Grass Marsh. In: Journal of Ecology, Bd. 68, 1980, S. 547–559.

Richter, D.: Darstellung von Methoden zur rechnerischen Bestimmung der Gebietsverdunstung. Abhandlungen des Meteorologischen Dienstes der DDR, Bd. 98. Berlin 1969.

Schmiedecken, W.: Die Bestimmung der Humidität und ihrer Abstufung mit Hilfe von Wasserhaushaltsberechnungen – ein Modell (mit Beispielen aus Nigeria). In: Lauer, W. (Hrsg.): Klimatologische Studien in Mexiko und Nigeria, Beiträge zum Problem der Humidität und Aridität. Colloquium Geographicum, Bd. 13, 1978, S. 135–159.

Schmiedecken, W. u. Stiehl, E.: Wald und Wasserhaushalt. Klimatologische und hydrologische Untersuchungen in der Rureifel. In: Eriksen, W. (Hrsg.): Studia Geographica. Festschrift für W. Lauer. Colloquium Geographicum, Bd. 16, 1983, S. 165–195.

Schnelle, F.: Beiträge zur Phänologie Europas I. 5 Mittelwertskarten, Erstfrühling bis Herbst. Berichte des Deutschen Wetterdienstes, Bd. 14, Nr. 101. Offenbach 1965.

– : Beiträge zur Phänologie Europas II. Berichte des Deutschen Wetterdienstes, Bd. 16, Nr. 118. Offenbach 1970.

Schröder, D.: Der Wasserverbrauch verschiedener Kulturpflanzen und seine Beziehungen zu Düngung, Ertrag, Niederschlag und Wurzelwachstum. Diss. Bonn 1971.

– : Der Wasserverbrauch des Weizens und Roggens und seine Beziehungen zu Düngung, Ertrag, Niederschlag und Wurzelwachstum. In: Zeitschrift für Acker- und Pflanzenbau, Bd. 138, 1973, S. 300–318.

Sellers, P. J. u. Lockwood, J. G.: A Numerical Simulation of the Effects of Changing Vegetation Type on Surface Hydroclimatology. In: Climatic Change, Bd. 3, 1981, S. 121–136.

Stocker, O.: Die Abhängigkeit der Transpiration von Umweltfaktoren. In: Ruhland, W. (Hrsg.): Handbuch der Pflanzenphysiologie, Bd. 3: Pflanzen und Wasser. Berlin u. a. 1956, S. 436–488.

Troll, C.: Karte der Jahreszeiten-Klimate der Erde. In: Erdkunde, Bd. 18, 1964, S. 5–28.

Walter, H.: Die Vegetation der Erde in ökophysiologischer Betrachtung. Bd. II: Die gemäßigten und arktischen Zonen. Stuttgart 1968.

– : Vegetation und Klimazonen. Die ökologische Gliederung der Geo-Biosphäre. 4. Aufl., Stuttgart 1979.

Wechmann, A.: Hydrologie. München/Wien 1964.

Wendling, U.: Zur Messung und Schätzung der potentiellen Verdunstung. In: Zeitschrift für Meteorologie, Bd. 25, 1975, S. 103–111.

INTERANNUAL VARIATIONS OF SUMMER PRECIPITATION IN EAST ASIA: THEIR REGIONALITY, RECENT TREND, AND RELATION TO SEA-SURFACE TEMPERATURE OVER THE NORTH PACIFIC[*]

With 12 figures

Masatoshi Yoshino and Takashi Aoki

Zusammenfassung: Interannuelle Variabilität der Sommerniederschläge in Ostasien: Regionalität, rezenter Trend und Zusammenhänge mit der Meeresoberflächentemperatur über dem Nordpazifik

Zur näheren Untersuchung der interannuellen Variabilität der Sommerniederschläge in Ostasien wurde der Mittelwert und die Standardabweichung des Niederschlags im Juni und Juli dargestellt und eine Regionalisierung nach der Clusteranalyse für die 25jährigen Niederschlagsbeobachtungen 1956–1980 vorgenommen. Dabei zeigen sich auffallende Beziehungen zur Aktivität und Lage sowohl der Mai-yü und Bai-u Frontalzonen als auch der eurasiatischen Polarfrontalzone. Weiterhin wurden auch die langfristigen Veränderungen der Niederschläge diskutiert. Dabei konnte gezeigt werden, daß die Niederschläge seit der zweiten Hälfte der 60er Jahre in allen Regionen stärkerer Polarfront-Aktivität abnehmen, was mit dem langfristigen Temperaturtrend der nördlichen Hemisphäre übereinstimmt. Kurzfristige Niederschlagsveränderungen traten ebenfalls parallel zu den Temperaturveränderungen auf, allerdings nicht mehr seit den 70er Jahren. Schließlich wurden die Korrelationskoeffizienten zwischen den Gebietsniederschlägen und der Oberflächentemperatur des Meeres

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(SST) über dem Nordpazifik für drei zurückliegende und zwei vorausgehende Jahre berechnet. Dabei ergaben sich in einigen Monaten für verschiedene Gebiete signifikante Korrelationen, z. B. für die Kalifornien-Strömung, den Kuroshio und die zentrale Subtropische Antizyklone.

1. Introduction

Summer precipitation, called Bai-u in Japan and Mai-yü in China, is one of the essential climatic components in East Asia. It has been a subject for many years not only for climatological studies, but also for practical purposes such as agriculture, electric power, water supply, etc.

In the present study, an attempt is made first to clarify the regionality of its interannual variation, secondly to describe the changing trends during the last 30 years, and thirdly to analyze the relationship with the sea-surface temperature (SST) over the North Pacific. The first results may contribute to a regional division of climates in East Asia as a whole which has never been dealt with before. The second part of this study will show an actual variation pattern of regional precipitation, which is more important for considering the climatic changes. The third part has been one of the main topics of climatology in recent years for understanding the air-sea interaction mechanism in macro-scale climatic processes.

We are particularly indebted to the *Institute of Geography, Chinese Academy of Sciences* in Beijing, and *North Korean Hydro-Meteorological Services* in Pyongyang, for having made available to us the climatological data used in this study.

