THE USE OF A COMMON REFERENCE PERIOD FOR EVALUATING CLIMATIC COHERENCE IN TEMPERATURE AND SALINITY RECORDS FROM ALASKA TO CALIFORNIA

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INTRODUCTION

One of the major aims of the California Cooperative Oceanic Fisheries Investigations has been to correlate fluctuations in fish catches with fluctuations in the oceanic environment. Toward this end, it has been necessary to evaluate the scale of variability of ocean temperature and salinity for periods of a month, season, year, decade and longer.

The area of interest has expanded from Southern California waters to include the area from Cape San Lucas to the Gulf of Alaska. When the widescale warming in the eastern North Pacific took place between 1957 and 1959, our horizons were again expanded to include the western North Pacific in search of cause and effect relationships which might explain these large-scale changes (Sette and Isaacs, 1960).

The ultimate aim in studying climatic records is to make prediction of climatic events possible.

One of the most useful groups of data which have shed light on the climatic changes of the ocean is that of the daily temperature and salinity observations at shore stations between La Jolla, California, and Yakutat, Alaska. (U.S. Coast and Geodetic Survey, 1956, 1958; SIO Ref. 60-30, 1960; Fish. Res. Bd. of Canada, 1947-1960.)

There are two important reasons why these shore station data are so valuable: First, there is a very high positive correlation between air temperatures at adjacent meterological stations and sea-surface temperatures at shore stations (Hubbs, 1948; Tully, 1938); Second, it has been possible to correlate sea-surface temperature anomalies up to 150 miles offshore with sea-surface temperature anomalies at nearby shore stations, and thus indirectly with air temperatures along the Pacific coast (Reid, Roden, Wyllie, 1958; Robinson, 1957).

Therefore it has been possible to extrapolate physical conditions in the California Current region for periods where observations in the open ocean were unavailable, and to use these probable values to extend our understanding of the relation between the occurrence and behavior of marine organisms with changes in their physical environment.

There are 24 shore stations along the Pacific coast with almost continuous data. The periods over which the data have been taken, however, vary from 13 years at Santa Monica to 44 years at La Jolla. While it may be preferable to use the entire length of record when studying variability at individual stations, it is impossible to properly evaluate differences among stations without using a common base of reference.

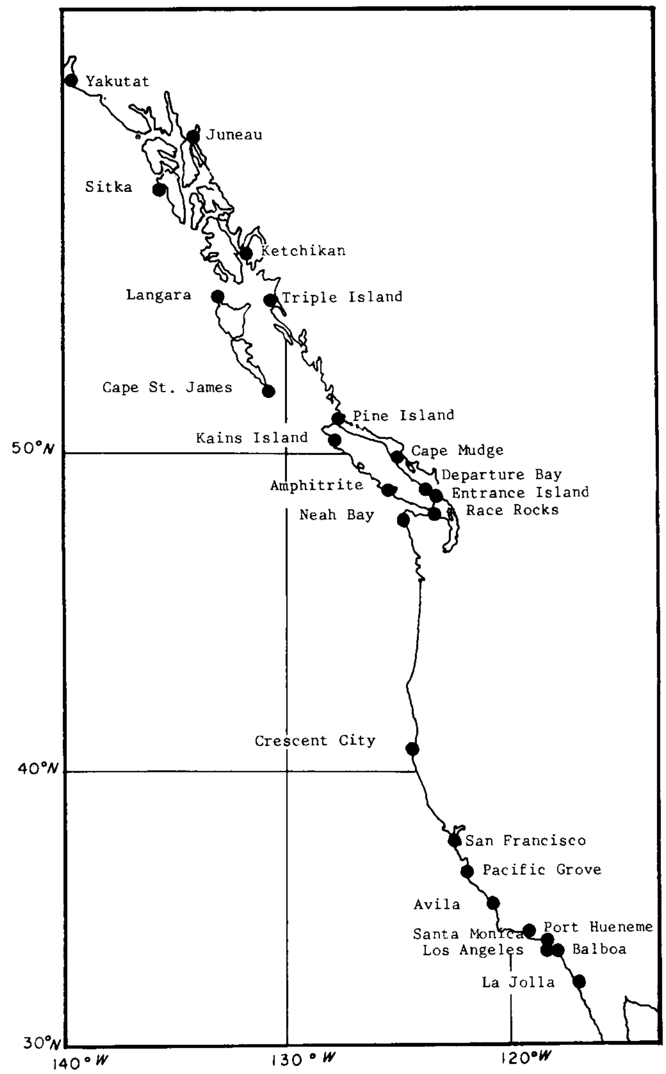

FIGURE 1. Shore Station Locations.

Temperature and salinity anomaly charts were therefore prepared, using means from the period 1949-1958 as a common reference base, for twenty-four Canadian and American shore stations whose locations are shown in figure 1. Before the publication of the charts, Japanese, Canadian and American oceanographers agreed to use the period 1950-1959 as a common base of reference, not only for shore stations' data but also for open ocean data in the North Pacific. Therefore, in order to make the charts which had already been completed more useful, and to relate

[1] Contribution from the Scripps Institution of Oceanography.

