The Climatic Change during Past Centenary in Taiwan Area

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ABSTRACT

With a peculiar topography, Taiwan lies in the intersection zone of the tropical and the sub-tropical belts, with an area of 35,981 km^2, the Central Mountain range lying to the east coast of the Taiwan area, 64% of its topography is mainly of mountainous regions.

Data from stations situated over the plain area, mountainous regions and off-island areas are selected in order to carry out a climatological data analysis around Taiwan area. It is found that, based on the standard normal values for 3 consecutive periods (i.e. 1901-1930, 1931-1960, 1961-1990), the temperature increases are over plain areas and off-island stations, the precipitation increase over the northern part of the Taiwan area.

By applying the auto-correlations and harmonic analysis on the above mentioned data and stations, the results come out as that there are two significant peaks for the yearly temperature auto-correlation spectrum, the 1st peak appears approximately as a 5.7 years period and the 2nd with a period of 44 years. Same methods are also carried out on the yearly rainfall data, and it shows that the 1st peak is 2.7-3.1 years in period, and the 2nd peak is also 44 years in period.

INTRODUCTION

The long-range change of climate can heavily affect our daily life, national economic development as well as agricultural production. A lot of people are greatly careful in comparing the climate between current and past years. Frequently, they have simple questions. For example "Is the weather in the Taiwan area hoter than ever?", "Is the rainfall here decreased somehow?". It is usually easier to ask than to describe, that is because that from all different kinds of point of view (such as locations and time periods) they might have a quite different answer. In this paper we are interested in the variations of single weather element and know that the total variation or oscillation of a meteorological variate with time can be described as the sum of several oscillations. Certain oscillations will be regular; others will be irregular. There are eight names which will be used to describe the climatic change. They are described as follows:

1. the climatic discontinuity - to cease from mean value of climatic
2. the climatic fluctuation - an irregular variation, an instance of systematic variation
3. the climatic oscillation - swinging back and forth with a steady uninterrupted rhythm
4. the climatic periodicity - the recurrence at regular intervals

5. the climatic rhythm - uniform or regular recurrence of strong and weak elements (as seasonal variations)
6. the climatic trend - a general inclination or tendency
7. the climatic vacillation - swaying from one side to the other with a short time to stay or linger
8. the climatic variation - the change or deviation from the normal (30-year average)

The statistics techniques were used to quantify the tendency and fluctuation in temperature, precipitation, sunshine duration, mean cloudness, pressure, relative humidity, evaporation, soil temperature and the number of times with Typhoon invaded Taiwan area. People would like to know the future. The best known measure of persistence for a continuous variable is the coefficient of aut-ocorrelation. Auto-correlation means correlation with itself. In other words, auto-correlation coefficients are ordinary linear correlation coefficients between a time series and the same time series with a later time interval. By analyzing the seasonal preci-pitation in auto-correlation coefficients, we have found an evident sign, the coefficients of the correlation between winter and summer rainfalls and between spring and autumn rainfalls are negative significantly. Which means, there will be much rainfall in summer (autumn) if the rainfall is little in winter (spring) (Wei, 1974).

In this report the selected stations and map curves are selected according to the year sequence, in order to display annual weather elements with long period variation. Also by applying the auto-correlation coefficients spectrum analysis we try to deduce special phenomena to offer some predictors for long-term weather prediction. And we believe that is a great help for the decision makers.

DATA SELECTED

Almost one hundred years ago, the sea trade began to flourish between the West and the Far East. In order to meet the demand of navigation. The weather observation service in Taiwan area was operated at Keelung, Tanshui, Anping (Tainan), Takou (Kaohsiung), Fisherman Island (Penghu) and Nanchia (Oluanpi) by lighthouse and customhouse in 1885 (Ching dynasty Kuang-hsu 11). The first group of formal weather stations were established at Taipei, Taichung, Tainan, Hengchun and Penghu in 1896, and then other stations was established at plain area (city), mountainous regions and off-island areas such as Taitung in 1901, Hualien in 1911, Alishan in 1933, Yushan in 1943, Lanyu in 1940 etc. Data from stations situated over the plain area, mountainous regions and off-island area are selected as figure 1 (CWB, 1991).

The population and air pollution problems usually have a direct influence on the meteorological observations, especially in the metropolitan area, such as Taipei and Kaohsiung; but Pengchiayu, Tawu and mountainous regions still keep the original environment. We therefore select seme stations with ten-year temperature data from the"Summary Report of Meteorological Data" (CWB, 1992) Vol. II - Vol. V for the comparison of every ten-year de-

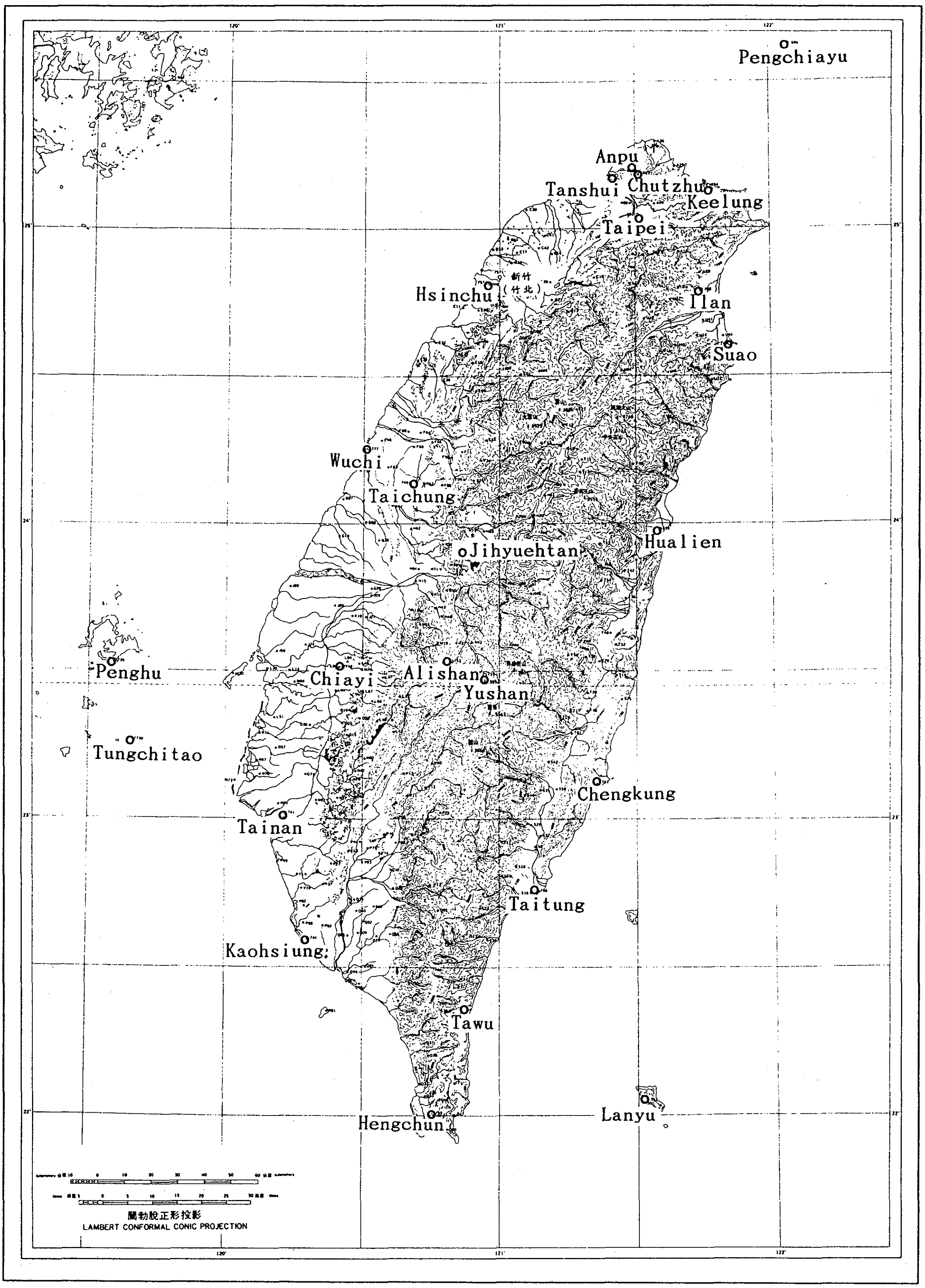


Figure 1. Geographic distribution of selected weather stations

parture values between selected stations and Pengchiayu station (Table 1). From Table 1, it is clearly perceived that from the last ten-year temperature departures, we may find that there are almost 0.5°C difference at the stations in the metropolitan cities and 0.3-0.4°C at Hsinchu and Alishan stations, only small difference in other stations. It is deduced that the urban effect is unremarkable in Taiwan area except Taipei, Kaohsiung and Hsinchu cities.

Table 1. The selected stations ten-year mean temperature (°C) and the departures that come from Pengchiayu

Area	Station	Alt (m)	Temperature (°C) 1951-60 a*	1961-70 b	1971-80 c	1981-90 d	Departure's departure d-(a+b+c)/3
metropo-litan	Taipei	6	22.3	22.2	22.3	22.7	0.5
	Kaohsiung	2	24.3	24.2	24.4	24.8	0.5
urban	Keelung	27	22.3	22.2	22.1	22.3	0.1
	Hsinchu	34	22.0	22.0	22.1	22.3	0.3
	Taichung	84	22.8	22.7	22.8	22.8	0.1
	Hualien	16	23.0	22.8	23.2	23.1	0.1
	Tainan	14	23.9	23.9	24.1	23.8	0.1
	Taitung	9	24.2	24.0	24.1	24.3	0.2
rural	Tanshui	19	22.3	22.1	22.2	22.1	-0.1
	Chengkung	33	23.6	23.4	23.7	23.7	0.1
	Tawu	8	24.9	24.7	24.8	24.8	
	Hengchun	22	25.2	25.0	25.0	24.9	-0.1
Moun-tainous regions	Anpu	826	16.9	16.5	16.6	16.7	-
	Chutzehu	607	18.3	18.3	18.5	18.4	-
	Jihyuehtan	1015	19.5	19.2	19.1	19.3	0.1
	Alishan	2413	10.8	10.4	10.4	10.9	0.4
	Yushan	3845	4.0	3.7	3.7	4.0	0.2
Off-island	Pengchiayu	102	21.8	21.6	21.8	21.7	-
	Penghu	11	23.3	23.2	23.3	23.2	-
	Lanyu	324	22.6	22.3	22.5	22.7	0.2

* a, b, c and d are the temperature departures between selected station and Pengchiayu station

The annual and diurnal variation of weather elements are in typically regular climatic rhythms. It is often easier to cover up the unremarkable climatic periodicity and climatic fluctuation, thus the yearly data instead of monthly and hourly data for analysis are selected.