2. Previous studies

In China, climatic divisions have been studied by combining the climatological elements over many years. The studies by Chu (1929) and Tu (1936) are considered important forerunners in this connection. Based on these results, Lu (1954), Chang et al. (1956), and the *Natural Division Committee, Academia Sinica* (1959) presented the climatic divisions of China, with consideration being given to the aridity index (K) of G. T. Selianinov (K = E/r, where E is the potential evaporation and r precipitation) as well as the subjective divisions made in the early period, i. e. de Martonne's aridity index, and Köppen's or Thornthwaite's classification system (Zhu 1962, Watts 1969). Qion et al. (1965) and Lu et al. (1965) introduced a slightly modified index for the climatic division of China expressed by the ratio of moisture deficit and precipitation. In recent studies on agro-climatic regions, Qiu et al. (1980) and Qiu (1983) also used the same index for the 3rd-order division. In short, there are few studies on climatic division by precipitation with the aid of a statistical method. Therefore, Yoshino et al. (1984) tried to perform a regional division by using the annual amount of precipitation and the variation type of annual precipitation by means of principal component analysis method. As a result, China was subdivided into 3 regions governed by 11 different types of variation. This study also shows that summer precipitation is the determing factor of annual variation tpyes and, therefore, the regional division. For China, the climatic division is still being studied, however, without statistical methods (Chen 1982).

On the other hand, many attempts have been made to divide the climatic regions of Japan. A comprehensive review has been given elsewhere together with a new division in five orders from macro-scale to micro-(local-)scale (Yoshino 1980). Nomoto et al. (1983) recently proposed to apply the eigenvector analysis for a regional division of Japan according to precipitation. Kikuchibara (1984) investigated in detail regional divisions of Japan with the aid of statistical methods, however, without applying them to other regions of Asia or the world.

For the remaining regions of East Asia, some results have been published on climatic division by applying de Martonne's, Köppen's or Thornthwaite's system. Details are not provided due to lack of space.

In conclusion, it may be stated that no attempt has been made to study the regional division of climate or of precipitation for East Asia as a whole.

With regard to the changing pattern of summer precipitation in East Asia, the following facts have been established for Japan. The secular variation curve of annual precipitation during the 30-year period from 1951–1980 shows a marked maximum for the Fifties with a gradual decrease in the later decades (*Japan Met. Agency* 1984). In the case of summer precipitation, the picture is somewhat different: After a maximum in the early Fifties, a second sharp maximum occurred at the beginning of the Seventies, which was particularly striking in Southwest Japan. These maxima were caused by the increased activity of the so-collad Bai-u front during the period mentioned above. Similar patterns are found with regard to the secular changes of the number of days with 1–30 mm/day and 30–50 mm/day in Tokyo (Yonetani 1978).

Quite similar trends have been reported for summer rainfall in China: ZHANG (1981) showed that Shanghai and Quangdong experienced a wet period in the Fifties as opposed to a dry period in the Sixties. WANG et al. (1981a) as well showed the longer Mai-yü period with increased rainfall in the Fifties and a shorter one with scarce rainfall in the Sixties.

From a study on the chronology of summer rainfall patterns over East Asia it becomes evident that the wet years tended to occur in the Fifties and the dry years in the Sixties (YOSHINO a. URUSHIBARA 1982). It was also concluded that they are attributable to the zonal index anomalies at the 500-mb level of the northern hemisphere and the positional shift of the Pacific and Eurasian polar frontal zones.

The relationship between the interannual variation of summer precipitation and SST over the North Pacific have been studied intensively in recent years. Particularly variations of summer rainfall (Mai-yü period) in the Yangtze River region or other parts of China were analyzed in relation to SST in the Kuroshio region for the preceding winter at a high significance level (*Long-Range Weather Forecasting Group, Inst. Atmos. Sci., Acad. Sinica* 1978). Also GUO et al. (1979), SHA et al. (1979), PAN (1978), LI H.-ZH. (1978) and *Long-Range Weather Forecasting Group, Inst. Atmos. Sci., Acad. Sinica* (1979) have stressed the importance of SST for predicting summer rainfall in China. In the last paper, the distribution of correlation coefficients between rainfall in June and the SST in October or November of the preceding years shows significant positive correlation areas in the Kuroshio region in the low latitudes of the southwestern part of North Pacific, and negative areas in the California Current region or the eastern part of the equatorial Pacific.

From one of our previous studies on summer precipitation in the six main regions of East Asia and on SST over the North Pacific, it becomes evident that the areas showing a high significance level are the California Current area, the Alaska Current area, the Humboldt (Peru) Current area, the Anti-Equatorial Current area, the Equatorial Current area, and the central part of the Pacific (YOSHINO a. XIE 1983). It was also pointed out that these areas are subject to a seasonal shift that depends on the respective location of the rainfall regions.

In conclusion, the following phenomena should be studied: (i) The seasonal movement of significant correlation areas and their relationship with the ocean circulation and atmospheric circulation, (ii) the lag effect of SST, and (iii) the areal division or selection of points grouped by using the high level correlations. The present study was carried out by taken into account the problems specified above.

3. *Data and analysis method*

Monthly rainfall data of a 25-year period from 1956 to 1980 were used for the months of June and July. These data were also utilized for determining the mean monthly rainfall for June and July. The rainfall data were taken from 150 Chinese, Korean and Japanese stations, which were selected in such a manner that they show an approximate even spacing. The area covered for the analysis and the numer of stations are considered to be large enough to represent the characteristics of monthly rainfall over East Asia.

The first step in the analysis consists in the standardization of the cubic root of monthly rainfall at each station. The rainfall field is denoted by $P(s, t)$, where $s = 1$ to 150 stations and $t = 1$ to 25 years from 1956 to 1980 for each month of June and July, including the mean for these two months.

We define $Pa(s, t) = \{P(s, t) - Pm(s)\}/S(s)$, where Pm and S are the mean and the standard deviation calculated for a 25-year period. Thus, the mean of Pa is 0.0 and its standard deviation 1.0 for each station, which facilitates a comparison of the time series of rainfall at 150 stations.

In order to classify the regional distribution of the interannual variation of monthly rainfall, a cluster analysis is carried out for the standardized data. In cluster analysis, a measure of similarity or measure of difference $D(s_1, s_2)$ between the two time series profiles, i. e. $Pa(s_1, t)$ and $Pa(s_2, t)$, is defined by:

$$D(s_1, s_2) = [\sum_{t=1}^{25} \{Pa(s_1, t) - Pa(s_2, t)\}^2]^{1/2}.$$

This is the usual Euclidian distance between two 25-dimensional vectors. A small distance implies that the profiles at the stations are similar, whereas, a large distance between two stations arises from disparities in the interannual variations. The stations at the minimum distance are amalgamated to a cluster. Then its nearest neighbour is added. The distance between two clusters is calculated from the centroids of the stations in the cluster. This clustering process is continued until the regions are classified relevantly.