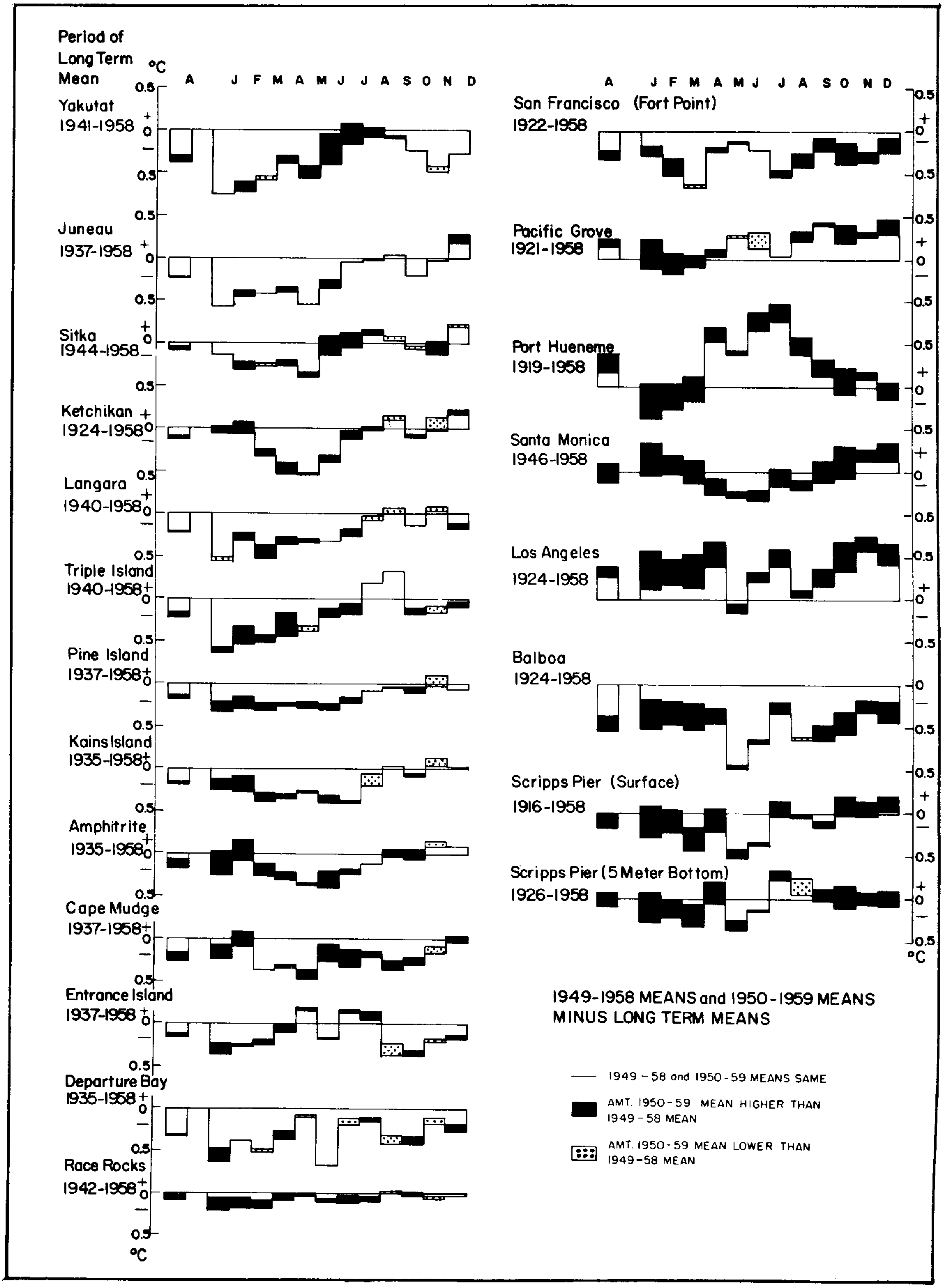

FIGURE 2. Relation of 10-year temperdture means to long period means.

