Climatic Change and Rice Production in Taiwan[1]

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ABSTRACT

The purpose of this paper is threefold: 1) to study the climate changes in Taiwan; 2) to provide an alternative way to forecast long-term weather; and 3) to examine the impact of weather conditions on rice production. Instead of utilizing simulation techniques, this paper employs an economic approach to evaluate the potential impact of climatic change on agricultural production in Taiwan. Since rice is the major crop in Taiwan, the data on rice yields and weather from 1901 to 1991 are used to assess the influence of weather variations on rice production. The production function of rice is assumed to be a Leontief function.

INTRODUCTION

Since the Industrial Revolution, the use of fossil fuels and the spread of chemicals have dramatically increased. The increase in the carbon dioxide (CO_2) and other greenhouse gases due to the industrialization and the ever-expanding burning of fossil fuel and tropical forests have lead to the greenhouse effect and probable global warming, acid rain, the depletion of the ozone layer, desertification, and water pollution. Predicting the impact of climate change on the environment is a subject still in its infancy. A doubling of the carbon dioxide (CO_2) level is often used to assess climatic change impact. Rosenzweig (1988) utilizes the general circulation models (GSMs) to forecast the climate changes and predicts that a doubling of the CO_2 concentration in the atmosphere will alter precipitation amounts and frequency as well as increase the average global temperature by 1.5°C to 4.5°C. Such climate changes are expected to lead to changes in economic activities and human welfare.

As a result, the concern about global climate change has been growing. Of special concern is t he increase in carbon dioxide (CO_2) concentration in the atmosphere and its relationship to the potential greenhouse effect. Although the evidence of actual or potential changes is not conclusive, climate change due to the buildup of greenhouse gases has resulted in the increasing importance of global interdependence. Whereas an increase inn atmospheric CO_2 is now imposed upon the world by the US, the USSE, and Western Europe, the developing countries will probably be important contributors by early in the next century. Yet it will be much more difficult to reach international consensus on controlling the emission of greenhouse gases because not all countries are affected to the same extent by the consequences of global warming or other climage changes. Due to the obstacles arising from the relationship between economic growth, industrialization, and the production of CO_2, it is expected that more needs to be done by way of regional agreements.

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Man-induced climatic change has been endangering parts of the natural and human environment. Among economic activities, agricultural productivity is of obvious importance to human welfare since climate is a major determinant of both the locational patterns and productivity of agricultural activities. It is thus not surprising that agriculture has been viewed as an area of concern regarding the causes and effects of climatic change. Indeed, agriculture has been the central focus of several studies dealing with the potential effects of climatic change. Most studies to date have evaluated the sensitivity of various aspects of agricultural activity to climate change. These aspects include yields, input use and locational patterns. The results of these economic evaluations suggest that climate change is not a food security issue, although ample regional adjustments are likely.

In this paper, our empirical focus will be on agriculture. The large simulation models have been criticized by many researchers. It is questioned whether these models can predict conditions substantially different from past observed data. This paper, thus, provides an economic model to explore the relationship between climate variations and rice production. Since climate change is likely to be a major research and policy issue well into the next decade, the purpose of this paper is: 1) to study how the climate changes in Taiwan; 2) to provide an alternative way to forecast long-term weather; and 3) to examine the impact of weather conditions on rice production. With modest additional effort, current economic research could be of substantial assistance to policy makers in exploring the implications of unilateral versus cooperative international strategies.

This paper proceeds as follows. First, climate change in Taiwan is discussed in the first section. Two places, Taipei and Tainan, are chosen for discussion and serve only as an introduction to further study. Secondly, an alternative way to forecast long-term weather is suggested. By formulating the weather fluctuations as stochastic processes, the time-series model ARIMA(p,d,q) is then employed to forecast long-term weather. Thirdly, the impact of climate variations on the average rice yield per ha are examined. Finally, conclusions are presented in the last section.

Climatic change in Taiwan: a few cases

The world climate results from the interactions of the atmosphere, the oceans, the lithosphere, and the biosphere. The world climate is mainly driven by solar heating, however its different components interact in a complex way to produce the changing patterns of atmospheric and oceanic circulation that determine climate and climatic change.

This paper first explicates how the climate has changed in Taiwan over the past 96 years (i.e., 1897-1992). The data are taken from the Central Weather Bureau. Our study will focus on a few weather variables related to agricultural production, such as mean temperature, mean minimum temperature, precipitation, and the sunshine duration. For the purpose of comparisons, two places, Tainan and Taipei, are chosen for the following reasons: Tainan is located in southern Taiwan while Taipei is located in northern Taiwan. Moreover, Tainan is chosen because it is located around the center of the Chi-Nan Plains where most rice is produced. On the other hand, Taipei is chosen because of its population size.

By conducting some statistical tests, this paper provides evidence of the existence of climatic change in Taiwan. Over the past 96 years, average temperatures have increased 0.9°C in Tainan. Tables 1 to 5 show us that the normal mean temperature in Tainan significantly increases about 1°C with a t value of 11.94 by comparing the two periods of 1900-1929 and 1963-1992. The mean minimum temperature in Tainan also significantly increases about 1.4°C from 19.04 to 20.41 with a t value of 14.19, while the normal mean maximum temperature in Tainan only increases 0.36°C from 28.56 to 28.90 with a t value of 2.74. However, the amount of precipitation in Tainan drops about 83mm from 1702 to 1617 but not significantly. In addition, the yearly amount of sunshine duration in Tainan decreases from 2602 hours to 2383 hours with a t value of 5.21.

By comparing them monthly, it shows us that the temperature around the middle of the year such as May, June, July, August, September, October are affected most in Tainan. It also indicates that summer is getting hotter and longer in Tainan. Overall, the monthly precipitation in Tainan does not change significantly in these two periods although the amount decreases in all months. Regarding the sunshine duration, the amounts in September, October, and November significantly decreases in Tainan. These results are displayed in the Figures 1 to 5.

Similarly, Tables 1-1 to 1-5 provide information on Taipei's normal mean temperature which has significantly increased about 0.8° C with a t value of 8.64 by comparing the two periods of 1900-1929 and 1963-1992. The normal mean minimum temperature also significantly increases about 1.2°C from 18.31 to 19.54 with a t value of 8.76, while the mean maximum temperature only increases 0.5°C from 25.98 to 26.54 with a t value of 4.82. However, the amount of precipitation raises about 94mm from 2104 to 2198 with an insignificant t value. In addition, the yearly amount of the sunshine duration decreases 134 hours from 1629 to 1495 with a t value of 3.68.

By comparing them monthly, it shows us that the temperature in July, August, September, October and November are affected most. Like Tainan, the monthly precipitation does not change significantly in these two periods although the amount decreases in all months. Regarding the sunshine duration, the amounts in June, July, and September decreases significantly. These results are displayed in Figures 1-1 to 1-5.

Finally, the changes in the yearly typhoon occurrence and its maximum wind velocity are studied. The data show that the yearly typhoon occurrence has decreased from 4.13 to 3.03 with a t value of 2.74. However, the yearly maximum wind velocity has significantly increased from 34.20 to 56.07 meters per second with a t value of 7.75. Meanwhile, the yearly mean maximum wind velocity has also increased from 24.17 to 46.31 meters per second with a t value 9.23. This may be because a warmer world would be a moister one, thus, typhoons gain more energy from the condensation of water vapor than before. The results are shown in Table 6 and in Figure 6-8.

This final result is consistent with Steve Lamber's simulation result. Dr. Lamber, who is with the Canadian Climate Centre in Ontario, has employed a computer simulation model to look for the impacts of double CO_2 level on the number of storms between 30° north and the Arctic. He has found the number of weak storms drops a lot but the number of intense storms grows a bit and do more damage. The risk of storms rises.

Long-term weather forecasts: ARIMA(p,d,q) models

One major source of uncertainty in agricultural production comes from nature like the weather fluctuations since nature is usually hard to predict. The weather fluctuations can, thus, be formulated as stochastic processes in general. For the purpose of this research, only five weather variables, i.e., mean temperature, mean maximum temperature, mean minimum temperature, precipitation, and sunshine duration, will be forecast for Tainan.

The time-series model used in this paper, ARIMA(p,d,q), was first introduced by Box and Jenkins (1976). Let W(t) stand for the general weather variable. Assume $\{W(t), t \geq 0\}$ is a stationary stochastic process. In this paper, W(t) and W_t will be used interchangeably. To forecast $\{W(s), s > t\}$, let W(t) is an integrated autoregressive-moving average process of order (p,d,q). That is,

$$\Delta^d W_t$$
$$= \phi_1 \Delta^d W_{t-1} + \phi_2 \Delta^d W_{t-2} + \ldots + \phi_p \Delta^d W_{t-p} + \varepsilon_t - \theta_1 \varepsilon_{t-1} - \ldots - \theta_q \varepsilon_{t-q},$$

where Δ denotes the difference operator, the parameters $\phi_1, \phi_2, \ldots, \phi_p, \theta_1, \ldots, \theta_q$ may be positive or negative, and the random disturbances are assumed to be independently distributed across time. Each ε_t is assumed to be generated by the same "white noise" process, so that $E(\varepsilon_t)=0$, $E(\varepsilon_t^2) = \sigma^2$, and $E(\varepsilon_t \varepsilon_{t-k})=0$ for $K \neq 0$. Stationarity requires that $\Sigma \phi_i < 1$ and $\Sigma \theta_j^2 < \infty$. For notational ease, let B be a backward shift operator. The operator B imposes a one-period time lag each time it is applied to a variable. Namely, $BW_t = W_{t-1}$, $B^2W_t = W_{t-2}$, $\ldots, B^nW_t = W_{t-n}$. Using this operator, the ARIMA(p,d,q) process can be rewritten as

$$(1- \phi_1 B - \phi_2 B^2 - \ldots - \phi_p B^p) \Delta^d W_t = (1- \theta_1 B - \ldots - \theta_q B^q)\varepsilon_t,$$

Or

$$\varepsilon_t = \theta^{-1}(B)\phi(B) \Delta^d W_t,$$

where $\theta(B)=(1- \phi_1 B- \ldots - \phi_p B^p)$ and $\phi(B)=(1- \theta_1 B - \ldots - \theta_q B^q)$

The values of p and q for each relevant weather variable are determined from the autocorrelation function and the partial autocorrelation function. Let θ and ϕ be the vectors of autoregressive parameters $(\phi_1, \phi_2, \ldots, \phi_p)$ and the vector of moving average parameters $(\theta_1, \theta_2, \ldots, \theta_q)$ respectively. The estimation problem is to find values of θ, ϕ that minimize the sum of the following squared errors:[2]

$$S(\theta, \phi) = \Sigma_t \varepsilon_t^2 = \Sigma_t [\varepsilon_t \mid \theta, \phi, W]^2$$

[2] By assuming the error terms are all normally distributed and independent, with mean 0 and variance σ^2, maximum-likelihood estimate is the same as the least-squares estimate. For details, please see Pindyck and Rubinfeld (1981) for reference.

Since the equation is nonlinear in the parameters, it can be estimated by an iterative nonlinear estimation routine.[3]

The monthly weather data which began in 1897 and ended in 1992 are taken from the Central Weather Bureau. A total of 1152 monthly observations are employed to model each weather process by the ARIMA model. The following estimation results are obtained for the monthly average mean temperature (TEMPAVG), the monthly average mean maximum temperature (TEMPMAX), the montly average mean minimum temperature (TEMPMIN), the the monthly total precipitation (RAINFALL)[4], and the monthly total sunshine duration (SUNDUR).

$$(1-0.7153\, B^1)(TEMPAVG_t - TEMPAVG_{t-12}) = (1-0.5183\, B^1)\ (1-0.9377\, B^{12})\varepsilon_t$$
(10.57) (6.30) (83.82)

Model AIC = 3092.87

$$(1-0.8199\, B^1)(TEMPMAX_t - TEMPMAX_{t-12}) = (1-0.6010\, B^1)\ (1-0.9255\, B^{12})\varepsilon_t$$
(20.23) (10.78) (74.98)

Model AIC = 3478.52

$$(1-0.8482\, B^1)(TEMPMIN_t - TEMPMIN_{t-12}) = (1-0.6746\, B^1)\ (1-0.9292\, B^{12})\varepsilon_t$$
(20.46) (12.06) (72.52)

Model AIC = 3168.27

$$(1+ 0.6780B^{12})(1+0.4695B^{24})(1+0.1997B^{36})(RAINFALL_t - RAINFALL_{t-12}) = \varepsilon_t$$
(26.30) (15.90) (6.41)

Model AIC = 14886.96

$$(SUNDUR_t - SUNDUR_{t-12}) = (1 - 0.9019\, B^1)\ \varepsilon_t$$
(61.25)

Model AIC = 11330.02

The realized time-series data for the mean temperature, mean maximum temperature, mean minimum temperature, total amount of precipitation, total hours of sunshine duration are shown in Figures 9-13. A 120-period (i.e. 10 years) forecast that begins in 1993-January and ends in 2002-December is provided in Table 7. However, due to the limitation of space, only the 11-year actual data and their forecasted values that begins in 1990-January and ends in 2000 are illustrated in Figures 14-18.

Rice production and weather variations

This section summarizes our assessment of implications of possible climate change and

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[3] SAS package is used in this study to obtain the parameters' estimates.

[4] Due to the limited memory capacity, our forecasts in precipitation are not as good as the other weather processes. By using the mainframe computer, the results can be better.

weather variations for rice production in Taiwan from 1901 to 1991. To assess the impact of the weather factors on the agricultural sector is the focus of this paper. Rice production is chosen because rice is one of the major sources of food in Taiwan. Data on pre-War Rice yield data and area planted in rice, which began at 1901 and ended at 1945, are taken from Taiwan Fifty Years Statistics Abstract. After 1945, they are taken from Taiwan Food Statistics Book published by the Taiwan Food Bureau. Since Taiwan has experienced tremendous economic and population growth during the last two decades, the number of hectares to plant rice has also increased dramatically although it decreases lately due to the continuing increases in GNP. However, population growth and economic growth has affected the amount of land in planting rice as well as the total rice production. Therefore, to exclude these growth effects, data on the average rice yield per ha instead of the total rice yield are used in this study.

To analyze the impact of weather on rice production, a production-function approach is employed. First, let Q_t be the rice yield at time t, AQ_t be the rice yield per ha, K_t be the amount of land in planting rice, L_t be other inputs used to produce rice such labor, machinery, fertilizer, .., and so on. $W^*(t)$ is a vector of weather inputs. At each time t, the rice production function, f(.), is assumed to be a fixed-coefficient production function and f(.) exhibits constant returns. Then, f(.) is given by $\min(K_t/a, L_t/b)$ with constant parameters a and b. This is known as the Leontief production function. It is well known that land resource is scarce in Taiwan. Land, not machinery or labor, is the biggest constraint in agricultural production in the long run. Land is difficult to be substituted by other inputs such as labor or machinery although machinery and labor can be substituted with each other within a certain extent. Hence, Leontief production function is used in this paper. A technological progress factor, A(t), is also taken into account. Finally, the random component, $\xi^*(t)$, is assumed to have a multiplicative effect, instead of having an additive effect, on rice production. Namely,

$Q_t = A(t)f(K_t, L_t)W^*(t)\xi^*(t)$, where $f(K_t, L_t) = \min(K_t/a, L_t/b)$,
for every t, and a and b are fixed over time.

$$AQ_t = \frac{Q_t}{K_t} = A(t)f(\frac{L_t}{K_t})(W_t^*)^\beta \xi_t^*.$$

AQ_t exhibits having an exponential growth curve which is displayed in Figure 20. Let us take the logarithms of both sides and we obtain:

$$\log(AQ_t) = \log A_t + \log f(\frac{L_t}{K_t}) + \beta \log W_t^* + \log \xi_t^*.$$

Since the production function is assumed to be constant returns to scale, $f(K_t, L_t)/K_t = f(L_t / K_t)$. Furthermore, because a and b are fixed over time, $f(L_t / Kt)$ is constant over time.

$$Let\ A_t = e^{\alpha_0+\alpha_1 t+\alpha_2 t^2},$$

$$f(\frac{L_t}{K_t})=e^{\gamma_0},$$

$$\xi_t^*=e^{\xi_t},$$

$W_t^* = e^{W_t}$

Then,

$$\log AQ_t = \alpha_0 + \alpha_1 t + \alpha_2 t^2 + \gamma_0 + \beta W_t + \xi_t$$

$$= (\alpha_0 + \gamma_0) + \alpha_1 t + \alpha_2 t^2 + \beta W_t + \xi_t \,,$$

$$where\, \xi_t = \nu_t + \rho_1 \xi_{t-1} + \rho_2 \xi_{t-2},\ 0 \le \rho_1 \,,\ \rho_2 < 1.$$

By taking the logarithms of both sides, we obtain a quadratic time trend model with an order-two autoregressive error term. The models are estimated by the least squares method. T values are reported in parentheses under the coefficient estimates.

$$E(\log AQ_t | W_t) = \underset{(-0.732)}{-0.0297} + \underset{(4.367)}{0.0081}\, t + \underset{(4.808)}{0.00008679}\, t^2, \quad R^2 = 0.9475,$$

Model F value = 794.16 with d.f. =(2,88)

After detrend, the residuals are fitted into a model with an AR(2) error process to obtain the estimates of parameters, β, which is the impact of weather on rice production. When the model is fitted by four monthly weather variables, i.e., TEMPAVG, TEMPMIN, RAINFALL, SUNDUR, with an AR(2) error process, this model can explain 79.45% of the sample variation of the residuals. However, in the empirical study, we choose only a few weather variables which are critical to rice production. The empirical result is shown in Table 8. Among those variables, four variables, April-sunshine duration, October- Precipitation, April-mean temperature, and April-mean minimum temperature, are significant at 10%. Our empirical study shows that precipitation in October is significantly negatively related to average rice yield per ha while sunshine duration in April is positively related to average rice yield per ha. In October, it is around the harvest time and the rainy weather will be a great damage to the harvest. These sixteen weather variables can explain 64.12% of the rest of the sample variations.

