REGIMES AND EVENTS IN RECENT CLIMATIC VARIABLES

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ABSTRACT

Nonseasonal behavior of the marine and atmospheric environment in the eastern North Pacific and western North America are participants in the variability of a larger climate system. Recent climatic history displays extreme events and some longer term regimes that are often related. These extreme events are examined in the context of the overall variability, and details of their time and space scales are discussed.

RESUMEN

El comportamiento no estacional del ambiente atmosférico y marino en el Pacífico Norte oriental y Norteamérica occidental son participantes de la variabilidad de un sistema climático mayor. La historia climática reciente exhibe efectos extremos y algunos regímenes de período más largo que están frecuentemente relacionadas. Estos efectos extremos son examinados en el contexto de la variabilidad total, y se discuten los detalles de sus escalas tiempo y espacio.

INTRODUCTION

An excellent example of short-period climatic variability is provided by the surface temperature in the central and eastern North Pacific Ocean over the last few decades (see Figure 1). The heat stored in large regions of the North Pacific has apparently undergone considerable interannual or anomalous fluctuations, with time scales ranging from a few months to a few decades. The longer time scale variations, emphasized by the dark low-pass filtered curve in Figure 1, has the quality of regimes, whereas the unfiltered curve shows the shorter term variations, which one might call events. Instead of being randomly distributed in time, the extreme events are mostly found in the midst of a general anomalous period. Thus, although they are often regional in scope, the extreme events are usually linked to a broader scale and longer lived condition (i.e. a regime). Since both time scales have important effects on biota, etc., both, to some degree, are treated in this article.

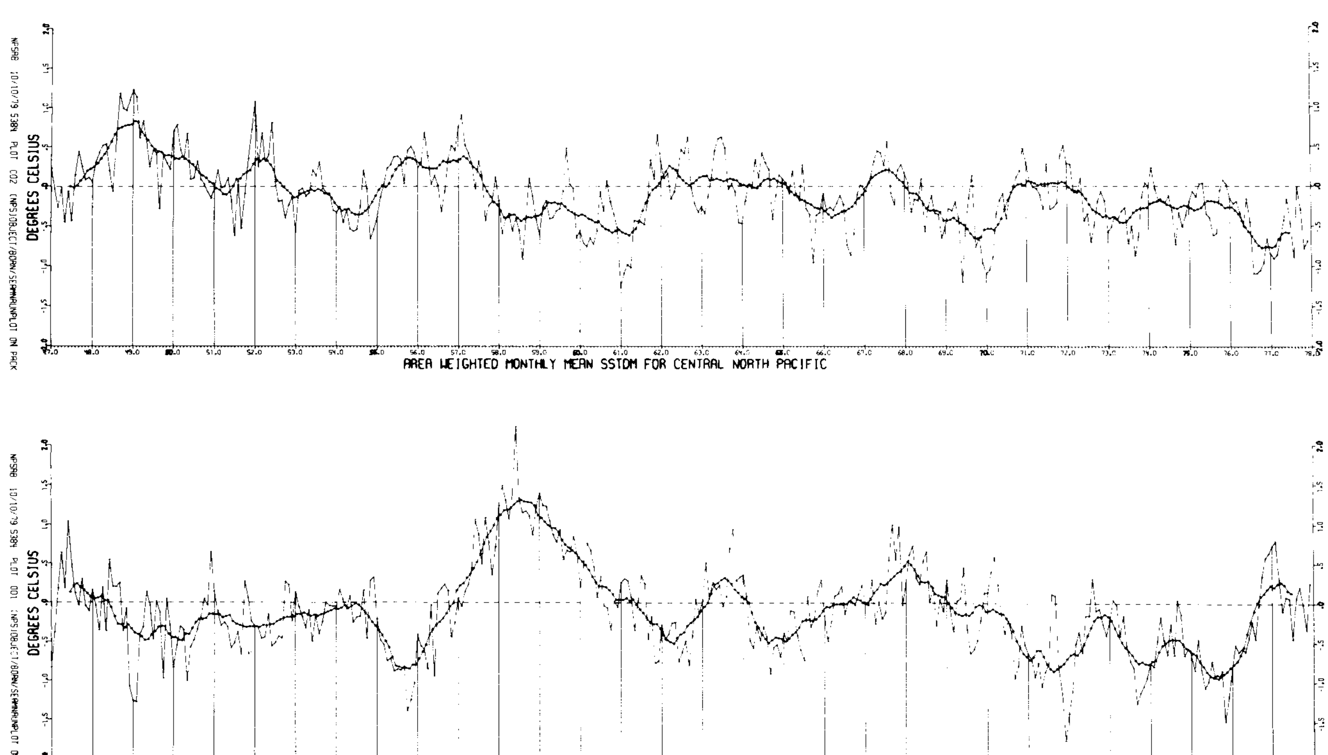


Figure 1. Area weighted sea-surface temperature (SST) for the central (30°N to 50°N, 150°W to 180°W) and eastern (20°N to 55°N, and east of 130°N) North Pacific. Light curve is monthly anomaly, dark curve is 12-month centered running mean; both are in degrees Celsius.

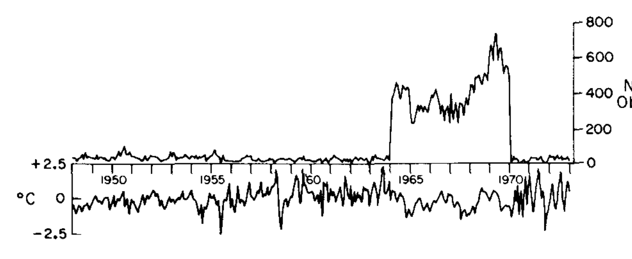
This report is concentrated on short-term climatic variations. These are just a small subset of the continuum of scales that represent the climate variability. For instance, the proxy records of tree rings and marine sediments, discussed by Douglas (this volume) and Soutar and Crill (1977), offer a look at climatic fluctuations on a scale beyond that of the directly measured data, which is what is treated here. Reliable direct observations of atmospheric, oceanic, and other climate variables are limited to the most recent few decades and are in many ways insufficient for thorough statistical descriptions of climate variability or for adequate verification of many theories of climatic change. However, they do provide a valuable glimpse of recent short-period fluctuations, with some notable extremes and regimes.

Examples shown here are taken from the eastern North Pacific and west coast of North America, of general interest to the CalCOFI audience. This material is descriptive. The major issues addressed are the spatial and temporal scales of anomalous variability, seen through the window of directly sampled observations. Events (relatively short-period fluctuations) are mentioned as well as regimes (more persistent, longer term fluctuations), because the mechanisms that force physical and biological transitions are often confined to these short storm-like periods. It is clear that these extreme events are sometimes linked to the background provided by the larger scale regime (see Namias 1973). This short-period climatic time scale is important because it contains significant variability and includes the periods of months to years over which many important management decisions must be made.