SST data were taken from the materials compiled by the *Institute of Geography, Academia Sinica,* and the *Shanghai Central Meteorological Observatory* (1979, 1980) and from the maps *(NOAA, Southwest Fisheries Center)* at 5-degree mesh point intervals in the North Pacific for each month from 1951 to 1980. Correlation coeffi-

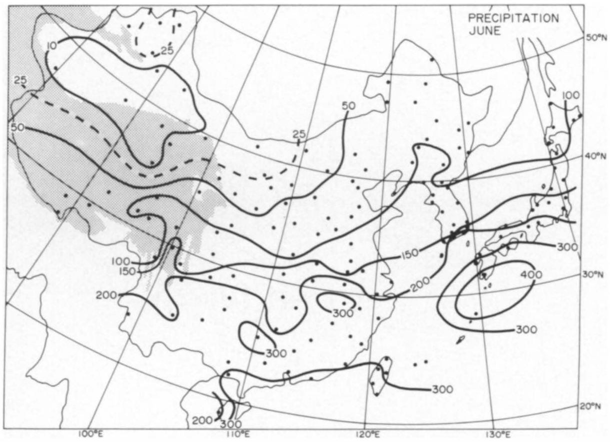

Fig. 1: Precipitation (mm) in June, mean 1956-1980

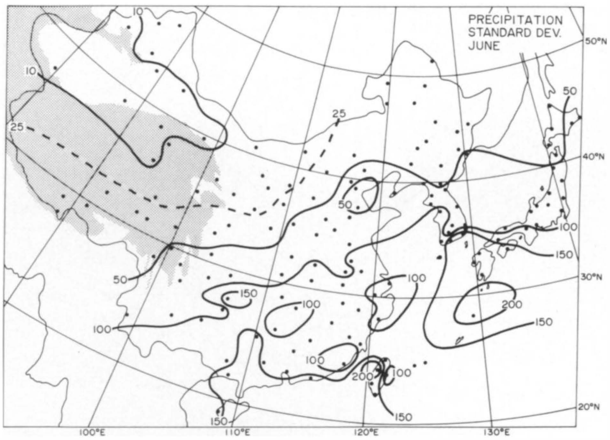

Fig. 2: Standard deviation of monthly precipitation (mm) in June, 1956-1980

cients between monthly precipitation and the SST were also calculated on the basis of the thirty-year records. The calculation is carried out by combining monthly precipitation with the SST for the three previous and the two subsequent years.

4. General description of summer precipitation

The distribution patterns of monthly precipitation in June, July, and June plus July are discussed in brief, although they have already been described in the Climatic Atlases for China (*Central Met. Bureau* 1979), Japan (*Japan Met. Agency* 1971) and for Korea (*Central Met. Office* 1962).

In order to provide a clear picture of the distribution features in East Asia as a whole, the following general description is given:

In June, as shown in Fig. 1, the area receiving more than 200 mm of rainfall covers South China and Southwest Japan. The maximum amount of 400 mm occurs in South Kyushu and the northern parts of Nansei Shoto, where the Bai-u front is significantly developed. The only exception is the west coast of Hainan Island, which receives less than 200 mm. In North and Northeast China as well as northern Japan rainfall is less than 100 mm, in which the rainy season has not yet set in. The distribution of standard deviation of precipitation in June, as given in Fig. 2, also shows a close relationship with the Bai-u front activities; namely Southwest Japan, including the southernmost part of the Korean Peninsula, shows a standard deviation of more than 150 mm. On the other hand, the South China coast and some parts of Taiwan, where the typhoon frequencies are subject to great interannual variations, also experience a standard deviation of more than 150 mm. In short, the Mai-yü and the Bai-u regions receive more than 150 mm of precipitation per month with a standard deviation of about 100 mm, while the typhoon regions have more than 300 mm of monthly rainfall with a standard deviation of 150 mm for the month of June.

In July, the zonal precipitation maxima indicated by the 300 mm isohyet are to be found on the Pacific coast, Southwest Japan and the central parts of the Korean Peninsula, as can be seen from Fig. 3. These zones with two maxima are quite striking as has already been emphasized in previous studies (Yoshino 1963, 1965, 1966), i. e. the southern maximum coincides with the normal position of the Pacific polar frontal zone and the northern one with the easternmost part of the Eurasian polar frontal zone extending from Mongolia to the Korean Peninsula. In another interpretation, it may be said that the southern maximum occurs during the stronger summer monsoon and the northern one during the weak summer monsoon, as has been shown in synoptic climatological models by Tanaka (1980). These areas of maximum rainfall are enclosed by the 200 mm isohyet clearly showing the Bai-u and Mai-yü frontal zones. Another area with heavy rainfall extends from Taiwan to the coast of South China and further to Yunnan and Guangxi.

Fig. 4 shows the distribution of standard deviation of monthly precipitation for July. The western part of South China, the eastern part of Central China, the Korean Peninsula, and the western portion of Central Japan show a standard deviation of more than 100 mm. In the western part of Kyushu and the southern part of Taiwan values of 200 mm can be regi-