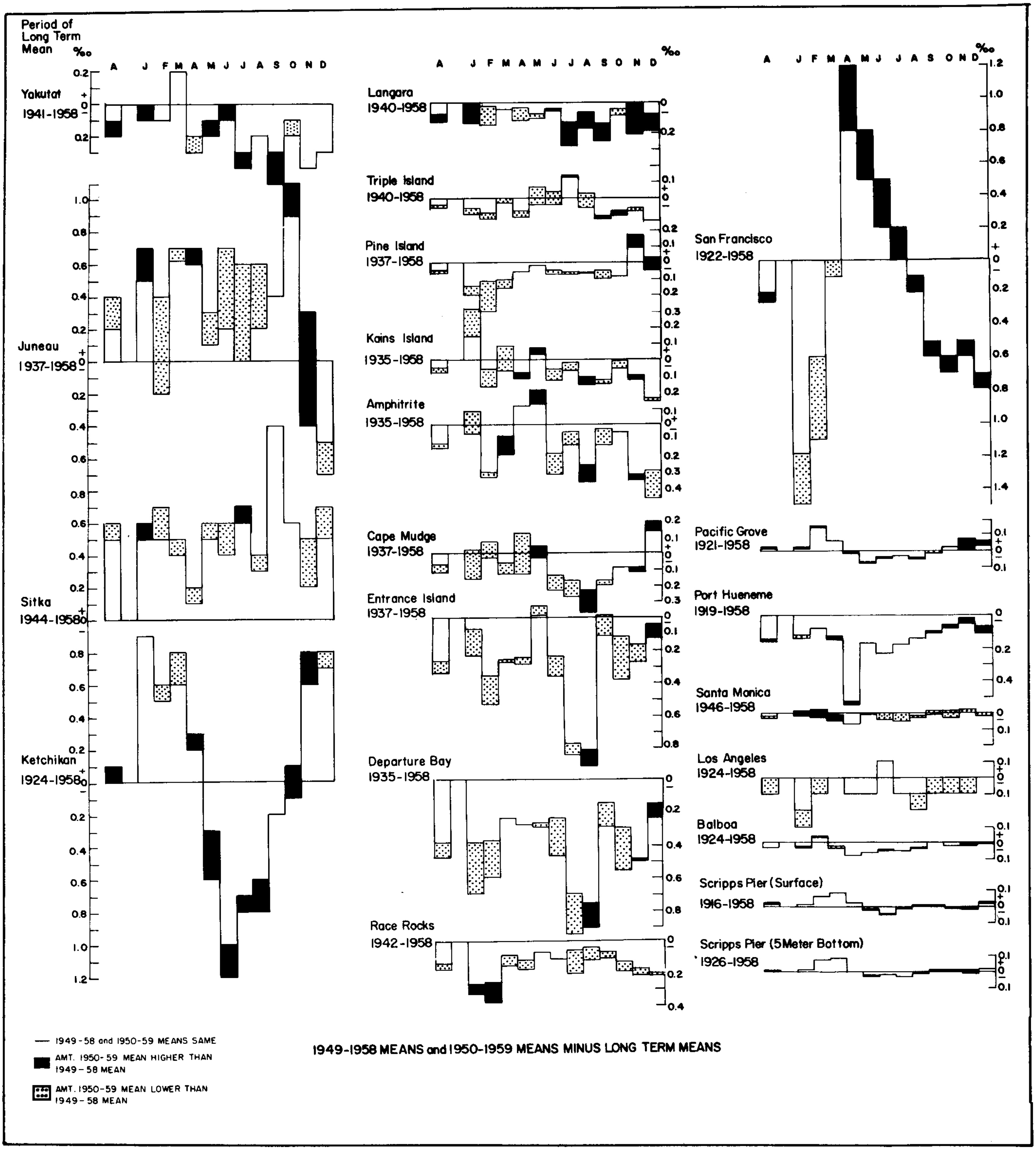

FIGURE 3. Relation of 10-year salinity means to long period means.

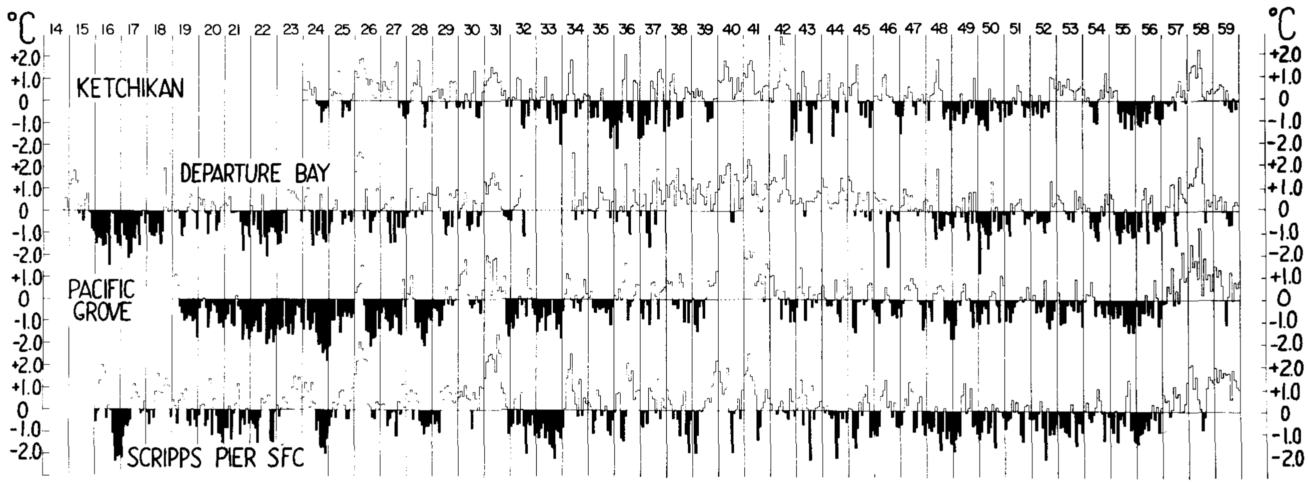

FIGURE 4. Chronological Temperature Anomalies based on 1950-1959 reference period.

them to the 1950-1959 reference period, changes and additions were made in the charts prior to publication, permitting an evaluation of the effect of altering the base period, as well as meeting the original objectives.

The relation of the 1949-1958 and the 1950-1959 ten-year monthly and annual means to each other and to the long-term means for each of twenty stations is shown for temperature in figure 2, and for salinity in figure 3. Four stations were omitted because data were incomplete for the period of reference.

The chronological temperature anomaly charts for all 20 stations were not redrawn based on the 1950-1959 reference period. Instead, only four key stations, each typical of the nearby area, were redrawn. Stations selected were Ketchikan, Alaska; Departure Bay, Vancouver Island, B.C.; Pacific Grove and La Jolla, California. Figure 4 presents the temperature anomalies based on the 1950-1959 reference period for these stations.

The chronological temperature and salinity charts based on the 1949-1958 reference base and anomaly charts for individual stations plotted by months for all years are included in SIO Ref. 60-30 (1960). Both 1949-1958 and 1950-1959 reference period means are given on the individual station charts.

