# Sea Surface Temperature Anomalies in the Eastern North Pacific and Associated Wintertime Atmospheric Fluctuations over North America, 1960–73[1]

JEFFERY C. ROGERS[2]

*Great Lakes Environmental Research Laboratories, NOAA, Ann Arbor, Mich. 48104*

(Manuscript received 23 December 1975, in revised form 21 April 1976)

ABSTRACT

Data on monthly sea surface temperatures (SST) over the eastern North Pacific as well as surface pressure and 1000–500 mb layer thickness over North America during the period 1960–73 were analyzed. Factor analysis of the SST data, used to find areal patterns of anomalous SST in the ocean, revealed that while three large regions dominated the eastern North Pacific from 1960 to 1970 there was a change, possibly during 1971, resulting in the predominance of a new region called the southwestern oceanic region. At nearly the same time there was noted a reversal in the tendency toward abnormally cold winters throughout the eastern United States.

Fluctuations in pressure and thickness over North America associated with anomalous periods of warm and cold water in the original three SST cells were then analyzed. The east-central North Pacific and Gulf of Alaska regions were found to be associated with statistically significant fluctuations in pressure near the Gulf of Alaska and in thickness over west-central Canada. The southeastern oceanic region was associated with statistically significant fluctuations in pressure near the Pacific anticyclone and in thickness over a large area centered on the Arctic archipelago.

## 1. Introduction

The possibility that sea surface temperature (SST) anomalies have an effect on the development and persistence of both long- and short-term climatic fluctuations has been studied extensively. Bjerknes (1965) investigated air-sea interactions possibly present during the "Little Ice Age" from 1650 to 1850. Namias (1965, 1969, 1972) has dealt with the relationship between the North Pacific Ocean and climatic fluctuations over North America during the last two decades. He pointed out that during the period 1958–71 the winters were colder than normal over the eastern United States and warmer than normal west of the Rockies. After investigating the influence of SST anomalies on the persistence of that temperature regime, it was found that changes in the SST anomaly patterns were associated with both the onset and reversal of the temperature regime in 1958 and 1971, respectively (Namias, 1972).

While it is not yet possible to prove cause-and-effect relationships between large-scale air-sea interactions, knowledge of them is important for long-range forecasting and climatic modeling. Sawyer (1965) and Ratcliffe and Murray (1970) have either discussed or developed procedures for using SST patterns in long-range forecasts of temperature and pressure anomalies In addition, Bjerknes (1966, 1969), Namias (1971) and Rowntree (1972) have discussed the nature of meridional and downstream influences on the atmosphere by the oceans. For both modeling and forecasting it is important to know the nature of the heat transfer in the ocean-atmosphere system and the specific regions affected by their interaction.

Some of the particularly important areal regions or cells in the oceans which may interact with the overlying atmosphere downstream have been reported upon. Ratcliffe and Murray (1970) have found that regional SST anomalies near Newfoundland are useful in making long-range forecasts of pressure over Britain. Namias (1969) has concentrated on SST patterns in the north Pacific, while Bjerknes (1966, 1969) has dealt with SST's in the tropics.

The purpose of this paper is to show (i) that SST cells and their temporal variation can be easily found and delineated in the oceans by using $Q$-mode factor analysis and (ii) that when the SST cells for the eastern North Pacific found in (i) were anomalously warm or cold fluctuations in atmospheric pressure and 1000–500 mb thickness were noted over specific regions of North America. The period of time studied, 1960–73, spans the 1971 wintertime temperature pattern change over the United States. SST data from the western North Pacific and the tropics were not included here. However, the results indicate that SST anomalies in the eastern

[1] GLERL Contribution No. 36.

[2] Present affiliation: Institute of Arctic and Alpine Research, University of Colorado, Boulder 80309.

North Pacific are associated with fluctuations in pressure where the Aleutian low and Pacific subtropical high pressure cells are climatologically positioned, as well as with atmospheric thickness at high latitudes over Canada.

## 2. Data

The data used in this study consist of SST's from the eastern North Pacific, atmospheric thickness of the 1000–500 mb layer over North America, and surface pressure over North America.

Sea surface temperature data for the period January 1960–September 1973 (165 months) were taken from charts prepared by the National Marine Fisheries Service. Monthly average SST's were tabulated at 98 grid points between 20° and 60°N and between 120° (or the west coast of North America) and 180°W at intervals of 5° of latitude and longitude. Grid points northwest of the Aleutians were not included. A monthly average SST for the period 1960–73 was then computed for each of the grid points. This monthly average was considered to be normal for the study and it was used later to compute the SST departures from normal for individual months.

