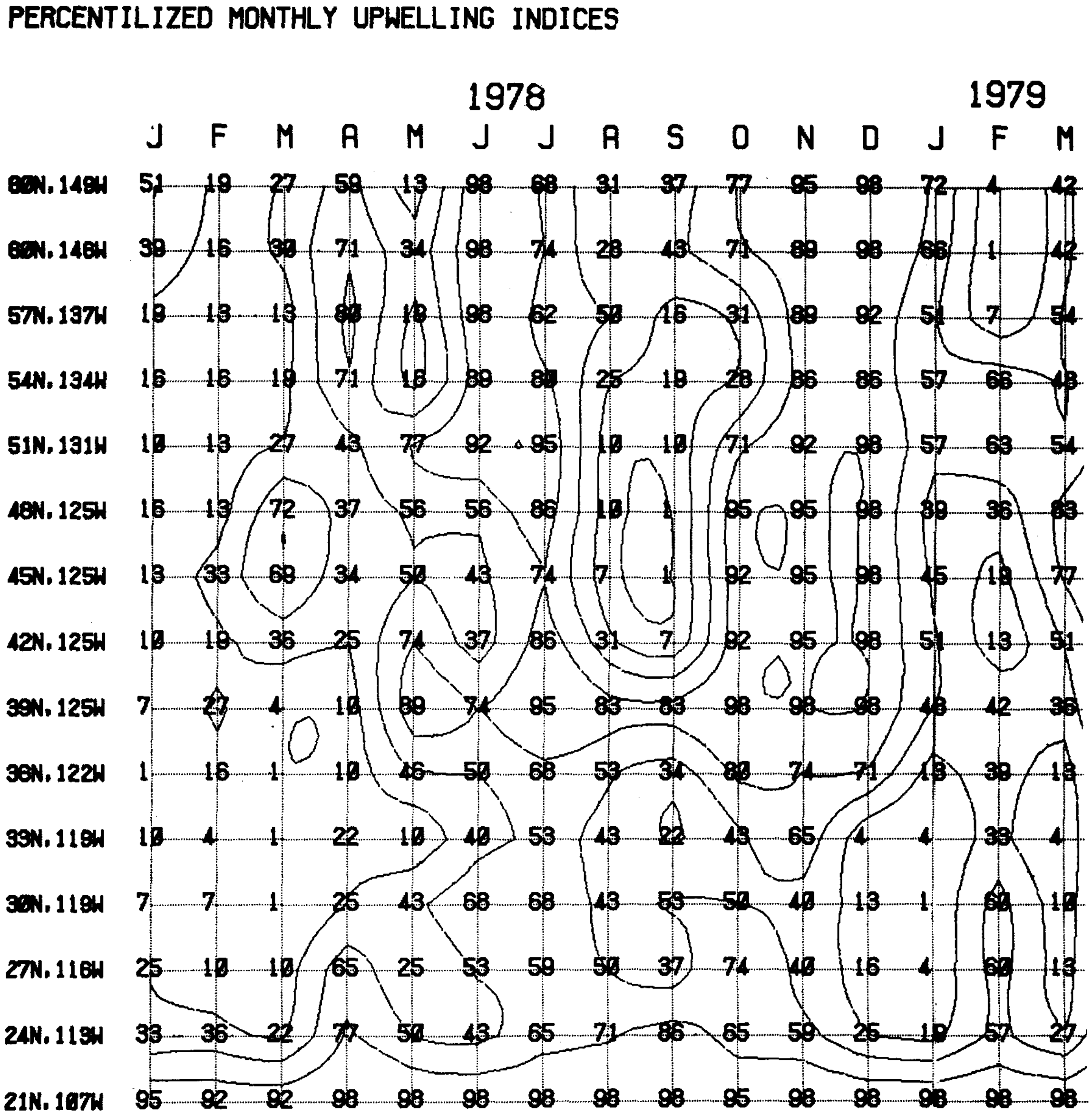

Figure 5.--Monthly upwelling index values for January 1978-March 1979, in percentiles of the frequency distributions made up of the 34 values for each month and location in the 34-year (1946-79) time series. Locations in the Gulf of Alaska are toward the top of the figure; those off Baja California are toward the bottom. The contour interval is 25 percentiles. Values above the 50th percentile indicate stronger than normal upwelling, while those below the 50th percentile indicate weaker than normal upwelling.

sea level from a long-term mean are remarkedly coherent in time and space. In particular, they showed that periods of high sea level can be traced southward along the coast from Alaska to Chile and are associated with above normal sea-surface temperatures along the coast and with El Niño occurrences in the Eastern tropical Pacific.

Some sea-level data are available for west coast tide stations during 1978.[4] Anomalies of monthly means from the long-term mean are presented in Figure 6 for five stations with the most complete data records. Above normal sea levels occurred along the California coast in 1940-41, 1957-59, and 1972-73, as discussed by Bretschneider and McLain, and were associated with major El Niño occurrences. The periods of above normal sea level can be traced northwards to Alaska but are obscured there by effects of storms.

In 1976 there was a minor El Niño and high sea levels were observed at California stations in late 1976. High sea levels also occurred in the winters of 1977-78 and 1978-79, probably as a result of onshore wind-driven transport. Data from the northern stations, particularly Yakutat, AK, are incomplete, but show low sea levels in late 1978. Possibly higher than normal levels existed in early 1978 in response to onshore transport.

Sea-Surface Temperature

Spatial Variations - Analyzed maps of sea-surface temperatures (SST) and their anomalies from a long-term monthly mean are published monthly in Fishing Information and are not reproduced here. (also see Appendix.) These maps showed that a large pool of cooler than normal water formed in the northeastern Pacific during late 1977 and persisted into 1978. In early 1978 the pool was located at 35°-40°N, 140°W to 180°, and was bordered on the east and north by a coastal strip of warmer than normal water. By May the pool had expanded northward to the Alaska coast and by August it reached eastward to the California coast. Breakup of the anomaly pattern then began, and by December a warmer than normal pool occupied the central portion of the northeastern Pacific surrounded by cooler than normal water. This general pattern persisted through March 1979.

Temporal Variations - Johnson et al. (1976, 1978) presented time series plots of SST for selected 5-degree squares of latitude and longitude in the North Pacific. These squares, called Index Stations, were chosen because of a relatively large number of available ship weather observations. Johnson et al. chose 10 such areas along the coast of the northeast Pacific from the central Aleutian Islands to Equador (Table 1). Time series of SST for these areas for 1931-79 are shown in Figures 7 and 8 as anomalies from a long-term mean (1948-67).[5] Because of the scarcity of SST data from the Bering Sea, air temperature data[6] from St. Paul, Pribilof Islands, are also also included in Figure 7. Details of fluctuations of SST along the coast are discussed later.

SST's along the coast of North and

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[4] Provided by J. R. Hubbard, Tides and Water Levels Division, National Ocean Survey, NOAA, Rockville, MD 20852. Recent data are provisional and are based on preliminary datums. The time series of monthly mean sea levels have been detrended to eliminate long-term trends, and corrected for the inverse barometer effect of atmospheric pressure. The 19-year period 1949-67 was used as a long-term mean for sea level to correct for nodal tide effects (Bretschneider and McLain 1979).

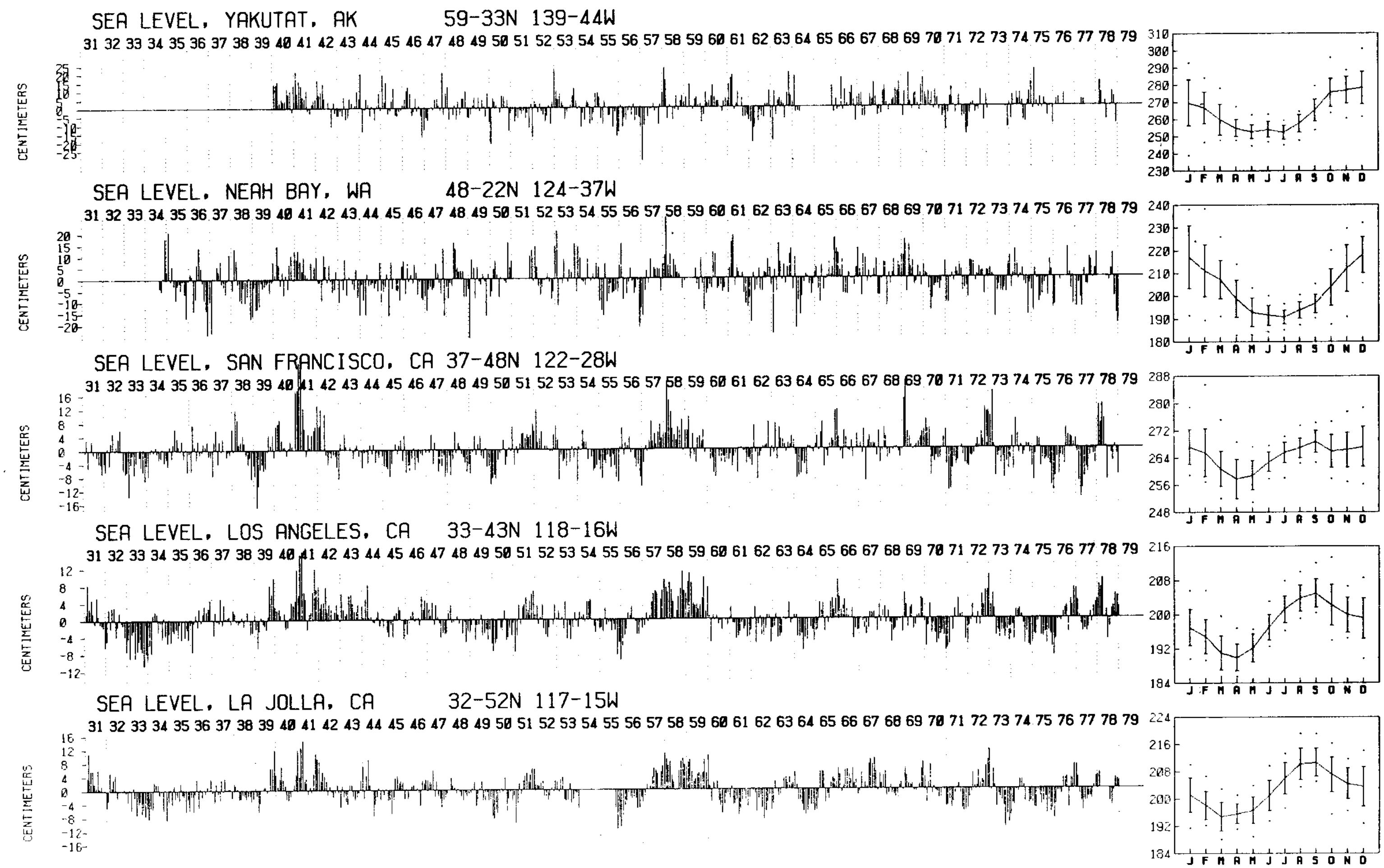

Figure 6.--Time series for 1931-79 of anomaly of sea level in centimeters from the long-term mean reference period 1949-67 at tide gages from Alaska to California. Data from J. R. Hubbard, National Ocean Survey, NOAA, Rockville, MD 20852.