In sum, our whole model can explain about 98.92 percent of the sample variation in terms of R^2 if using all of the four available monthly weather information. It can also be used in forecasting future average rice yield per ha with the help of those long-term weather forecasts from the previous section. Climate change will influence precipitation, groundwater recharge, stream flow, and other factors involved with water supply. This, in turn, will affect available irrigation water. However, the above results do not consider the social cost of irrigation water use and its availability. Although rice yield may not be affected much by the climate change due to the technological progress, it will affect the water requirements for irrigation. Water requirements are then expected to increase substantially.

CONCLUSIONS

Concern over human-induced climate change is likely to be considered as one of the paramount social issues at the century's end. Potential changes in climatic phenomena due to industrialization and agricultural activities that produce carbon dioxide and other greenhouse gases could have unreproduced impact upon land use, population migration, economic activity, species diversity, and the survival of entire nations, particularly island nations and those with large populations concentrated along their coasts.

Some general concluding remarks are in order. This study first illustrates the climate changes in Tainan and in Taipei from 1897 to 1992. Our findings show that mean temperature has gradually increased over the past 96 years. In southern Taiwan, the summer is getting significantly longer and hotter. The yearly amount of precipitation has decreased in the south and increased in the north, but not significantly. The sunshine duration has also decreased in both places.

Secondly, this study provides a method to conduct the long-term weather forecasts. Since the weather data are stationary although they all possess the seasonal factor, a time-series model, ARIMA(p,d,q), is employed to forecast the weather series. Five monthly weather series observed from 1897 to 1992 in the Tainan station, i.e., mean temperature, mean maximum temperature, mean minimum temperature, precipitation, and the sunshine duration, are taken from the Central Weather Bureau. The empirical results indicate that this approach is very practical and useful especially in forecasting the long-term weather.

Finally, this paper examines the impact of climate variations on the average rice yield per ha in Taiwan. A constant-return fixed-coefficient production function is assumed. The empirical study shows us that technological progress has played an important role in rice production over the past 96 years. It explains about 95% of the sample variation in the average rice yield per ha. Four weather conditions, namely, mean temperature, mean minimum temperature, precipitation, and the sunshine duration, can explain about 80% of the rest of the sample variations. This study also shows that four variables, April-sunshine duration, October-precipitation, April mean temperature, and April mean minimum temperature, are significant at 10%. Thus, with the help of long-term weather forecasts, our model could provide the forecast for the future average rice yield per ha.

It is often argued that "agriculture is an activity that can readily adapt to changes in environmental conditions, by switching crops, developing new hybrids, irrigation, and so on. Yet there is evidence that, in practice, agriculture is slow to reduce its vulnerability to climatic conditions. Technological developments, economic structures and government support policies often reinforce this inertia" (Smith, 1988). Agricultural systems may adapt, but without an improved understanding of implications and options under changing and persistently variable climates, this adaptation may be at considerable social and environmental cost. Although this paper shows that the climatic change does not affect the rice yield much since technological growth has outweighed the climatic effects, the irrigation water use might increase substantially which needs to be further studied. Water resource has become scarcer in southern Taiwan due to climate change. Climate change has resulted in a longer, warmer, drier season in southern Taiwan. To maintain the agricultural production, water resource used in irrigation, which accounts for 75% of the water use, now must compete with other uses. Thus, although rice yield may not be affected much by climate change, the social cost to produce rice, such as the large amount of water use for irrigation, may be great.

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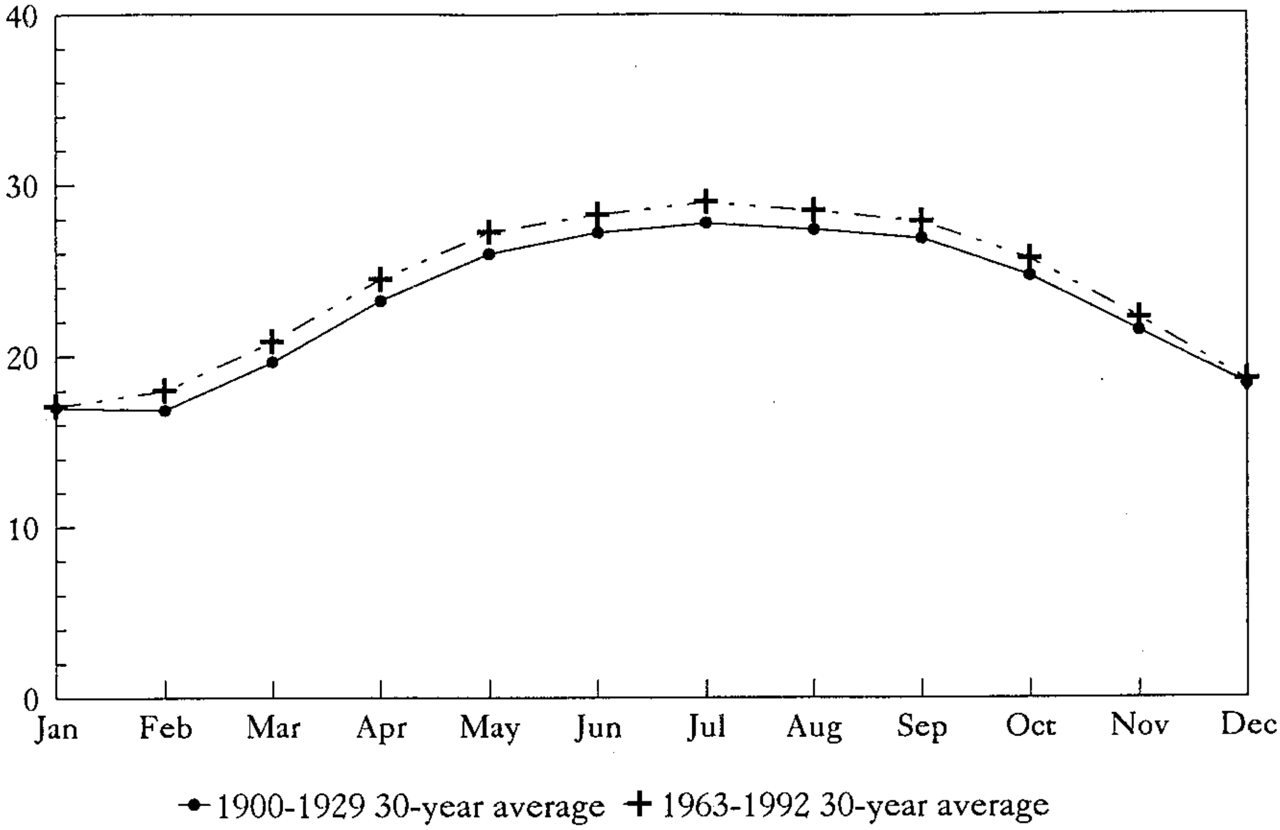