CLIMATIC VARIATION

According to the definition of World Meteorological Organization (WMO), the "normal" in climatic data means the average of observation values in any continuous 30 years period. If the period selected at 1901-1930, 1931-1960, 1961-1990, ..., interval can also be called climatological the standard normal (WMO, 1966).

First, we select a case of 1901-1930 from I period, 1931-1960 from II period and 1961-1990 from III period, and compared the climatological standard normal for the 3 consecutive periods on temperature, precipitation and sunshine duration.

From the period I to III, the temperature increased 0.5-0.9°C in plain area, and 0.6°C in off-island area. It changed only 0-0.3°C from period II to III over the whole area. It is quite evident that temperature increased from period I to II (Table 2).

Table 2. Temperature standard normal and difference in variation between periods

			* Standard normal (°C)			Variation value (°C)		
Area	Station	Alt	I	II	III	I-II	I-III	II-III
	Tanshui	@19	21.6	22.1	22.1	0.5	0.5	0
Plain	Keelung	27	21.7	22.1	22.2	0.4	0.5	0.1
	Taipei	6	21.6	22.1	22.4	0.5	0.8	0.3
	Taichung	84	22.1	22.7	22.8	0.6	0.7	0.1
	Tainan	14	23.0	23.7	23.9	0.7	0.9	0.2
	Taitung	9	23.4	23.9	24.1	0.5	0.7	0.2
	Kaohsiung	2	x	24.3	24.4			0.1
	Hengchun	22	24.3	24.9	25.0	0.6	0.7	0.1
Mountain regions	Alishan	2413	x	10.7	10.6			-0.1
Off-island	Pengchiayu	102	x	21.5	21.7			0.2
	Penghu	11	22.6	23.1	23.2	0.5	0.6	0.1

Note: * period I = 1901-1930, II = 1931-1960, III = 1961-1990
@ station altitude in meters
x the data was not complete

As for the variation of monthly temperature (Table 3), there is almost no variation in January, only small variation in June and December.

Table 3. Monthly temperature variation from period I to III

Unit : °C

Station	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Ann.
Taipei	0.1	0.9	0.8	0.9	0.9	0.4	0.9	0.9	0.9	1.2	1.0	0.5	0.8
Taichung	0.0	1.0	0.8	0.9	0.7	0.5	0.8	0.6	0.7	1.0	1.0	0.2	0.7
Tainan	-0.1	1.0	1.1	1.2	1.2	1.0	1.2	1.1	0.9	1.0	0.8	0.1	0.9
Taitung	-0.2	0.7	0.6	0.8	0.9	0.6	1.2	1.2	0.9	0.9	0.8	0.2	0.7
Hengchun	0.0	0.8	0.6	0.7	0.8	0.5	0.8	0.7	0.8	1.0	0.8	0.2	0.7
Penghu	0.0	0.9	0.8	0.9	0.8	0.4	0.8	0.7	0.7	0.7	0.6	0.3	0.6

As for precipitation (Table 4), it increased from period I to II in the whole Taiwan area and the cloud amount had the same feature. In the northeastern part of Taiwan, it shows a great increase when compared with periods, there were 737mm (25%) rainfall increase at Keelung; 251mm (13%) at Tanshui from period I to III; and 167mm (9%) at Pengchiayu from period II to III. According to the monthly mean, we may find the rainfall increments in August, September and October were clearer than in other months (Hsiao,1988). In the southwestern part of plain area, off-island and mountainous regions the rainfall amount decreased in period III.

Table 4. Precipitation standard normal and the variation between periods by percentage

	Item		* Standard normal (mm)			Variation (%)		
Area	Station	(Alt)	I	II	III	I-II	I-III	II-III
Plain area	Tanshui	@19	1896	2027	2147	6	13	6
	Keelung	27	2927	3395	3664	16	25	7
	Taipei	6	2096	2099	2180	0	4	4
	Taichung	84	1723	1802	1600	5	-7	-11
	Tainan	14	1731	1991	1546	15	-11	-22
	Taitung	9	1783	1884	1847	6	4	-2
	Kaohsiung	2	x	1900	1619			-15
	Hengchun	22	2132	2457	1964	15	-8	-20
Mountain regions	Alishan	2413	x	4269	3962			-7
Off-island	Pengchiayu	102	1591	1780	1947	12	22	9
	Penghu	11	982	1090	954	11	-3	-12

Note: * period I = 1901-1930, II = 1931-1960, III = 1961-1990
@ station altitude in meters,
x the data was not complete

As for sunshine duration (Table 5), it is especially noteworthy that the amount of hours in period III was reduced in most stations except Keelung and Pengchiayu. From the monthly value analysis, we find the sunshine duration was increased in winter but decreased in summer at Keelung and Pengchiayu, other stations were decreased in each season.

Table 5. Sunshine duration standard normal and the variation between periods by percentage

Item			* Standard normal (hr)			Variation (%)		
Area	Station	(Atl)	I	II	III	I-II	I-III	II-III
Plain	Tanshui	@19	x	x	1600			
	Keelung	27	x	1259	1284			2
	Taipei	6	1640	1645	1522	0	-7	-7
	Taichung	84	2474	2462	2215	0	-10	-10
	Tainan	14	2606	2650	2421	2	-7	-9
	Taitung	9	1896	1859	1783	-2	-6	-4
	Kaohsiung	2	x	2433	2153			-12
	Hengchun	22	2375	2484	2448	5	3	-1
Mountain regions	Alishan	2413	x	1751	1735			-1
Off-island	Pengchiayu	102	1608	1624	1642	1	2	1
	Penghu	11	2265	2152	2099	-5	-7	-2

Note: * period I = 1901-1930, II = 1931-1960, III = 1961-1990
@ station altitude in meters
x the data was not complete

CLIMATIC TREND AND CLIMATIC FLUCTUATION

Secondly, we would like to know the secular trend on the above mentioned data. Using moving average method (9 years interval) to ignore the irregular oscillations (less than 10 years) and smooth the curves, we will get the display of the observations (see figure 2-10).

Temperature

After a statistical analysis of the variation with time sequence of the annual mean temperatures. Temperature probably rose 1°C or a little higher starting from 1897 to the present century, but showed a relative minimum around 1917-1927 followed by an abrupt rise in some area amounting to almost over 1°C in the 1930's (Figure 2), and the greatest changes in evaporation also exceeded the magnitude of the corresponding changes, and from around 1920 the running mean temperature went up gradually to a sumit in 1955, after 1959 the air temperature was generally 0.5 to 1°C below their peak attained only 5-15 years earlier. The general rise of temperature is seen to be a world-wide phenomenon (Lamb, H.H. 1969), which was however much more strongly marked in the Arctic than elsewhere and was the strongest in winter. The warming also seems to have culminated about 1940, and temperature levels have declined since to about what they were around 1920 changes (Lamb, 1963).