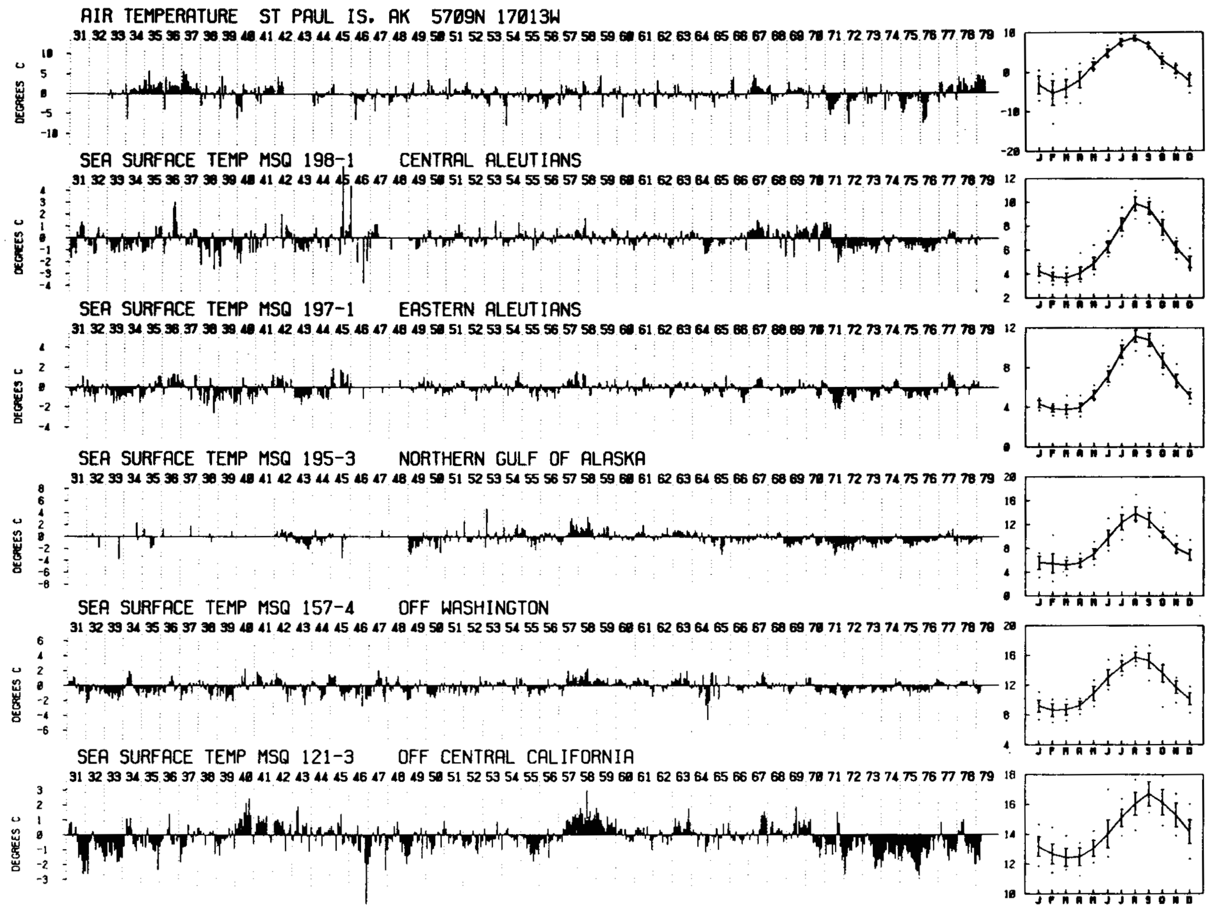

Figure 7.--Time series for 1931-79 of anomaly of air temperature in degrees Celsius at St. Paul Island, AK, and sea-surface temperature in degrees Celsius from the long-term mean reference period 1948-67 at five 5-degree squares of latitude and longitude along the coast from the Aleutian Islands to California. Air temperature data for St. Paul Island and sea-surface temperature data for 1931-71 from the National Climatic Center, EDIS, Asheville, NC 28801; SST data for 1972-79 from Fleet Numerical Oceanography Center, Monterey, CA 93940.

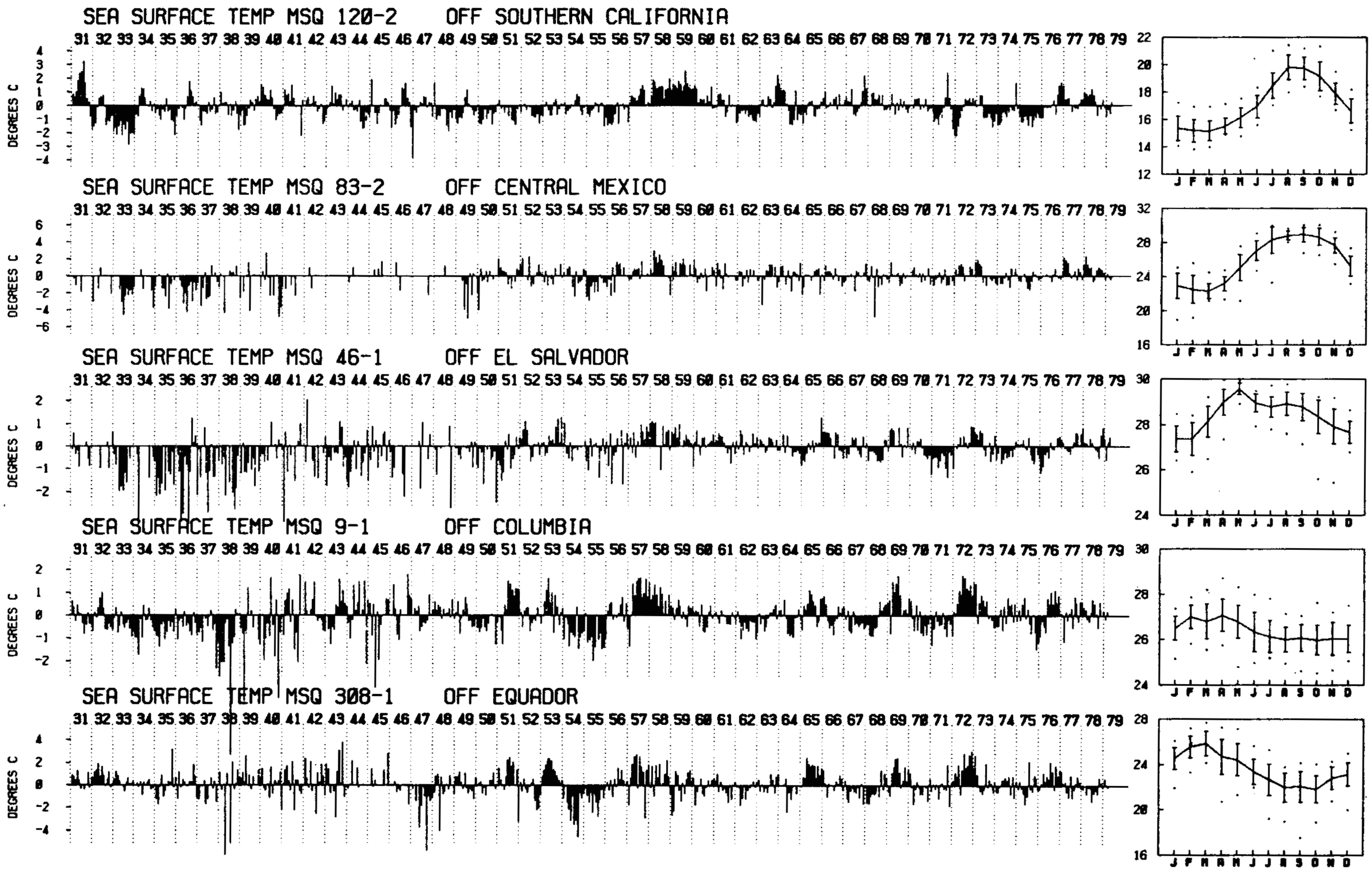

Figure 8.--Time series for 1931-79 of sea-surface temperature in degrees Celsius from the long-term mean reference period 1948-67 at five 5-degree squares of latitude and longitude along the coast from California to Ecuador. Data for 1931-71 from the National Climatic Center, EDIS, Asheville, NC 28801; data for 1972-79 from Fleet Numerical Oceanography Center, Monterey, CA 93940.

Central America have shown similar variations with time along extensive stretches of coast. Temperatures in the early 1940's and during 1958-59 were above normal over most of the coast, while temperatures in the early 1930's, late 1940's, 1955-56, 1970-71, and 1974-75 were below normal in most areas. The years 1972-73 and 1976 had above normal temperatures along the Central American coast in association with recent El Niño occurrences, but had near or below normal temperatures in the northern areas.

A prolonged period of below normal SST in the Bering Sea and Gulf of Alaska during 1971-76 was broken in 1977, and temperatures along the coast have been near or above normal since then. In early 1977 air temperature at St. Paul Island and SST from the Aleutians (square 198-1) to Washington (square 157-4) became near or warmer than normal. Off California, SST's remained generally below normal except for near normal temperatures off central California (121-3) and above normal off southern California (120-3) in the winter of 1976-77 and in early 1978. This pattern continued to the south off Central America with above normal temperatures in winter 1976-77 and early 1978. Off Ecuador (square 308-1), SST's have been near normal since 1977.

Table 1.--Locations of Index Stations for time series of sea-surface temperature data along the coast of the northeast Pacific Ocean.

Location	Latitude	Longitude	Marsden 5° square
Central Aleutians	50°-55°N	170°-175°W	198-1
Unimak Pass	50°-55°N	160°-165°W	197-1
Gulf of Alaska	55°-60°N	140°-145°W	195-3
Off Washington	45°-50°N	125°-130°W	157-4
Off Central California	35°-40°N	120°-125°W	121-3
Off Southern California	30°-35°N	115°-120°W	120-2
Off Central Mexico	20°-25°N	105°-110°W	83-2
Off El Salvador	10°-15°N	90°- 95°W	46-1
Off Colombia	0°- 5°N	80°- 85°W	9-1
Off Ecuador	0°- 5°S	80°- 85°W	308-1

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[5] Monthly means of merchant ship injection surface temperatures made by the Pacific Environmental Group, NMFS, Monterey, CA 93940. Means by 5-degree squares are means of four submeans by 1-degree squares to reduce spatial bias effects. Data of 1931-71 are from Marine Deck (TDF-11), National Climatic Center, EDIS, Asheville, NC 28801, and data 1972-79 are from weather reports received by Fleet Numerical Oceanography Center, Monterey, CA 93940.

[6] Local climatological data. National Climatic Center, EDIS, Asheville, NC 28801.

REGIONAL CONDITIONS

Eastern Bering Sea

Surface Pressure - Persistence of a deep Aleutian low surface atmospheric pressure system south of the Alaska Peninsula during winter 1977-78 resulted in strong easterly winds over the eastern Bering Sea during January, February, and even March 1978. Winds weakened in the spring transition period, becoming southeasterly during April and northeasterly during May. A major shift to westerly wind velocity components occurred in June with generally southwesterly summer winds shifting to weak westerly winds by September. The Aleutian low reformed at the normal time, in October, over the Gulf of Alaska, but its center was shifted slightly westward towards the Bristol Bay area, bringing strong easterly to northeasterly winds over much of the Bering Sea coast. The low shifted far into the western Bering Sea in November, and remained there through January 1979, bringing anomalous warming with the associated strong, persistent, moist southwesterly winds contrasting markedly with the cool, dry continental easterlies of the previous year. In February 1979 the low divided into a split system which brought a return of easterly winds reminiscent of conditions in early 1978.

Ice - The extent of ice cover in winter and the timing of the ice breakup in spring can be determined from infrared images from orbiting satellites. Weekly charts of ice distribution issued by the U.S. Navy and the National Environmental Satellite Service, NOAA, provide information on ice conditions in the eastern Bering Sea. A graphical representation of the mid-month positions of the ice edge for the ice seasons of 1977-78 and 1978-79 is shown in Figure 9. For comparison, the position of maximum ice extent during the previous season (April 1977) is also shown.

Overall, the trend of decreasing ice cover observed in recent years continued, progressing from above normal ice cover in 1976 to below normal coverage in 1979. Some differences in ice development were evident compared to last year. The very rapid northward retreat of the ice edge in late spring (May-June) 1978 was followed by a very slow ice advance in autumn 1978. This was apparent in the one-month delay, November vs. December, in the southward advance of ice through Bering Strait to St. Lawrence Island. In addition to the delay, the December 1978 ice extent was much less than in 1977, and similar conditions persisted through January 1979. An abrupt advance of the ice edge occurred in February 1979 when it attained the same position as in February 1978. However, in Bristol Bay the seaward extent of ice exceeded that of the entire previous year even though it was apparently short-lived.