Figure1. Tainan Monthly Mean Temperature

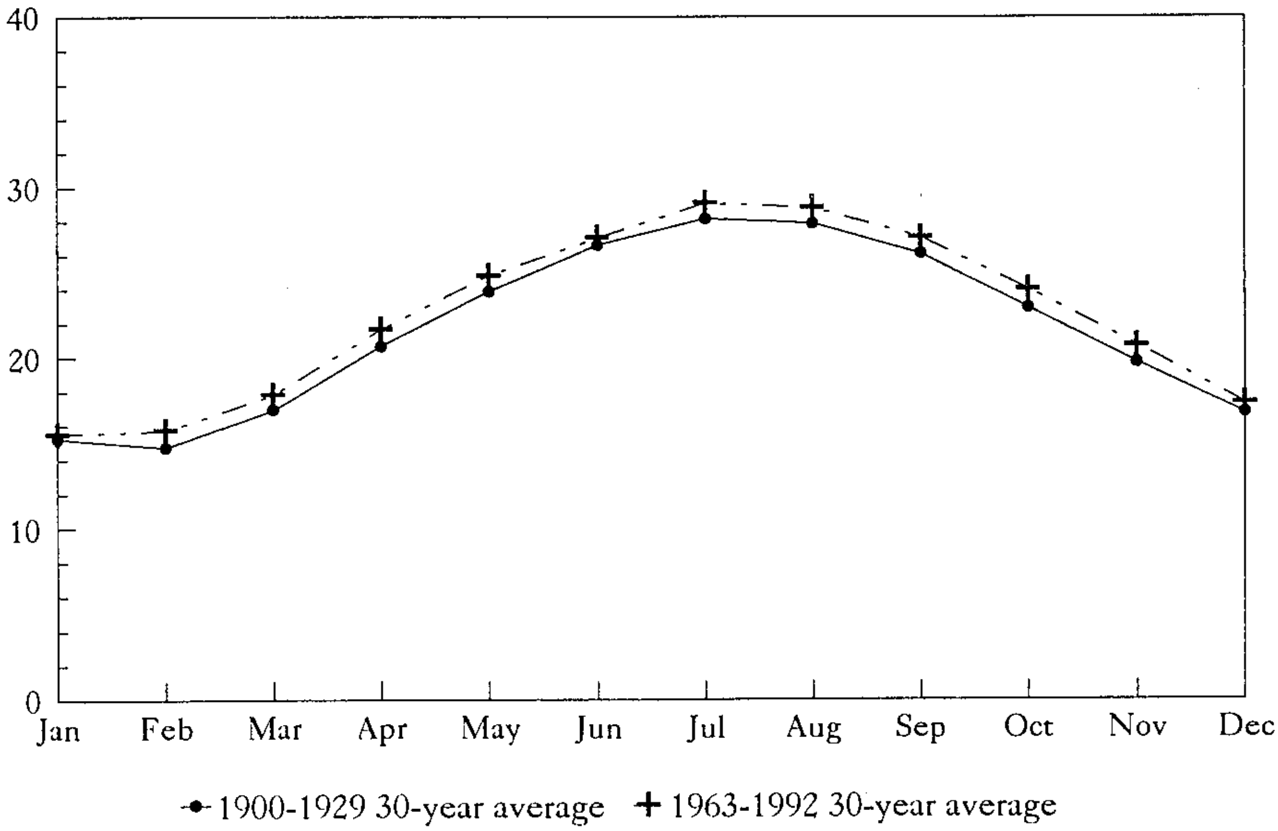


Figure1.1 Taipei Monthly Mean Temperature

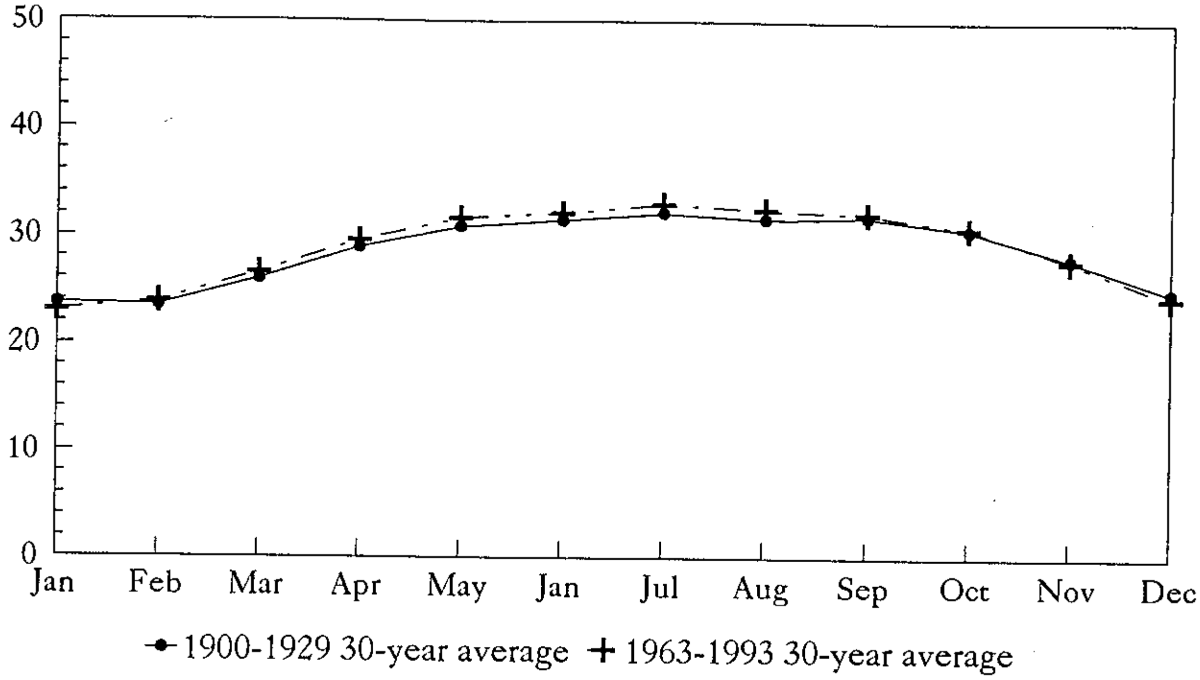


Figure2. Tainan Monthly Mean Maximum Temperature

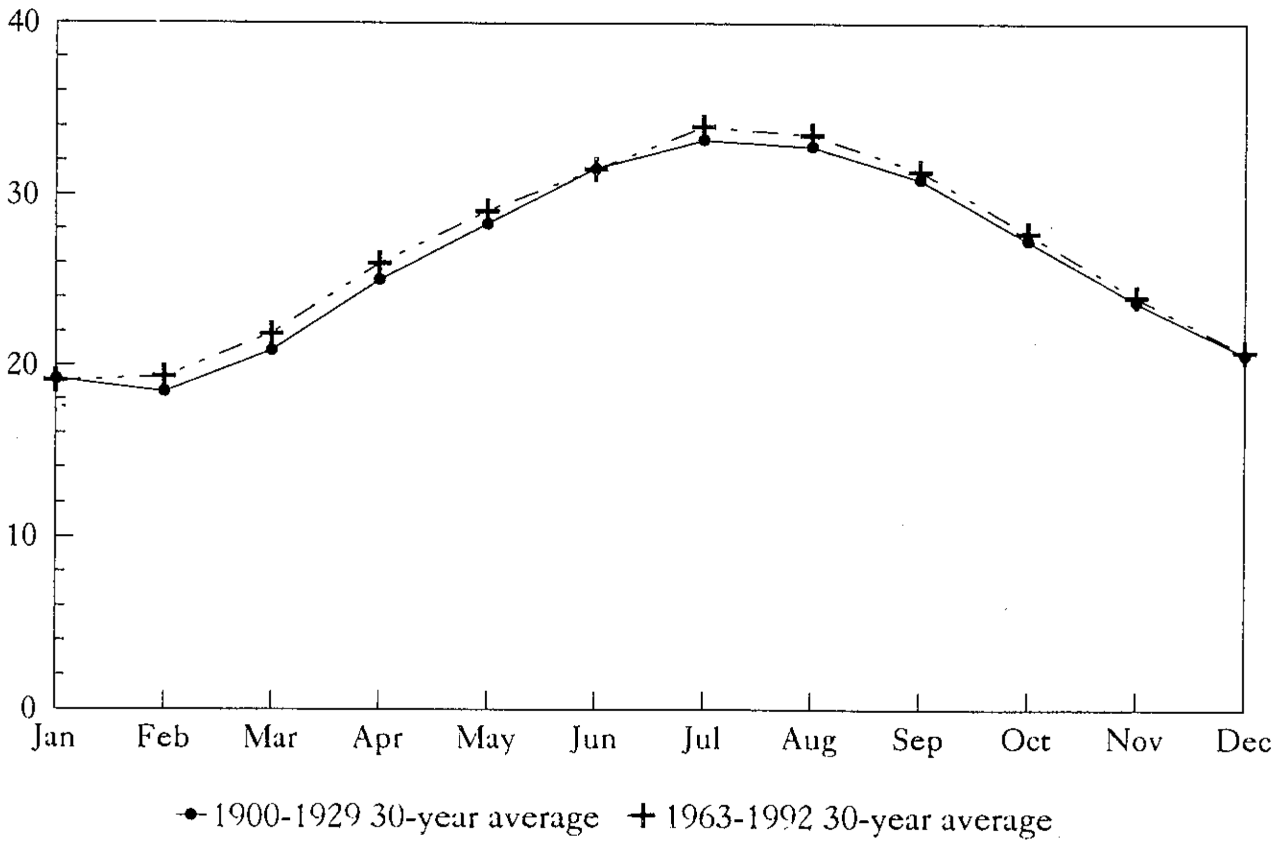


Figure2.1 Taipei Monthly Mean Maximum Temperature

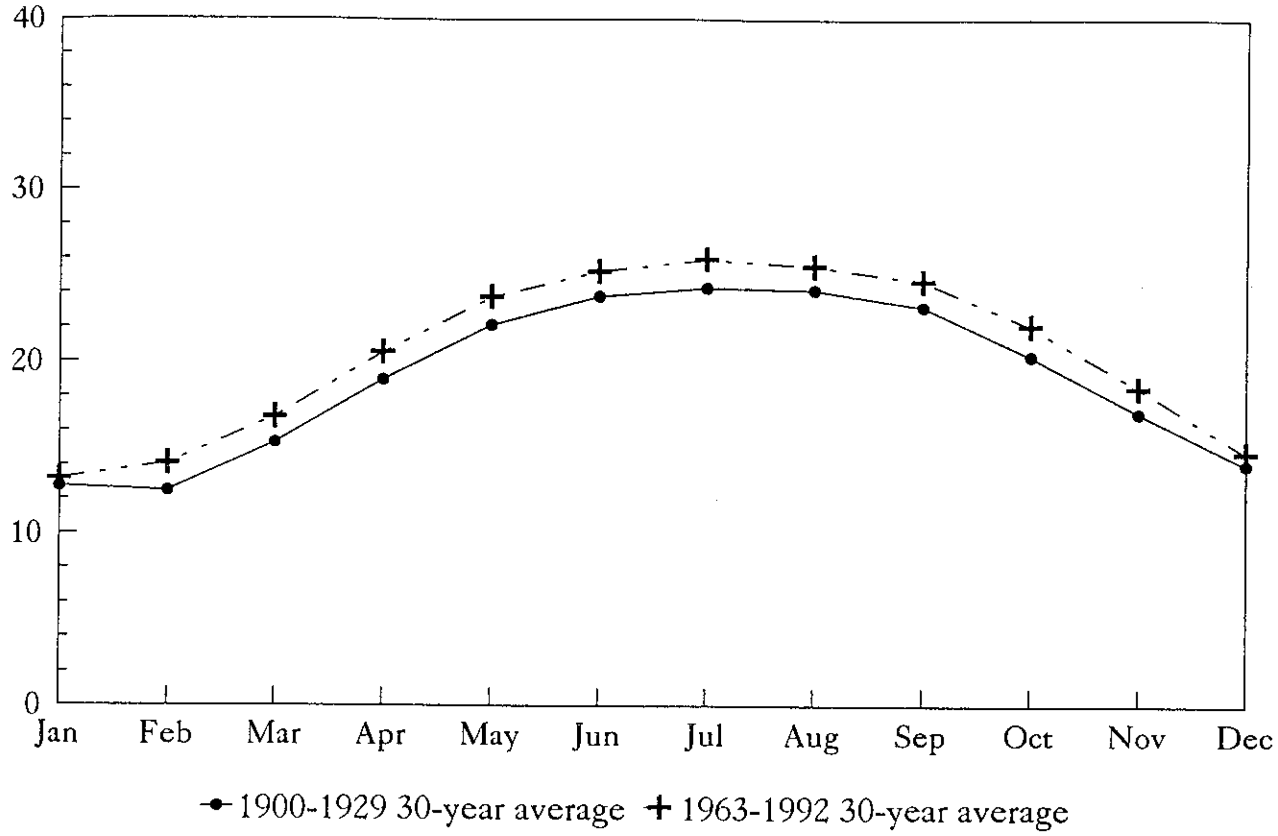


Figure3. Tainan Monthly Mean Minimun Temperature

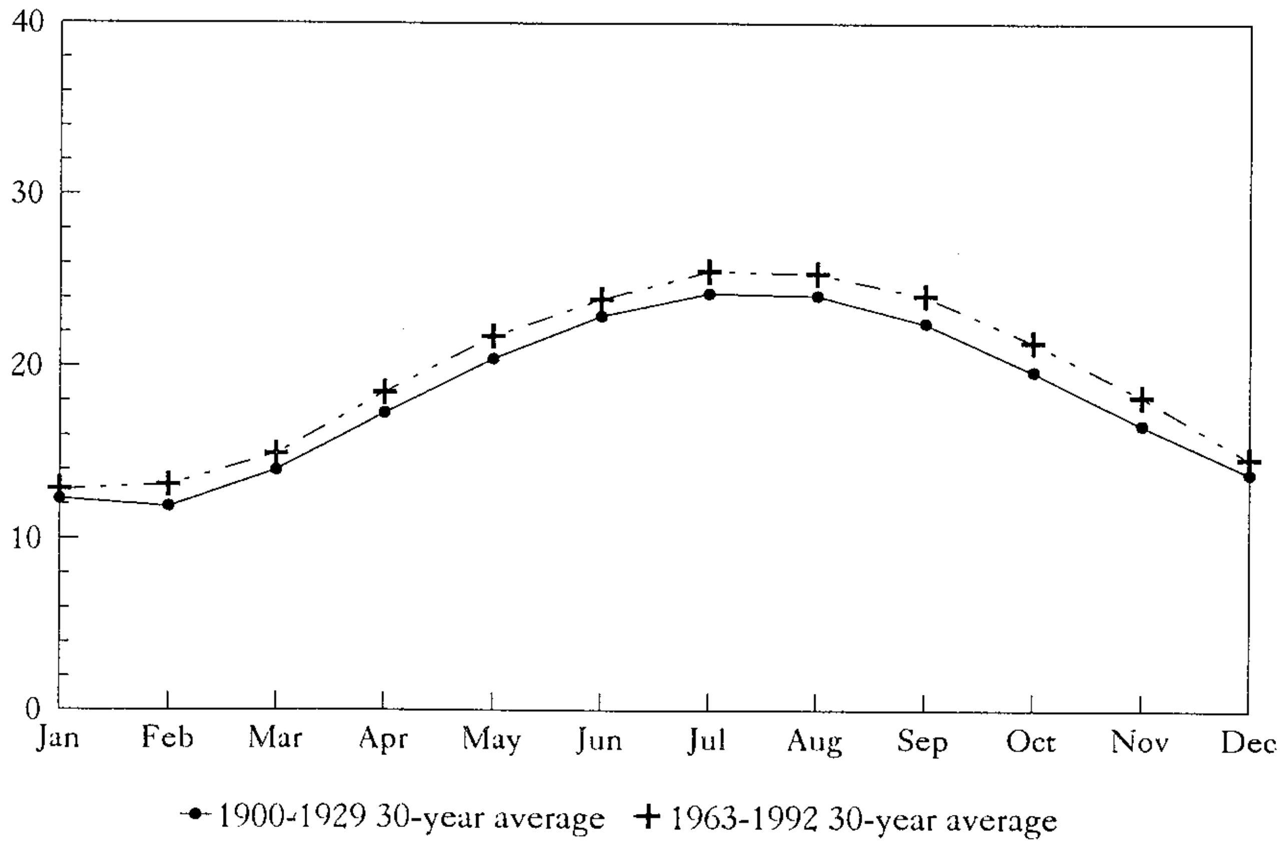


Figure3.1 Taipei Monthly Mean Minimum Temperature

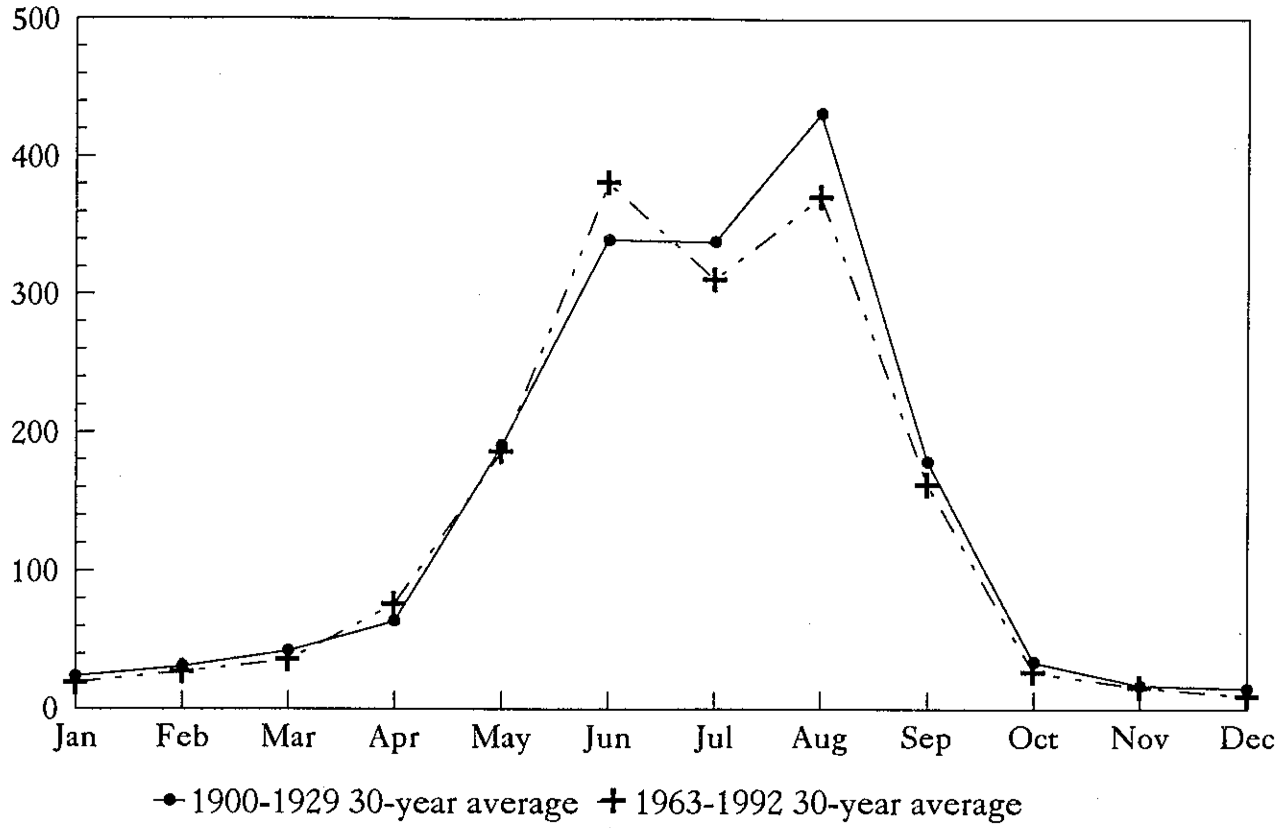


Figure4. Tainan Monthly Precipitation

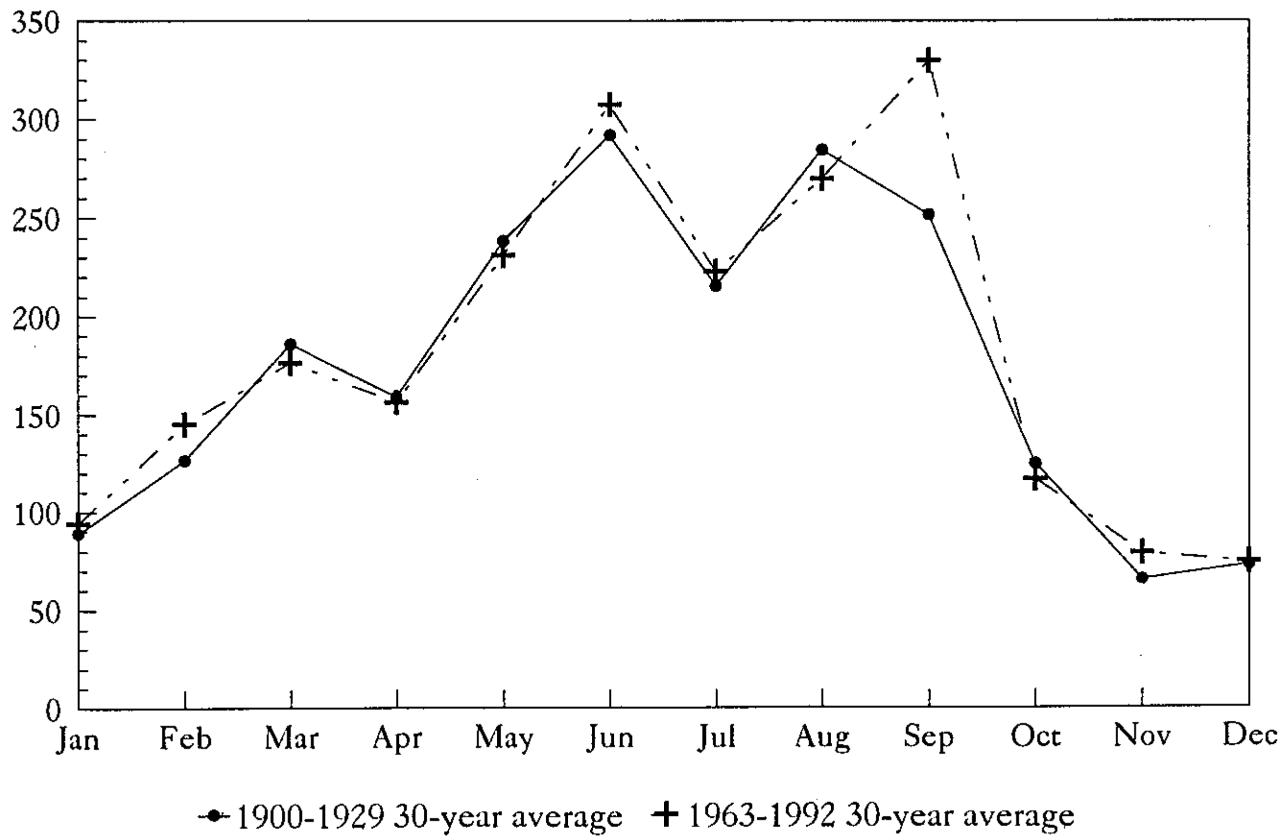