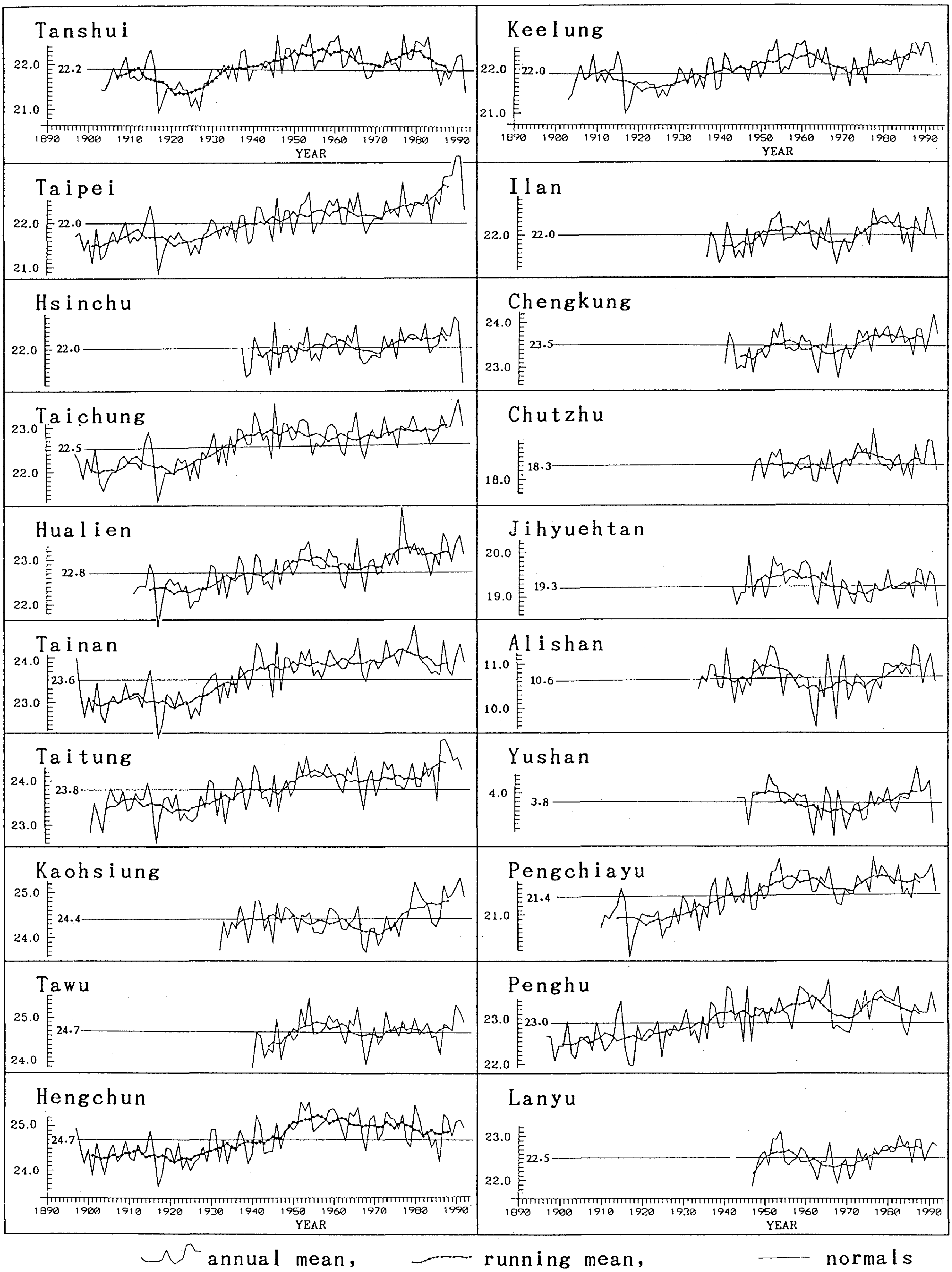
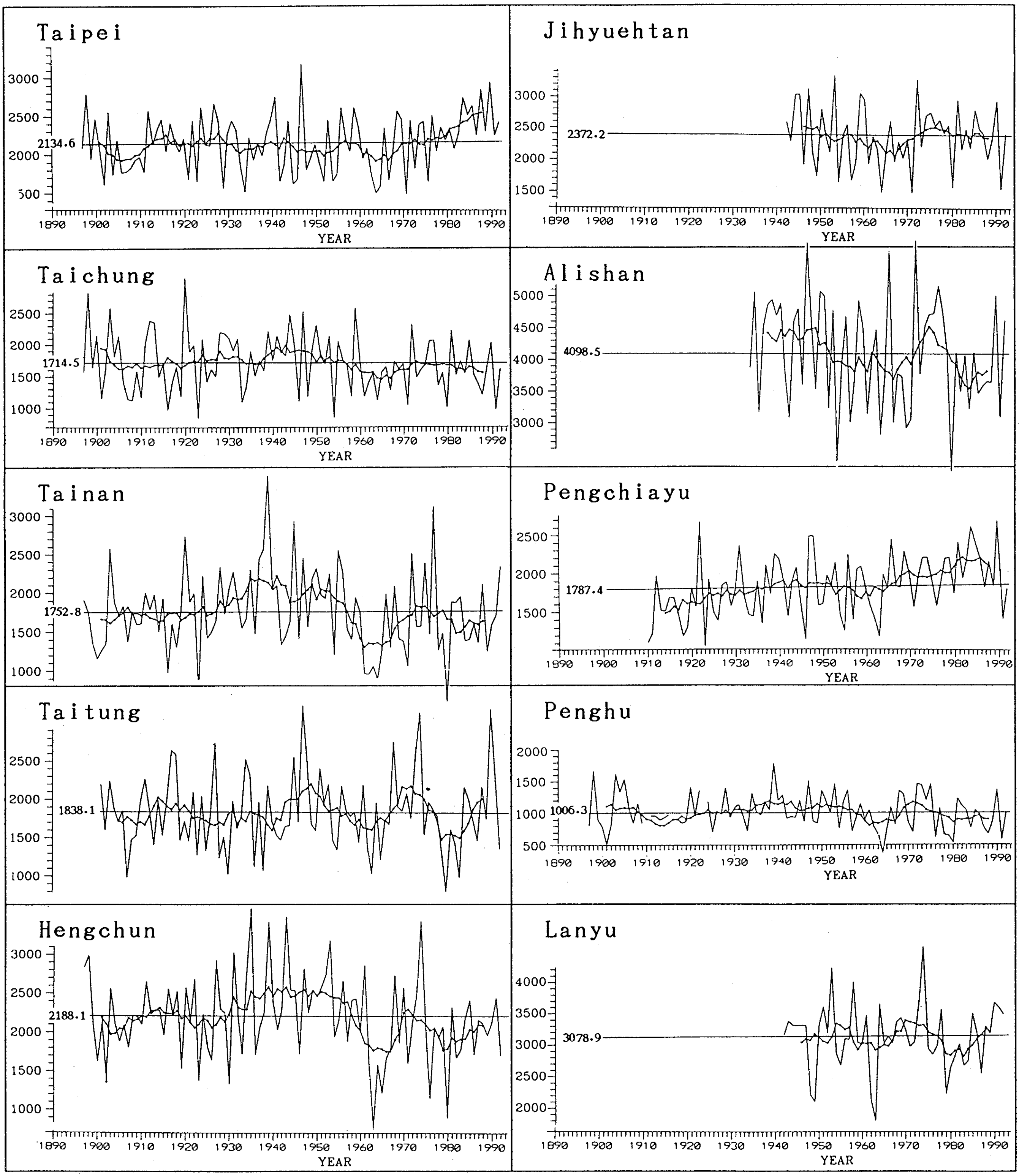


Figure 2. Long-term changes in annual mean temperature (°C) and nine-year running means, normals was listed at left.

Precipitation

No unanimous climatic trend and climatic discontinuity were occured on the running mean of precipitation, but the quasi-biennial oscillation of yearly precipitation appeared at all weather stations in Taiwan area, and less rainfall was occured in 1963 and 1980 at most stations.



annual mean, running mean, normals

Figure 3. Long-term changes in annual amount of precipitation (mm) and nine-year running means, normals was listed at left.

Sunshine duration

The physics of near surface layers of the atmosphere is both interesting and important chiefly because of the large variations in conditions occurring in them, both with respect to space and time. This arises largely from the fact that it is mainly at the ground surface that radiant energy from the sun is absorbed and communicated to the soil as heat and to the atmosphere as heat and evaporated moisture (latent heat) (Deacon, E. L. 1969), such a variety of exposures to sun (temperature, sunshine duration, cloudness), precipitation, evaporation, relative humidity, wind etc., exist that, in its entirety, the study is of rather formidable complexity. In this report the climatic information will be supplied to the scientist to do the advanced research (Lydolph, Paul E. 1985). The running mean sunshine duration was continuously reduced from around 1960 to the present, down almost to 400-500 hours (15-25%)(Figure 4) in most stations except Kaohsiung, Chiayi, Tawu and Lanyu stations.

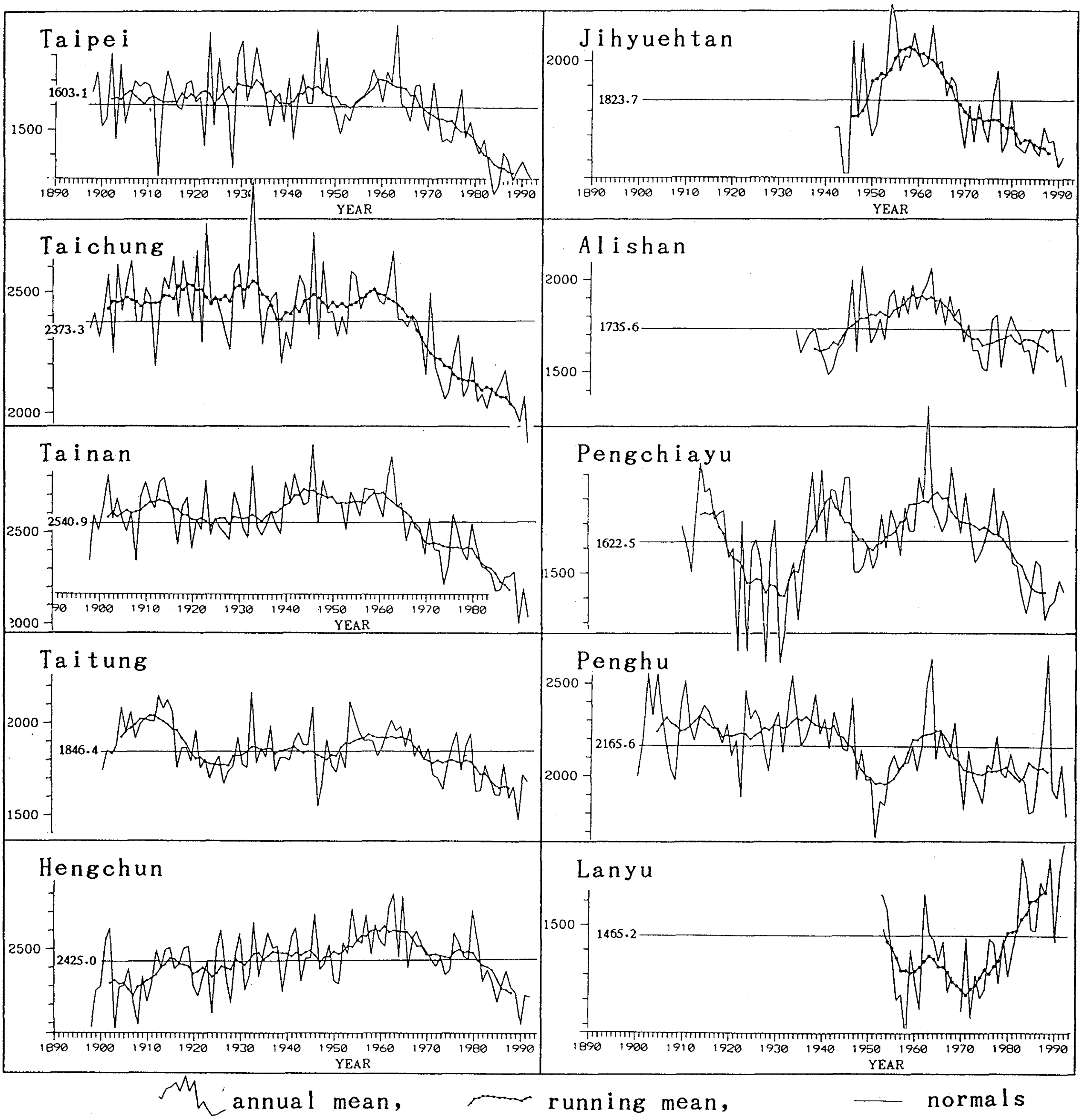


Figure 4. Long-term changes in annual amount of sunshine duration (hr) and nine-year running means, normals was listed at left.

Mean cloudness

The more the direct solar radiation is cut off by clouds, the greater the effect of diffuse sky radiation and smaller differences of radiation on slopes is. It was less cloudness and rainfall with more sunshine duration in 1963; from 1935 to 1955, a more cloudness period over the whole plain and off-island area except mountainous regions.