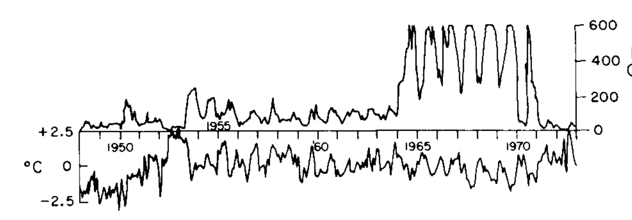
THE NATURE OF THE RECENT CLIMATIC RECORD

The longest directly measured climatic variables are surface temperature and precipitation, with some records of the west coast of the United States extending back into the 1800's (see Roden 1964, 1965; Kuhn in preparation). However, it is well known that the weather at the surface is influenced by the character of mid-troposphere, where adequate records have been collected routinely only since the end of World War II. Recent work has established the important role of other members of the globally linked climate system, such as the Southern Hemisphere, the polar ice sheets, and marine atmospheric and oceanic conditions. Unfortunately, the sampling of the entire climate system has been spatially nonuniform and temporally erratic. It is only during the last few years that serious attempts have been made at truly global sampling, which naturally needs many years of data to establish a clear description of the climatic scale of variability. A concerted effort to monitor global weather is underway by several worldwide cooperating institutions in the Global Atmospheric Research Program (GARP; see Fleming et al. 1979).

Much of the climatic information over the oceans is derived from island stations, ocean weather ships, routine surface marine reports from merchant and naval vessels, and recently from satellites. Despite all this, a reliable climatology is still hard to establish: island stations are not uniformly positioned, especially in the extratropics; many of the ocean weather station occupations have been recalled due to expense of operations, ending several unique series of nearly continuous open ocean data; satellite measurements are presently only marginally accurate (Barnett et al. 1979). For much of the synoptic scale ocean surface climatology, merchant ship observations provide the wealth of information. However, there are also numerous problems associated with these data. They are nonuniformly sampled in space (depending on ship tracks) and time (depending on season, etc.), and rather coarse areal and time averaging is necessary to construct meaningful maps of surface variables. Not only is there the usual seasonal variation in sampling density, but there have been large changes in the number of data from year to year and decade to decade, as illustrated for the Atlantic Ocean Marsden Square areas of sea-surface temperature in Figure 2. Part of this has historical causes, such as the general drop off in sampling density during the World War II period, but it appears that some of these aberrations, such as pre-1964 and post-1970 on Figure 2, resulted from a failure of various agencies to completely compile or process the data (not a trivial task). This



Atlantic SST (lower) and Number of Observations (upper) at Marsden Square 1
Latitude 5°N, Longitude 5°W



Atlantic SST (lower) and Number of Observations (upper) at Marsden Square 184
Latitude 55°N, Longitude 35°W

Figure 2. Examples of sea-surface temperature (SST) records in the North Atlantic for 10 degree (Marsden Square) averages centered as indicated; numbers of observations per month (upper) and monthly anomalies (lower). Notice how number of observations are modulated by time of year in Marsden Square 184 and also large difference in number over time. Also see how SST variance changes with sampling density.

inhomogeneity introduces artificial variability into the data series. Finally, a subtle, but serious, problem arises from the fact that most vessels avoid storm regions and hence the sampling misses the extreme portion of the variability in the surface data fields, which account for a large part of the interaction in the air-sea system.

Subsurface oceanic characteristics are known only in a long-term-mean sense, except for a few selected points and areas. This is due to a lack of routine synoptic subsurface sampling, which is more costly and time consuming than surface monitoring and is of little interest in routine maritime operations. There are, of course, several climatologies in the long-term-mean sense (see Levitus and Oort 1977), but the interannual variability of such important fields as the upper ocean thermal field is quite poorly known except for a few rather specialized points or areas (see White and Haney 1978). The upper oceanic thermal field is of interest because it plays an important role in the global heat budget of the climate system.

Despite its less than perfect state, the recent, directly observed record has yielded an interesting picture of the workings of the climate system on time scales of months to a few years, a few details of which are discussed below.

INTERANNUAL VERSUS ANNUAL VARIATIONS

It is important to distinguish between regular annual variations and the differences from normal, or the interannual variations (called anomalies, deviations from normal, or deviations from the long-term mean). The normal, or annual, signal of a particular variable is in practice constructed by taking the mean over some extended period of time for each sub-period of the year (months or seasons in this case). The interannual or anomalous signal is the difference between the observed value and this long-term-mean. In the case of events and regimes, we focus on these interannual components of the variability.

First, we compare the size of interannual variability to the size of annual variability. This is shown in the Western Hemisphere on a surface area temperature in the three panels of Figure 3, which presents the standard deviation of seasonal anomalies, root mean square (RMS) value representing the seasonal cycle, and the ratio of these two quantities. From this comparison, it is seen that the seasonal interannual variability is smaller than the regular seasonal amplitude, but of the same order of magnitude, which indicates the importance of the seasonal variability. There is a large contrast between the ratio of interannual to annual variability for continental and oceanic situations. Although the anomalous component is generally much greater on the continent than the ocean, the seasonal cycle is proportionately greater still, and in this sense the relative importance of the interannual variability is greatest over the oceans. Finally, note the general increase in the ratio toward tropical latitudes, caused by large seasonal anomalies (like El Niño) superimposed on a rather small seasonal signal.

Hence, we find a large, important interannual signal in low latitudes. Also, the smaller scale "noise" tends to be smaller in lower latitudes with less transient storm occurrence. The temperature fields, as well as other important variables, have large spatial coherence (see Barnett 1978b). This suggests that lower latitudes embrace areas where the interannual variation plays an important part in the overall dynamics of the short-term climate system. The low latitudes, then, offer a fruitful region of study to augment the understanding of the climate system gained from higher latitudes.

TIME SCALES AND SPECIFIC EXAMPLES

Short-term regimes in atmospheric and oceanic variables are hard to define. There are always transient (storm-like) disturbances that obscure the lower frequency components, particularly in the atmosphere. On the other hand, the anomalous component of the oceanic thermal structure has been shown to exhibit persistence over periods of several months. This contrast between the upper ocean and the faster changing lower troposphere is illustrated with autocorrelation functions of North Pacific sea-surface temperature and 700 mb height in Figure 4 (see Namias and Born 1970). It is thought that this disparity between time scales causes the upper ocean to act as a stablizing agent for the rather turbulent atmospheric circulation regime. For this reason, sea-surface temperatures have been explored as prime candidates for short-term climate predictors (see Namias 1975; Barnett 1978b; and Newell 1979).

