Northwest and Alaska Fisheries Center

National Marine Fisheries Service

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A Preliminary Evaluation of Surface Winds, Their Anomalies, Effects on Surface Currents, and Relations to Fisheries

October 1985

NOTICE

A PRELIMINARY EVALUATION OF SURFACE WINDS, THEIR ANOMALIES, EFFECTS ON SURFACE CURRENTS, AND RELATIONS TO FISHERIES

An introductory study on application of wind data in fisheries, prepared in part by Dr. Felix Favorite for Resource Ecology and Ecosystem Simulation Task of Northwest & Alaska Fisheries Center, Contract No. VSC 252

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WIND FIELDS, NORTH PACIFIC OCEAN

Introduction

The purpose of this initial study is to make a preliminary assessment of the possible significance of wind anomalies in depicting surface current anomalies in the northern Pacific Ocean, using available data on currents in the 1950's and 1960's and wind data from 1946 to 1984. The intent was not to summarize or evaluate the myriad oceanographic or air-sea investigations, nor to analyse exhaustively the nearly 4 decades of monthly maps of mean surface wind anomalies, which would be a length and costly process, but to explore the general character of these data and to discover and investigate several readily apparent, anomalous conditions and events, with particular emphasis on the Gulf of Alaska, the area of particular interest to the NWAFC.

Although even today oceanographic observations are still non-synoptic and fragmentary, records of surface winds extend back a number of centuries and correlations with ocean conditions have been sought continually as aids to marine commerce with regard to safety as well as economy of time and fuel. The increased activities in oceanographic research and cooperation from large numbers of foreign and domestic fishing vessels have considerably enhanced the marine environment data base and permit more definitive studies, satellite imagery has improved interpretations of storm activity particularly identifying the locations of storm centers, and large computers allow rapid and accurate compilation, integration, and presentation of the various information. Thus it is time to seek ways to apply this knowledge to fisheries investigations. Positive results should lead to the development of ocean models applicable to fishery problems as well as studies related to fish behavior such as distribution, abundance, migration, egg and larvae dispersal, and other purposes.

Monthly mean surface wind anomalies

The wind fields were derived from the Fleet Numerical Oceanography Center's 00Z daily synoptic pressure fields (Ingraham et al. 1983). Mean u and v components are computed for each month and the anomalies, representing a departure from the long-term mean winds (1946-1983), are plotted by computer at 880 grid points of a 20x44 portion of a 63x63 polar stereographic grid for the northern hemisphere - resulting in this case of a set of 456 maps of monthly mean wind anomaly vectors, a total of nearly a half million vectors. Subsequently, as discussed later, a set of monthly mean wind maps and some annual and seasonal sets were also required.

Because the visual perusal of wind anomalies on such a grand scale is a relatively new possibility, one is immediately impressed with the immense variety of the subtly organized but varied shapes of implied small- and large-scale monthly mean patterns of eddies and large gyres. And even after lengthy and laborious screening of the maps one is awed by difficulties of ascertaining, much less describing, significant events. Effort was focused on the period 1960-1971, in which analyses of monthly mean sea level pressure revealed 42 storm centers north of 40°N with anomalies greater than 10 mb (Favorite et al. 1973). These occurred largely in winter in the central and eastern parts of the region with positive (high pressure centers) and negative (low pressure centers) anomalies equally represented (Fig. 1a and b). Sixteen of these centers had anomalies greater than 15 mb, and 8 of these were selected as representative of the uniformity as well as the variety of some of the monthly mean wind anomaly fields associated with major and thus highly ordered events.

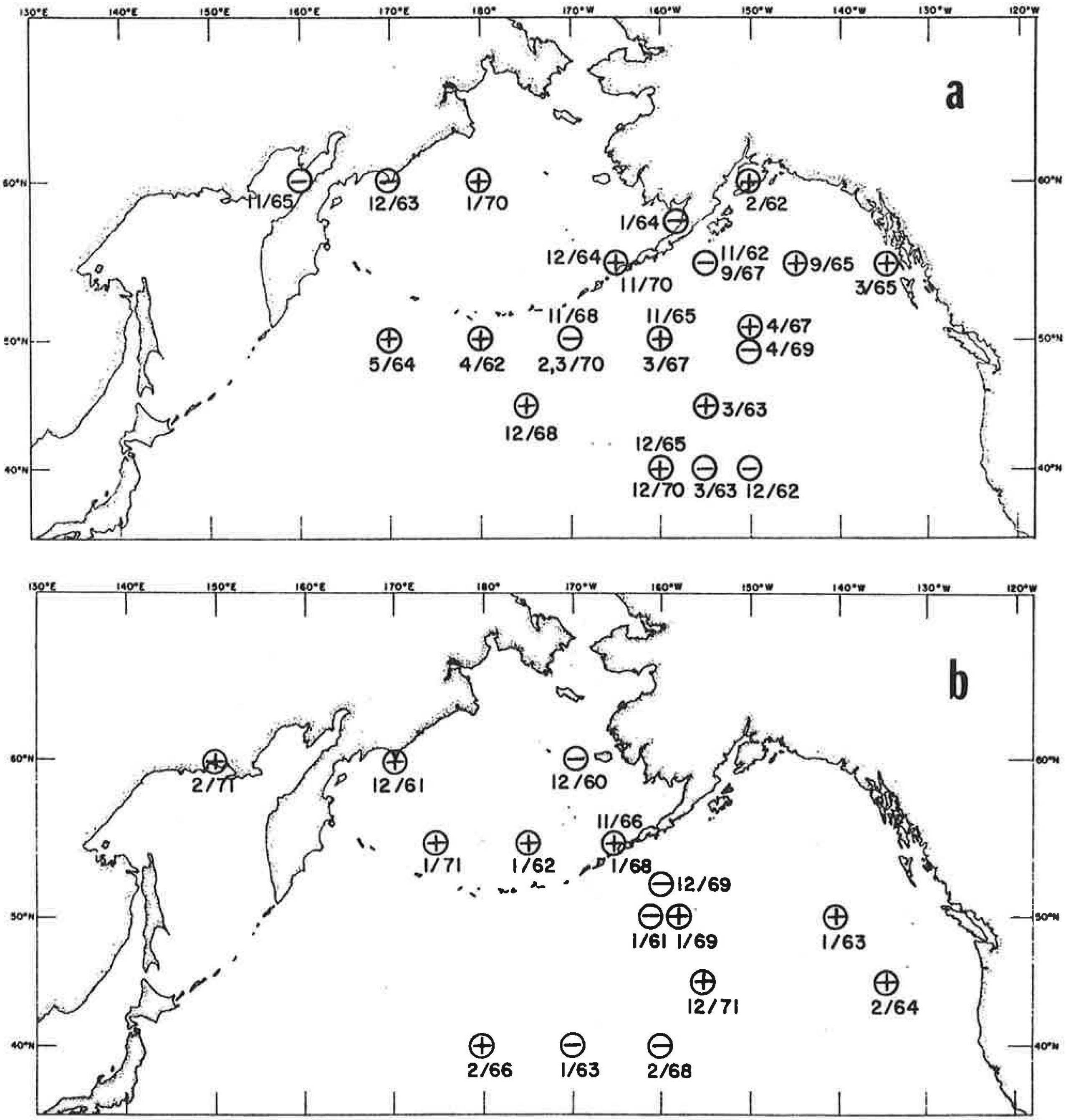
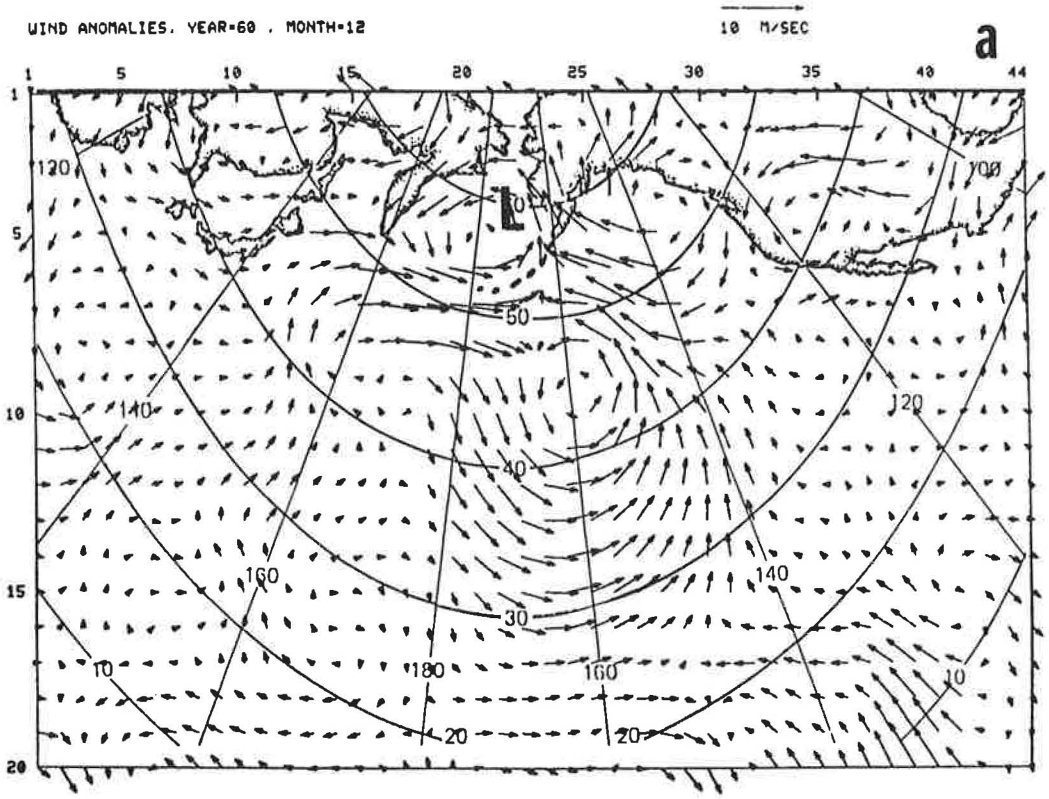


Figure 1.--Locations and dates (mo. and yr.) of monthly mean sea level pressure anomalies of a - 10 to 15 mb and b - greater than 15 mb during 1960-1971.

First, monthly mean wind anomaly maps for December 1960 and 1969 (Fig. 2a and b) indicate the vast extent of the effects of intense low pressure systems, largely transpacific north of 40°N and, in the central portion, meridionally across 30° of latitude, over 3,000 km (Fig. 2b). It is also apparent that the intensity of a low is not necessarily a measure of its extent because in December 1960 (Fig. 2a) it's apparent that the low centered at 45°N, 160°W exerted considerably more influence on conditions than the deep one of small extent indicated. Second, the maps for December 1961 and 1971 (Fig. 3a and b) reflect the complex fields of anomalous winds associated with intense high pressure systems. The large latitudinal extent of meridional wind anomalies (i.e. southerly anomalous winds along 160°W) are a rather common occurrence. Third, the maps for January and February 1968 (Fig. 4a and b) show the rapid shift in mean anomalous winds from one month to the next when mean conditions change from an intense high pressure system (January) to an intense low pressure system (February). Conditions in December 1967 do not herald those in January 1968, but those in February 1968 were quite similar to those in March 1968. Particularly significant are the February wind anomalies influence on conditions between 180° to 160°W from roughly 25° to 65°N, a distance of 4,300 km. And fourth, the maps for January 1963 and February 1964 (Fig. 5a and b) indicate, in the former, the occurrence of both a major high and low pressure system in the same month and, in the latter, strong, mean anomalous winds limited to the eastern side of the ocean as well as an indication of the difficulty of ascertaining patterns in areas of weak anomalies characteristic of the western Pacific in this map.

Thus, it's obvious (and anticipated) that monthly mean wind anomalies clearly reflect not only major but (other potential) oceanic disturbances even



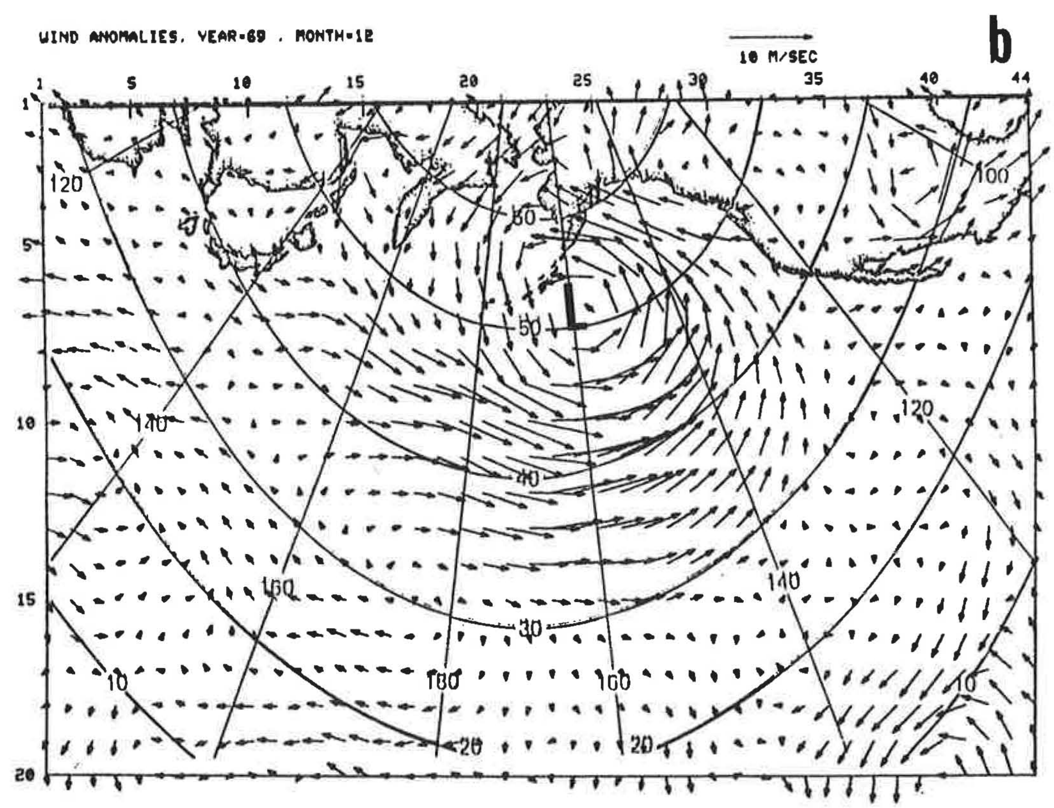
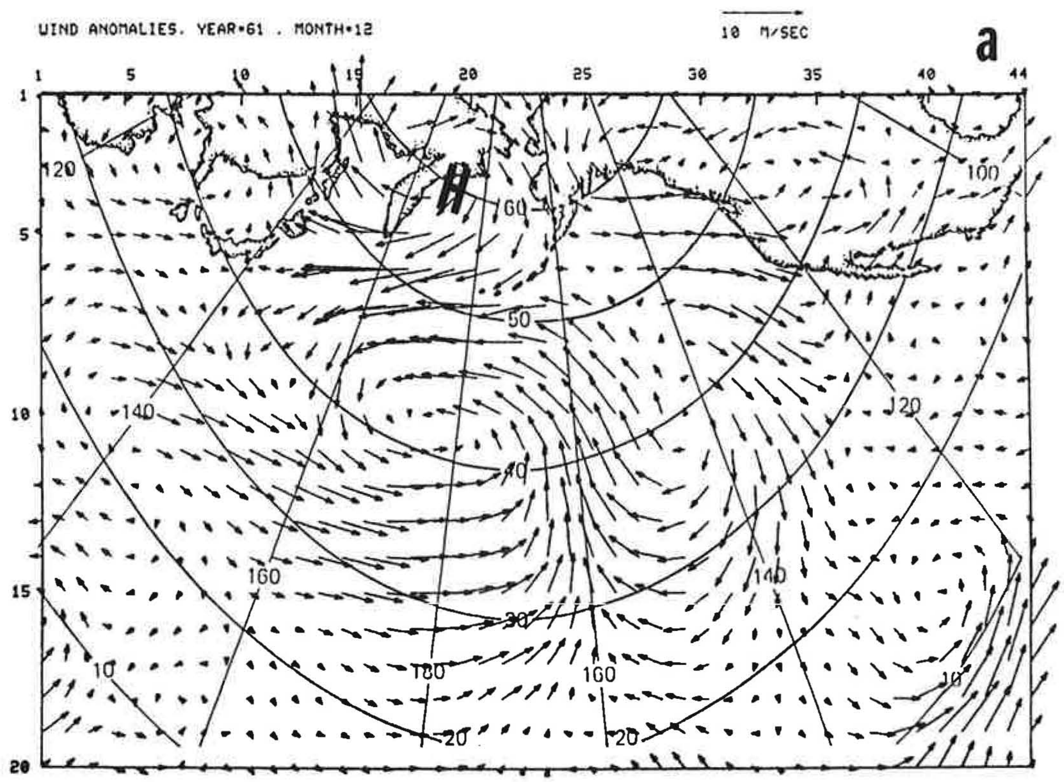


Figure 2, a and b.--Monthly mean wind anomalies for December 1960 and 1969 associated with low pressure centers (L) indicated in Fig. 1(b).