Temperature - Air temperatures over the eastern Bering Sea reflected the warming trend observed since 1977. Whereas unusually cold conditions had occurred during the period 1971-76, with two pairs of adjacent severe winters (1970-71, 1971-72 and 1974-75, 1975-76), recent conditions have been unusually warm. The warm conditions resulted from the predominantly southerly geostrophic winds observed over the area during much of the year. Large positive anomalies occurred in late 1978 and particularly in early 1979 due to the early shift of the center of the Aleutian low to the west and its persistence there for several months. At St. Paul Island, Pribilof Islands, air temperatures (Fig. 7) were above normal in all but four months during January 1977-May 1979 and 2.0°C or more above normal in 15 out of the 29 months of the period. The year 1979 will apparently be very warm on the average as air temperatures during January-May at St. Paul were 3.4°-4.7°C

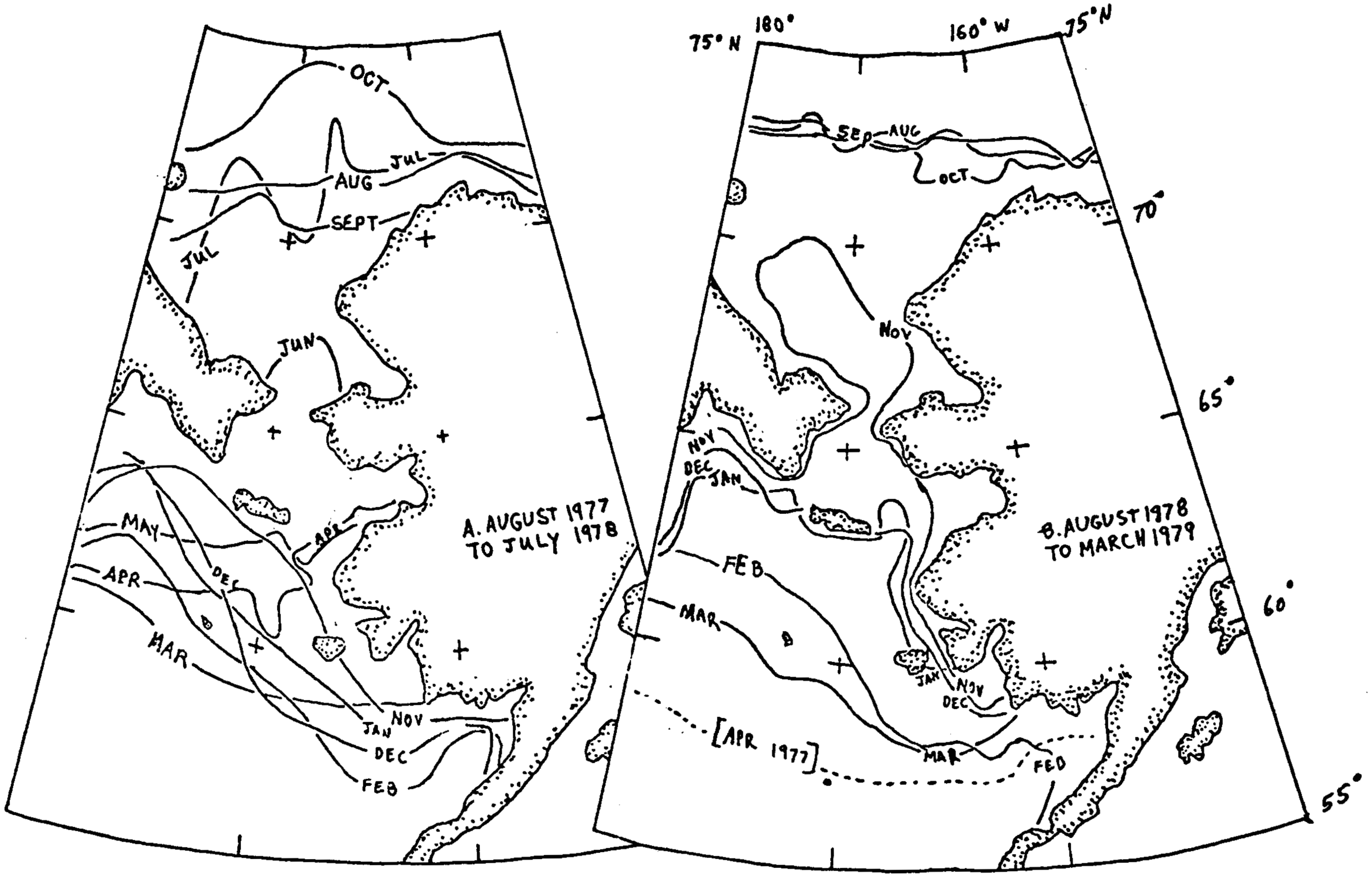

Figure 9.--Midmonth locations of the ice front in the eastern Bering and Chukchi Seas during August 1977-March 1979, and, for comparison, April 1977. Plotted from data of the National Environmental Satellite Service and from ice cover analyses from the U.S. Naval Polar Oceanography Center, Suitland, MD 20393.

above normal.

Sea surface temperature data from the area show trends similar to the air temperatures. At square 197-1 (Fig. 7) SST's were above normal during most months of the period June 1977-March 1979, although in contrast to the St. Paul air temperatures, SST's were warmest in 1977 and more moderate, but still above normal during 1978 and early 1979.

Bottom temperatures from the area did not show as clear a trend. Bottom temperatures in 1978 indicated the outer shelf area near the Pribilof Islands to be about 1°C warmer than in 1977 and the inner shelf area (near 57°30'N, 163°W) to be about 1°-2C° colder than in 1977. Although data for 1979 are not yet available, the extent and general wind conditions indicated that the bottom temperatures in 1979 will be anomalously warm and similar to 1978.

The timing and location of herring spawning in Bristol Bay may be related to water temperatures and ice conditions.[7] Cold conditions that existed in spring 1976 were associated with a shift of some herring spawning from the north shore to the south shore of Bristol Bay. Warm conditions in early 1979 caused herring spawning to be up to two weeks early, commencing in mid-April along the north shore of the bay.

Northward shifts in the distribution of herring and shrimp may also occur over the shelf near the Pribilof Islands in response to mild temperature conditions. In an area near the Pribilofs normally fished by foreign trawlers in winter, a survey by the Northwest and Alaska Fisheries Center in March 1978 found only trace quantities of herring. The absence of herring was explained by a northward shift in the distribution of stocks associated with warm water temperatures.[8] A similar survey for shrimp in June and early July 1978 in the same region found only low shrimp concentrations in regions of normally significant abundance. Relatively high catches were made only along the northwest edge of the survey area.[9]

Other species were probably affected by the recent mild conditions as well. Straty and Jaenicke[10] found faster growth rates of juvenile Bristol Bay sockeye salmon in a warm year, 1967, than a cold year, 1971. Possibly mortality of sockeye due to predation was higher in 1971 than 1967 due to the slower growth rates. Also cold conditions in 1971 and 1972 may have caused the 1971 seaward migrants to remain an extra year at sea. Warm conditions in recent years thus may result in rapid growth and low mortality of sockeye. The recent mild conditions may also result in stronger year classes of various flounders (such as yellowfin sole, rock sole, flathead sole, and Alaska plaice).[11]

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[7] Reported on page 25 of the Monthly Report for April 1979, Northwest and Alaska Fisheries Center, NMFS, Seattle, WA 98112.

[8] Reported on page 27 of the Monthly Report for March 1978, Northwest and Alaska Fisheries Center, NMFS, Seattle, WA 98112.

[9] Reported on page 25 of the Monthly Report for July 1978, Northwest and Alaska Fisheries Center, NMFS, Seattle, WA 98112.

[10] Straty, R. R., and H. W. Jaenicke. Estuarine influence of salinity, temperature, and food on the behavior, growth, and dynamics of Bristol Bay sockeye salmon. Unpublished manuscript. Northwest and Alaska Fisheries Center, NMFS, Seattle, WA 98112.

[11] Reported on pages 25-27 of the Monthly Report for March, 1978, Northwest and Alaska Ficheries Center, NMFS, Seattle, WA 98112.

Pacific cod and Alaska pollock move onto the inner continental shelf in the eastern Bering Sea in summer months. During cold years, however, this movement is normally much less than during years with warmer temperatures (see footnote 11). Recent mild conditions would probably increase this inshore migration.

Runoff - The discharge of both the Yukon and Kuskokwim Rivers (Fig. 10) has a strong seasonal cycle with maximum discharge in summer (peaking in June) due to snow and ice melt, and minimum discharge in winter due to freezeup of the watersheds. The pulse of summer discharge has been below normal in recent years, particularly during 1974, 1976, and 1978. Although numerical data are not yet available for winter 1978-79, discharge during this period is reportedly about 10% greater than the previous year. Discharge of the Kvichak River, which is much more persistent in time than that of the Yukon or Kuskokwim Rivers due to the stabilizing effects of lakes in the watershed, was also below normal in 1974, 1976, and 1978.

Aleutian Islands to Icy Bay

Ice - Ice conditions in Prince William Sound and Cook Inlet were mild in both winters 1977-78 and 1978-79, and most bays were ice free by March of each year.

Temperature - Anomalies of sea surface temperatures along the southwest coast of Alaska are presented as time-distance matrices in Figure 11. In Marsden 5^{o} square 197-1 (Fig. 7) south of the Peninsula, SST's had been below normal during 1971 to 1976 with the exception of fall 1974. Temperatures became anomalously warm in summer and fall 1977 and have been more nearly normal since then. Farther east at the head of the Gulf of Alaska (square 195-3, Fig. 7) SST's were generally similar, but were slightly below normal in 1978 and 1979.

During January-May 1978 SST's from Unimak Pass to Kodiak Island (Fig. 11) were above normal, became below normal during summer and early fall 1978, and were mixed the remainder of the period. SST's off Prince William Sound were colder than normal throughout 1978 and early 1979 as indicated at square 195-3.

Although historical bottom temperature data are sparse for this area, it is possible to compare bottom temperature regimes for the mid-shelf (about 50-150 m depth) near Kodiak Island for the period late winter-early spring for three consecutive years: 1976, 1977, and 1978 (using data collected on OSCEAP cruises) and also during the cold year 1972 (from a NWAFC cruise). Bottom temperatures of about $2^{o}C$ occurred off Kodiak Island in May 1972, whereas mid-shelf temperatures in 1976, 1977, and 1978 were 2^{o}-$3^{o}C$ warmer ($3.7^{o}C$, $5.7^{o}C$, and $4.5^{o}C$, respectively). It is interesting to note that during the warm year, 1977, the permanent subsurface $5^{o}C$ temperature maximum at about 250 m, associated with warm westward advection in the Alaskan Stream just seaward of the shelf break, was not clearly discernible for the first time.

Runoff - Several rivers flow into Cook Inlet, and the resulting dilute surface water flows southwestward through Shelikof Strait, north of Afognak and Kodiak Islands. However, the major river discharge at the head of the Gulf of Alaska is from the Copper River. Like the Yukon and Kuskokwim, the Copper River has a strong seasonal cycle with minimum discharge in winter and maximum discharge in summer, peaking in July (Fig. 10). At the time of this writing, data were available only through September 1978 and indicated above normal discharge in 1978.