Data on 1000–500 mb thickness were tabulated at 95 grid points during the 38 winter months (December, January and February) of the period January 1961–February 1973 between 30° and 80°N and 50° and 160°W. The data points are located at 5° intervals of latitude and 10° intervals of longitude. These data, taken from the monthly maps of the Deutscher Wetterdienst (1961–73), were not available for that large portion of the Pacific and Atlantic Oceans between 30° and 50°N for most of the study period; hence, the absence of atmospheric thickness data over the ocean. This source of data provided an opportunity to study ocean-atmosphere interactions over the entire continent; previous studies have generally excluded the higher latitudes. Normals of thickness and monthly departures from those normals for 1961–73 were computed at each grid point for each month. One advantage in using the 1000–500 mb atmospheric thickness departures from normal lies in the fact that they are proportional to temperature departures in that layer and thus shed some light on the relationship between SST's and air temperature anomalies over the continent. Atmospheric data were only collected for winter months since the largest variations in temperature and pressure occur during that season.

Surface pressure data for the same 38 winter months as used for thickness were also tabulated from the maps of the Deutscher Wetterdienst (1961–73). These data were collected at 113 grid points between 30° and 80°N and 50° and 180°W, excluding grid points in the Pacific Ocean between 30° and 50°N. Normals for 1961–73 were then tabulated for each grid point for each of the three winter months and then departures from normal were computed for all 38 months. As it is the purpose of this study to identify atmospheric fluctuations occurring between 1960 and 1973 during months of anomalous SST, long-term normals of pressure and 1000–500 mb thickness were deleted in favor of getting departures from normal relative to the study period. Namias (1969) has shown that during the period 1961–67 SST's everywhere in the eastern Pacific were above the long-term mean (1900–39) given by the U. S. Naval Hydrographic Office (1944). In view of this, those long-term normals were abandoned in favor of the 1960–73 normals, thus including only those anomalies of SST relative to the period under study.

## 3. Factor analysis of sea surface temperature

Before studying atmospheric pressure and thickness fluctuations during periods of anomalous ocean conditions, an attempt was made to identify individual SST cells or regions constituting the eastern North Pacific. The existence of individual SST regions is suggested by the results of a correlation analysis made by Namias (1969). His analysis indicated vast regions in the North Pacific with high SST autocorrelations between adjacent seasons. Another way of finding these regions is through the use of a *Q*-mode factor analysis, a mathematical-statistical tool capable of discerning the spatial relationships in a set of variables over a large area for a given period of time.

Two related procedures, *R*-mode factor analysis and principal component analysis, have been used by meteorologists (Christensen and Bryson, 1966; Kutzbach, 1970). These investigations were concerned with reducing a large number of meteorological variables into a smaller set of variables while still accounting for a high percentage of the original variance. The smaller set of meteorological variables, called either factors or principal components (depending on the technique being used), was then used to establish a basis for weather classifications, weather types or forecasting procedures. *Q*-mode factor analysis, largely unused by meteorologists, will not create a smaller set of meteorological variables; rather it will take a large number of sample sites over an area where several variables are measured and then reduce them to groups of sites where similar patterns of variance exist. These spatial groups of sites become the *Q*-mode factors. If these groups or factors comprise grid-point sites which are all adjacent, then coherent areal patterns or regions of SST with similar variance have been established. The differences between these three techniques are relatively minor and are related to small details about how the mathematical manipulations are made or how analysis of the data is performed. All are generally labeled "factor analysis."

In this study the factors, or areal SST patterns, were obtained from a $98 \times 98$ matrix describing the spatial covariance among the grid points (i.e., a correlation matrix) for the period of analysis. Reference is made to other meteorological studies using a correlation matrix as a starting point in their factor or component analysis (Christensen and Bryson 1966; Kutzbach, 1970). The *Q*-mode feature of this analysis of the correlation matrix attempted to discover if the 98 grid-point space could be reduced to a smaller number of spatial factors which still account for a large portion of the variance of the original data. Considered vectorially each of the 98 grid points represents a vector space and the factor analysis reduces the size of the space based on the redundancy in the original correlation matrix (e.g., groups of original vectors all pointing in the same direction).

The correlation coefficient ($r_{ij}$) between any two of the grid-point vectors **i** and **j** may be considered as the cosine of the angle of their intersection (Rummel, 1967). The smaller the angle between the vectors (large $r_{ij}$ value) the greater their relationship and both may eventually become parts of the same factor if they continue to be highly or poorly correlated with the same remaining vector grid points. As the correlation coefficient approaches zero the vectors have nearly a 90° separation, while obtuse angles approaching 180° are inversely related vectors. The configuration of the vector combinations in this complex 98 dimension space reflects the interrelations in the data. The most highly correlated vectors will cluster together, while those that are completely unrelated will be at nearly right angles. Each cluster of vectors represents a new factor and each is highly uncorrelated with the others although as a group they still account for a majority of the original variance (Rummel, 1967). The procedure used in this analysis to separate the spatial SST factors in the above-mentioned manner was a varimax rotation of the matrix.

In determining the factor to which each original grid point belongs one analyzes a 98×4 matrix of factor loadings (where 4 is the number of factors most frequently found in this study). The factor loadings of each of the variables across the factors may be considered similar to correlation coefficients and by arbitrarily choosing a relatively high-loading cutoff value one picks the factor each point belongs to. The value chosen for this study was ±0.700 and if all four loadings were below that value for a given grid point, it was considered to belong to none of the factors. Factor analysis output usually includes the percentage of original data variance which factors account for and those results are presented below.

