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Indices for Mid-Latitude North Pacific Winter Wind Systems; an Exploratory Investigation

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ABSTRACT: Biological distributions and fish migrations during the spring and summer in the mid-latitude N Pacific are believed to be affected by the large-scale wind systems during the preceding winter. These wind systems are related to the field of atmospheric pressure which, on a monthly or quarterly time scale, show pronounced interannual variations. This exploratory investigation is concerned with measures of the large-scale wind systems that are indicative of their intensity, location, and size, and that can be derived from monthly or quarterly sea-level pressure distributions. Of interest are the NW, W, and SW wind systems which are related to the pressure gradients between the Siberian High and Aleutian Low, the Aleutian Low and the N Pacific Subtropical High, and the Aleutian Low and the N American High, respectively. Interannual changes in the winter sea-level pressure distribution pattern are primarily the result of changes in the pressure and zonal displacements of the Aleutian Low near 50°N. This property permitted simple derivation of wind indices from grid values of N hemisphere mean winter pressures distributions for the years 1947 to 1985. Indices, presented as normalized anomalies, are for the meridional component of the wind system at 50°N over the ocean W and E of the Aleutian Low, for the westerlies S of the Aleutian Low and for the longitude of this Low. The paper concludes with a discussion of the limitations of the indices in terms of reflecting characteristic atmospheric pressure distribution patterns, an examination of the relationship between wind anomalies and El Nino events, and a discussion of the results in terms of oceanographic, climate, and biological implications.

Introduction

The wind stress at the sea surface is the key factor in the transfer of heat, moisture, and momentum between ocean and atmosphere. These processes affect not only the ocean-atmosphere climate system but also properties of water motion. Water motion such as is involved in mixing of the surface layer and wind driven surface currents are believed to affect biological processes, particularly those involved during the early stages of life. Currents, either directly or indirectly, may also affect the distribution and migration of marine life. It is useful, therefore, to investigate whether monthly or quarterly measures of the wind systems over the mid-latitudes of the N Pacific can be developed that are indicative of their intensity, location, and size.

In this exploratory investigation it is simpler and more instructive to infer properties of the wind systems from sea level atmospheric pressure distributions than from averages of directly observed winds as often is done in climatological investigations. Eber and Sette (1959) calculated indices of the mean monthly geostrophic wind over the N Pacific for the years 1926 to 1958. The indices were pressure differences determined at 36 locations over the principal currents from pairs of sea level pressures 350 to 600 nautical miles apart. In the present investigation interest is in indices of the large-scale wind systems derived from the major pressure systems rather than in geostrophic winds over limited sections of the ocean. This approach, however, can be used only during mid-summer and mid-winter when the pressure systems are well developed.

Air-sea interaction processes over the mid-latitude N Pacific are most active during the fall and winter months. It is believed that during these months oceanographic conditions are created that will persist and affect biological distributions and fish migrations during the subsequent spring and summer. This investigation, therefore, is concerned only with indices that reflect anomalies in winter wind systems rather than with those, such as the Eber-Sette indices, that can be used in time-series analyses.

North Pacific Mid-Latitude Winter Wind Systems

The long term mean January sea level pressure chart reproduced from Fleet Numerical Oceanography Center (FNOC) files (Fig 1) shows that the Aleutian Low (AL) dominates the mid-latitude N Pacific. The lowest pressure occurs near latitude 50°N and longitude 175°E. A ridge of high pressure extends across the Pacific from America to Asia between latitudes 20° and 30°N, with the highest pressure occurring near latitude 30°N and longitude 130°W. This cell of highest pressure is referred to as the Subtropical High (STH) and is linked to the Continental High over W N America. On the W side of the N Pacific the pressure of the ridge increases and is linked to the Siberian High (SH) near latitude 48°N and longitude 95°E. (The SH is outside of the area shown in Fig 1 but near the same position in Fig 2). In contrast to the winter pattern when the AL dominates, in summer the Subtropical High dominates over the N Pacific (Fig 1, lower panel).

Associated with these pressure cells are the principal wind systems. The dominant system in

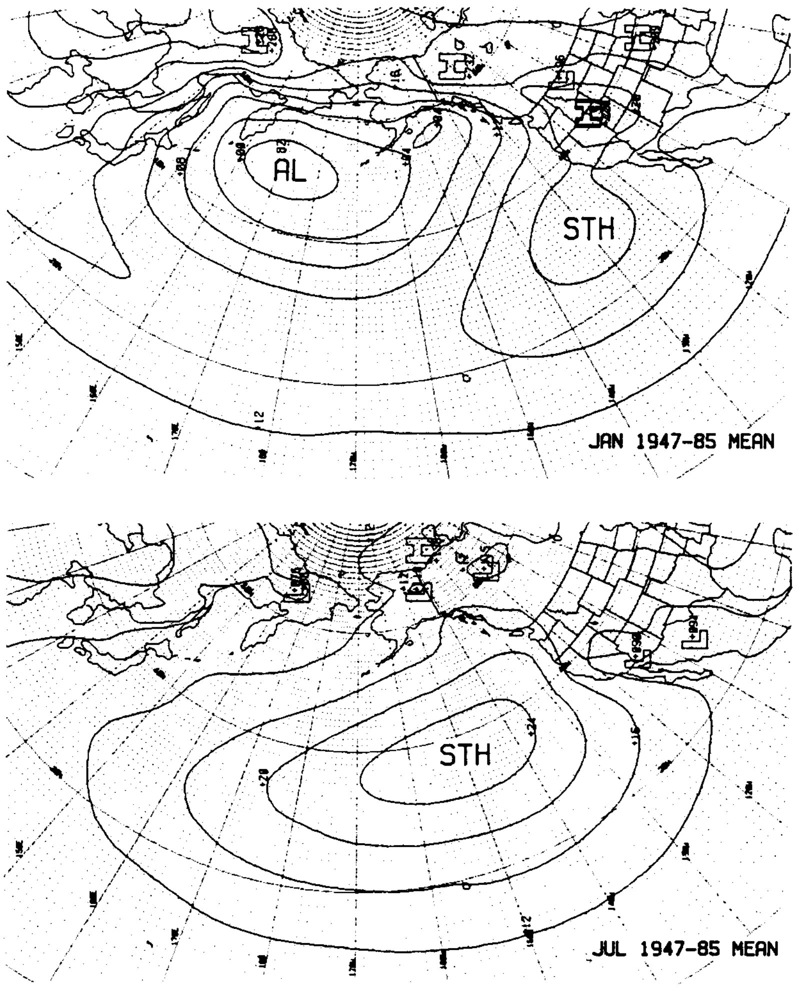
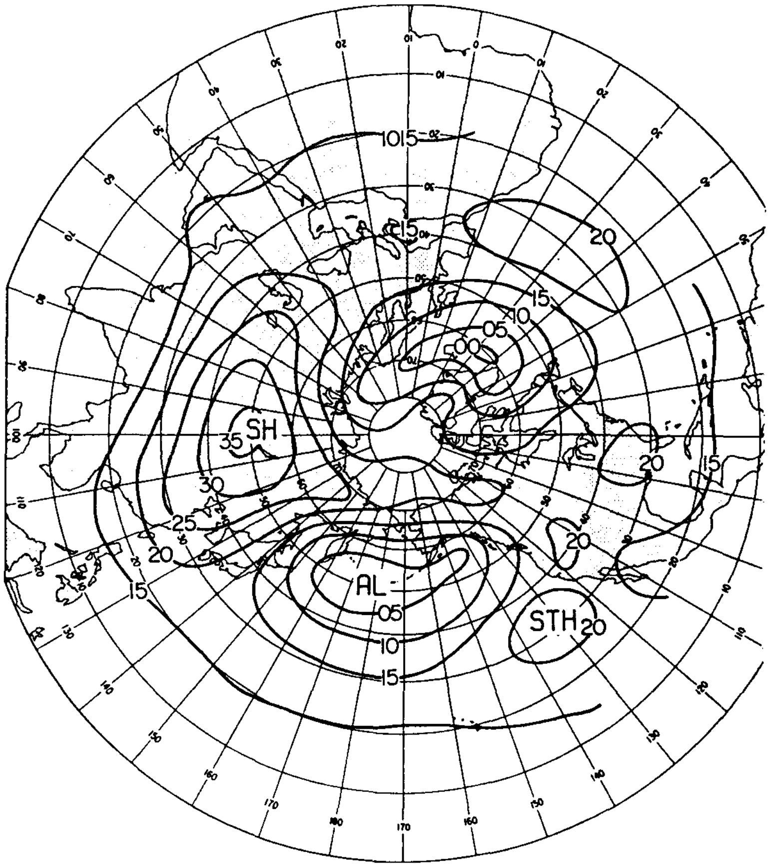


