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Climate Change in Hong Kong

by

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摘要

本報告對香港天文台自一八八四年成立以來在香港觀測所得的氣象數據進行了趨勢分析。

研究顯示香港的氣象要素呈下列趨勢: 平均及平均最低表面氣溫上升, 氣溫日際變化下降, 寒冷日子減少, 對流層底層溫度上升, 對流層高層及平流層底層溫度下降, 能見度下降, 雲量增多, 有雷暴出現的日子增加, 太陽總輻射量減少及總蒸發量下降。引致上述趨勢的因素包括全球變暖和城市化。

Abstract

In this report, trend analyses were carried out on meteorological observations made in Hong Kong since the establishment of the Hong Kong Observatory in 1884.

The following trends were observed: rise in mean temperature and mean minimum temperature at the surface, decrease in daily diurnal temperature range, decrease in the number of cold days, increase in lower tropospheric temperature, decrease in upper tropospheric and lower stratospheric temperatures, decrease in observed visibility, increase in cloud amount, increase in the number of days with thunderstorms, decrease in global solar radiation, and decrease in total evaporation in Hong Kong. Factors contributing to the observed trends include global warming and urbanization.

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1. Introduction

1.1. The Intergovernmental Panel on Climate Change (IPCC) was jointly established by the World Meteorological Organization (WMO) and the United Nations Environmental Programme (UNEP) in 1988 to assess available scientific and socio-economic information on climate change, its impact and the options for mitigating climate change and adapting to it; and to provide scientific, technical and socio-economic advice to the Conference of the Parties (COP) to the United Nations Framework Convention on Climate Change (UNFCCC).

1.2. From 1990 onwards, IPCC has produced a series of authoritative assessment reports, special reports and technical papers on climate change. According to the IPCC Third Assessment Report (2001), the global mean surface temperature, discounting the effects of localized temperature rises due to urbanization, has increased by 0.6 ± 0.2°C in the 20th century. The IPCC Third Assessment Report also concluded that over the last 50 years, the estimated rate and magnitude of warming due to increase in greenhouse gas alone are comparable with, or larger than, the observed warming.

1.3. Observed to occur at the same time with the global warming are changes in the climate in many parts of the world, such as increase in globally averaged water vapour and rainfall; and increase in interannual variability of rainfall in high latitude areas. There are also changes in climate variability as well as frequency and intensity of extreme weather and climate events such as El Nino, very hot and very cold weather, rainstorms, droughts and tropical cyclones in different parts of the world. Such changes have significant impacts on natural and human systems and have to be monitored.

1.4. Regional or local climate change may occur in tandem with the global climate change but can also be greatly affected by regional or local effects in particular urbanization. The present study aims to determine the climate change in Hong Kong through trend analyses of a number of meteorological observations made locally. An attempt was made to differentiate the changes due to global warming and those due to urbanization.

2. Meteorological Observations

2.1. The oldest meteorological station in Hong Kong is located at the Hong Kong Observatory Headquarters in Tsimshatsui. Observations started in 1884, and records were available continuously apart from a break during World War II (1940-1946). In this study, climate trend analyses were carried out mainly on the data collected at the Hong Kong Observatory Headquarters.

2.2. Situated at the centre of Kowloon, the temperature and other weather elements at the Hong Kong Observatory Headquarters are inevitably influenced by some degree of urbanization. Therefore, this study also made use of the temperature data from meteorological stations located at Ta Kwu Ling, Lau Fau Shan, Cheung Chau and Waglan Island which are rural or island locations. A map showing the locations of these stations is given in Figure 1.

2.3. The stations at Ta Kwu Ling and Lau Fau Shan are situated in the rural areas of the New Territories. They are automatic weather stations which commenced operation in 1985. Reliable data records which became available since 1989 were analysed. They are taken to be representative of the countryside in Hong Kong. However, they also have not escaped completely from the effects of urbanization though to a lesser degree in recent years since new town development has taken place not too far from these stations.

2.4. The station at the outlying island Cheung Chau was established in 1959 and moved to its present location in 1970. It is situated in an open environment on a mountain ridge and is more than 10 km away from the urban areas of Hong Kong Island. The population of Cheung Chau has remained at about 20,000 for many years and the pace of building development is slow. Because of the large differences in height and environment of the two locations, only data after 1970 were used.

2.5. Waglan is an unpopulated island of 0.1 km^2 situated about 19 km southeast from the Hong Kong Observatory Headquarters. The station on top of the island started operation in 1953, but hourly temperature readings were only available after 1968.

2.6. The meteorological station at King's Park, situated about 2 km north of the Hong Kong Observatory Headquarters, is the only station in Hong Kong making upper air observations, global solar radiation and evaporation. The station started operation in 1951. Reliable uninterrupted solar radiation and evaporation data became available since 1964. This study used only the data collected from 1964 onwards. For upper air measurements, 12 UTC radiosonde ascents were introduced in 1969 in addition to 00 UTC ascents. Only upper air data since 1969 were used in this study.

2.7. Basic information on the meteorological stations and the type of data used in this study are listed in Table 1. Station details and further descriptions on the measurement of meteorological parameters can be found in the "Summary of Meteorological Observations in Hong Kong 2002" published by the Hong Kong Observatory.

3. Data Analysis

3.1. Long-term trend analyses were carried out for key meteorological parameters that might be influenced by global warming and/or urbanization. There are many statistical methods for calculating trends and testing their significance, including parametric methods such as regression and t-test (e.g. Easterling et al., 1997; Karl et al., 1993) and non-parametric methods such as Mann-Kendall test (e.g. Qian and Giorgi, 2000; Quereda Sala et al., 2000). This study adopted the most commonly employed regression method and t-test. Following Easterling et al. (1997), a paper referenced in IPCC (2001), and also Karl et al. (1993), linear regression lines were fitted to the parameters by least squares. The long-term trend could then be inferred from the slopes of these straight lines. Two tailed t-test was applied to test the statistical significance of the trends at 5% significance level.

3.2. The test statistics *t* for testing the null hypothesis H_0: $trend = 0$ against the alternative hypothesis H_1: $trend \neq 0$, is given by:

$$t = r\sqrt{\frac{n-2}{1-r^2}}$$

where *r* is the correlation coefficient and follows a *t* distribution with *n*-2 degrees of freedom.

3.3. The parameters analysed in this study are as follows:

(a) Annual and seasonal mean temperatures, mean daily maximum temperatures and mean daily minimum temperatures at the surface (i.e. 1.2 m above ground);

(b) Annual number of very hot days (daily maximum temperature ≥ 33.0^{o}C) and cold days (daily minimum temperature ≤ 12.0^{o}C);

(c) Annual mean temperatures in the lower troposphere (850-300 hPa), upper troposphere (300-100 hPa) and lower stratosphere (100-50 hPa);

(d) Annual percentage of time of occurrence of reduced visibility (below 8 km; cases due to fog, mist or rain excluded);

(e) Annual mean cloud amount;

(f) Annual mean daily total global solar radiation;

(g) Annual total evaporation;

(h) Annual and seasonal rainfall;

(i) Annual number of heavy rain days (days with hourly rainfall greater than 30 mm);

(j) Annual number of days with thunderstorms; and

(k) Annual number of tropical cyclones landing within 300 km of Hong Kong.

4. Results and Discussion

4.1. In this report, trends are statistically significant at 5% level unless otherwise stated. Spring refers to the period from March to May, summer from June to August, autumn from September to November and winter from December to February.

4.2. Surface temperature

4.2.1. Surface temperature recorded at the five stations Hong Kong Observatory Headquarters, Ta Kwu Ling, Lau Fau Shan, Cheung Chau and Waglan Island have been analysed in the present study. The trend in the annual mean temperature at the Hong Kong Observatory Headquarters, the station with the longest record was analysed and compared with the trend in global mean temperature. The trends in annual mean temperature at the other four rural and island stations were also analysed to estimate the effect of urbanization.

4.2.2. It is well recognized that urbanization has a strong influence on the diurnal temperature range (Easterling et al., 1997). Changes in the annual mean diurnal range at the Hong Kong Observatory Headquarters was also examined.

4.2.3. In the present study, the daily mean temperature was taken as the average value of the 24 hourly temperature readings in a day. Daily diurnal temperature range was computed as the difference between the daily maximum and minimum temperatures. Based on the daily maximum, daily mean, daily minimum and daily diurnal range data, annual and seasonal average values were derived.

4.2.4. The temperature data were subjected to homogeneity test before they were used in trend analysis. Peterson *et al.* (1998) gave a review of the methods for homogeneity adjustments. Student's t-test could be used to assess homogeneity when metadata indicates a specific date with a major change.

4.2.5. Manual observations were replaced by automatic observations together with a change from mercury-in-glass thermometers to digital platinum resistance thermometers in 1981 at the Hong Kong Observatory Headquarters, in 1992 at Cheung Chau and in 1989 at Waglan Island. The temperature time series of these three stations were first de-trended and then subjected to the Student's t-test. Results of the t-test are given in Table 2. There was no evidence of data inhomogeneity due to changes in instruments and observational practices at these stations.

4.2.6. At the Hong Kong Observatory Headquarters, temperature readings are available for the 118 years period from 1885 to 2002, apart from a break during the World War II from 1940 to 1946. Analysis of the annual mean temperature data showed that there was an average rise of 0.12°C per decade in that 118 year period (Figure 2). The annual mean temperature rose from 22.0°C in the late 19th century (1891 - 1900) to a mean of 23.5°C in the most recent 10 years (1993 - 2002). In post-war years from 1947 to 2002, the average rise amounted to 0.17°C per decade, similar to the finding of 0.15°C per decade at the Hong Kong Observatory Headquarters from 1947 to 1999 by Ding et al. (2002). The warming at the Hong Kong Observatory Headquarters has become significantly faster in the period 1989 to 2002, at a rate of 0.61°C per decade.

4.2.7. There are considerable differences between the changes in the daily minimum temperature and the daily maximum temperature at the Hong Kong Observatory Headquarters. The contrast in the trends is depicted in Figure 3. In the 56-year period after World War II, the annual mean daily minimum temperature shows a rising trend of 0.28°C per decade. Earlier study by Koo and Chang (1989) also found that the minimum temperature has a rising trend of 0.24°C per decade during the period 1947 to 1987. In line with the rising trend in the 56-year period, the number of cold days (daily minimum temperatures ≤ 12°C, the criterion for issuing Cold Weather Warning) in a year has been decreasing at about 3 days per decade (Figure 4). In the 1950s, the number of cold days averaged about 28 days per year. In the most recent ten years (1993 to 2002), it averaged only about 13 days annually, a drop of more than 50% in half a century. On the other hand, there has been very little change in the daily maximum temperature (Figure 3). The frequency of occurrence of very hot days (daily maximum temperatures ≥ 33°C, criterion for issuing Very Hot Weather Warning) has remained largely unchanged at about 11 days per year (Figure 4).