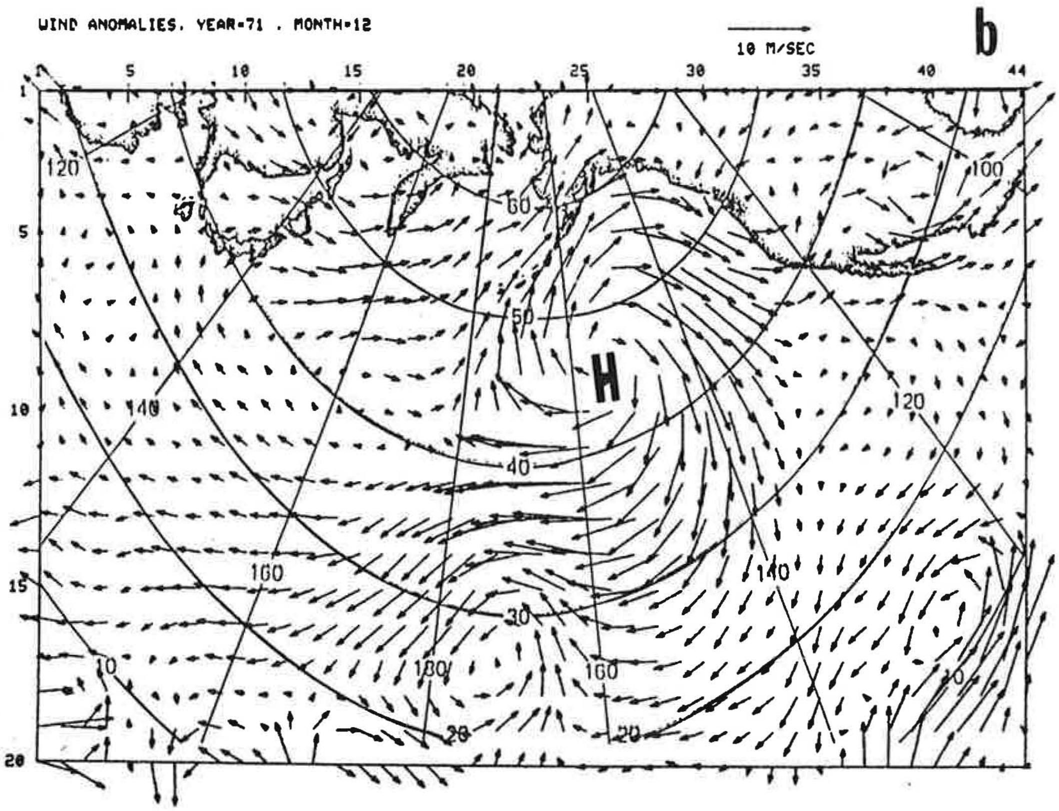


Figure 3, a and b.--Monthly mean wind anomalies for December 1961 and 1971 associated with high pressure centers (H) indicated in Fig. 1(b).

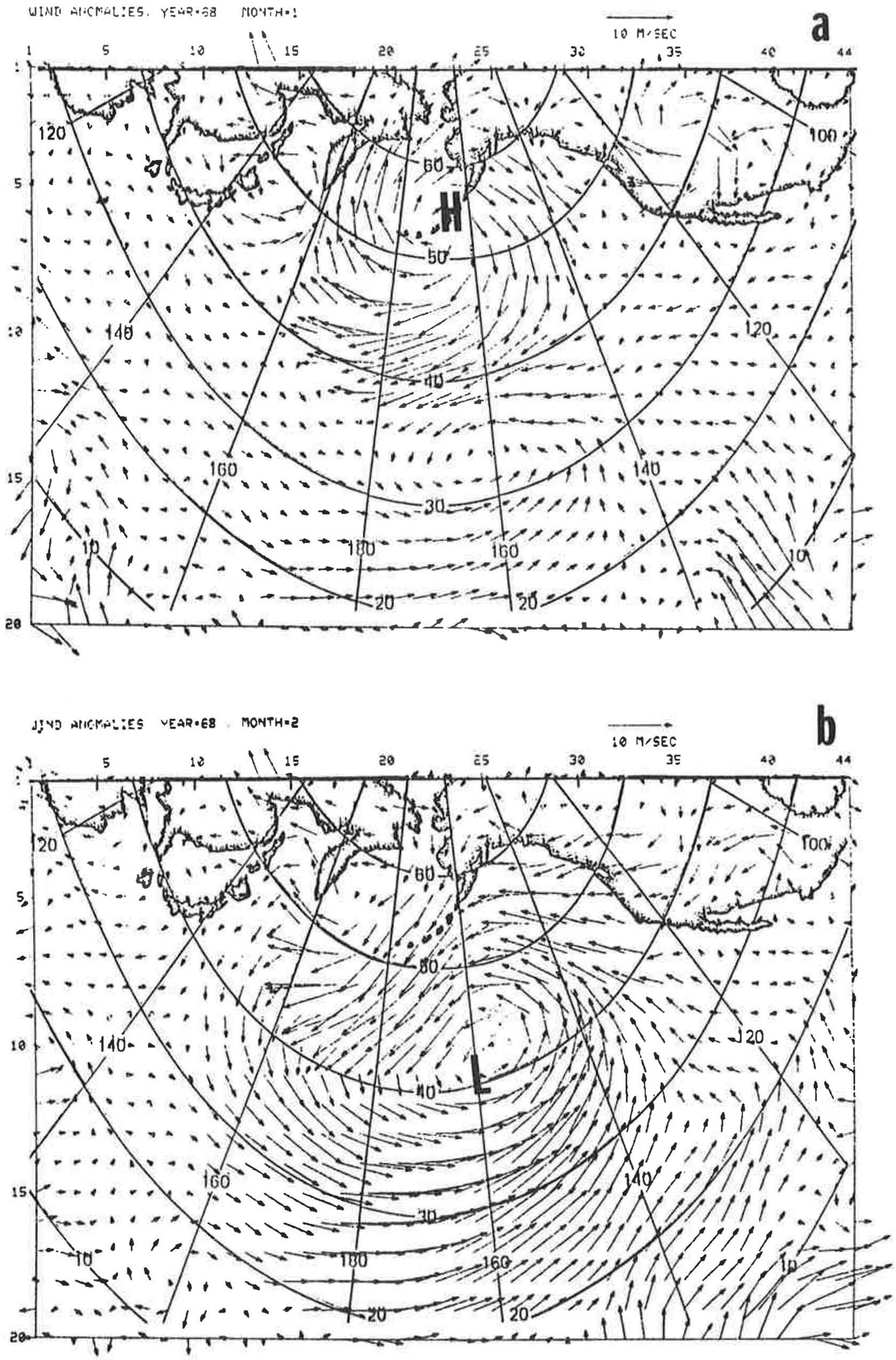


Figure 4, a and b.--Monthly mean wind anomalies for January and February 1968 associated with low (L) and high (H) pressure centers indicated in Fig. 1(b).

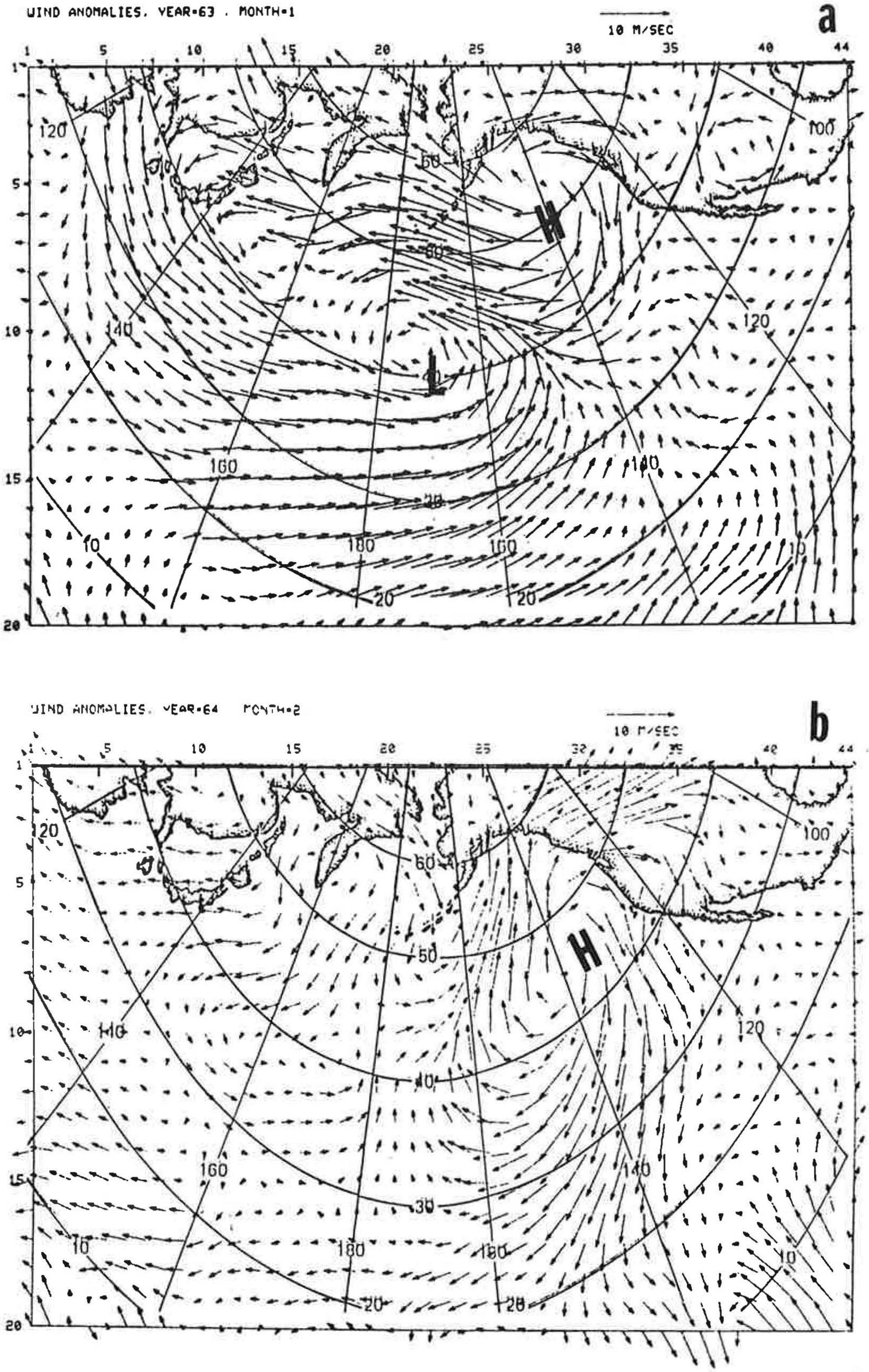


Figure 5, a and b.--Monthly mean wind anomalies for January 1963 and February 1964 associated with low (L) and high (H) pressure centers indicated in Fig. 1(b).

though at low wind speeds anomaly vectors may provide some confusion when velocities less than normal (same direction but reduced magnitude) result in plots of vectors opposing actual winds. However, because of this dilemma sets of monthly mean and long-term mean wind maps (1946-1984) were constructed. Since largely only the Aleutian low and mid-Pacific high are the major annual features, long-term monthly mean mean winds (Appendix I) reflect only cyclonic or anticyclonic systems related to these two centers; but other significant cyclonic or anticyclonic systems are also readily apparent in monthly mean wind fields; at times a specific feature may stand out more clearly in the mean wind anomaly fields but sometimes its extent and continuity may be more clearly defined in the mean wind fields.

Another method of denoting major events, particularly along coastlines, is inspection of sea level data in which most major anomalies are wind related. Data from Yakutat to La Jolla from 1920-1984 (Fig. 6) indicate two periods of marked anomalies (increases) in the interval 1946-1984, these are in 1958 and 1983, periods of unusually warm coastal waters. Both events were quasi-synoptic at all locations suggesting the cause to be widespread and of more than one month duration. Both events are well known to oceanographers and a single dominant cause for them has been elusive. Using monthly mean wind maps (to avoid possible misdirected anomaly vectors) and a single criterion that the southern extent of westerly winds (characteristic of the southern edge of a low pressure system) between 180° and 160°W had to extend below 30°N (reflecting a cyclonic system of considerable magnitude). In only one instance during the period 1946-1984 did this requirement occur for a period of 4 consecutive months - December 1982, January, February, and March 1983. Although the wind patterns were similar throughout the 4-month period, velocities increased in intensity

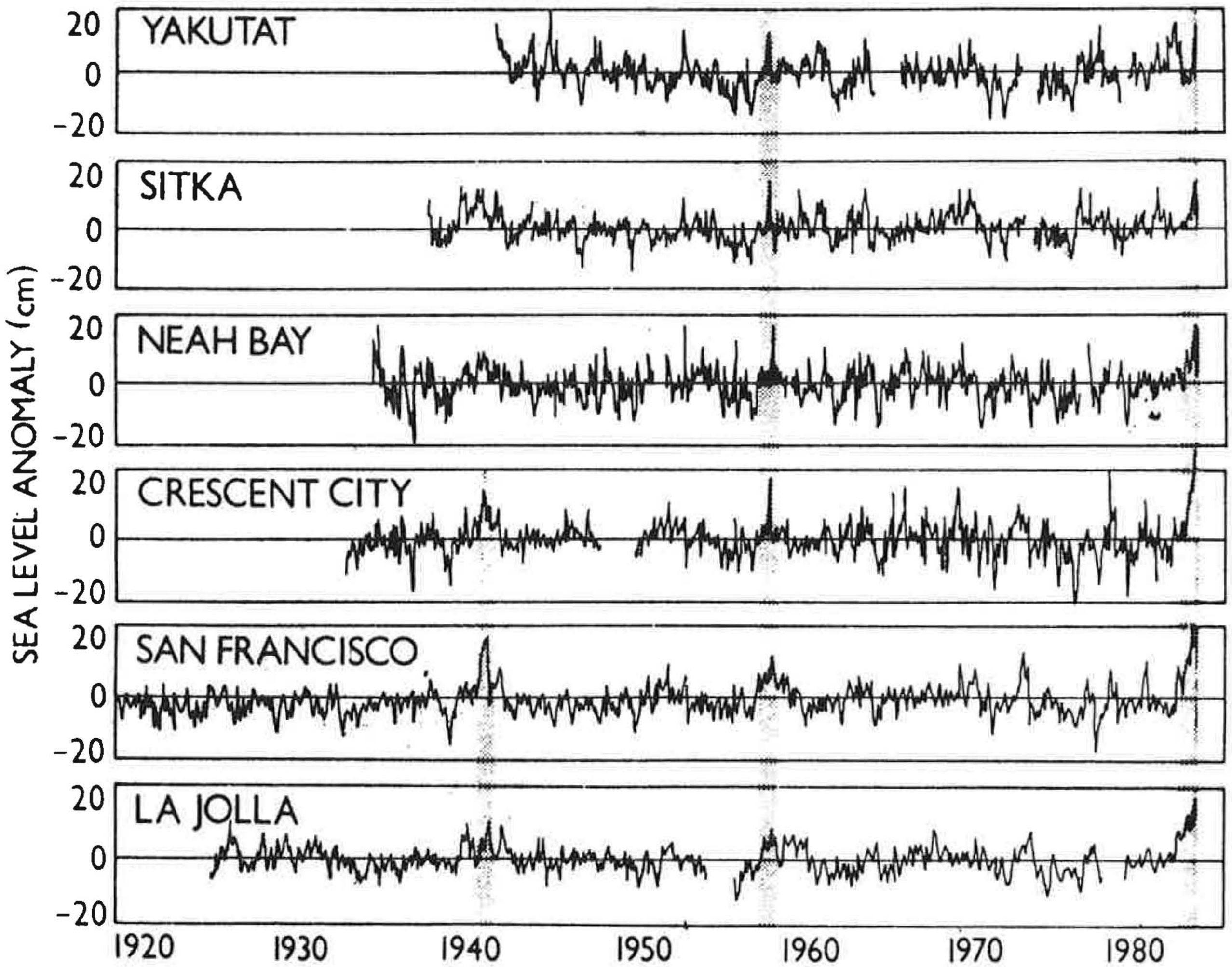


Figure 6.--Sea level anomalies along the west coast (from Reed and Schumacher, contr. 737 PMEL).

through March (Fig. 7a) and by March monthly mean wind anomalies (Fig. 7) indicate the effects of the low pressure center to extend at least from 17° to 70°N (between 180° and 160°W), nearly 6,000 km (Fig. 7b). The intense southerly winds advecting warm water along the west coast of North America, the eastward Ekman component of which would tend to increase sea level along the coast are evident. This period, 1982-1983, is referred to as the "El Nino" event. Although the wind systems in 1958 were similar in many respects, the westerly winds extended south of 30°N (between 180° and 160°W) only in January and February--of course this criterion is only a measure of the oceanic extent of the low and not necessarily the intensity of mean winds along the coast during this period.