Striking examples of regimes are the El Niño conditions usually centered in the eastern tropical Pacific, often in the Southern Hemisphere. El Niño is the occurrence of abnormally warm ocean surface temperature off the coast of Peru usually during northern winter, with associated atmospheric aberrations, such as heavy precipitation in the central Pacific (see Figure 5). The low latitude atmosphere-ocean system, as mentioned in the previous section, possesses strong, rather low frequency anomalous behavior, of which El Niño plays a major part (regionally). El Niño occurrences are spaced at roughly 6-year intervals (but nonperiodic), with varying degrees and duration, as seen from the time series in Figure 5. Perhaps the most impressive El Niño occurrence in recent times was the 1957-58 case, when the warming spread far beyond the lower latitudes into the eastern North Pacific (see Figure 6). This coupled oceanic and atmospheric system conspired to produce such anomalies in the physical realm as to decimate or translate entire biological populations and alter the distribution of species for several seasons. The "regime" that prevailed during 1957 and 1958 was the topic of an exciting past CalCOFI Sym-

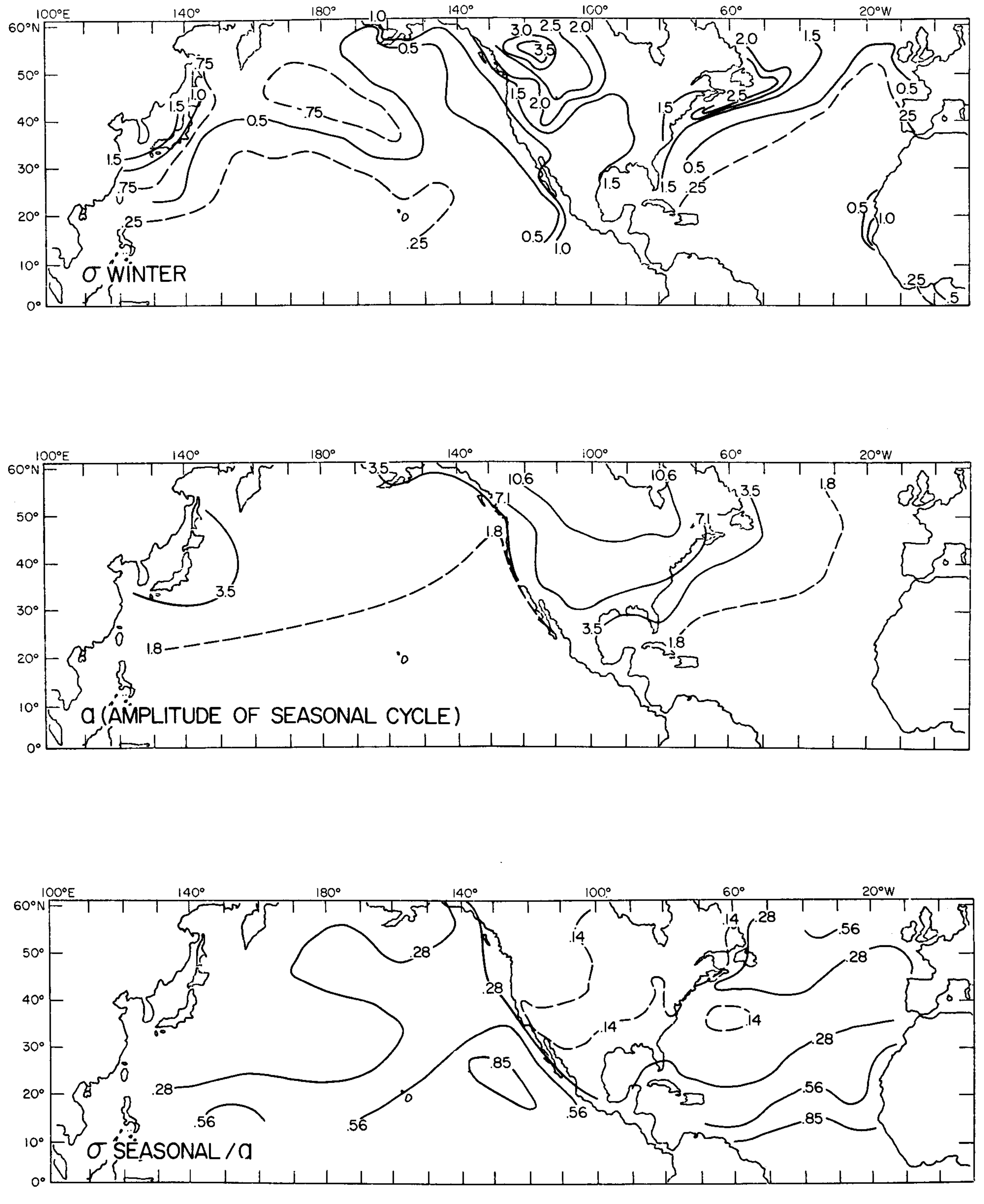


Figure 3. Seasonal versus interannual variability for oceanic and continental surface temperature.

posium (see Sette and Isaacs, eds., 1960). In fact, Namias (1972) contended that this 1957-58 event "ushered in a new regime that has a relatively warmer eastern North Pacific and cold central Pacific" that lasted through the 1960's (see Figure 7). The impact in higher latitudes during 1957-58 is indicated by a graph showing seasonal temperature anomalies at San Diego (Figure 8). It is interesting to note that the extreme short-period events that contributed to these various seasonal averages were not isolated random cases but seem to be fostered by the general large-scale regime.

Another striking example of an intense regime in the short-term climate system is the sequence of droughts that plagued the State of California and other parts of the west coast of North America during the winters of 1976 and 1977 (see State of California 1977; Namias 1978 a,

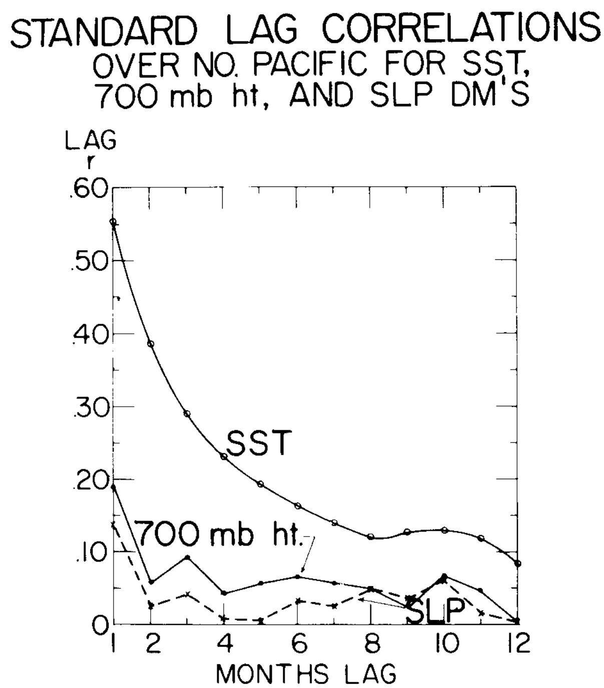


Figure 4. Overall autocorrelation functions at monthly lags for patterns of sea-surface temperature (SST), 700 mb height, and sea-level pressure (SLP) in the North Pacific. (After Namias and Born 1970).

1978b). Persistent high pressure and the usual accompanying subsidence resulted in the diverting of winter storms (from which California gets most of its precipitation) to the north, and consequent dry conditions prevailed (see Figure 9). The unusual nature of the situation involved the tenacity of the dryness and the fact that two dry winters occurred back-to-back. Again, the ocean was a partner, with concomitant strong anomalous sea-surface temperature patterns in the North Pacific (see Namias 1979). Although cause and effect relationships between the upper oceanic thermal structure and the overlying atmospheric flow pattern are still uncertain and require further research, it is clear that large, persistent sea-surface temperature anomalies are *strongly* associated with their atmospheric counterparts.