Figure4.1 Taipei Monthly Precipitation

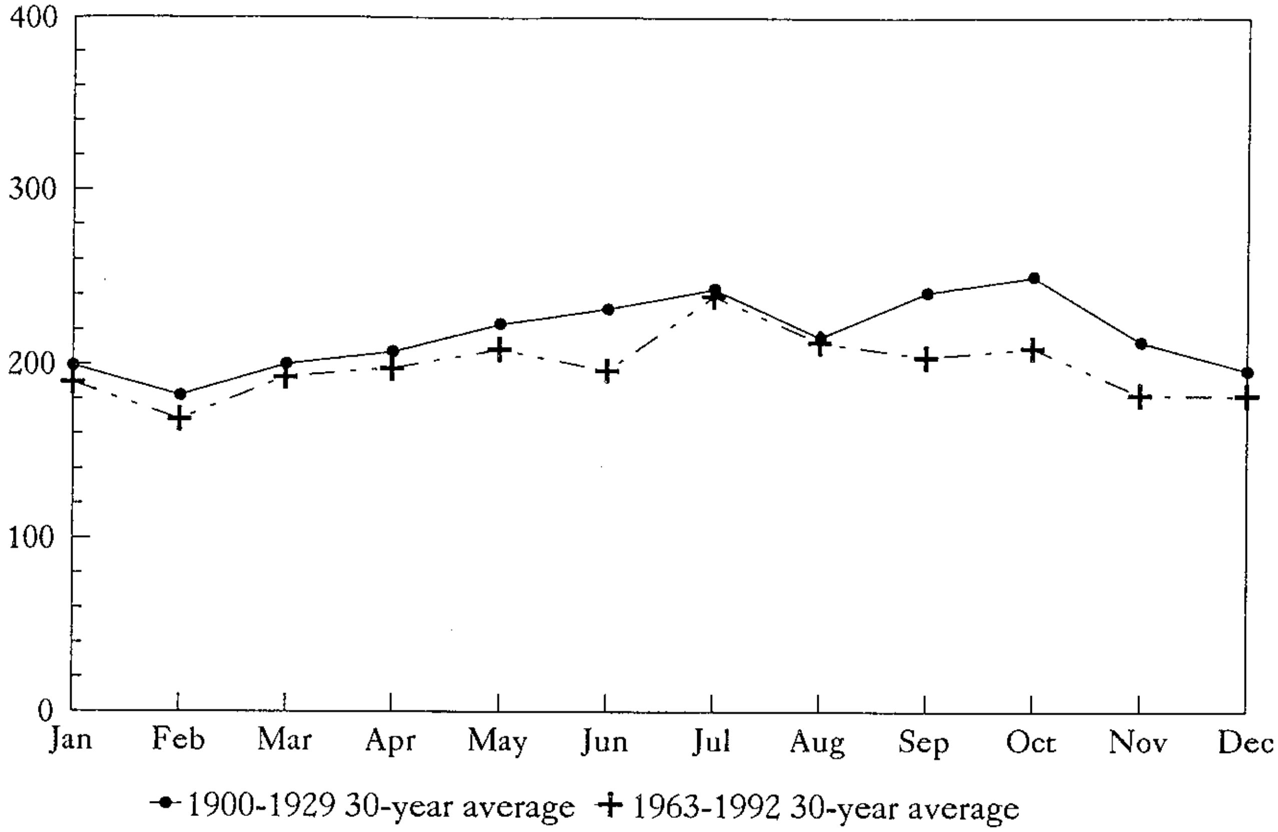


Figure5. Tainan Monthly Sunshine Duration

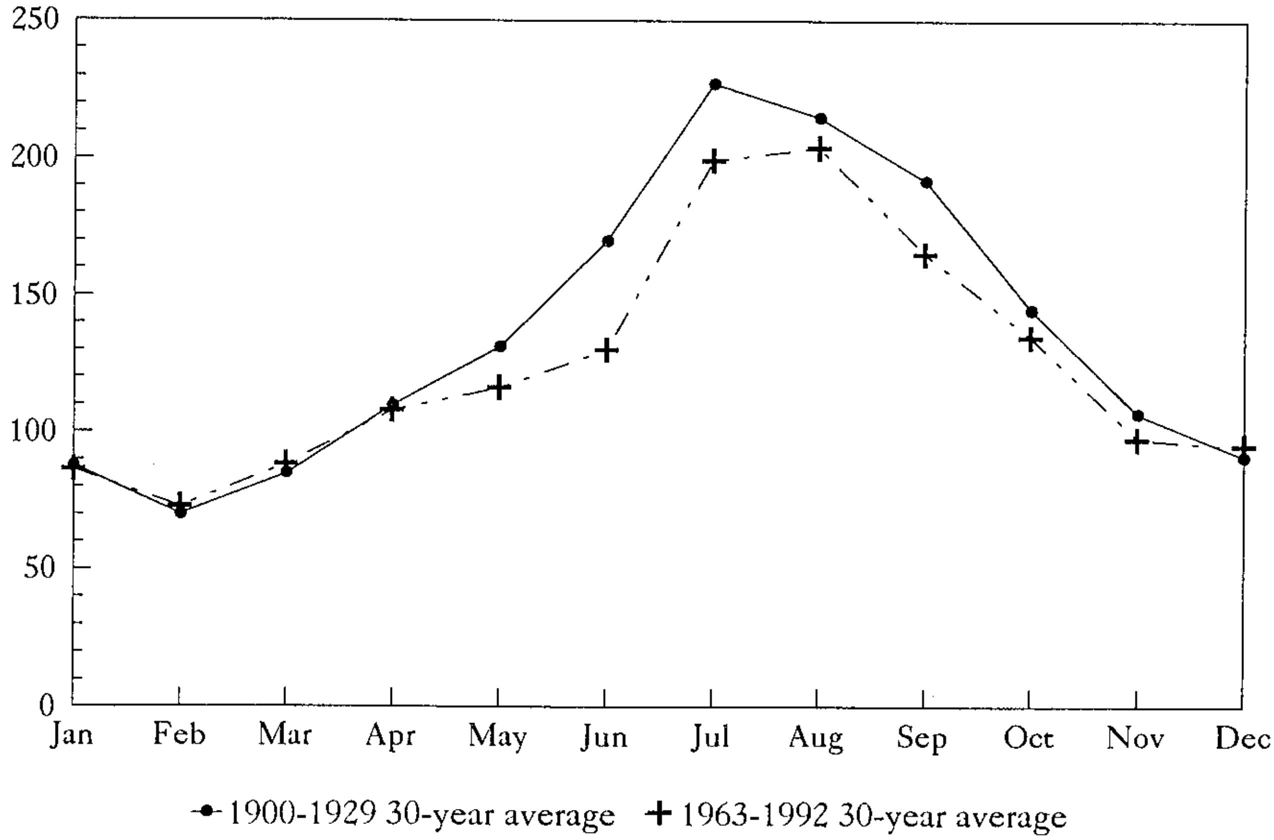


Figure5.1 Taipei Monthly Sunshine Duration

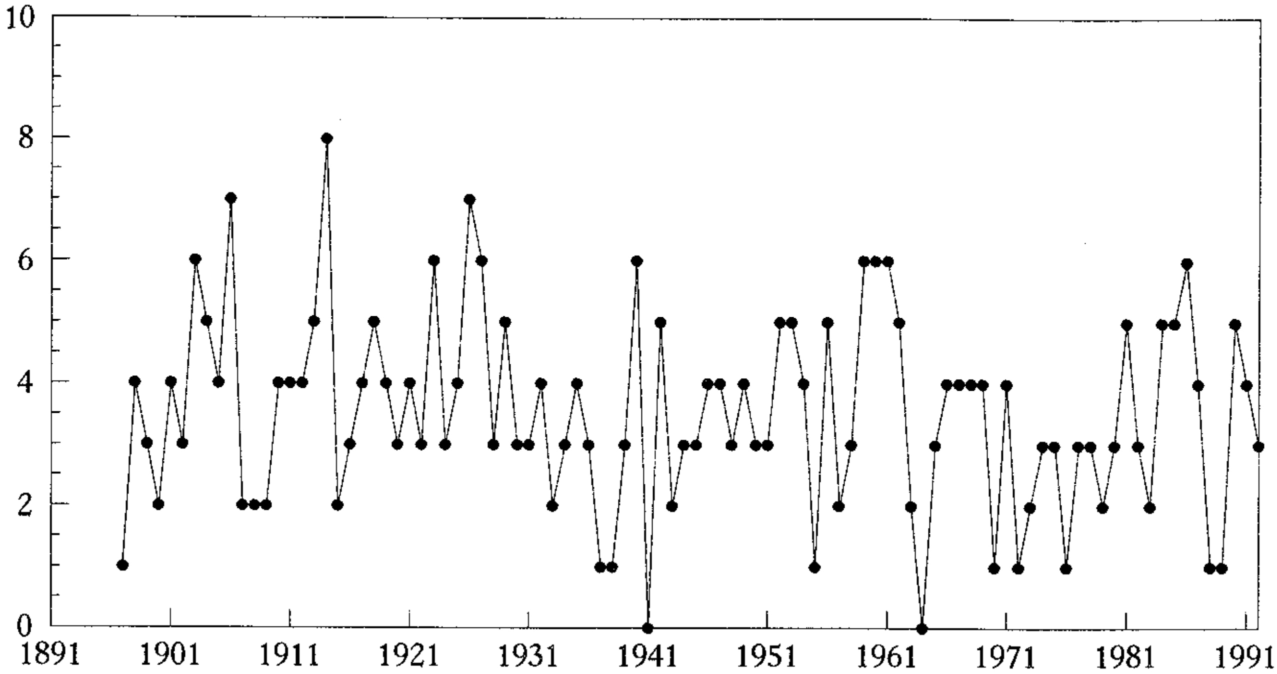


Figure 6. Typhoon Occurrence in Taiwan (1897 - 1992)

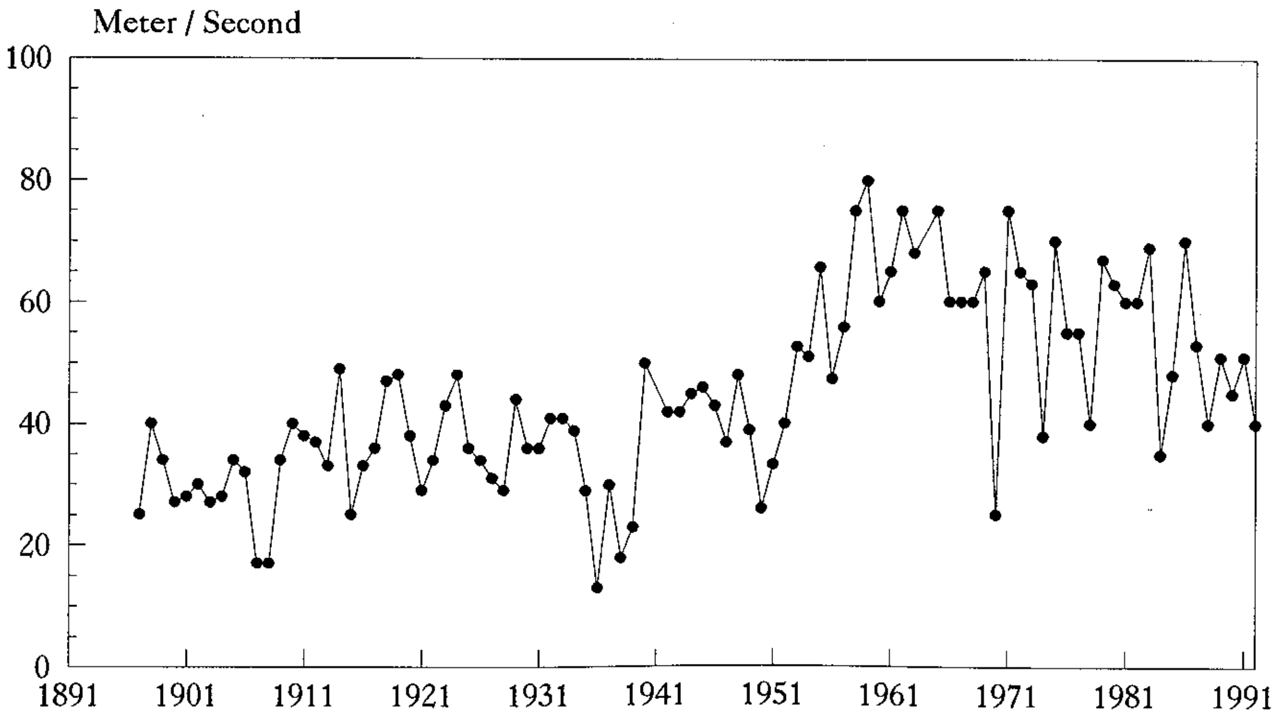


Figure 7. Max Wind Velocity - Typhoon in Taiwan (1897 - 1992)

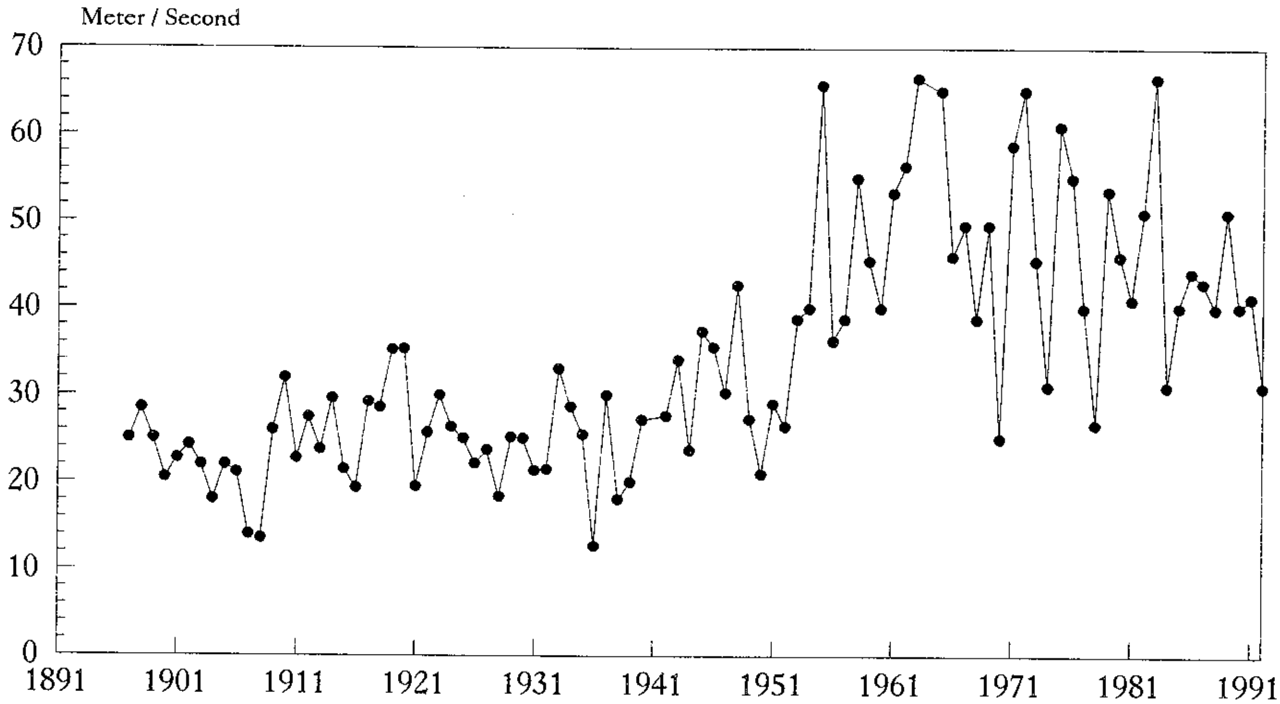
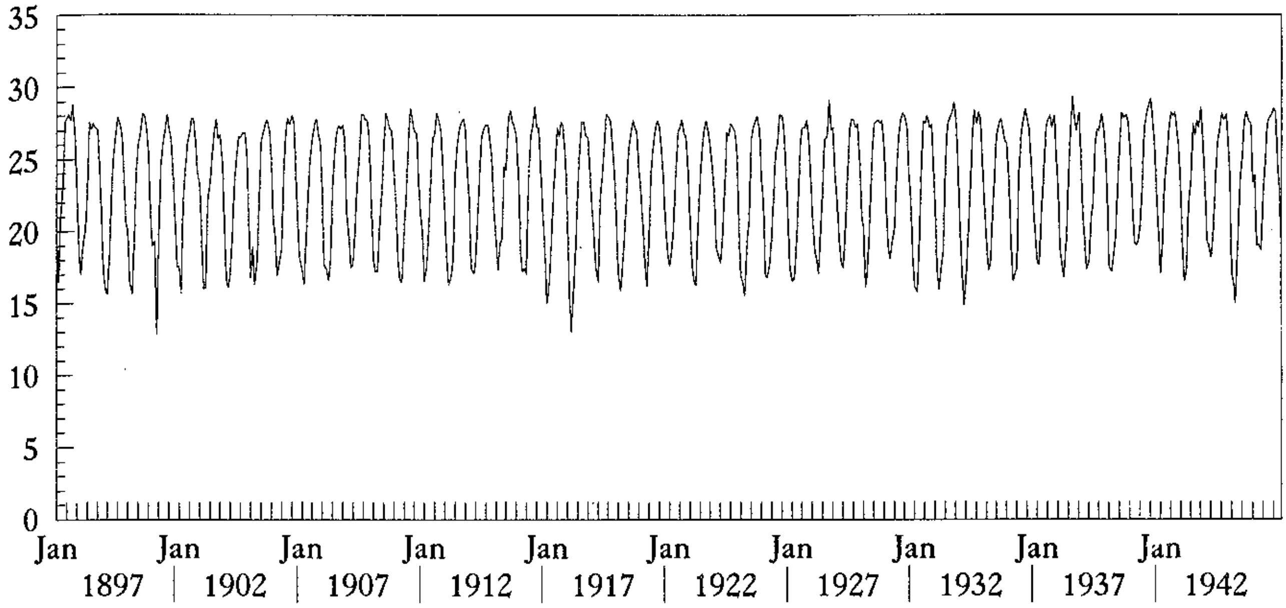


Figure 8. Mean Max. Wind Velocity - Typhoon in Taiwan (1897 - 1992)



—Mean Temperature (1897 - 1946)