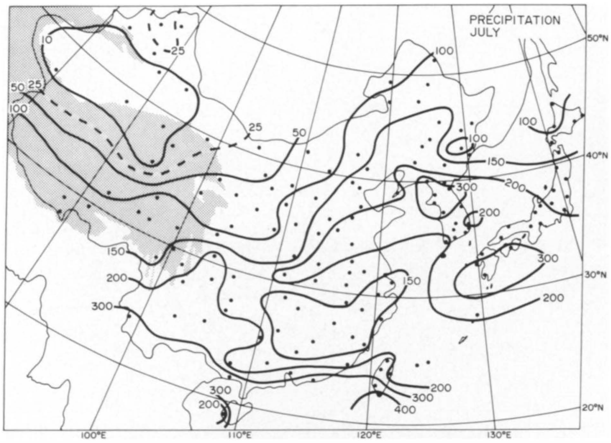

Fig. 3: Precipitation (mm) in July, mean 1956–1980

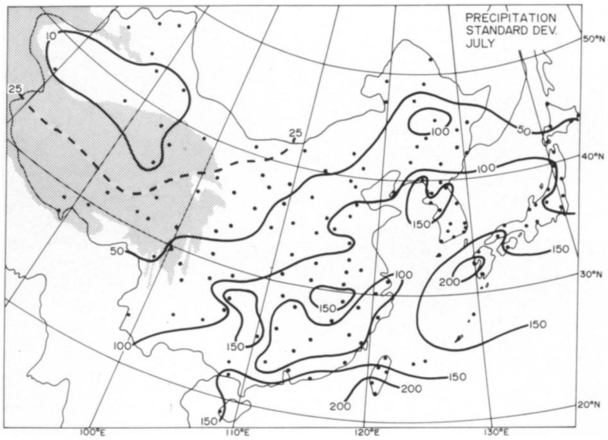

Fig. 4: Standard deviation of monthly precipitation (mm) in July, 1956–1980

stered. In short, the areas experiencing more than 150 mm represent the active Bai-u frontal zone, the Mai-yü frontal zone and typhoon (or ITCZ) zone.

5. *Regional divisions*

The following section deals with the result of cluster analysis for the interannual variations of precipitation at the 150 stations 1956–1980. Fig. 5 shows the regional division by grouping the stations, which have the same rainfall tendencies for the month of June. In this connection, it becomes clearly evident that Region I appears in a zonal form stretching from the eastern part of the Tibetan Plateau to the Ryukyu islands across South China. Region II is located in the southwestern and central parts of Japan, whereas Region III occupies wide areas of North China, the Korean Peninsula and some parts of North Japan. Regions IV, V and VI are distributed in various parts of China, but are not mentioned here as a result of their location. Types of Regions VII and VIII are considered a variant or similar type of Regions II and III.

In July, Regions I, II and III show the same location as in June, i. e. Region I is located in South China and Region II in Japan (excluding Hokkaido) also covering the lower Yangtze River region. Similarily, Region III mainly covers Northeast China and Hokkaido as shown in Fig. 6. The seasonal change of the area covered is striking; Regions I and III become smaller in July, whereas Region II grows larger.

This change is attributable to the great effects of the Bai-u and Mai-yü fronts in July, which show parallel interannual variations. Both the shape and location of Region I are also interesting in terms of synoptic climatology. The zones are similar in both month, but show a slight southward shift in July, extending from Yunnan to Taiwan across Guangxi and Guangdong. However, their southernmost parts are not included in Region I. So far, only one study exists, which clearly shows that the southward shift of synoptic climatological phenomena is related to the rainfall received in June and July in East Asia: Tanaka (1980) showed the southward shift of the ITCZ in the maps of geopotential height at the 850-mb level in June and July.

If we take a closer look at the shape of Region III, we will notice a branch extending in a northwestern direction to Northeast China, which may correspond to the eastern part of the Eurasian polar frontal zone (Yoshino 1963, 1965). The main part of Region III

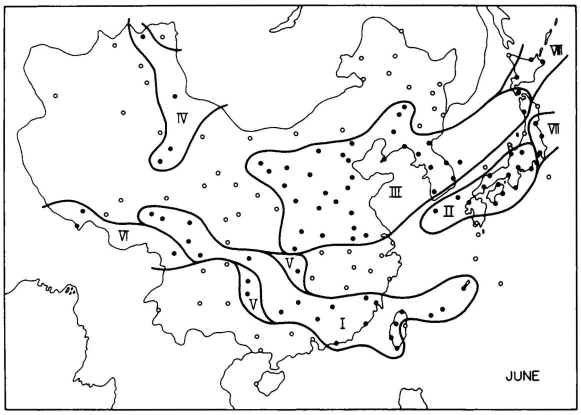

Fig. 5: Regional division of East Asia by interannual variation of precipitation in June, 1956–1980

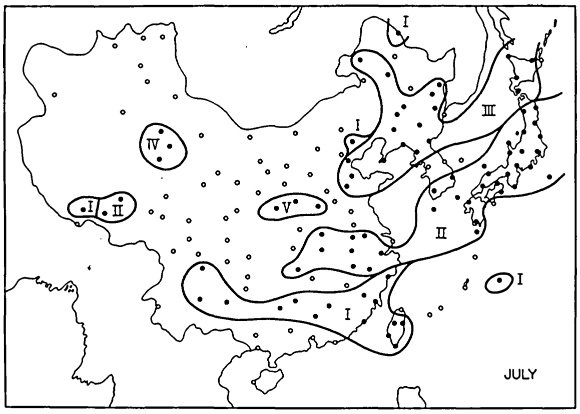

Fig. 6: Regional division of East Asia by interannual variation of precipitation in July, 1956–1980

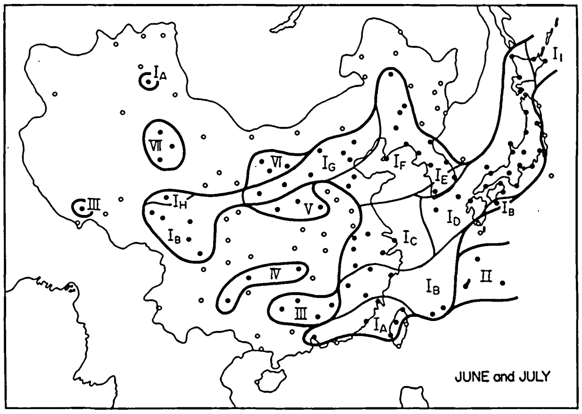

Fig. 7: Regional division of East Asia by interannual variation of precipitation in June plus July, 1956–1980

runs from west of the Bo Hai to the southeastern part of Northeast China and further to Hokkaido, extending in a zonal form from southwest to northeast. This shape and location has often been analyzed in synoptic climatological studies (KURASHIMA 1968).

Fig. 7 shows the regional division of East Asia according to precipitation for June plus July. Since the numbering of Regions differs from that of Figs. 5 and 6, it is difficult to compare them with each other. However, the following facts are noticeable: Regions I_A, I_B and III of Fig. 7 roughly correspond to Region I of Figs. 5 and 6. Regions I_C and I_D are very similar to Region II whereas Region I_F corresponds to Region III for precipitation of June and July. It is quite remarkable that Regions I_G and I_H, which are grouped into the Region I family, extend from the eastern part of the Tibetan Plateau to the North China plain, which means that all of these Regions are under the influence of the polar frontal zones in a broader sense. This is also reflected by the regional division of China according to the change of seasonal patterns of precipitation (YOSHINO a. CHIBA 1984). The border line between Regions I and II in this study corresponds to that of Regions I_H and I_G of Fig. 7 in the present study. Region II of the other study has a marked summer maximum of precipitation, whereas Region I has no significant maximum. In addition, Regions I_H and I_G of Fig. 7 have almost the same location as the SD (semi-dry) regions determined by QION a. LIN (1965). North of this region are the D (dry) regions of their climatic division of China, which is based on dryness-wetness criteria.