4.2.8. The increase in daily minimum temperature and relatively little change in daily maximum temperature resulted in a reduction of daily diurnal temperature range. The annual mean daily diurnal range decreased at a rate of 0.28°C per decade from 1947 to 2002 (Figure 5).

4.2.9. Seasonally, both the mean daily minimum temperature and the mean temperature in post-war years were rising for all the seasons. The rate of rise of the daily minimum temperature was largest in winter (0.35°C per decade) and smallest in summer (0.23°C per decade). As for the daily mean temperature, the rate of rise was also greatest in winter (0.21°C per decade), but smallest in autumn (0.12°C per decade). The trends in the mean daily maximum temperature for all the seasons were not statistically significant at 5% level and small when compared with that of the mean daily minimum temperature or the mean temperature (Figure 6). Based on data from 36 meteorological stations in Guangdong, Liang and Wu (1999) also found that both the mean temperature and the mean minimum temperature in Guangdong in winter had risen during the period 1960 to 1996.

4.2.10. At Ta Kwu Ling and Lau Fau Shan, the annual mean temperatures rose by 0.15°C and 0.19°C per decade respectively since 1989, though not statistically significant at 5% level (Figure 7 and 8). At Cheung Chau and Waglan Island, based on the annual mean temperature observed since 1971 and 1968 respectively, the rate of rise was about 0.05°C per decade but was not statistically significant at 5% level (Figure 9 and 10). The observed trends at the four rural and island stations in Hong Kong, taken together, are broadly consistent with the rise of 0.44°C for the southern China in the period 1951 to 2000 (equivalent to 0.09°C per decade) (Qin et al., 2003a). Qin et al. (2003a) also pointed out that warming occurred all over mainland China and that the trends are much larger in mid to high latitudes compared with lower latitudes.

4.2.11. Many researchers (e.g. Easterling et al., 1997; Karl et al., 1993; Quereda Sala et al., 2000) attributed the marked increase in annual mean minimum and mean temperatures as well as reduction in annual mean diurnal temperature range to global warming and local effects such as urban heat island. In Hong Kong, the difference in temperature trends among the five stations Hong Kong Observatory Headquarters, Ta Kwu Ling, Lau Fau Shan, Cheung Chau and Waglan Island can be attributed to differences in the effects of urbanization, global warming and modulation of the ocean.

4.2.12. The temperature trend at the Hong Kong Observatory Headquarters is typically the effects of urbanization which leads to the formation of what is called an urban heat island where temperatures are higher than their rural surroundings. Urban heat island is caused by a combination of factors including changes in surface as vegetation is replaced by concrete and tarmac, reduced air ventilation due to buildings, anthropogenic heat production and motor vehicle emissions (Lee, 1992). In many cities, urbanization differentially affects the minimum and the maximum temperatures (Karl et al., 1993). Compared to non-urban areas, urban heat island effect raises night time temperatures more than day time temperatures (IPCC, 2001).

4.2.13. Temperature differences that develop between an urbanized area and the rural landscape are in essence a result of dissimilarity in radiative fluxes (Figure 11). Buildings and other concrete surfaces in the urban areas retain the heat produced by incoming solar radiation during the day and release the heat in the form of long-wave radiation during the night. High-rise buildings also inhibit the transfer of long-wave radiation to the atmosphere. This results in a slower fall of temperatures at night and a higher minimum temperature than when buildings were absent. Urban heat island effect tends to manifest itself strongest during night time under cloudless skies and light wind conditions (Oke, 1978). In Hong Kong, Leung and Ng (1997) has pointed out that on clear and calm nights in winter, urban heat island effect may account for the large difference (8°C or above) in the daily minimum temperatures between urban and rural stations.

4.2.14. Urbanization often causes an increase in suspended particulates in the atmosphere and thus a decrease in visibility (see also Section 4.4). As a result, the amount of solar radiation reaching the ground decreases (see also Section 4.6). The rise in temperature during daytime is reduced but this may be more or less be offset by the heat generated from air conditioning and other urban activities. The net result is little change in the daily maximum temperature. Overall, the annual mean temperature rises but at a slower rate than the annual mean daily minimum temperature.

4.2.15. Greenhouse gases in the atmosphere absorb terrestrial long-wave radiation and re-radiates it downward to earth, resulting in a rise of surface temperature. Most of the observed global warming over the last 50 years is likely to have been due to the increase in greenhouse gas concentrations (IPCC, 2001). To assess the potential contribution of global warming to temperature rise in Hong Kong, the temperature time series at the Hong Kong Observatory Headquarters is compared with the global one (Figure 12).

4.2.16. In Figure 12, the global mean temperature dataset are sourced from the Climate Research Unit (CRU), University of East Anglia at its web site http://www.cru.uea.ac.uk/cru/data/temperature/. This was the same dataset used in the analysis in IPCC(2001). In both time series, the annual mean temperature anomalies are referenced to the respective 1961-1990 mean values. Similar to IPCC (2001), a 21-point binomial filter was applied to filter the decadal effects. For the binomial filter, the weights were set to be proportional to the binomial coefficients, in contrast to equal weightings in a simple moving average filter. The weights b_0 to b_N of an $N + 1$ point binomial filter were computed as follows:

$$b_k = \frac{c_k}{\sum_{k=0}^{N} c_k} \qquad k = 0,1,\ldots..,N$$

where $$c_k = \frac{N!}{k!(N-k)!}$$

4.2.17. It can be observed from Figure 12 that the temperature at the Hong Kong Observatory Headquarters followed more or less the same trend as the global temperature during the pre-World War II period. In the post-war years, there were two periods with notable temperature rises at the Hong Kong Observatory Headquarters. The first was from mid-1950s to mid-1960s. The second period of rise began in the early 1980s, which was in line with the global trend of significant warming in the past two decades. A faster rate of warming at the Hong Kong Observatory Headquarters compared to the global trend since the early 1980s can be attributed to the effects of high density urban development.

4.2.18. At Cheung Chau and Waglan Island, as no significant temperature rise could be seen since the 1970s, the moderating effect of the sea has probably nullified to a large extent the effects of global warming. This is consistent with IPCC (2001)'s finding that the warming rate is faster in land areas than in sea areas for many parts of the world. During the period 1989 to 2002, the annual mean temperatures at Ta Kwu Ling and Lau Fau Shan rose by about 0.15°C and 0.19°C respectively, slightly less than the global rate of 0.21°C for the same period. These two stations can be taken as representing regions in Hong Kong that have been less affected by urbanization. In contrast, the Hong Kong Observatory Headquarters recorded an additional rise of 0.4°C per decade due to urbanization.

4.3. Upper air temperature

4.3.1. Daily upper air temperature data at pressure levels 850, 700, 500, 400, 300, 250, 200, 150, 100, 70 and 50 hPa obtained from 00 and 12 UTC radiosonde ascents were used in the present study. The tropopause in Hong Kong is at about 100 hPa and there is little interseasonal variation (Leung et al., 2003). Following IPCC (2001), the lower troposphere is defined in this report as the layer between 850 and 300 hPa, the upper troposphere as the layer between 300 and 100 hPa and the low stratosphere as the layer between 100 and 50 hPa. Daily mean temperature in the lower troposphere is taken as the average temperature at 850, 700, 500, 400 and 300 hPa at 00 and 12 UTC. Daily mean temperatures in the upper troposphere (300-100 hPa) and the lower stratosphere (100-50 hPa) were similarly computed. Based on these daily mean temperatures, annual mean temperatures were calculated.

4.3.2. Figure 13 shows the time series of the annual mean temperature anomalies in the lower troposphere, upper troposphere and the lower stratosphere. In order to compare with the global mean assessed by IPCC (2001), the anomalies in Figure 13 were referenced to the same 12-year mean of 1979 to 1990. Trend analysis shows that the annual mean temperature were increasing at 0.16°C per decade in the lower troposphere above Hong Kong but decreasing at 0.25°C per decade and 0.64°C per decade in the upper troposphere and lower stratosphere respectively. These results are consistent with the IPCC (2001) finding that the troposphere has warmed relative to the stratosphere globally.

4.3.3. Enhanced greenhouse effect is a main contributor to the observed increasing trend in the lower troposphere and decreasing trend in the lower stratosphere (National Academy of Sciences, 1989). Depletion of stratospheric ozone contributes to the observed stratospheric cooling globally. Ozone absorbs solar ultra-violet (UV) radiation and releases heat. Less ozone in the stratosphere leads to less absorption of UV radiation and thus less heat released.

4.3.4. It is interesting to note from Figure 13 (a) that although there was a warming trend over the lower troposphere, abrupt temperature drops occurred in some years that followed major volcanic eruption or that were associated with strong El Nino onset. Temperature anomaly of -0.64°C was found in 1992, a year after the eruption of the volcano Pinatubo in June 1991. In contrast to the cooling in the lower troposphere, a positive temperature anomaly of 1.3°C was found in the lower stratosphere in 1992 (Figure 13 (c)). During a gigantic volcanic eruption, sulphuric gases are emitted into the lower stratosphere where they are converted into sulphate aerosols. According to Wright (2001), these aerosols absorb incoming solar radiation and thus heat the lower stratosphere. Apart from absorption, the aerosols also reflect the incoming radiation and thus reduce the amount of solar radiation reaching the lower troposphere.

4.3.5. Apart from 1992, large negative temperature anomalies of magnitude greater than 0.5°C were also observed in the lower troposphere in 1971, 1972, 1982 and 1997. All these years except 1971 were strong El Nino onset years. Wang et al. (2000) also observed such lower tropospheric cooling over the western North Pacific in strong El Nino years.

4.3.6. Gaffen (1994) assessed the 63-station network for monitoring tropospheric and stratospheric temperature for the globe and found that about 43% of the records of those stations had inhomogeneities. In Hong Kong, radiosonde model Vaisala RS13 was used from 1969 to 1974 (Wong and Yu, 1998), RS18 from 1975 to 1980, RS21 from 1981 to 1983, RS80 from 1984 to 1998 and RS90 since 1999. The mean temperature anomalies from the Hong Kong's radiosonde ascent at 200 hPa level were analyzed and it was found that the anomalies obtained during the periods using RS18, RS21 and RS80 were statistically significant different from each other at 1% level (Gaffen, 1994). Thus care must be taken in interpreting the results of trend analysis of the upper air temperature given above because of the inhomogeneity.