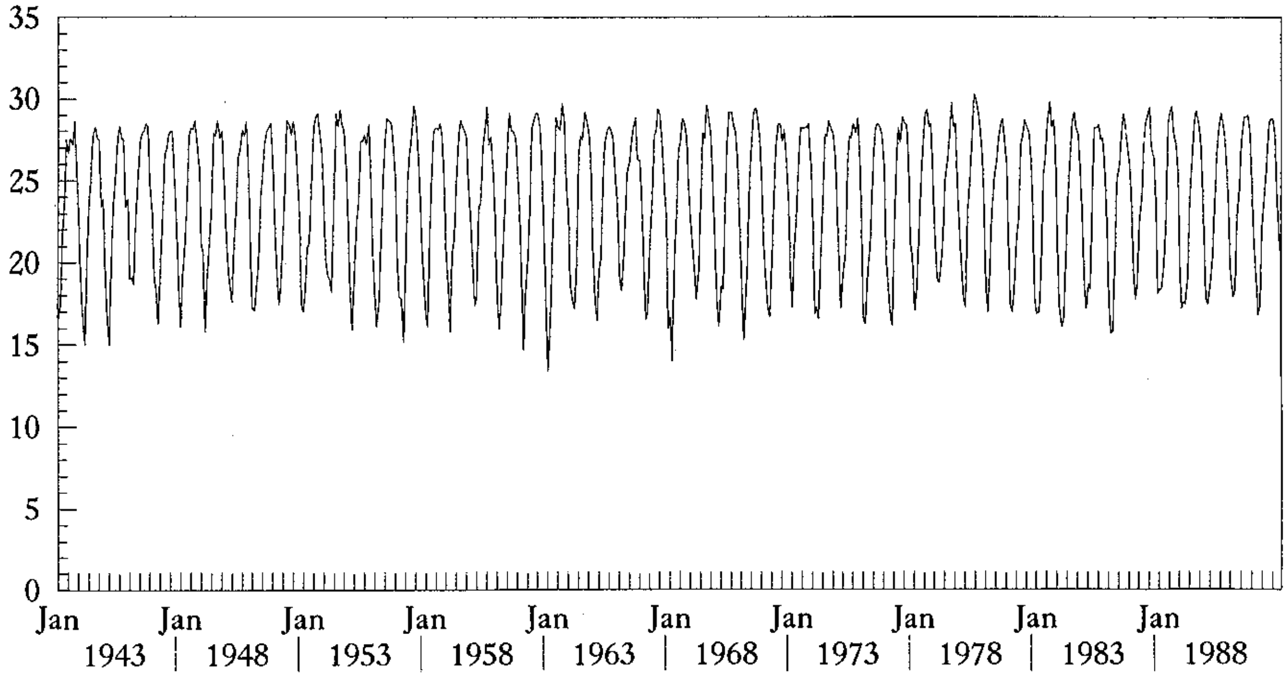
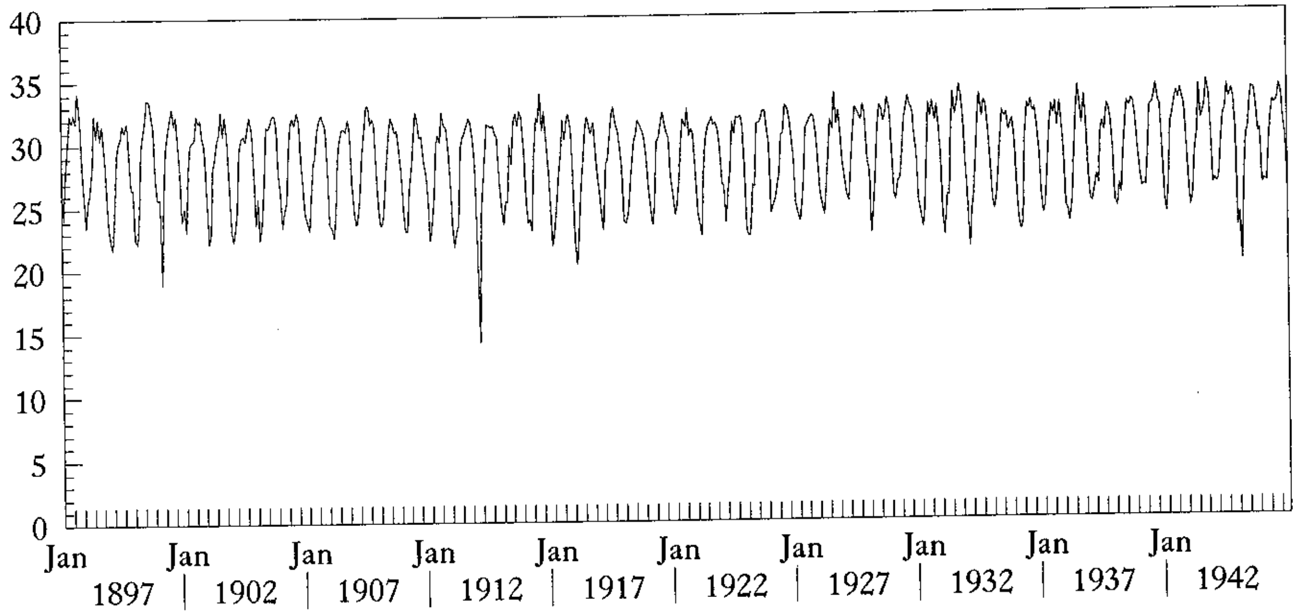


Figure 9. Mean Temperature (1943 - 1992)



—Mean Maximum Temperature (1897 - 1946)

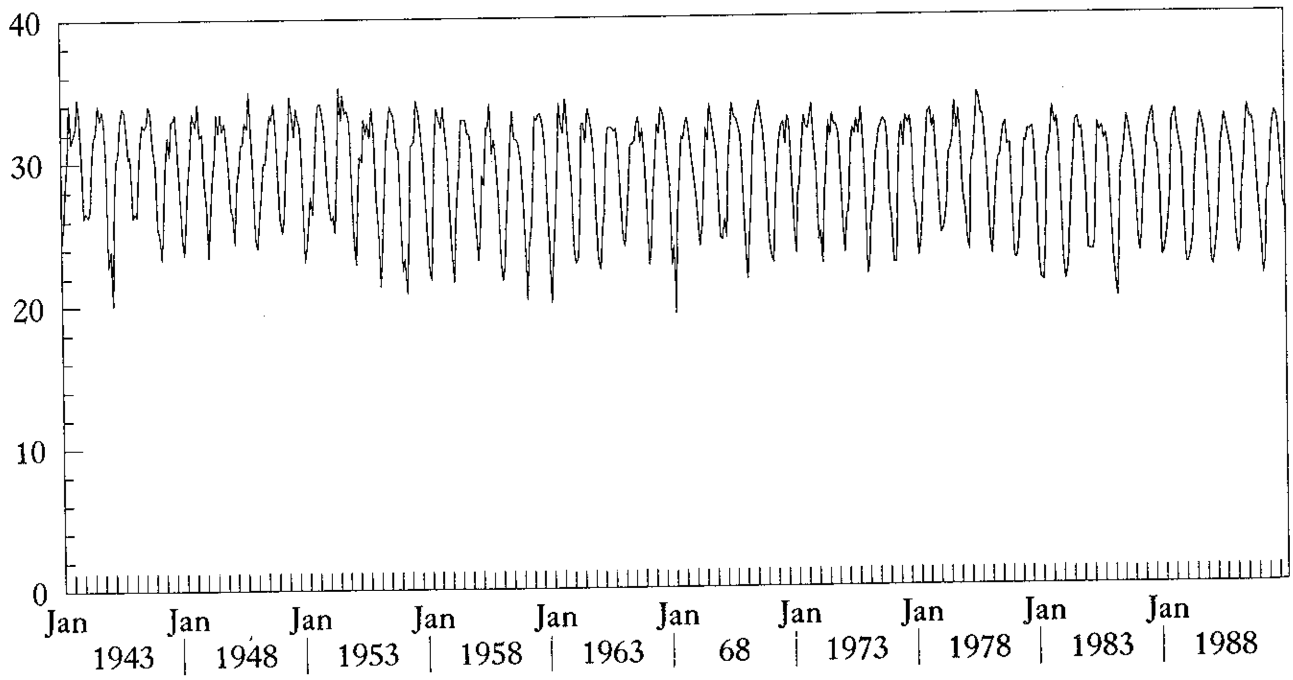
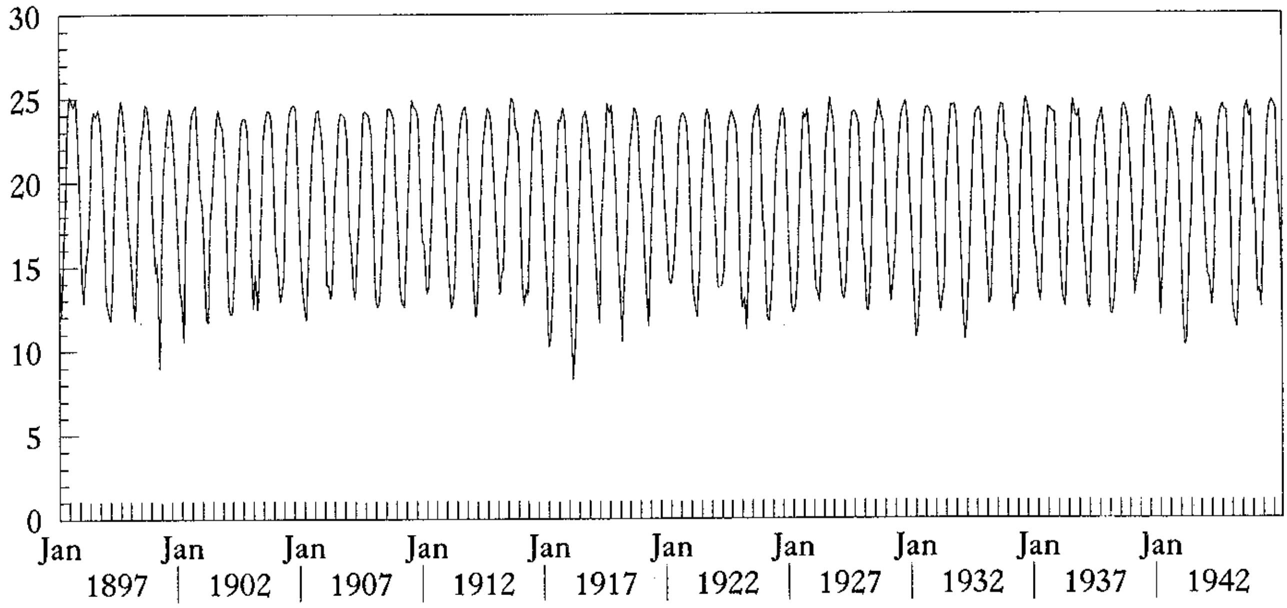


Figure 10. Mean Maximum Temperature (1943 - 1992)



—Mean Minimum Temperature (1897 - 1946)

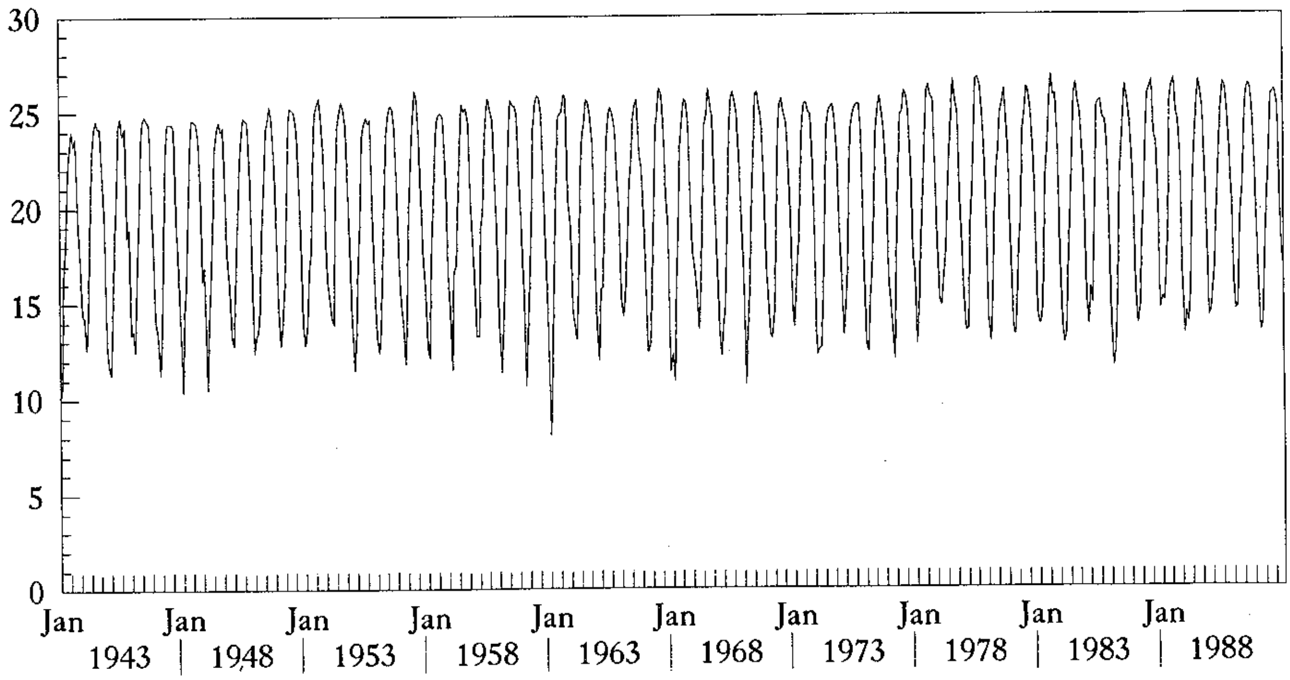
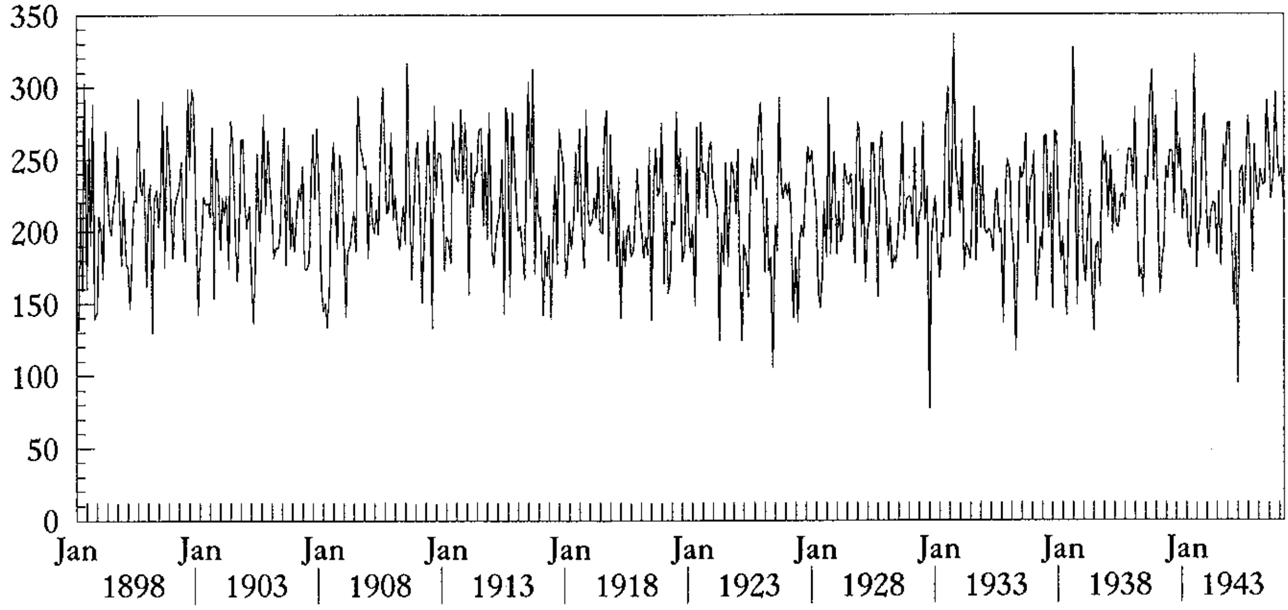


Figure 11. Mean Minimum Temperature (1943 - 1992)



—Sunshine Duration (1898 - 1946)