SPATIAL BEHAVIOR

A most remarkable feature of monthly and longer scale anomalous variability in the atmosphere and in the ocean is the large continuous nature and rather large amplitude of the spatial patterns that often exist. The length scales are on the order of hundreds to a few thousand kilometers. Although it might seem that an average over these periods (monthly and longer) of seemingly noisy, transient daily events would approach zero, it in fact has amplitudes that in many cases rival that of the daily events. Although explanations for this quasi-stationary standing wave tendency of the short-term climate system are not completely known, part of the reason for this behavior is probably intrinsic to the interactive behavior of the atmospheric and oceanic flow systems. Stabilizing influences might come from the lower boundary in the form of upper ocean and cryospheric heat sources, soil moisture transfers, and other surface characteristics that might influence albedo.

The spatial coherence is well illustrated in numerous West Coast and eastern Pacific examples. The large-scale nature of the mid-latitude surface temperature field, extending from the eastern North Pacific through the western half of the United States, is illustrated in Figure 10, in this case with the aid of empirical orthogonal

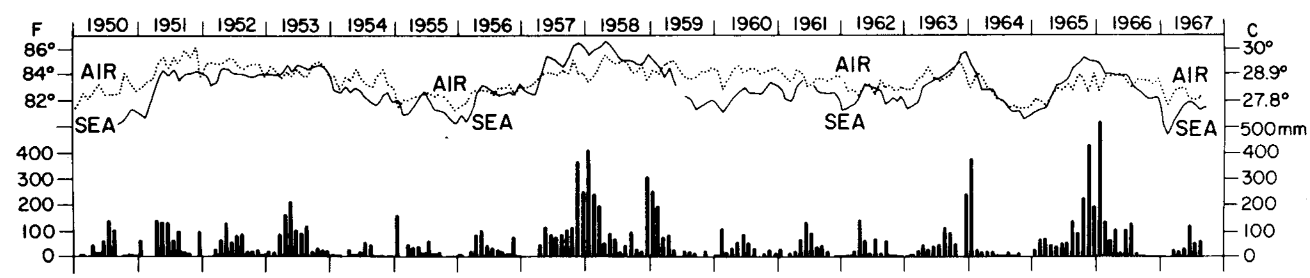


Figure 5. Time series of air temperature (dark curve in °F), surface temperature (dotted curve in °C), and precipitation (bar graph in mm) at Canton Island (172°W, 3°S). (After Bjerknes 1969.)

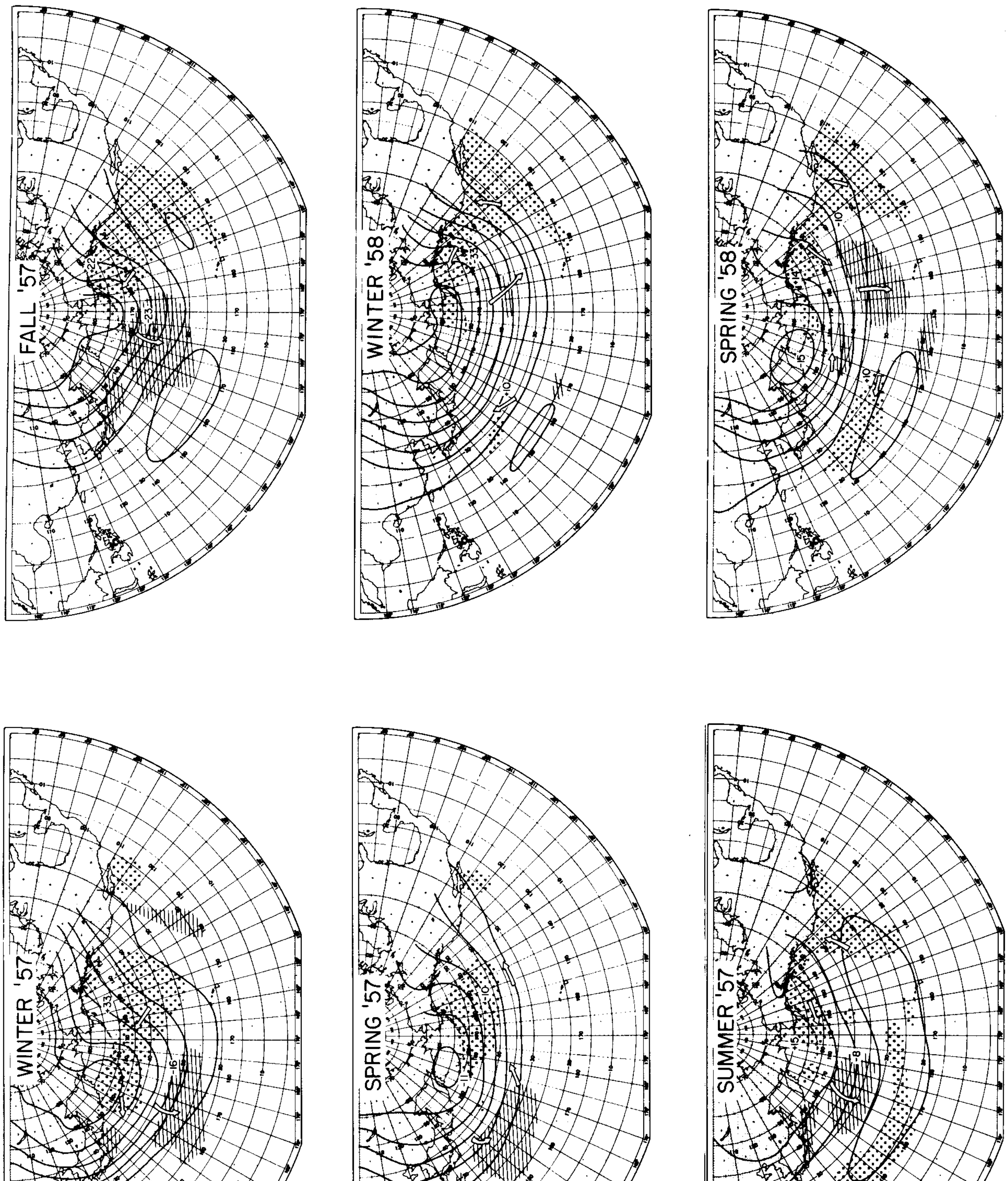


Figure 6. Sea-surface temperature (SST) anomalies (base period 1947-66) and 700 mb contours for winter, 1956-57. Stippled areas are more than 1°F below 20-year mean and hatched areas more than 1°F below. Numbers (expressed in tens of feet) are placed at centers of 700 mb anomalies. Arrows fly in direction of principal anomalous geostrophic flow (i.e. parallel to isopleths of height anomaly which are not reproduced). (After Namias 1972).