4.4. Visibility

4.4.1. Visibility is often treated as an indicator of visual air quality (Sloane, 1982). Particulates suspended in the atmosphere are the primary cause for the reduction in the visibility. Suspended particulates in the atmosphere normally consist of a mixture of sulphates, nitrates, carbonaceous particles, sea salt and mineral dusts (Menon et al., 2002). They are produced by a variety of processes, both natural such as duststorms and volcanic activity, and anthropogenic such as fossil-fuel and biomass burning. They have lifetime of days to weeks and therefore have a significant regional effect. To examine the change in visual air quality, meteorological influence was first screened out from the visibility data. Following the practice of Chang and Koo (1986), cases of visibility impairment that was concurrent with reports of fog, mist and rain were excluded in this study. The number of hours of reduced visibility below 8 km observed from the Hong Kong Observatory Headquarters each year was counted. The percentage of time of occurrence of reduced visibility in a year was then calculated as the number of hours of reduced visibility divided by the total number of hours that observations were made in that year.

4.4.2. The visibility observed at the Hong Kong Observatory Headquarters from 1968 to 2002 has a deteriorating trend (Figure 14). In the early 1970s, the Hong Kong Observatory Headquarters experienced reduced visibility of below 8 km for about 2% of the time. By 2002, it has increased to some 9%, around 4 times that of the early 1970s. The annual percentage of time of occurrence of reduced visibility was increasing at a rate of about 1.9% per decade over the 35-year period. Since the mid 1980s, the rate was higher at about 4.1% per decade.

4.4.3. Apart from the Hong Kong Observatory Headquarters, a deterioration in visibility was also found in observations at Cheung Chau (Cheng et al, 1997). Cheng et al (1997) also found that a stable lower atmosphere and light winds are two favourable meteorological conditions for the occurrence of reduced visibility at the Hong Kong Observatory Headquarters. These favourable conditions were often associated with the onset of a weak northerly surge or a lull in the northeast monsoon. Reduction in visibility was also observed during the approach of tropical cyclones from the east or southeast. Synoptic weather charts showed that it was related to the northwesterly winds over Hong Kong associated with the outer circulation of tropical cyclones and the stable atmosphere rendered by subsidence of air and light winds occurring ahead of tropical cyclones.

4.5. Cloud amount

4.5.1. An increase in cloud amount can cause a decrease in diurnal temperature range by reducing the solar incoming radiation during day time and trapping of long-wave radiation at night. The diurnal temperature range has decreased since the 1950s worldwide and the coincidental increases in total cloud cover are often cited as a likely cause for the observed decrease in diurnal temperature range (Dai and Trenberth, 1999). As reported in Karl et al. (1993), there is a general increasing trend in cloud cover over Canada, the United States, Europe, the Indian subcontinent and Australia. Over much of China, however, cloud cover exhibited decreasing trends between 1951 and 1994 (IPCC, 2001).

4.5.2. In Hong Kong, cloud amount is reported in oktas hourly by trained observers at the Hong Kong Observatory Headquarters. The daily mean cloud amount is taken as the average value of the observed hourly cloud amount in a day. Based on these daily mean cloud amounts, annual mean values were calculated.

4.5.3. Cloud amount data observed at the Hong Kong Observatory Headquarters has been digitized since 1961. Analysis of the digitized data indicates that the annual mean cloud amount has been increasing at a rate of 1.8% per decade in the period 1961 to 2002 (Figure 15). One potential cause for the increase in cloud amount over Hong Kong could be the increase in the concentration of condensation nuclei in the air (that favoured the formation of clouds), which is known to be associated with urbanization.

4.6. Global solar radiation

4.6.1. Both the increase in the concentration of suspended particulates and the increase in cloud amount would reduce the amount of solar radiation reaching the surface. At King’s Park, the amount of solar radiation reaching Hong Kong is recorded continuously by thermo-electric pyranometers. There was a decreasing trend in the observed global solar radiation since observations began in the mid-1960s (Figure 16). The mean value of daily global solar radiation between 1964 and 2002 was 13.7 MJm^{-2}. For the whole 39-year period, the annual mean daily global solar radiation has decreased by about 26%, at a rate of 1 MJm^{-2} per decade. This is similar to the finding of Stanhill and Kalma (1995) that the solar radiation in Hong Kong declined by more than one-third over the period 1958 to 1992. Apart from Hong Kong, reduction in global solar radiation also occurred in other cities and has been described by Landsberg (1981).

4.7. Evaporation

4.7.1. Evaporation measurements are made daily at King's Park using evaporation pans with evaporation surface 0.18 m above ground. In general, the amount of evaporation depends on the amount of solar radiation received, the relative humidity of the atmosphere as well as the wind speed.

4.7.2. Accompanying the decrease in global solar radiation, the annual total evaporation recorded at King's Park also decreased by 40% from the 1960s to 2002 (Figure 17), at a rate of 184 mm per decade (the mean value between 1964 and 2002 being 1405 mm).

4.8. Rainfall

4.8.1. In the 56-year period after the World War II, the annual total rainfall at HKO increased from 2265 mm in the 1950s to 2518 mm in the 1990s. It represents an increasing trend of about 65 mm per decade (or 3% relative to the long-term mean of 1961-1990), though not statistically significant at 5% level (Figure 18). This observed trend lies close to the top of the range viz. 20 to 60 mm per decade in southern China in the past 50 years (Qin et al., 2003b). For the whole China, Zhai et al. (1999) found that there were regional differences in rainfall trends. While northwestern China was having a relatively larger positive trend in rainfall, northeastern China, southwestern China and northern China were all exhibiting negative trends.

4.8.2. At the Hong Kong Observatory Headquarters, the annual rainfall trend is small when compared to the year-to-year fluctuations. The strength of El-Nino Southern Oscillation (ENSO) and the winter monsoon in the preceding winter are important factors affecting the interannual variability of the rainfall (Chang and Yeung, 2003). From Figure 18, interdecadal change in the annual rainfall is apparent also.

4.8.3. Seasonally, the rainfall at the Hong Kong Observatory Headquarters has been increasing for all the seasons, but not statistically significant at 5% (Figure 19). The rate of increase for spring, summer, autumn and winter were 25 mm (4.7%), 34 mm (3.1%), 0.28 mm (0.06%) and 4.7 mm (4.8%) per decade respectively. In absolute terms, the increase in seasonal rainfall was largest in summer.

4.8.4. The frequency of occurrence of heavy rain events has increased slightly after the World War II. In this study, the annual number of heavy rain days is taken to be days with hourly rainfall greater than 30 mm, which is the criterion for issuing Amber Rainstorm Warning. The annual number of heavy rain days has been increasing from about 4.5 days a year in 1947 to about 7 days in 2002, at a rate of 0.4 days per decade, but not statistically significant at 5% level (Figure 20).

4.8.5. Chow (1986) proposed that the urban heat island effect might be one of possible factor for the increase of rainfall amount and heavy rain days. Chow (1986) also found that rainfall in the rainy season of Shanghai was increasing faster in urban areas compared to rural areas. In Hong Kong, the urban heat island effect might have increased cloudiness and precipitation as thermal circulation was created in the surrounding region. Heavy rain events resulting from intense convective activity in cases of trough of low pressure or unstable southwest monsoon might have been enhanced. Increased roughness from cities is also a factor for augmentation of precipitation (Shepherd et al., 2002). Chow (1986) observed in case studies on Shanghai that rain-producing systems such as stationary fronts often lingered longer over the urban area and increased the rainfall there as compared with the rural areas. The increase in concentration of suspended particulates and hence condensation nuclei might also have helped the formation and development of rain-bearing cloud.

4.8.6. A study on regional variation of rainfall trends in Hong Kong during the last 50 years (Sun and Evans, 2002) has found that the apparent increases in annual rainfall were concentrated in the central part of Hong Kong. Sun and Evans (2002) postulated that these increases were very unlikely to be a direct result of global climate change but might be due to the urban heat island effect. Their study was based on trend analysis of gridded rainfall data interpolated from annual isohyetal analyses.

4.9. Thunderstorms

4.9.1. Thunderstorms commonly occur between April and September in Hong Kong. The parent cumulonimbus cloud typically covers an area of a few kilometers in diameter with vertical extents of ten kilometers or more. The typical life span of a cumulonimbus cloud is a couple of hours.

4.9.2. Thunderstorm is reported by observers at the Hong Kong Observatory Headquarters. The number of days with thunderstorm reported each year was counted. The annual number of days with thunderstorms was found to increase at about 1.7 days per decade in the period 1947 to 2002 (Figure 21), in line with the trend for heavy rain days.

4.9.3. The urban heat island effect might have been a cause for the increase in thunderstorm days. The additional heating might have helped to trigger the formation of deep convection. In large city like Atlanta of the United States, urban heat island has been shown to enhance and possibly to initiate thunderstorms (Dixon and Mote, 2003).

4.9.4. Under certain conditions, tornadoes, waterspouts and hailstorms occur in Hong Kong. On average, the occurrence of waterspouts and hailstorms is once every one to two years while tornadoes are rare. Because of the rarity, no trend analysis has been performed on their occurrence.

4.10. Tropical cyclones

4.10.1. Prediction of how global warming may affect the frequency, intensity or tracks of tropical cyclones is highly uncertain (IPCC, 2001). There are no discernible global trends in the number of tropical cyclone, intensity or location from historical data analyses (Sellers et al., 1998).

4.10.2. For the northwestern Pacific, the annual number of tropical cyclones has become more variable since about 1980. There was an increase from 1981 to 1994, which was preceded by a nearly identical magnitude of decrease from about 1960 to 1980 (Chan and Shi, 1996).

4.10.3. In the South China Sea, the annual number of tropical cyclones landing over the south China coast within 300 km of Hong Kong in the past 40 years has decreased from about 3 tropical cyclones in the 1960s to about 2.5 in the 1990s, at a rate of about 0.17 per decade which was not statistically significant at 5% level (Figure 22).

4.10.4. From Figure 22, a periodicity of about 3 to 4 years is discernible suggesting the influence of ENSO. Generally speaking, the number of tropical cyclones affecting Hong Kong is fewer in El Nino years than La Nina years. The reasons for fewer tropical cyclones to affect the south China coast in El Nino years especially in late typhoon season (September to November) are an eastward shift in the mean tropical cyclone genesis positions in these years, and a weaker subtropical ridge over the western North Pacific which steers tropical cyclones more to the northwest than to the west away from the South China Sea (Leung and Leung, 2002; Wu et al., 2003). The observed decreasing trend in the annual number of tropical cyclone, though not statistically significant, may be due to more frequent occurrences of El Nino events since the 1980s.

5. Conclusion

5.1. The analysis of temperature records shows that Hong Kong has been warming up during the past 118 years, in line with the global warming trend. This is also consistent with the warming trend in China mainland in the past 50 years. In the period 1989 to 2002, the rural areas of Hong Kong have been warming up at a rate of about 0.2°C per decade. At the Hong Kong Observatory Headquarters in the heart of urban Hong Kong, the corresponding rise was about 0.6°C per decade. The difference of 0.4°C per decade between temperatures in urban and rural areas may be attributed to the effects of high density urban development.