In conclusion, the following summaries may be provided for the regional division of precipitation in June–July: (i) Broad region; Regions I_A–I_H are statistically grouped as one unit. In this region, the activities of the polar frontal zones may vary parallel from year to year. (ii) Strictly speaking, Region I_C reflects the Mai-yü frontal zone, Region I_D the Bai-u frontal zone and Region I_F the eastern part of the Eurasian polar frontal zone. (iii) It is interesting to note that Region I_C is influenced by the more tropical character of the Mai-yü polar frontal zone and Region I_D by the more polar frontal nature of Bai-u frontal zone. (iv) Regions I_H and I_G are located on the border between the arid and wet regions in China, and their parallelism of year-to-year variation, their zonal shapes and direction should be noted. (v) Regions I_C and I_D which, as shown above, are characterized by the polar frontal zones, correspond to Köppen's Cf climate, with an annual frequency of occurrence exceeding 25% (YOSHINO a. URUSHIBARA 1981).

6. *Secular variations in the main regions*

This section of the study deals with the secular variations of area-average precipitation in the respective main regions determined in the preceding part of the study. The calculation results of the long-term variations in June and July in Regions I, II and III for the period 1956–1980 are shown in Figs. 8 (a) and (b). It is remarkable that the variations differ from region to region and from June to July. 2-, 3- and 4-year cycles are observable in the secular changes, but the series of years is not long enough to evaluate these cycles statistically.

Qualitatively the following facts can be seen from Figs. 8 (a) and (b): (i) In Region I the maxima and minima in the June and July curves mainly occur in opposite phases before 1968 and after 1968. (ii) In Region II the maxima and minima in June and July

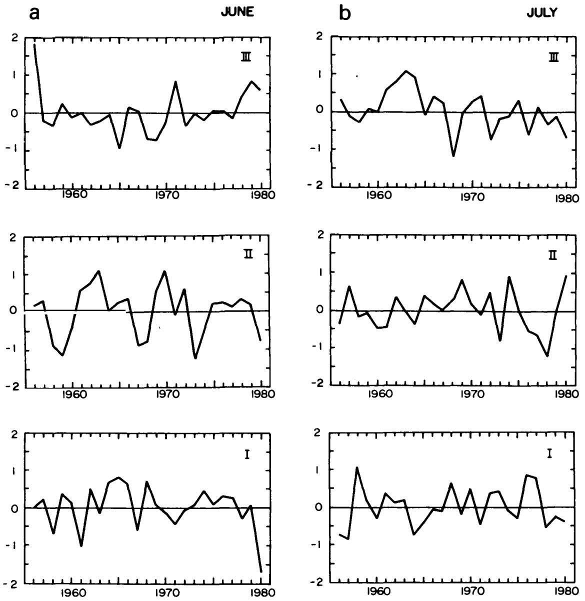

Fig. 8: Secular variations of precipitation in Regions I, II, and III in June (a) und in July (b). Y-axis: standardized values

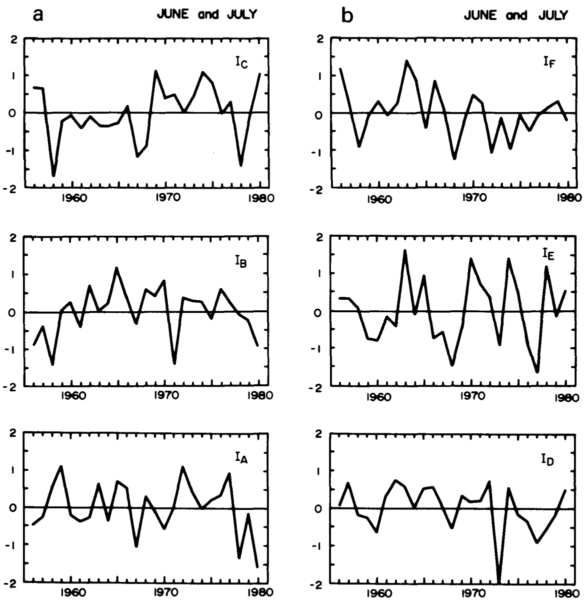

Fig. 9: Secular variations of precipitation in Regions I_A–I_C (a) and in Regions I_D–I_F (b) in June and July. Y-axis: standardized values

largely occur in same years prior to 1974, but not after 1974. (iii) Region III shows the same trends as Region II. (iv) A general decreasing trend is only observable in July for the secular change in Region III. The other curves do not show any distinct trends.

In Figs. 9 (a) and (b), the secular variations of precipitation for June plus July in Regions I_A–I_F are shown. They reveal the following facts: (i) The clear minima in Regions I_B, I_C and I_F occurred in 1958; in Regions I_A, I_B and I_C in 1967; in Regions I_D, I_E and I_F in 1968; in Regions I_D and I_E in 1973 and 1977; and in Regions I_A and I_C in 1978. (ii) The maxima show similar characteristics. (iii) The maxima and minima mainly occurred in the same years in Regions I_D and I_E.

Fig. 10 shows the secular change of precipitation in June/July in the entire area of Region I. This figure presents as general view of the trend summer precipitation in the polar frontal zone of East Asia during the years 1956–1980. In this connection, the following characteristic features are observable: (i) A general decreasing trend prevails after the second half of the Sixties. (ii) Clear minima appeared in 1958, 1968, 1973, and 1978. (iii) In contrast to this, there are no distinct maxima. High amounts of precipitation occurred in 1962, 1963, 1966, 1969, 1970, 1974, 1975, and 1979. The fact (i) mentioned above has been reported in previous papers for Shanghai (Wang et al., 1981) and for the Yangtze River region (Sha et al., 1979). It may also be interpreted as a result of the decreasing frequency of occurrence of the Bai-u frontal zone (Yoshino a. Kai 1974). The minima in 1958 and 1968 have generally been reported as droughts in the Mai-yü period (Yoshino a. Urushibara 1982). In these years with minimum rainfall the average zonal index (40–60° N, 90–170° E) shows a marked positive anomaly for June and July at the 500-mb level.