The grid-point sites with factor loadings greater than 0.700 across each factor were then plotted on a map of the eastern North Pacific and found to have spatial coherence. The resultant SST patterns (shown in Fig. 1) were named as follows, based on their position in the area under study: 1) the east-central North Pacific region (ECNP), 2) the southeastern oceanic region (SEOR), 3) an undefined region to be discussed later, and 4) the Gulf of Alaska region. The grid-point sites in Fig. 1 which are not part of any of the four regions did not have factor loadings higher than 0.700 across any of the original four factors.

These four regions accounted for 92.5% of the total unrotated variance in the original set of 98 SST sites. Unrotated total variances are reported here since rotated variances are a mathematical manipulation and thus artificial (Rummel, 1967). Table 1 shows the total unrotated variance accounted for by each region. The ECNP accounts for 85.3% of the original total unrotated variance while the SEOR and Gulf of Alaska accounted for 4.1% and 1.3%, respectively. These percentages indicate the strength and comprehensiveness of a region in terms of its ability to reproduce the

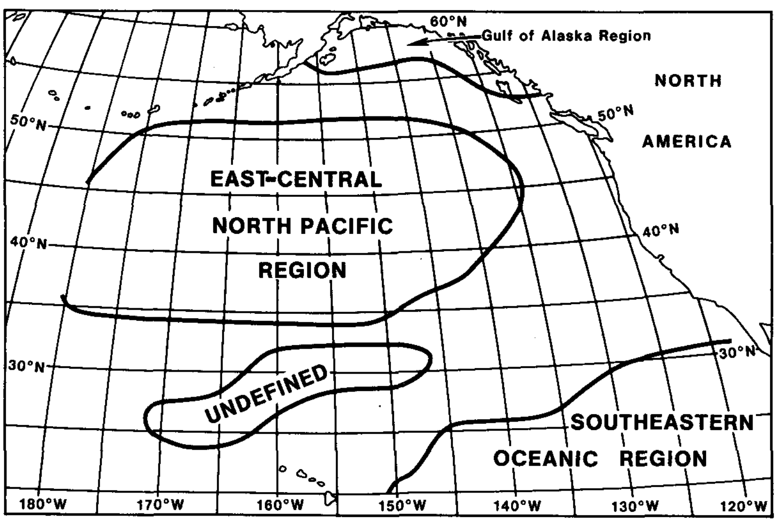


FIG. 1. Independent patterns of sea surface temperature derived from factor analysis of 1960–73 data. Factor analysis of the data from 1960–67 yields identical results except that there is no undefined region.

TABLE 1. Total variances (%) accounted for by each SST region for four periods 1960–73.

| | Total period 1960–73 | Subperiods 1960–67 | 1968–70 | 1971–73 |
|---|---|---|---|---|
| ECNP | 85.3 | 85.4 | 86.1 | 1.8 |
| SEOR | 4.1 | 4.1 | 2.5 | 2.2 |
| Undefined | 1.8 | NP* | NP* | NP* |
| Gulf of Alaska | 1.3 | 1.7 | 2.4 | 1.1 |
| SWOR | NP* | NP* | 2.4 | 90.9 |

* Not present in the factor analysis of that subperiod.

original variance of the SST at all 98 grid points. While the ECNP accounts for most of the original variance, the SEOR and Gulf of Alaska are unique regions and they still account for a small percent of the total variance which the ECNP does not cover.

The temporal changes in the SST regions were also studied. By trial and error combinations of years (a seasonal analysis of the SST's would have been hampered by a lack of data), three subperiods were found during which there were variations in the SST regions. The subperiods are as follows:

1. 1960–67 (96 observations in the analysis)—when the eastern North Pacific was warmest (Namias, 1969).
2. 1968–70 (36 observation)—the period preceding the 1971 SST pattern change noted by Namias (1972).
3. 1971–73 (33 observations)—the period during which the SST pattern changed.

Table 1 shows the percentage of the total variance of the SST data for the eastern Pacific associated with each region. The results indicate a change in the SST patterns during the 1971–73 subperiod. The total variance accounted for by ECNP dropped from 86.1% in 1968–70 to 1.8% in 1971–73. A new region, shown in Fig. 2 and named the southwestern oceanic region (SWOR), then accounted for 90.9% of the total variance.

Table 1 indicates that the SST regions from 1960–67 were the same as those in Fig. 1 for the entire period 1960–73 except that the undefined region did not exist. The undefined region of Fig. 1 is therefore the result of SST region changes starting in 1968–70. Since its location in Fig. 1 corresponds to the sites constituting the SWOR in Fig. 2, the undefined region is a result of the emergence of the SWOR.

It is demonstrated that factor analysis can identify large coherent regions of SST fluctuation in an ocean. The technique can be easily applied to larger oceanic regions. In addition, it would be reasonable to investigate seasonal patterns and SST changes when larger quantities of data are available for reliable analysis. The cells or regions which emerged in the analysis are largely independent of each other since factor analysis is designed to show uncorrelated patterns of variance across the factors. Factor analysis cannot tell us whether the SWOR was a new warm pool of water in the Pacific or a physical southwestward progression of the currents which helped form the ECNP. Factor analysis also cannot easily tell us if the SST pattern changes occurred relatively abruptly (in 1971) or gradually over the period 1968–71.