5.2. The reduction in visibility, increase in cloud amount and decrease in global solar radiation in Hong Kong might also be related to high density urban development. Though not statistically significant, the annual rainfall and the number of heavy rain days have increased during the period 1947 to 2002 whereas the number of tropical cyclones affecting Hong Kong has decreased during the period 1961 to 2002.

5.3 This study has focused on the changes in the climate in Hong Kong in the past. The future change in temperature in Hong Kong against the background of global warming is of interest and will be the subject of another study.

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Table 1. Basic information of meteorological stations, and the type of data used in this report

Station	Position/Altitude*	Data used	Period	Remarks
Hong Kong Observatory Headquarters	22° 18’ N, 114° 10’ E 32m	Hourly temperature; Daily maximum temperature; Daily minimum temperature;	1885 to 1939; 1947 to 2002	Started operation in 1884. No data between 1940 and 1946 during World War II.
		Hourly visibility;	1968 to 2002	
		Hourly cloud amount;	1961 to 2002	
		Hourly rainfall.	1947 to 2002	
King’s Park	22° 19’ N, 114° 10’ E 65m	Daily total global solar radiation; Daily total evaporation.	1964 to 2002	Started operation in 1951. Total evaporation and global solar radiation measurements began in 1957 and 1959 respectively. 12 UTC upper air temperature data available since 1969.
		00 and 12 UTC upper air temperature.	1969 to 2002	
Ta Kwu Ling	22° 32’ N, 114° 09’ E 12m	Hourly temperature.	1989 to 2002	Started operation in 1985.
Lau Fau Shan	22° 28’ N, 113° 59’ E 34m	Hourly temperature.	1989 to 2002	Started operation in 1985.
Cheung Chau	22° 12’ N, 114° 02’ E 72m	Hourly temperature.	1971 to 2002	Started operation in 1959. Moved to its current location in 1970 and changed to an automatic weather station in 1992.
Waglan Island	22° 11’ N, 114° 18’ E 56m	Hourly temperature.	1968 to 2002	Started operation in 1953. Hourly temperature available since 1968. Changed to an automatic weather station in 1989.

* The altitude refer to the height above mean sea level

Table 2. Summary of the results of Student's t-test for testing data inhomogeneity due to changes in instruments and observational practices at the Hong Kong Observatory Headquarters, Cheung Chau and Waglan Island

Station	Period	Number of years	Detrended annual mean temperature		t-value	Degree of freedom	Critical values at 5% significance level	Significance at 5% level (Yes or No)
			Mean	Standard deviation				
Hong Kong Observatory Headquarters	1947-1980	34	-0.101	0.303	-0.923	53	±2.006	No
	1982-2002	21	-0.018	0.362				
Cheung Chau	1971-1991	21	-0.077	0.309	0.336	29	±2.045	No
	1993-2002	10	-0.119	0.357				
Waglan Island	1968-1988	21	-0.010	0.333	-0.269	32	±2.037	No
	1990-2002	13	0.030	0.534				

Figure 1. Location map of meteorological stations

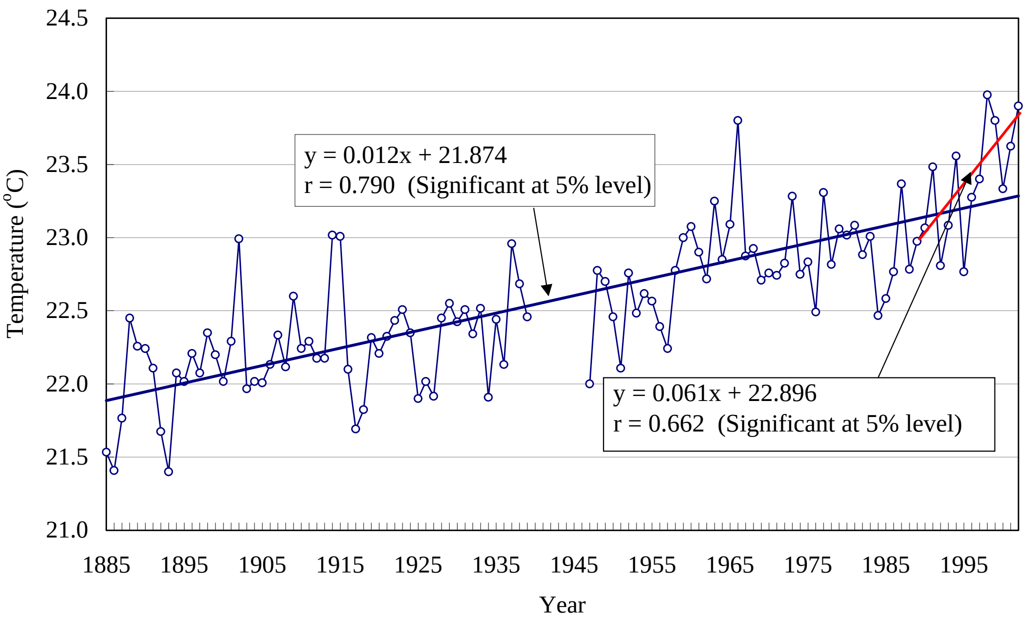


Figure 2. Annual mean temperature recorded at the Hong Kong Observatory Headquarters (1885-2002). Data are not available from 1940 to 1946

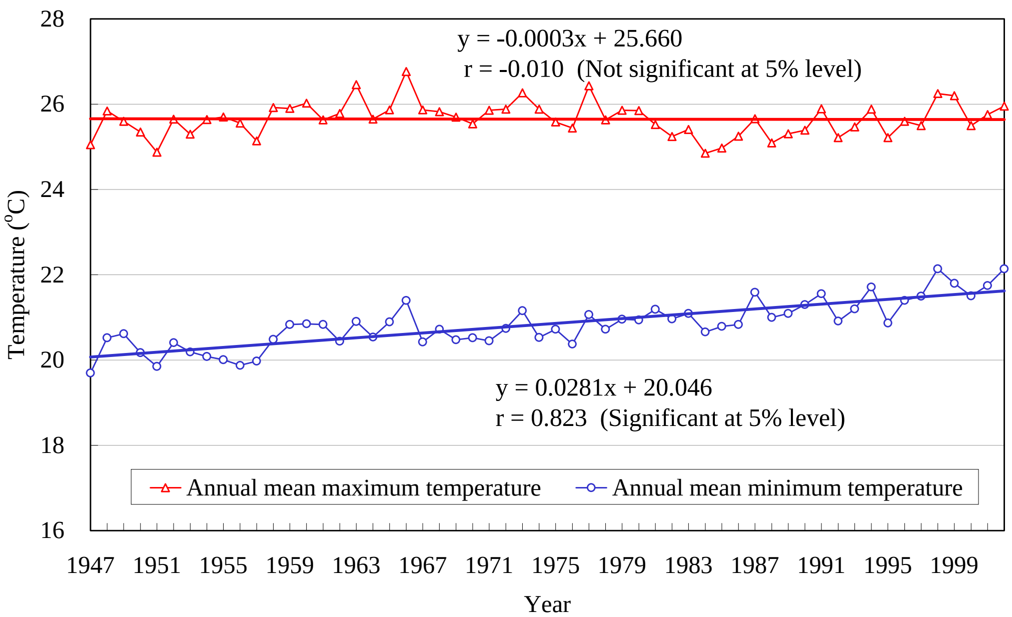


Figure 3. Annual mean daily maximum and minimum temperatures recorded at the Hong Kong Observatory Headquarters (1947-2002)

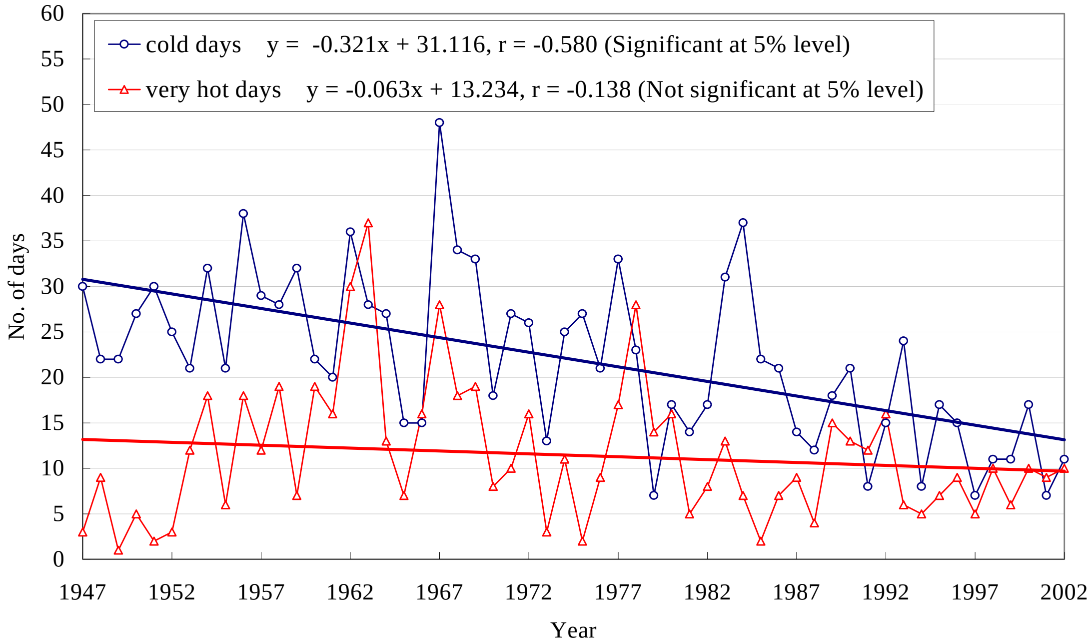


Figure 4. Annual number of very hot days (daily maximum temperatures ≥ 33°C) and cold days (daily minimum temperatures ≤ 12°C) at the Hong Kong Observatory Headquarters (1947-2002)