The fact (i) strikingly coincides with the curves showing the temperature change in the lower layers of the atmosphere over the northern hemisphere compiled by H. Flohn (Lamb 1981). In addition, the maxima and minima of precipitation in June and July of Region I mainly coincide with the maxima and minima of the temperature variations before 1970. After

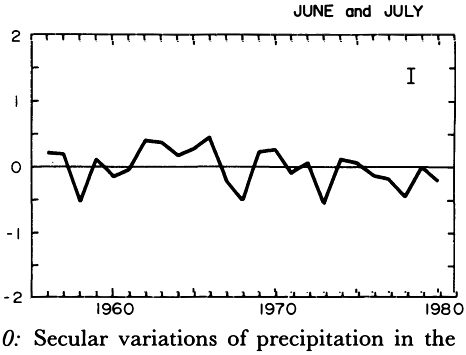

Fig. 10: Secular variations of precipitation in the entire area of Region I in June and July, 1956–1980

about 1970, the maxima and minima occurred independently in these curves and/or in an opposite phase. However, it is interesting to note that the maxima and minima in July of Region III shown in Fig. 8 (b) appeared in a same phase as the temperature change in the northern hemisphere, even after 1970. Therefore, it must be concluded that, due to decreasing temperatures in the northern hemisphere during the period of observation (HARLEY 1980), summer precipitation has generally been decreasing in the region of the polar frontal zones over East Asia. The interannual variation of precipitation, the maxima and minima, however, coincide with the air temperature variation in the northern hemisphere before approximately 1970. After this year, both variations are not synchronous and some times even contrary to each other. This means that the synoptic climatological process has changed under the influence of the lower temperature conditions, especially after 1974. However, precipitation in July in Northeast China and Hokkaido which is influenced by the Eurasian polar frontal zone still shows a certain parallelism with the temperature variation in the Seventies.

7. *Relation to sea surface temperature*

This section deals with the relationships between the average precipitation in the respective main regions, which have been determined in the previous chapter, and the sea surface temperature (SST) over the North Pacific by calculating correlation coefficients. The precipitation data are identical with those used in the preceding chapter. The correlations were calculated between the annual amount of precipitation in June and/or July and the monthly SST of a period from January of the third year before to December of the second year after. Thus for every year of the period 1956–1980 72 correlation coefficients between precipitation and SST were calculated at each point at 5° latitude and 5° longitude intervals in the Northern Pacific. To summarize the correlation calculation results, the following "degree of correlation" was defined. As the correlation coefficient for a significance level of 5% is ± 0,40, the "degree of correlation" was defined as the sum of the correlations higher than |0.40|. The positive and negative correlations were added up separately. The calculations were made for precipitation in June in relation to the SST, for July, and for June/July in Regions I, II and III.

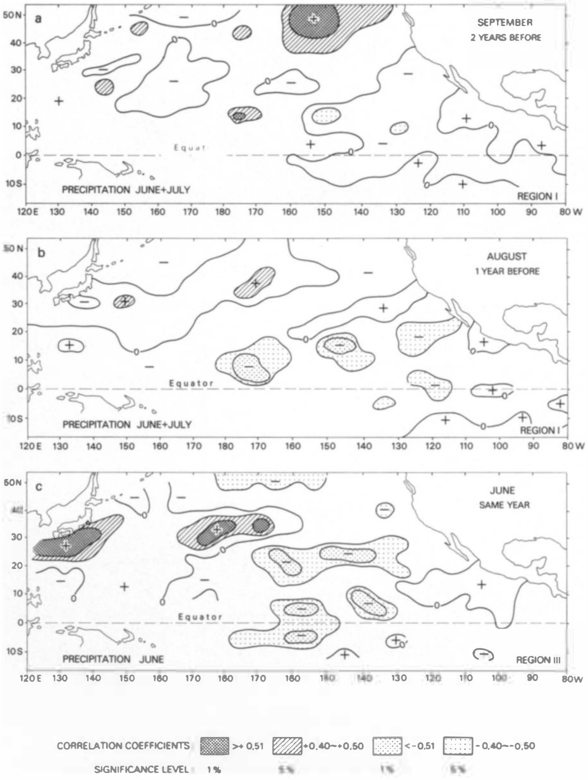

Fig. 11: Distributions of correlation coefficients between:
(a) June plus July precipitation in Region I as shown in Fig. 7 and the SST in September of the second year before;
(b) June plus July precipitation in Region I as shown in Fig. 7 and the SST in August of the previous year;
(c) June precipitation in Region III as shown in Fig. 5 and the SST in June of the same year

Examples of the distribution of correlation coefficients are given in Figs. 11 (a), (b), and (c). Fig. 11 (a) illustrates the distribution of the correlation coefficients for precipitation in June plus July in Region I, which is shown in Fig. 7, and the SST in September of the second year before. In Fig. 11 (b) the precipitation is correlated with the SST of the month of August of the previous year.

In the preliminary study on the climatic anomalies in East Asia and the SST over the North Pacific (YOSHINO a. XIE 1983), the correlations were only calculated for a two-year period. In Fig. 11 (a), the significant positive correlations are found in the Alaska Current area and central and southern parts of the anticyclonic area of the North Pacific, while the negative ones occur only in isolated locations of the southeastern part of the anticyclonic region. In Fig. 11 (b), the significant positive correlations are found east of the date line at 35 or 40° N, whereas rather broad