Fig 1
Sea level pressure, 1947-85 mean January, upper panel;
1947-85 mean July, lower panel

Fig 2
Winter sea level pressure, 1947-72 mean (Namias 1975)



winter, the westerlies, is that produced by the pressure gradient between the AL and the ridge of high pressure to the S (Fig 1). Another winter wind system is that produced by the pressure gradient between the AL and SH pumping cold, dry Arctic air over the W N Pacific. On the E side of the ocean the pressure gradient between the AL and the high pressure over N America produces a southerly wind component with warm, humid air. An all year system that is not a part of this investigation, the NE trades, is produced by the pressure gradient between the subtropical ridge of high pressure and the equatorial pressure trough. The cyclonic circulation about the AL, therefore, consists of three wind systems: The northwesterlies over the W, the westerlies over the central, and the southwesterlies over the E N Pacific. Because the December and February sea level pressure patterns resemble the extremum pattern in January the mean winter (December, January, and February) sea-level pressure distribution is similar to the January pattern (Fig 2).

From the sea-level pressure pattern shown in the lower panel of Fig 1 it is evident that the trade wind system is the dominant N Pacific wind system during the summer. On the W side of the ocean winds have a weak southerly component but on the E side the high gradient between the STH and the low pressure over California produces strong winds with a northerly component. The seasonally altering wind directions produce upwelling in summer and downwelling in winter along the mid-latitude coast of North America (Bakun 1973; Nelson 1977).

Individual Year Sea Level Pressure Distributions

The January sea level pressure patterns and their associated wind systems, vary from year to year and distinct types of distributions can be recognized. The examples shown are reproduced from FNOC files. The first pair of pressure patterns with a well developed AL (Fig 3) illustrate differences in the STH. In 1955 (upper panel) the STH is a separate, identifiable pressure system but in 1961 (lower panel) the STH appears only as a projection of the North American High extending out over the E Pacific. The STH is therefore not always a distinct pressure cell as it appears in long-term mean pressure charts. Other types of distribution patterns are primarily related to changes in size and location of the AL. Examples are shown in Fig 4 where the AL was displaced from its central Pacific location eastward into the Gulf of Alaska as in 1958 (upper panel) or westward toward Kamchatka as in 1969 (lower panel). Fig 5 shows an example of a ridge of high pressure (a blocking ridge) splitting the AL into an E and W cell as in 1956 (upper panel), and an other example, as in 1971 (lower panel), when the AL is not well defined. During some winters the E mid-latitude N Pacific is dominated by high pressure. In this distribution the pressure gradient E of the AL, but not necessarily the position of the AL, is displaced westward. Fig 6 shows an example that occurred in 1957.

From these subjective descriptions of pronounced differences in the pressure distribution patterns one can infer that there must be pronounced year to year variations in the intensity, location, and size of the principal wind systems. The question to be addressed below then is: can simple indices be derived that reflect the dif-