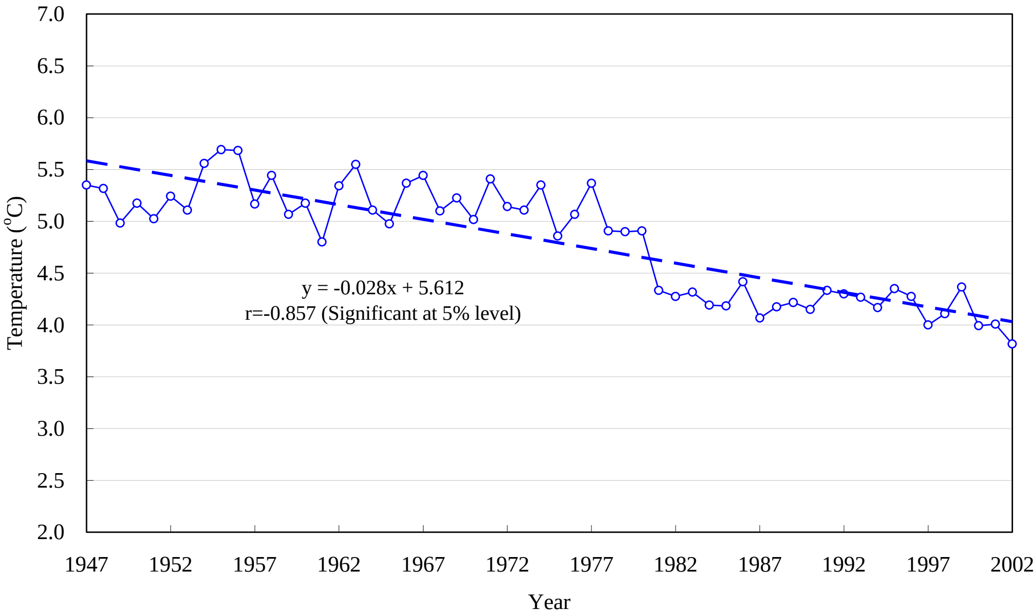


Figure 5. Annual mean daily diurnal range recorded at the Hong Kong Observatory Headquarters (1947-2002)

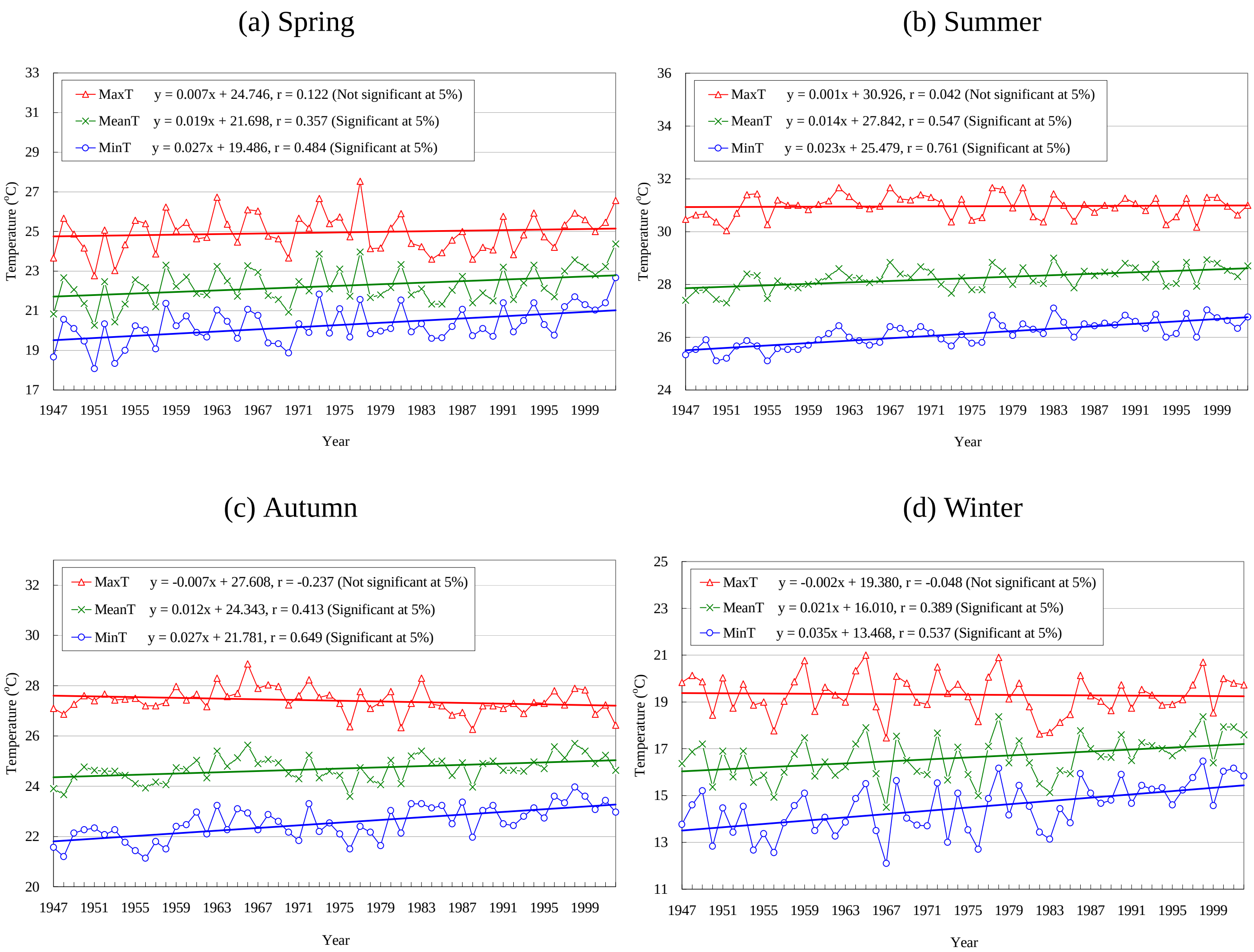


Figure 6. Seasonal mean daily maximum, mean and daily minimum temperatures recorded at the Hong Kong Observatory Headquarters (1947-2002)

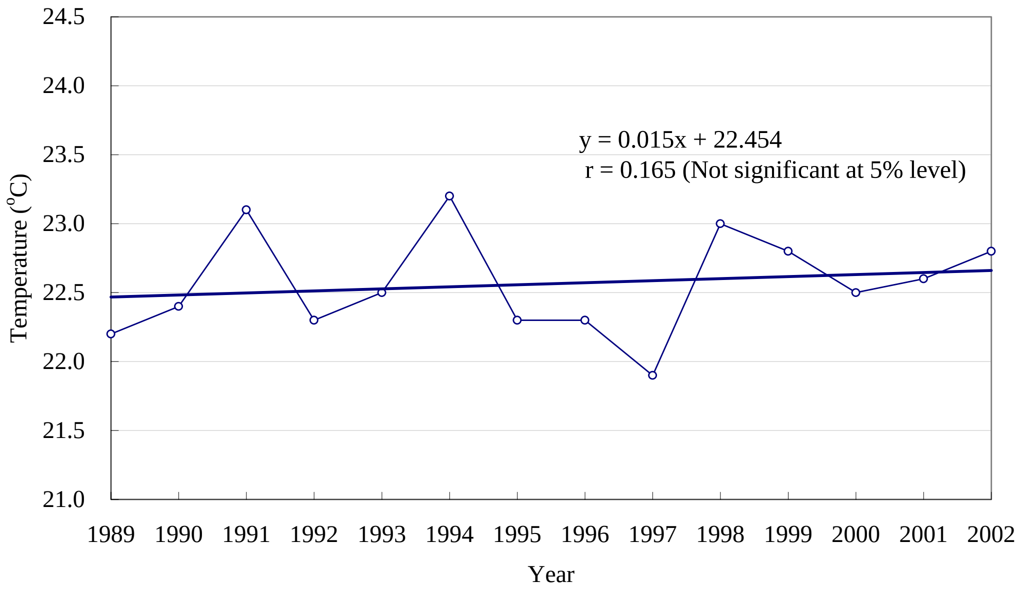


Figure 7. Annual mean temperature recorded at Ta Kwu Ling (1989-2002)

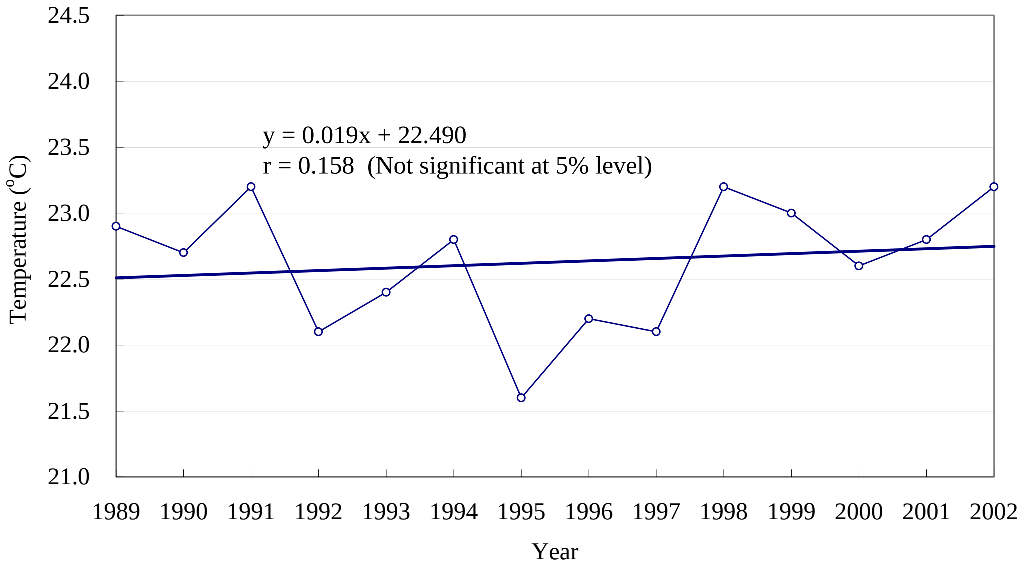


Figure 8. Annual mean temperature recorded at Lau Fau Shan (1989-2002)

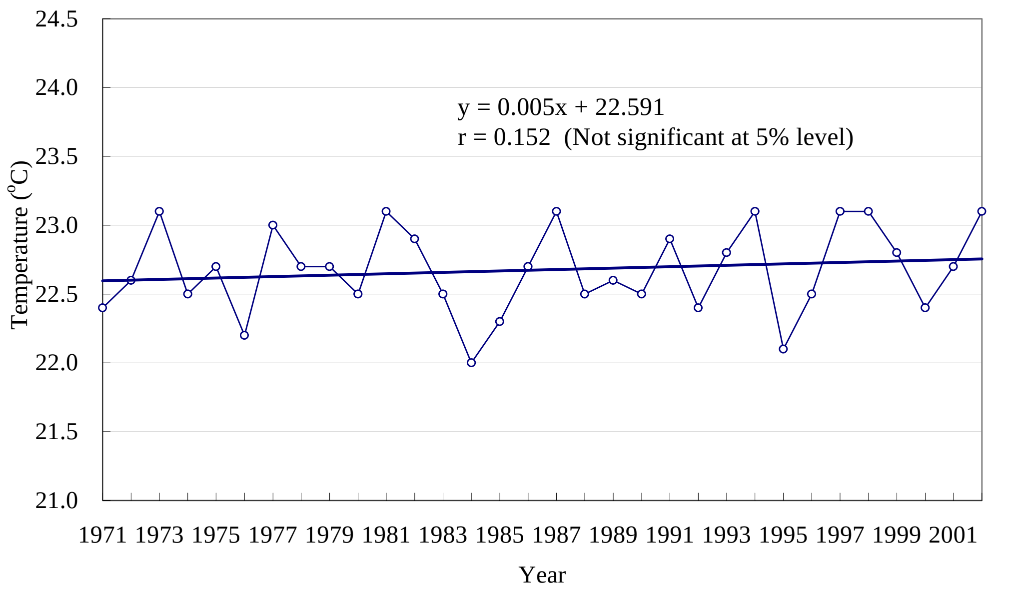


Figure 9. Annual mean temperature recorded at Cheung Chau (1971-2002)