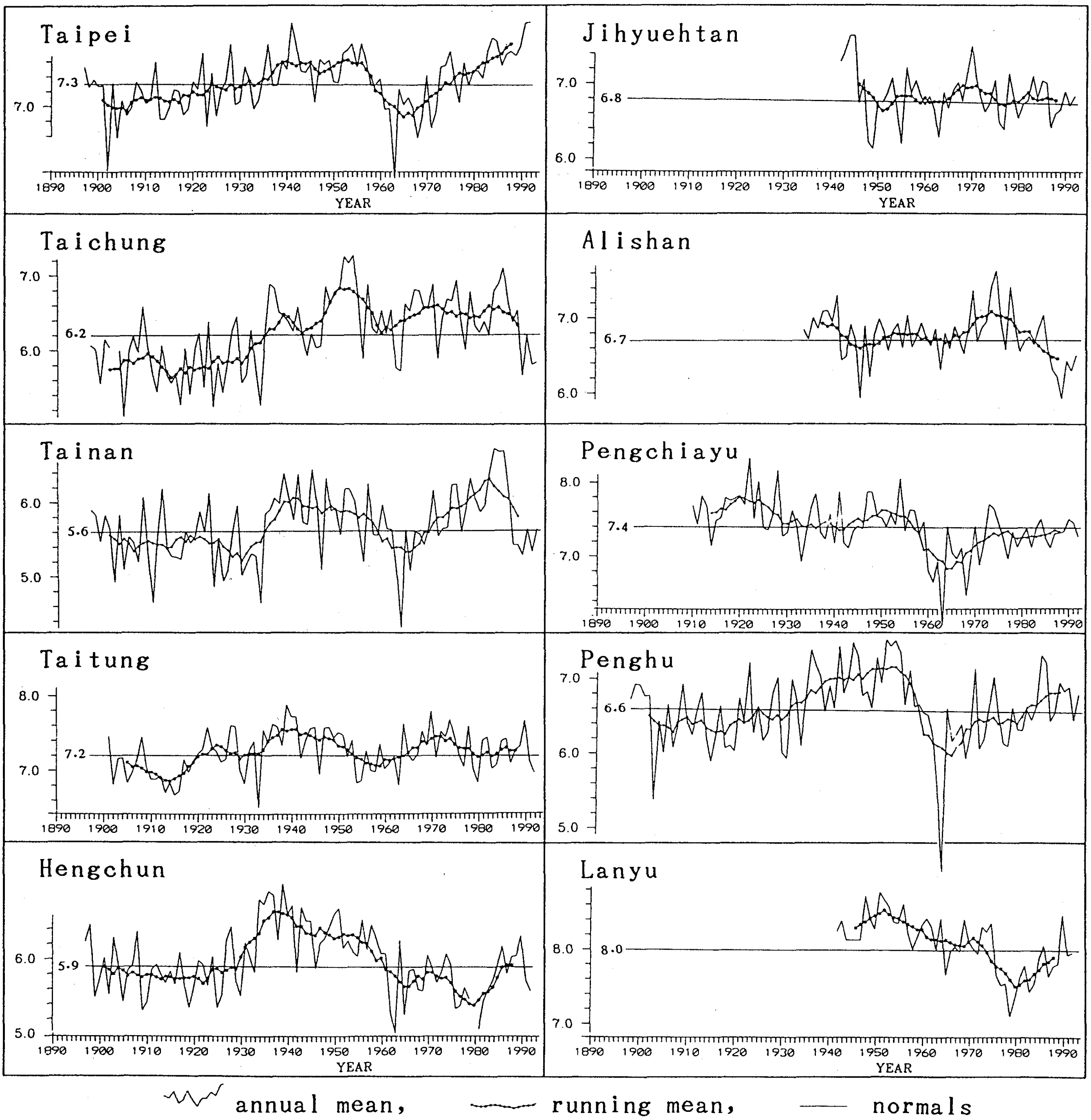


Figure 5. Long-term changes in annual mean cloudness (1-10) and nine-year running means, normals was listed at left.

Pressure

During the epochs of climatic change, especially since 1930, standard deviations of pressure have been rather greater. In many cases, there was an increase of 0.6-1.8 mb changes on the nine-year running mean of annual pressure during the past centuty. The 1926, 1932, 1963, 1983 and 1987 were the high pressure years, and 1898, 1920, 1950, 1974 and 1984 were the low pressure years.

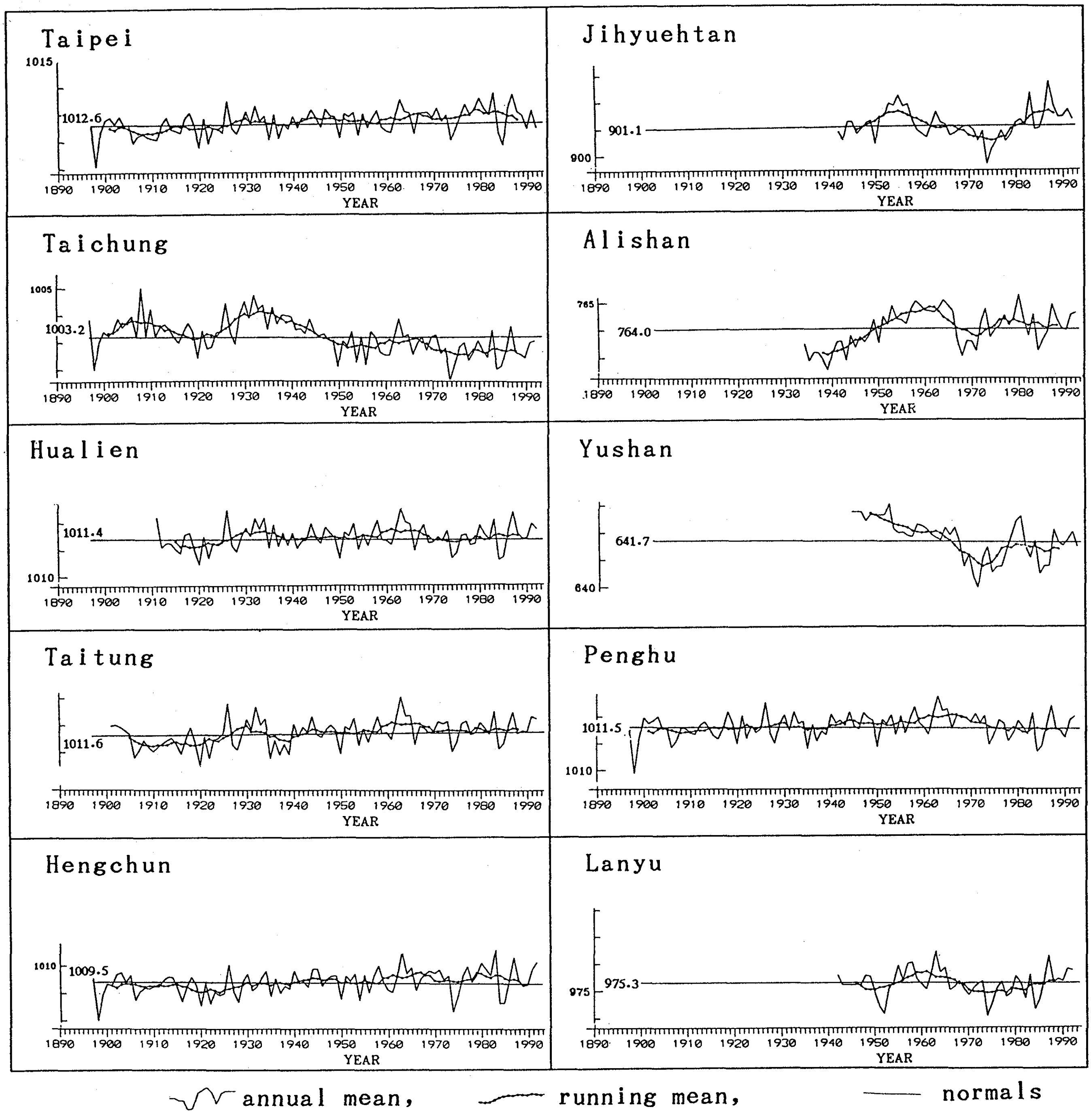


Figure 6. Long-term changes in annual mean pressure at station (mb) and nine-year running means, normals was listed at left.

Relative humidity

The air over Taiwan is moistened in general, more figures are available for relative humidity (Figure 7). As in all tropical areas the means of relative humidity are quite high. They showed a general decrease since 1953, in the western part of Taiwan, the changes almost arrived 8%.

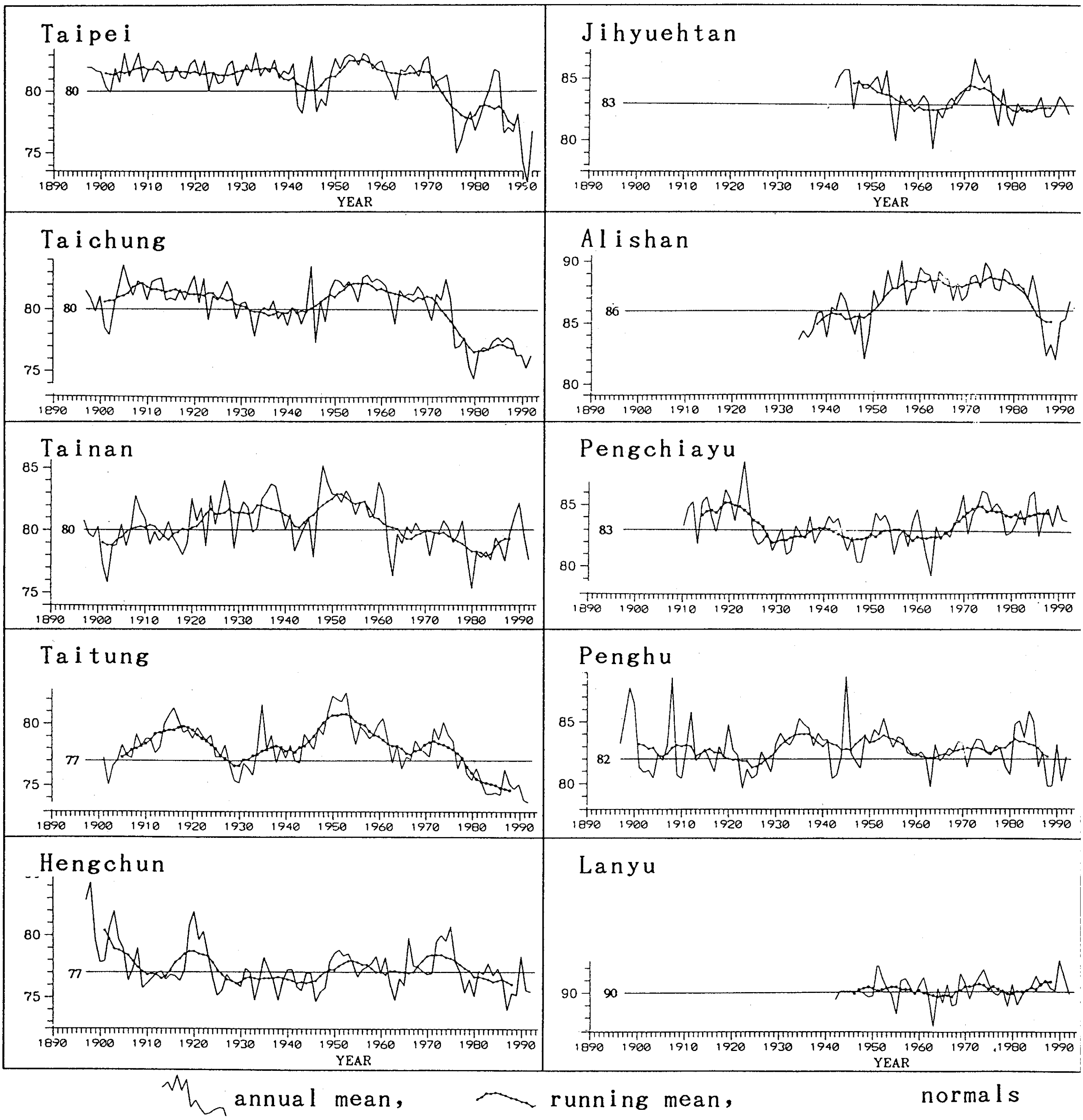


Figure 7. Long-term changes in annual relative humidity (%) and nine-year running means, normals was listed at left.