The following points will be discussed in reference to the anomaly charts published in SIO Ref. 60-30 (1960) and to figures 2, 3 and 4. Station-to-station coherence, for the purpose of this discussion, is defined as the agreement in sign of temperature (or salinity) anomalies when computed from the same base of reference. 1. Sampling error for monthly temperature and salinity means and their respective anomalies. 2. The relation of the 1949-1958 and the 1950-1959 reference periods to each other and to the long-term means at each station. 3. The extent of station-to-station temperature coherence; visible evidence of coherence; statistical evidence of coherence; the relation of incidence of coherence to time of year; comparison of coherence computed for 20 stations with that computed for 4 key stations; prediction of coherence; and relation of magnitude of anomalies to incidence of coherence. 4. Evidence of persistence of higher- or lower-than average temperatures, and the relation of persistence to coherence. 5. Salinity coherence as shown in SIO Ref. 60-30 (1960). 6. The relation of temperature anomalies to salinity anomalies.

DISCUSSION

Sampling error in shore station data: In order to evaluate the reliability of the monthly temperature and salinity means and the anomalies derived from them at the shore stations, it is necessary to examine variability and the standard error of the means (σ_m). The standard deviations of temperature at shore stations within single months vary from 0.2°C. in winter to 2.0°C. in summer and σ_m from 0.04°C. to 0.37°C.

For the Southern California stations the standard deviations of salinity within individual months are very low, because there is little rainfall and runoff. Here σ_m is usually less than $0.01^0/_{00}$. However, at the Alaskan and British Columbian stations there is excess precipitation and runoff with resulting extreme ranges in salinity. San Francisco falls in this class also, because of the tremendous river runoff which empties into San Francisco Bay. Sample standard deviations of salinity for individual months at these northern stations range from $0.16^0/_{00}$ to $5.00^0/_{00}$. The standard error of the means, based on these values, ranges from $0.03^0/_{00}$ to $0.91^0/_{00}$. At both northern and southern stations the anomalies from month to month and from year to year exceed the possible sampling error.

The relation between the 1949-1958 and the 1950-1959 reference periods to each other and to the long-term means at each station is shown in figures 2 and 3. For both figures base period anomalies were computed at each station by subtracting the long-period means from the 1949-1958 monthly and annual means, and also from the 1950-1959 means.

Relation between ten-year and long-term means: The 1949-1958 temperature means (Fig. 2) were lower than the long-term means at three of the northern stations in all months. At other northern stations the period from July to December included several positive anomalies. The negative anomalies for the same months were smaller than in the first six months. At three southern stations—Pacific Grove, Port Hueneme and Los Angeles—the anomalies were predominantly positive, while at the remaining southern stations the anomalies were predominantly negative. There are marked differences between anomalies at Port Hueneme, Santa Monica, Los Angeles and Balboa. The long-period record at the latter two stations covers the same years, so it would appear that the marked differences at these two nearby stations are due to local effects, which may be the construction of Los Angeles harbor and/or the modifications to the harbor at Newport. On the other hand, there may have been real differences in the circulation at these two localities.

The 1950-1959 means are, in general, higher than the 1949-1958 means, but they, too, are lower than the long-term means. These differences are greater at the southern stations than at the northern stations. With the exception of Port Hueneme and Los Angeles, the 1950-1959 means agree more closely with the long-term means than did the 1949-1958 means.

It is important to note that the differences between the ten-year temperature means and the long-term means never exceed 0.5°C.[2] Thus, the change in the common reference period principally effects those months and years with small deviations. The spectacularly different years (e.g.—1931, 1933, 1941, 1958) would still stand out regardless of the base of reference.

Unlike the relatively systematic temperature relation discussed above, the salinity relation between the ten-year reference period means and the long-period means is random and confused. Figure 3 shows that the patterns of the anomalies, even for stations where long-term records are of the same length, seem to have little relation to each other. Port Hueneme, generally little affected by runoff, had such low salinities following a very heavy rainfall in April, 1958, that the 1949-1958 April mean salinity was very much lower than the long-term mean. The ten-year mean is so low, in fact, that the April values in the Port Hueneme salinity anomaly charts are all positive except for 1958.

There is also a random and confused relation between the salinity means of the two ten-year periods at all stations north of and including San Francisco. For example, the 1950-1959 mean salinities are lower than the 1949-1958 means 60% of the time; however, the differences occur irregularly in time and randomly from Yakutat to San Francisco. Differences south of San Francisco are so small that no trend can be detected.

Temperature Coherence: Station-to-station coherence as defined on page 124 is visibly evident in the chronological temperature anomaly charts. The most complete evidence of station-to-station coherence is published in SIO Ref. 60-30 (1960), where both temperature and salinity chronological anomaly charts for 20 stations are available. Figure 4, based on the 1950-1959 reference period at Ketchikan, Departure Bay, Pacific Grove and La Jolla, is similar to the charts for all 20 stations based on the 1949-1958 reference period in all major features. Inspection reveals the strikingly widespread north-to-south and station-to-station agreement in the well-known warm years (1926, 1931, 1941, 1957-1959) and in the cold years (1933, 1950, 1955, 1956). Another visible climatic feature which emerges from both the temperature charts of SIO Ref. 60-30 (1960) and figure 4, is that changes from positive to negative anomalies, or vice versa, do not occur at the same time from north to south. Note, for example, that the warm period of 1957-1959 ended earlier in the north and persisted through 1959 in the south.