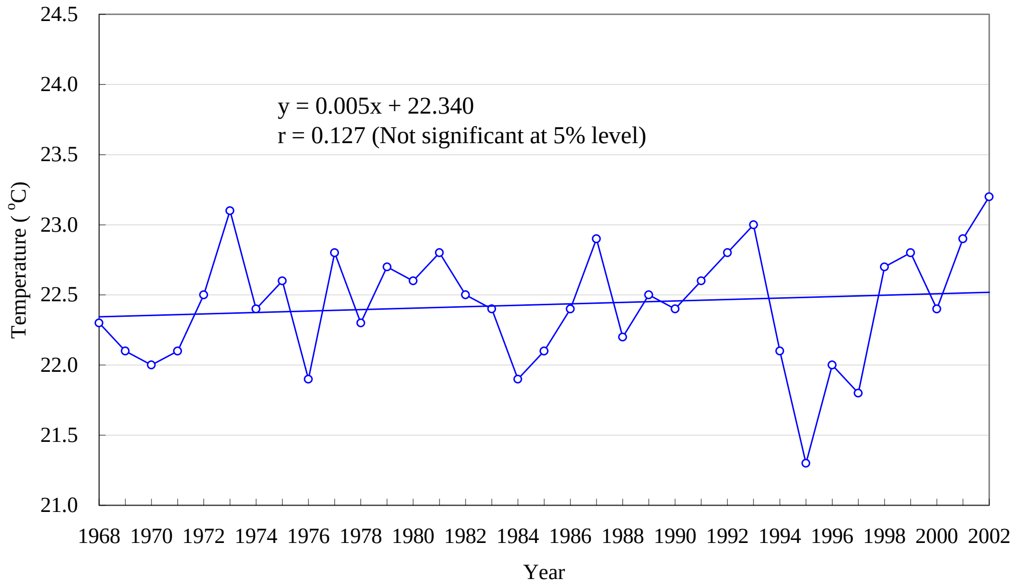


Figure 10. Annual mean temperature recorded at Waglan Island (1968-2002)

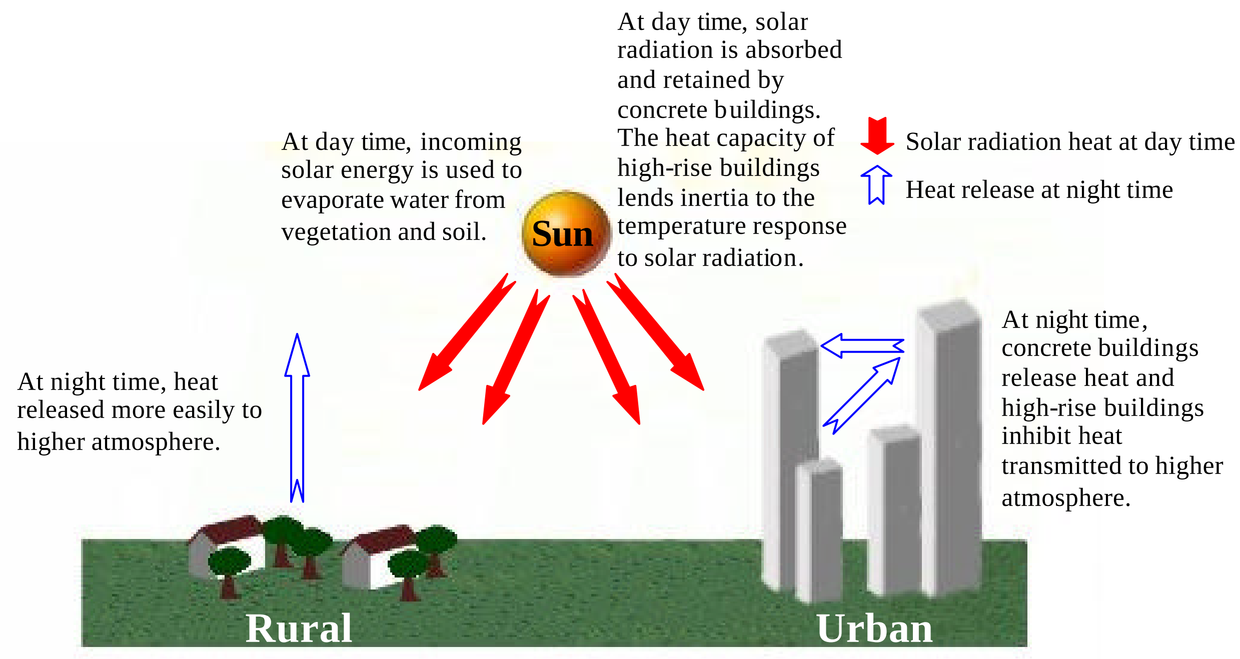


Figure 11. A schematic diagram showing the dissimilarity in radiative fluxes between urban and rural areas

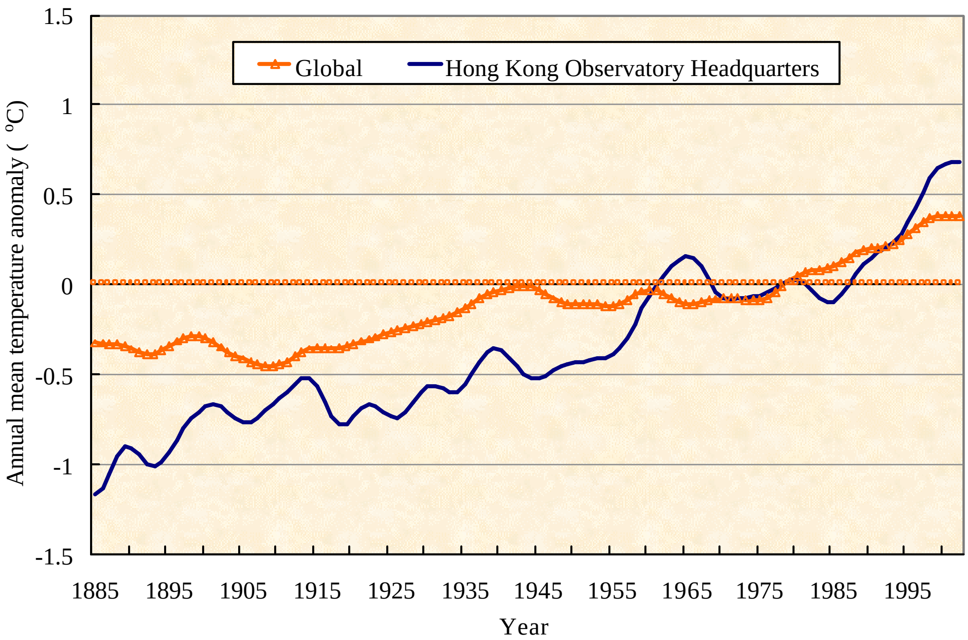
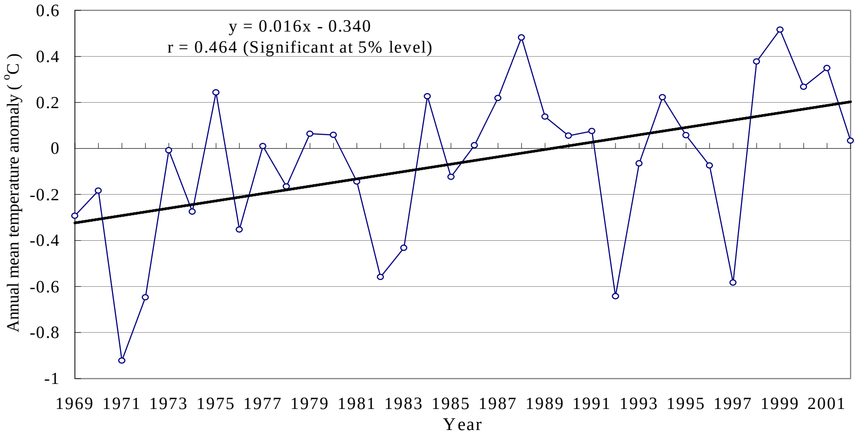
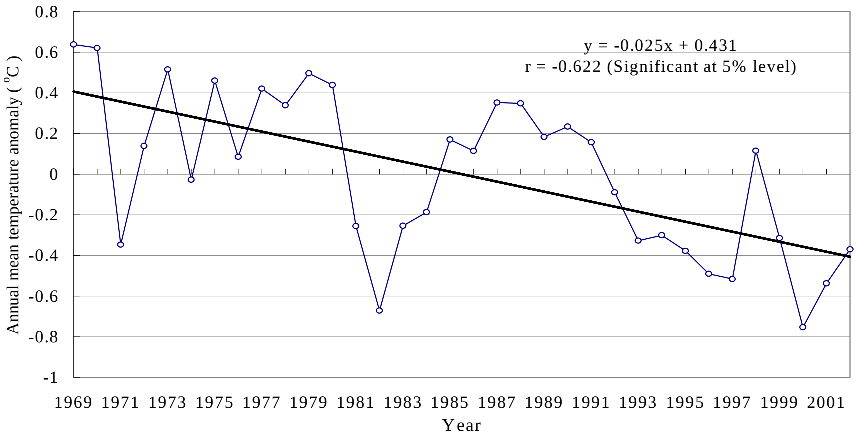


Figure 12. Annual mean temperature anomalies globally and at the Hong Kong Observatory Headquarters (with reference to the respective 1961-1990 mean values, 21-point binomial filtering is applied to both time series. Prior to filtering, interpolation was made in the Observatory Headquarters' time series for the war-time period with missing data from 1940 to 1946)

(a) Lower troposphere (850-300 hPa)



(b) Upper troposphere (300-100 hPa)



(c) Lower stratosphere (100-50 hPa)