## 4. Atmospheric variation during regional SST anomalies

### a. *Pressure*

An attempt was made to determine if anomalous SST conditions in the three regions shown in Fig. 1 were associated with changes in atmospheric pressure and 1000–500 mb layer thickness over North America. The SST regions were considered anomalously warm or cold if a majority of the grid-point temperatures in the region

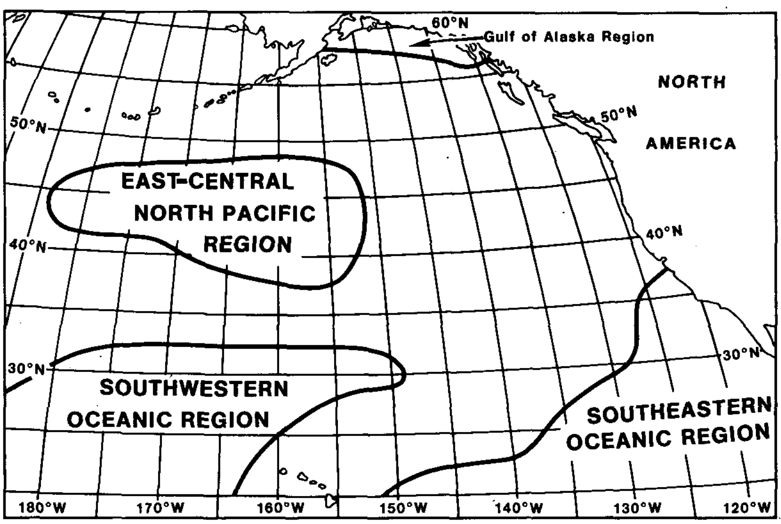


FIG. 2. As in Fig. 1 except for 1971–73 data.

Table 2. Winter months of SST anomaly by region.

| East-central North Pacific | | Gulf of Alaska Region | | Southeastern Oceanic Region | |
|---|---|---|---|---|---|
| Warm | Cold | Warm | Cold | Warm | Cold |
| Dec. 1961 | Jan. 1961 | Feb. 1961 | Jan. 1965 | Feb. 1963 | Dec. 1960 |
| Jan. 1962 | Feb. 1961 | Feb. 1963 | Feb. 1965 | Dec. 1966 | Dec. 1961 |
| Feb. 1962 | Dec. 1968 | Jan. 1964 | Dec. 1971 | Feb. 1968 | Feb. 1964 |
| Dec. 1964 | Dec. 1969 | Dec. 1969 | Jan. 1972 | Dec. 1968 | Feb. 1971 |
| Jan. 1965 | Jan. 1970 | Feb. 1970 | Feb. 1972 | Jan. 1969 | Dec. 1971 |
| Feb. 1965 | Feb. 1970 | | Dec. 1972 | Feb. 1969 | Feb. 1972 |
| Dec. 1970 | Dec. 1972 | | Feb. 1973 | | |
| Jan. 1971 | Jan. 1973 | | | | |
| Feb. 1971 | Feb. 1973 | | | | |
| Dec. 1971 | | | | | |
| Jan. 1972 | | | | | |
| Feb. 1972 | | | | | |
| 12 cases | 9 cases | 5 cases | 7 cases | 6 cases | 6 cases |

were 2°F above or below the 1960–73 normals for a particular month. Using this criterion, the months when each of the three regions were anomalously warm or cold are shown in Table 2. The entire set of months which had anomalously high or low SST's in a region are referred to as the warm and cold cases for that region. Differences in pressure and thickness over North America between warm and cold sea cases were then computed.

A two-tailed $t$ test (Davis, 1973) was used to determine if the differences in pressure and thickness were statistically significant. In this test

$$t=\frac{\bar{X}_1-\bar{X}_2}{S_p\left[\left(\frac{1}{n_1}\right)+\left(\frac{1}{n_2}\right)\right]^{\frac{1}{2}}},$$

where $\bar{X}_1$ and $\bar{X}_2$ are the sample means during opposite SST conditions, $n_1$ and $n_2$ the number of observations, and $S_p$ is a pooled standard deviation derived by

$$S_p^2=\frac{(n_1-1)S_1^2+(n_2-1)S_2^2}{n_1+n_2-2}.$$

The $F$ test (Davis, 1973) revealed that the variances from all the statistically significant pairs of mean pressures and thicknesses were drawn from the same population satisfying a major criterion for application of the $t$ test. The data may not be considered entirely random, however, since there is some temporal coherence (adjacent months in one winter). The Welch test (Ratcliffe, 1974) was also applied to the SST cases where sufficient observations were available to use Welch test critical value tables (Mack, 1967). It was