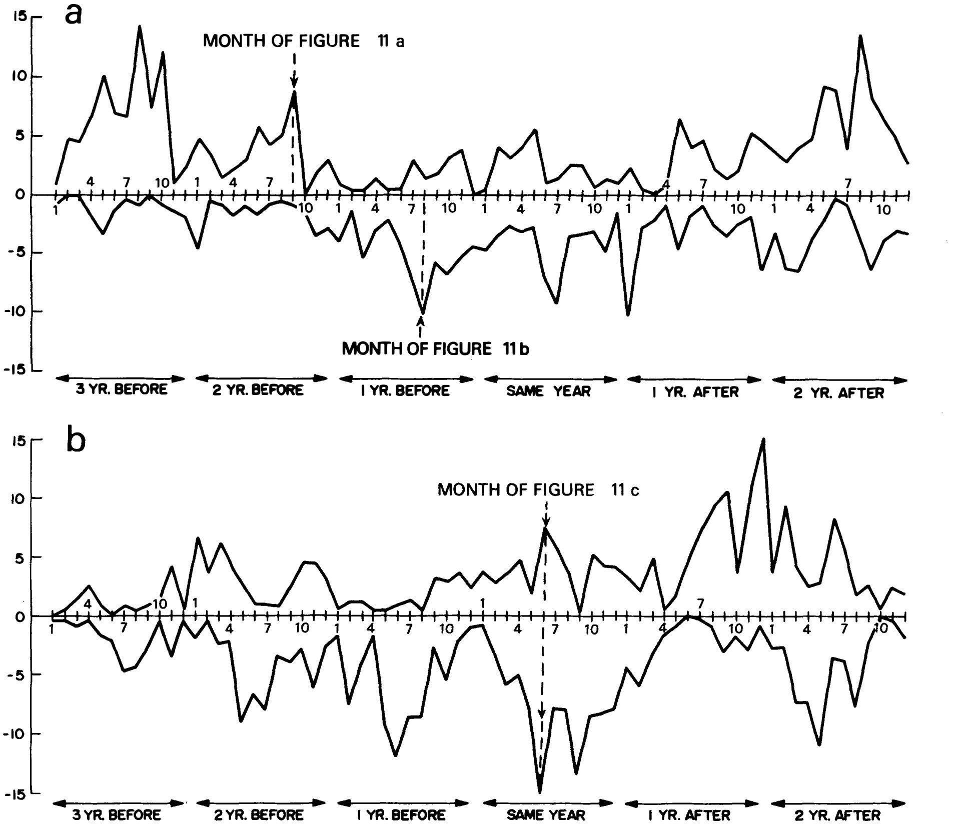

Fig. 12: Secular change of degree of correlation between:

(a) June plus July precipitation in Region I as shown in Fig. 7 and the SST of the period from January of the third year before to December of the second year after. Y-axis shows the „degree of correlation“ (cf. text)

(b) June precipitation in Region III as shown in Fig. 5 and the SST of the same period

negative areas extend from the California coast into a west-southwestern direction to the central part of Pacific, i. e. the North Equatorial Current. Determination of these areas with correlations at a higher significance level are particularly important for providing information for longe-range weather forecasting.

One example of the distribution of the simultaneous correlation coefficients is shown in Fig. 11 (c), i. e. the correlation coefficients of precipitation for June in Region III, as shown in Fig. 5, and the SST for June of the same year. The significant positive correlations are found in the Kuroshio area and in the central part of the North Pacific. In contrast to this, significant negative correlation coefficients are observable in the eastern part of the central North Pacific and the mid-section of the Equatorial Current. One additional area with negative correlation values is located in the Bering Current area.

Fig. 12 (a) shows the monthly change in the degree of correlation between the June plus July precipitation in Region I, as shown in Fig. 7, and the SST. From this figure it becomes apparent that the positive correlation values do not prevail for the SST in the year before and in the same year. However, it indicates positive relationships with the SST in the third previous years and in the second succeeding years. The negative correlation values, however, are quite marked in the previous year and in the same year. Fig. 12 (b) presents the same time series, however, for the precipitation in the month of June in Region III, as shown by Fig. 5. In this case, the negative correlation values prevail in June of each year, except in the subsequent year.

The reason for such long-term fluctuations is not clear, but will be particularly interesting for studies on climatic air-sea interaction processes. Some short-term fluctuations can also be detected by further statistical investigations into the monthly change in the degree of correlation.

The *Long-Range Weather Forecasting Group, Institute of Atmospheric Science, Academia Sinica* (1979) presented a map showing the distribution of correlation coefficients between precipitation in the lower Yangtze River region in June and the SST in the North Pacific. This result and the results gained in the preliminary study for Region C (YOSHINO a. XIE 1983) correspondend well with those of the present study. CHAO et al. (1984) wrote that a long-term in-phase oscillation of 32–48 months (3–4 years) exists for the tropical SST, the intensity of the subtropical anticyclone and the cloudiness over the central North Pacific. The long-term fluctuations mentioned above should show some of these relationships. Further studies on these subjects are necessary.

8. *Summary and conclusion*

The present study first provides a general view on the precipitation distribution patterns in June, July and June/July that are based on the mean values and standard deviations for the period 1956–1980. Secondly, a regional division was attempted by applying the cluster analysis method to the precipitation values recorded at the 150 stations for 1956–1980. Thirdly, the secular variations in the main regional units were studied. Finally, annual variations of precipitation in June, July and June/July were analyzed for the main regions in relation to the SST over the North Pacific. The most important results can be summarized as follows:

(1) The regional divisions according to the interannual variations of precipitation in June, July and June/July are closely related with the seasonal change in the Mai-yü and Bai-u frontal zones as well as with the eastern-most part of the Eurasian polar frontal zone.

(2) Summer precipitation in the region influenced by the frontal zones decreases in the second half of the Sixties. This long-term trend coincides with the temperature change in the lower layers of the troposphere over the northern hemisphere.

(3) The maxima and minima obvious in the short-term fluctuation coincide with those of the air temperature in the northern hemisphere before 1970. After this year, both variations are not parallel or out-of-phase, which means that the synoptic climatological process has changed under the influence of lower temperature conditions, particularly after 1974.

(4) The correlation coefficients between the spatial distribution of mean precipitation in the main regions and the SST of the 3 previous yeras (lag-correlation) and the 2 subsequent years were calculated for the areas in the North Pacific. Significant correlations were found in the California Current, the Alaska Current, the North Equatorial Current, the Kuroshio, and the Central Subtropical Anticyclone areas in some months of the five-year period mentioned above.

References

Central Meteorological Bureau: Climatic atlas of the People's Republic of China. Map Publication Office, Beijing 1979.

Central Meteorological Office, Republic of Korea: Climatic atlas of Korea, 1931–1960. 1962.

CHANG, P.-I. et al.: A preliminary study on dividing Chinese climate. In: A tentative division of natural landscape of China. Science Publ., Beijing 1956, 37–49.

CHAO, JI-PING, FU, CONG-BIN and JI, JIN-JUN: Large-scale tropical air-sea interaction studies. Tropical Ocean-Atmos. Newsletter 25, 1984, 12–13.