Evaporation

The changes of amplitude of the annual evaporation were very small before 1961, then tended to reduce. During the last 30 years, the amount was reduced 100-400mm. The changes of evaporation at Tainan and Taitung are going in opposite directions (Figure 8). The evaporation of moisture from the soil is an important factor in climate. It exerts strong influence on the energy budget owing to the high latent heat of vaporization of water, and the relation between evaporation and precipitation is a major factor governing climate and the characteristics of soils and plants communities occurring in any region, the changes of earth temperature are shown in Figure 9. also.

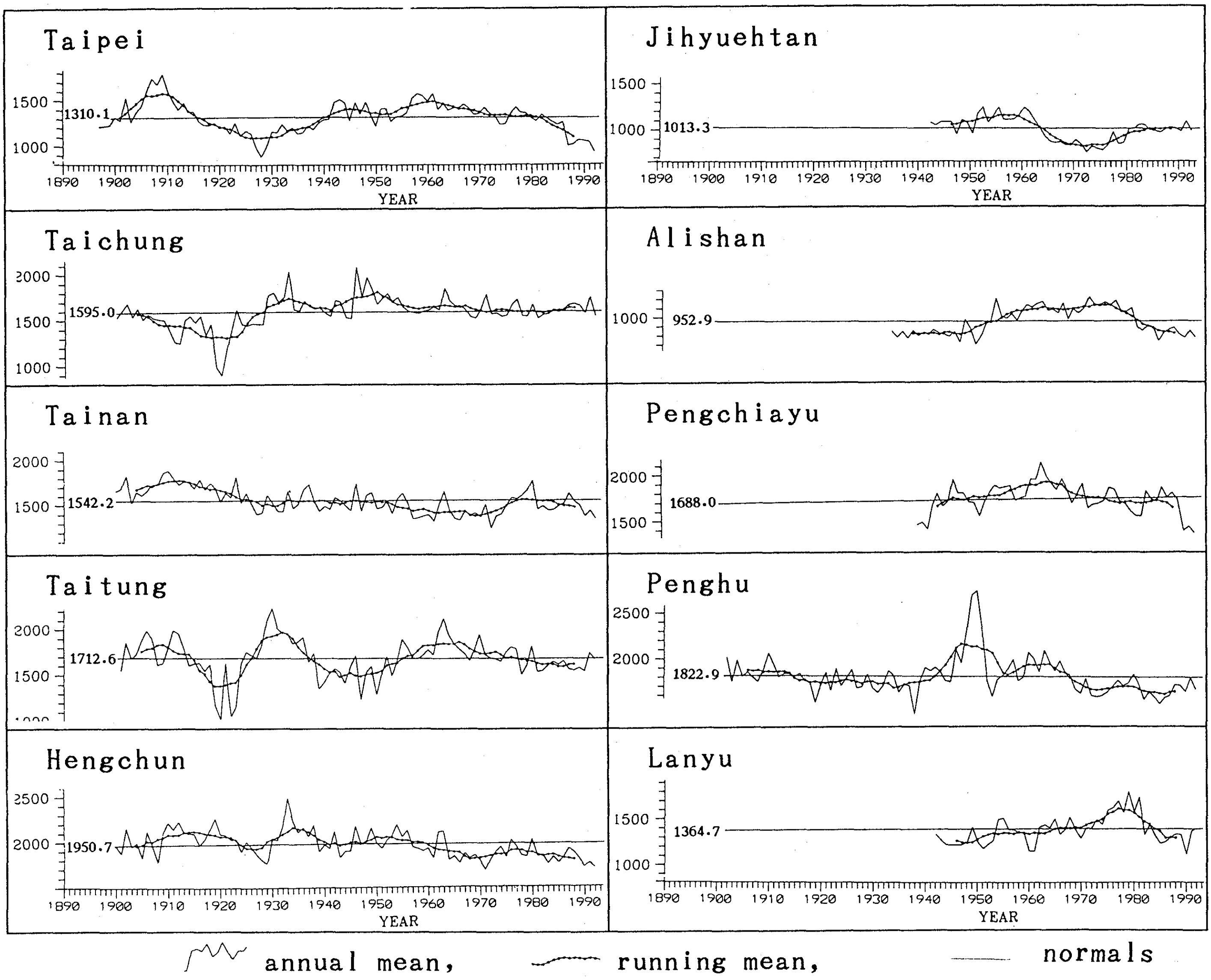


Figure 8. Long-term changes in annual amount of evaporation (mm) and nine-year running means, normals was listed at left.

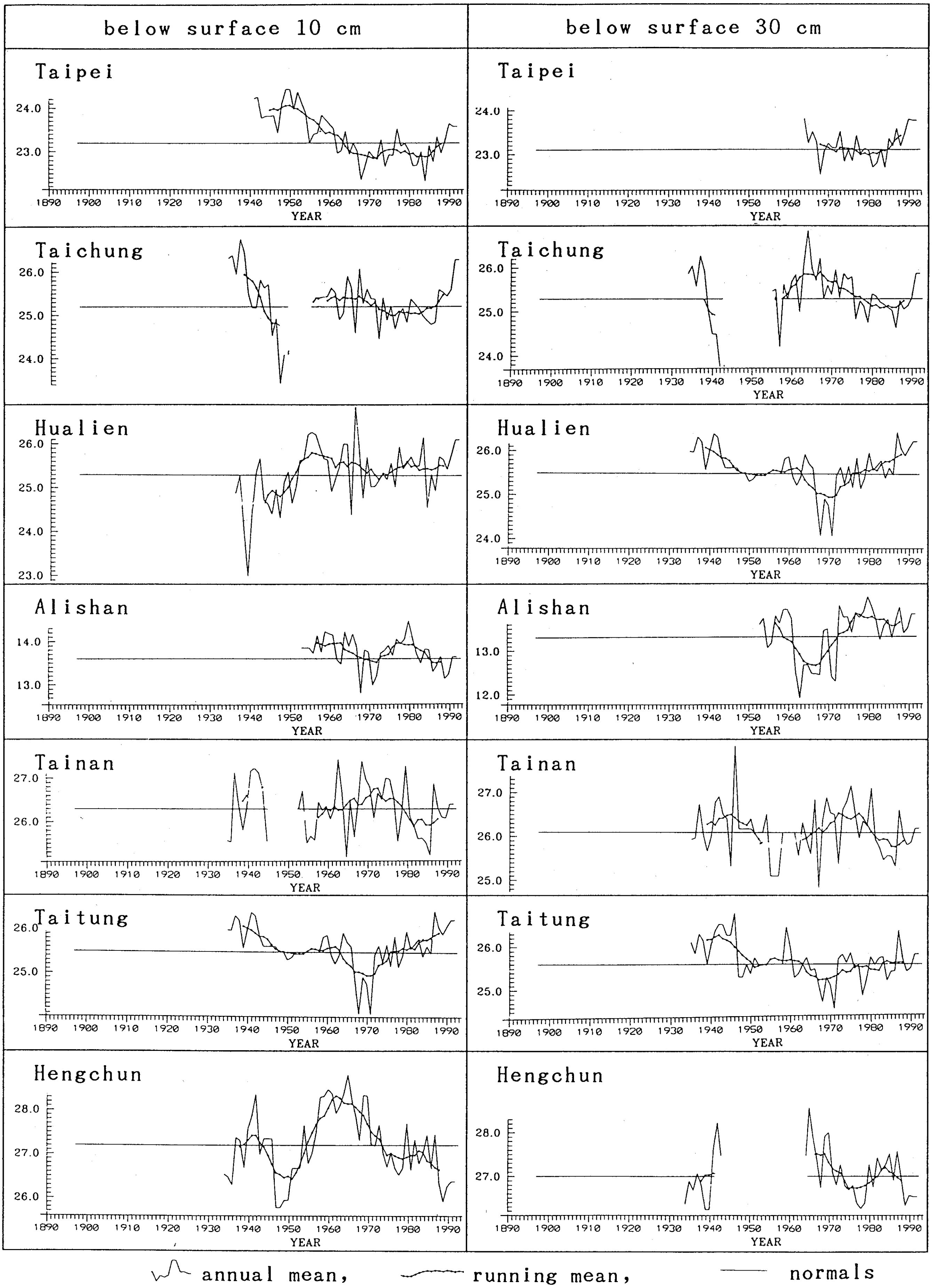
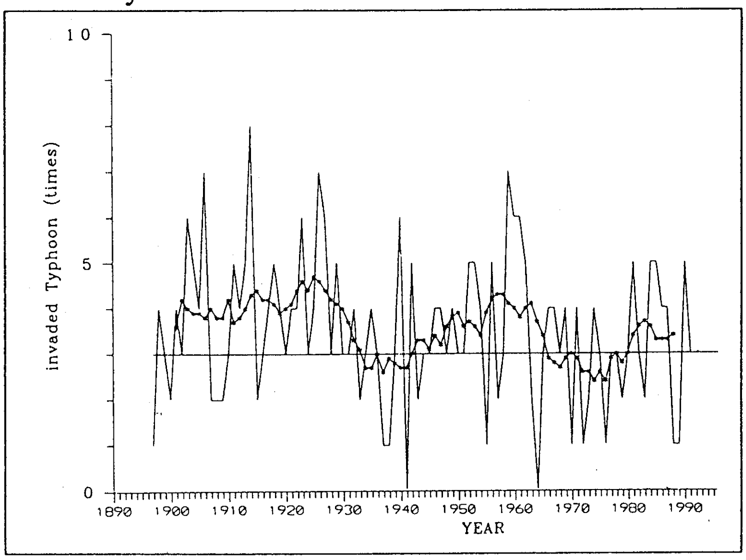


Figure 9. Long-term changes in annual mean of earth temperature °C and nine-year running means.