Geostrophic currents

It was not until the mid-1950's that any realistic effort could be made to produce maps of geopotential topography (geostrophic flow) of the northern Pacific Ocean even on a seasonal basis because of the paucity of non-synopticity of station or serial data. The most extensive data of transpacific coverage in a given period of one to several months was obtained in summer 1958, primarily June to August, and the surface geostrophic flow field (0/1000 db) presented by Dodimead and Favorite (1961) bears little resemblance to the 3-month (June, July, August 1958) mean winds except in the northeast Pacific (Fig. 8a and b). Strong (>1 knot) and highly organized western boundary currents off Japan are in sharp contrast to the weak and variable winds. And, since this flow field is largely controlled by the distribution of mass below any significant seasonal effects on the surface layer, it is impossible for valid surface currents obtained by the geostrophic method to reflect the large gyres indicated by surface winds in the previous section. This is not to imply

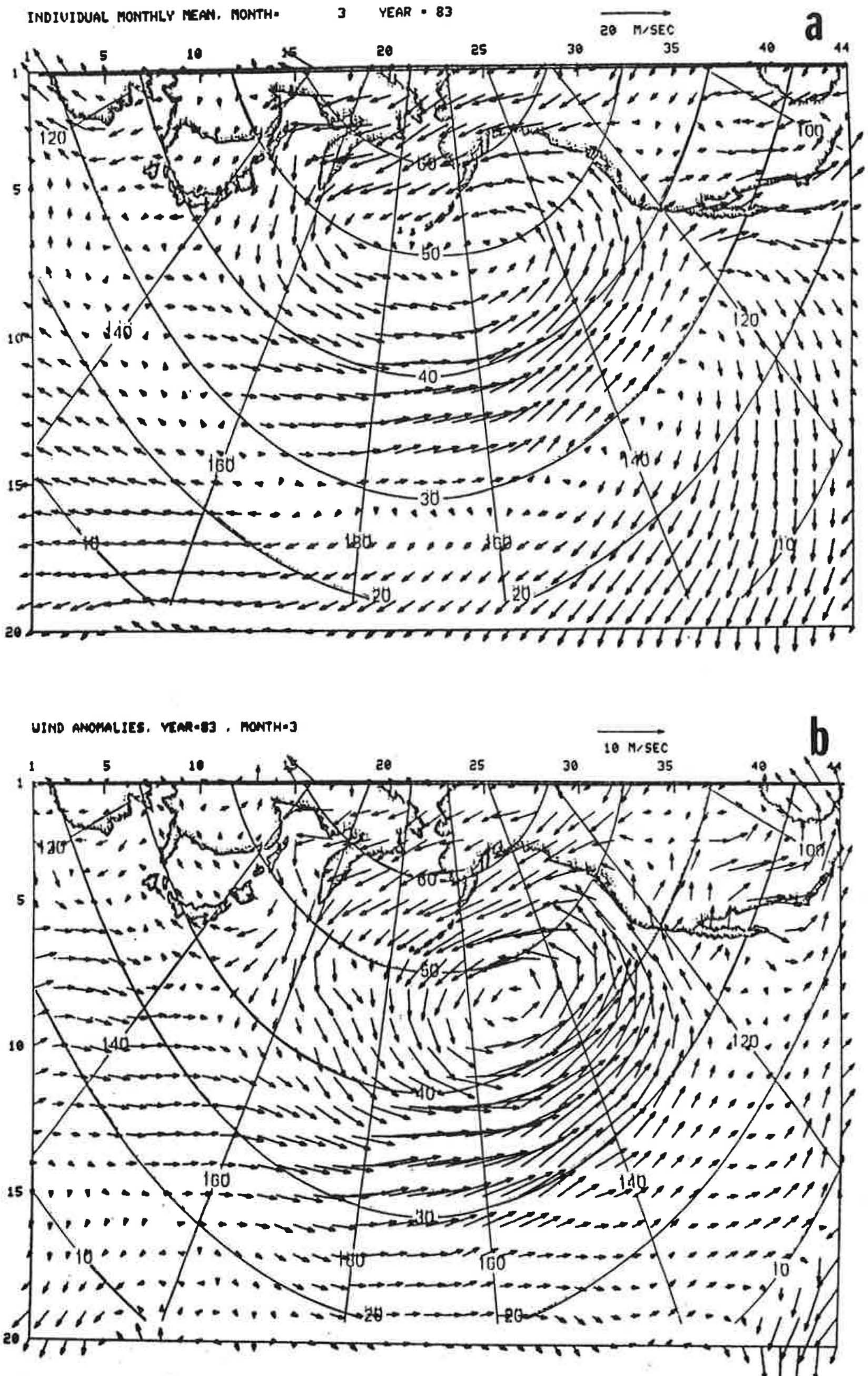
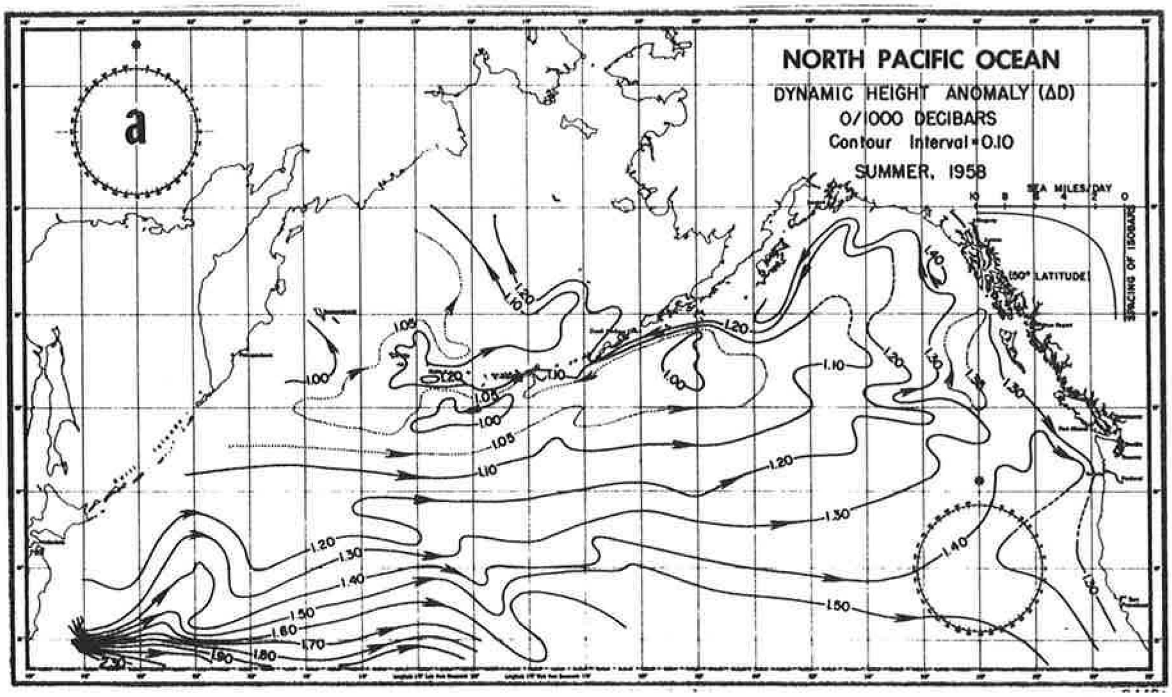


Figure 7, a and b,--Monthly mean (a) winds and (b) wind anomalies, March 1983.



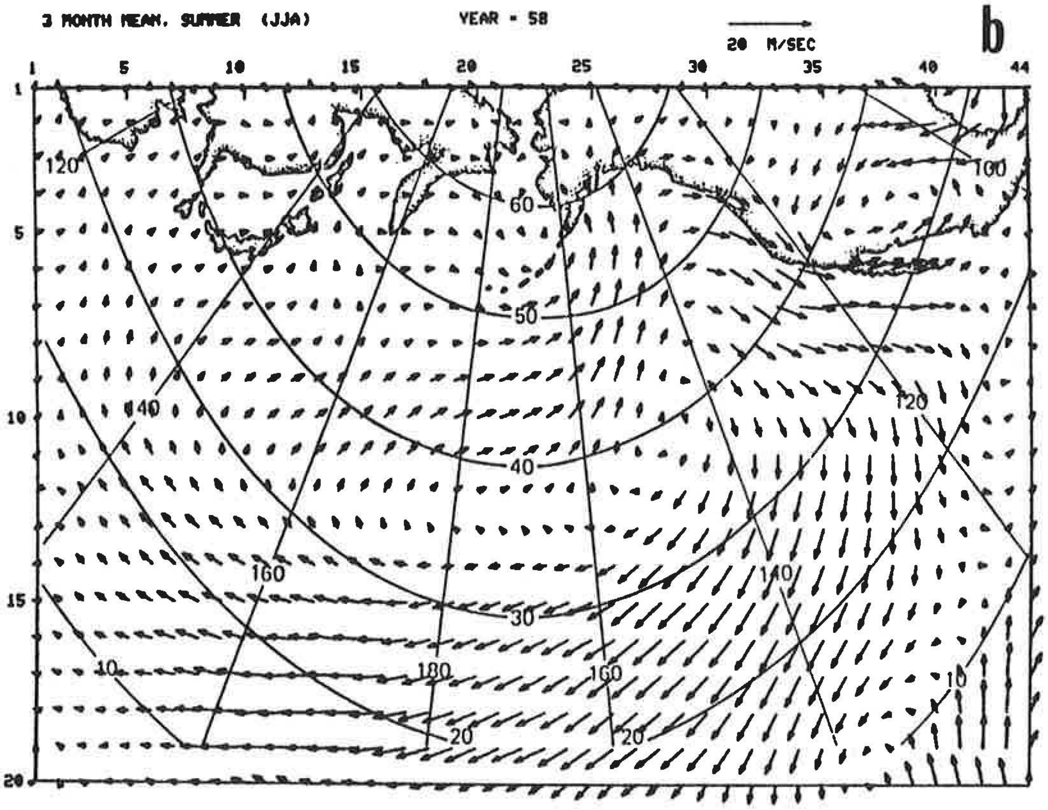


Figure 8, a and b.--Maps of (a) surface geostrophic flow in summer 1958 (from Dodimead and Favorite 1961), and (b) 3-month mean wind (June, July, August).

that surface winds would not have a pronounced effect on surface drift but any such movement would not be validly reflected in calculations of geostrophic flow. It is interesting to note that some drift bottle releases off the northeast coast of Japan return to Japan within a year or so, rather than making an eastward transpacific transit. They may be carried southward by anomalous winds in the western Pacific out of the transpacific Subarctic Current southward to 35°N and around an anticyclonic geostrophic gyre to Japan.

Satellite tracked drifters

The weak and variable currents associated with eastern boundary currents off the west coast of North American permit surface winds to have a pronounced effect on flow in this area, and an extensive release of satellite tracked drifters in 1976-77 (Kirwan et al. 1978) provides considerable evidence of this. Although there are numerous drift bottle studies in this area, the results (release and recovery points only) are insignificant for this study when compared to daily positioning of drifters. Twenty-three satellite tracked drifters were released in the northeastern Pacific in summer 1976. The absence of any extensive oceanographic station data during the period of tracking made it necessary to use a mean geostrophic field for flow comparison but general agreement was found (Fig. 9).

One drifter released near 37°N, 162°W in July 1976 (just prior to the above experiment) and tracked for 96 days completed four revolutions about an anti-cyclonic eddy roughly 100 km in diameter which moved west-southwestward (contrary to the eastward flow north of this location) at only 2 cm/sec while actual drifter speeds of 6-12 cm/sec occurred (Fig. 10). However, plots of movements of other individual drifters through six consecutive monthly intervals (Oct. 1976-Mar. 1977) conform remarkably well to our corresponding monthly mean

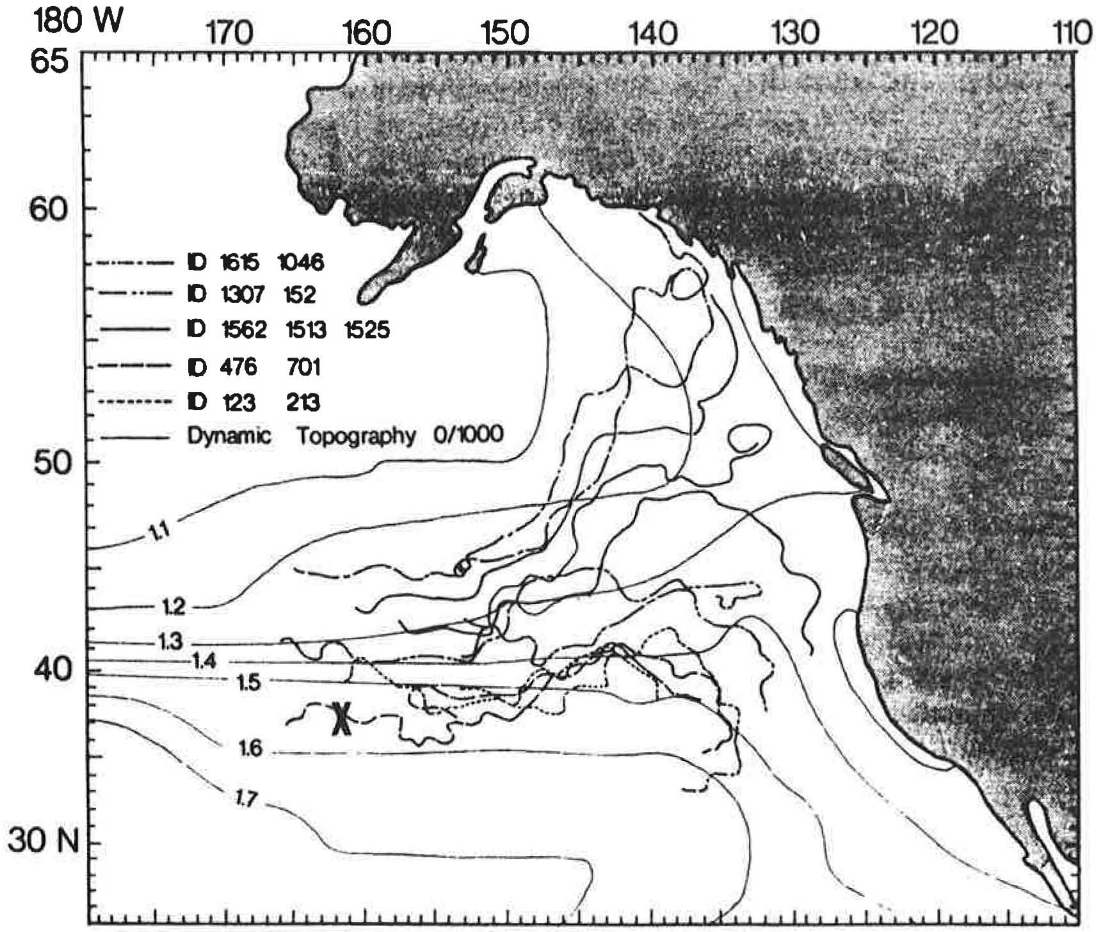


Figure 9.--Eleven drifter trajectories superimposed with the 0/1000 db mean annual dynamic topograph (from Kirwan et al., 1978).

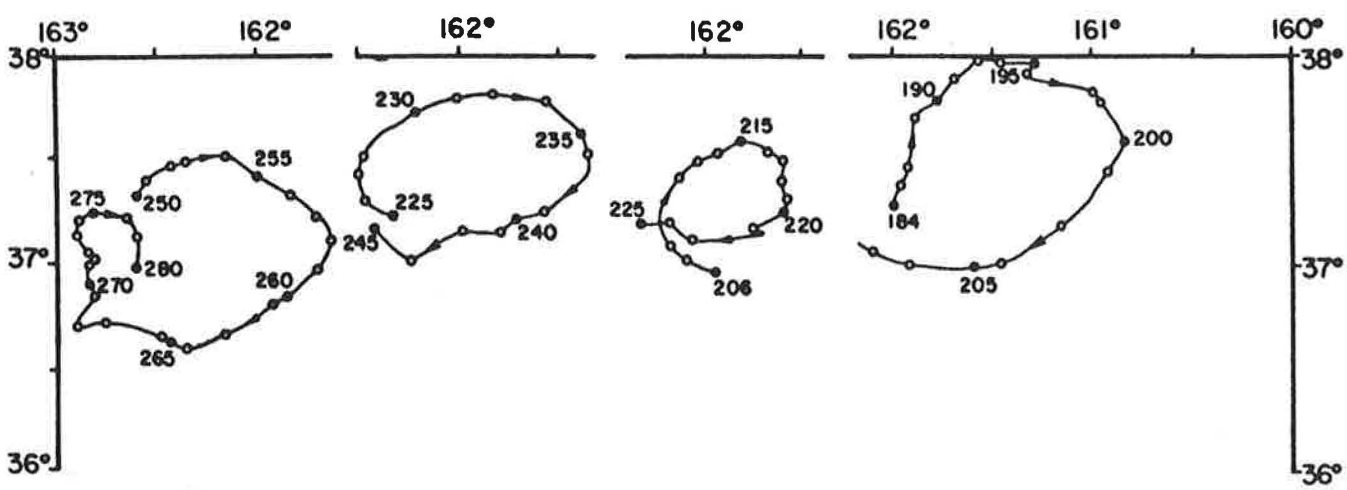


Figure 10.--The trajectory from day 184 through 280/76 of drifter released at (X) in Fig. 9.

wind fields as shown in comparisons of three months: October 1976, easterly movement - January 1977, northeasterly movement - March 1977, north/south divergence (Fig. 11a, b and c). The highly ordered trajectories appear what can best be described as somewhat sinusoidal, with amplitudes of approximately 50 km, that may or may not be wind related, but the overall patterns and changes in trajectories are inescapably wind influenced, if not dominated. The speed of advance was roughly 6 miles/day (13 cm/sec). It should also be pointed out that the monthly mean winds field for October (Fig. 11a), the month when the drifter trajectories in Fig. 10 were completed, indicates an east-west shear zone along 35-37°N that would explain the westerly drift and eddy formation at this location. These results suggest that drift patterns in this offshore area based on long-term monthly mean winds and appropriately modified by monthly mean or mean anomalous winds might bear a useful resemblance to reality provided estimates of speeds can be devised.

Gulf of Alaska flow

Although evidence of significant effects of surface winds on surface flow south of the Gulf of Alaska is welcome, it should not be all that surprising. Favorite (1967) provided evidence that volume transport out of the Gulf is driven primarily by the action of wind-stress; thus even subsurface flow is wind-related but in a rather complex manner and a lengthy discussion is not warranted here. Simply put, the Alaskan gyre, a subsidiary of the main north Pacific gyre, is largely the result of the distribution of mass slowly adjusting, over perhaps centuries, to winter forcing associated with the Aleutian low to a quasi-equilibrium state that understates wind-driven flow in winter and overstates the effects of weak winds in summer because of the extended time required for the water column to adjust. However, reliable estimates of

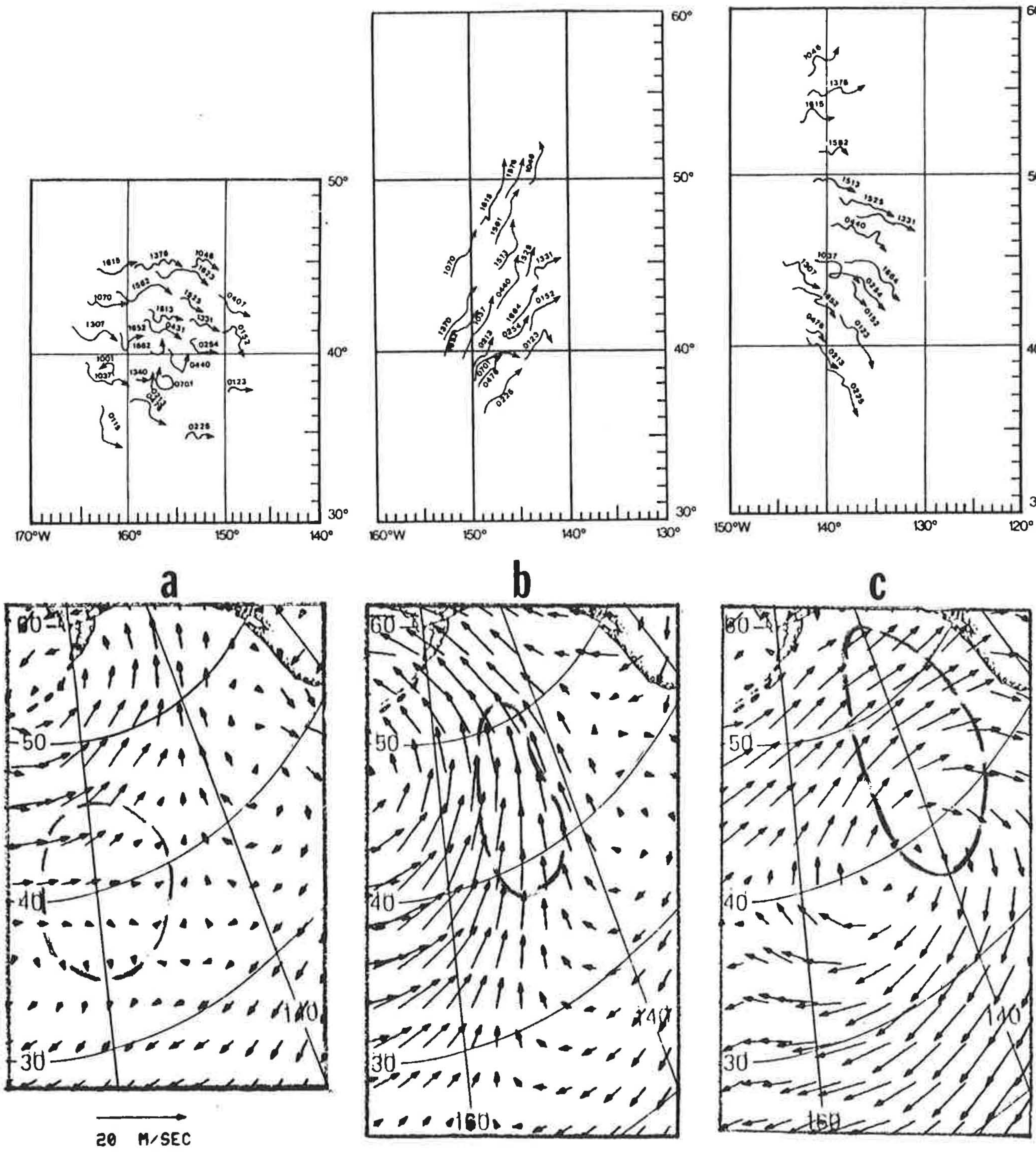


Figure 11.--Comparisons of satellite tracked drifters (from Kirwan et al., 1978) and monthly mean winds for (a) October 1976, (b) January 1977 and (c) March 1977.