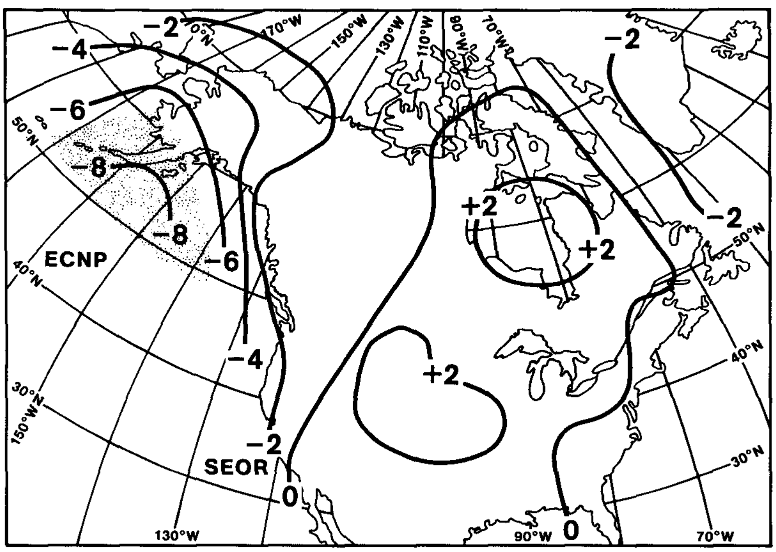


Fig. 3. Mean pressure difference (mb) over North America obtained by subtracting pressure during warm ECNP months from pressure during cold ECNP months. Stippling shows the areas where the difference is significant at the 5% level using a two-tailed $t$ test.

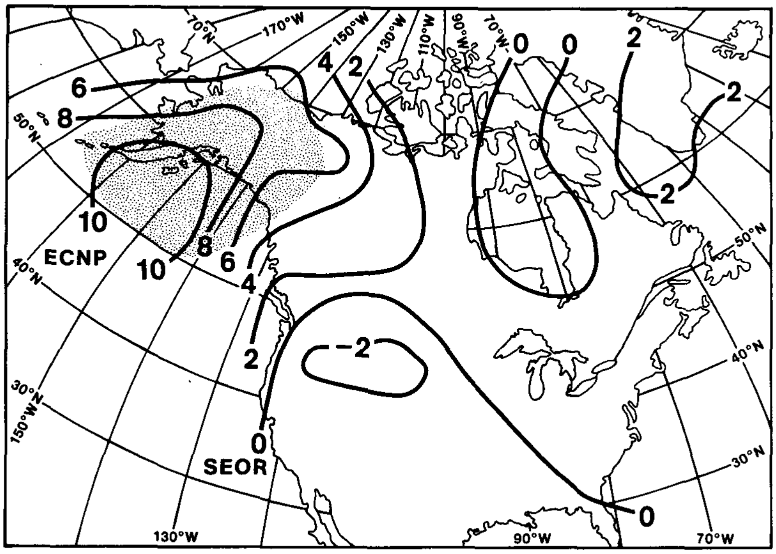


FIG. 4. As in Fig. 3 except that the difference was obtained by subtracting pressure during warm Gulf of Alaska months from pressure during cold Gulf of Alaska months.

found that the two-tailed $t$ test and the Welch test identified virtually the same areas of statistical significance in the data, largely due to the similarity of the equations for the tests. The 5% level for statistical significance was chosen.

The results of a pressure difference computation between the warm and cold ECNP cases are shown in Fig. 3. The average pressure for the 12 warm case months (Table 1) was subtracted from the average pressure for the 9 cold case months. Fig. 3 shows that the greatest difference between periods of opposite SST conditions in the ECNP was $-8$ mb, southeast of the Aleutians. This $-8$ mb pressure difference was statistically significant and was evenly divided between the cold and warm ECNP, being $-4$ mb and $+4$ mb, respectively. Except for western Alaska the maximum pressure differences over North America was between 2 and 4 mb.

Fig. 4 shows the pressure difference occurring between months with a cold Gulf of Alaska and months with a warm Gulf of Alaska. The maximum pressure difference was 10 mb and was still centered southeast of the Aleutians, although it was more nearly centered in the Gulf of Alaska. Although the 10 mb pressure difference occurs over nearly the same region as in Fig. 3, it is now a positive difference and the warm sea cases are subtracted from the cold sea cases. A cold Gulf of Alaska was associated with a 2–4 mb positive

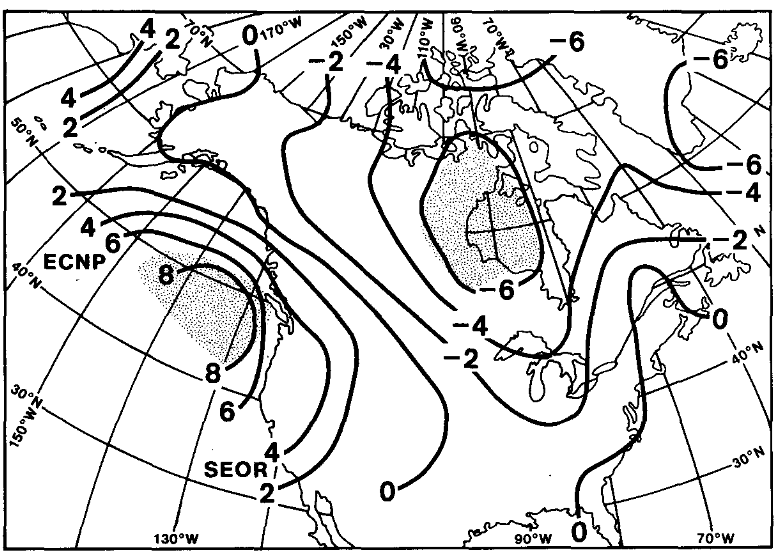


FIG. 5. As in Fig. 3 except that the difference was obtained by subtracting pressure during warm SEOR months from pressure during cold SEOR months.