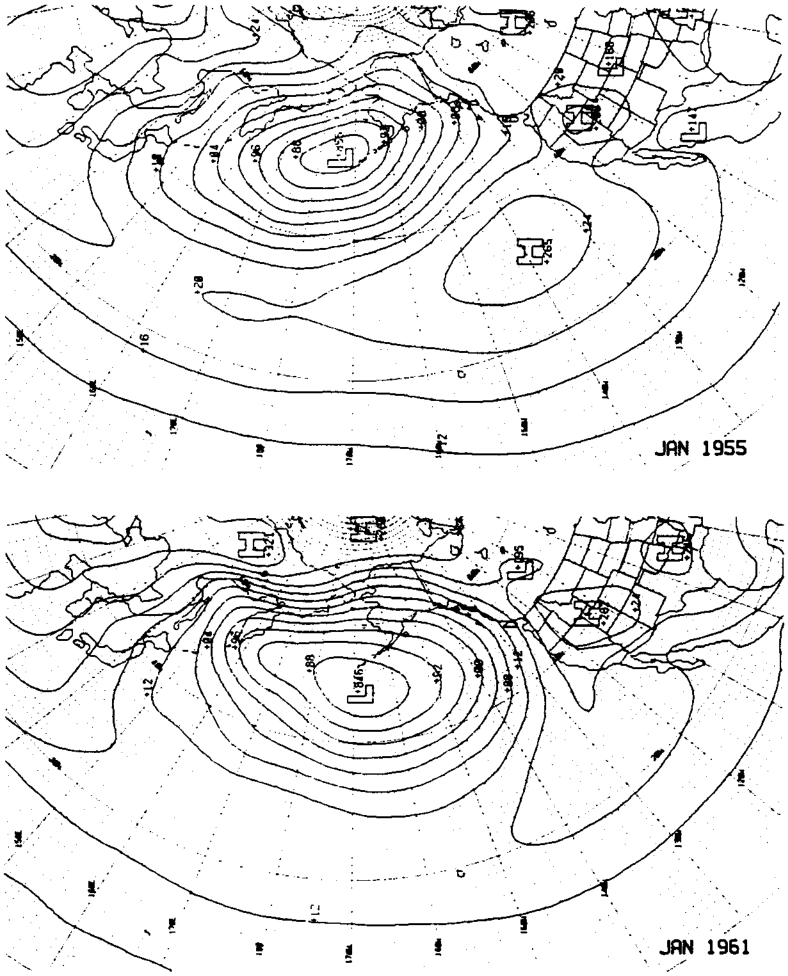


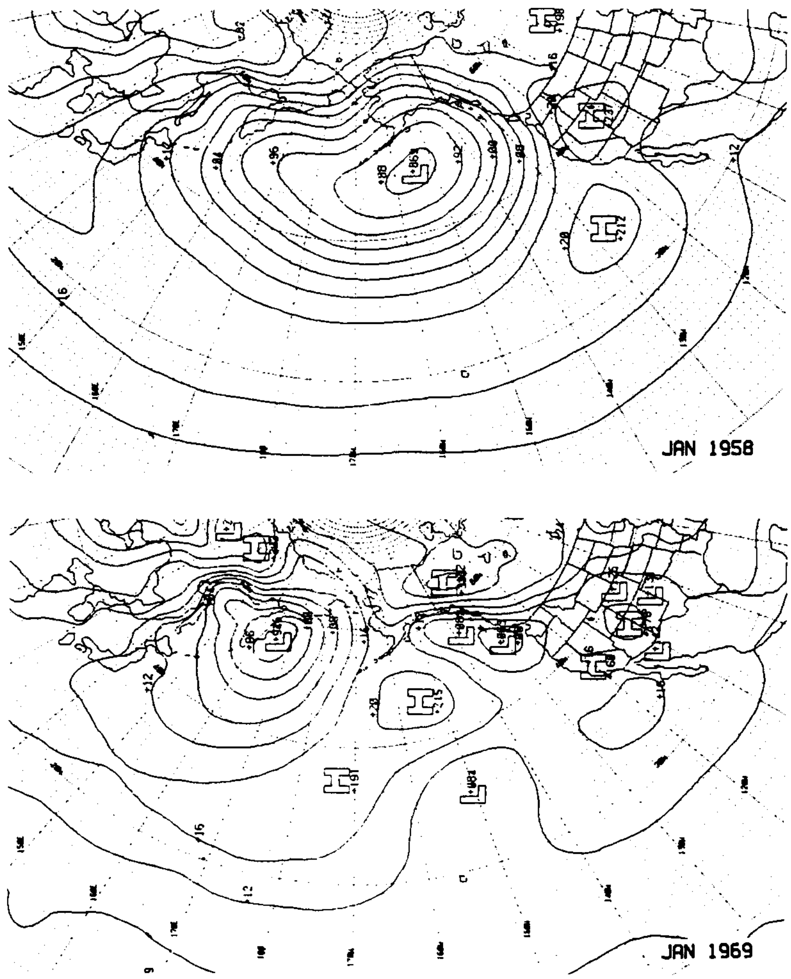
Fig 3
Sea level pressure, January 1955, upper panel; 1961, lower panel

ferences in the atmospheric pressure patterns as well as the characteristics of the associated wind systems?

Location of Atmospheric Pressure Centers

To begin the investigation, the 1951 to 1983, monthly mean January sea level atmospheric pressure charts produced by the National Meteorological Center, were used to pick the latitude and longitude of the AL, SH, and STH. The positions are approximate because (1) the charts ranged from the initial hand-contoured to the present computer produced versions with methods of production changing with advancing computer capabilities; (2) although high and low pressure centers are well defined on long-term monthly mean pressure charts, this is not always the case on monthly charts for individual years. The location of the SH was always well defined. The AL was well defined in most Januaries but there were some years when it was a trough or area of low pressure extending from E to W over a large segment of the N Pacific. In these cases the location of lowest pressure was chosen subjectively. When the STH was not well defined the center of the protruding lobe of high pressure was chosen as the position of the STH. The 1951-83 mean position of the three pressure centers together with standard deviations and

Fig 4
Sea level pressure, January 1958, upper panel; 1969, lower panel



extremes are listed in Tab 1. Years when the AL was split into an E and W cell were not included in these calculations but the locations of these cells fell within the range of the AL listed in Tab 1.

The important result of this preliminary investigation is the small variance in the latitude and longitude of the SH, the STH, and in the latitude of the AL relative to the large variance in the longitude of the AL. The longitude of the AL, remaining near 50°N, largely determines the sea level atmospheric pressure pattern. This behavior of the AL simplifies development of indices which will depend primarily on its longitude and pressure.

Indices of Atmospheric Pressure Distribution Patterns

A number of curve fitting procedures, using grid point values of analyzed fields, are available to aid in examining the year to year differences in the zonal distribution of pressure at lat. 50°N. One convenient procedure is harmonic analysis. If the analysis is restricted to the first harmonic which is a simple sinusoidal fit, then only three values in the function

$$S(x) = A(0) / 2 + C(1) \cos(w(x - P(1))) \quad (1)$$

describe the gross pressure distribution along the latitude band: A (0) / 2 is the mean pressure;

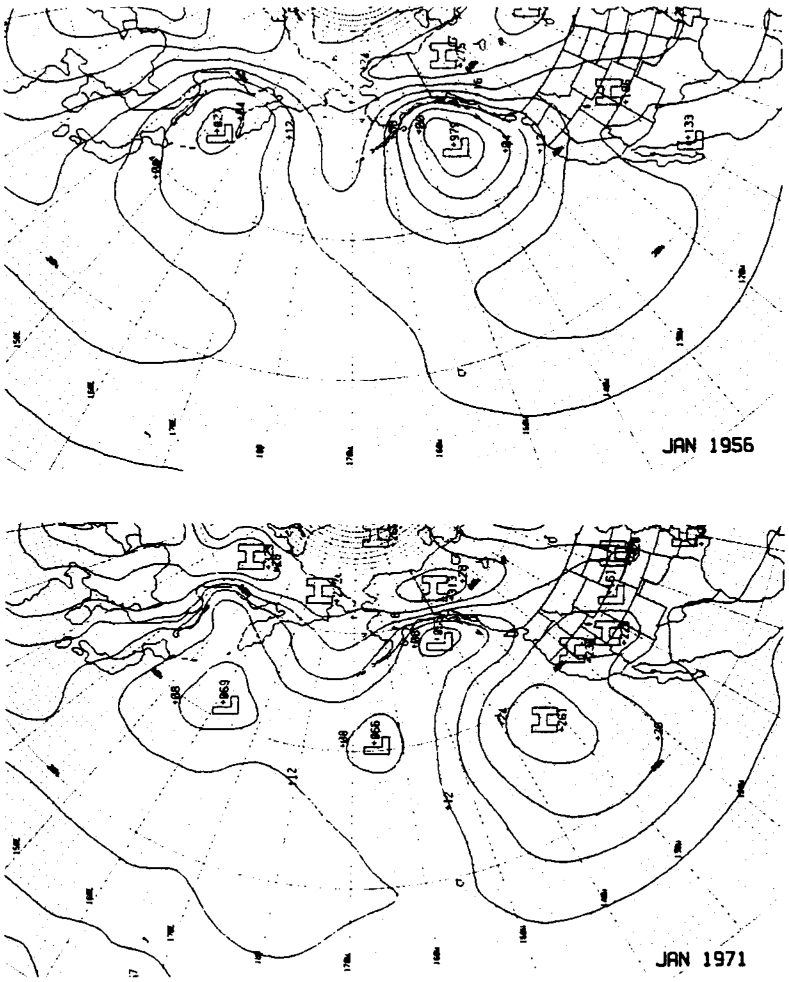
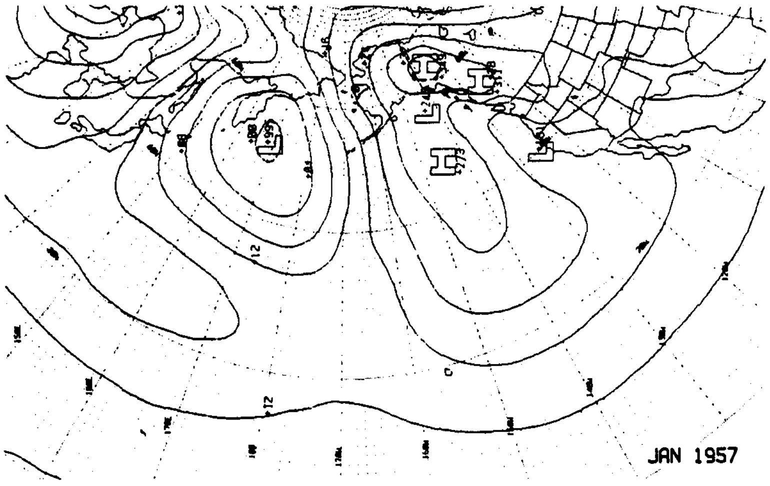