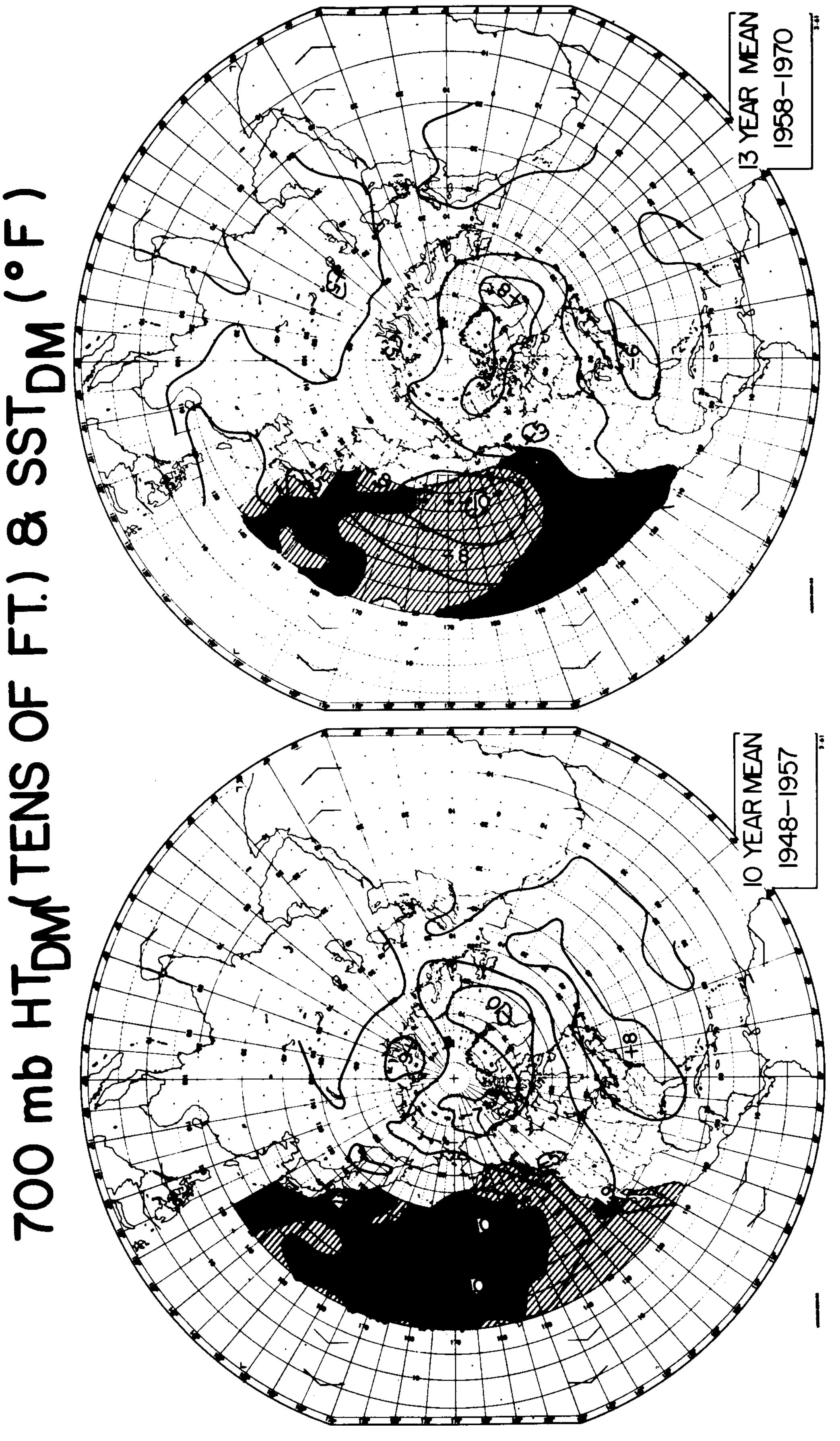


Figure 7. Comparison of anomalous Pacific sea-surface temperature (SST) and hemispheric 700 mb height over the 10-year period 1948-57 and 1958-70. Shaded and hatched areas represent SST anomalies greater than and less than zero, respectively. Note the shift in pattern between the two periods.

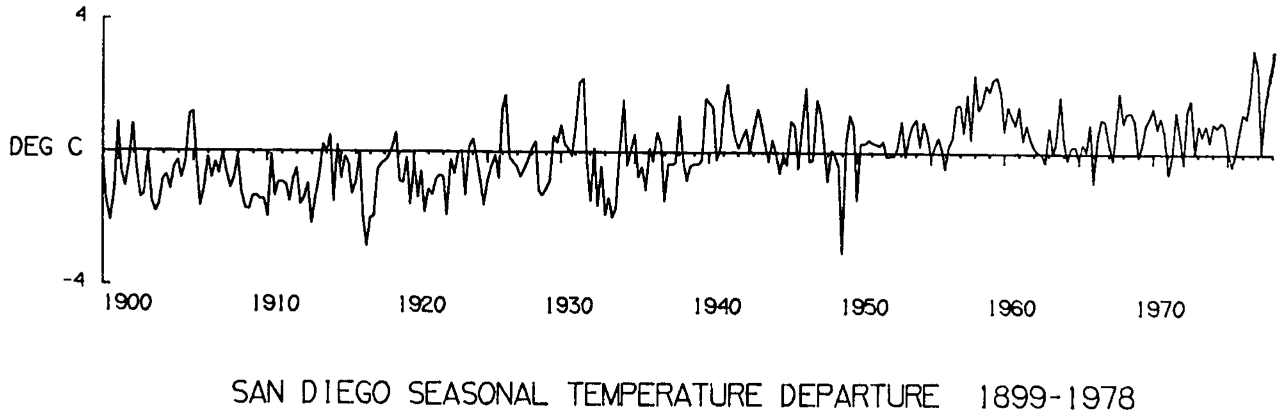


Figure 8. San Diego seasonal temperature departure (1899-1978). Notice the prolonged warm period centered around 1958.