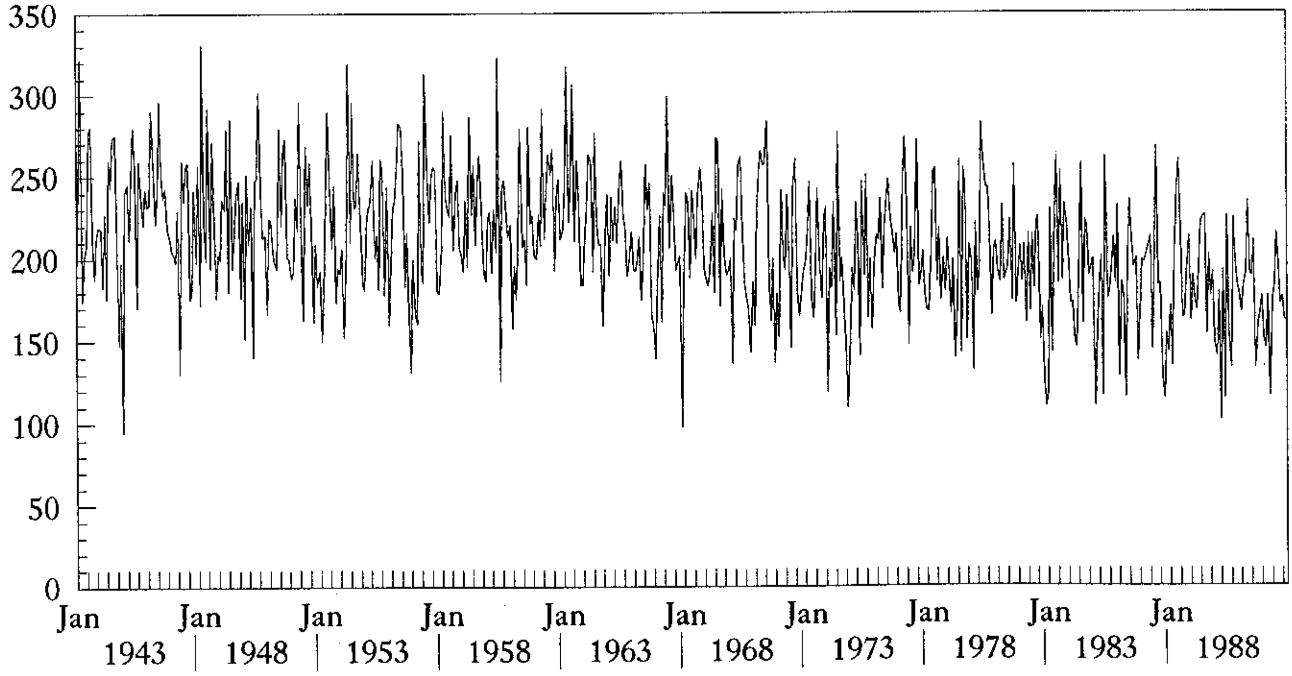
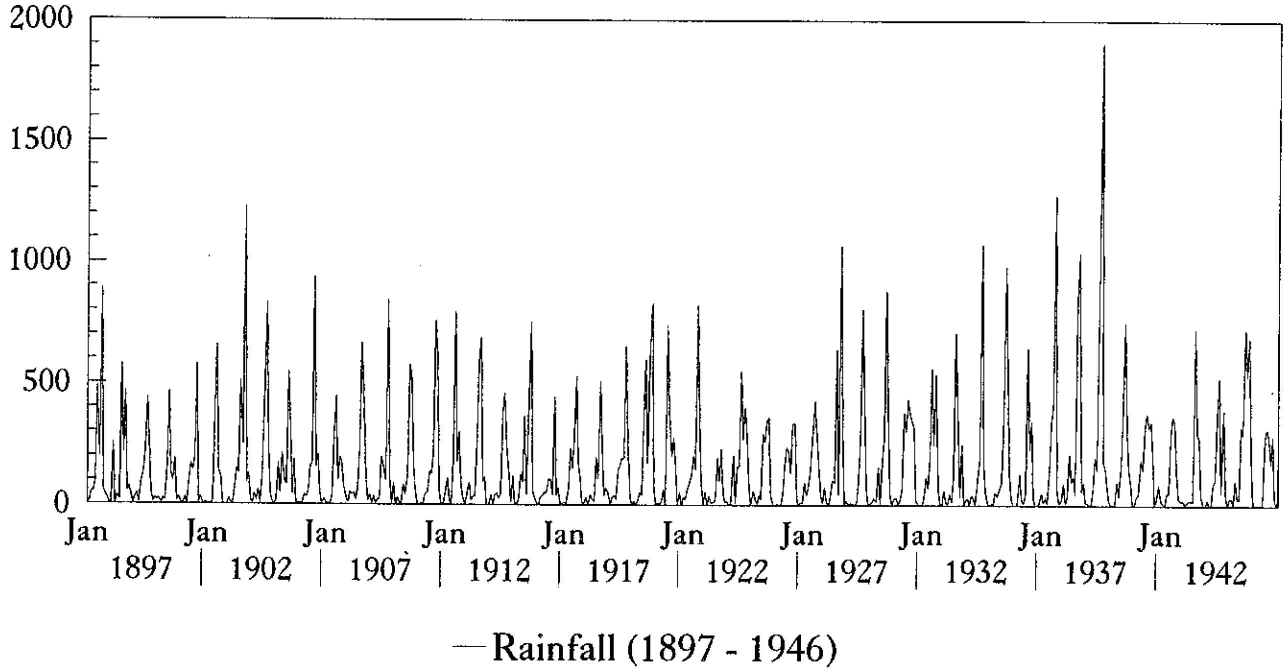


Figure 12. Sunshine Duration (1943 - 1992)



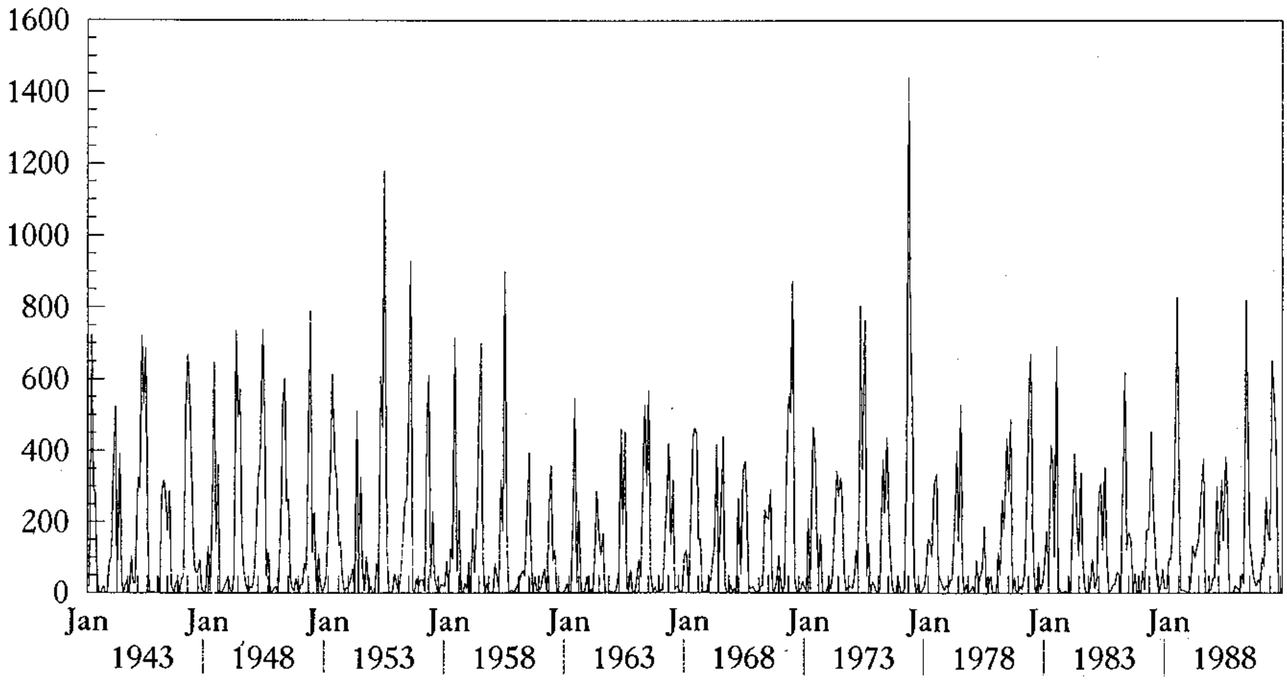


Figure 13. Rainfall (1943 - 1992)

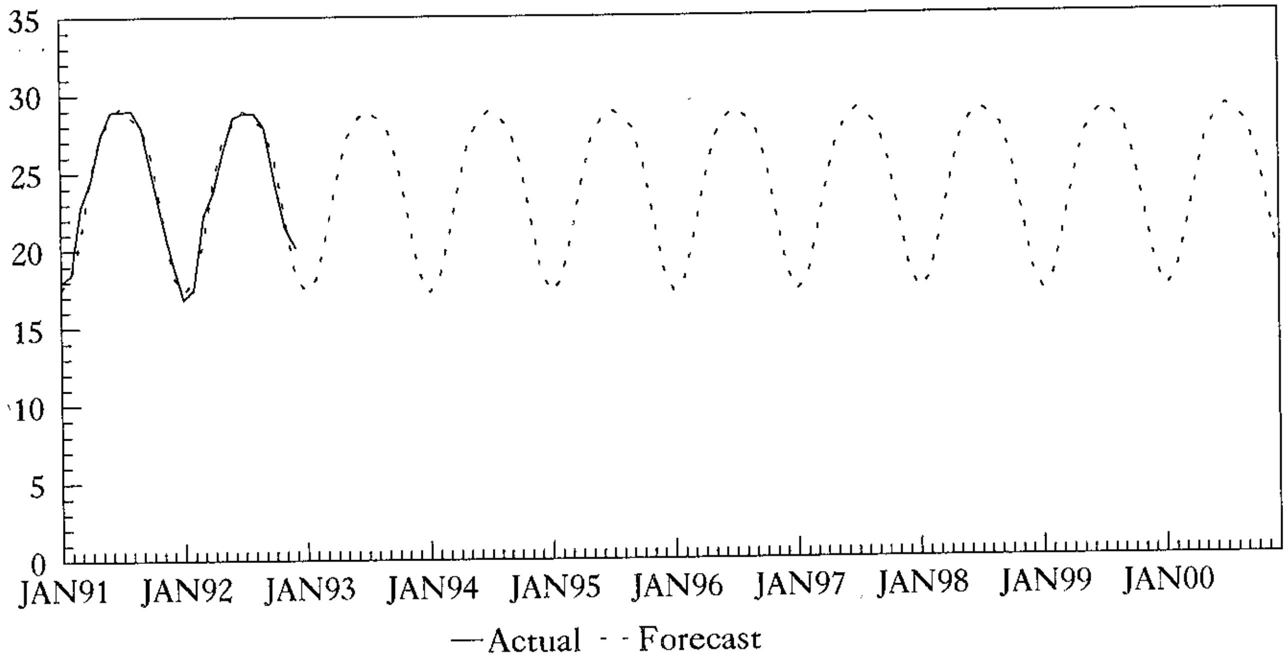


Figure 14. 120 - Month Forecast of Mean Temperature (Tainan, 1991 - 2000)

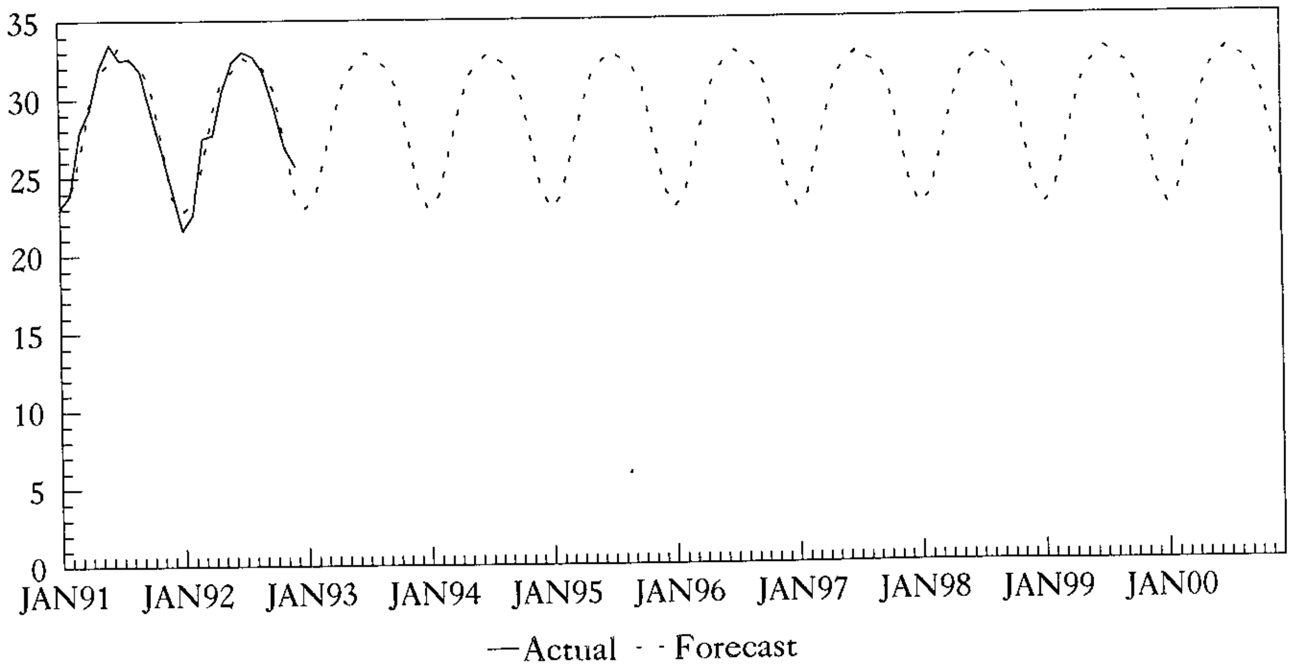


Figure 15. 120 - Month Forecast of Mean Maximum Temperature (Tainan, 1991 - 2000)

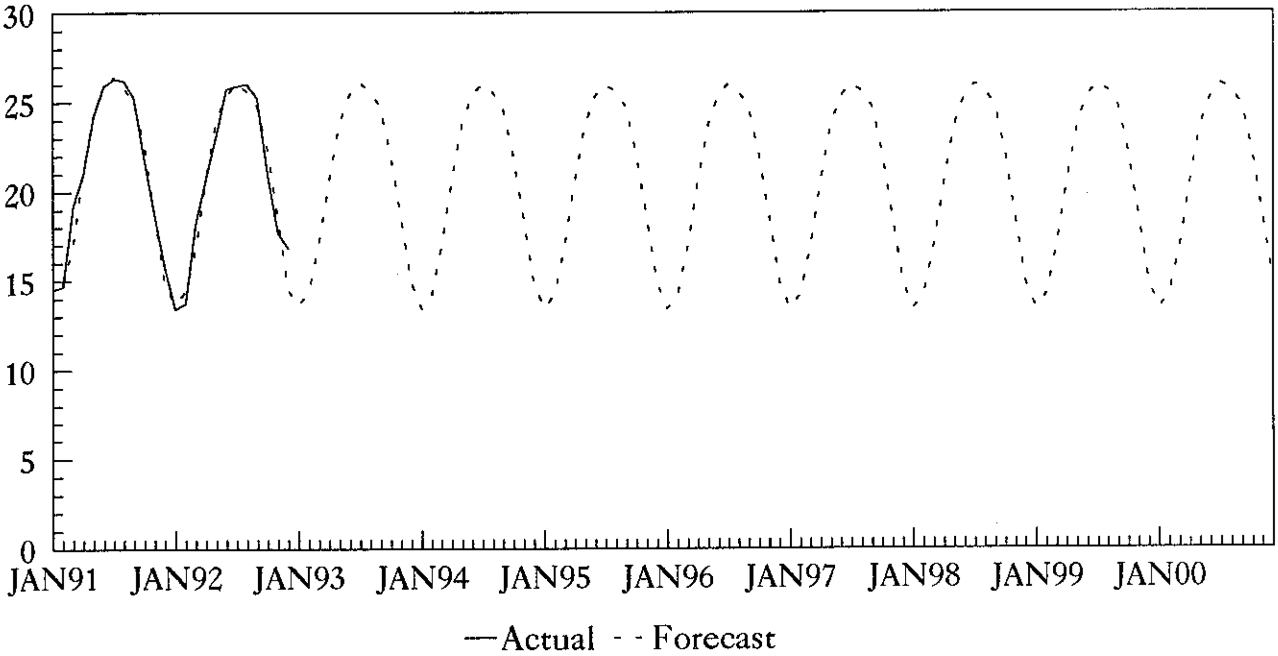


Figure 16. 120 - Month Forecast of Mean Minimum Temperature (Tainan, 1991 - 2000)

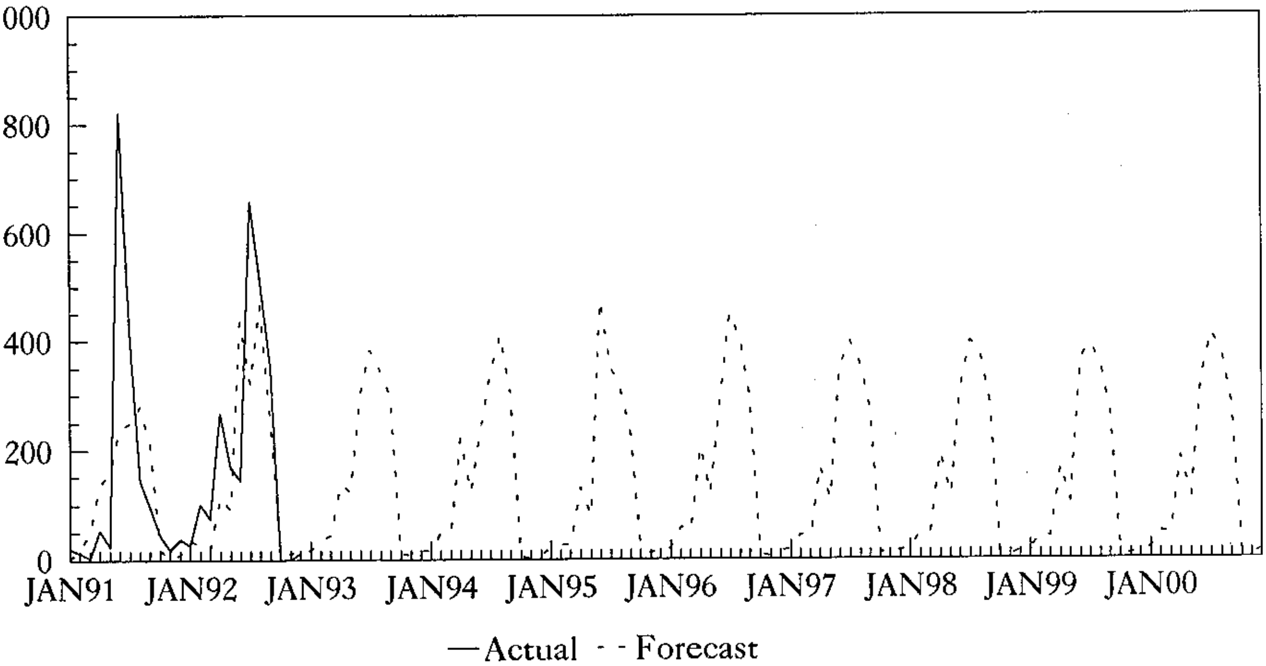


Figure 17. 120 - Month Forecast of Precipitation (Tainan, 1991 - 2000)