Invaded Typhoon

Typhoon (tropical cyclones) of the North Western Pacific Ocean forms an important feature of weather over Taiwan area and Eastern Asia countries. As is well known, the passage of these cyclonic disturbances over land was associated with very heavy rains and strong winds, particularly in coastal areas, resulted in considerable loss of lives and properties. If the eye of the typhoon made landfall (landing) in Taiwan area or its path (Typhoon strong wind scope) went through Taiwan area, it would cause a loss of lives and properties, and it is called ''Invaded Typhoon'' (Chi, 1978). The times of Typhoon invaded Taiwan area monthly and annually were listed in Table 6, and annual climatological standard normals were decreased from 4.1 times (1901-1931) to 3.1 times (1961-1990). By refering to figure10.a, it is perceived that there are three peaks and two troughs, the peak occured near 1926, 1956 and 1982, the trough occured around 1937 and 1974. By applying the auto-correlations and harmonic analysis on the above data, the fundamental period is set to 108-year, it comes out as shown in Figure10.b, 3 significant peaks are selected, they are harmonic number 3, 16 and 35, and are equivalent to the period of 34, 7 and 3.1 years.



annual mean, running mean, normals

Figure10.a Long-term changes in annual times of invaded Typhoon and nine-year running means.

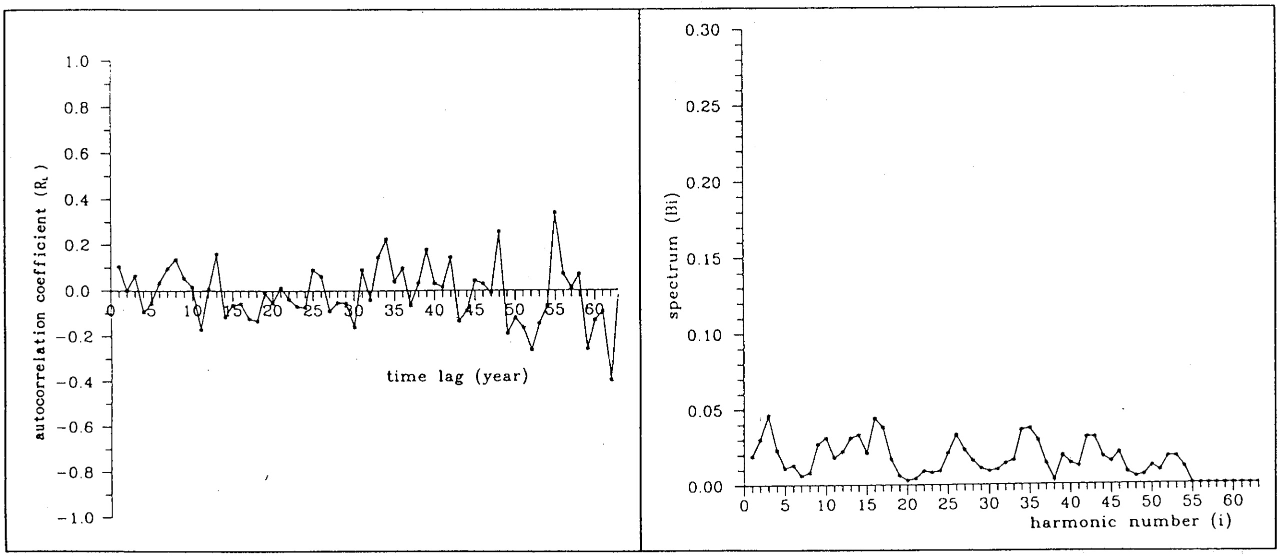


Figure 10.b Auto-correlation coefficent and its spectrum of the times of invaded Typhoon

Table 6. Monthly and annual frequencies of invaded Typhoon in the Taiwan area, 1897-1992

Yr\Mo	Jan.	Feb.	Mar.	Apr.	May	June	July	Aug.	Sep.	Oct.	Nov.	Dec.	Ann.
1897	-	-	-	-	-	-	-	1	-	-	-	-	1
1898	-	-	-	-	-	1	-	2	1	-	-	-	4
1899	-	-	-	-	1	-	-	2	-	-	-	-	3
1900	-	-	-	-	-	-	1	-	1	-	-	-	2
1901	-	-	-	-	1	-	-	2	-	1	-	-	4
1902	-	-	-	-	-	-	-	3	-	-	-	-	3
1903	-	-	-	-	-	-	1	4	-	1	-	-	6
1904	-	-	-	-	-	1	3	1	-	-	-	-	5
1905	-	-	-	-	-	1	1	1	1	-	-	-	4
1906	-	-	-	-	2	-	1	1	1	2	-	-	7
1907	-	-	-	-	1	1	-	-	-	-	-	-	2
1908	-	-	-	-	1	-	-	1	-	-	-	-	2
1909	-	-	-	-	-	-	-	-	2	-	-	-	2
1910	-	-	-	-	-	-	1	2	1	-	-	-	4
1911	-	-	-	-	-	-	1	2	1	-	-	-	4
1912	-	-	-	-	-	-	-	2	2	-	-	-	4
1913	-	-	-	-	-	-	2	1	2	-	-	-	5
1914	-	-	-	-	-	2	2	2	2	-	-	-	8
1915	-	-	-	-	-	-	-	1	-	1	-	-	2
1916	-	-	-	-	-	-	-	2	-	1	-	-	3
1917	-	-	-	-	-	-	2	1	1	-	-	-	4
1918	-	-	-	-	-	1	1	1	-	2	-	-	5
1919	-	-	-	-	-	-	1	2	1	-	-	-	4
1920	-	-	-	-	-	-	2	-	1	-	-	-	3
1921	-	-	-	-	-	-	1	2	1	-	-	-	4
1922	-	-	-	-	-	-	-	1	2	-	-	-	3
1923	-	-	-	-	-	-	1	3	1	1	-	-	6
1924	-	-	-	-	-	-	1	1	1	-	-	-	3
1925	-	-	-	-	-	-	2	1	1	-	-	-	4
1926	-	-	-	-	-	-	2	2	2	1	-	-	7
1927	-	-	-	-	1	1	2	2	-	-	-	-	6
1928	-	-	-	-	-	-	1	1	1	-	-	-	3
1929	-	-	-	-	-	1	3	1	-	-	-	-	5
1930	-	-	-	-	1	-	2	-	-	-	-	-	3
1931	-	-	-	-	-	-	-	2	1	-	-	-	3
1932	-	-	-	-	-	-	2	1	-	1	-	-	4
1933	-	-	-	-	-	-	-	-	1	1	-	-	2
1934	-	-	-	-	-	-	1	1	1	-	-	-	3
1935	-	-	-	-	-	-	2	2	-	-	-	-	4
1936	-	-	-	-	-	-	-	2	1	-	-	-	3
1937	-	-	-	-	-	-	-	1	-	-	-	-	1
1938	-	-	-	-	-	-	-	-	1	-	-	-	1
1939	-	-	-	-	-	-	1	1	-	1	-	-	3
1940	-	-	-	-	-	-	3	2	1	-	-	-	6
1941	-	-	-	-	-	-	-	-	-	-	-	-	0
1942	-	-	-	-	-	-	3	1	1	-	-	-	5
1943	-	-	-	-	-	-	2	-	-	-	-	-	2
1944	-	-	-	-	-	-	1	1	1	-	-	-	3
1945	-	-	-	-	-	-	-	-	3	-	-	-	3
1946	-	-	-	-	-	1	2	-	1	-	-	-	4
1947	-	-	-	-	1	1	-	1	-	1	-	-	4
1948	-	-	-	-	-	-	1	-	2	-	-	-	3
1949	-	-	-	-	-	-	1	-	2	1	-	-	4
1950	-	-	-	-	-	1	-	-	-	1	1	-	3
1951	-	-	-	-	-	-	-	1	1	1	-	-	3
1952	-	-	-	-	-	1	1	-	1	-	2	-	5
1953	-	-	-	-	-	1	1	2	1	-	-	-	5
1954	-	-	-	-	-	-	-	1	1	-	2	-	4
1955	-	-	-	-	-	-	-	1	-	-	-	-	1
1956	-	-	-	1	-	-	-	1	3	-	-	-	5
1957	-	-	-	-	-	1	-	-	1	-	-	-	2
1958	-	-	-	-	-	-	1	1	1	-	-	-	3
1959	-	-	-	-	-	-	1	3	1	1	1	-	7
1960	-	-	-	1	-	1	1	3	-	-	-	-	6
1961	-	-	-	-	1	-	1	2	2	-	-	-	6
1962	-	-	-	-	-	-	1	2	1	1	-	-	5
1963	-	-	-	-	-	-	1	-	1	-	-	-	2
1964	-	-	-	-	-	-	-	-	-	-	-	-	0
1965	-	-	-	-	-	1	1	1	-	-	-	-	3
1966	-	-	-	-	1	-	-	1	2	-	-	-	4
1967	-	-	-	-	-	-	1	1	-	1	1	-	4
1968	-	-	-	-	-	-	1	-	2	-	-	-	3
1969	-	-	-	-	-	-	1	1	1	1	-	-	4
1970	-	-	-	-	-	-	-	-	1	-	-	-	1
1971	-	-	-	-	-	-	2	-	2	-	-	-	4
1972	-	-	-	-	-	-	-	1	-	-	-	-	1
1973	-	-	-	-	-	-	1	-	-	1	-	-	2
1974	-	-	-	-	-	-	1	-	1	1	-	-	3
1975	-	-	-	-	-	-	1	1	1	-	-	-	3
1976	-	-	-	-	-	-	-	1	-	-	-	-	1
1977	-	-	-	-	-	-	2	1	-	-	-	-	3
1978	-	-	-	-	-	1	-	1	-	1	-	-	3
1979	-	-	-	-	-	-	-	2	-	-	-	-	2
1980	-	-	-	-	-	-	1	1	1	-	-	-	3
1981	-	-	-	-	-	2	1	1	1	-	-	-	5
1982	-	-	-	-	-	-	1	2	-	-	-	-	3
1983	-	-	-	-	-	-	1	-	1	-	-	-	2
1984	-	-	-	-	-	1	1	3	-	-	-	-	5
1985	-	-	-	-	-	1	1	1	1	1	-	-	5
1986	-	-	-	-	-	1	1	1	1	-	-	-	4
1987	-	-	-	-	-	-	2	-	1	1	-	-	4
1988	-	-	-	-	-	1	-	-	-	-	-	-	1
1989	-	-	-	-	-	-	-	-	1	-	-	-	1
1990	-	-	-	-	1	1	-	2	1	-	-	-	5
1991	-	-	-	-	-	-	1	1	1	-	-	-	3
1992	-	-	-	-	-	-	-	1	2	-	-	-	3
TOT	0	0	0	2	12	25	82	104	77	26	7	0	335

CLIMATIC PERIODICITY

In addition, we would like to know the periodic fluctuations on the above mentioned data. By using time series analysis methods, the curve fitting computation is completed. In fitting a curve, the first step is to decide which the probable form of the relationship between the variates is. This relation may be already known. For example, the variation of temperature with height in the troposphere has in most cases been found to be linear, on the one hand this is very useful in the data check and adjustment, such as the pressure equipment was changed its altitude of observation position, on the other hand they can filter the tendency. Checking the long-range history records and making some adjustment of discontinuous data are the very important preparative work.