Principal Tracks of Centers of Cyclones at Sea Level, North Pacific

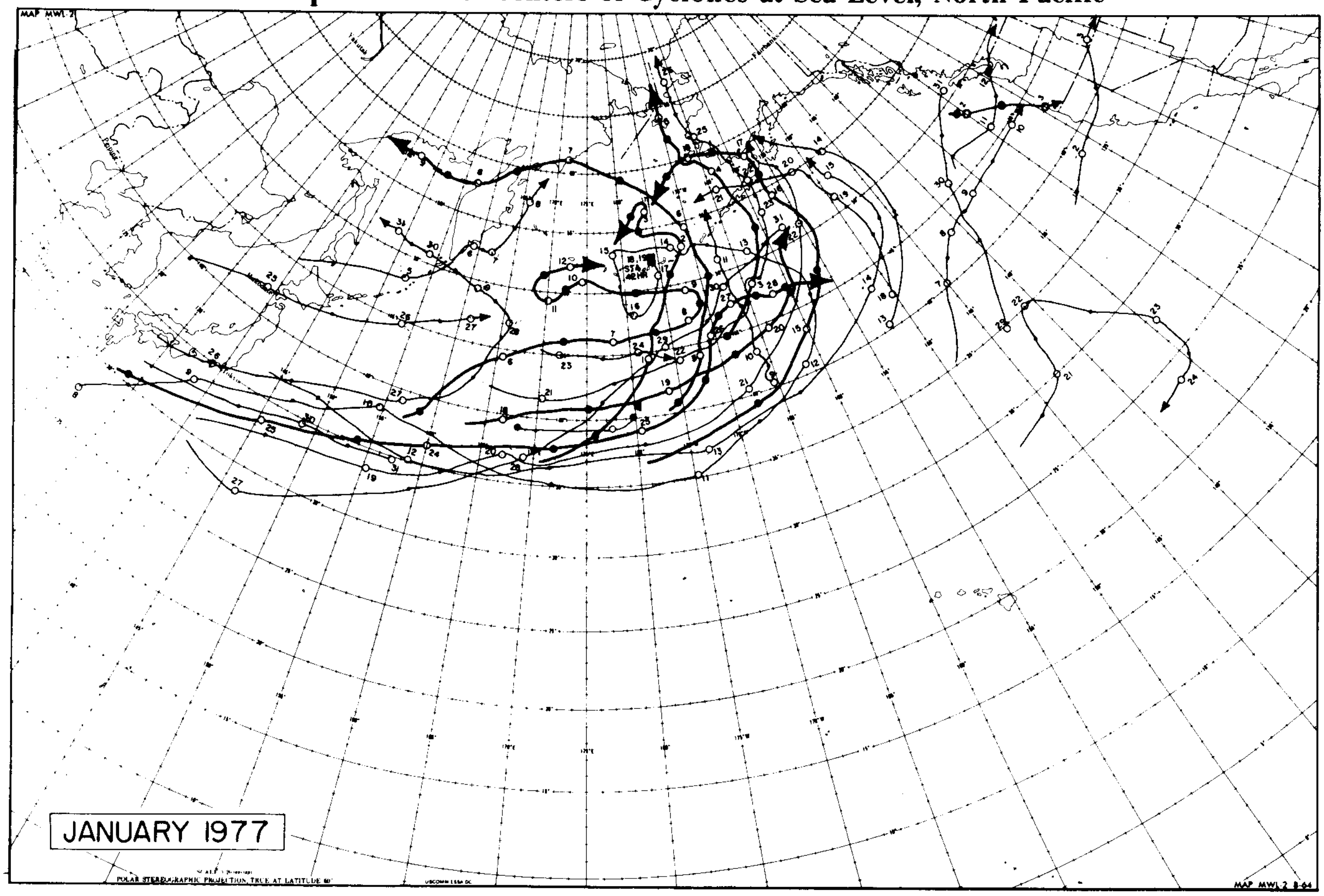


Figure 9. North Pacific storm tracks observed for January, 1977. Notice the relative absence of storms entering the West Coast region due to the strong ridge that was present during the heart of the 1977 drought. (From U.S. Department of Commerce, Mariners Weather Log, 1977.)

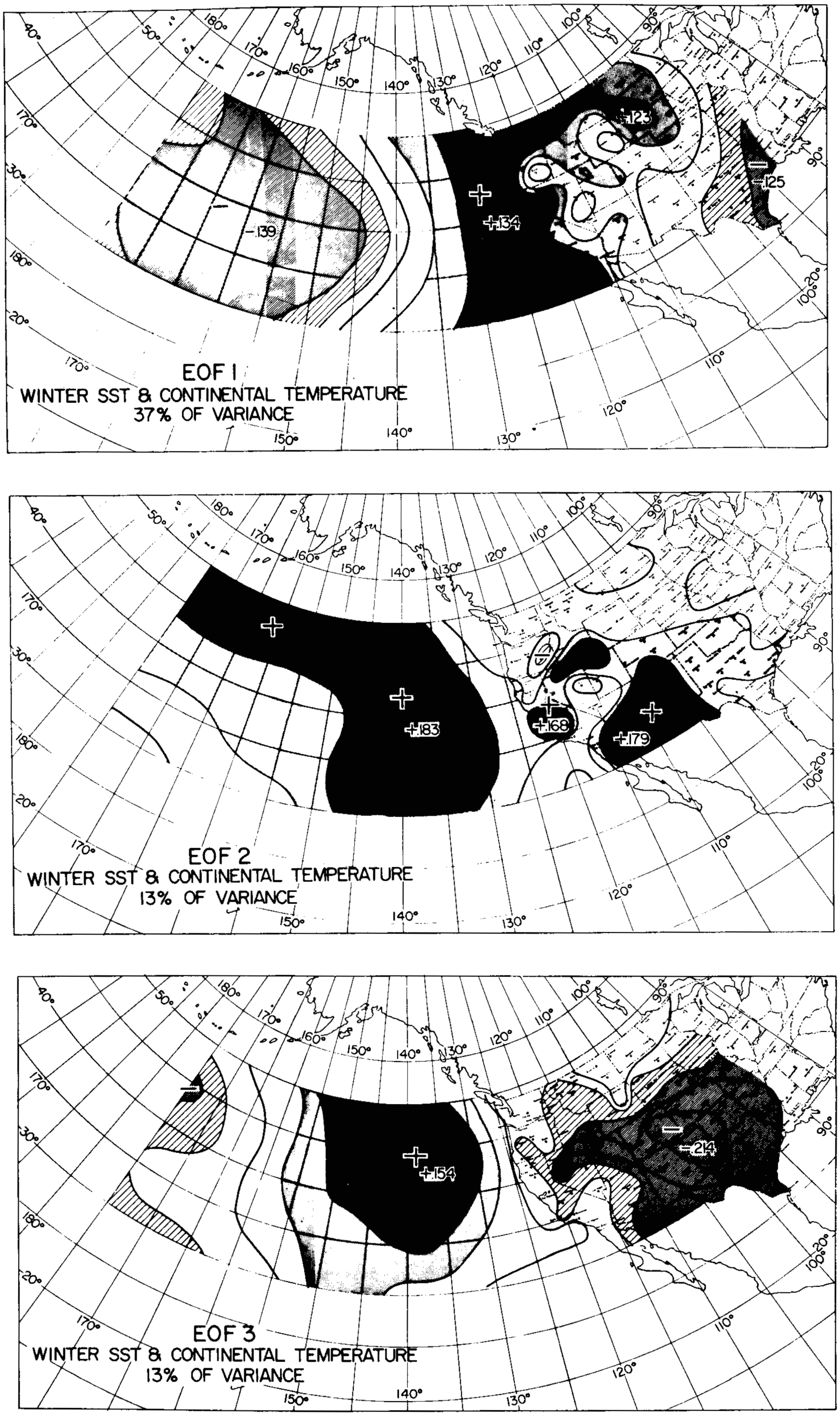


Figure 10. Empirical orthogonal functions (EOF) of surface temperature field based on winter data from 1948-72.

functions (EOF's). The first three patterns of covariability indicate a planetary wave length scale (4,000-6,000 km in this case) and together account for over 60% of the total surface temperature field. These patterns indicate that much of the anomalous temperature variability occurs in the zonal direction, also indicative of atmospheric long waves. Also, the patterns seen in this subarea of the Northern Hemisphere are reflective of larger patterns for the entire Hemisphere (see Barnett 1978a).