Fig 5
Sea level pressure, January 1956, upper panel; 1971, lower panel

Fig 6
Sea level pressure, Januar 1957



C (1) is the amplitude reflecting the magnitude of the pressure change along the latitude band; and P (1), the phase angle, in this application reflects the zonal displacement of the minimum pressure. The segment of the latitude band to be analyzed determines the value of w. The variable x is the longitude.

In this exploratory investigation the harmonic analyses were performed using the grid values of the winter (December, January, February) sea level pressure fields for 1947 to 1972, of Namias (1975) together with the updates to 1985 which were kindly provided by Dr. Namias. The grid values at lat. 50°N are 10° of longitude apart. The latitude band analyzed ranged from long. 150°E, in the Sea of Okhotsk, to 130°W near the Canadian coast. The assumed wavelength, then, is 80 degrees of longitude with x = 0 at long. 150°E and x = 8 at long. 130°W.

Results of the analyses which were carried out to the second harmonic, are listed in Tab 2. The fitted curves for selected years are shown in Fig 7 to 11. Normalized anomalies of A (0), C (1), and P (1) are shown in Fig 12.

Of interest in Tab 2 are the amplitudes, C (1), and the phase angles, P (1). All values of C (1) are positive except those for 1950, 1956, and 1969. The negative values indicate a phase shift of half a wavelength and mean that high pressure is found at the longitudes where low pressures normally occur. These years are those with a blocking ridge such as that illustrated in Fig 5.

The average phase angle, excluding the blocking ridge years, is -0.9. This means that the minimum of the sinusoid is 9 degrees of longitude to the W of mid-wave (170°W) or at 179°W. Again excluding the blocking ridge years, all but two phase angles are negative. These years are 1958 and 1983, the pronounced El Niño years, when the minimum of the sinusoid is shifted E of mid-wave to 162° and 161°W, respectively.

Fig 7 to 11 illustrate how well the harmonic curves fit the grid point values of pressure. The distribution of pressure across the Pacific at 50°N is not harmonic and consequently relatively large departures of the analytic curve from the grid values are to be expected. The largest departures tend to be at 150°E and 130°W. When these

Tab 1
1951-83 mean position, standard deviation, and extremes of the Aleutian Low, the Siberian High, and the N Pacific Subtropical High

	Mean	Std. Dev.	Extremes	
Aleutian Low	50° N	3.8	59° N	41° N
	179° W	14.9	157° E	160° W
Siberian High	48° N	1.9	51° N	46° N
	97° E	5.0	90° E	108° E
Subtropical High	32° N	5.0	48° N	24° N
	132° W	6.6	158° N	121° W

two positions, located in the Sea of Okhotsk and near the E boundary of the Pacific, are excluded then the simple sinusoid (solid line) explains between 80 and 90% of the variance. The analytic curve which includes the second harmonic (dotted line) improves the fit and explains 85 to 95% of the variance.

An example of the blocking ridge years is shown in Fig 7. The zonal distribution of pressure for the pronounced El Niño years of 1957/58 and 1982/83 in which the eastward shift of lowest pressure is clearly evident, are shown in Fig 8 and 9. An example of the westward shift of lowest pressure which also is the blocking ridge year 1969, is shown in Fig 10. Finally Fig 11 for 1971 is an example when the AL was not well defined.

Tab 2 Constants in the function for the distribution of sea level pressure at 50°N between 150°E and 130°W, $S (x) - 1000 = A (0) / 2 + C (1) \cos (w (x-P (1))) + C (2) \cos (w (2x-P (2)))$ mb, for each winter of 1947 to 1985. $w = 360 / 8$, $x = 0$ at long 150°E, $x = 8$ at long. 130°W

Year	A (0)	C (1)	P (1)	C (2)	P (2)
1947-72 mean	10.0	3.7	-1.2	1.6	-0.4
1947	15.4	4.6	-1.5	1.4	-0.8
1948	10.8	5.4	-1.2	1.7	-0.6
1949	18.5	7.4	-1.9	2.1	-1.0
1950	19.8	-6.4	1.5	1.2	-1.2
1951	21.1	2.8	-1.7	1.4	0.2
1952	12.6	3.5	-2.0	1.1	0
1953	-1.2	6.1	-0.2	1.5	-0.2
1954	9.6	3.9	-0.3	1.7	-0.4
1955	13.0	6.2	-1.5	1.8	-1.0
1956	18.6	-4.4	0.1	1.6	0
1957	18.5	7.6	-1.4	1.1	-1.4
1958	0	4.3	0.8	2.7	0.5
1959	8.8	2.7	-0.6	2.9	-0.4
1960	3.8	5.8	-0.9	1.6	-0.9
1961	-2.4	5.5	-0.3	2.2	-0.8
1962	15.0	5.6	-1.5	1.4	-1.0
1963	5.8	5.6	-0.5	2.3	-0.9
1964	0.6	7.9	-0.2	2.2	-0.8
1965	9.2	4.1	-1.6	1.8	-0.4
1966	7.2	4.9	-1.8	1.5	-0.2
1967	2.8	4.6	-1.5	2.0	0.2
1968	9.1	2.7	-1.7	2.0	-0.5
1969	15.1	-4.0	1.3	0.8	1.4
1970	-4.1	6.9	-0.1	2.2	-0.4
1971	14.4	1.7	-1.0	0.6	-1.2
1972	19.1	4.0	-1.8	0.9	0.4
1973	9.1	3.3	-1.1	1.9	-0.9
1974	3.8	3.7	-0.9	1.6	-0.9
1975	7.2	4.8	-0.6	1.4	-0.5
1976	5.6	5.2	-0.7	1.9	-1.2
1977	-7.0	11.4	-0.4	3.2	-0.9
1978	-0.8	5.4	-0.5	2.0	-0.2
1979	13.6	6.0	-1.4	1.5	-0.9
1980	6.1	3.7	-0.6	2.2	-0.8
1981	-0.4	7.9	-0.1	1.2	-1.3
1982	15.5	2.5	-1.7	1.1	-0.6
1983	-7.1	7.8	0.9	2.4	0.3
1984	6.8	4.0	-0.9	3.0	-0.9
1985	11.2	7.6	-1.0	1.6	-1.1

The analysis is based on data from Namias (1975) plus updates

The normalized anomalies for 1947 to 1985 of the mean pressure, A (0), the amplitude, C (1), and the phase angle, P (1) are shown in Fig 12. The calculations for the anomalies of P (1) do not include those for the blocking ridge years of 1950, 1956, and 1969. Although anomalies in the mean atmospheric pressure at lat. 50°N are presented in Fig 12A, they are not important in terms of wind driven currents. The anomalies in the amplitude (Fig 12B) are important, however, and not necessarily related to the mean pressure. There were seven years with an amplitude of more than one standard deviation above average, indicating higher than average geostrophic winds. Amongst these years 1977, with an amplitude more than three standard deviations above average, stands out. There were seven years with an anomaly of more than one standard deviation below average, meaning that winds associated with the AL were below average also.