A quantitative expression of the station-to-station coherence of temperature anomalies was obtained by determining the percentage of the total number of stations having temperature anomalies of the same sign, either positive or negative. This was done for the 20 stations used in S10 Ref. 60-30 (1960), (Table 1) and for the four stations in figure 4 (Table 2). Note in Table 1 that the number of stations with temperature data ranges from 10 in 1935 to 20 in 1946 and subsequently, and in Table 2 that data were not collected at Pacific Grove in 1940. Percentages for 1935-1959 appear in Table 1 only where there is a 95% probability that the coherence could not have happened by chance. This requires that the sign of the anomalies must be the same at 80% of the stations when based on 10 stations, and at 70% of the stations when based on 20. The percentages in Table 2 are included for comparative purposes even though agreement at 3 out of 4 stations (75%) is not significant at the 95% probability level. Table 1, based on the larger number of stations, is, consequently, the best estimate of coherence. Bold face percentages in both tables indicate that at the majority of the stations the anomalies were positive. A —, with no percentage listed above, indicates that coherence was not statistically significant, and the monthly anomaly was positive at the majority of the stations. Blank spaces indicate the majority of monthly anomalies were negative and coherence was not statistically significant.

The effect of the shift of base reference period on the percentages of positive and negative anomalies occurs when the anomalies are small, for statistical evidence shows that 50% of the changes in the two ten-year means were 0.1°C. or less and never exceeded 0.5°C. In a previous reference to figure 2, it was noted that means for both ten-year periods were generally lower than the long-term means at most stations, although those of the 1950-1959 period were closer to the long-term mean. The use of either ten-year base reference period not only produces the expected result of nearly equal numbers of positive and negative anomalies within the individual ten-year reference periods, but also results in larger numbers of positive anomalies in the years 1935-1949. It is worth noting that there is a surprising similarity in percentages of positive monthly and annual temperature anomalies. Using the 1949-1958 base reference period, Table 1 shows that 64% of the monthly anomalies and 68% of the annual anomalies were positive at the majority

[2] 75% of the differences between the means of the two ten-year periods at the northern stations were 0.1°C. or less and exceeded 0.25°C. only twice. At the southern stations, only 27% of the differences were as small as 0.1°C. or less, and 26% exceeded 0.25°C.

TABLE 1

SIGNIFICANT PERCENTAGES OF TEMPERATURE COHERENCE BASED ON 10-20 STATIONS

No. of Stations	Year	Month 1	2	3	4	5	6	7	8	9	10	11	12	Annual Anomalies
10	1935	—	—	90			—				80	100	80	
11	1936	**82**	—	—	82	**82**	—	—	—	—	**91**	**82**	—	**82**
15	1937	73	87	**80**		—	**80**	—		**73**	**73**	**86**	**73**	—
14	1938	**86**	—	**86**	—	—	—		—	—	—			—
14	1939	**86**				—	—	—	—	—	—	**86**	**100**	—
16	1940	**100**	**100**	**94**	**94**	**94**	**75**	—	—	**94**	**94**	—	**94**	**83**
17	1941	**94**	**100**	**94**	**100**	**94**	**94**	**82**	**88**	—	**82**	**100**	**94**	**100**
18	1942	**95**	**95**	**95**	**95**	**72**	**83**	**89**	—	—	**83**			**95**
18	1943	—	**72**	**72**	**83**		—		**72**	—	**95**	**95**	**95**	**78**
19	1944	**95**	**90**	**90**	—	**74**	—		—	—	**84**	**89**	—	**84**
19	1945	**95**	**90**	**74**	—	—					—	90	79	—
20	1946	**75**	—	**70**	—	**85**	**95**	**75**		—		90	90	**70**
20	1947	70	—	**100**	**85**	**90**	**90**	**70**	—	—	**80**		90	**95**
20	1948	**85**		—		**70**	**75**	—	—			90	100	
20	1949	100	100		70	**80**	—			—	80	**70**	85	95
20	1950	100	100	70	70	100		**75**		—			—	80
20	1951	—		85	—			**80**	—		—	—	80	
20	1952				75		95	80	90	95	**90**	—	**70**	85
20	1953	**90**	**75**	—	—			**80**		—	—	**70**	—	**70**
20	1954	**100**	**85**	**80**	70	75				—		**80**	—	—
20	1955	**70**	**70**	—	85	90	95	95	75	90	100	100	100	100
20	1956	80	90	100	90	70	90	80		80	75	100	80	100
20	1957			—		**75**	**85**	**80**	**75**	**90**	**95**	**95**	**90**	**95**
20	1958	**100**	**100**	**100**	**100**	**100**	**90**	**70**	**85**	**75**	—	—	**85**	**100**
20	1959	**90**	**95**	**95**	**100**	**85**	**85**	**90**	—	—	**75**		**75**	**95**
No. of years	sig.	20	15	17	14	16	13	13	6	7	15	16	18	17

Bold type—Positive anomalies at majority of stations—percentage significant.
Dash—Positive anomalies at majority of stations—percentage not significant.
Light type—Negative anomalies at majority of stations—percentage significant.
Blank—Negative anomalies at majority of stations—percentage not significant.