Focusing on a smaller region, the west coast of the United States, we can examine the variability in a nearly meridional cross section, with the help of surface temperature and precipitation. First, a chart of the time series of monthly temperature anomalies for 21 stations along the coast indicates the signal level and a large degree of correspondence between neighboring stations (Figure 11). The ability of empirical orthogonal functions (EOF's) to reduce a highly interrelated data set like this is illustrated in Figure 12. The first two EOF's (patterns shown in Figure 12), comprise roughly 83% and 70% of the variance of entire temperature and precipitation field, respectively, of the 21 stations. In both, the first EOF exhibits the tendency for the anomalous variability to be of like sign all along the coast (for instance all stations warmer than normal or all stations colder than normal), which agrees with our first example showing zonal alignment. This pattern dominates both the temperature and precipitation fields. It would prevail in a winter such as 1976-77 (see Figure 9), when a strong ridge dominated the entire west coast of the United States with resulting warm, dry conditions. In contrast, the second EOF shows a smaller scale meridional behavior, with warm in the north, cold in the south anomalous conditions (or vice versa). Again this function appears for both the temperature and precipitation fields. Physically, it probably represents the occurrence of a northern or southern storm track in the winter period. Notice that EOF 2 accounts for at most half of the variability of the first function.

FINAL REMARKS

There is considerable physical evidence for the occurrence of large space and time scales of interannual variability. In the physical realm, much work is needed to understand the causal mechanisms and interactions of this scale of behavior in order to predict their occurrence. In the biological realm, there are indications of important influences by short-term climatic fluctuations on various biological populations (see McGowan 1974; Tont and Platt 1979), which are discussed in part by Tont and Delistraty (1980) in this symposium. This area of application of climate research is in many ways interesting to those concerned with the growing problem of resource management, and it deserves greater attention.

LITERATURE CITED

Barnet, T.P. 1978a. Estimating variability of the surface air temperature in the Northern Hemisphere. Mon. Wea. Rev. 106(9):1353-1367.

__________. 1978b. The role of the oceans in the global climate system. *In* J.R. Gribbin (ed.), Climatic change.

Barnet, T.P., W.C. Patzert, S.C. Webb, and B.R. Bean. 1979. Climatological usefulness of satellite determined sea-surface temperatures in the tropical Pacific. Bull. Amer. Meteor. Soc. 60(3):197-205.

Bjerknes, J. 1969. Global ocean-atmosphere interaction. First published in Rapports et Procés-Verbaux, Vol. 162, 1972 as the Convenors Address: Symposium on Physical Variability in the North Atlantic Ocean, Internat. Counc. Explor. Sea (ICES), Dublin, 25 September 1969.

Douglas, A.V. 1980. Geophysical estimates of sea-surface temperatures off western North America since 1671. Calif. Coop. Oceanic Fish. Invest. Rep. 21: (this volume).

Fleming, R.J., T.M. Kaneshige, W.E. McGovern, and T.E. Bryan. 1979. The global weather experiment II. The second special observing period. Bull. Amer. Meteor. Soc. 60(11):1316-1322.

Kuhn, G.G. (in preparation) Coastal zone geology and related sea cliff erosion, Santa Margarita River (Oceanside) southward to Bataquitos Lagoon (Carlsbad), (1880-1980). (To be submitted to NOAA Sea Grant publication.)

Levitus, S., and A. Oort. 1977. Global analysis of oceanographic data. Bull. Amer. Meteor. Soc. 58(12):1270-1284.

McGowan, J.A. 1974. The nature of oceanic ecosystems, P. 9-28 *In* C.B. Miller (ed.), The biology of the oceanic Pacific, Oregon State Univ. Press, Corvallis.

Namias, J. 1972. Large-scale and long-term fluctuations in some atmospheric and oceanic variables. *In* David Dyrssen and Daniel Jagner (eds.) Nobel Symp. 20, Almqvist and Wiksell, Stockholm, p. 27-48.

__________. 1973. Birth of Hurricane Agnes—triggered by the transequatorial movement of a mesoscale system into a favorable large-scale environment. Mon. Wea. Rev. 101(2):177-179.

__________. 1975. Short period climatic variations. Collected works of J. Namias 1934 through 1974 (2 Vols.) Univ. Calif. San Diego, 905 p.

__________. 1978a. Recent drought in California and western Europe, Rev. Geophys. Space Physics 16(3):435-458.

__________. 1978b. Multiple causes of the North American abnormal winter 1976-1977. Mon. Wea. Rev. 106(3):279-295.

__________. 1979. Northern Hemisphere seasonal 700 mb height and anomaly charts, 1947-78, and associated North Pacific sea surface temperature anomalies. *In* A. Fleminger (ed.), Calif. Coop. Oceanic Fish. Invest. Atlas No. 27, 282 p.

Namias, J., and R.M. Born, 1970. Temporal coherence in North Pacific sea-surface temperature patterns. J. Geophys. Res. 75(30):5952-5955.

Newell, R.E. 1979. Climate and the ocean. Amer. Sci. 67:405-416.

Roden, G.I., 1964. On the duration of non seasonal temperature oscillations. J. Atmos. Sci. 21:510-518.

__________. 1965. On atmospheric pressure oscillations along the Pacific Coast of North America, 1873-1963. J. Atmos. Sci. 22: 280-295.

Sette, O.E., and J.D. Isaacs (eds.). 1960. The changing Pacific Ocean in 1957 and 1958. Calif. Coop. Oceanic Fish. Invest. Rep. 7:217 p.

Soutar, A., and P.A. Crill. 1977. Sedimentation and climatic patterns in the Santa Barbara Basin during the 19th and 20th Centuries. Geol. Soc. Amer. Bull. 88:1161-1172.