Anomalies in the phase angle (Fig 12C) reflect the E-W shifts in the longitude of the AL. These shifts determine over what portion of the N Pacific winds will have a northerly or southerly component in the direction of flow. There were two outliers, one in 1958 and the other in 1983, when the lowest pressure was displaced eastward by more than two standard deviations from the mean longitude. All together, there were six years when the anomalous position was one or more standard deviation to the E and seven years when it was more than one standard deviation to the W of the mean location.

Representations of the atmospheric pressure distribution along 50°N as in Fig 7 to 11, can be used to infer qualitative information about the zonal distribution of pressure gradients, particularly when the second harmonic is added in generating the curves. The first derivative of the analytic expression gives the distribution of the zonal pressure gradient, excluding the E and W sides of the latitude band where the harmonic fit is not good. It is simpler, however, to obtain pressure gradients directly from the grid point values of the analyzed monthly or quarterly pressure distributions produced by meteorological services.

Indices of the Large-Scale Wind Distribution

Wind systems associated with the AL are the northwesterlies to the W, the southwesterlies to the E and the westerlies to the S of the AL. Indices of components of these winds are the large-scale pressure gradients between the longitude at 50°N of the AL and 160°E, near Kamchatka, and the longitude of the AL and 130°W, near the Canadian coast. The westerly index is the pressure gradient between 50°N and 25°N at the longitude of the AL. The gradients together with the distances between the location of the AL and the W and E reference locations, and the longitude of the AL are listed in Tab 3. The data source was, as before, the winter grid values of Namias (1975).

Fig 13 shows the normalized anomalies in the northerly (panel A), southerly (panel B), and westerly (panel C) components of the wind, W, E, and S of the AL, respectively. The anomaly in the longitude of lowest pressure along 50°N is shown in Fig 13D. The northerlies are only a part of the large wind system associated with the pressure gradient between the SH and the AL that affects E Siberia as well as the W portion of the N Pacific. The most frequent longitude of the AL from 1947 to 1985 was 170°E (Tab 3). With an average longitude, for the same years, at 176°E less than 20% of the latitude band over the Pacific was under the influence of the northerly wind component. Anomalies in this wind component, therefore, primarily affect the W boundary region of the ocean.

The anomaly of the southerly wind component E of the AL was more than one standard deviation higher than average during six years. These winters included the pronounced El Niño years of 1958 and 1983 as well as that of 1977. The southerly wind component was more than one standard deviation weaker than average in 1956 and 1969, the blocking ridge years.

The westerly indices depend upon the pressure of the AL and that of the subtropical ridge in the central part of the ocean, S of the AL. Variation in the latter is small in comparison to the former so that again, the pressure of the AL is the dominant factor in the pressure gradient. There were five winters with winds one standard deviation stronger than average. The largest positive anomalies occurred in 1977 and 1983. The westerlies were weakest in 1956, a blocking ridge year, and in 1971, and 1982 when the amplitude of the pressure variation along 50°N was small.

Fig 13D shows that there were six years with anomalous displacements of the AL to the E by more than one standard deviation. The largest anomalies occurred during the pronounced El Niño years of 1958 and 1983. The largest westward displacements occurred during the blocking ridge years of 1950, 1956, and 1969.

The direction of displacement of the AL in Fig 13D agrees with that in Fig 12C except during three years when the anomaly was small. The outlier years, 1958 and 1983, appear as such in both representations. The other outlier years are those with a blocking ridge which show as the largest westward displacements in Fig 13D. These years were anomalous also in the harmonic analysis but were not plotted in Fig 12C.

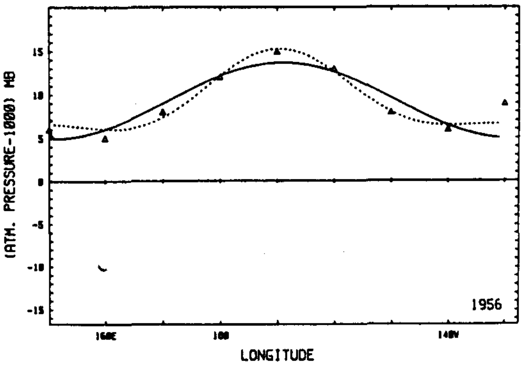


Fig 7 Harmonic fit, winter 1956, of sea level pressure between 160°E and 130°W at 50°N: first harmonic solid line; first plus second harmonic, dashed line. (See text and Tab 2.) Triangles are grid values from Namias (1975)

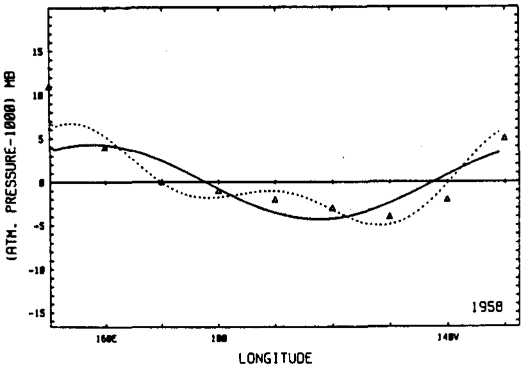
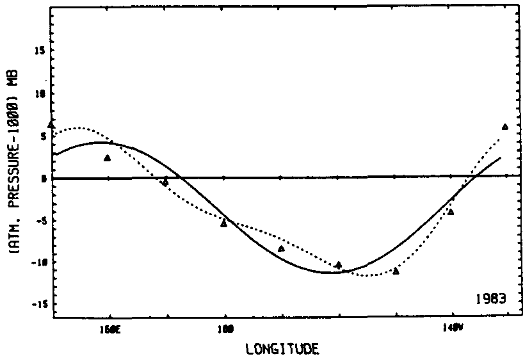