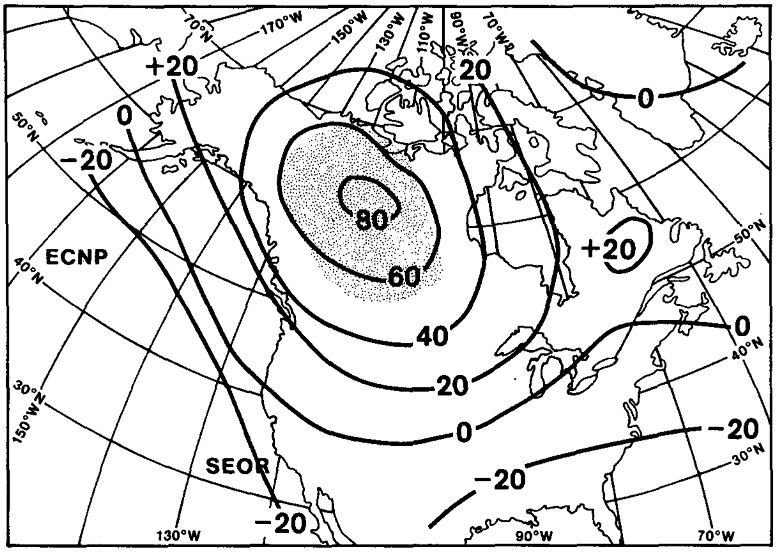


FIG. 6. Mean thickness difference (geopotential meters) over North America obtained by subtracting thickness during warm ECNP months from thickness during cold ECNP months. Stippling shows the areas where the difference is significant at the 5% level using the two-tailed *t*-test.

pressure departure while a warm Gulf of Alaska was associated with a negative 8 mb departure from the 1961–73 normals. Again, the pressure differences over the continent were relatively small compared with those near Alaska and the Gulf of Alaska. The area of statistical significance is larger here than in Fig. 3 due to greater mean pressure differences over Alaska combined with lower standard deviations in pressure.

Fig. 5 shows the pressure difference occurring between months comprising cold and warm SEOR cases. The maximum pressure difference was at least 8 mb west of the Pacific Coast of North America at 45°N. This region is near the climatological position of the Pacific subtropical anticyclone. In addition, there were fluctuations in pressure of more than 6 mb over northwestern and southwestern Greenland as well as western Hudson Bay. During the warm SEOR case the pressure was about 4 mb below the 1961–73 normals and averaged about 4 mb above normal during cold sea cases. Over western Hudson Bay the pressure anomaly was +6 mb and 0 during warm and cold sea cases, respectively.

### *b. Thickness*

Fig. 6 shows the mean thickness difference in the atmosphere between months comprising the cold and warm ECNP cases. The maximum statistically significant thickness difference was over 80 geopotential meters (gpm) centered at 60°N, 120°W in western Canada. During the warm ECNP months the mean thickness departure was just under 40 m above normal in that region. Thicknesses during the warm ECNP cases were subtracted from those of the cold cases.

Fig. 7 shows the mean thickness difference between months comprising warm and those comprising cold Gulf of Alaska cases. The maximum thickness difference was over −120 gpm centered at 60°N, 110°W in west central Canada. While the position of the maximum associated with the Gulf cases is once again similar to the position of the ECNP maximum (Fig. 6 and Figs. 3 and 4), the signs of the difference computation are opposite. In general it was found that the sign of departure from normal in the ECNP was opposite that which existed in the Gulf of Alaska during any given month. The SEOR SST departures generally were opposite those of the ECNP and similar to those of the Gulf of Alaska. One may see the contrast in SST departures in Table 2 by comparing months common to more than one region.

Fig. 8 shows the mean thickness difference between months comprising warm and cold SEOR cases. The maximum thickness difference was over −80 gpm over Baffin Island but was statistically significant to the west over the nearby archipelago. The Baffin Island region was part of a large area in the eastern Canadian Arctic where secondary pressure fluctuations were noted during opposite SEOR cases (Fig. 5). Secondary maxima of thickness also were noted in Fig. 8 in the western Alaska-Bering Straits region and near the central Rockies.