Salinity - Further information on the surface salinity minima area reported last year for 1977 (McLain et al. 1979) is now available for late

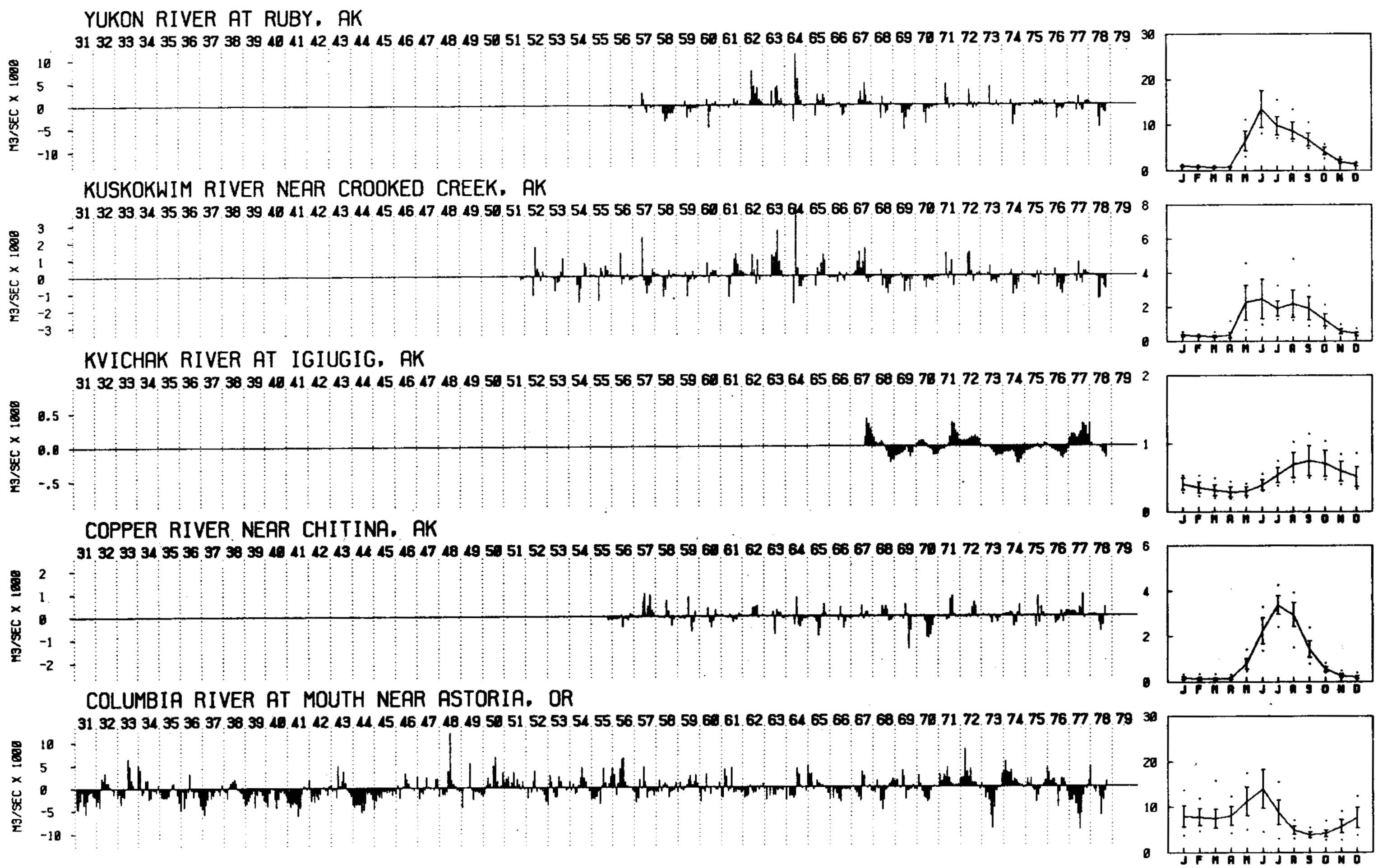
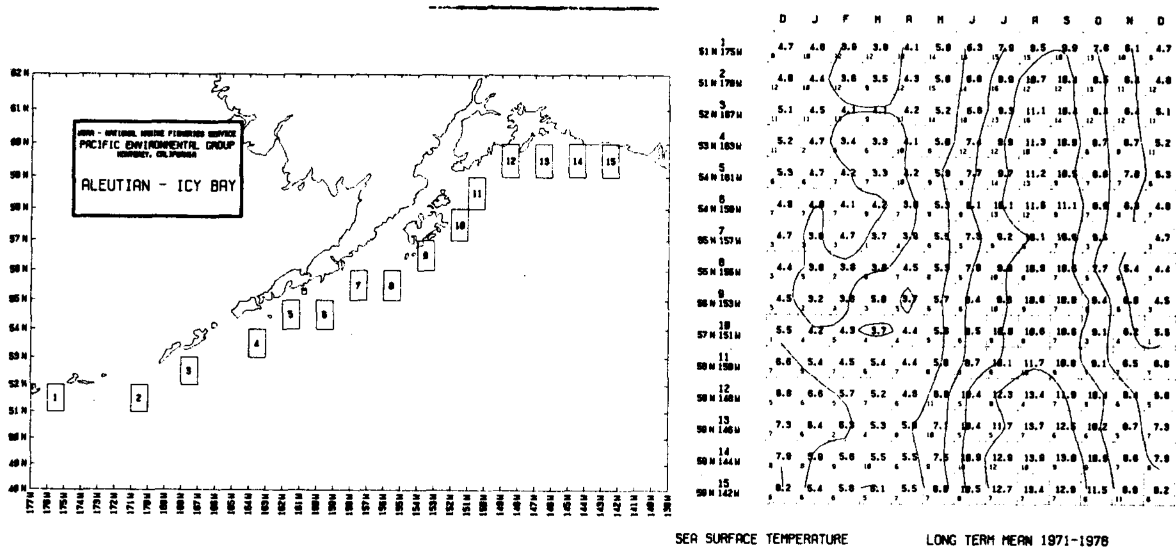


Figure 10.--Time series for 1931-79 of anomaly of river discharge into the ocean in thousands of cubic meters per second from the long-term mean reference period 1948-78. This is a different reference period than the 1948-67 period used in the remainder of the text to allow computation of a mean for the Kvichak River for which data start in 1967. Data from U.S. Geogological Survey. Data for Columbia River are extrapolated to the mouth of the river from observations upstream.



	1978 J	F	M	A	M	J	J	A	S	O	N	D	1979 J	F	M
1 51N 175W	-.5 (3)	-.2 (4)	0.6 (3)	0.1 (2)	-.0 (5)	0.7 (2)	-1.0	0.5 (1)		-.3 (2)	-.1 (2)	0.0 (1)	-1.4 (2)	1.1 (1)	-.0 (1)
2 51N 170W		0.6 (2)	0.1 (3)	1.2	0.5 (10)	0.6 (3)	-1.1	0.3 (2)	1.7				-.4 (2)	0.5 (1)	
3 52N 167W		1.1	-.6 (2)	1.5	0.6 (4)	1.5	-2.3	-1.4		1.0				-.1 (1)	0.4 (1)
4 53N 163W	-.9 (1)	-.1 (4)	0.0 (2)	-.2 (2)	-.5 (7)	2.1	1.1	-1.0	0.3 (2)		1.6		-.9 (1)	-.4 (1)	
5 54N 161W	0.2 (13)	0.6 (10)	1.3	-.1 (23)	-.0 (51)	0.1 (7)	-1.0	-.2 (6)	0.7 (5)	0.2 (3)	0.5 (9)	-.3 (1)	0.1 (5)	-1.0	1.0 (13)
6 54N 159W	0.1 (12)	-.1 (14)	-.0 (21)	0.5 (60)	-.1 (42)	-1.5	-.9 (21)	-1.1	-.5 (6)	-1.3	1.5	2.0	1.0	-1.0	-.0 (12)
7 55N 157W	2.1	-.3 (4)	0.7 (6)	0.4 (16)	-.1 (41)	-.6 (33)	0.7 (4)	0.7 (1)	-.3 (2)				2.0	-2.5	
8 55N 155W	-.0 (5)	0.0 (46)	1.7	0.6 (5)	1.5	-.3 (10)	-.9 (1)	-.2 (4)	-.7 (2)	1.0	1.1	1.3	0.9 (2)	0.2 (1)	1.2
9 56N 153W	1.0	-.1 (4)	-.1 (5)	0.0 (8)	0.4 (11)	-.5 (43)	-1.1	0.5 (2)	0.5 (5)	-.5 (5)	0.9 (12)		0.9 (5)	-.3 (2)	
10 57N 151W	0.2 (76)	0.0 (128)	0.4 (181)	-.1 (147)	-.1 (9)	-.2 (16)	-1.5	-.7 (31)	-2.3 (64)	-2.3 (80)	-1.0 (126)	-1.3 (140)	-.5 (74)	0.2 (3)	0.0 (4)
11 58N 150W	0.2 (2)	-.2 (12)	-.6 (7)	0.3 (5)	0.3 (14)	-.7 (12)	0.0 (9)	0.9 (3)	-.2 (1)	-.7 (5)	0.6 (6)	-1.0 (1)	-2.1 (1)	-.4 (4)	-.5 (5)
12 59N 148W		-1.0			-1.2	-.6 (5)	-.9 (2)							-1.7	
13 59N 146W	-1.5		0.6 (1)	-2.6	0.1 (2)	-.1 (2)			-.6 (1)			-2.3			
14 59N 144W	-1.0	-1.3	0.0 (1)	0.7 (5)	-2.0	-2.4	-1.7	-.6 (6)	-2.4	-1.0	-2.0	-1.7	-1.1	-1.2	
15 59N 142W	0.7 (1)				-1.6		-1.5	-.3 (2)							

Figure 11.--Time-space matrix for January 1978-March 1979 of anomaly of sea-surface temperature (lower) in degrees Celsius from the long-term mean reference period 1948-67 for a line of 1-degree squares along the coast from the Aleutian Islands to Ice Bay (locations shown in upper left). The long-term mean temperature values are shown in upper right and are based on data from the National Climatic Center, EDIS, Asheville, NC 28801.

summer 1978.[12] A marked seaward penetration of a low-salinity (31.6°/oo) plume from the Copper River area (Fig. 12) extending 80 km south of the shelf break well into the oceanic regime of high-salinity (>32.6°/oo) water was discovered. The seaward terminus of the plume reflected an anomalous eastward movement near the origin of the westward flowing boundary current, the Alaskan Stream. It is now evident that two sources of dilution, the Copper River in the northern Gulf and a tongue of low-salinity water from in the eastern Gulf, can contribute on a year-round basis to an anomalous offshore salinity minima area east of Kodiak Island (Ingraham 1979). Thus considerable complexity in surface flow is implied by the surface salinity distributions of 1977 and 1978. This may have considerable influence on the variability of the transport of ichthyoplankton, particularly halibut larvae, as well as on the seaward migration path of salmon smolts from southeast Alaska, British Columbia, Washington, and Oregon.

Icy Bay to Strait of Juan de Fuca

Temperature - Sea-surface temperatures along the coast of southeast Alaska and British Columbia (square 157-4; Fig. 7) were below normal from mid-1970 until mid-1976 (except for fall 1974), warmer than normal during early 1977 and early 1978, and colder than normal in early 1979. SST's plotted as time-distance matrices (Fig. 13) reflected the same pattern in 1978 but in greater detail: warmer than normal in early 1978, mixed until October, and colder than normal during November 1978-March 1979 (particularly at the southern end of the area off Vancouver Island).

Related bottom temperature data are sparse, but Douglas and Wickett (1978) found bottom temperatures up to about 2°C above normal off Vancouver Island during a groundfish survey in early March 1978. SST's at that time and location were about 0.8°C above normal (Fig. 13).

Surface and subsurface temperature data in the inside passages of southeastern Alaska during winter are available for the last three years from expendable bathythermograph (XBT) observations at 13 stations from Dixon Entrance northwards to Juneau.[13] Temperatures at the southern stations of the series are normally higher both at the surface (Fig. 14a) and at 90 m depth (Fig. 14b) than those at the northern stations. This is consistent with past SST's taken at Coast Guard lighthouses during the period 1959-74. Monthly mean SST data are not available from the lighthouses for the 1977-79 period; however, the 1979 XBT surface temperature observations are in the lowest 20 of observations from other available SST data sources for late January-early February. The cooling trend of the past two years is reflected in the late winter temperatures taken at 90 m at the 13 stations where the 1977 temperatures averaged 0.7°C higher than those in 1978 and the 1979 temperatures averaged 1.5°C lower.

Salinity - Measurements of surface salinity were made off the coast from Icy Bay to southeastern Alaska during summer 1977 by the Polish research vessel, Professor Siedlecki, and during summer 1978 by the NOAA research vessels, Miller Freeman and Oceanographer. The distributions of surface

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[12]Cruise No. 78-03, RV Miller Freeman, Northwest and Alaska Fisheries Center, NMFS, Seattle, WA 98112.

[13]XBT observations made from RV John N. Cobb and provided by R. R. Straty, Northwest and Alaska Fisheries Center, NMFS, Auke Bay, AK 99821.