mean flows can be made and this is fortunate because it is unlikely that the massive oceanographic cruises in the 1950's and 60's will be repeated. Thus relations to geostrophic flow are mute. Only through tracking drifters or estimating flow through wind anomaly fields can flow patterns be ascertained. Unfortunately, however, there is ample evidence that flow around the Gulf near the shelf is very complex. The large seaward movement of dilute, coastal water west of Queen Charlotte Island (over several hundred kilometers) in summer 1958 was probably caused by the anomalous northward flow in spring across the mouths of the Columbia River and Strait of Juan de Fuca, but certainly not aided by the persistent westerly winds at this time indicated by the monthly mean wind fields. In addition, the well-documented OCSEAP satellite tracked drifters that revealed the large, long-term eddy near Middleton Island in summer 1976, and the eastward trajectories from the high speed western boundary current, the Alaskan Stream, shown not only by distributions of properties, but by satellite tracked drifters, are caused by land configurations or hydrodynamic imbalances rather than winds. However, it is apparent that surface drifters seaward of the shelf edge are greatly influenced by winds. For example, the trajectory of the drifter reported by Reed (1980) that spun out of the Alaskan Stream south of the Alaska Peninsula and recirculated in the Gulf in fall 1978, conforms closely to monthly mean winds from October to December.

Long-term and cyclic events

Since wind fields are derived from sea level pressures, it is easier to seek some order in these extremely variable vector wind fields through analyses of sea level pressure distribution. Sorkina (1963) analyzed over 16,000 synoptic pressure maps and noting the repetitive annual effects of the

Aleutian low and mid-Pacific high pressure systems derived 8 basic types of pressure fields as well as their probability of occurrence, duration, and annual succession (Table 1). An extraordinary achievement that assists in analyses of wind fields; however, in summarizing long-term patterns, she admits discrepancies between her assessments and those of A. A. Girs (Table 2) and neither was able to report transpacific cyclic phenomena beyond annual cycles.

Table 2.--Comparison of intensity of the Aleutian low in the first half of this century.

Duration	Girs	Sorkina
1911-20	Weak	Intense
1921-29	Intense	Intense
1930-37	Quasi-stable	(Quasi-stable)
1938-41	Intense	(Quasi-stable)
1942-48	Quasi-stable	(Quasi-stable)
1949-57	Weak	Intense1/

1/ No data for 1949-53

Nevertheless unusual ocean conditions along the west coast of North America in 1958 that corresponded to a period of sunspot maxima led Favorite and Ingraham (1976) to investigate periodicity in transpacific sea level pressure data. They discovered a shift in the mean position of the Aleutian low in winter (Oct.-Mar.) from the northeastern to northwestern Pacific during periods of sunspot maxima (both positive and negative) and back during sunspot minima over a number of decades, but the overall mean pressure fields remained quite similar (Fig. 12 - note anomalous position for 1955-58). However, in the preparation of this present report, a paper by Danielson et al. (1957) was reviewed and some interesting results uncovered as they found a suggestion of a 12-year periodicity of winds of force 8 or greater in the Gulf of Alaska area as a result of compiling a 3-year running mean of January ship reports

Table 1.--Basic types and subtypes of synoptic sea level pressures.

Type	Characteristics	Type	Characteristics
1	Summer - anticyclonic	a	Weakening of cyclonic activity at the polar front
		b	Intensification of the polar front
2	Summer - with trough from south Asian sector of the tropical front	a	Weakening of cyclonic activity at the polar front
		b	Intensification of cyclonic activity at the polar front
3	Autumn and spring - with intensification of cyclonic activity at the meridional trade wind front		
4	Winter - with meridionally displaced lows at the polar front between two cells of high pressure	a	Lows do not become stationary
		b	One region of stationary lows
		c	Two regions of stationary lows
5	Winter - with meridionally displaced lows at polar and trade-wind fronts between three cells of high pressure	a	Lows do not become stationary
		b	One region of stationary lows
		c	Two regions of stationary lows
6	Winter - with a broad central low	a	Without intensification of the western section of the polar front
		b	With intensification of the western section of the polar front
7	Spring and autumn - with latitudinally displaced lows at the polar front, pushing the weakened belt of high pressure back to the south	a	Beginning of weakening of the subtropical anticyclone
8	Spring and autumn - with arctic intrusions	b	Marked weakening of subtropical anticyclone and its breaking up into several weakly defined cells

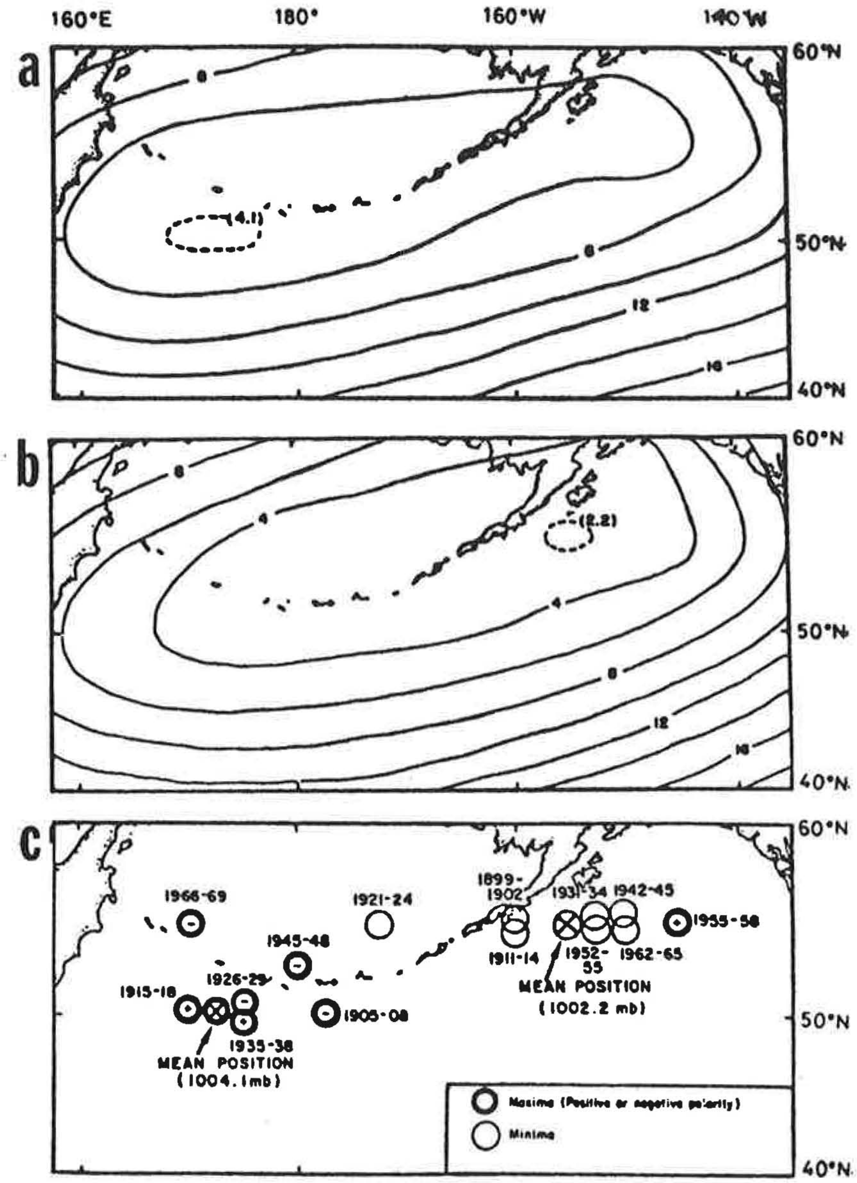


Figure 12.--Mean sea level pressure distributions (mb-plus 1000) for winter half-years (October-March) of 3-year periods centered around sunspot maxima (a), and sunspot minima (b); and locations of centers of the Aleutian Low for individual periods (c)--1899 to 1974 (from Favorite and Ingraham 1976).

from 1900 - 1938 (Fig. 13). Because a subsequent data peak in 1951 interrupted the cycle (1910, 1922, 1934) by falling between the 2 presumed subsequent maxima - 1946 (no data) and 1958 - evidently the matter was not pursued further. But this discrepancy may be explained by the fact that the normal interval between sunspot minima and maxima (5-6 yr.) was reduced almost in half in the mid-1930's and early 1940's (maxima to minima interval remained normal); the minima cycle was as follows: 1901.7, 1913.6, 1923.6, 1933.8, 1944.3, and 1954.3. Thus, the intense winds in the Gulf of Alaska reported by Danielson et al. not only preceded the year of sunspot minima by a reasonably constant amount, 1-2 yr. (it would appear likely that if 1953 data were available 1952 would reflect a higher maxima that 1951), but also when the mean center of the Aleutian low was shifting toward or was centered in the Gulf of Alaska. This relationship should be given additional study because it indicates a sophisticated, long-term order that is probably related to wave phenomena associated with polar air masses and could have far-reaching consequences.

This study has shown that mean wind anomaly vector fields are essentially a form of data "overkill" at this stage of ocean science because most of the information sought is available in mean wind fields. However, the ability to obtain such data at various locations may have application to specific small-scale projects. Also it would appear that even though three low pressure systems may transit an area within the span of a month that mean monthly fields provide adequate information on general processes. And in the instance described, monthly mean wind fields showed a remarkable correlation with surface flow over a period of six months, a fall and winter period, and undoubtedly even longer if the original basic drifter data could be acquired. It would appear that any deviation of drift from wind vectors in the area discussed would probably occur only when the influence of boundary conditions imposed by the continental land mass are encountered. Unfortunately this is the area of most

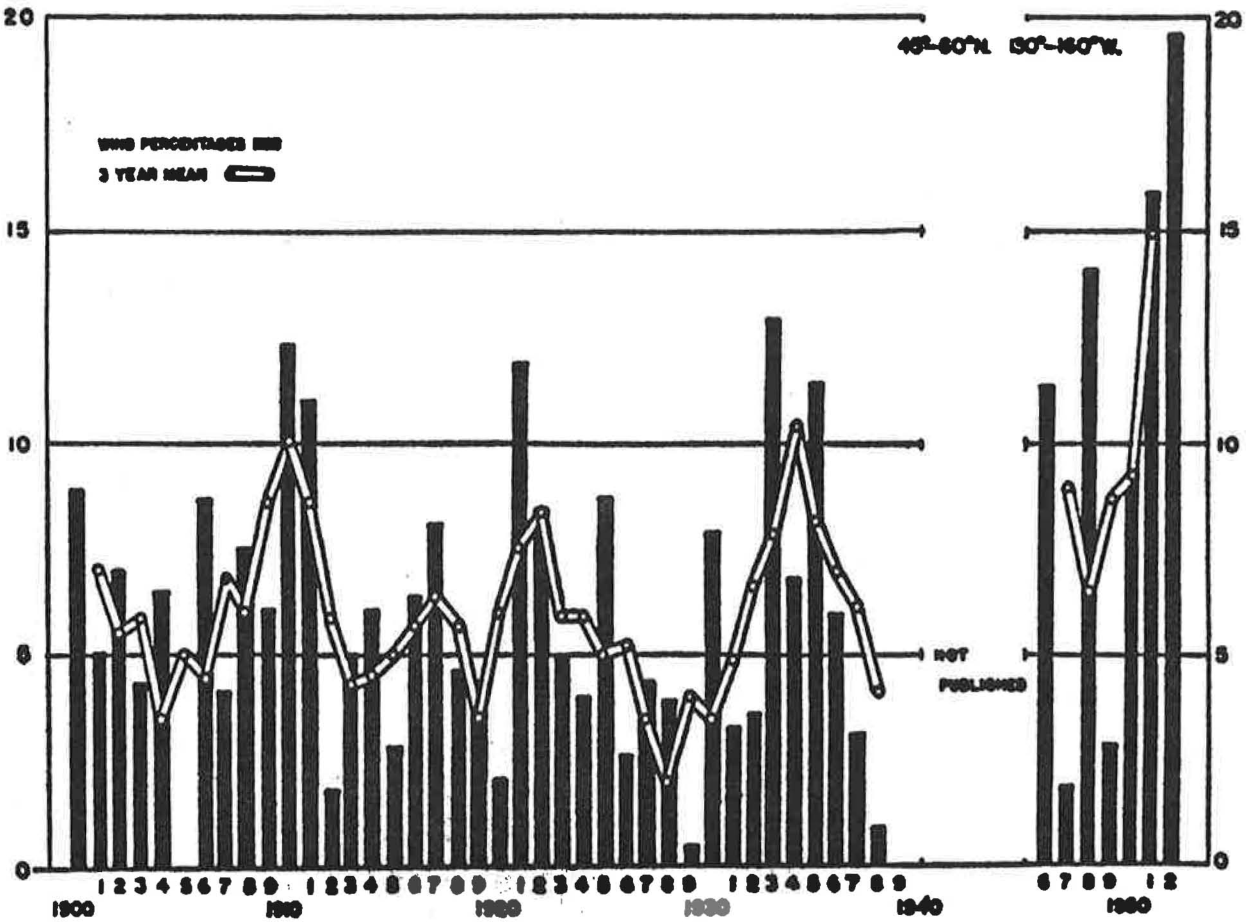


Figure 13.--Percentage of winds of force 8 or greater which were reported by ships in the Gulf of Alaska, January 1900-1952 (from Danielson et al., 1957).

concern to fisheries interests. Nevertheless renewed interest in surface flow in segments of the Alaskan gyre based on mean winds should prove rewarding. Relationships with geostrophic (thermohaline) flow are apparent but it is impossible to acquire such data over large areas and, because of limitations in the geostrophic method, in many instances more accurate surface trajectories may be implied or ascertained by mean wind data.

Relations to fisheries

The NMFS and its predecessor agencies have always had two mandates: to conduct fisheries research and to aid the fisheries industry. Political considerations have always insured that emphasis was placed on the latter. Only recently with the encroachment of foreign fisheries and demands for multispecies management have any attempts at holistic studies been attempted. Only shortsightedness could have permitted fisheries studies in the northeastern Pacific over the last half century to be limited to adult stages of only a few commercial species, particularly in view of the fact that during the last several decades federal funds equal or larger than those allocated to marine fisheries have been obtained by biological oceanography groups to study plankton; such studies are largely exclusive of fish forms, investigations which have been zealously guarded as the exclusive domain of fishery biologists even though studies of fish eggs, larvae, and juveniles were rarely carried out in subarctic waters. Thus very little is known about the distribution and movements of marine fish for the first 1 to 3 years in the ocean, prior to the time they enter commercial fisheries. However, although local fisheries investigations do not appear to have benefited from practices of those of much longer duration and scope conducted for centuries in other areas such as the Grand Banks and European waters, it should be pointed out that useful fisheries knowledge in the northeastern Pacific extends back only about a century.

When one considers possible relationships among winds, associated ocean currents, and fisheries first thoughts are of phenomena such as wind mixing of the surface, transient eddies and fronts, and similar short-term events associated with the highly variable nature of winds; then one recognizes large gyres and seasonal events such as upwelling and downwelling; and, finally, of course, aperiodic, long-term phenomena such as intrusions of anomalous water types such as those associated with El Nino events. Thus, ocean conditions represent complex adjustments to numerous periodic and aperiodic internal and external forces. It should be apparent that we are not prepared to deal with short-term associations, except perhaps in extremely limited areas; intermediate-range events are more tractable, at least the gross effects thereof; and, long-term associations require an extensive data base that is missing and will require decades to acquire.