Fig 8 Same as Fig 7. Winter 1958

Fig 9 Same as Fig 7. Winter 1983



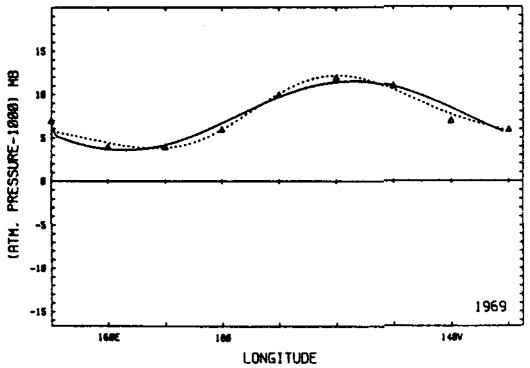


Fig 10 Same as Fig 7. Winter 1969

Fig 11 Same as Fig 7. Winter 1971

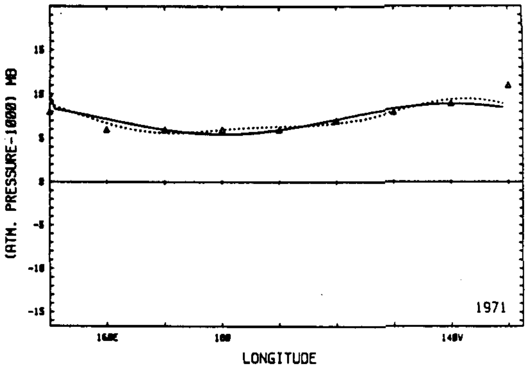
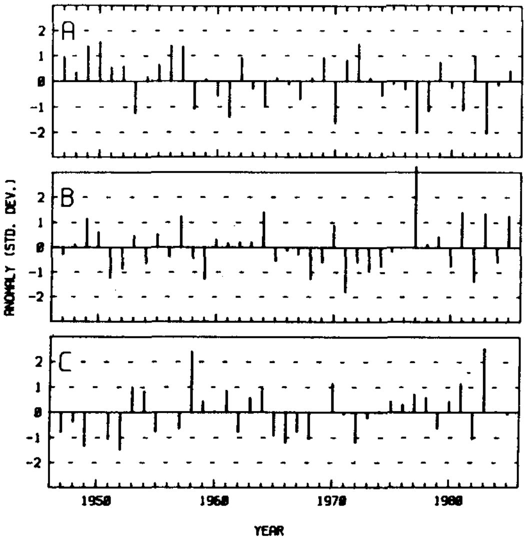


Fig 12 Normalized anomalies, winters 1947 to 85, of harmonic constants: panel A, the mean pressure at 50°N, A (0) / 2; panel B, the amplitude, C (1); panel C, the phase angle, P (1). (See text and Tab 2 for details)



The Strength of the Wind Systems

Normally the section of the N Pacific under the influence of the northerly wind component is small. This influence may not be small, however, during years when the AL is displaced eastward of its normal position. In the transfer of energy from ocean to atmosphere through evaporation, not only is the magnitude of the wind speed important, but also the area of ocean under the influence of the wind. Also in biological considerations, the area as well as the intensity of a wind system may be important. An index that reflects both intensity of the wind and area of influence can be obtained by multiplying the pressure gradient by an index of the area. For purposes of this exploratory investigation, I used as the area index the square of the distance between the same high and low pressures as were used to calculate the gradient. The gradient times area index, the "strength" of the wind system, for the northerly and southerly wind components is listed in the last two columns of Tab 3 labeled S1 and S2. The anomalies of the strength are plotted in Fig 14.

Fig 14A shows that the strength of the wind system W of the AL was near or slightly below average (less than one standard deviation) during most winters. During seven years this index was near one or more standard deviations higher than average. The highest anomalies of more than two and four standard deviations occurred during 1958 and 1983, respectively. During these years the AL was displaced to the E of its normal position and in most of the same years the pressure gradient was higher also.

Fig 14B shows that the strength of the wind system E of the AL was weakest during 1958 and 1983. The strength of this system can also be weaker than average when the amplitude in the pressure distribution at 50°N is low as it was in 1971 or when there is a blocking ridge in the central Pacific as it was in 1956 and 1969. The strength of the system was more than two standard deviations higher than the mean during 1977. During this year the amplitude of the pressure distribution at 50°N was the highest of the 39 winters shown.

Discussion

From this exploratory investigation it is clear that characteristics of winter sea level atmospheric pressure distributions over the mid-latitude N Pacific can be quantified in terms of wind indices. These indices, in turn, can be used to identify years with anomalous pressure distributions. One method of deriving indices involves fitting a sinusoid to the sea level pressure distribution along 50°N. This is an elegant method because only three constants are required to quantify the distribution (Tab 2). The

Year	L1	G1	L2	G2	G3	X (2)	S1	S2
1111	707	-2.83	4242	2.59	-5.64	170	-1.41	46.67
1947	707	-1.41	4242	2.83	-4.54	170	-0.71	50.91
1948	707	-4.24	4242	3.54	-6.54	170	-2.12	63.64
1949	707	-1.41	4242	3.30	-6.00	170	-0.71	59.39
1950	0	.00	4949	1.82	-5.09	160	.00	44.55
1951	707	-2.83	4242	1.89	-4.91	170	-1.41	33.94
1952	707	-1.41	4242	1.65	-5.64	170	-0.71	29.70
1953	2121	-3.30	2828	4.95	-8.54	190	-14.85	39.60
1954	1414	-2.12	3535	2.55	-5.27	180	-4.24	31.82
1955	707	-2.83	4242	3.30	-6.18	170	-1.41	59.39
1956	0	-2.83	4949	0.81	-3.27	160	.00	19.80
1957	707	-5.66	4242	3.30	-4.91	170	-2.83	59.39
1958	3535	-2.26	1414	6.36	-7.64	210	-28.28	12.73
1959	707	-2.83	4242	2.59	-6.18	170	-1.41	46.67
1960	1414	-2.12	3535	4.53	-7.64	180	-4.24	56.57
1961	1767	-2.26	3181	5.03	-7.64	185	-7.07	50.91
1962	707	-2.83	4242	3.06	-4.36	170	-1.41	55.15
1963	1767	-1.70	3181	5.34	-4.73	185	-5.30	54.09
1964	2121	-3.77	2828	7.07	-8.73	190	-16.97	56.57
1965	707	-1.41	4242	2.59	-5.64	170	-0.71	46.67
1966	707	-1.41	4242	2.83	-7.64	170	-0.71	50.91
1967	707	-2.83	4242	3.30	-7.64	170	-1.41	59.39
1968	707	.00	4242	2.36	-5.27	170	.00	42.42
1969	353	.00	4595	0.44	-5.09	165	.00	9.19
1970	2121	-3.30	2828	6.36	-8.73	190	-14.85	50.91
1971	1767	.00	3181	1.57	-3.27	185	.00	15.91
1972	707	-2.83	4242	1.65	-4.36	170	-1.41	29.70
1973	707	-1.41	4242	2.36	-6.73	170	-0.71	42.42
1974	707	-1.41	4242	2.83	-5.45	170	-0.71	50.91
1975	1414	-2.83	3535	3.39	-6.54	180	-5.66	42.42
1976	1414	-1.41	3535	4.24	-6.54	180	-2.83	53.03
1977	1767	-5.66	3181	8.80	-10.18	185	-17.68	89.09
1978	1414	-3.53	3535	3.96	-7.82	180	-7.07	49.49
1979	707	-2.83	4242	3.30	-6.36	170	-1.41	59.39
1980	707	-2.83	4242	2.59	-5.82	170	-1.41	46.67
1981	2121	-5.18	2828	7.07	-7.82	190	-23.33	56.57
1982	707	.00	4242	1.41	-4.18	170	.00	25.45
1983	3535	-3.96	1414	11.31	-10.00	210	-49.49	22.63
1984	707	.00	4242	3.54	-5.45	170	.00	63.64
1985	1414	-2.83	3535	5.37	-5.82	180	-5.66	67.17

Tab 3 Indices of winter wind systems. X (2) is the longitude of lowest pressure at 50°N. L1 and L2 are distances in km between X (2) and 160°E and X (2) and 130°W. G1, G2, and G3 are the pressure gradients in 1000 mb/km, W, E, and S of the AL (see text). S1 and S2 are indices of the strength of the wind systems in .001 mb.km, W and E of the AL (see text). X (2) < 180 is E, X (2) > 180 is 360-X (2) W. Year 1111 is the 1947-72 mean winter

sinusoidal fit is a first order approximation and not good near the W and E sides of the latitude band analysed. Nevertheless, the amplitude of the sinusoid is a good index of the magnitude of the pressure variation or "intensity" of the AL and therefore also of the associated wind systems. Important also is the year-to-year variation in the longitude of the AL. This characteristic is reflected by the phase angle of the sinusoid. The major anomalies in the longitude of minimum pressure such as occurred in 1958 and 1983, are indicated without uncertainty by the phase angle but there is uncertainty, particularly in the magnitude of the phase angle anomaly, when displacements are in the range of one standard deviation or less.