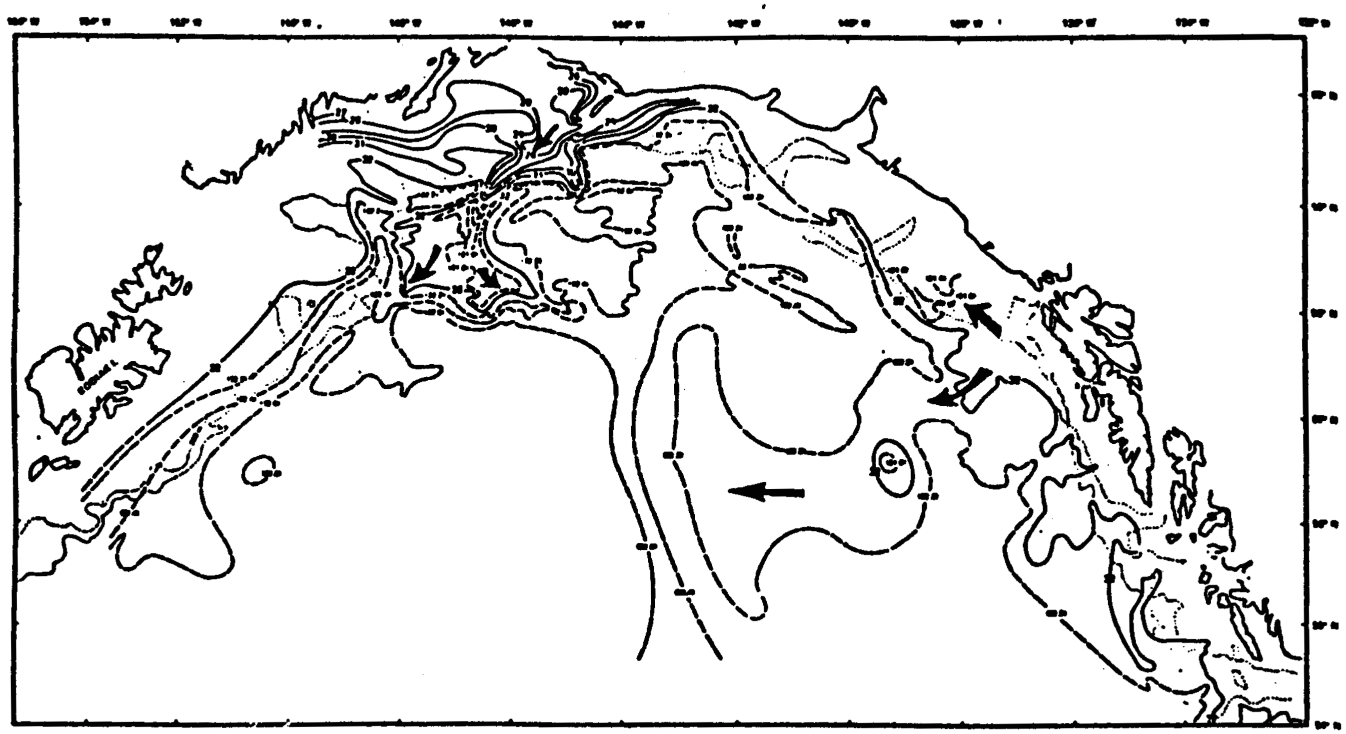
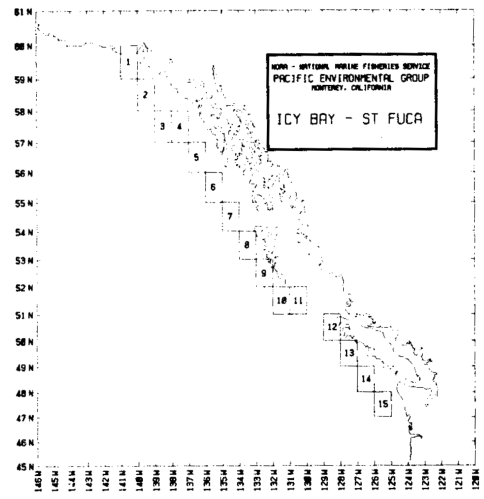
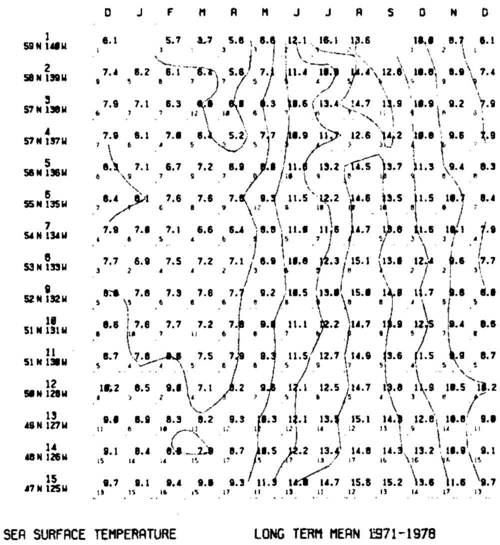


Figure 12.--Surface salinity in parts per thousand for summer 1978. Data were obtained from the NOAA research vessel (RV) Miller Freeman, the University of Alaska RV Acona, the Korean RV Oh Dae San, and the NOAA RV Oceanographer.





	1978												1979		
	J	F	M	A	M	J	J	A	S	O	N	D	J	F	M
1 59 N 140 W															
2 58 N 139 W	0.1 6				0.8 1	-.3 2	2.1 1	-1.6 1	0.6 1						-1.5 6
3 57 N 138 W	-1.0 1	-1.3 1					0.4 1					-1.2 1			
4 57 N 137 W	-.2 3				-2.3 3	0.1 3	0.8 2		0.2 1						
5 56 N 136 W		-.5 2			2.0 4	-1.1 1				-1.1 1					-1.2 1
6 55 N 135 W	-.9 1	-.5 2				-1.0 2									-1.3 2
7 54 N 134 W	1.9 1	0.1 4	-.2 3	1.6 1		0.1 1	0.8 1	-1.4 2			0.5 1	-.9 1	-.1 2		
8 53 N 133 W	2.1 1	-2.0 2	1.1 2	0.7 3	-1.2 1		0.3 5	-1.2 4	0.4 1	1.0 1		-.1 3	-.7 2	-.7 3	-1.0 2
9 52 N 132 W	-.3 5	0.1 8	-.1 4	1.3 4	-.9 7	1.0 5	-.3 13	-1.1 7	-.7 3	0.1 7	0.9 6	0.1 6	-.9 5	0.1 7	-1.6 4
10 51 N 131 W	0.9 3	-1.0 2	1.0 11	0.2 16	-.2 8	-.6 5	1.1 11	-1.5 4	-.5 1	-1.0 7	0.7 7	0.3 9	-.4 5	-1.1 11	-.1 5
11 51 N 130 W	0.4 2	0.1 7	1.2 2	1.3 10	0.8 9	0.7 7	-.2 8	-.5 6	0.0 6	1.0 2	0.1 5	-.2 4	-.6 3	-2.3 4	-.4 10
12 50 N 128 W	0.2 6	-1.4 6	1.1 4	1.1 9	1.0 5		0.4 7	-1.6 2	0.1 2	0.2 8	0.6 2	-3.0 1	-.5 1		0.4 4
13 49 N 127 W	0.2 12	-.3 10	0.8 14	0.1 12	0.9 18	-1.1 4	-2.1 6	-.9 2	0.1 3	-.1 10	-1.0 5	-.1 4	-1.7 15	-1.4 6	-.5 12
14 48 N 126 W	1.5 7	-.2 4	-.2 14	0.3 3	1.1 19	0.9 10	0.0 4	0.6 29	0.0 5	1.0 3	0.2 4	0.3 11	-1.3 10	-1.2 3	-.0 7
15 47 N 125 W	-1.4 3	-.3 8	0.4 5	0.8 5	0.7 16	0.6 60	-.9 74	-.2 7	0.3 6	1.7 2	-2.5 2	-1.1 2	-1.4 5	-1.9 8	0.5 14

Figure 13.--Time-space matrix for January 1978-March 1979 of anomaly of sea-surface temperature (lower) in degrees Celsius from the long-term mean reference period 1948-67 for a line of 1-degree squares along the coast from Icy Bay to the Strait of Juan de Fuca (locations shown in upper left). The long-term mean temperature values are shown in upper right and are based on data from the National Climatic Center, EDIS, Asheville, NC 28801.

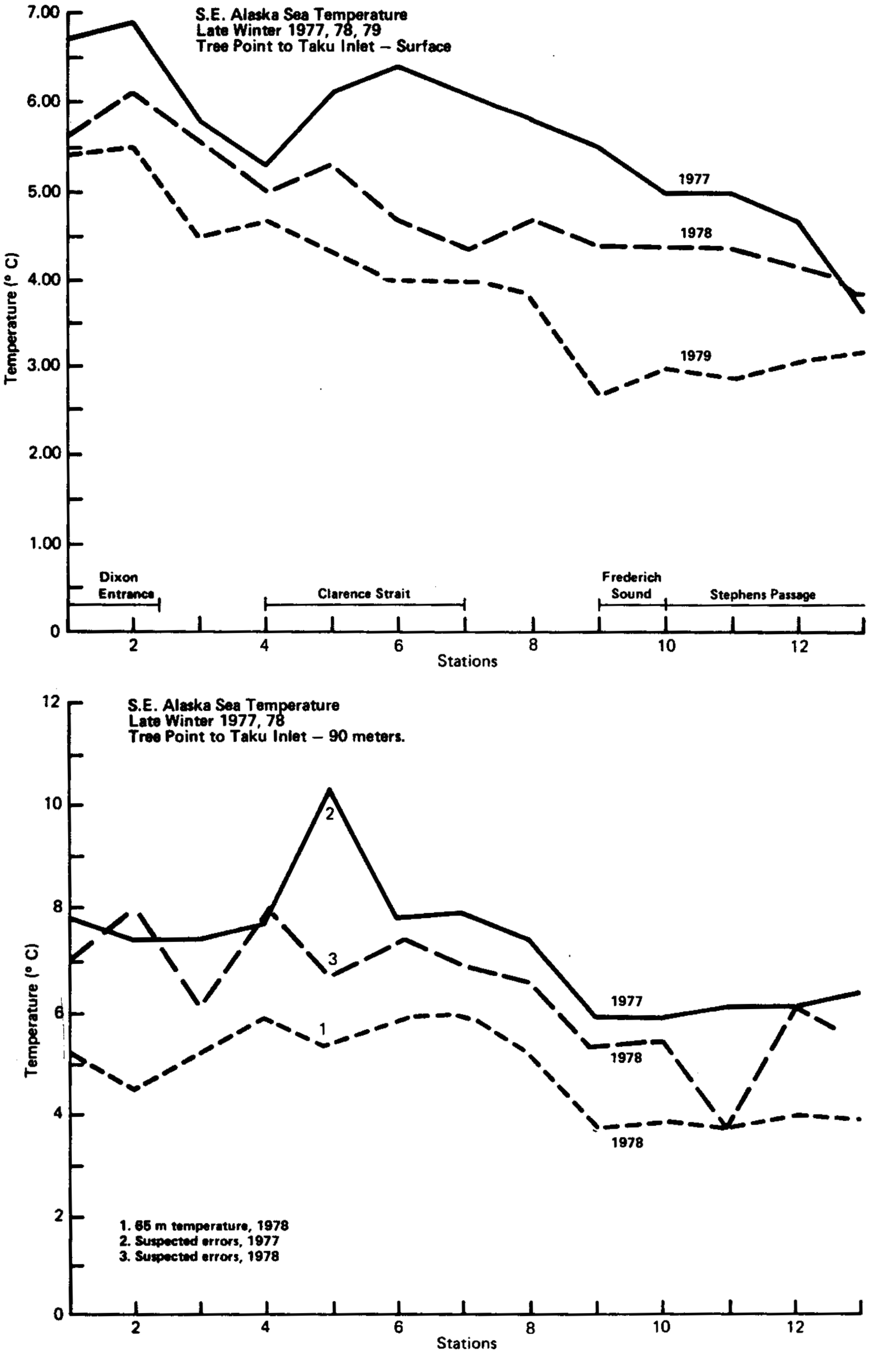


Figure 14.--a. Sea-surface temperature in degrees Celsius for late winter 1977, 1978, and 1979 from Tree Point to Taku Inlet, Alaska (upper).

b. Temperature at 90 m in degrees Celsius for late winter 1977 and 1978, and at 65 m depth in 1978 from Tree Point to Taku Inlet (lower).