Wind mixing of the surface layer has been extensively studied and considerable local information has been obtained at Ocean Station "P". Response time is only a matter of hours and relations between mixed-layer depth (m) and wind speed (kts) during spring and early summer is largely linear after 12 hrs up to wind speeds of 40 kts (20m/s) (Fig. 14) and probably well beyond. Information on variations in mixed-layer depth and stability in the water column in spring and summer can be applied to interpretations of phytoplankton production and translated into abundances of zooplankton and other forage organisms. However, major aspects of such phenomena are complex with important changes occurring in periods of days or weeks that cannot be effectively isolated and identified by monthly mean wind fields. If one wished to pursue this study, weekly wind fields could be programmed and an excellent place to start would be comparisons of these fields with the weekly maps of ocean temperature, and mixed-layer

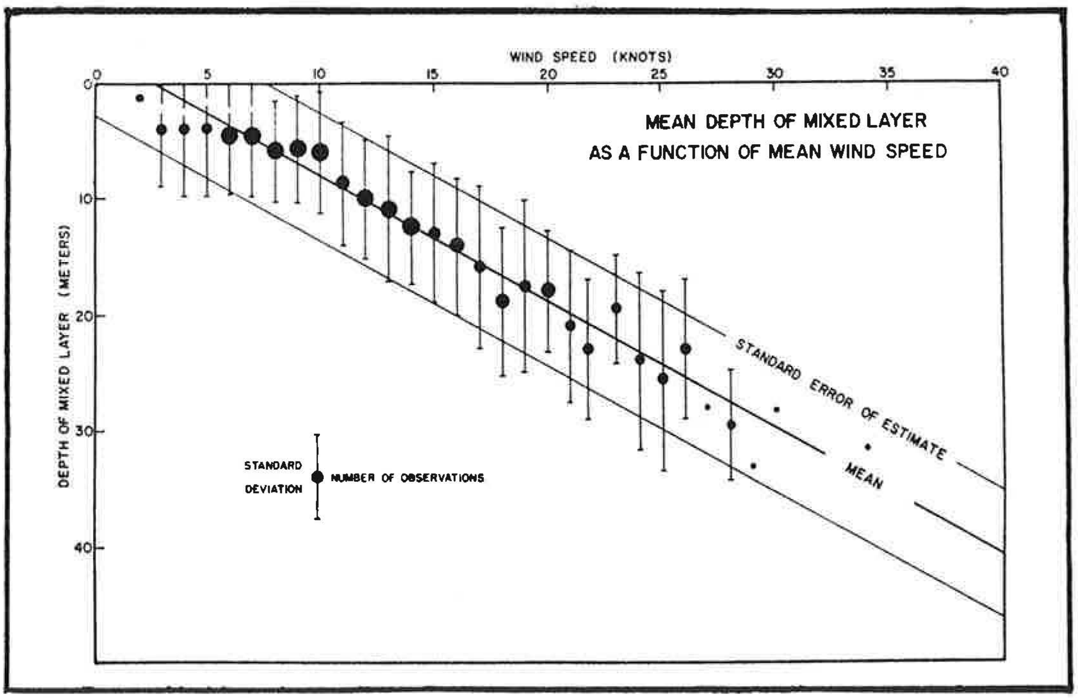


Figure 14.--Mean depth of the surface mixed layer during the heating season at Ocean Station "P" (50°N, 145°W) as a function of wind speed during the preceding 12 hours (from Tully 1965).

depths (based on BT information) issued by the Pacific Oceanographic Group and Canadian Weather Service (Metoc Centre) in the 1970's. Of course the biological information is missing but one could get an estimate of the complexity and magnitude of such studies as well as locations where profitable field studies could be instigated.

In relation to eddies and fronts, we know that mesoscale eddies about 100 km in diameter are ubiquitous in the large-scale eastward flow off the west coast of the Pacific Northwest (Kirwan et al., 1978). These are embedded in the flow and not necessarily related to local winds. Two examples of coastal eddies detected by satellite-tracked buoys show time and space scales that are too small to permit monthly evaluations of large perturbations in flow that undoubtedly influence marine organisms. One such event occurred seaward of Sitka in April 1977 (Fig. 15); the eddy about 100 km in diameter with a period of about two weeks of course is not represented in the coarse monthly mean wind field but the northward drift is. Unless identified during field operations, such eddies could result in erroneous interpretations of fish (for example, salmon moving around the eddy) migration routes ascertained by direction of fish entry into gillnets or even purse seines. The other event, west of Kayak Island in July 1976 (Fig. 16), had an eddy with a similar period but a reduced diameter and its probable cause was the obstruction to flow posed by the island. However, if such local phenomena are not detected by a program of wind assessments, it will be of limited value to fisheries in such areas. Perturbations in the coastal regime and near the shelf edge are perhaps the rule rather than the exception and identifications of these are best left to analyses of satellite imagery (Fig. 17); in winter the boundaries of cold inshore water are easily discernable and in summer river runoff equally so. Further, OCSEAP studies

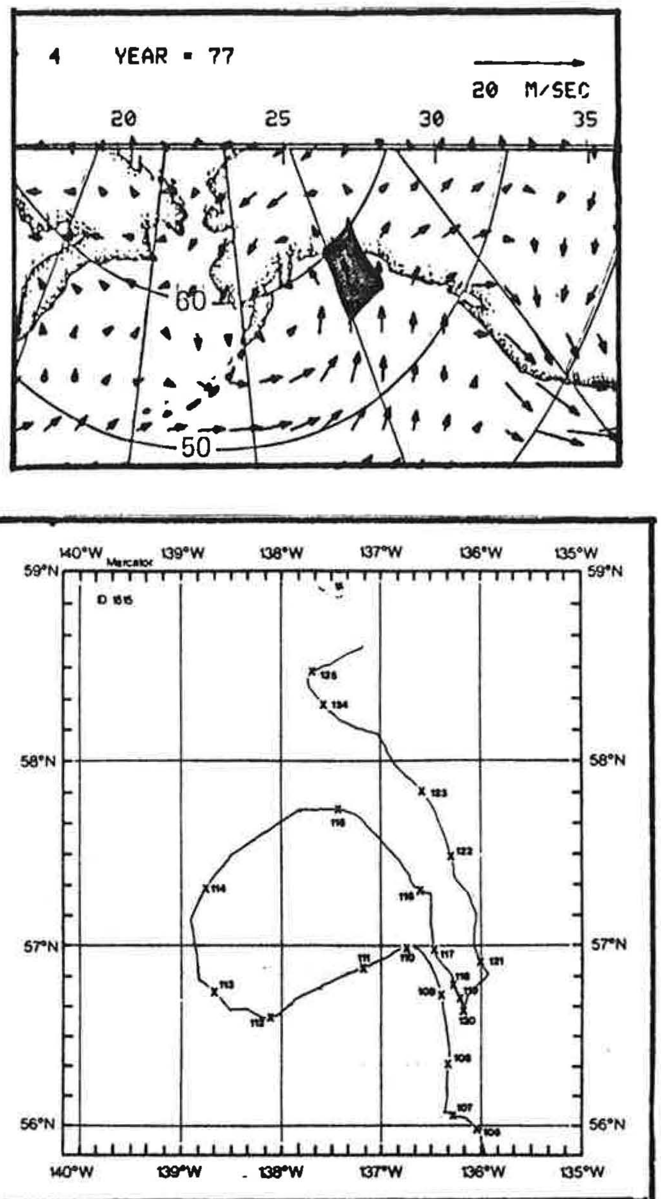


Figure 15.--Track of a satellite-tracked, drogued buoy, ticks show interpolated positions at 1200 GMT during the period April 16 to May 5, 1977 (from Kirwan et al., 1978) and monthly mean wind field for April 1977 reflecting correspondence to the northward drift but not to the two-week eddy.

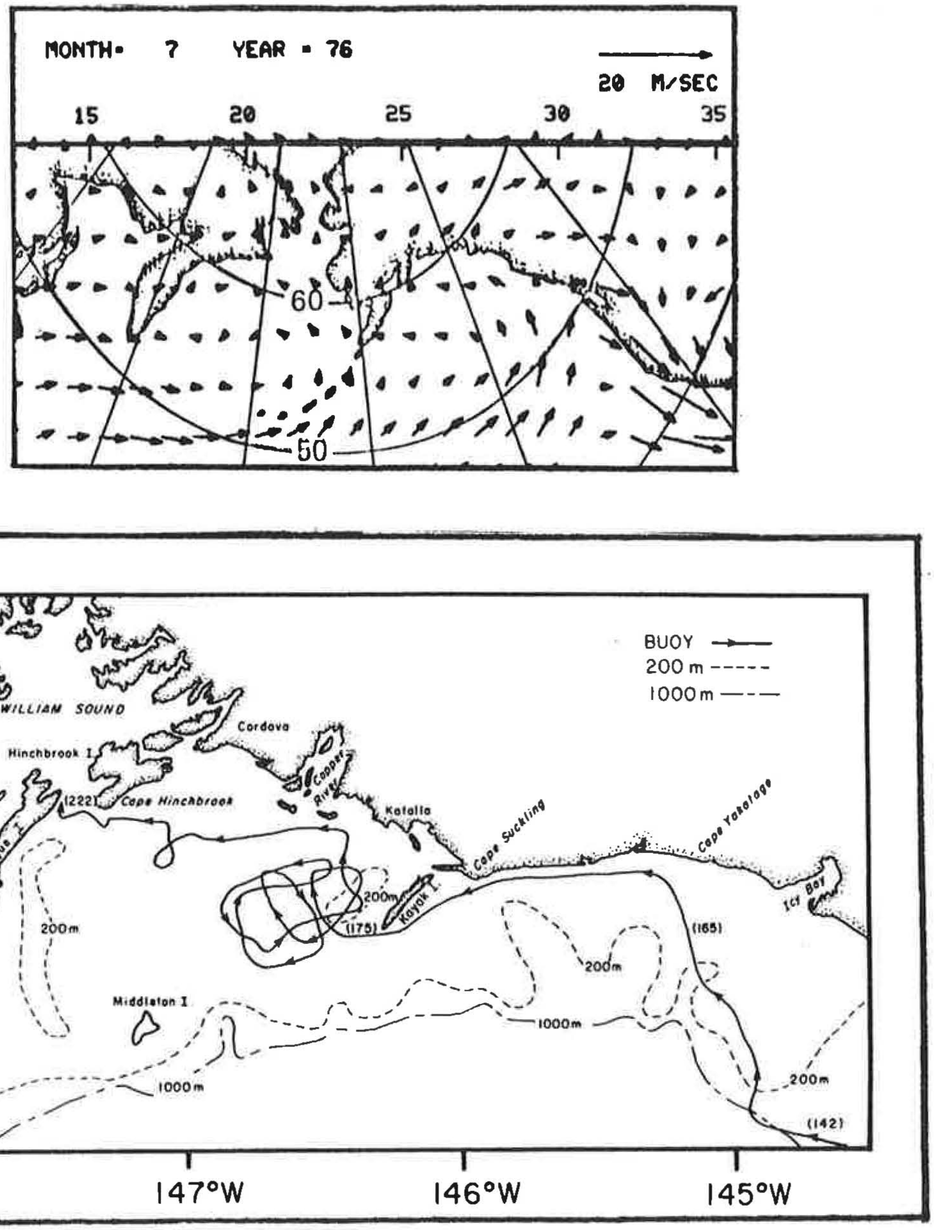


Figure 16.--Track of an OCSEAP satellite-tracked, drogued buoy in 1976 (no's in parens indicate days) showing eddy structure west of Kayak Island and monthly mean wind field for July 1976.

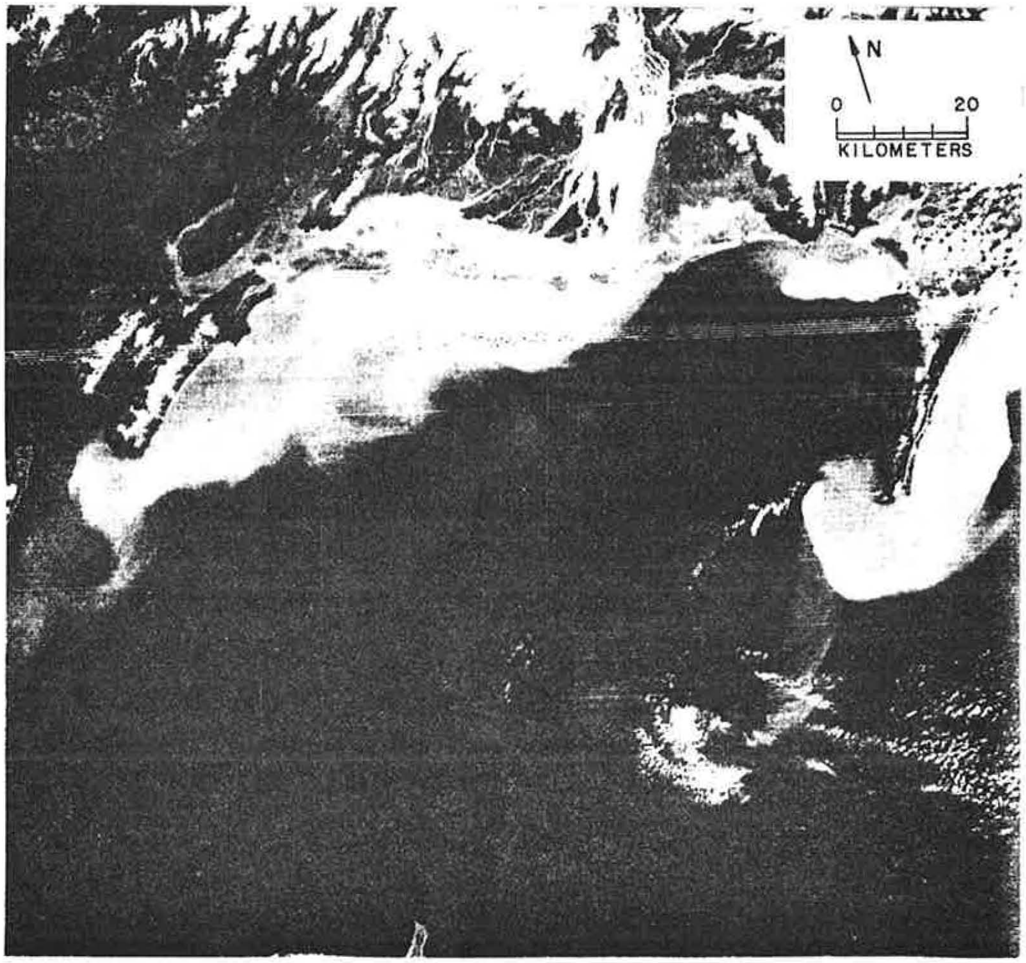


Figure 17.--LANDSAT - 1 image between Montague and Kayak Islands, August 14, 1973.

at the head of the Gulf have indicated that gross sea level pressure fields (based on widely spaced data) do not reflect the complexity of actual distributions.

Fronts, or shear zones, concentrate plankton at or near the surface and usually denote areas of fish concentrations. Discounting tidal phenomena and because of the absence of any abrupt wind shear zones, the only true front in the Gulf is near the shelf edge in the western part of the Gulf at the boundary of the sluggish shelf water and the offshore high speed (1-2 kts) Alaskan Stream. Southwest flow in the Alaskan Stream is a function of the total meridional transport of mass northward into the Gulf and is directly related to the curl of the wind stress ($\text{curl}_z\ \tau$), which can be computed, but this discussion is limited to surface wind effects. Although surface winds along the axis of flow may retard or accelerate surface flow (discussed later), winds normal to the flow will have only limited effects because the flow extends to great depths. Although extensive plankton studies have been made over the shelf in the Kodiak area (Kendall et al., 1980), none have been made specifically in the axis of the stream, nor have any fish trawls other than bottom trawls been made in this area; however, it has been postulated that this narrow band of high speed flow approximately 100 km seaward of Kodiak Island and 200 km seaward of the Alaskan Peninsula may serve as a reference to migrating salmon (Favorite and Ingraham 1972). But no fisheries studies have been made or planned.

Although seaward excursions of river runoff in many cases cannot be classified as fronts, they provide indications of coastal environments that may be important to migrating salmon and even transport for eggs, larvae, and juveniles of pelagic fish, groundfish, and shellfish. There are only a few years for which data are available on such excursions, one is 1958. In summer dilute coastal water (<32.5 $^{0}/oo$) was found over 700 km seaward (westward) of the Canadian coast yet monthly mean winds for June, July, and August reflect no westward components and would not serve to signal this unusual event (Fig. 18). Another instance is the southward extrusion of dilute water from the Copper River at the head of the Gulf in September 1978 (Fig. 19). Winds in this area were southerly (toward the north) in July, August, and September (see Fig. 19) and thus apparently didn't contribute to the salinity distribution and certainly wouldn't permit forecasting the event. In this instance also one could expect this excursion to affect the distribution of eggs, larvae, and juveniles in the surface layer and certainly the movements of Copper River salmon. However, in 1978 a satellite-tracked, buoy experiment of large scale and time was conducted (Reed 1980) that permits a reassessment of INPFC interpretations of the Alaskan gyre and provides insight into the longstanding query that reaches to the heart of fish production in the Gulf--if there is a continually westward flow around the northern and western periphery of the Gulf that obviously transports eggs, larvae, and juveniles of fish and shellfish out of the area, why don't population centers gradually move westward; heretofore, only contranatant movement has provided the only acceptable answer (Skud 1977).