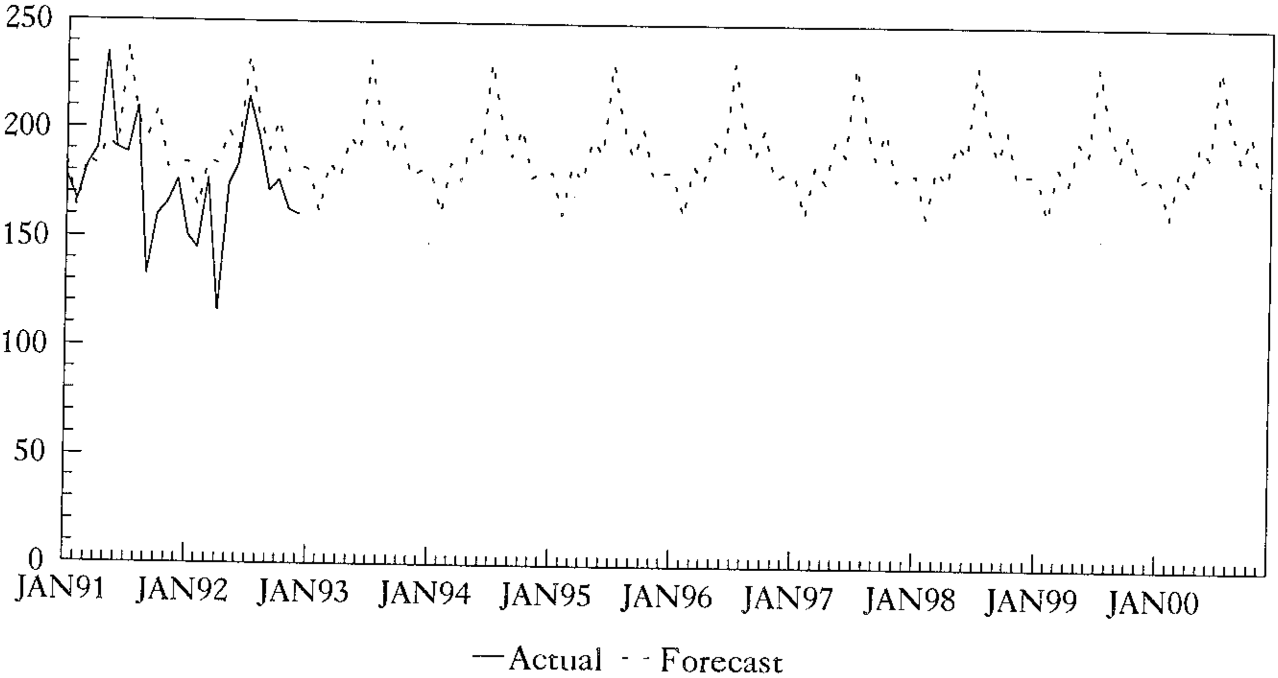


Figure 18. 120 - Month Forecast of Sunshine Duration (Tainan, 1991 - 2000)

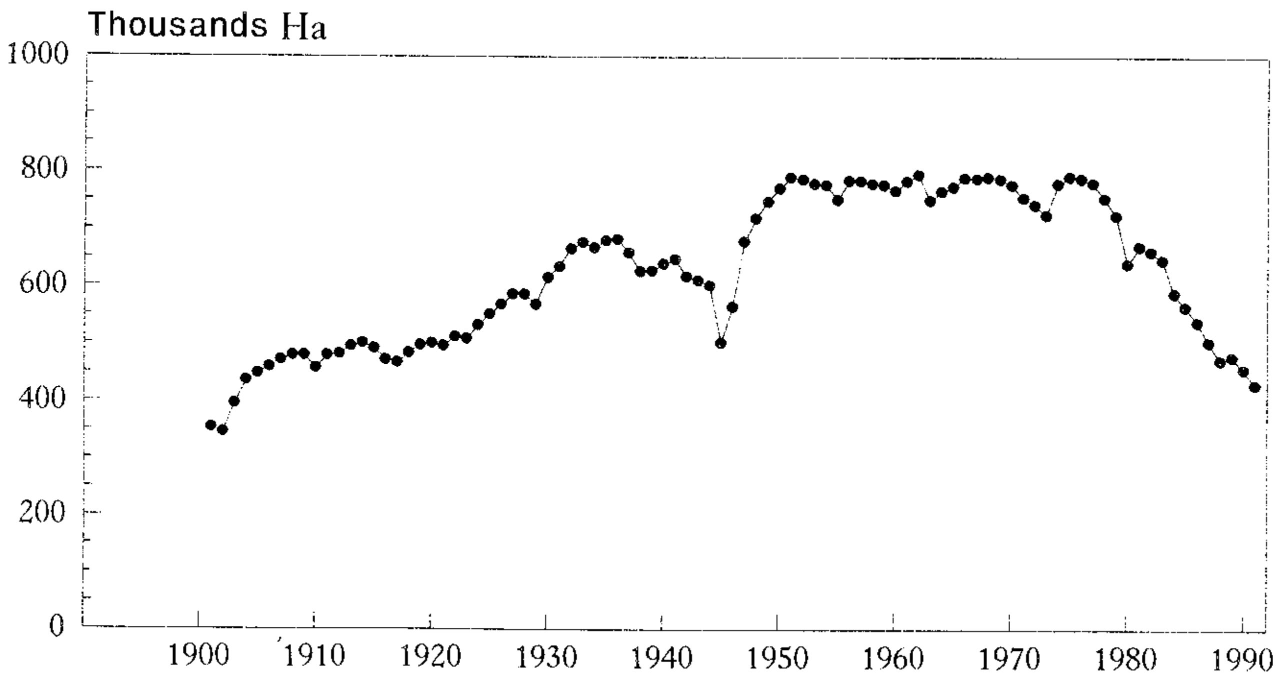


Figure 19. Area Planted in Rice (1901 - 1991)

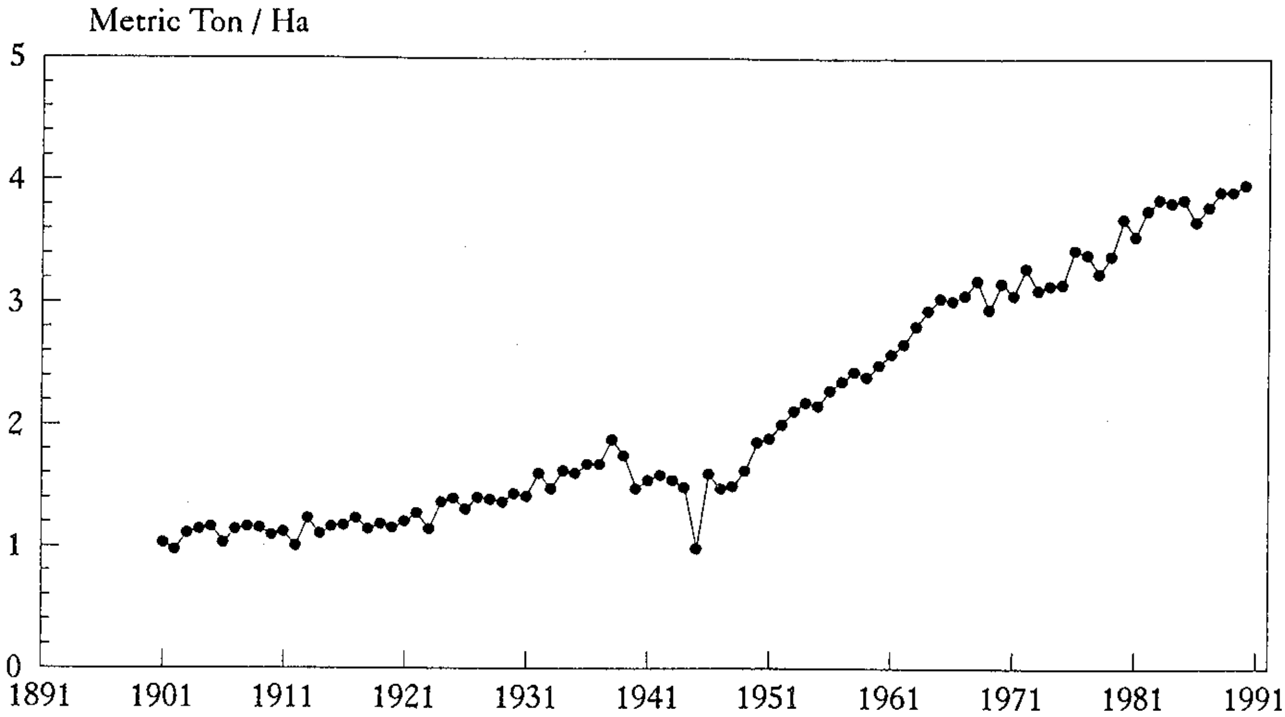


Figure20. Average Rice Yield Per Ha in Taiwan (1901 - 1990)

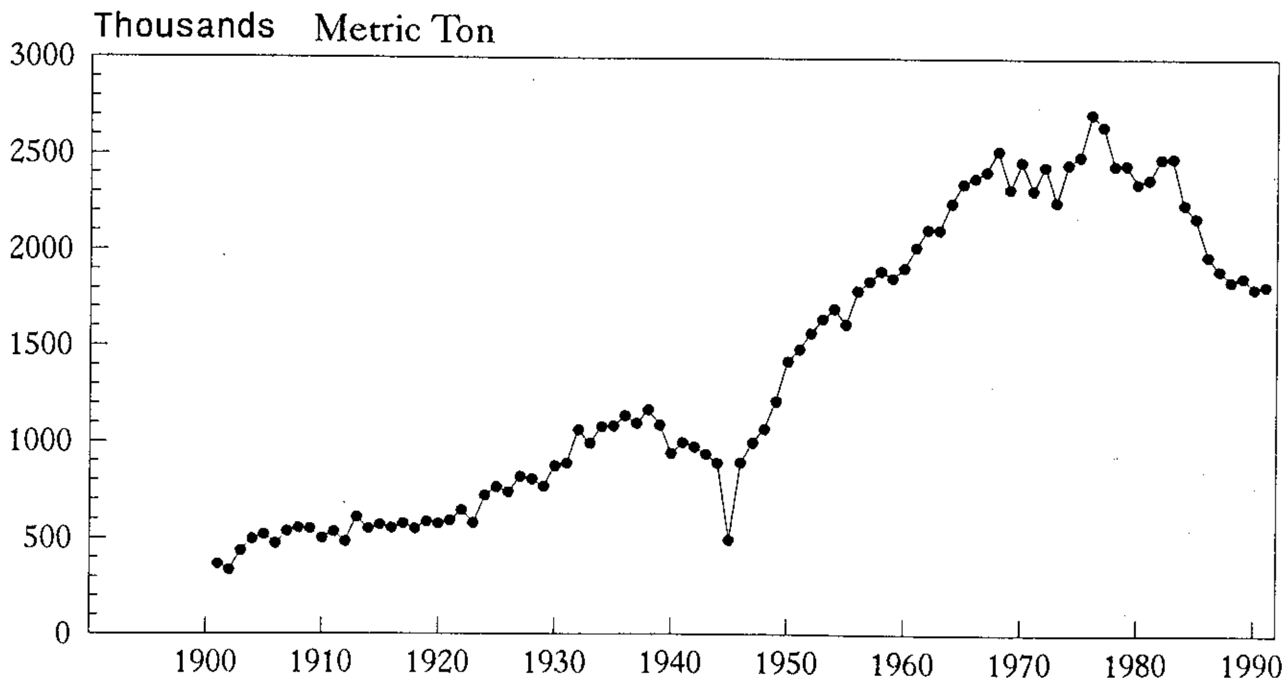


Figure21. Rice Production in Taiwan (1901 - 1991)

Table 1 Tainan Monthly Mean Temperature

Unit: °C

Month	1900 - 1929 30 - year average	1963 - 1992 30 - year average	T - Value
January	16.98 (1.17)	17.06 (1.13)	0.2686
February	16.80 (1.21)	17.95 (1.48)	3.2811
March	19.61 (1.20)	20.82 (1.33)	3.6829
April	23.20 (0.86)	24.46 (0.95)	5.4336
May	25.94 (0.68)	27.19 (0.82)	6.4004
June	27.19 (0.60)	28.23 (0.69)	6.2565
July	27.74 (0.52)	28.97 (0.53)	9.0207
August	27.39 (0.43)	28.48 (0.52)	8.9002
September	26.85 (0.47)	27.83 (0.56)	7.3619
October	24.66 (0.87)	25.65 (0.77)	4.6814
November	21.48 (0.80)	22.22 (0.96)	3.2445
December	18.35 (1.15)	18.59 (1.21)	0.7851
Average	32.01 (0.32)	23.96 (0.29)	11.9425

Table 2 Tainan Monthly Mean Maximum Temperature

Unit: °C

Month	1900 - 1929 30 - year average	1963 - 1992 30 - year average	T - Value
January	23.66 (1.37)	22.97 (1.21)	2.0644
February	23.43 (1.26)	23.81 (1.75)	0.9747
March	25.89 (1.31)	26.49 (1.41)	1.7076
April	28.83 (1.02)	29.53 (1.26)	2.3532
May	30.77 (0.90)	31.59 (1.05)	3.2407
June	31.41 (0.68)	32.10 (0.88)	3.3936
July	32.10 (0.88)	32.89 (0.64)	4.0002
August	31.56 (0.66)	32.44 (0.69)	5.0343
September	31.78 (0.62)	32.09 (0.80)	1.6885
October	30.58 (0.85)	30.71 (0.78)	0.6350
November	27.91 (0.88)	27.69 (0.96)	0.9103
December	24.86 (1.30)	24.31 (1.38)	1.5974
Average	28.56 (0.41)	28.90 (0.53)	2.7405

Table 3 Tainan Monthly Mean Minimum Temperature

Unit: °C

Month	1900 - 1929 30 - year average	1963 - 1992 30 - year average	T - Value
January	12.71 (1.34)	13.17 (1.44)	1.2655
February	12.46 (1.28)	14.06 (1.39)	4.6447
March	15.26 (1.13)	16.75 (1.36)	4.6108
April	18.92 (0.77)	20.52 (0.91)	7.3397
May	22.12 (0.66)	23.73 (0.72)	9.0720
June	23.78 (0.46)	25.24 (0.56)	11.0619
July	24.27 (0.31)	25.94 (0.51)	15.2213
August	24.18 (0.33)	25.55 (0.48)	12.8975
September	23.21 (0.64)	24.68 (0.63)	8.9487
October	20.37 (1.17)	22.09 (1.00)	6.1257
November	17.06 (0.99)	18.51 (1.19)	5.1290
December	14.09 (1.32)	14.75 (1.38)	1.9059
Average	19.04 (0.36)	20.41 (0.38)	14.1921

Table 4 Tainan Monthly Precipitation

Unit: °C

Month	1900 - 1929 30 - year average	1963 - 1992 30 - year average	T - Value
January	23.36 (34.80)	18.96 (22.79)	0.5793
February	30.78 (41.98)	26.64 (32.20)	0.4286
March	41.71 (41.74)	35.34 (42.90)	0.5829
April	63.36 (58.68)	75.67 (80.50)	0.6767
May	189.85 (141.32)	185.48 (126.00)	0.1263
June	339.14 (202.02)	380.49 (282.17)	0.6527
July	337.57 (252.41)	310.57 (190.14)	0.4679
August	431.16 (297.26)	370.50 (213.31)	0.9081
September	179.12 (178.47)	162.33 (144.54)	0.4004
October	33.95 (35.35)	26.47 (44.91)	0.7169
November	16.88 (28.36)	15.55 (22.33)	0.2028
December	14.77 (19.13)	8.99 (11.48)	1.4184
Total	1701.65 (437.68)	1617.00 (530.70)	0.6740

Table 5 Tainan Monthly Sunshine Duration

Unit: °C

Month	1900 - 1929 30 - year average	1963 - 1992 30 - year average	T - Value
January	198.97 (28.77)	189.37 (29.91)	1.2671
February	181.85 (27.88)	168.37 (33.30)	1.6991
March	199.92 (34.24)	192.63 (30.52)	0.8710
April	206.95 (44.28)	197.46 (41.96)	0.8520
May	222.90 (39.07)	208.53 (41.11)	1.3872
June	231.71 (42.98)	196.01 (42.40)	3.2395
July	243.00 (41.57)	238.72 (31.35)	0.4499
August	215.27 (39.38)	212.48 (41.09)	0.2688
September	241.41 (29.36)	204.15 (35.02)	4.4660
October	250.39 (29.36)	209.52 (33.23)	5.5041
November	213.16 (27.87)	182.81 (28.76)	4.1512
December	196.87 (30.98)	182.51 (30.55)	1.8081
Total	2602.41 (122.77)	2382.56 (195.62)	5.2138