Figures supplied by J. Ingraham, Northwest Fisheries Center, NMFS, Seattle, WA 98112.

salinity indicated that, north of 58°N, the trend of the isohalines was northwesterly and parallel to the shoreline, apparently reflecting longshore processes in the absence of major freshwater sources. South of 58°N tongues of dilute water (<32.0°/oo) extended about 100 km seaward near local sources of runoff. The major feature, reported for the first time in 1977 and again evident in 1978, was the bifurcation in coastal flow near 58°N. This bifurcation was evident as a tongue of low-salinity (<32.0°/oo) water pointing toward the northwest in 1977, but in 1978 the major tongue had a salinity of about 0.2°/oo higher and the axis of the tongue trended more perpendicular to shore in a westward to southwestward direction (Fig. 12). Near 55°N a wide band of water with a salinity less than 32.4°/oo suggested that the extent of the major effects of coastal dilution was about 100 km farther seaward in 1978 (142°W). True oceanic salinities of 32.6°/oo were not encountered until nearly mid-Gulf (about 144°W) during both years.

Coastal Circulation - As has been mentioned, in late 1977 and early 1978 onshore Ekman transport was stronger and more toward the northeast than normal along the coast of southeastern Alaska and British Columbia. As a result, the northward flow of the Gulf of Alaska Gyre was intensified and SST's were above normal. Douglas and Wickett (1978) attributed the above normal bottom temperatures off Vancouver Island in early 1978 to stronger than normal onshore Ekman transport of warm surface waters from the southwest with convergence and sinking of surface water at the coast.

Numerous unusual biological events were observed in the area, although their relation to the onshore transport is as yet poorly understood. These included failure of the acorn barnacle, *Balanus cariosus*, to settle during its normal winter settling season; accentuated settlement and growth of two other barnacle species during the winter months (both of these species usually are most vigorous during a July-October interval); accentuated algal growth on the shore (diatoms especially, but also *Ulva* and *Nereocystis*); a massive incursion, on shore, of salps in unheard of quantity; numerous comments by fishermen of blue sharks in very close to shore and in unusual abundance; and finally, unusually few Japanese glass floats coming ashore.[14]

Reports from salmon trollers[15] confirm the massive intrusion of salps off southeastern Alaska in summer 1978 and also the occurrence then of saury and sea turtles (leatherbacks). Both of the latter species normally occur in offshore waters to the south and thus may have been transported to coastal waters of southwestern Alaska by anomalous northward, onshore transport. Wickett[16] suggested that "the early strong Ekman transport to the northeast is associated with the unprecedented large percentage (70) of adult Fraser River sockeye that returned to the river through Queen Charlotte Strait instead of using the Straits of Juan de Fuca." Part of the mechanism is believed to be a northern displacement of a plume of low-salinity water from

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[14] These observations were made by Dr. R. T. Paine and his graduate students of the Department of Zoology, University of Washington, Seattle, WA 98195, at a site near the tip of the Olympic Peninsula in Washington and at Glacier Bay, Alaska (Lasker 1978).

[15] B. L. Wing, Northwest and Alaska Fisheries Center, NMFS, Auke Bay, AK 99821. Personal communication.

[16] P. Wickett. Pacific Biological Station, Nanaimo, BC V9R 5K6, Canada. Personal communication.

Queen Charlotte Sound (cf. Fig. 12). The herring roe fishery in Barkley Sound just inshore of the survey area reported on by Douglas and Wickett (1978) was disrupted by the unusual behaviour of the fish which spawned at greater than normal depths."

Adult pink salmon returns to Little Port Walter Bay, Baranof Island, in southeastern Alaska in 1978 had an unusually high ocean survival (Herd 1979). However, this was probably more related to conditions in 1977 when salmon fry entered the ocean than in 1978 when the adults returned.

Strait of Juan de Fuca to Gulf of California

Temperature - Anomalies of sea-surface temperature along the west coast of the United States had somewhat similar trends as in areas to the north. At square 121-3 (Fig. 7) off central California, SST's have been below normal almost continuously since mid-1970 with short above normal periods in mid-1977 and early 1978. At squares 120-2 off southern California and 83-2 off the Gulf of California, the basic pattern of variation was similar to that at square 121-3 except that it was shifted to slightly more positive anomalies. Thus at squares 120-2 and 83-2, SST's were below normal in early 1971 and 1972 and again in 1973 and 1975, above normal in late 1976 and early 1978, and near normal values in late 1979.

Figures 15 and 16 give more details on SST variations along the coast during 1978 and early 1979. Along the California coast, north of Point Conception (34°-40°N; Fig. 15) SST's were anomalously warm during early 1978 during the period of extreme low upwelling, but fell to below normal levels in June. Farther north (41°-48°N) the above normal SST's persisted until November when anomalous cooling became evident. SST's were uniformly below normal during winter 1978-79 and the anomalies were generally negative by 1°-2°C. By March 1979 SST's returned to normal values.

Along the coast of southern California and Baja California (Fig. 16), the fluctuations of SST were similar to those observed to the north. Above normal SST's occurred in early 1978 and persisted until summer and early fall when anomalous cooling occurred. SST's were below normal off Baja California in fall and into winter 1978-79, but were again near normal in March 1979.

Runoff - Maximum mean monthly runoff of the Columbia River[17] into the ocean normally occurs in June and minimum discharge normally occurs in September. However, the seasonal variation of runoff can vary markedly from year to year. For example, in 1977 minimum monthly mean discharge occurred in July (McLain et al. 1979) and the maximum (roughly four times the minimum) occurred in December. These variations were caused by drought during most of 1977 and heavy precipitation in winter 1977-78.

Conditions in 1978 indicated a return to more normal trends with some exceptions. Above normal runoff continued through March 1978 (Fig. 10). The maximum discharge occurred in May 1978, rather than June, and the June discharge was nearly 50 less than normal.

Coastal Circulation - During January-March 1978 southerly winds occurred over California during anomalous high pressure and drought conditions. As has been mentioned, upwelling during this period was extremely low (Fig. 5)

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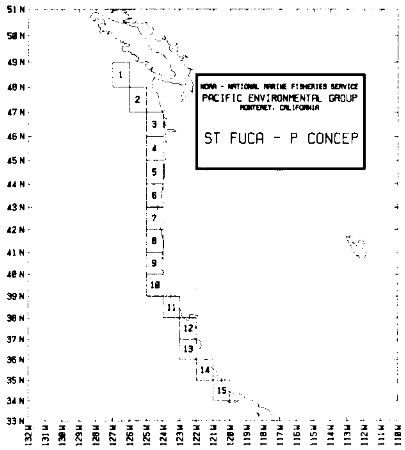
[17] S. F. Kapustka, U.S. Geological Survey, Portland, OR 92708. Personal communication.

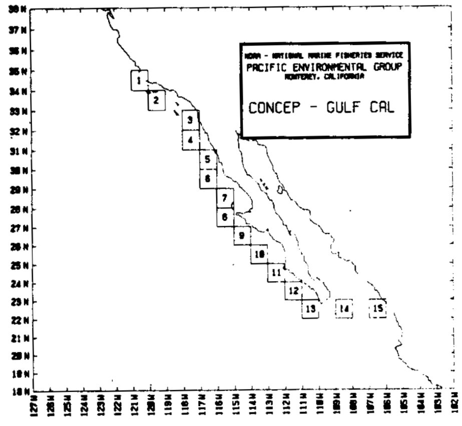


	D	J	F	M	A	M	J	J	A	S	O	N	D
1 48N 126W	9.1 (15)	8.4 (14)	8.0 (14)	7.8 (15)	8.7 (17)	10.5 (15)	12.2 (17)	13.4 (13)	14.0 (17)	14.3 (16)	13.2 (15)	10.9 (16)	9.1 (15)
2 47N 125W	9.7 (13)	9.1 (15)	9.4 (16)	9.0 (15)	9.9 (17)	11.3 (11)	14.0 (13)	14.7 (11)	15.0 (12)	15.2 (13)	13.8 (10)	11.8 (17)	9.7 (13)
3 46N 124W	10.3 (9)	9.7 (9)	9.2 (14)	9.0 (15)	10.0 (14)	11.9 (13)	13.8 (14)	15.0 (14)	15.7 (14)	15.4 (14)	13.5 (13)	12.0 (15)	10.3 (9)
4 45N 124W	10.8 (12)	9.9 (14)	9.6 (13)	9.5 (18)	10.2 (16)	11.8 (17)	13.9 (16)	14.0 (13)	15.0 (17)	15.3 (17)	13.9 (14)	12.0 (16)	10.8 (12)
5 44N 124W	11.1 (17)	10.2 (13)	9.9 (18)	9.7 (18)	10.2 (17)	11.2 (16)	13.6 (16)	14.0 (14)	14.5 (15)	14.6 (14)	14.0 (17)	12.1 (14)	11.1 (17)
6 43N 124W	11.1 (16)	10.6 (15)	10.1 (14)	9.8 (17)	10.5 (18)	11.5 (16)	13.0 (16)	13.1 (15)	13.8 (12)	14.0 (18)	13.9 (13)	12.1 (16)	11.1 (16)
7 42N 124W	11.7 (17)	10.5 (14)	10.5 (15)	10.5 (18)	10.4 (17)	11.4 (17)	11.9 (18)	11.8 (18)	12.6 (14)	13.3 (18)	13.1 (17)	12.6 (16)	11.7 (17)
8 41N 124W	11.9 (17)	11.0 (15)	10.7 (16)	10.6 (18)	10.6 (17)	11.3 (18)	12.[illegible] (18)	11.9 (15)	12.3 (16)	13.0 (18)	12.8 (16)	12.2 (17)	11.9 (17)
9 40N 124W	12.9 (17)	11.1 (15)	10.8 (16)	10.8 (18)	10.8 (17)	11.8 (18)	11.8 (18)	12.0 (17)	12.7 (14)	13.2 (17)	13.2 (17)	12.6 (18)	12.9 (17)
10 39N 124W	12.7 (19)	11.5 (20)	11.4 (18)	11.1 (20)	10.7 (20)	11.6 (20)	12.1 (20)	12.6 (20)	12.9 (20)	13.7 (19)	13.5 (19)	13.3 (20)	12.7 (19)
11 38N 123W	12.8 (19)	11.6 (19)	11.8 (19)	11.4 (20)	11.3 (20)	11.6 (20)	12.0 (20)	12.6 (19)	13.5 (20)	13.7 (18)	14.0 (20)	13.5 (20)	12.8 (19)
12 37N 122W	12.7 (19)	12.2 (19)	12.3 (18)	12.2 (20)	12.1 (18)	12.7 (19)	13.6 (20)	14.2 (19)	14.6 (20)	15.8 (20)	15.2 (19)	14.8 (20)	12.7 (19)
13 36N 122W	13.7 (19)	12.8 (20)	12.4 (19)	12.3 (20)	12.4 (20)	12.7 (20)	13.5 (20)	14.3 (20)	14.6 (20)	15.6 (20)	15.1 (19)	14.3 (20)	13.7 (19)
14 35N 121W	13.9 (20)	12.9 (20)	12.9 (20)	12.7 (20)	12.5 (20)	12.5 (20)	13.5 (20)	14.3 (20)	14.9 (20)	15.6 (20)	15.5 (20)	14.8 (20)	13.9 (20)
15 34N 120W	14.4 (19)	13.6 (20)	13.4 (19)	12.9 (20)	12.9 (19)	13.2 (20)	14.0 (20)	15.5 (20)	16.1 (17)	16.6 (20)	16.1 (20)	15.4 (20)	14.4 (19)