Three drogued (20 m) buoys were released at the shelf edge off Kodiak Island in July and moved southwestward in the Alaskan Stream (Fig. 20). Two subsequently moved southeastward and thence northward reaching the head of the Gulf in December, six months later (one of which returned to the vicinity of Kodiak Island in January 1979); and, the third moved farther southwestward than the other two before turning eastward and only reached mid-Gulf by January 1979

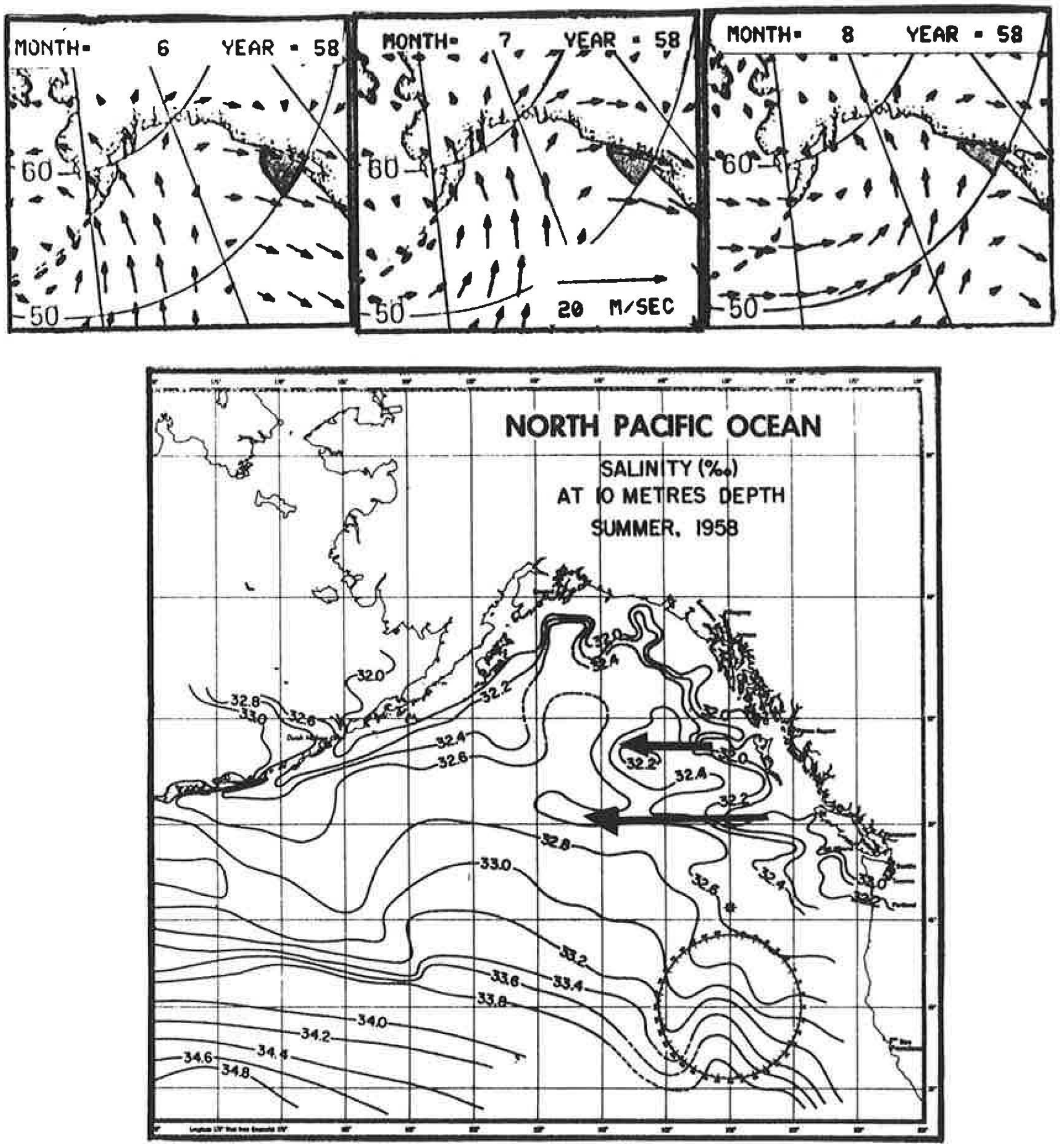


Figure 18.--Westward extrusion of dilute coastal water off Canadian coast, summer 1958 and monthly mean wind fields for June, July, and August 1958 indicating northerly winds (southern flow) along the coast.

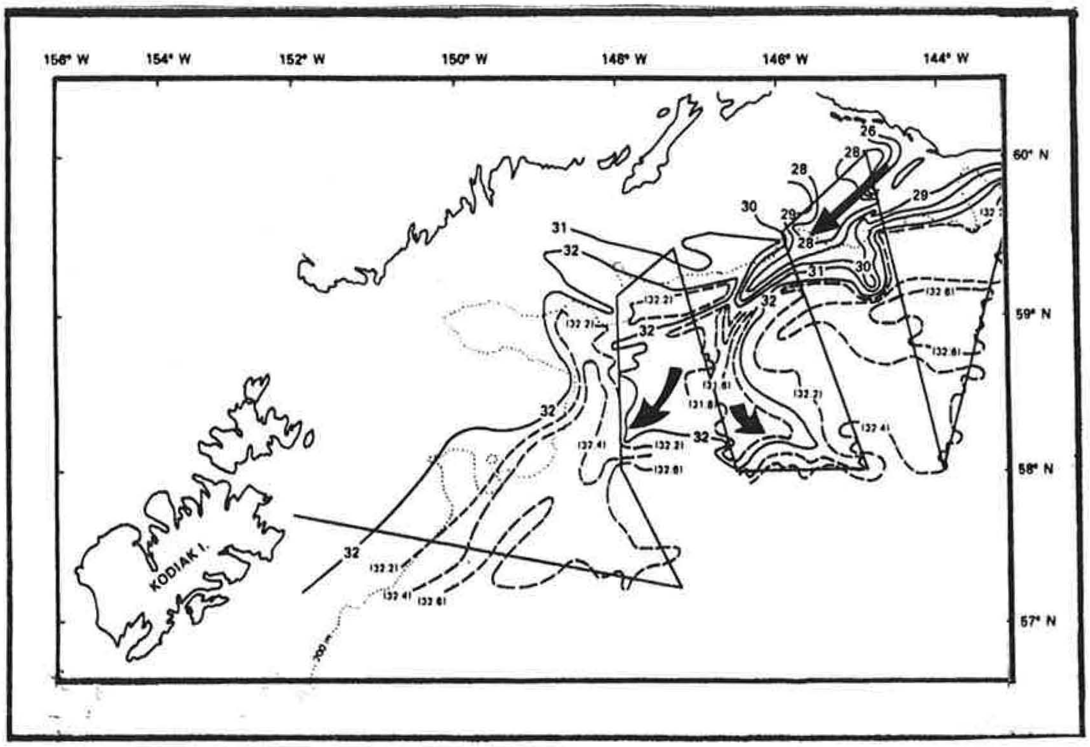


Figure 19.--Southward extrusion of dilute coastal water (surface salinity $^{o}/oo$) off the Copper River 1-6 September 1978, straight lines indicate cruise track, RV MILLER FREEMAN (from Ingraham 1979). For monthly mean wind field see Fig.

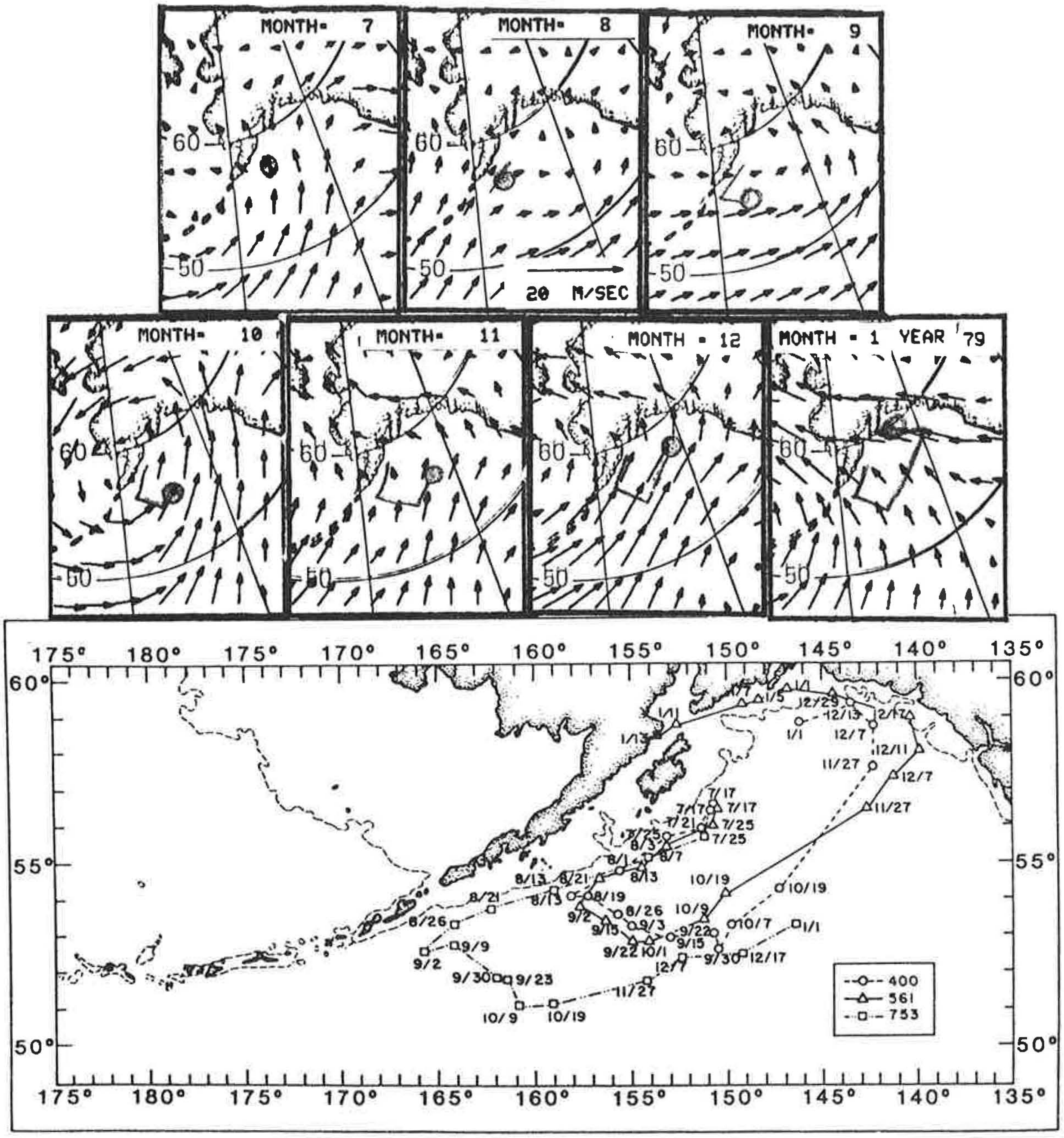


Figure 20.--Tracks of 3 satellite-tracked, drogued buoys, July 17, 1978 to January 1979, and monthly mean wind fields during this period. Buoy drift generally corresponds to wind field except in boundary current in July and August.

when tracking ceased. During July and August southwest velocities in the Alaskan Stream (15-29 cm/s) were as much as one-fourth those to be expected in this area, and although monthly mean winds for July and August opposed this flow, it is more likely that the buoys were not, or did not remain, in the axis of the Stream. Nor is it apparent that winds were responsible for their southeastward ejection from the Stream, but the subsequent drift of buoys No. 400 and 561 in September, once out of this boundary current, and in the following months corresponds closely to concurrent wind vectors--the abrupt northeast movement in October that continued through December and the westerly movement of buoy No. 561 at the head of the Gulf in January reflects a close association with wind vectors similar to those reported in the first section of this report.

It was not the southeast ejection from the Stream that was interesting, such events are common (Fig. 21) and believed to be associated with the dynamics of flow but are probably influenced also by wind. The presence of northward flow west of the center of the Gulf and the information provided by the monthly mean wind fields suggest a reevaluation of our concept of the Alaskan gyre that has existed since the INPFC studies a quarter century ago.

When in early exploratory stages of geophysical investigations one expects data to be usually distributed over large gaps of space and/or time because of the cost per data point and seeks gross associations or relations that not only permit but provide the motivation or perhaps even justification for further study. Possible relations between flow in the Alaskan gyre and movements of Pacific salmon is a case in point. The results of intensive and extensive INPFC studies from the mid-1950's and well into the following decade are well documented in the literature.

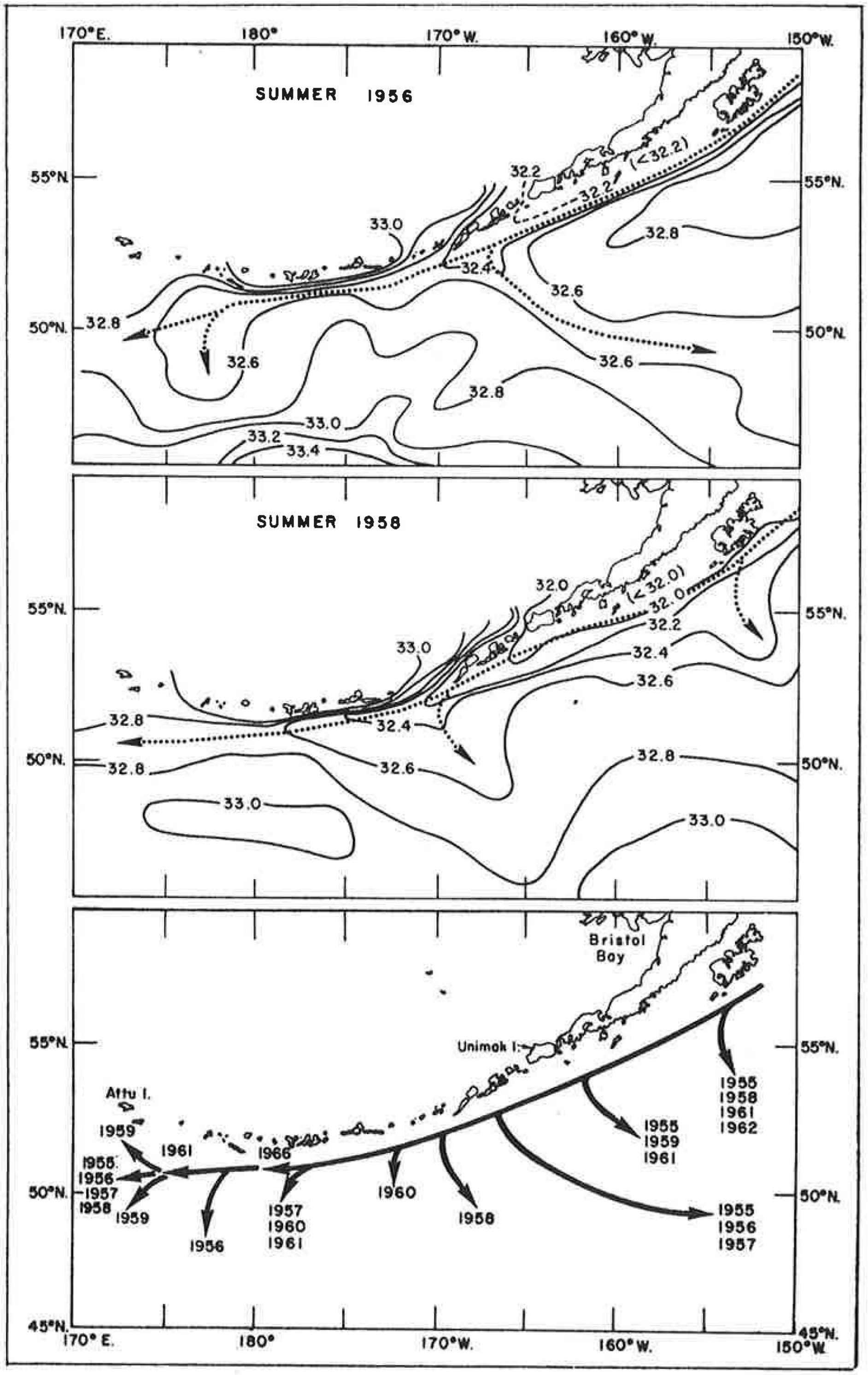


Figure 21.--Variability in location of southern branches of the Alaskan Stream 1955-1962 and accompanying surface salinity distributions in summer 1956 and 1958 (from Favorite 1969).

Prior to INPFC studies on Pacific salmon it was believed that salmon remained year-round within the influence of parent streams and their absence in winter was attributed to overwintering at depth over the shelf edge from which they rose in spring near river mouths. However, by the mid-1950's a broad oceanic distribution was recognized and the large Alaskan gyre was considered a possible mechanism to return outmigrants back to river mouths on the west coast. The distance around the gyre of about 5000 km could be completed within a year in currents of 16 cm/sec, a reasonable speed though in excess of geostrophic flows. Those salmon spending more than one year in the ocean could use the first roundtrip as reinforcement for eventual return one or several years in the future. Extensive oceanographic observations in the Gulf in the late 1950's failed to substantiate IHC drift bottle evidence of an eddy in the northwestern Gulf and evidence from distributions of water properties and geostrophic flow (wherein the distribution of mass calculated from depths of 1000 and 2000 m masked the effects of conditions in the shallow, 100 m, surface layer) suggested the presence of a gyre that encompassed much of the northern part of the northeastern Pacific (Fig. 22). Although only meager oceanographic observations were available in winter, compared to those in summer, marked increases in northward total integrated transports in the eastern Gulf as well as in sea level along the coast gave credence to the concept that the large, cyclonic Aleutian low maintained the gyre that extended across the Gulf. However, inspection of the monthly mean wind fields from 1946-83 indicate that south-westerly winds generally predominate over much of the Gulf and are quite persistent because of the high velocities in the southeastern quadrant of the Aleutian low in winter and reduced velocities in the northwestern quadrant of the Pacific high in summer. Monthly mean wind fields were synthesized into winter (Dec., Jan., Feb.) and summer (June, July, Aug.) fields to characterize this flow.

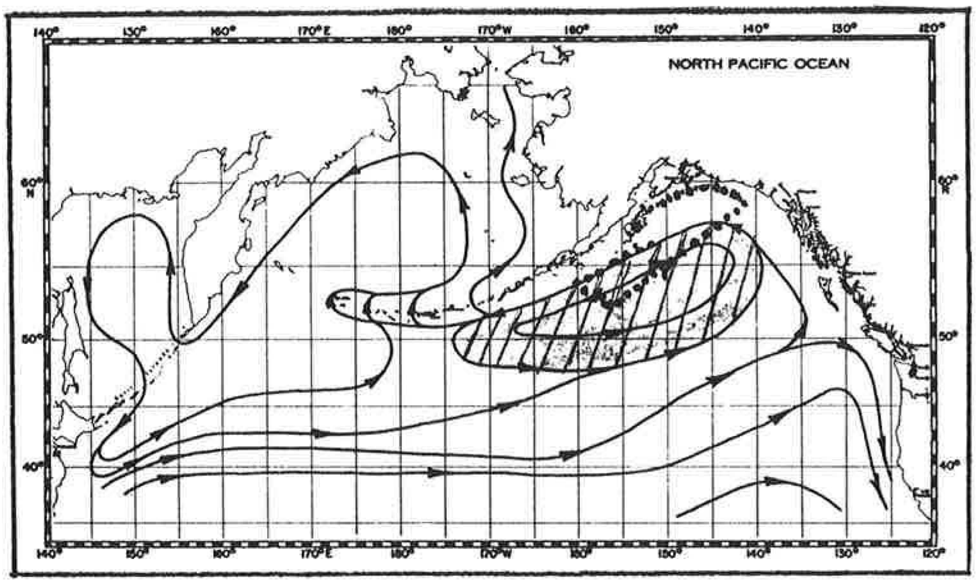


Figure 22.--Schematic diagram of surface circulation relative to 200 decibars (from Dodimead et al., 1963). Dots indicate general track of 2 satellite-tracked, drogued buoys reported by Reed (1980).