The "harmonic analysis" is a type of analysis most commonly applied to the periodic variations of the meteorological parameters. According to mathematical principles, any function that is given at every point in the interval can be represented by a infinite series of sine and cosine functions. In the case of meteorological data, observation exists only at discrete points, not continuously. In this study, temperature means and precipitation amounts are selected yearly. Equal spacing of the observations will be assumed in the following discussion. If only a finite number of points exist in the interval to be analyzed, a finite number of sines and cosines will be able to account for all the observations. The first "harmonic" has a period equal to total period (fundamental period) studied. The second harmonic has a period equal to half the fundamental period and the third harmonic has a period of one-third of the fundamental. In general, if the number of observations is N, the number of harmonics equals N/2. The different harmonics are isolated so that each can be created as an independent entity, for each may have a different physical cause. Usually it is impossible to account for the complete variation at once, but the individual harmonics can be explained. However, each harmonic does not have a distinct physical meaning, because the harmonics are used to account for the annual data variation. Therefore, in this study harmonic analysis only provides a mathematical representation equivalent to the periodic function. We may write the complete series :

$$Y = Y + \sum_{i=1}^{i=N/2} [A_i \sin (\frac{360°}{P} it) + B_i \cos (\frac{360°}{P} it)]$$

In other words, the time series equals the mean plus the sum of all N/2 harmonics. In these expressions, P is the fundamental period or the total period of the periodic function. P is not always equal to N. We may change the fundamental period for selecting the significant periods and developing the future values of the variables (observations).

The period of years taken to represent a climatic epoch should be long enough to cover a reasonable sample of the shorter-term variations that occurred. (For this, half century periods may be preferable to the 30 years hitherto conventionally adopted in climatology; though in some connections, it is necessary to consider individual years or decades separately and 20~30-year periods have the convenience of being about the shortest for adequate statistical study.) (Lamb,1969)

Observe the differences (along the Y axis) between the ploted points and the curve, from left to right in the above moving average diagram. Form progressive sums of these differences. Over one century variation of temperature in Taiwan was found (Hsiao,1973), the least square function was used to get the tendency of meteorological elements.

Regression line of Y on X, if Y is the tendency T, and X is the time sequence t then

$$T = a + b\,t \tag{1}$$

here f(Y) = T is f(X) = t

$$b = \frac{N\Sigma Yt - \Sigma Y \Sigma t}{N\Sigma t^2 - (\Sigma t)^2}$$

$$a = \frac{\Sigma t^2 \Sigma Y - \Sigma t \Sigma Yt}{N\Sigma t^2 - (\Sigma t)^2} = \frac{\Sigma Y}{N} - b\frac{\Sigma t}{N}$$

When the trend shows definite curvature, a parabola is sometimes fitted by least squares. Let the equation for the regression curve (parabola) be

$$T = a + bt + ct^2 \tag{2}$$

Then a, b and c can be found as:

$$a = \frac{\Sigma t^4 \Sigma Y - \Sigma t^2 \Sigma Y t^2}{N\Sigma t^4 -(\Sigma Y \Sigma t)^2}$$

$$b = \frac{N\Sigma Yt - \Sigma Y \Sigma t}{N\Sigma t^2 - (\Sigma t)^2}$$

$$c = \frac{N\Sigma Yt^2 - \Sigma Y \Sigma t^2}{N\Sigma t^4 - (\Sigma t^2)^2}$$

$$y = Y - T \tag{3}$$

here Y is observation variable

After eliminating tendency effect from the observation data, through auto-correlation coefficient spactrum and harmonic analysis with smoothing estimate, we may presume periods of the irregular oscillations (Brooks,1953). Originally, correlograms are used to estimate important periods in the time series and auto-correlation coefficients are useful in the prediction of future values of the time series. The autocorrelation coefficient are defined (Brooks,1953 and Panofsky, 1965) as below:

$$R_L = \frac{\Sigma (y_i - \overline{y}) (y_{i+1} - \overline{y})}{(N - L)\sigma^2} \tag{4}$$

L is the interval, called the time lag, if the lag is zero, the auto-correlation coefficient is one, σ is the standard deviation, N is the number of observations.

auto-correlation coefficient spectrum

$$B_i = \frac{R_o}{m} + \frac{2}{m} \sum_{L=1}^{m-1} [R_L \cos (\frac{360°}{2m} iL)] + \frac{R_m}{m} (-1)^i \qquad (5)$$

m is the number of lags used, and N the original number of observations.
i is the number of harmonic

Tukey, John W. suggested to improve the spectral estimates by forming the smoothed estimate (Panofsky, 1965).

$$B'_o = 0.54\, B_o + 0.46\, B_1$$
$$B'_i = 0.23\, B_{i-1} + 0.54\, B_i + 0.23\, B_{i+1} \qquad (6)$$
$$B'_m = 0.46\, B_{m-1} + 0.54\, B_m$$

The harmonic analysis is not always required to determine all N/2 harmonics; in fact, usually the first two, or at most three, harmonics describe the variation of periodic function sufficiently well, so, in this paper we select the first three harmonics, inspected by Schuster method (Hu,1978), the set significant level is 0.3, then, if the amplitude is $C_1 \geq 4\sigma^2/N$. The result means the i's harmonic remarkable.

harmonic variance:

$$Vi = \frac{C_i^2}{2\sigma^2} \qquad (7)$$

C_i is the amplitude of the i'th harmonic

$$C_i^2 = A_i^2 + B_i^2 \qquad (8)$$

$$A_i = \Sigma \frac{2}{N} [y \sin(\frac{360°}{P} it)] \qquad (9)$$

P is fundamental period, the quantity i is called the ''number of the harmonic'' and is an integer between 1 and N/2.

$$B_i = \Sigma \frac{2}{N} [y \cos (\frac{360°}{P} it)] \qquad (10)$$

The following figures illustrate the determination of the spectrum of annual mean temperature and annual precipitation amount obtained from ''Summary report of meteorological data'' (CWB,1955-1992). Figure 11 (i) gives auto-covariances from lag 1 to lag 64. No periodicities are particularly obvious in the auto-covariances. Figure 11 (ii) shows the spectrum obtained by harmonic analysis of the serial products of Figure 11 (i). The spectrum shows that most of the energy of the variance of temperature is produced by longer periods.

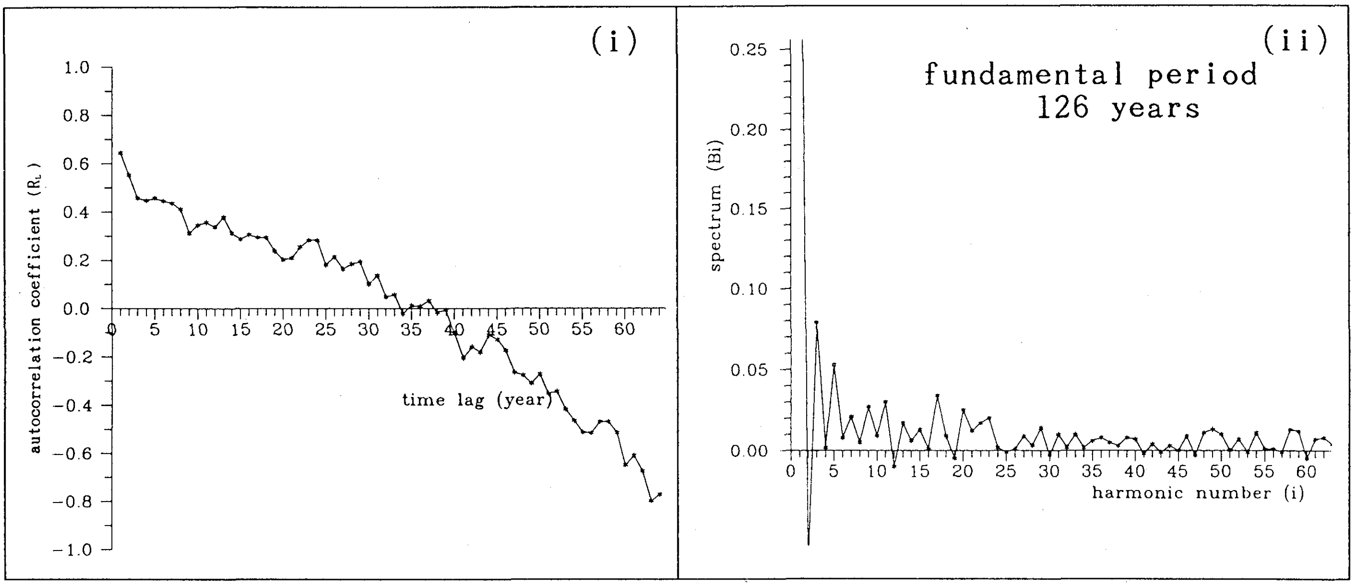


Figure 11. (i) auto-correlation functions of annual mean temperature in Taipei
(ii) the spectrum obtained by harmonic analysis of the serial products of auto-covariance in Figure 11 (i)

When we processed the temperature data with equation (1) and (3) for eliminating the influence of tendency, an oscillation of about i = 2 and 15 was accepted, that was equivalent to periodicity of 44 and 5.7 years (Figure 12, 13, 14, 15) and the results of periodic analysis of temperature and precipitation are listed in Table 7.