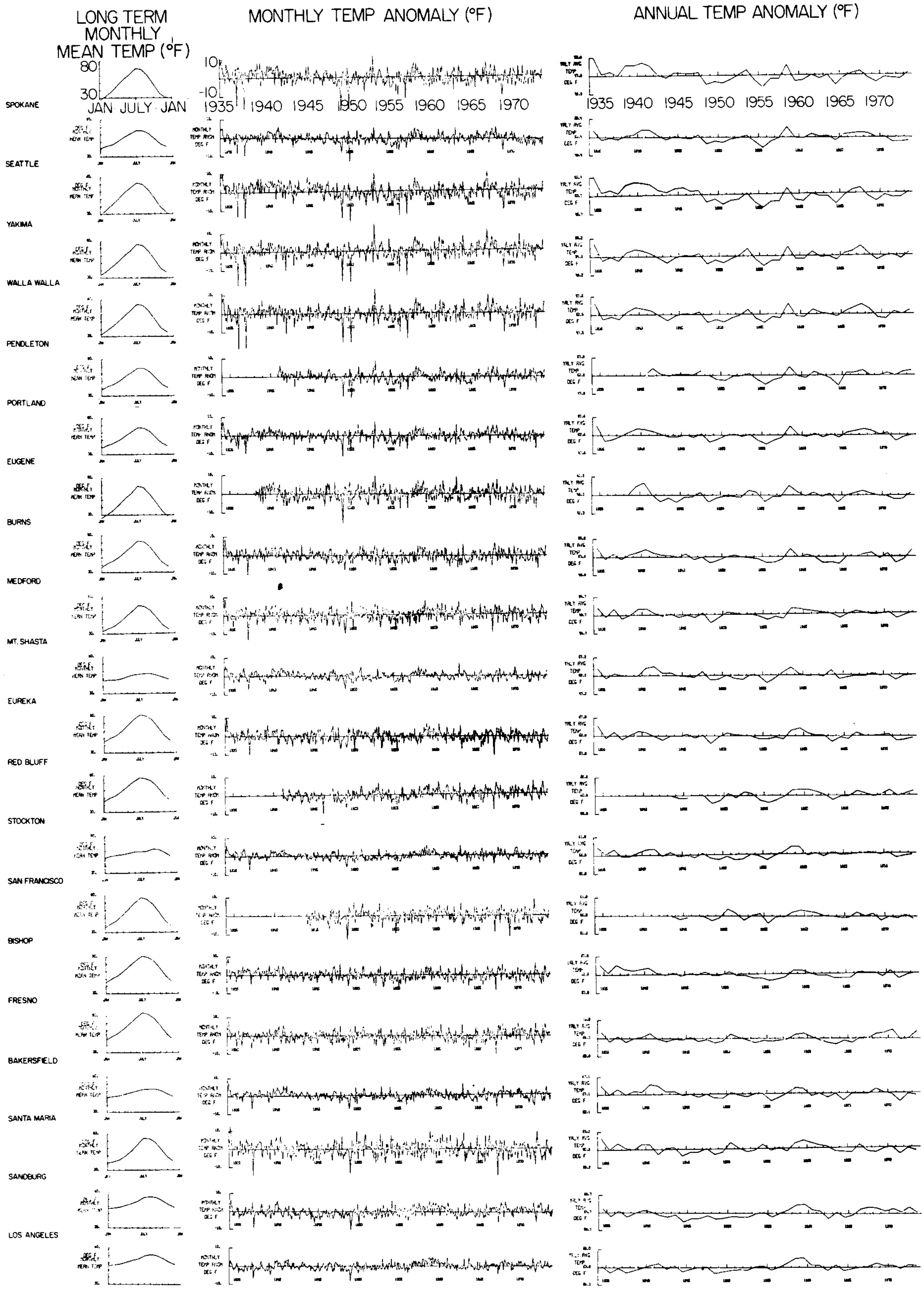


Figure 11. Surface temperature at 21 stations on the west coast of the United States. Graphs of long-term mean, monthly anomalies, and annual anomalies for (1934-73). Note the coherence between stations.

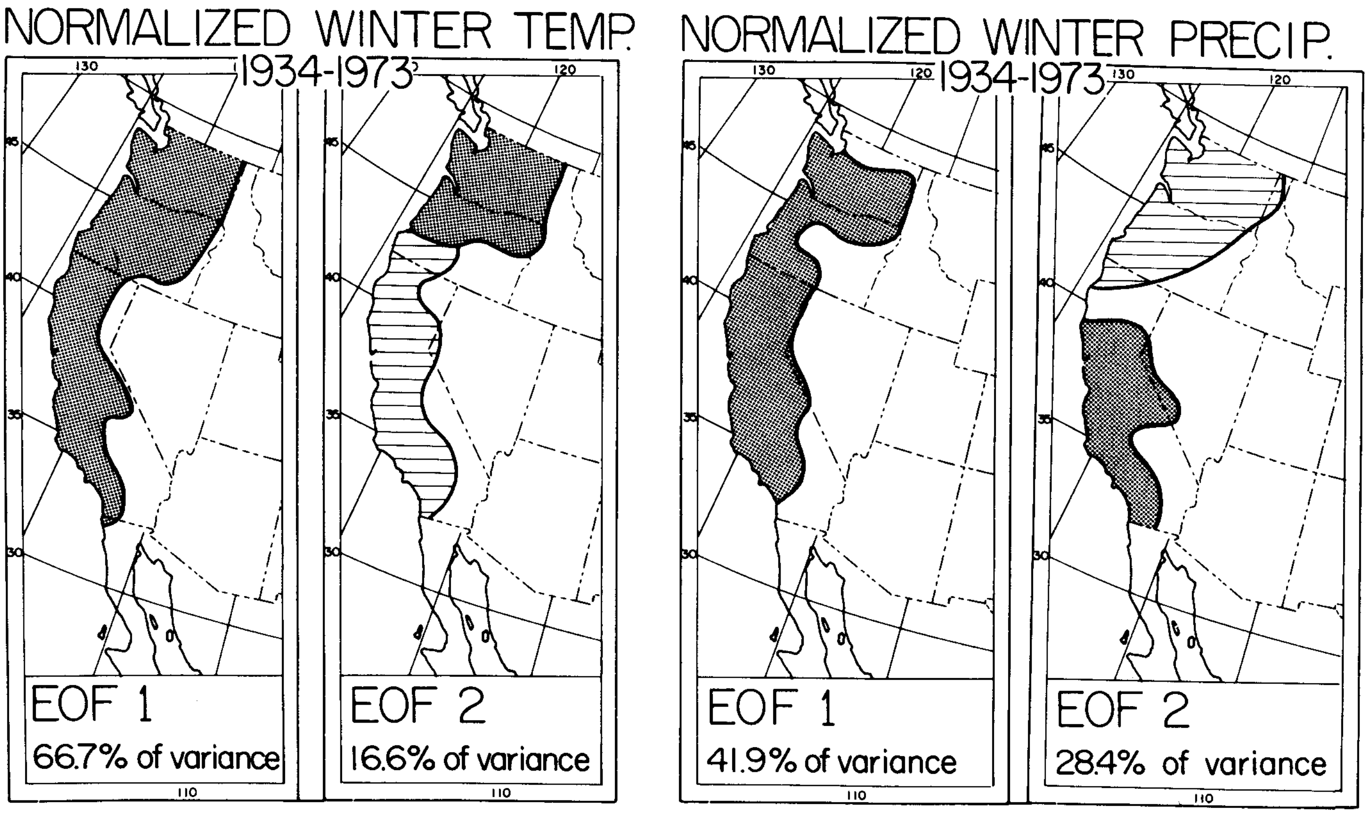


Figure 12. The first two empirical orthogonal functions (EOF) of surface temperature and precipitation for the 21 West Coast stations shown in Figure 11.

State of California. 1977. The continuing California drought, 148 p.

Tont, S.A., and D.A. Delistraty, 1980. The effects of climate on terrestrial and marine populations. Calif. Coop. Oceanic Fish. Invest. Rep. 21: (this volume).

Tont, S., and T. Platt. 1979. Fluctuations in the abundance of phytoplankton on the California Coast. P. 11-18 *In* E. Naylor and R.G. Hartnoll (eds.) Cyclic Phenomena in Marine Plants and Animals. Pergamon Press, Oxford and New York, p. 11-18.

U.S. Deptartment of Commerce. 1977. Mariners Weather Log, 21(4).

White, W.B., and R. Haney. 1978. The dynamics of ocean climate variability. Oceanus 21(4):33-39.