### *c. Discussion*

A comparison of Figs. 3, 4, 6 and 7 indicates that atmospheric fluctuations associated with both a warm ECNP and a cold Gulf of Alaska develop over nearly the same areas as do those atmospheric fluctuations associated with a relatively cold ECNP and a warm Gulf of Alaska. In the first situation, the Gulf of Alaska surface pressure is above normal and the 1000–500 mb

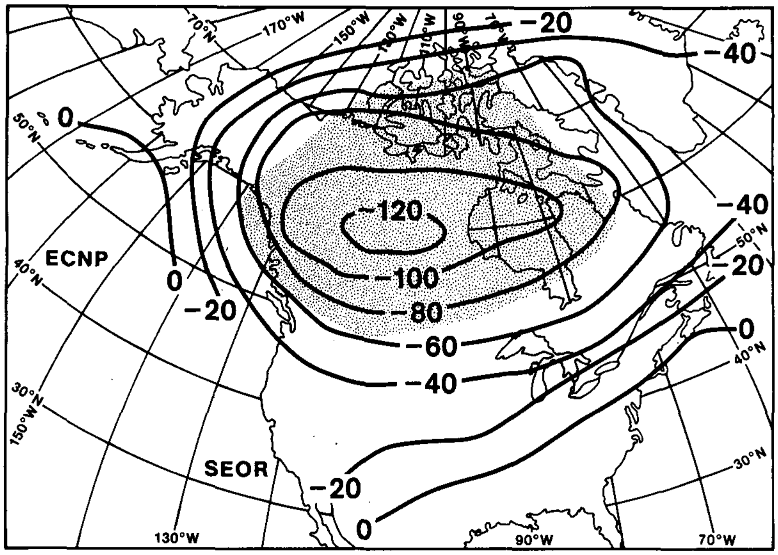


FIG. 7. As in Fig. 6 except that the difference was obtained by subtracting thickness during warm Gulf of Alaska months from thickness during cold Gulf of Alaska months.

thickness is below normal in west-central Canada. In the cold ECNP/warm Gulf situation, pressure over the Gulf is generally below normal while thickness in west-central Canada is above normal.

The similarity in the regions of atmospheric fluctuation associated with SST anomalies in the ECNP and Gulf is due to a tendency for both of these regions to be anomalously and opposingly warm or cold at the same time. Table 2 clearly indicates this tendency. There it is shown that three of the five warm Gulf of Alaska months (February 1961 and 1970, and December 1969) were part of the nine cold ECNP months. In addition, five of the seven cold Gulf months (January 1965 and 1972, February 1965 and 1972, and December 1971) were part of the 12 warm ECNP months. The conclusion that may be drawn from this similarity in the occurrence of SST anomalies is that one of these regions, particularly the smaller Gulf of Alaska, is not associated with any atmospheric fluctuations, but rather is a shadow of the ECNP. The number of months comprising the Gulf of Alaska cases are fewer than the months with ECNP anomalies and thickness and pressure fluctuations associated with Gulf SST anomalies (Figs. 4 and 7) are "noisier", being over 40 m and 2 mb larger than those associated with the ECNP (Figs. 3 and 6).

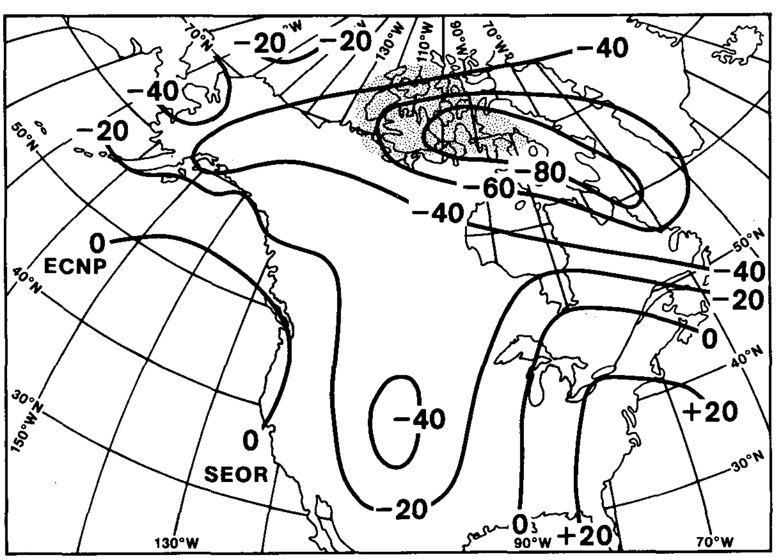


FIG. 8. As in Fig. 6 except that the difference was obtained by subtracting thickness during warm SEOR months from thickness during cold SEOR months.

Factor analysis of the 1971–73 SST data indicates that the region accounting for the greatest amount of original variance shifted from the ECNP to the SWOR. With that change, perhaps indicative of a general cooling in the ECNP, the Aleutian cyclone may have been less prone to shift southward and deepen as described by Namias (1972). The results presented here are in concurrence with those of Namias (1972) who also reported a change in SST patterns (as well as in wintertime air temperatures over the southeastern United States).