TABLE 2

PERCENTAGE OF TEMPERATURE COHERENCE BASED ON FOUR KEY STATIONS

No. of Stations	Year	Month 1	2	3	4	5	6	7	8	9	10	11	12	Annual Anomalies
4	1935	**100**	**75**	100	100			—	75		75	100	75	75
4	1936		75		75	**75**	**75**	75	75		**100**	**100**	**75**	**75**
4	1937	100	75	75	100	75	**100**	**100**	75	**75**	**75**	**100**	**75**	
4	1938	**75**	**75**	**100**	—	**75**	75		**75**	**75**	—	—	—	**75**
4	1939	**100**	—	—	**75**	—	**75**	**75**	**75**	**75**	**75**	**100**	**100**	**75**
3	1940	**100**	**100**	**100**	**100**	**100**	—			**100**	**100**	—	**100**	**100**
4	1941	**100**	**100**	**100**	**100**	**100**	**100**	**75**	**75**	**75**	**75**	**100**	**100**	**100**
4	1942	**100**		**100**	**75**	**100**	**75**	**75**	—	**75**	**75**		75	**75**
4	1943		**100**	**75**	**75**	—	**75**					**100**	**100**	**75**
4	1944	**100**	**75**	**75**	—	—	75		75	—	**75**	**75**	75	**75**
4	1945	**100**	**100**	—	75	—		75		75	**100**	75	75	**75**
4	1946	—	—	—	—	**75**	**100**	**75**	—	—	75	100	100	75
4	1947	75	75	**100**	**100**	**100**	**100**			—	**75**	—	75	**75**
4	1948	—	100	—	—	**75**	**75**	—	—	75	100	100	100	75
4	1949	100	100	75	75	**75**	**75**	75		**75**	100	—	100	100
4	1950	100	100	100	75	100	—	**75**	—		100	75	75	100
4	1951	100	100	100		75		—	**75**	75			75	100
4	1952	75	75	75	100	—	100	75	75	100	—	—	—	75
4	1953	**75**	—	—	—	75	75	—	75	**75**	—	—	—	—
4	1954	**75**	**75**	**75**	75	75	75	75	—	—	75	—	—	75
4	1955	—	—	—	75	100	100	100		75	100	100	100	100
4	1956	100	100	100	75		100	75		—		100	75	100
4	1957	75	75	**75**		**75**	**75**		—	**75**	**100**	**100**	**75**	**100**
4	1958	**100**	**100**	**100**	**100**	**100**	**100**	**75**	**75**	**75**	**100**	**100**	**100**	**100**
4	1959	**100**	**100**	**100**	**100**	—		**75**		75	**100**	**75**	**75**	**100**
No. of years	100%	14	11	11	8	7	8	2	0	2	10	12	9	10
No. of years	75-100%	20	20	18	18	17	19	15	11	16	19	16	21	23

Bold type—Positive anomalies at majority of stations—percentage significant.
Dash—Positive anomalies at majority of stations—percentage not significant.
Light type—Negative anomalies at majority of stations—percentage significant.
Blank—Negative anomalies at majority of stations—percentage not significant.

of the stations. Table 2, using the 1950-1959 base reference period, shows 57% positive monthly anomalies and 56% positive annual anomalies.

The bottom row of numbers in Table 1 represents the total number of years in which significant coherence occurs in a given month; hence, coherence is best in December and January, and poorest in August and September. Turning to Table 2, the row of figures next to the bottom represents the number of years in which there is complete agreement in the sign of the anomalies at all stations. The results are too conservative, so the second row of figures is given for 75-100% coherence. Now the results are too liberal an estimate of coherence, pointing up the difficulty in dealing statistically with only four stations.

One of the major purposes in studying long-period records is to develop relations which will make the prediction of climatic events possible. In Table 1, 1935-1959 station-to-station coherence was significant at the 95% probability level in 170 of the 300 months (57%). However, analysis of data from 20 stations is time consuming and data are not received immediately from all stations. Therefore, a detailed comparison was made of the results using all 20 stations and those based on four key stations in order to determine how good an estimate of coherence could be made on the basis of the four stations alone (Table 3).

Table 3's consideration of four key station coherence at 100%, 75%, and 50%, shows the extent to which accurate coastwise prediction would have failed. With four-out-of-four (100%) coherence, prediction coastwise would have been right in 82 out of 94 months; however, such a conservative prediction would have failed to anticipate 88 additional cases of coastwise coherence which actually occurred. With three-out-of-four (75%) coherence, predictions for coastwise coherence would have been correct for only half of the time, or 58 months. Fifteen of the remaining months would have been assigned incorrect signs for their respective anomalies: during these months anomaly signs at the majority of the stations were actually opposite those at three of the four key stations. With two-out-of-four (50%) coherence and the probability of any coherence reduced to chance, there were 90 instances where no coastwise coherence would have been predicted; yet, in 28 of these months significant coherence did occur among the 20 stations.

TABLE 3

COMPARISON OF COHERENCE COMPUTED FOR 10-20 STATIONS AND THAT COMPUTED FOR 4 STATIONS

Coherence 4 Stations	Coherence All Stations	No. Monthly Anomalies	Sub-Total	No. Annual Anomalies
100%	Significant, same sign	82		9
100%	Not significant, same sign	11		1
100%	Not significant, diff. sign	1	94	
75%	Significant, same sign	58		6
75%	Not significant, same sign	43		5
75%	Significant, diff. sign	1		1
75%	Not significant, diff. sign	14	116	1
50%	Significant	29		1
50%	Not significant	61	90	1
	Totals	300	300	25

Two questions arise concerning the absence of any significant coastwise coherence during about half of the months of the past 25 years. Are the northern and southern parts of our coasts in different climatic regimes? Or, recognizing that there are local effects which differentiate stations near the more typical four key stations, is the conspicuous absence of coherence related to the size of anomalies during those periods when local effects might be masking widespread climatic effects?