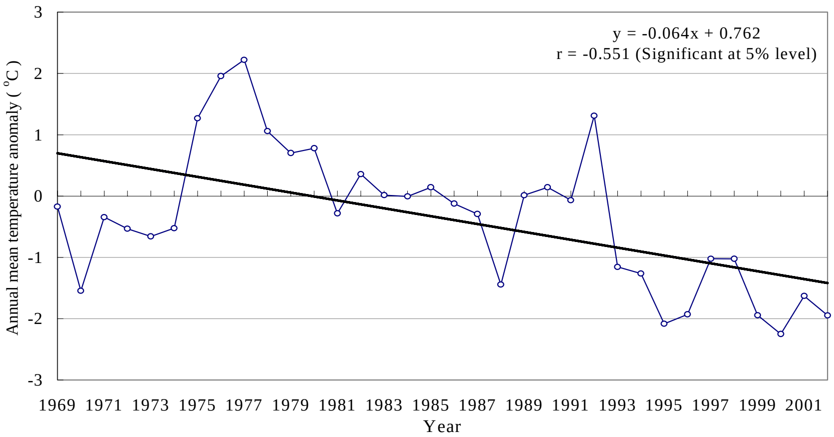


Figure 13. Annual mean temperature anomalies (with reference to the 1979-1990 mean values) in the (a) lower troposphere; (b) upper troposphere; and (c) lower stratosphere observed at King's Park (1969-2002)

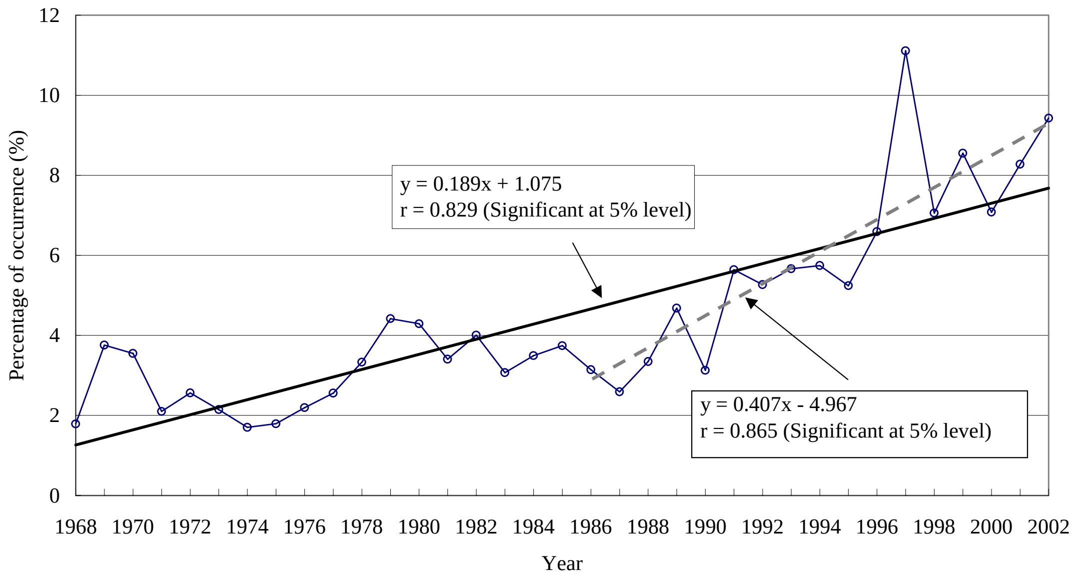


Figure 14. Annual percentage of time of occurrence of reduced visibility below 8 km (cases due to fog, mist or rain excluded) observed at the Hong Kong Observatory Headquarters (1968-2002)

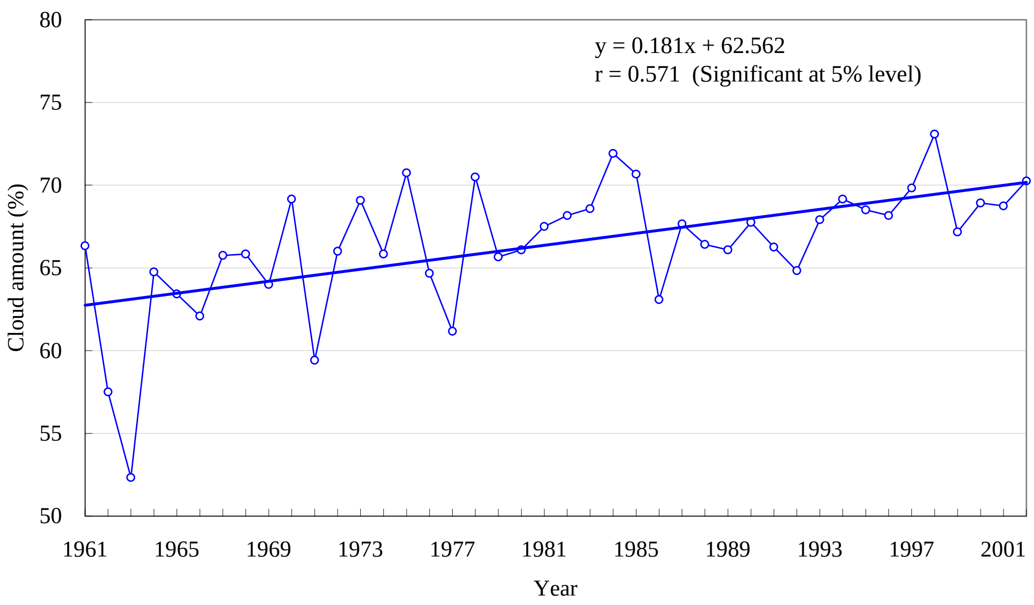


Figure 15. Annual mean cloud amount recorded at the Hong Kong Observatory Headquarters (1961-2002)

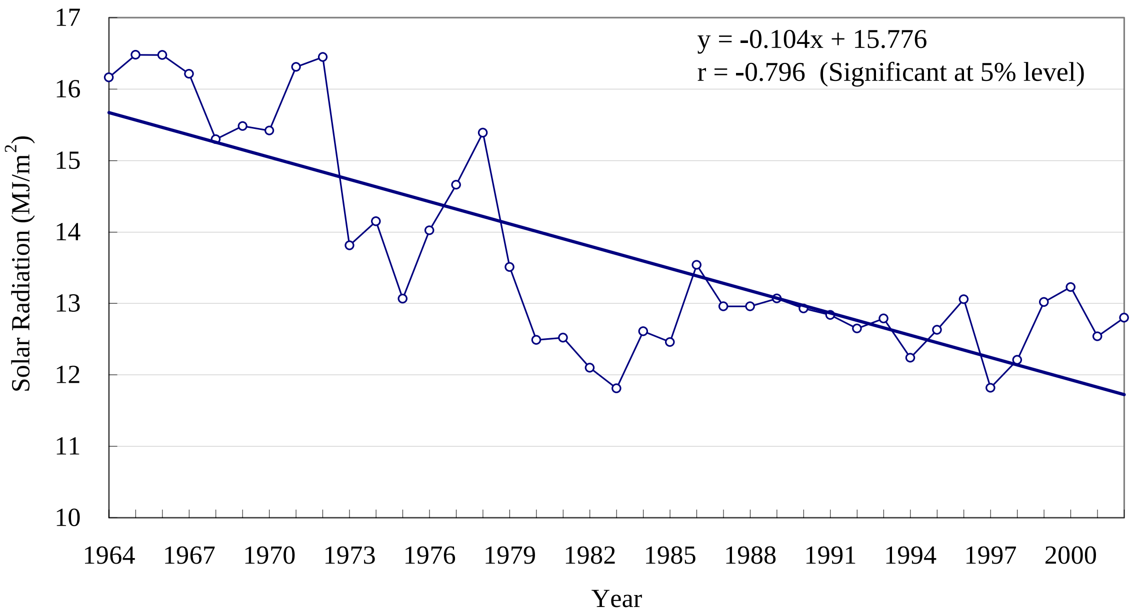


Figure 16. Annual mean daily total global solar radiation at King's Park (1964-2002)

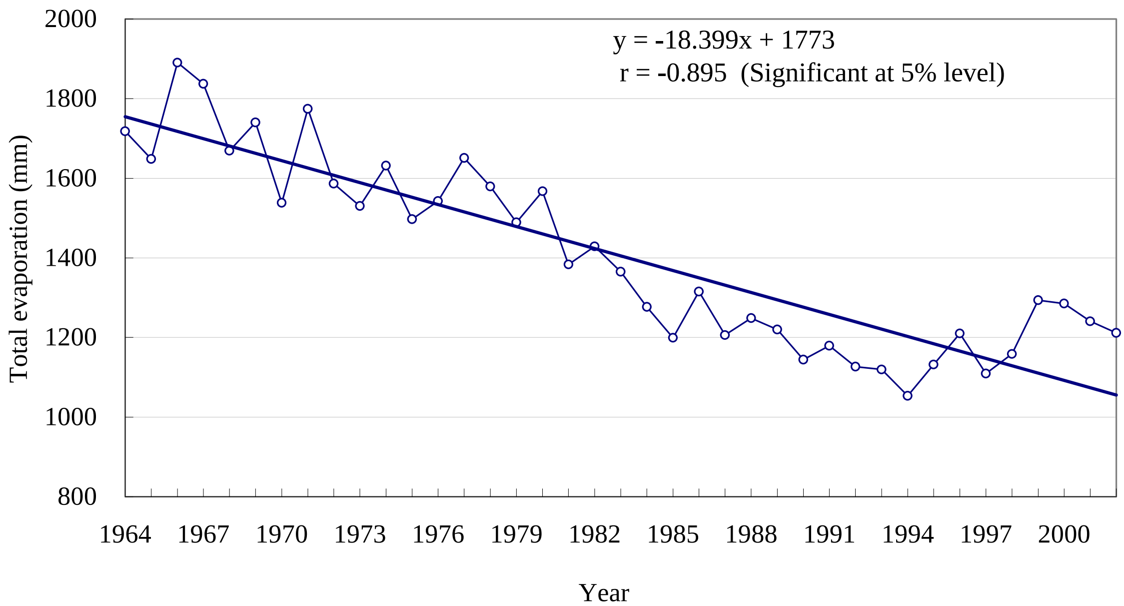


Figure 17. Annual total evaporation at King's Park (1964-2002)

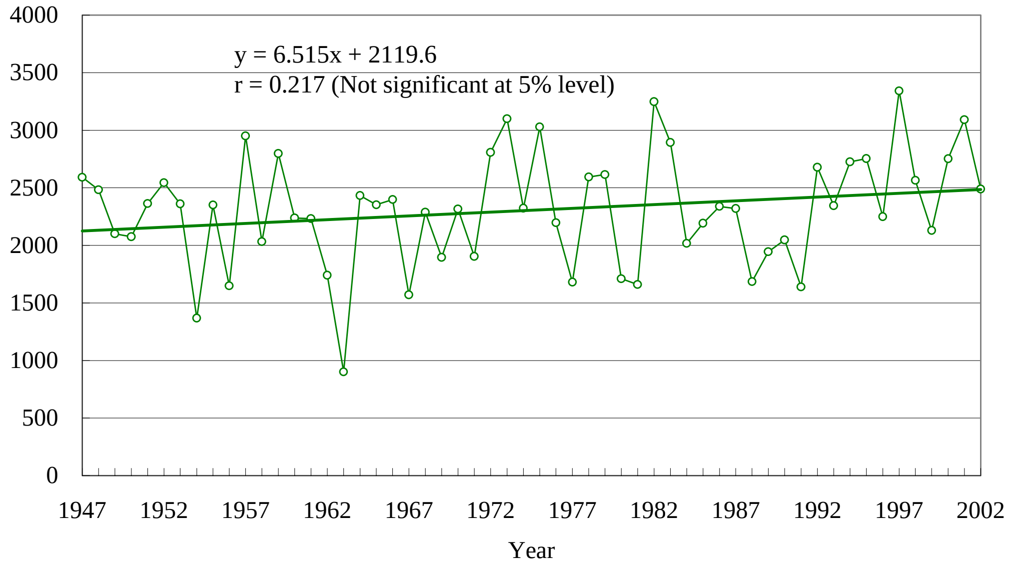


Figure 18. Annual rainfall at the Hong Kong Observatory Headquarters (1947-2002)