## 5. Concluding remarks

It has been shown, by using *Q*-mode factor analysis, that individual cells or regions having characteristic patterns of variance can be found in the oceans. During various months of the period 1960–73 these cells became anomalously warm and cold at various times. The atmospheric fluctuations associated with these periods of warm and cold seas suggest three general patterns as follow:

1) Anomalies of SST in the eastern North Pacific cells are associated with statistically significant surface pressure fluctuations near the major regions of cyclogenesis and anticyclogenesis closest to the oceanic cell.

2) Anomalies of SST in the eastern North Pacific are associated with statistically significant fluctuations in the 1000–500 mb layer several thousand kilometers downstream at high latitudes and away from the major centers of action. The ECNP case (Fig. 6) tends to reflect differences in thickness in northern regions where Arctic air masses either form or traverse before they move toward the eastern United States.

3) The location of the SST regions and their sign of anomaly with respect to one another may be of prime importance in studying circulation changes. This was suggested by the change in the number of SST cells from three to four at approximately the same time as the reversal of the temperature regime across the United States. Table 2 also shows that the Gulf and SEOR generally had opposite signs of anomaly to those of the ECNP before 1971. That pattern may also have changed afterward, since in December 1972 and February 1973 (Table 2) SST's in both the Gulf and ECNP were anomalously low.

The detection of short-term climatic fluctuations using changes in the regional patterns of SST anomalies needs further investigation. Analysis of SST anomalies and concurrent atmospheric fluctuations will do this by extending the area of study to other oceans and other time periods, using historical SST data. The results presented here demonstrate that regional patterns of SST anomalies in the eastern North Pacific are associated with fluctuations in atmospheric pressure and thickness over specific areas of North America, a relationship which may be useful in future modeling of the ocean-atmosphere system.

*Acknowledgments.* The author would like to thank Dr. Karel Bayer of the University of Wisconsin-Milwaukee, Department of Geography; Mr. John Dobnick of the University of Wisconsin-Milwaukee, Computer and Management Services Division, for assistance in setting up the necessary computer programs; and Mr. Dick James in cooperation with the Great Lakes Environmental Research Laboratory for his capable cartographic work. This study was partially funded by the Sea Grant Program project 144:E524—Long Range Ice Forecasting.

REFERENCES

Bjerknes, J., 1965: Atmosphere-ocean interaction during the "Little Ice Age" (seventeenth to nineteenth centuries, A.D.). *Proc. WMO-IUGG Symp. on Research and Development Aspects of Long-Range Forecasting*, Boulder, Colo., WMO Tech. Note No. 66, 77–88.

——, 1966: A possible response of the atmospheric Hadley circulation to the equatorial anomalies of ocean temperatures. *Tellus*, **18**, 820–829.

——, 1969: Atmospheric teleconnections from the equatorial Pacific. *Mon. Wea. Rev.*, **97**, 163–172.

Christensen, W. I., Jr., and R. A. Bryson, 1966: An investigation of the potential of component analysis for weather classification. *Mon. Wea. Rev.*, **94**, 697–709.

Davis, John C., 1973: *Statistics and Data Analysis in Geology*. Wiley, 550 pp.

Deutscher Wetterdienst, 1961–73: *Die Grosswetterlagen Europas*. Monthly, Offenbach auf main, Deutscher Wetterdienstes.

Kutzbach, J. E., 1970: Large-scale features of monthly mean Northern Hemisphere anomaly maps of sea level pressure. *Mon. Wea. Rev.*, **98**, 708–716.

Mack, C., 1967: *Essentials of Statistics for Scientists and Technologists*. Plenum Press, 174 pp.

Namias, J., 1965: Short-period climatic fluctuations. *Science*, **147**, 696–706.

——, 1969: Seasonal interaction between the North Pacific Ocean and the atmosphere during the 1960's. *Mon. Wea. Rev.*, **97**, 173–192.

——, 1971: The 1968–69 winter as an outgrowth of sea and air coupling during antecedent seasons. *J. Phys. Oceanogr.*, **1**, 65–81.

——, 1972: Experiments in objectively predicting some atmospheric and oceanic variables for the winter of 1971–72. *J. Appl. Meteor.*, **11**, 1164–1174.

Ratcliffe, R. A. S., 1974: The use of 500 mb anomalies in long-range forecasting. *Quart. J. Roy. Meteor. Soc.*, **100**, 234–244.

——, and R. Murray, 1970: New lag associations between North Atlantic sea temperatures and European pressure applied to long-range weather forecasting. *Quart. J. Roy. Meteor. Soc.*, **96**, 226–246.

Rowntree, P. R., 1972: The influence of tropical east Pacific ocean temperatures on the atmosphere. *Quart. J. Roy. Meteor. Soc.*, **98**, 290–321.

Rummel, R. J., 1967: Understanding factor analysis. *J. Conflict Resolution*, **11**, 444–480.

Sawyer, J. S., 1965: Notes on possible causes of long-term weather anomalies. *Proc. WMO-IUGG Symposium on Research and Development Aspects of Long-Range Forecasting*, Boulder, Colo., WMO Tech. Note No. 66, 227–248.

U. S. Naval Hydrographic Office, 1944: *World Atlas of Sea Surface Temperatures*. H. O. Publ. No. 225, Washington, D. C.