TABLE 4

AGREEMENT IN SIGN OF ANOMALIES AT FOUR KEY STATIONS

Coherence 4 Stations		No. Monthly Anomalies	Sub-Total	No. Annual Anomalies
100%		94	94	10
75%	La Jolla differed	35		3
75%	Ketchikan differed	28		8
75%	Departure Bay differed	28		1
75%	Pacific Grove differed	25	116	1
50%	Ketchikan-Departure Bay alike Pacific Grove-La Jolla alike	45		2
50%	Ketchikan-Pacific Grove alike Departure Bay-La Jolla alike	24		0
50%	Ketchikan-La Jolla alike Departure Bay-Pacific Grove alike	21	90	0
	Totals	300	300	25

For purposes of examining the first question, a tabulation of the precise way in which coherence occurred among the four stations was constructed (Table 4). In 31% of the months, all four stations had the same anomaly sign. In 39% of the months, one of the four had a different sign. Though La Jolla differed most frequently, the differences, percentagewise, were not significant among the four stations. In the remaining 30% of the months, there is coherence between different pairs of stations. The two northern stations (Ketchikan and Departure Bay) have similar but opposite anomaly signs to those of the two southern stations (Pacific Grove and La Jolla), twice as frequently as either of the other two possible combinations. (Note: Table 7 gives additional evidence of somewhat higher frequency of coherence when we separate the complete group of 20 stations into northern and southern components.) It is of utmost importance to note, however, that coherence among all four stations results twice again as frequently as when the northern pair is not coherent with the southern pair. The previously noted north to south time lag in climatic events partly accounts for those periods which show no coherence.

Relation of magnitude of anomalies to coherence: In order to investigate the second question, the mean absolute value of anomalies for all 20 stations, disregarding their signs, was computed. Correlograms (Fig. 5) were constructed for the relationship between the annual, February and August mean absolute anomalies and coherence at the stations cov-

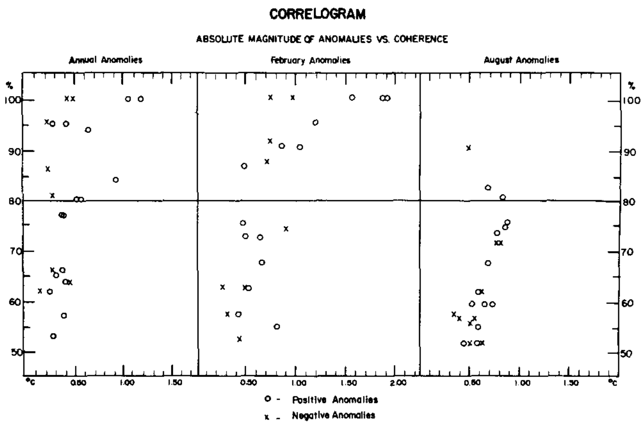

FIGURE 5. Correlogram. Absolute Magnitude of Anamolies vs. Coherence.

ered in Table 1. Regretfully, the correlograms failed to demonstrate any linear relationship between the anomalies and the coherence. It was of interest to note, however, that when the magnitude of the mean anomaly was greater than 1.0°C., the coherence was statistically significant. Unfortunately, this occurred only twice in the past 25 years for annual anomalies, five times for February anomalies, and not at all for August, the largest mean absolute anomaly for August being only 0.85°C.

Because two of the four key stations are located at major scientific institutions and would be first to receive notice of major climatic changes, La Jolla and Departure Bay records were examined further for a possible relationship of the magnitude of their respective monthly anomalies to the incidence of 100% coherence at all four stations (Tables 5 and 6). Investigation disclosed that anomalies at La Jolla and Departure Bay were greater than 1.0°C. during 37% of those months with 100% coherence at all four sta-

TABLE 5

RELATIONSHIP OF MAGNITUDE OF MONTHLY TEMPERATURE ANOMALIES AT LA JOLLA TO COHERENCE AT FOUR KEY STATIONS

(La Jolla Monthly Anomalies)

Size of Anomalies	No. monthly Anomalies	Sub-Total	No. Months Coherence was 100%	Sub-Total
0.0°C-1.0°C	215	215	62	62
1.0° -1.5°	53		18	
1.6° -2.0°	24		10	
2.1° -2.5°	7		3	
2.6° -3.0°	1	85	1	32
Totals	300	300	94	94

TABLE 6

RELATIONSHIP OF MAGNITUDE OF MONTHLY TEMPERATURE ANOMALIES AT DEPARTURE BAY TO COHERENCE AT FOUR KEY STATIONS

(Departure Bay Monthly Anomalies)

Size of Anomalies	No. monthly Anomalies	Sub-Total	No. Months Coherence was 100%	Sub-Total
0.0°C-1.0°C	225	225	66	66
1.1° -1.5°	50		19	
1.6° -2.0°	14		4	
2.1° -2.5°	6		3	
2.6° -3.0°	4		1	
3.1° -3.5°	1	75	1	28
Totals	300	300	94	94

tions. Unfortunately, however, there was nearly as large a percentage (29%) of the months with 100% coherence at all four stations when the La Jolla and Departure Bay anomalies were 1.0°C. or less.[3] Though about one-fourth of the 300 months in the past 25 years La Jolla had anomalies greater than 1.0°C., in only 9% of those 300 months did anamolies greater than 1.0°C. concur with 100% coherence at the four key stations. The same was approximately true at Departure Bay. Therefore, if the magnitude of anomalies at either station is useful in prediction at all, it is only that they might serve to alert us to possible widespread coherence.