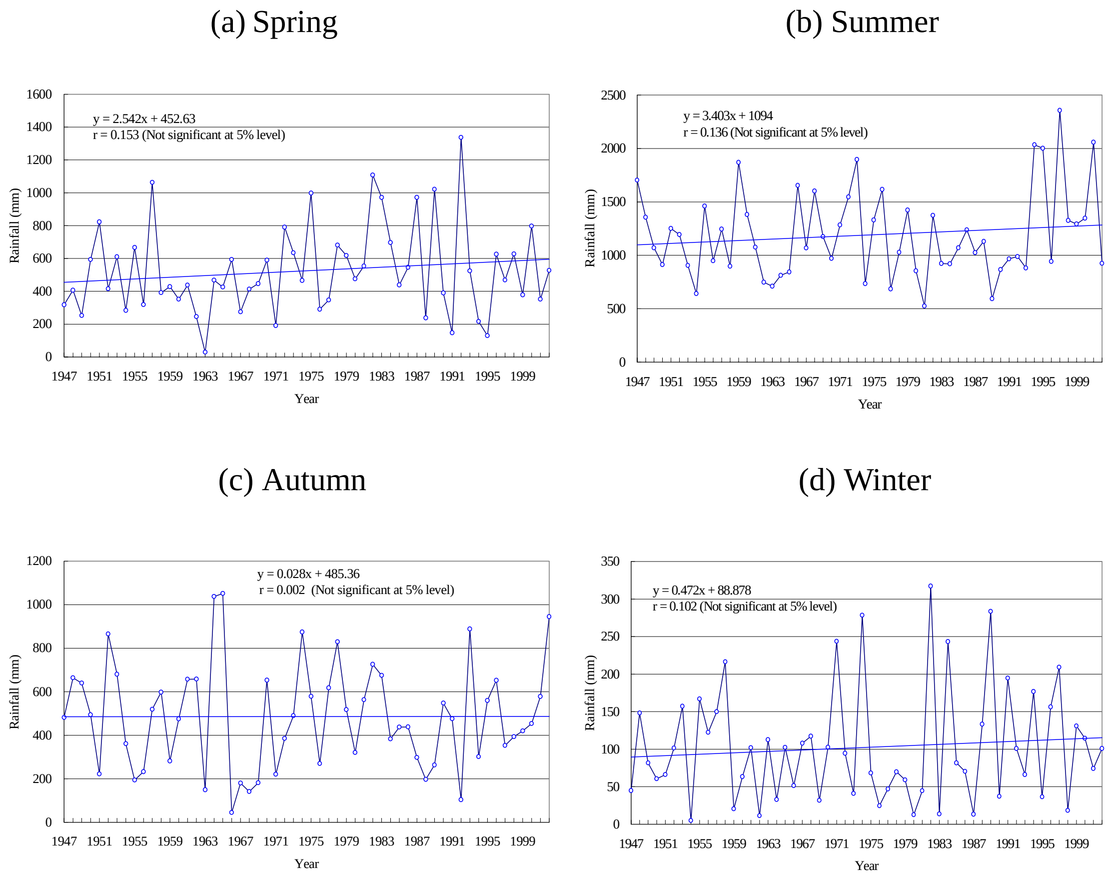


Figure 19. Seasonal rainfall at the Hong Kong Observatory Headquarters (1947-2002)

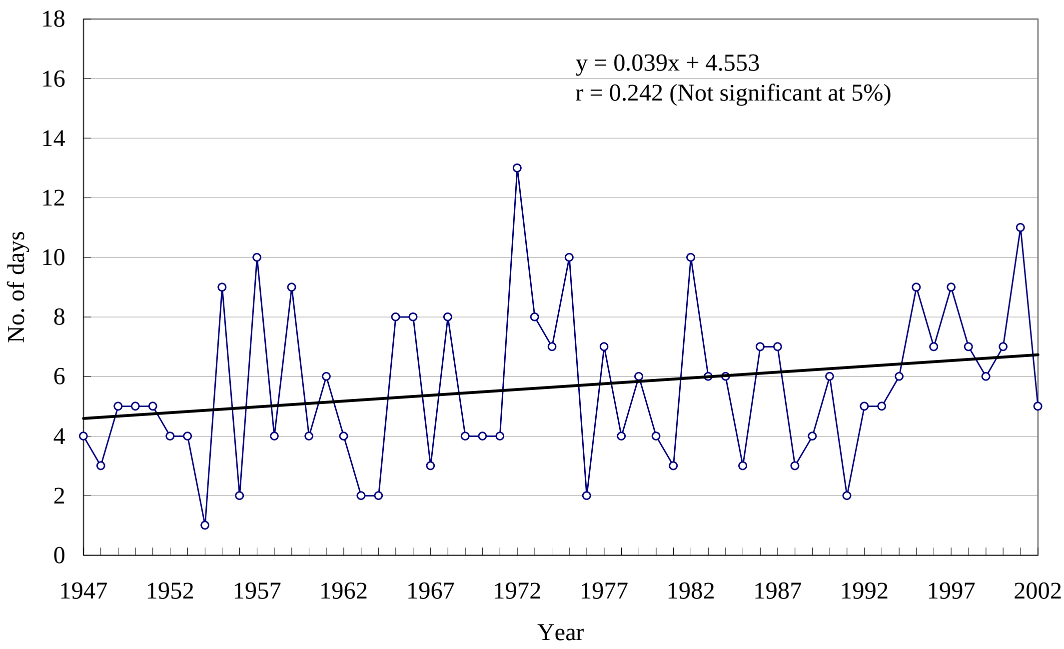


Figure 20. Number of days with hourly rainfall greater than 30 mm recorded at the Hong Kong Observatory Headquarters (1947-2002)

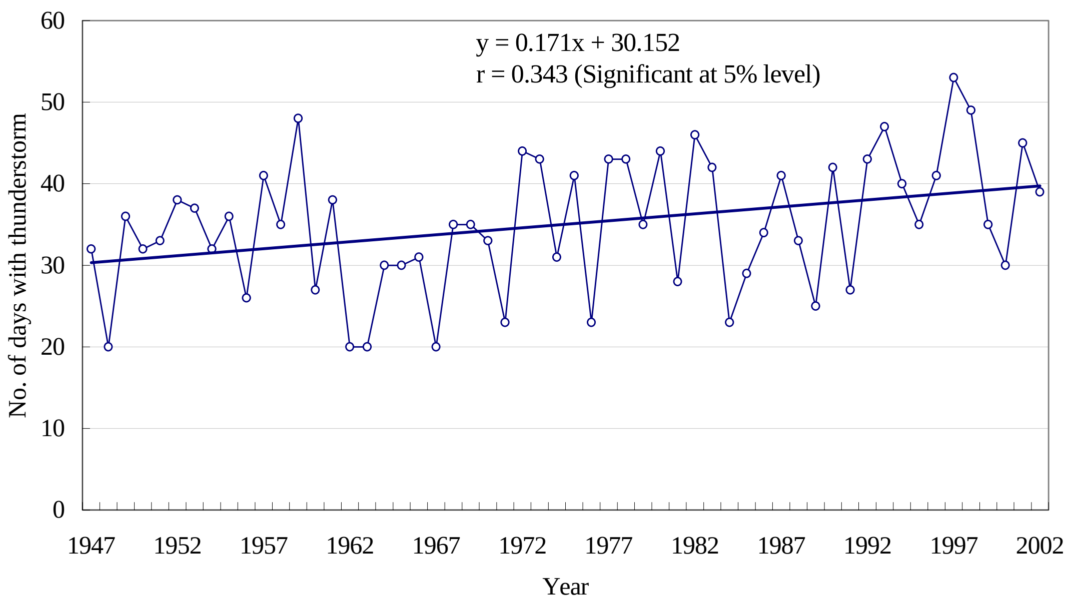


Figure 21. Annual number of days with thunderstorm (1947-2002)

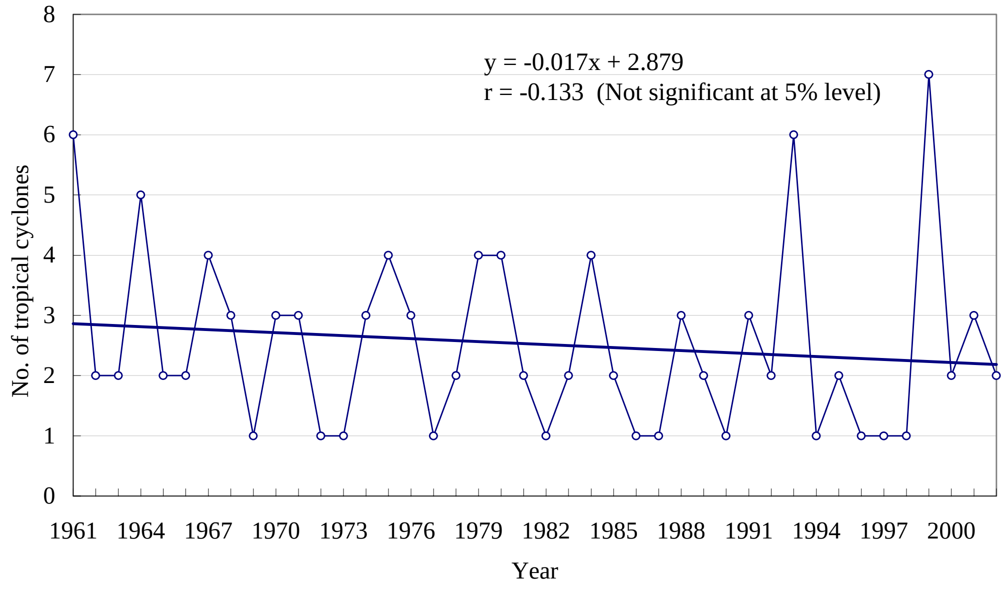


Figure 22. Annual number of tropical cyclones landing over the south China coast within 300 km of Hong Kong (1961-2002)