SEA SURFACE TEMPERATURE LONG TERM MEAN 1971-1978

	1978 J	F	M	A	M	J	J	A	S	O	N	D	1979 J	F	M
1 48N 126W	1.5 (7)	-.2 (4)	-.2 (14)	0.3 (3)	1.1 (19)	0.9 (10)	0.0 (4)	0.6 (29)	0.0 (5)	1.0 (3)	0.2 (4)	0.3 (11)	-1.3 (10)	-1.2 (3)	-.0 (7)
2 47N 125W	-1.4 (3)	-.3 (8)	0.4 (5)	0.8 (5)	0.7 (16)	0.6 (60)	-.9 (74)	-.2 (7)	0.3 (6)	1.7 (2)	-2.5 (2)	-1.1 (2)	-1.4 (5)	-1.9 (6)	0.5 (14)
3 46N 124W	0.2 (220)	0.6 (240)	0.6 (253)	-.3 (229)	-.5 (16)	2.2 (13)	-.7 (173)	-1.0 (35)	-.3 (152)	0.7 (170)	-.4 (168)	-.3 (205)	-2.0 (120)	-2.4 (203)	-.8 (249)
4 45N 124W	0.3 (5)	0.7 (8)	1.4 (5)	0.7 (10)	0.5 (7)	1.9 (110)	0.2 (54)	0.1 (12)	0.9 (14)	1.4 (17)	-1.5 (6)	-1.4 (4)	-1.0 (1)	-1.2 (3)	0.4 (6)
5 44N 124W	0.5 (5)	1.5 (11)	2.0 (5)	1.3 (6)	0.7 (13)	1.6 (218)	-.5 (170)	0.2 (76)	0.9 (36)	1.4 (23)	0.2 (10)	-.6 (4)	-1.4 (6)		1.0 (10)
6 43N 124W	0.3 (3)	1.1 (13)	1.9 (8)	0.7 (3)	0.4 (5)	1.3 (89)	0.5 (118)	0.9 (105)	2.0 (47)	1.2 (8)	-.7 (2)	-2.0 (6)	-1.2 (7)	-1.8 (3)	-.6 (11)
7 42N 124W	1.5 (3)	0.8 (5)	0.7 (5)	0.6 (8)	1.0 (4)	2.1 (27)	1.1 (27)	0.1 (9)	2.2 (3)	-1.4 (1)	-.1 (6)	-.5 (3)	-.5 (7)	-2.0 (5)	-.9 (6)
8 41N 124W	0.5 (4)	0.4 (10)	2.0 (7)	0.8 (12)	1.3 (5)	1.1 (127)	0.4 (153)	1.4 (6)	2.0 (6)	1.7 (2)	2.6 (11)	-1.9 (5)	-1.5 (5)	-2.0 (4)	-.2 (19)
9 40N 124W	1.0 (6)	1.7 (11)	1.5 (7)	1.3 (13)	0.9 (12)	0.7 (50)	-.3 (47)	0.2 (9)	0.0 (3)	1.5 (6)	-.4 (13)	-2.1 (10)	-.4 (8)	-1.8 (5)	0.6 (19)
10 39N 124W	0.7 (11)	1.2 (17)	1.4 (8)	1.6 (21)	0.3 (13)	-.1 (10)	0.5 (7)	0.5 (10)	0.4 (7)	-.5 (8)	-1.5 (14)	-2.3 (14)	-.7 (12)	-1.4 (10)	0.3 (31)
11 38N 123W	1.3 (6)	1.2 (8)	0.4 (4)	1.2 (10)	-.1 (9)	-.2 (14)	-.2 (7)	0.6 (12)	0.8 (6)	0.1 (6)	-1.5 (9)	-1.5 (12)	-.7 (4)	-.9 (6)	0.1 (26)
12 37N 122W	1.4 (2)	0.1 (8)	0.2 (4)	1.3 (7)	-.5 (5)	-1.1 (2)	-1.0 (2)	0.8 (5)	-1.6 (5)	0.1 (2)	0.2 (3)	-.6 (5)	-.4 (6)	-2.0 (3)	-1.3 (8)
13 36N 122W	0.5 (9)	0.6 (14)	1.3 (10)	0.9 (10)	-.5 (18)	-1.6 (13)	-1.1 (25)	0.6 (12)	-.7 (9)	0.4 (5)	-1.6 (13)	-1.9 (35)	-1.0 (13)	-1.6 (7)	0.1 (24)
14 35N 121W	0.8 (12)	0.7 (15)	1.5 (17)	0.7 (16)	-.4 (19)	-1.0 (7)	0.5 (14)	-.8 (10)	-1.4 (14)	-1.4 (5)	-.5 (13)	-.9 (11)	-1.1 (15)	-1.1 (14)	0.3 (16)
15 34N 120W	2.0 (1)	-1.5 (5)	2.0 (8)	-.3 (6)	0.4 (12)	-1.6 (5)	-2.4 (8)	-.4 (7)	-.9 (5)	1.1 (3)	0.4 (9)	-.3 (7)	-1.2 (8)	-.4 (4)	-.9 (8)

Figure 15.--Time-space matrix for January 1978-March 1979 of anomaly of sea-surface temperature (lower) in degrees Celsius from the long-term mean reference period 1948-67 for a line of 1-degree squares along the coast from the Strait of Juan de Fuca to Point Conception (locations shown in upper left). The long-term mean temperature values are shown in upper right and are based on data from the National Climatic Center, EDIS, Asheville, NC 22801.



	D	J	F	M	A	M	J	J	A	S	O	N	D
1 34N 120W	14.4	13.6	13.4	12.9	12.9	13.2	14.0	15.5	16.1	16.6	16.1	15.4	14.4
2 33N 119W	15.0	14.4	14.3	14.3	14.4	15.0	15.9	17.6	18.6	18.7	18.3	16.6	15.0
3 32N 117W	16.4	14.9	14.7	15.0	15.7	16.2	17.2	19.0	20.0	19.0	19.1	17.6	16.4
4 31N 117W	16.7	15.6	15.1	15.1	15.7	16.4	17.1	18.5	20.0	20.0	19.2	17.9	16.7
5 30N 116W	17.1	15.9	15.6	15.4	15.8	16.2	16.8	18.5	19.9	20.2	19.4	18.2	17.1
6 29N 116W	17.5	16.2	15.9	15.7	15.9	16.4	17.1	18.6	20.1	20.5	19.9	18.7	17.5
7 28N 115W	18.2	17.0	16.2	15.8	16.0	16.2	16.9	18.7	20.3	21.0	20.5	19.4	18.2
8 27N 115W	18.8	17.4	16.6	16.1	16.1	16.4	17.0	19.1	20.6	21.7	21.3	20.0	18.8
9 26N 114W	20.1	18.5	17.7	16.9	16.6	16.8	17.4	19.8	21.9	23.0	22.7	21.2	20.1
10 25N 113W	21.2	19.5	18.6	17.6	17.2	17.2	18.0	20.9	23.3	24.6	24.1	22.7	21.2
11 24N 112W	22.5	20.5	19.3	18.2	17.8	17.5	18.2	22.0	24.9	26.2	25.8	23.9	22.5
12 23N 111W	23.6	21.6	20.3	19.3	18.8	18.6	19.4	23.4	26.6	27.5	26.7	25.1	23.6
13 22N 110W	24.4	22.5	21.4	20.8	20.8	20.6	21.9	25.2	27.9	28.3	27.5	26.2	24.4
14 22N 108W	25.4	23.1	22.5	22.6	22.5	24.0	25.0	27.1	28.9	29.0	29.0	27.3	25.4
15 22N 106W	26.1	24.4	24.0	22.9	24.0	27.1	27.7	30.1	28.7	29.9	27.0	26.2	26.1

SEA SURFACE TEMPERATURE CONCEP - GULF CAL LONG TERM MEAN 1978-1979

	1978 J	F	M	A	M	J	J	A	S	O	N	D	1979 J	F	M
1 34N 120W	2.0	-1.5	2.0	-.3	0.4	-1.6	-2.4	-.4	-.9	1.1	0.4	-.3	-1.2	-.4	-.9
2 33N 119W	1.0	0.7	-.1	-.7	-.6	-.9	-.1	0.2	1.3	-.8	-1.0	-1.2	-2.4	-.6	-.5
3 32N 117W	1.7	1.2	2.4	1.8	0.3	1.6	-.2	1.2	0.1	1.4	0.8	-1.2	-.2	-.4	0.3
4 31N 117W	1.3	1.3	0.6	1.1	0.7	0.4	0.5	0.2	-.0	0.1	-.4	0.0	-.2	-.4	0.1
5 30N 116W	1.0	0.4	0.7	1.2	1.0	1.0	-.2	0.1	-1.7	-.4	0.2	-1.4	-.3	-.6	0.1
6 29N 116W	1.7	1.2	1.0	0.5	0.9	0.9	0.5	-.2	-1.1	0.5	0.6	-.3	-.2	-.7	0.0
7 28N 115W	1.0	0.3	0.9	0.9	0.7	0.2	-1.7	0.5	-1.3	-.7	-.1	-1.7	-1.0	-.8	0.9
8 27N 115W	0.3	1.0	1.7	0.3	0.4	1.4	0.2	-.5	-1.5	0.4	0.4	-.4	-1.0	-1.4	-.1
9 26N 114W	1.0	0.4	1.2	1.1	0.8	0.2	0.1	-1.0	-2.0	0.1	-.0	-1.1	-1.0	-1.5	0.2
10 25N 113W	1.6	1.1	1.1	0.6	1.4	-1.0	-1.0	-.9	-2.0	-.4	-.4	-1.5	-1.0	-.8	-.2
11 24N 112W	1.2	0.5	1.7	0.4	0.9	1.0	1.0	0.6	-1.4	-1.0	-1.5	-1.2	-.5	-1.0	-.2
12 23N 111W	0.9	0.9	0.4	0.8	0.3	0.4	1.0	1.3	-.9	0.5	0.7	-1.9	-1.4	-1.2	0.1
13 22N 110W	1.7	1.5	0.6	-.0	0.1	0.5	-.4	0.4	-1.3	0.7	0.2	-1.7	-.7	-1.3	-.4
14 22N 108W	0.9	0.5	-.6	0.3	0.2	-1.2	0.9		0.7	0.6	1.0	-1.1	-1.3	-1.0	-1.4
15 22N 106W		0.0									-.5	-2.3		-2.0	-.6

Figure 16.--Time-space matrix for January 1978-March 1979 of anomaly of sea-surface temperature (lower) in degrees Celsius from the long-term mean reference period 1948-67 for a line of 1-degree squares along the coast from Point Conception to the Gulf of California (locations shown in upper left). The long-term mean temperature values are shown in upper right and are based on data from the National Climatic Center, EDIS, Asheville, NC 28801.

and the opposite circulation, downwelling, occurred. Ekman transports at points off California (Fig. 2) were also weaker than long-term mean conditions during this period. Sea-surface temperatures were up to 2°C above normal during December-April. These conditions were associated with apparently stronger than normal transports by the northward flowing, near shore California Counter Current (Davidson Current).

The effects of increased northward transport by the California Counter Current on marine populations remain unclear. Parrish and Bakun (1979) suggested that the extremely low upwelling indices during early 1978, together with associated warmer than normal SST's, could have allowed anomalous northward migration of southern species along the coast. Commercial swordfish landings in 1978 in southern California were nearly double the previous record (set in 1978) and may have resulted from increased northward advection.

Anomalously strong northward advection along the coast, combined with above normal SST's, may also explain unusual recoveries of tagged billfish off southern California in October 1978.[18] Of the several thousand marlin tagged by the Southwest Fisheries Center, all those previously recovered had been taken to the south and southwest of San Diego, off Baja California and central Mexico, around the Hawaiian Islands, and near the Marquesas Islands in the southeast Pacific. None before had ever been recovered off southern California.

Other unusual occurrences of tropical species were reported in summer 1978. A triggerfish (a tropical reef fish) was caught near Monterey, CA, on September 20, 1978.[19] Radovich (1960) discussed anomalous catches of various species, including triggerfish, along the California coast during the unusual warm period in 1957 and 1958.

The onshore Ekman transport in early 1978 appeared to concentrate anchovy larvae near shore and allow improved reproductive success. Seckel et al. (1978) described the large-scale atmospheric circulation over the west coast during the period 1976-78 and the upwelling conditions that resulted from that circulation. They suggested that onshore Ekman transport during early 1978 (and the resulting weak upwelling indices) apparently concentrated anchovy larvae and their forage organisms near the California coast and resulted in good spawning success relative to the spawning stock size. In other years when onshore transport is less apparent, spawning success may be reduced by loss of larvae to offshore areas. Seckel et al. further suggested that the large numbers of young-of-the-year anchovy observed in southern California waters during spring and summer 1978 and unusually large concentrations of young fish as far north as Monterey Bay appear to support their hypothesis.