Table 1.1 Taipei Monthly Mean Temperature

Unit: °C

Month	1900 - 1929 30 - year average	1963 - 1992 30 - year average	T - Value
January	15.24 (1.14)	15.49 (1.28)	0.7893
February	14.70 (1.21)	15.71 (1.37)	3.0289
March	16.91 (0.92)	17.82 (1.18)	3.3328
April	20.66 (1.10)	21.66 (1.15)	3.4410
May	23.88 (0.82)	24.81 ((1.06)	3.7894
June	26.61 (0.81)	27.03 (0.94)	1.8502
July	28.15 (0.57)	29.07 (0.77)	5.2613
August	27.87 (0.59)	28.80 (0.62)	5.9572
September	26.12 (0.81)	27.08 (0.88)	4.4057
October	22.92 (1.01)	24.03 (1.03)	4.1967
November	19.68 (0.90)	20.70 (1.06)	4.0282
December	16.72 (1.17)	17.30 (1.28)	1.8521
Average	21.62 (0.32)	22.48 (0.45)	8.6385

Table 2.1 Taipei Monthly Mean Maximum Temperature

Unit: °C

Month	1900 - 1929 30 - year average	1963 - 1992 30 - year average	T - Value
January	19.15 (1.14)	19.04 (1.23)	0.3224
February	18.42 (1.41)	19.32 (1.90)	2.0933
March	20.84 (1.32)	21.86 (1.64)	2.6743
April	25.01 (1.58)	25.97 (1.56)	2.3816
May	28.29 (1.02)	29.04 (1.40)	2.3861
June	31.52 (1.19)	31.50 (1.13)	0.0666
July	33.20 (0.82)	33.98 (0.82)	3.6874
August	32.83 (0.93)	33.50 (0.74)	3.0832
September	30.88 (0.89)	31.37 (1.10)	1.8670
October	27.30 (1.11)	27.74 (1.26)	1.4364
November	23.73 (1.09)	24.03 (1.29)	0.9739
December	20.62 (1.32)	20.76 (1.56)	0.3757
Average	25.98 (0.41)	26.54 (0.49)	4.8249

Table 3.1 Taipei Monthly Mean Minimum Temperature

Unit: °C

Month	1900 - 1929 30 - year average	1963 - 1992 30 - year average	T - Value
January	12.30 (1.26)	12.84 (1.71)	1.3744
February	11.87 (1.41)	13.11 (1.37)	3.4739
March	13.98 (0.84)	14.92 (1.24)	3.4581
April	17.27 (0.91)	18.45 (1.09)	4.5415
May	20.42 (0.81)	21.74 (0.95)	5.8323
June	22.91 (0.55)	23.89 (0.92)	4.9669
July	24.21 (0.40)	25.51 (0.81)	7.8692
August	24.10 (0.45)	25.39 (0.78)	7.8079
September	22.50 (0.95)	24.09 (1.02)	6.2239
October	19.67 (1.18)	21.39 (1.27)	5.4307
November	16.59 (1.08)	18.23 (1.18)	5.6231
December	13.79 (1.41)	14.64 (1.42)	2.3083
Average	18.31 (0.36)	19.54 (0.67)	8.7555

Table 4.1 Taipei Monthly Precipitation

Unit: °C

Month	1900 - 1929 30 - year average	1963 - 1992 30 - year average	T - Value
January	88.82 (54.29)	93.93 (59.85)	0.3466
February	126.54 (72.64)	144.99 (131.73)	0.6719
March	185.89 (99.84)	176.21 (114.26)	0.3494
April	158.95 (100.93)	156.08 (112.56)	0.1039
May	238.11 (110.72)	231.11 (114.64)	0.2407
June	291.94 (134.71)	307.27 (167.48)	0.3906
July	215.04 (116.89)	222.29 (111.12)	0.2463
August	284.36 (168.95)	269.41 (146.08)	0.3665
September	251.27 (182.73)	329.74 (198.17)	1.5944
October	124.66 (129.98)	116.81 (107.15)	0.2551
November	65.23 (38.85)	78.71 (52.96)	1.1243
December	72.85 (59.06)	74.33 (37.91)	0.1150
Total	2103.65 (331.26)	2197.84 (391.62)	1.0057

Table 5.1 Taipei Monthly Sunshine Duration

Unit: °C

Month	1900 - 1929 30 - year average	1963 - 1992 30 - year average	T - Value
January	87.49 (30.05)	86.20 (35.91)	0.1509
February	69.91 (28.61)	72.77 (27.23)	0.3966
March	84.89 (28.02)	88.41 (36.41)	0.4192
April	109.68 (31.71)	107.83 (28.26)	0.2394
May	131.17 (36.53)	116.04 (39.58)	1.5382
June	169.60 (43.71)	129.92 (27.41)	4.2124
July	226.97 (34.90)	199.03 (32.63)	3.2035
August	214.87 (39.94)	204.85 (33.96)	1.1517
September	191.85 (33.46)	165.05 (29.82)	3.2748
October	144.83 (38.19)	134.66 (36.40)	1.0555
November	106.71 (30.09)	97.51 (29.66)	1.1930
December	91.09 (26.81)	94.96 (23.37)	0.5950
Total	1629.17 (133.82)	1494.78 (154.26)	3.6018

Table 6 Typhoon Occurrence and Wind Velocity

Month	1900 - 1929 30 - year average	1963 - 1992 30 - year average	T - Value
Occurrence	4.13 (1.61)	3.03 (1.50)	2.7379
Max Velocity	34.20 (8.22)	56.07 (12.86)	7.7546
Mean Velocity	24.17 (5.33)	46.31 (11.80)	9.2342

Table 7. Long-Term Weather Forecasts
(1993-January to 2002-December) For Tainan

Date	Tempavg	Tempmax	Tempmin	Rainfall	Sundur
JAN 93	17.3379	23.0100	13.6209	17.4060	180.8880
FEB 93	18.0935	23.8088	14.3550	37.2312	161.5224
MAR 93	20.9503	26.5260	17.0556	43.1076	184.6649
APR 93	24.3056	29.1794	20.6017	138.0134	176.8932
MAY 93	27.0971	31.4639	23.7755	123.0803	196.4941
JUN 93	28.3120	32.2641	25.4297	303.3859	189.5441
JUL 93	28.9461	32.9307	26.0594	384.5675	231.9292
AUG 93	28.4441	32.3910	25.6415	345.1840	204.5001
SEP 93	27.7865	31.9648	24.7543	299.0646	188.0720
OCT 93	25.5680	30.5372	22.1148	10.6105	201.5052
NOV 93	22.1607	27.5231	18.5592	7.8982	178.4163
DEC 93	18.6303	24.2015	14.8754	15.6463	181.1420
JAN 94	17.1621	22.8600	13.4416	15.4309	180.8880
FEB 94	17.9677	23.6859	14.2029	49.5246	161.5224
MAR 94	20.8603	26.4252	16.9266	51.9977	184.6649
APR 94	24.2412	29.0967	20.4923	221.6669	176.8932
MAY 94	27.0511	31.3961	23.6827	122.3330	196.4941
JUN 94	28.2791	32.2085	25.3510	230.7093	189.5441
JUL 94	28.9226	32.8851	25.9926	342.0920	231.9292
AUG 94	28.4273	32.3536	25.5849	411.1127	204.5001
SEP 94	27.7744	31.9342	24.7063	303.4900	188.0720
OCT 94	25.5594	30.5121	22.0740	4.3172	201.5052
NOV 94	22.1545	27.5025	18.5246	2.2697	178.4163
DEC 94	18.6258	24.1846	14.8461	7.3922	181.1420
JAN 95	17.1589	22.8461	13.4167	19.4213	180.8880
FEB 95	17.9654	23.6745	14.1818	26.1699	161.5224
MAR 95	20.8587	26.4159	16.9087	26.8174	184.6649
APR 95	24.2401	29.0891	20.4771	130.7439	176.8932
MAY 95	27.0503	31.3898	23.6698	78.4871	196.4941
JUN 95	28.2785	32.2034	25.3401	473.1699	189.5441
JUL 95	28.9222	32.8809	25.9834	351.9148	231.9292
AUG 95	28.4270	32.3502	25.5770	311.8551	204.5001
SEP 95	27.7742	31.9313	24.6996	229.7273	188.0720
OCT 95	25.5593	30.5098	22.0684	20.5261	201.5052
NOV 95	22.1544	27.5006	18.5199	10.0195	178.4163
DEC 95	18.6258	24.1831	14.8420	20.1316	181.1420
JAN 93	17.1589	22.8449	13.4133	19.5603	180.8880
FEB 93	17.9654	23.6735	14.1789	57.2468	161.5224
MAR 93	20.8586	26.4150	16.9062	49.8822	184.6649
APR 93	24.2400	29.0884	20.4750	203.8440	176.8932
MAY 93	27.0503	31.3893	23.6681	118.9814	196.4941
JUN 93	28.2785	32.2029	25.3386	292.9701	189.5441
JUL 93	28.9222	32.8805	25.9821	449.0201	231.9292
AUG 93	28.4270	32.3499	25.5759	403.3011	204.5001
SEP 93	27.7742	31.9311	24.6987	295.1853	188.0720

Table 7. Long-Term Weather Forecasts
(1993-January to 2002-December) For Tainan (con't 1)

Date	Tempavg	Tempmax	Tempmin	Rainfall	Sundur
OCT 93	25.5593	30.5096	22.0676	8.7724	201.5052
NOV 93	22.1544	27.5004	18.5192	4.1496	178.4163
DEC 93	18.6258	24.1829	14.8414	13.8322	181.1420
JAN 97	17.1589	22.8447	13.4128	18.4503	180.8880
FEB 97	17.9654	23.6734	14.1785	43.0326	161.5224
MAR 97	20.8586	26.4149	16.9059	41.5793	184.6649
APR 97	24.2400	29.0883	20.4747	166.8232	176.8932
MAY 97	27.0503	31.3892	23.6678	108.7044	196.4941
JUN 97	28.2785	32.2028	25.3384	348.7944	189.5441
JUL 97	28.9222	32.8805	25.9819	397.9309	231.9292
AUG 97	28.4270	32.3498	25.5758	357.0626	204.5001
SEP 97	27.7742	31.9310	24.6986	276.8401	188.0720
OCT 97	25.5593	30.5096	22.0675	12.2440	201.5052
NOV 97	22.1544	27.5004	18.5191	6.9523	178.4163
DEC 97	18.6258	24.1829	14.8414	15.9089	181.1420
JAN 98	17.1589	22.8447	13.4127	17.6936	180.8880
FEB 98	17.9654	23.6734	14.1784	48.8288	161.5224
MAR 98	20.8586	26.4149	16.9059	46.6083	184.6649
APR 98	24.2400	29.0883	20.4747	191.9833	176.8932
MAY 98	27.0503	31.3892	23.6678	114.5951	196.4941
JUN 98	28.2785	32.2028	25.3384	307.9624	189.5441
JUL 98	28.9222	32.8805	25.9819	398.1909	231.9292
AUG 98	28.4270	32.3498	25.5758	380.2934	204.5001
SEP 98	27.7742	31.9310	24.6986	284.9940	188.0720
OCT 98	25.5593	30.5096	22.0675	9.5836	201.5052
NOV 98	22.1544	27.5004	18.5191	5.0164	178.4163
DEC 98	18.6258	24.1829	14.8413	13.2625	181.1420
JAN 99	17.1589	22.8447	13.4127	18.7962	180.8880
FEB 99	17.9654	23.6734	14.1784	41.5118	161.5224
MAR 99	20.8586	26.4149	16.9058	39.7391	184.6649
APR 99	24.2400	29.0883	20.4747	167.1622	176.8932
MAY 99	27.0503	31.3892	23.6678	103.3495	196.4941
JUN 99	28.2785	32.2028	25.3384	366.6900	189.5441
JUL 99	28.9222	32.8805	25.9819	391.7267	231.9292
AUG 99	28.4270	32.3498	25.5758	356.9842	204.5001
SEP 99	27.7742	31.9310	24.6986	267.4440	188.0720
OCT 99	25.5593	30.5096	22.0675	13.5671	201.5052
NOV 99	22.1544	27.5004	18.5191	7.0302	178.4163
DEC 99	18.6258	24.1829	14.8413	16.1496	181.1420
JAN 00	17.1589	22.8447	13.4127	18.7115	180.8880
FEB 00	17.9654	23.6734	14.1784	48.3153	161.5224
MAR 00	20.8586	26.4149	16.9058	45.0094	184.6649
APR 00	24.2400	29.0883	20.4747	184.6657	176.8932
MAY 00	27.0503	31.3892	23.6678	112.2080	196.4941
JUN 00	28.2785	32.2028	25.3384	323.4094	189.5441
JUL 00	28.9222	32.8805	25.9819	411.0845	231.9292

Table 7. Long-Term Weather Forecasts
(1993-January to 2002-December) For Tainan (con't 2)

Date	Tempavg	Tempmax	Tempmin	Rainfall	Sundur
AUG 00	28.4270	32.3498	25.5758	378.5679	204.5001
SEP 00	27.7742	31.9310	24.6986	282.7901	188.0720
OCT 00	25.5593	30.5096	22.0675	10.7887	201.5052
NOV 00	22.1544	27.5004	18.5191	5.5478	178.4163
DEC 00	18.6258	24.1829	14.8413	14.5420	181.1420
JAN 01	17.1589	22.8447	13.4127	18.5268	180.8880
FEB 01	17.9654	23.6734	14.1784	44.6306	161.5224
MAR 01	20.8586	26.4149	16.9058	42.6184	184.6649
APR 01	24.2400	29.0883	20.4747	175.3568	176.8932
MAY 01	27.0503	31.3892	23.6678	108.8122	196.4941
JUN 01	28.2785	32.2028	25.3384	340.2570	189.5441
JUL 01	28.9222	32.8805	25.9819	398.0479	231.9292
AUG 01	28.4270	32.3498	25.5758	366.8400	204.5001
SEP 01	27.7742	31.9310	24.6986	277.4369	188.0720
OCT 01	25.5593	30.5096	22.0675	11.7819	201.5052
NOV 01	22.1544	27.5004	18.5191	6.2885	178.4163
DEC 01	18.6258	24.1829	14.8413	15.1470	181.1420
JAN 02	17.1589	22.8447	13.4127	18.3183	180.8880
FEB 02	17.9654	23.6734	14.1784	46.2974	161.5224
MAR 02	20.8586	26.4149	16.9058	43.9548	184.6649
APR 02	24.2400	29.0883	20.4747	181.7258	176.8932
MAY 02	27.0503	31.3892	23.6678	110.3727	196.4941
JUN 02	28.2785	32.2028	25.3384	330.4821	189.5441
JUL 02	28.9222	32.8805	25.9819	399.7286	231.9292
AUG 02	28.4270	32.3498	25.5758	372.1094	204.5001
SEP 02	27.7742	31.9310	24.6986	279.4075	188.0720
OCT 02	25.5593	30.5096	22.0675	11.1313	201.5052
NOV 02	22.1544	27.5004	18.5191	5.8116	178.4163
DEC 02	18.6258	24.1829	14.8413	14.5600	181.1420

Table 8. Estimates of Weather Impact

Lag	Coefficient	Std Error	t Ratio
1	-0.32133311	0.11059924	-2.905383
2	-0.34537250	0.11059924	-3.122738

Autoreg Procedure

Yule-Walker Estimates

SSE	0.356395	DFE	72
MSE	0.00495	Root MSE	0.070356
SBC	-159.891	AIC	-207.598
Reg Rsq	0.3486	Total Rsq	0.6412

Variable	**DF**	**B Value**	**Std Error**	**t Ratio**
Intercept	1	-0.634759959	0.58995	-1.076
MAY_TEMPAVG	1	0.010087605	0.03692	0.273
OCT_TEMPAVG	1	0.025300242	0.04371	0.579
MAY_TEMPMIN	1	0.009664716	0.03158	0.306
OCT_TEMPMIN	1	0.001648446	0.03544	0.047
MAY_RAINFALL	1	-0.000050714	0.000079	-0.645
OCT_RAINFALL	1	-0.000564226	0.00020	-2.765
MAY_SUNDUR	1	-0.000191494	0.00040	-0.485
OCT_SUNDUR	1	-0.000242097	0.00046	-0.531
APR_TEMPAVG	1	-0.088214392	0.03376	-2.613
SEP_TEMPAVG	1	0.044722122	0.05086	0.879
APR_TEMPMIN	1	0.054902034	0.03086	1.779
SEP_TEMPMIN	1	-0.033212707	0.04141	-0.802
APR_RAINFALL	1	0.000191343	0.00015	1.258
SEP_RAINFALL	1	-0.000077111	0.000053	-1.457
APR_SUNDUR	1	0.001058557	0.00043	2.487
SEP_SUNDUR	1	-0.000132148	0.00040	-0.327