Persistence: The relationship of persistence to coherence, though suspected, has never been so conclusively evident as that revealed in Tables 1 and 2, figure 4, and SIO Ref. 60-30 (1960). Using auto-correlation computations, Roden and Groves (1960) had reported a significant tendency toward the persistence of temperature anomaly signs over periods of five months in an ocean area just off the Washington coast. But, Tables 1 and 2 and figure 4 show that when coherence is highly significant along the entire coast, persistence in the sign of the anomalies is apparent over even longer periods. For example, note that during the 1955-1956 period when significant coherence occurred coastwise, negative anomalies persisted for a period of 16 months without a break; and during 1957-1958, positive anomalies persisted for a period of 17 months. In fact, during the winter of 1958 there was a five-month period when positive anomalies persisted at all 20 stations. Because present records are too short, auto-correlation computation methods would fail to reveal the probabilities of reoccurrence of persistence over periods as long as 16 or 17 months.

Salinity Coherence: Coastwise station-to-station coherence in salinity anomalies was shown to be very poor in the chronological salinity charts published

[3] The fact that these percentages apply to both stations appears to be fortuitous. In less than 1% of the 300 months did both stations have anomalies greater than 1.0° C. with the same signs at the same time.

in SIO Ref. 60-30 (1960). It did not seem worthwhile to re-draw these charts on the 1950-1959 reference base even for the four key stations. Some of the features, however, are of general interest as noted below.

There is little resemblance between the northern and southern stations, but over smaller areas salinity coherence is good. For example, the southern salinity anomaly charts for La Jolla and Balboa are similar, as are the northern charts for Departure Bay and Entrance Island. Yet at three British Columbian stations, the salinity anomalies differ considerably from those for Departure Bay and Entrance Island: at Langara, Pine Island and Race Rocks, mixing is so intense and rapid that the effects of precipitation and runoff are minimized and variability from month to month and from year to year is lessened to such a point that the range of the anomalies is only slightly greater than that found for the southern stations.

Salinity coherence, extracted from the charts in SIO Ref. 60-30 (1960), is summarized in Table 7 for three periods—annual, February and August anomalies—and in three groups—all stations, northern stations

TABLE 7

NUMBER OF YEARS STATION-TO-STATION COHERENCE WAS SIGNIFICANT FOR SALINITY AND CORRESPONDING TEMPERATURE ANOMALIES

1935-1959 (25 years)

	Salinity	Temperature
ALL STATIONS (10-20)		
Annual Anomalies	7 (28%)	17 (68%)
February Anomalies	6 (24%)	15 (60%)
August Anomalies	9 (36%)	6 (24%)
NORTH STATIONS (4-13)		
Annual Anomalies	9 (36%)	15 (60%)
February Anomalies	11 (44%)	17 (68%)
August Anomalies	12 (48%)	8 (32%)
SOUTH STATIONS (5-7)		
Annual Anomalies	5 (20%)	14 (56%)
February Anomalies	6 (24%)	19 (76%)
August Anomalies	9 (36%)	8 (32%)

and southern stations. Coherence for the corresponding temperature anomalies is included in this table for contrast.

The table shows that while temperature coherence in August is least frequent, salinity coherence in August, even though it occurs only slightly oftener than August temperature coherence, is most frequent. Salinity coherence is also more frequent at the northern stations than at the southern stations or for the two combined. In the north, though coherence is almost as frequent in February as in August and though in both months it occurs more frequently than in the annual anomalies, even here salinity coherence occurs less than 50% of the time.

Relation Between Temperature and Salinity Anomalies: The temperature and salinity anomalies were examined to see if there was any relation between them during the exceptionally warm years of 1931, 1941 and 1957-1958, or during the exceptionally cold years of 1933 and 1955-1956. It was found that the warm years of 1941 and 1957-1958 were accompanied by low salinities (high precipitation) at most of the stations from north to south. This was not true, however, at the southern stations during 1931. Ketchikan, the only northern station with salinity observations at that time, showed very low salinities in the winter of 1930-1931 accompanying its higher than average temperatures.

In the cold years, there was no consistency in the temperature-salinity anomaly relationship from station to station, nor from one cold year to another.

CONCLUSIONS

The use of a common reference period has given us considerable new information about coastwise coherence in the northeastern Pacific. We can now accept station-to-station agreement or local station disagreement with more confidence. Large-scale climatic events and associated coherence were already well known, but now there is evidence that significant coastwise coherence in monthly temperature anomalies occurred during 57% of the months for the past 25 years and that coherence was highest in winter and lowest in August and September. Furthermore, in 17 of the 25 years there was significant coherence in annual temperature anomalies.

In comparison with the possibilities for coastwise prediction based on 20 stations, prediction based on four key stations would be either too conservative using the criteria of 100% coherence, or too liberal using the criteria of 75% coherence.

Coastwise, no linear relation between coherence and absolute magnitude of mean temperature anomalies exists, except for the occasional instances when mean anomalies exceeded 1.0°C. Respective mean anomalies for La Jolla and Departure Bay did exceed 1.0°C. more frequently, but these occasions were rarely concurrent with significant coastwise coherence. Thus, prediction of coherence on the basis of magnitude of anomalies at one of the major oceanographic institutions would have little probability of success.

There is evidence of a positive correlation between station-to-station coherence and persistence in time of positive and negative anomalies.

Coastwise coherence for salinity anomalies is generally poor. However, it is somewhat better in summer than in winter and also in the north if the sample stations are divided into north and south groups.

No clearcut relation exists between the signs of temperature anomalies and the signs of salinity anomalies.

Therefore, predictions of climatic events have low probability of success at present if based on statistics from past records of shore station temperatures and salinities. Namias (1960) and others are currently working toward clarification of the interaction of the atmosphere and the ocean. Perhaps when a better understanding of these physical inter-relationships is gained and when a major break-through toward successful long-range weather forecasting is made, we may be able to use these results in successfully predicting ocean temperatures.

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