Salinity - Salinities along the California coast were below normal during 1978 and early 1979, particularly in the first quarter of each year. Data on temperature and salinity at the surface and bottom (about 5 m) at Scripps Pier in La Jolla, CA, are shown in Figure 16. The origin of the low-salinity water is unclear; it may be due to such processes as increased advection of low-salinity water from northern areas, above normal precipitation, or decreased upwelling of high-

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[18]News release, October 17, 1978, Southwest Fisheries Center, NMFS, La Jolla, CA 92038. Two record recoveries made of tagged billfish off southern California.

[19]Monterey Peninsula Herald, September 20, 1978.

salinity water from depth. Low-salinity water was also observed off southern California in 1978 during CalCOFI cruises,[20] and was noted up to 1,500 km offshore of central California in surface salinity observations made by merchant ships.[21]

The time series of salinity at Scripps Pier in 1978-79 looks remarkably similar to that observed during the period 1941-42 (Fig. 17). Note also the occurrence of above normal temperatures at Scripps Pier in the winters of 1976-77 and 1977-78, and the similar above normal temperatures in the winters of 1939-40 and 1940-41.

Eastern Tropical Pacific

An important process causing variations of oceanographic conditions in the Eastern Tropical Pacific (ETP) from one year to the next is the so-called El Niño. When this event occurs, sea levels and sea-surface temperatures are above normal in the waters off Ecuador and Peru, the normal upwelling of nutrient-rich deep waters into the surface waters is disturbed and biological productivity of the area is reduced. Wyrtki (1978) suggested that the El Niño conditions normally follow periods of strong trade winds which pile water up in the western tropical Pacific. As the trade winds relax, eastward flow increases in the Equatorial Counter Current towards South America, raising SST's and sea levels along the coast, depressing the thermocline, and reducing the normal upwelling of nutrient-rich water from depth.

Southern Oscillation - The variation of atmospheric pressure across the tropical Pacific, called the Southern Oscillation, has been correlated with recruitment of skipjack tunas (IATTC 1978, 1979). Quinn (1978, 1979) developed an index of the Southern Oscillation as the difference in surface atmospheric pressure between Easter Island in the eastern Pacific and Darwin, Australia, in the western Pacific:

$$\text{S.O. Index} = P_{\text{Easter}} - P_{\text{Darwin}}.$$

A time series of this index is shown in Figure 18 for the period January 1948-June 1979. During 1970-71 the index was positive for many months, indicating a strong pressure difference across the Pacific and strong trade winds. In 1972 the difference fell rapidly, the trade winds relaxed, and SST's (squares 308-1, 9-1, and 46-1 in Fig. 8) and sea levels (data for California stations shown in Fig. 6) increased as a major El Niño developed (Miller and Laurs 1975). In 1973 the pressure difference increased, sea levels and SST's returned to more normal values, and the El Niño condition disappeared. In 1975-76 a weaker cycle occurred with a positive pressure difference in 1975, a falling difference in 1976, and a weak El Niño response. The pressure difference has remained negative (near zero in mid-1978) since 1976 for an unusually long period of time. Thus the trade winds have been weak for the last three years and the probability of a major El Niño in 1979 and early 1980 is very low.

Temperature - Oceanographic conditions in the ETP are commonly monitored from patterns of SST and its anomaly from a long-term mean. Maps of anomaly of SST in the ETP are published monthly in Fishing Information. The following discussion is based on those maps, and the reader is referred to them and the accompanying descriptions for details

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[20] R. Lynn, Southwest Fisheries Center, NMFS, La Jolla, CA 92037. Personal communication.

[21] J. F. T. Saur, Scripps Institution of Oceanography, La Jolla, CA 92038. Personal communication.

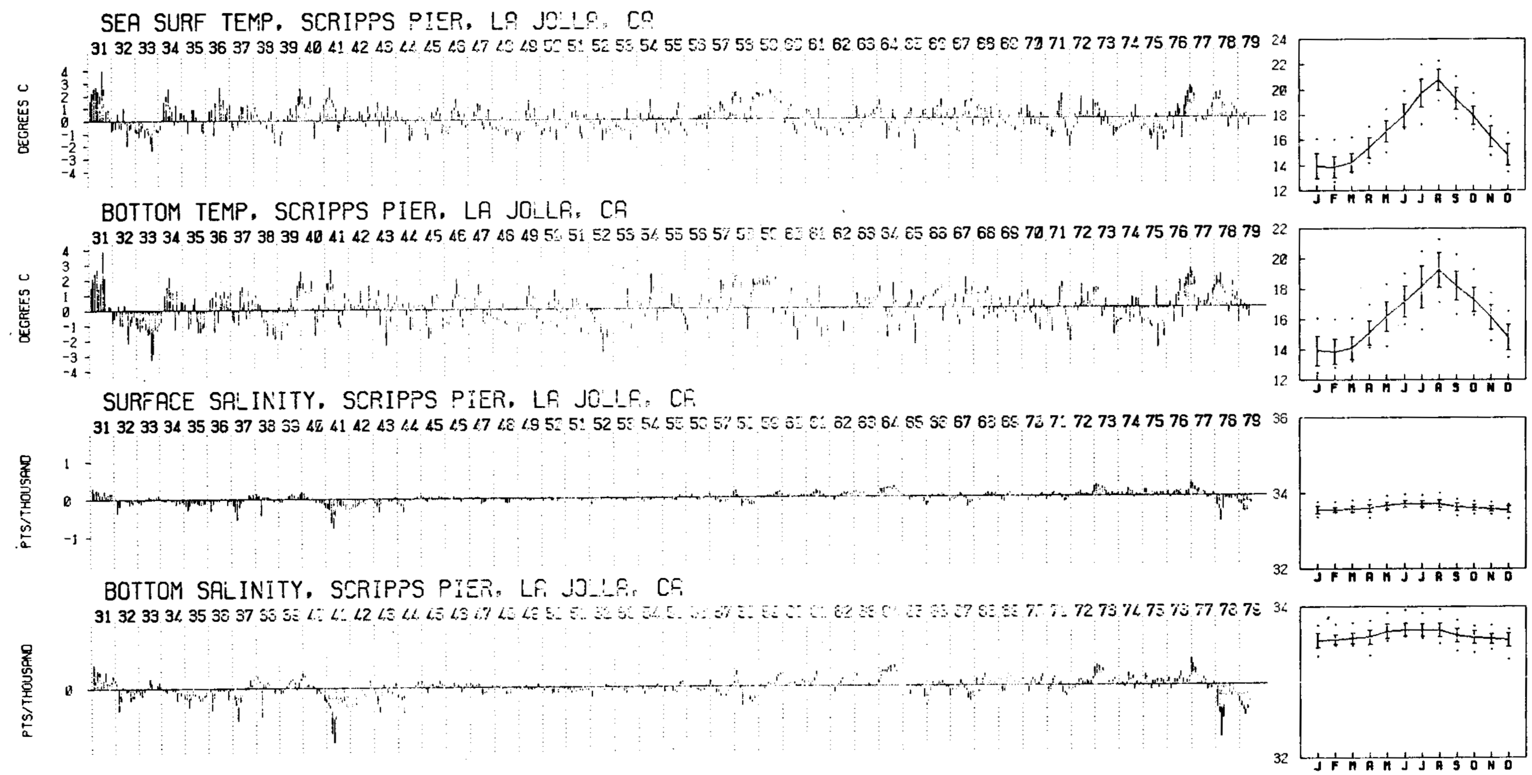

Figure 17.--Time series for 1931-79 of anomaly of temperature in degrees Celsius and salinity in parts per thousand at the surface and bottom (5 meters) at the end of Scripps Pier, La Jolla, CA, from the long-term mean reference period 1948-67. Data from C. Conway, Scripps Institution of Oceanography, La Jolla, CA 92038.

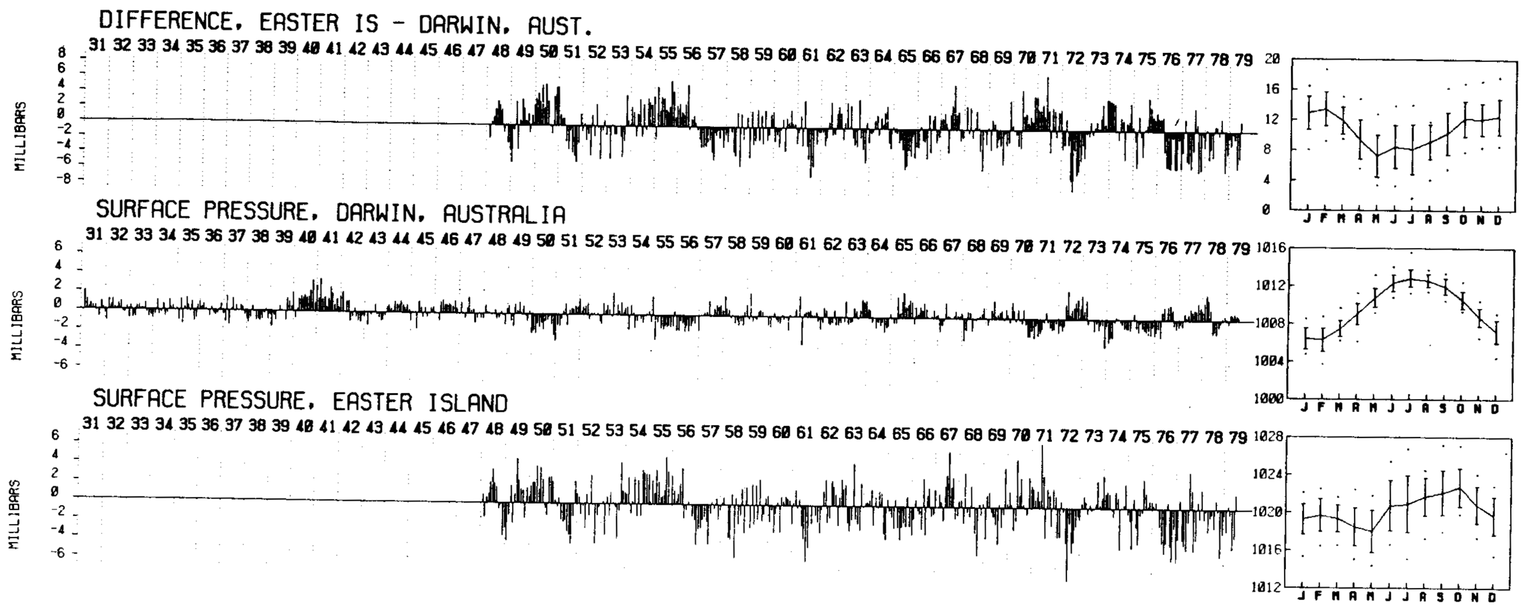

Figure 18.--Time series for 1931-79 of anomaly of surface atmospheric presure in millibars at Easter Island and Darwin, Australia, from the long-term mean reference period 1948-67. The difference between the two stations is an index of the Southern Oscillation. Developed by W. Quinn, Oregon State University, Corvallis, OR 97331.

of ocean conditions during 1978 and early 1979.

During January 1978 SST's were above normal over much of the ETP in the area west of 110°W due to weak trade winds and a relaxation of the subtropical high-pressure system off California. Upwelling off Peru and westward along the Equator caused below normal SST's east of 110°W as did strong wind mixing in the Gulfs of Tehuantepec and Panama and along the west coast of Nicaragua.

This general pattern persisted through February, but by March SST's had returned to near normal values over most of the area. Below normal SST's persisted in the Gulfs of Tehuantepec and Panama due to northerly winds blowing across Central America from the Gulf of Mexico.

In April the subtropical high-pressure system over the ETP continued weaker than normal. Lighter than normal winds and less than normal cloud cover resulted in above normal SST's in a large area southwest of Baja California. A dramatic increase in equatorial upwelling reduced SST's to below normal values in a broad band along the Equator from the coast of Peru to 180° and beyond.

Below normal SST's along the Equator continued as the dominant feature of the SST patterns from April through September. The colder than normal temperatures were typical of an "anti-El Niño" situation where the trade winds are moderately strong (note the positive pressure differences in mid-1978, Fig. 20) and upwelling of cold water along the Equator was intense.

The band of below normal SST's along the Equator broke up in fall, and by November SST's were near normal over the entire ETP, except for below normal SST regions along the equator near Equador, in the Gulf of Tehuantepec, and off Baja California. This general pattern of near normal SST's over the ETP with below normal SST pools near the coast persisted through March 1979.

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