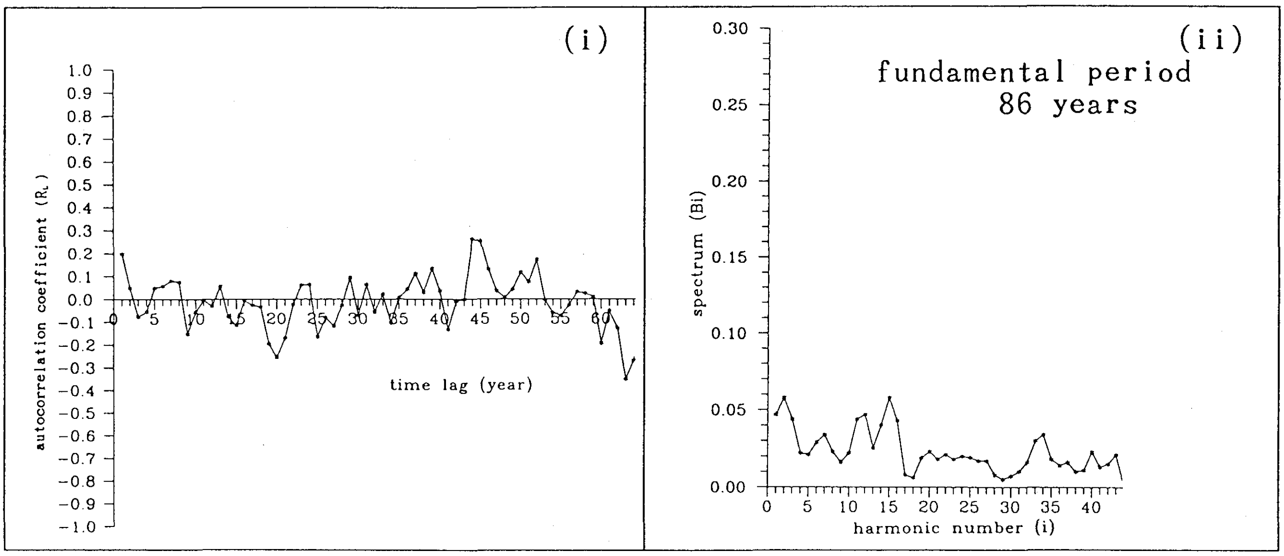


Figure 12. (i) auto-correlation functions of the residuals of annual temperature in Taipei after eliminate tendency by regression line equation (1) and (3)
(ii) the spectrum obtained by harmonic analysis of the serial products of figure 12 (i)

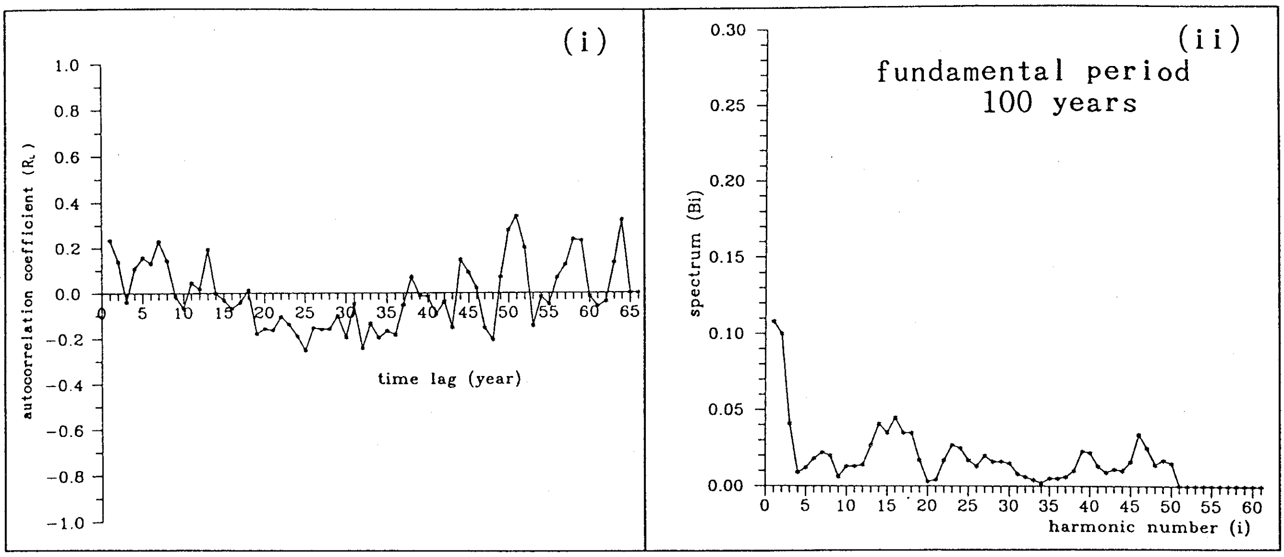


Figure 13. (i) auto-covariance of temperature in Taichung
(ii) spectrum of temperature

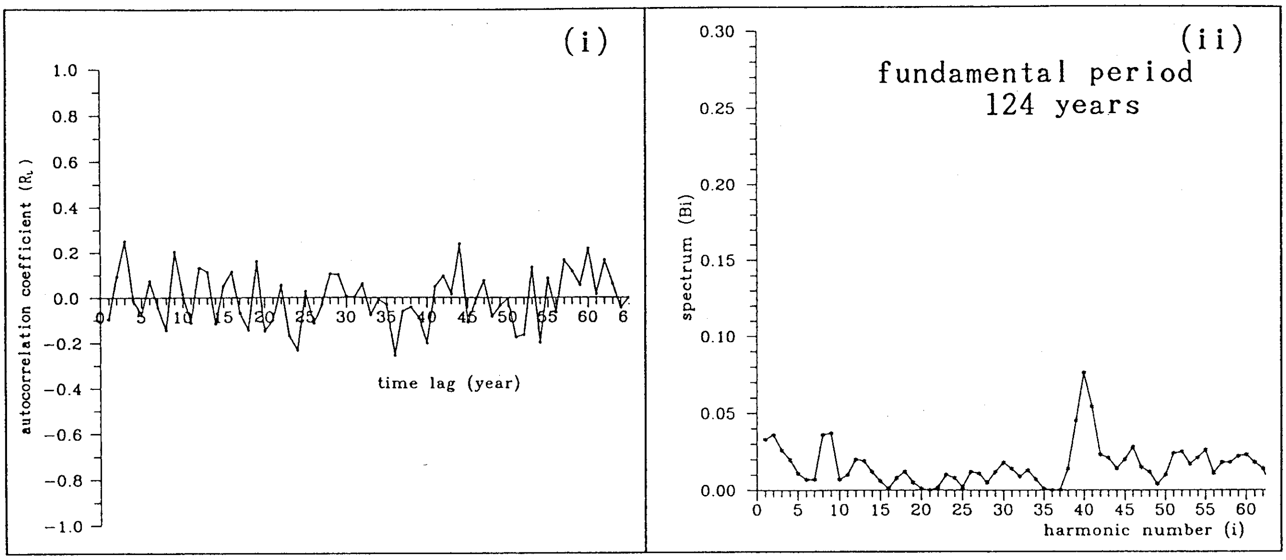


Figure 14. (i) auto-covariance of precipitation amount in Taipei
(ii) spectrum of precipitation in Taipei

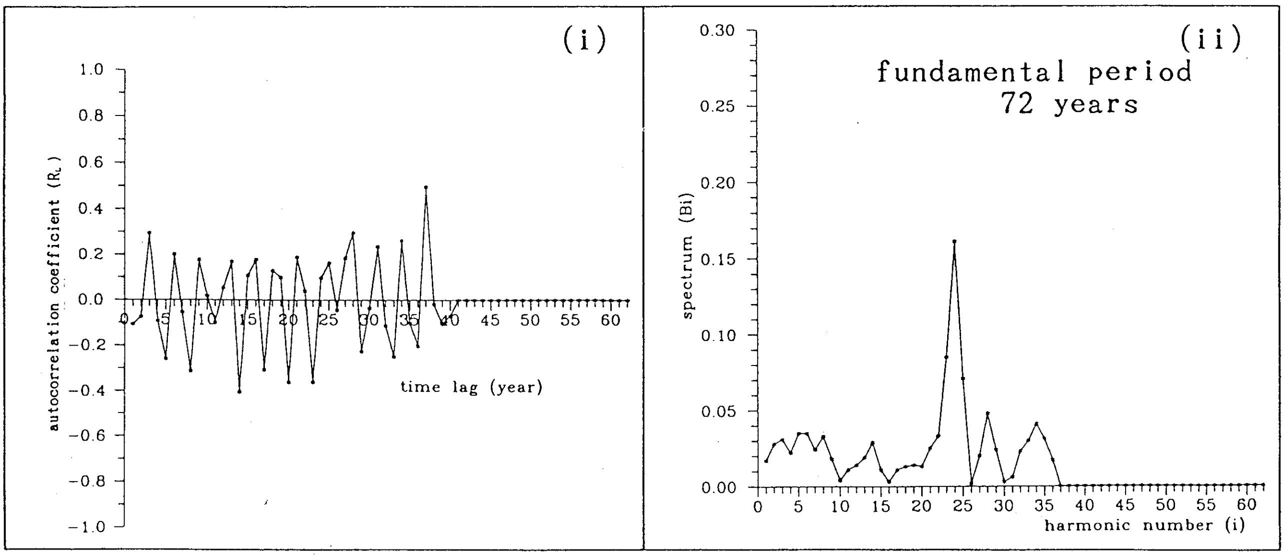


Figure 15. (i) auto-covariance of precipitation amount in Alishan
(ii) spectrum of precipitation in Alishan

Table 7. Results of periodic analysis of temperature and precipitation by auto-correlation coefficient spectrum

unit : year

Item		Temperature						Precipitation			
Station	(Atl)	higher		middle		lower		higher	middle	lower	
Taipei	(6m)		44		5.7		2.2	44		3.1	2.1
Taichung	(84m)	51	44		5.7		2.2	-	8.0	3.0	2.1
Tainan	(14m)		44		5.7		2.2	44	8.7		2.2
Taitung	(9m)		44	7.6	5.7		2.1	22		4.2	2.1
Hengchun	(22m)		22		5.4		2.2	44		4.3	2.1
Alishan	(2413m)		18			4.0	2.6	12		3.0	2.1
Pengchiayu	(102m)		17		8.4		2.2	44	8.4	4.1	2.1
Penghu	(11m)		17			4.4	2.2	16	7.8		2.7

CONCLUSIONS

(1) The temperature increases were over plain area and off-island stations
(2) The precipitation increases were over northeastern part of the Taiwan area.
(3) It is especially noteworthy that the amount of sunshine duration during last 20 years was reduced 10-25% at most stations except Lanyu, and Tawu stations.
(4) The changes of mean cloudness were not regularly opposite to the sunshine duration variation.
(5) One century variation of temperature in Taiwan revealed that annual mean temperature went up gradually during the early half of this century and reached its summit in 1955 then went down gradually to 1973 then up gradually.
(6) The quasi-biennial oscillation (2.1 years) of precipitation appeared at all weather stations in Taiwan, and 2.2 years (almost 26 months) periodic variation of temperature conformed to one another at all stations.
(7) The annual temperature spectrum revealed two highly significant maxima of variance: first with the period of 5.7 years, second with the period of 44 years, in plain area. Same methods were also carried out on the yearly precipitation data, and it showed that the periods were about 2, 3, 4, 8 and 44 years appeared in different stations.

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