Of the winter wind field in only 8 years (1950, 1956, 1958, 1965, 1969, 1971, 1982, and 1983) are there clear evidences of a mean cyclonic wind pattern in the Gulf area (north of 50°N, 130-160°W) and it is usually weak; 2 years (1957 and 1962) reflect unusually low, random net winds; and, the remaining 26 years indicate strong southwesterly to southerly winds (thus northerly surface flow) into the Gulf--winds that originate in nearly all instances from or southward of 40°N, in some instances from 30°N. In all instances mean winds at the head of the Gulf had a component to the northwest (although this may be an artifact of the computer model). Summer wind fields reflect low southwesterly winds through the Gulf with, in all instances, at the head of the Gulf a weak easterly component, although there is no oceanographic evidence that the latter change the constant westward oceanic flow in this area in summer to any degree.

Thus it would appear that, although below the surface layer geostrphic flow (steady-state) in the Gulf generally parallels the configuration of the basin with higher speeds near the shelf edge, particularly in the western boundary current (Alaskan Stream), and the Ridge Domain remains a major subsurface feature, decreasing winds and relaxed hydrostatic forces at the coast in spring and summer permit encroachment of surface coastal waters and associated biota seaward toward mid-Gulf areas. In late fall and throughout winter southwesterly winds drive this trans-Gulf surface layer and associated biota of coastal origin directly toward the head of the Gulf and thus back to shelf areas all across the head of the Gulf--a marvelous return mechanism for early life stages of organisms initially carried by or following coastal surface currents into offshore waters that is far more effective in a time and space sense than a peripheral westerly current around the head of the Gulf as implied by the Alaskan gyre concept.

Thus it would appear that, although below the surface layer geostrophic flow (steady-state) in the Gulf generally parallels the configuration of the basin with higher speeds near the shelf edge, particularly in the western boundary current (Alaskan Stream), and the Ridge Domain remains a major subsurface feature, decreasing winds and relaxed hydrostatic forces at the coast in spring and summer permit encroachment of surface coastal waters and associated biota seaward toward mid-Gulf areas. In late fall and throughout winter southwesterly winds drive this trans-Gulf surface layer and associated biota of coastal origin directly toward the head of the Gulf and thus back to shelf areas all across the head of the Gulf--a marvelous return mechanism for early life stages of organisms initially carried by or following coastal surface currents into offshore waters that is far more effective in a time and space sense than a peripheral westerly current around the head of the Gulf as implied by the Alaskan gyre concept.

True long-term or secular events occur infrequently in the ocean. These are related to polar waves, sunspot cycles, earth wobble, and other planetary and galactic changes and are responsible for usually subtle, gradual changes occurring over several years or decades or centuries. For example, mean surface Pacific Ocean temperatures in the early 1930's were one or more degrees colder than at any time since then. Such events may be of only historical interest today. However, the aperiodic El Nino event whose damaging effects on fisheries extend over a period of a year or more is considered long-term for our purposes here.

Anyone who believes that changes in oceanographic conditions do not affect fisheries has only to be informed or reminded of the recent El Nino event that so altered existing fisheries that the industry appealed to Congress for aid and relief. Although scientists seek as far afield as the equatorial regions for the origins and causes of such phenomena, there is good evidence that much of the transport in the northeastern Pacific is driven by local winds and extremely anomalous winds over an extended period of time are required to precipitate the changes associated with El Nino events. Thus, although the intense Pacific disturbance discussed earlier whose effects were felt at equatorial latitudes was the driving force for the 1983 event it was the fact that anomalous southerly winds (strength and persistence) along the eastern edge of the northeastern Pacific that caused the local changes, not necessarily any excessive long-term northerly transport caused by conditions in lower latitudes (that would probably be manifested at depth, >200 m, rather than at the surface). Analysis of monthly mean wind fields suggests that, although excessive northerly winds along the coast for one or two months may cause alterations in conditions that are not necessarily obvious to oceanographic or fishing interests, when conditions persist for three months changes in conditions should be apparent and for four or more months, as occurred in 1982-1983, an El Nino event (a northward transport of subtropic water into the subarctic area) is obvious. Thus, the monthly mean wind fields could have the potential to forewarn of an El Nino event if appropriate wind indices are compiled.

Discussion and Summary

Analyses of monthly mean wind fields and comparisons with satellite-tracked drogued buoys indicates that oceanographers enamored with geostrophic flow and Ekman transport have given short shrift to wind currents in the surface layer. These appear to have extensive continuity and perhaps provide more accurate information on surface drift and certainly much greater accuracy on surface current speeds in offshore areas, such as the central Gulf of Alaska and the divergence off the west coast, than "steady-state" geostrophic flow.

One should not accept the trajectories indicated in the Kirwan et al. experiment as representative of typical onshore flow in the northeastern Pacific, but only as events in time. In winter the eastward flow near 160°W in all probability would be northeasterly and if the experiment had commenced in fall instead of summer the drifters could have penetrated well into the Gulf before spring; and subsequent coastal movements would have been considerably different. In the experiment the drifters arrived off the Washington-Oregon coast in spring and moved southward off the coast, the closest approach being over 100 km. This is the period when strong southerly winds into the Gulf are reduced markedly and weak northerly winds along the coast commence increasing; coastal currents shift from northerly to southerly and upwelling results. During winter or during summer, as drift bottle studies indicate, some directly onshore flow would probably have been present. A number of time dependent scenarios could be postulated and constructed for mean flow in the northeast Pacific, and for anomalous or extreme flows; and these should be compared, not only against real-time events, but past and present data on fish stocks.

In terms of factors perpetuating stocks it appears very likely that from Oregon to the Alaskan Peninsula it is the strong southwesterly surface winds in winter that are responsible for transporting back to the coast, not only plankton, but juvenile fish, that respond to or are carried by surface plumes of coastal runoff that extend hundreds of kilometers into the oceanic regime. Perhaps significant here is the fact that during the recent OCSEAP studies related to oil risks to marine life at the head of the Gulf all the concern was devoted to the shelf area, whereas it appears likely that at least in late summer and early fall the area seaward of the shelf, all around the Gulf, may also have been particularly significant for early life stages of numerous forms. Although the effects of such onshore and offshore flows on individual species require investigation such processes may hold the key to the constant renewal of shellfish whose larvae are planktonic for extended periods and subject to wide dispersal by currents, but whose adult forms have a limited ability to perform contranatant migrations--this would be particularly pertinent in the northern Gulf where coastal flow is always westward and at times swift.

Further, in regard to salmon, it is still not known where and at what depth salmon overwinter in the ocean and the extensive continuity of northeasterly surface flows associated with southwesterly winds in the northeast Pacific do not contradict assumed shoreward migration patterns to west coast river systems. Certainly the permanence of the front and associated eddies indicated between 35-40°N near 160°W should be investigated in relation to salmon movements in winter and early spring as well as the eastern Pacific gyre near 35°N, 130-140°W. Studies of the north-south shift in the location of the divergence of surface easterly flow of the west coast should be rewarding in relation to onshore salmon movements as well as the presence or absence of subarctic or subtropic forage since it is apparent that this feature is more related to wind than internal hydrodynamic forces.

Critical to any studies of surface currents is the necessity of obtaining associated biological observations and the ability to investigate more thoroughly and in real-time extremely anomalous events. Because time frames associated with the latter cannot usually be predicted well in advance, the ability to acquire the services of a charter vessel on short notice is mandatory; research vessels, whose cruise plans are formulated 1-2 years in advance and cannot be altered, do not satisfy this requirement. Certainly the time has come when fisheries scientists in the northeastern Pacific should have facilities to investigate, monitor, and evaluate gross anomalous events on or off the coast in real-time.

Finally, it may seem perplexing that with such useful information to fisheries forthcoming from analyses of satellite-tracked buoys and mean winds that such programs have not been implemented long ago. One can only point out that drifting buoy programs were proposed by NMFS personnel as early as the 1960's (Favorite et al., 1965) and a proposed but not funded NMFS, Buoy Experiment Eastern Pacific (BEEP), was similar to that conducted by Kirwan et al. except that greater north-south extent of releases, which would have been considerably more informative, was advocated.

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APPENDIX

Long-term (1946-1983) monthly mean winds, January - December.

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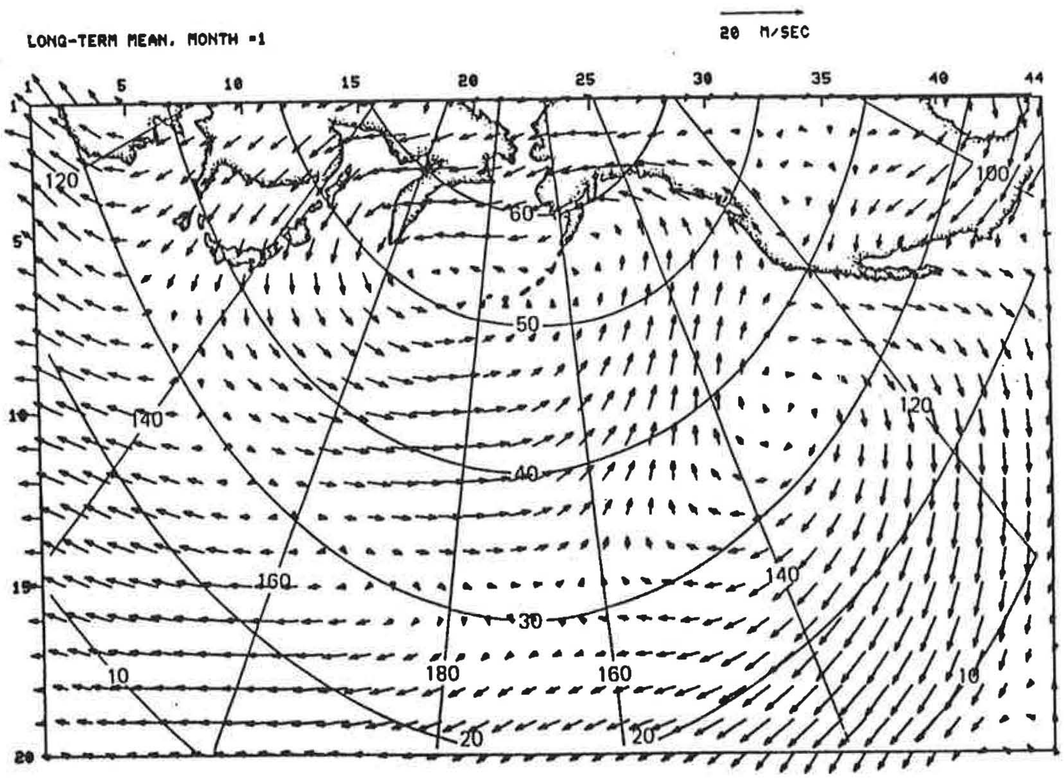

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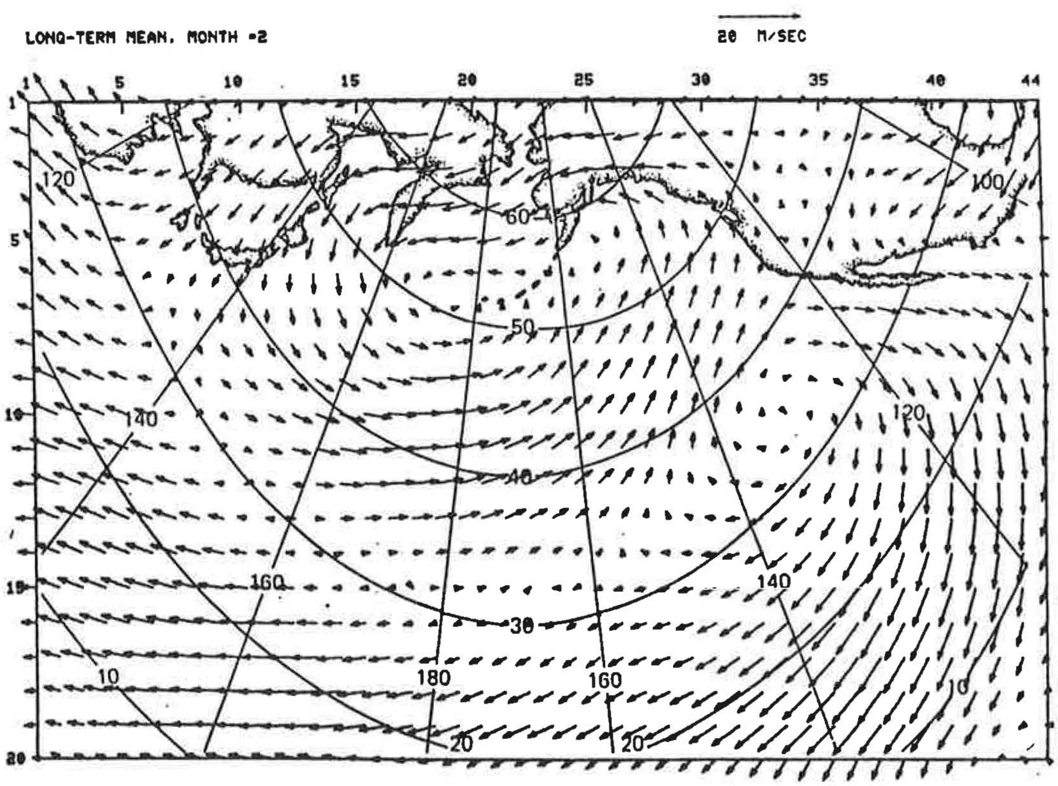