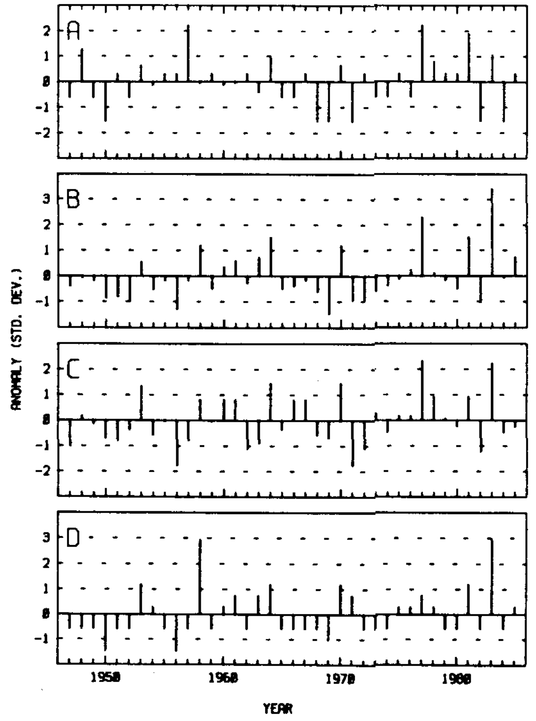
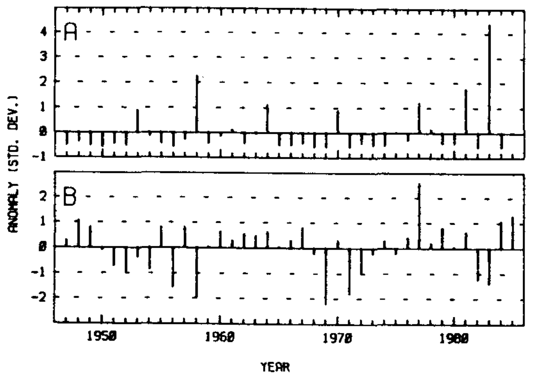


Fig 13 Normalized anomalies, winters 1947 to 85, of pressure gradients, panel A, between 160°E and AL at 50°N; panel B, between 130°W and AL at 50°N; panel C, between 25° and 50°N at longitude of the AL. Panel D, normalised anomalies of the longitude of the AL. (See text and Tab 3)

Fig 14 Normalized anomalies, winters 1947 to 85, of the strength index: panel A, wind system W of the AL; panel B, wind system E of the AL. (See text and Tab 3)



The second harmonic in the harmonic analysis materially improves the fit, particularly in terms of the longitude of minimum pressure. However, there are now five constants required to describe the distribution and the advantage of simplicity is lost.

A more direct way to obtain indices of the wind systems that are associated with the large-scale pressure distributions is to calculate the pressure gradient directly from the grid values of the pressure field. Only five variables are necessary to calculate six indices: (1) the longitude and (2) the pressure of the lowest pressure along lat. 50°N, the pressures at (3) the W and (4) the E reference positions, and (5) the pressure of the subtropical ridge at lat. 25°N and the longitude of minimum pressure at lat. 50°N. The indices are the longitude of the AL, the overall pressure gradients associated with the northerly and southerly wind components W and E of the AL, respectively, and of the westerly wind S of the AL (Tab 3). Additionally, there are the "strength" indices of the northerly and southerly wind systems W and E of the AL (Tab 3). These indices reflect the combination of wind intensity with area of influence of the wind systems, highlighting different aspects of the wind systems.

One shortcoming of these large-scale indices is that the detail in the zonal distribution of the gradient between the AL and the E and W boundaries is obscured. An example that may be important in some applications is the longitude of the maximum southerly wind component. A second shortcoming is that the years with a blocking ridge in the central portion of the ocean are not identifyable in the large-scale gradient analysis although these years appear as a large anomaly in the harmonic analysis.

A relatively frequent occurrence in the pressure distribution over the N Pacific is an area of high pressure over the E side of the ocean such as occurred in 1957 (Fig 6). This type of anomalous distribution also is not clearly reflected by the indices derived from either method. It is a simple matter, however, to calculate zonal pressure gradients between grid locations and so obtain both the longitude of highest gradient and indication of anomalous high pressure in the E N Pacific.

Modern statistical techniques and analyses of meteorological fields can be used to derive indices of the wind field that are useful in oceanographic applications. These techniques are not necessarily available to those investigating biological distributions that may be affected by large-scale anomalies in wind systems. Gridded values of monthly mean sea level pressure distributions on a finer scale than were used here are produced by meteorological services. These data are available to compute either monthly or quarterly values of the simple indices described.

El Niño and Longitude of the Aleutian Low

In his paper "Teleconnections from the equatorial Pacific" Bjerknes (1969) was the first to draw attention to the effects on the mid-latidude atmospheric circulation of the anomalously warm episodes in the central equatorial Pacific. Rowntree (1972), using a Geophysical Fluid Dynamics Laboratory model, tested and confirmed Bjerknes' hypothesis that the Aleutian low would deepen and shift eastward as a consequence of the anomalous equatorial warming. Figs 12C and 13D show that the outlier years in the eastward displacement of the AL were 1958 and 1983, the major equatorial warm episode (El Niño) years. In 1983 the AL deepened and the westerly index was more than two standard deviations above average, also. In 1958 the AL deepened and the southerly index E of the AL was more than one standard deviation above average. The westerly index, however, was less than one standard deviation above average (Fig 13C). The Bjerknes hypothesis holds during most of the lesser El Niño years as defined by Quinn et al. (1978) but there are exceptions. For example, the 1972 event was not reflected by the mid-latitude indices. In 1981, according to the indices shown in Fig 13, the AL was deeper and displaced eastward and the westerly and southerly indices were more than one standard deviation above average, but there was no El Niño. In 1977 when the AL was the deepest, the eastward displacement was less than one standard deviation above average.

Anomalous Wind Systems and Oceanographic Implications

An interesting result of the 1976/1977 NORPAX satellite tracked drift buoy experiment is shown in Fig 15 (McNally 1981). The buoy displacements from the beginning to the end of the month when plotted on the mean sea level atmospheric pressure charts for December 1976, January, February, and March 1977, show that the drift was parallel to the isobars and changed with the changing isobar pattern. From this result one can infer that the surface currents would be different and also anomalous during the years with anomalous pressure distribution patterns. McNally (1981) calculated that a certain wind and drift vector relationship holds for winds above 2.5 m/s. One can conclude from this result that there may be a threshold geostrophic wind above which the buoy displacement and isobar relationship is as during the drifter experiment.