CHEN, X.-J.: A new approach to the climatic division of China. Acta Met. Sinica 40, 1982, 35–48.

CHU, C.-CH.: Climatic provinces of China. Memoir Institute of Meteorology, Nanking, 1, 1929, 1–11.

GUO, Q.-Y. et al.: Classification of precipitation distribution during the wet season in China and its seasonal change. Dili-jikan 11, 1979, 16–39.

HARLEY, W. S.: The significance of climatic change in the northern hemisphere 1949–1978. Mon. Wea. Rev. 108, 3, 1980, 235–248.

Japan Meteorological Agency: Climatic atlas of Japan. Vol. 1, 1971.

– : Report on unusual weather and climate change III, 1984.

KIKUCHIBARA, H.: Regional division of Japan by precipitation. Geophys. Mag. 41, 1984, 61–157.

KURASHIMA, A.: Studies on the winter and summer monsoon in East Asia based on dynamic concept. Geophys. Mag., 34, 1968, 145–235.

LAMB, H. H.: Climatic changes and food production: Observations and outlook in the modern world. GeoJournal 5, 1981, 101–112.

LI, H.-ZH.: Air-sea interaction and its effect on the rainfall in the wet season in North China plain. Coll. Papers Inst. of Atmosph. Sci., Acad. Sinica 6, 1978, 116–129.

LI, M.-T. et al.: Advance in research of the influence of sea surface temperature anonaly on long-range weather process. Scientia Atmos. Sinica 3, 1979, 249–255.

Long-Range Weather Forecasting Group. Institute of Atmospheric Science, Academia Sinica: Anomalies of sea surface temperature in winter over the Pacific and its effects on the precipitation in the wet season in China. Coll. Papers. Inst. of Atmosph. Sci., Acad. Sinica 6, 1978, 1–12.

– : A highly possible physical factor in the long-range forecasting. Monographs on the medium- and long-range hydro-meteorological forecasting 1, 1979, 172–184.

LU, A.: The climatic provinces of China. Collected Sci. Papers, Meteorology. Peking 1954, 469–474.

Lu, Ch.-y. et al.: A study on the wet and dry periods and regionalization of China according to aridity. Acta Geogr. Sinica 31, 1965, 15-24.

Natural Division Committee, Academia Sinica: Climatic division of China. In: Natural division of China. Sci. Publ., Beijing 1959, 311-323.

Nomoto, Sh. et al.: An application of eigenvector analysis for regional division of climatic elements: Regional division of Japan by precipitation. Tenki 30, 1983, 385-392.

Pan, Y.-h.: A preliminary analysis on the heating field of ocean in winter and spring and lake districts rainfall season. Coll. Papers. Inst. of Atmosph. Sci., Acad. Sinica 6, 1978, 102-115.

Qion, Jh.-l. and Lin, L.-k.: A preliminary study on the dry and wet climatic regionalization of China. Acta Geogr. Sinica 31, 1965, 1-14.

Qiu, B.-j.: Further study on the regionalization of agroclimate of China. Acta Geogr. Sinica 38, 1983, 154-162.

Qiu, B.-J. and Lu, Q.-y.: A tentative regionalization of agroclimate of China. Acta Geogr. Sinica 35, 1980, 116-125.

Sha, W.-y. et al.: Relationship between the subtropical anticyclone and the Mai-yü rainfall in the lower course of the Yangze River and SST over the Pacific. Dili-jikan 11, 1979, 126-137.

Tanaka, M.: Role of the circulation at the 150 mb level in the winter and summer monsoon in the Asian and Australian regions. Climatological Notes 26, 1980, 1-134.

Tu, Ch.-w.: Climatic provinces of China. Memoir National Research Inst. Met., Nanking, Acad. Sinica, 8, 1936, 1-22.

Wang, Sh.-w., Zhang, P.-y. and Zang, D.-e.: Further studies on the climatic change during historical times in China. Proc. Tech. Conf. Climate, Asia and Western Pacific. WMO, 578, 1981 (a), 376-393.

Wang, Sh.-w., Zhao, Z.-c. and Cheng, Zh.-h.: Reconstruction of the summer rainfall regime for the last 500 years in China. GeoJournal 5, 1981 (b), 117-122.

Watts, I. E. M.: Climates of China and Korea. In: Climates of Northern and Eastern Asia. World Survey of Climatology 8. Amsterdam 1969, 1-117.

Yonetani, T.: Analysis of secular changes of precipitation at Tokyo. Tenki 25, 1978, 39-45.

Yoshino, M. M.: Rainfall, frontal zones and jet streams over East Asia. Bonner Met. Abh. 3, 1963, 1-129.

– : Four stages of the rainy season in early summer over East Asia (Pts. 1 and 2). Jour. Met. Soc. Japan II, 43, 1965, 231-245; 44, 1966, 209-217.

– : The climatic regions of Japan. Erdkunde 34, 1980, 81-87.

Yoshino, M. M. and Chiba, M.: Regional division of China by precipitation. Geogr. Rev. Japan. Ser. A. 57, 1984, 583-590.

Yoshino, M. M. and Kai, K.: Pressure pattern calendar of East Asia, 1941-1970, and its climatological summary. Climatological Notes 16, 1974, 1-71.

Yoshino, M. M. and Urushibara, K.: Regionality of climatic change over East Asia. GeoJournal 5, 1981, 123-132.

– : Interannual variation of water deficiency over East Asia. Sci. Rep. Univ. Tsukuba. Sec. A. 3, 1982, 39-66.

Yoshino M. M. and Xie, S.-m.: A preliminary study on climatic anomalies in East Asia and sea surface temperature in the North Pacific. Sci. Rep. Univ. Tsukuba. Sec. A. 4, 1983, 1-23.

Zhang, J.-ch.: On possible impacts of climatic variation on agriculture in China. Proc. Techn. Conf. Climate, Asia and Western Pacific. WMO, 578, 1981, 278-288.

Zhu, P.-h.: China's climate. Sci. Publ., Beijing 1962, 1-363.

Data Sources

Institute of Geography, Academia Sinica, and the *Shanghai Central Meteorological Observatory;* North Pacific Monthly Mean Sea Surface Temperature Data. Ocean Publ. Office, Beijing 1979, 1-463; 1980 1-324.

NOAA, Southwest Fisheries Center: Fishing Information. NOAA/National Marine Fisheries Service. La Jolla, California. Monthly.