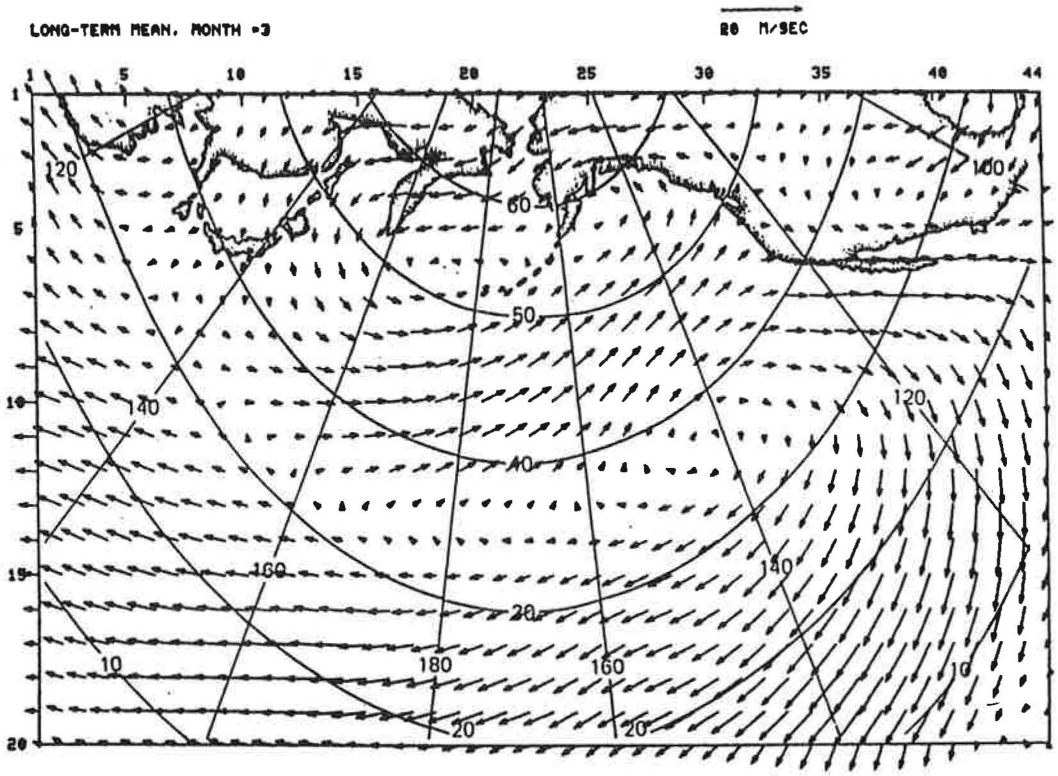
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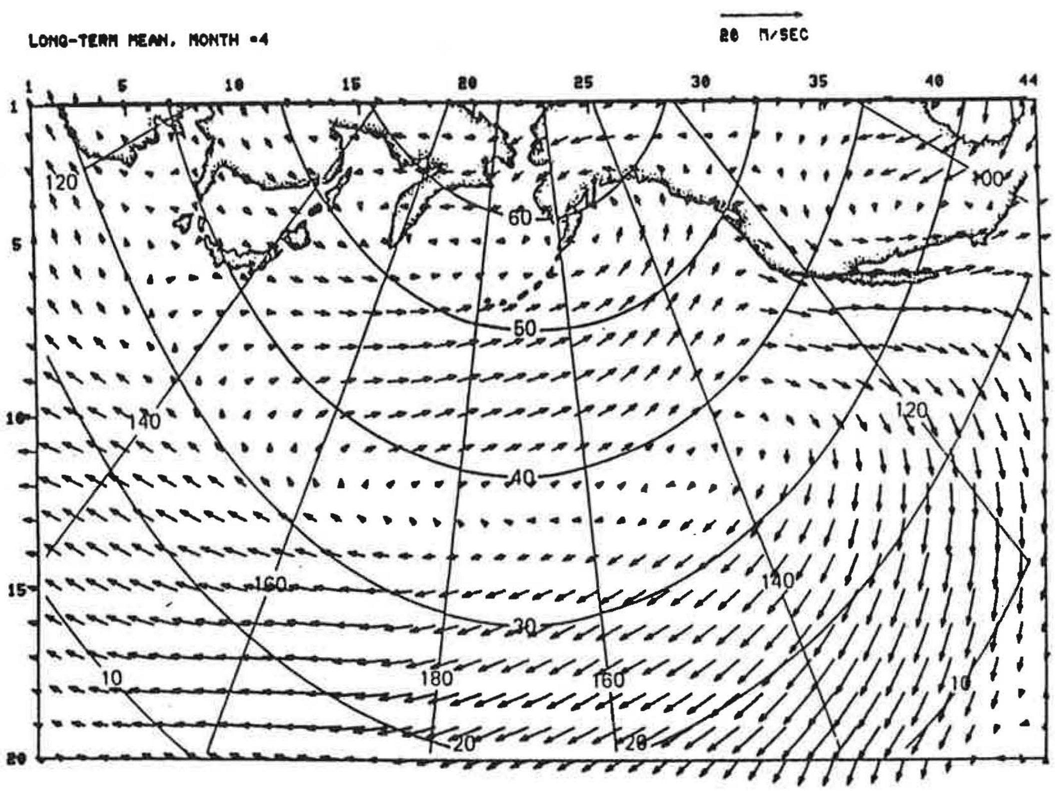
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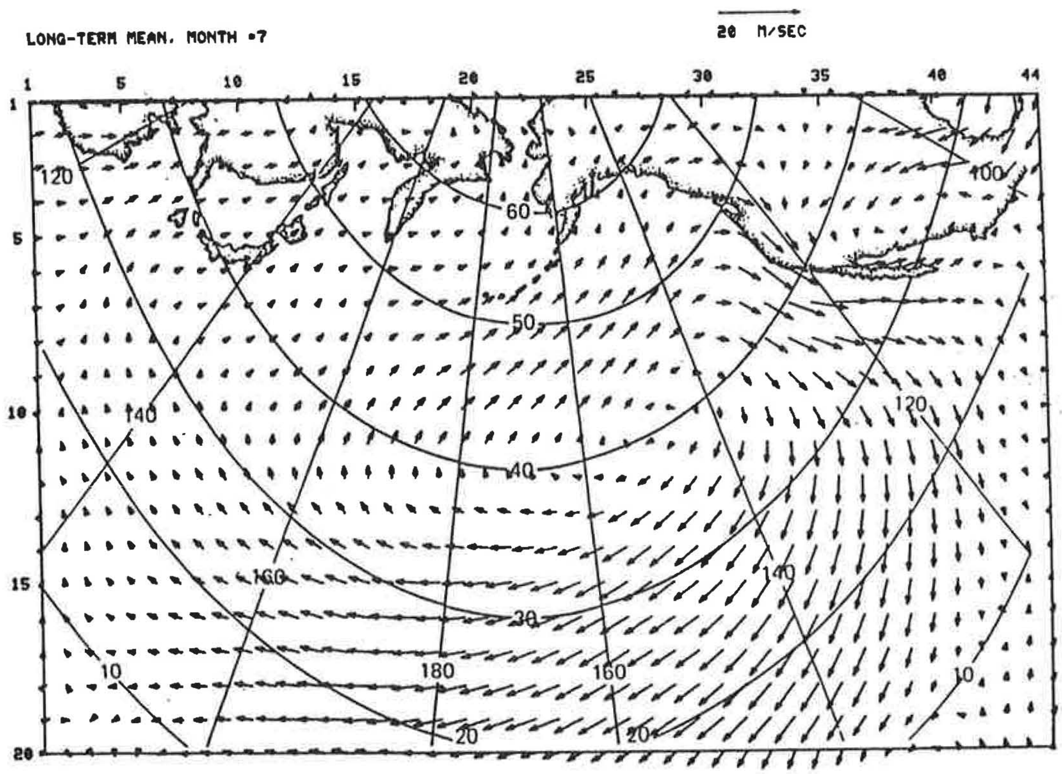
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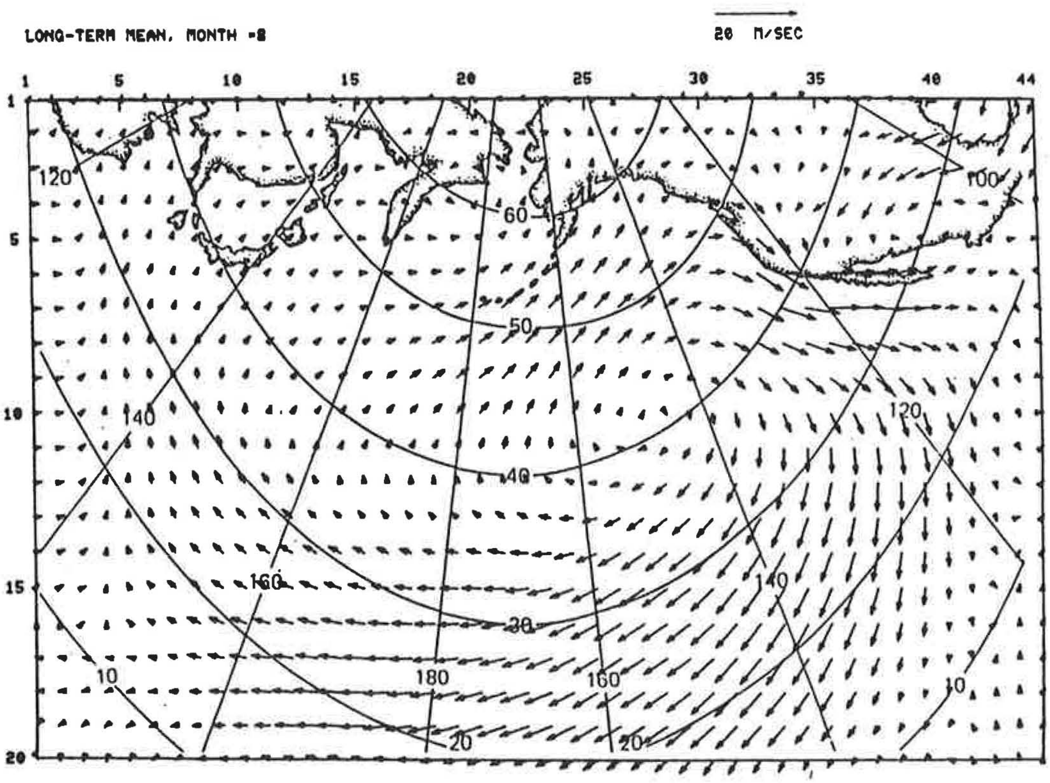
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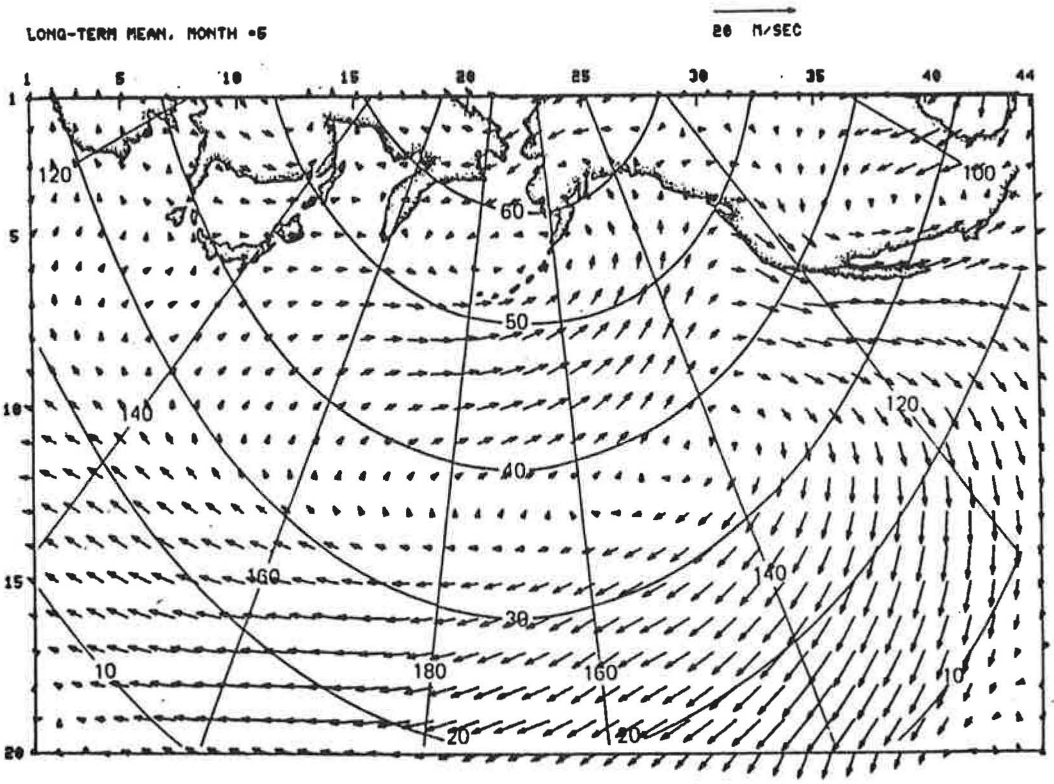
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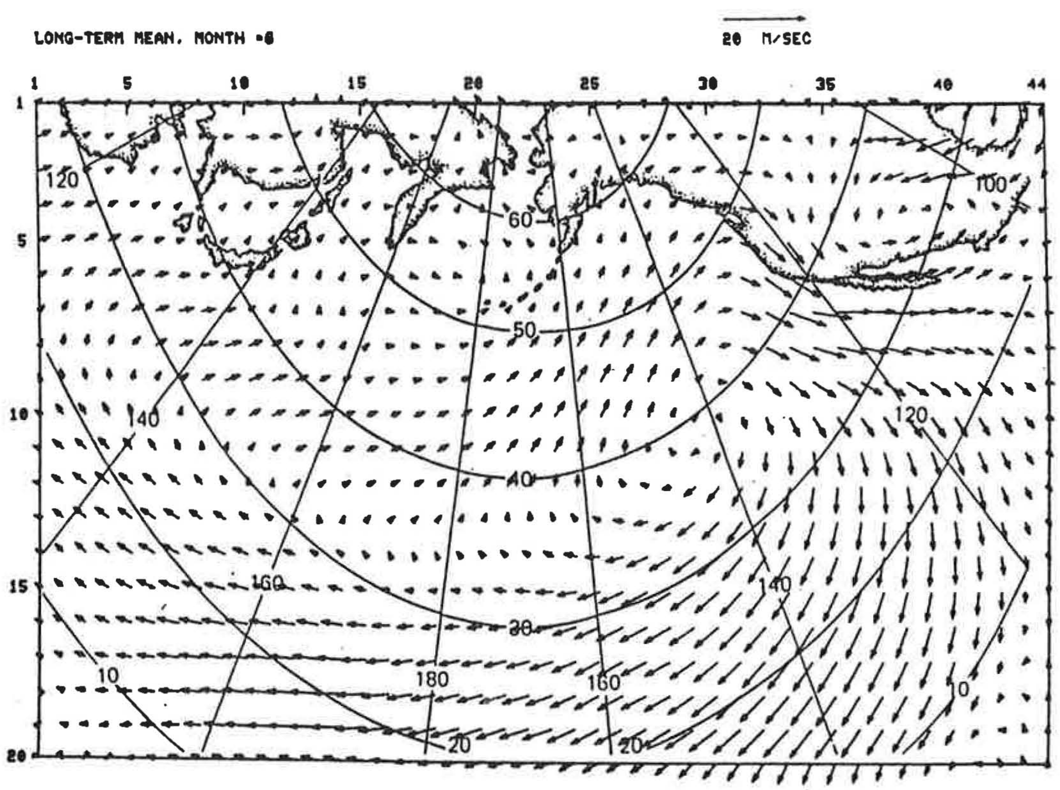
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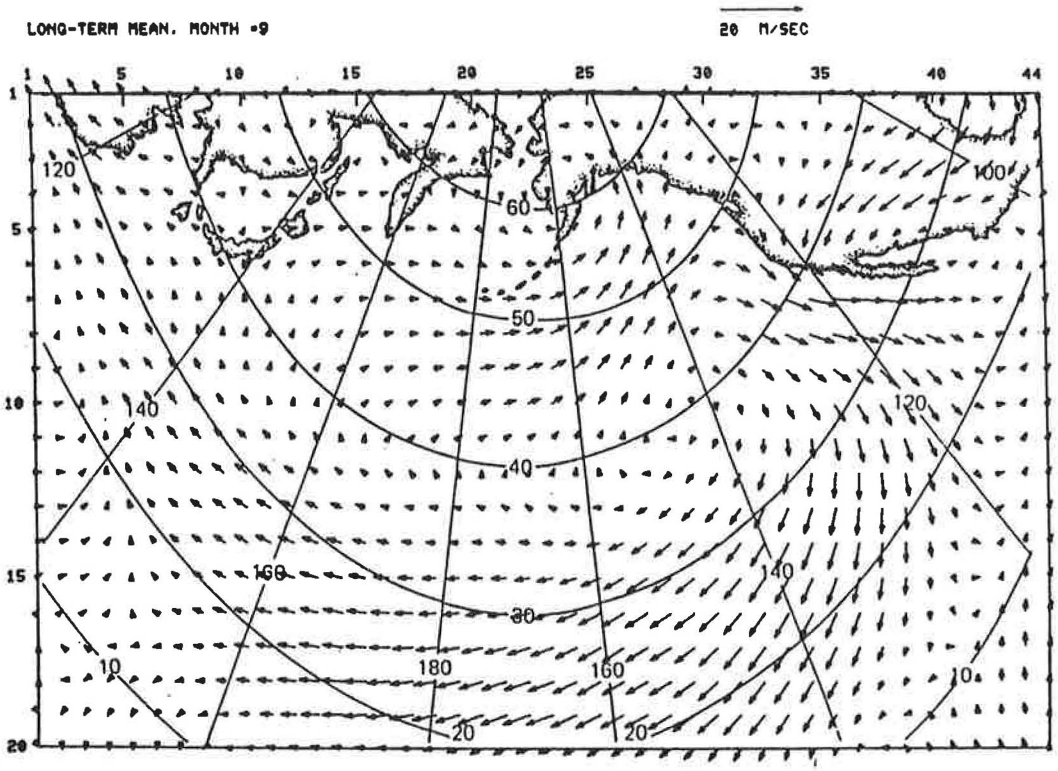
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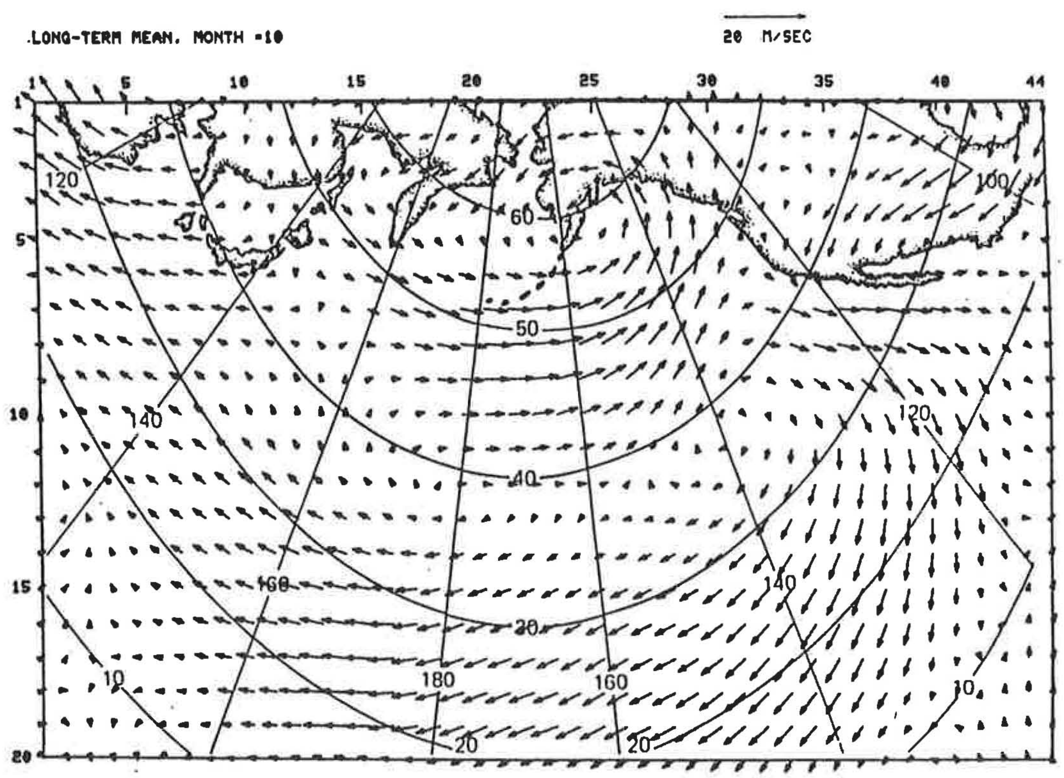
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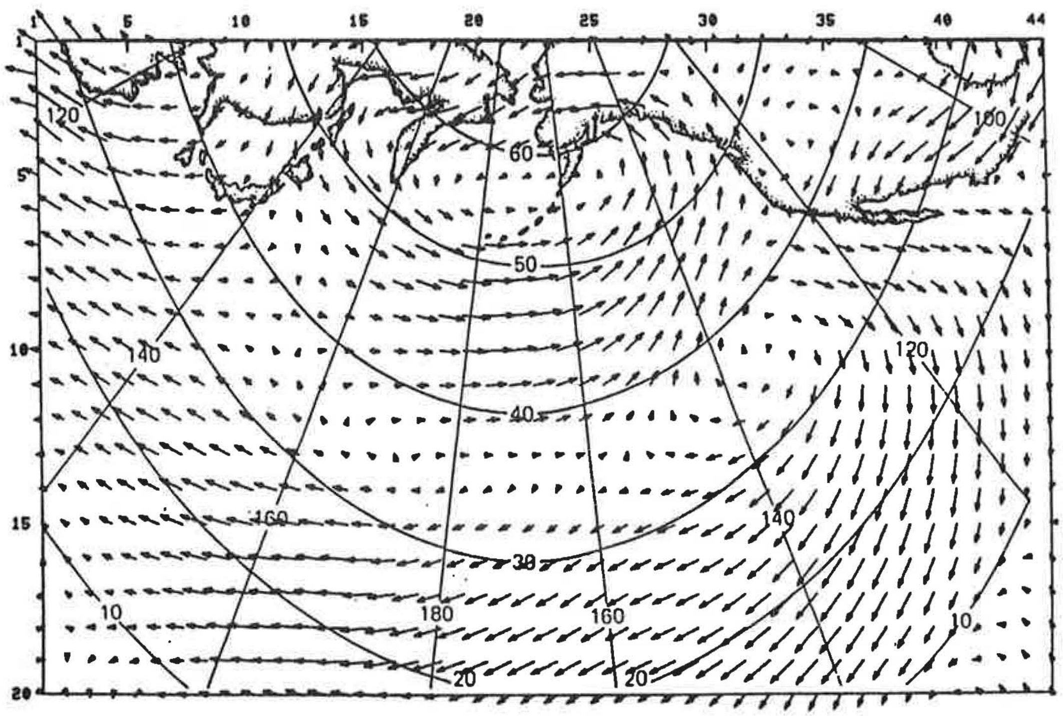

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