Fig 16 shows the drifting buoy pattern when wind speeds are less than 2.5 m/s as during the summer. Such a variable pattern is also to be expected during the winter months when atmospheric pressure gradients are small. Example years are 1971, those with a blocking ridge in the central Pacific, and those when high pressure dominates the E side of the ocean.

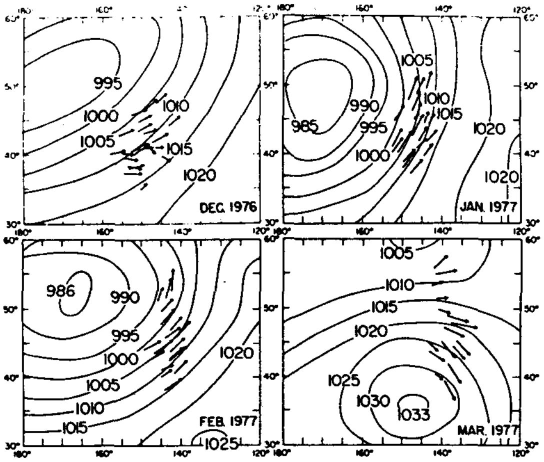
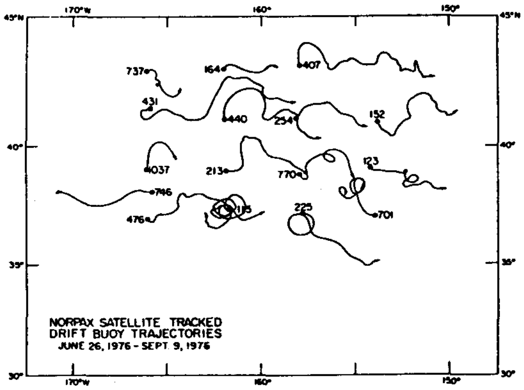


Fig 15 Drifter positions superimposed on monthly mean sea level pressure charts. The arrows indicate monthly displacements of individual drifters (McNally 1981)

The NORPAX drift buoy experiment took place during the winter of 1977 when pressure gradients were the highest in the 39 years examined here. There may have been other unique aspects to the circulation during this winter that caused the relationship between monthly isobar patterns and drifter direction. There is an element of uncertainty, therefore, when the drifter results are extrapolated to other years. This uncertainty can be resolved with additional drifter experiments.

Anomalous large-scale wind systems also affect other oceanographic processes, particularly those that change the sea surface temperature. The

Fig 16 Trajectories of drifters for the period June 1976 through September 1976. Solid dots indicate initial positions; solid triangles indicate last position (McNally 1981)



effects on the sea surface temperature of some of these such as those produced by the mixing of the surface water or by evaporation are difficult to determine with the data available here. The effect of advection on the sea surface temperature, however, is direct. During the winter sea surface isotherms, other than near the E and W boundaries, are approximately zonal in direction and therefore advection is most sensitive to changes in the meridional component of the wind driven surface current. The large-scale anomalies in the magnitude and direction of the pressure gradients, particularly E and W of the AL are expected to produce significant anomalies in the sea surface temperature distribution.

Anomalous Wind Systems and Climate Implications

Anomalous evaporation rates affect the atmosphere as well as the ocean because the atmosphere's primary source of energy is that latent in water vapor. During most years the longitude of the AL is in the W Pacific (Tab 3 and Fig 13D). This probably means that over a major portion of the mid-latitude N Pacific anomalies in evaporation rates are not so much a function of the difference between the saturation vapor pressure at the sea surface and the vapor pressure of the air as of anomalies in the wind speed. This situation changes, however, when the AL is displaced eastward and a relatively larger section of the latitude band comes under the influence of an air mass with a lower vapor pressure and, consequently, a higher vapor pressure difference. Although the increase in evaporation rate may be small, the increased area over which the higher evaporation rate takes place can significantly increase the total gain of energy of the atmosphere. The strength index (Fig 14) reflects this effect which is most pronounced during the El Niño years, such as 1958 and 1983. This conjecture must be verified, of course, by calculating the total evaporation over the appropriate areas of the mid-latitude N Pacific.

Anomalous Wind Systems and Biological Implications

The linkages between environmental anomalies and biological processes and distributions are most difficult to establish. Bakun and Parrish (1980) have described the difficulties and the progress that has been made in E boundary current regions. These difficulties equally apply to the open ocean regions. In terms of large-scale systems, Parrish, Nelson, and Bakun (1981) have related reproductive strategies of coastal fisheries species to major features in surface transport. For example, in the mid-latitude coastal region of the E N Pacific coastal fish species having pelagic larvae tend to spawn during winter when the surface wind drift is generally directed toward the coast. The winds responsible for the onshore drift are a part of the large-scale winter wind system and therefore also affected by its anomalies. Anomalies affecting the onshore drift are those occurring when high pressure dominates the E N Pacific and the maximum zonal pressure gradient has shifted westward. The onshore drift is also affected by the magnitude of the gradient associated with an eastward shift of the AL into the Gulf of Alaska.

In the proceedings of a meeting on the effects of the 1982/83 El Niño on the E subarctic Pacific (Wooster and Fluharty 1985) papers describe and attempt to link the environmental anomalies with biological distributions. It would be interesting to examine in the same manner years with a blocking ridge in the central Pacific (1950, 1956, 1969) or those with high pressure in the E Pacific such as 1957.

In the central Pacific little is known about the effect of the large-scale environmental winter anomalies on biological processes. Do these anomalies affect the subsequent spring bloom? Is the distribution and abundance of salmon and albacore forage affected? Do the inferred anomalies in the wind driven circulation affect the movement, distribution, and migration of salmon and albacore? What are the effects of anomalies in the size and location of the highest pressure gradients E of the AL?

There are wind related indices of importance to biological processes that cannot be derived from large-scale mean pressure distributions. A turbulent mixing energy indexc is an example.

Conclusion

The objective of this study has been to identify quantitatively various characteristics of the large (thousands of km) scale pressure systems that are obvious from inspection of monthly or quarterly charts and no attempt has been made to discuss their meteorological significance. J. Namias, a pioneer in extended weather forecasting, was the first to study associations in the anomalies of N Pacific sea surface temperature, atmospheric pressure and climate and has published numerous articles on the subject in meteorological journals.

There are limits to the information that can be extracted from large-scale pressure distributions. However, indices are still needed and can be derived, of the longitude and width of highest gradients E of the AL and of the anomalous condition when high pressure dominates the E N Pacific.

Only a few anomalous pressure distributions have been identified: 1. The zonal pressure gradient is anomalously low as in 1971, or high as in 1977. 2. The AL is displaced into the E N Pacific. 3. There is a blocking ridge in the central Pacific as in 1956. 4. High pressure dominates the E Pacific as in 1957. 5. Lowest pressure is shifted westward. This shift may be associated with either condition 3 or 4. Indices of these large-scale anomalies may be used to classify the effects of wind forcing on ocean processes and circulation and on biological processes and distributions. Eventually it may be possible to predict the oceanographic consequences of the large-scale anomalies.

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