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Trends in Hong Kong Climate Parameters Relevant to Engineering Design

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TRENDS IN HONG KONG CLIMATE PARAMETERS RELEVANT TO ENGINEERING DESIGN

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Abstract: *Past trends in the occurrences of severe weather events in Hong Kong and the Heating Degree-Days and Cooling Degree-Days relevant to engineering design were examined. Preliminary study results showed that the extreme daily minimum and maximum temperatures at the Hong Kong Observatory Headquarters exhibited statistically significant long term rising trends. The Heating Degree-Days showed a statistically significant falling trend while the Cooling Degree-Days showed a statistically significant rising trend. Regarding rainfall, the frequency of occurrence of extreme hourly, 2-hourly and 3-hourly rainfall amounts at the Hong Kong Observatory Headquarters increased significantly. Furthermore, the extreme 10-minute mean wind speed and maximum gust at Kai Tak showed statistically significant decreasing trends. On the other hand, the trends in the extreme 4 to 24-hourly rainfall at the Hong Kong Observatory Headquarters and the extreme 10-minute mean wind speed and maximum gust at Waglan Island were not significant. The return period for an hourly rainfall of 100 millimetres or more had shortened from 37 years in 1900 to 18 years in 2000. The return period for the daily minimum temperature at 4°C or lower had lengthened from 6 years in 1900 to 163 years in 2000.*

INTRODUCTION

The design of buildings and engineering systems require consideration of local climatic conditions and characteristics, in particular, the frequency and intensity of severe weather events and how these parameters change with time. This study examined the long term trends in the intensity and frequency of occurrence of events associated with ambient air temperature, rainfall and wind speed in Hong Kong relevant to engineering design. The long term trends in the Heating Degree-Days (*HDD*) and Cooling Degree-Days (*CDD*) parameters commonly used to estimate energy consumption in the thermal design of buildings (Lam 1995) were also analysed.

DATA AND METHODOLOGY

The daily maximum temperatures (T_{max}), daily minimum temperatures (T_{min}) and daily mean temperatures (T_{mean}), hourly rainfalls recorded at the Hong Kong Observatory Headquarters from 1885 to 2008 (apart from a break from 1940 to 1946 owing to World War II), the 10-minute mean speeds on the hour (U_{10}) and 1-second gusts (U_g) recorded at Waglan Island and Kai Tak from 1968 to 2008 and the tropical cyclone best track data of the Hong Kong Observatory from 1961 to 2008 were used in this study.

Trend analyses of the variations of the following weather events/elements and the time-dependent extreme value analyses of the annual extremes of ambient air temperatures, rainfall amounts and wind speeds were conducted:

(a) Annual occurrence of severe weather events

For ambient air temperature, variations of the annual occurrences of cold days with $T_{min} \leqq$ 12.0 °C, very hot days with $T_{max} \geqq$ 33.0 °C and hot nights with $T_{min} \geqq$ 28.0 °C from 1885 to 2008 were examined.

For rainfall, the variation of the annual occurrence of days with hourly rainfall exceeding 30 millimetres from 1885 to 2008 was examined.

As most of the severe weather events related to high winds occurred during the passage of tropical cyclones, in particular typhoons, variations of the annual numbers of tropical cyclones of any intensity and variations of the annual numbers of typhoons passing within 100, 200 and 300 kilometers of Hong Kong from 1961 to 2008 were examined.

(b) Heating Degree-Days and Cooling Degree-Days

Heating Degree-Days (*HDD*) and Cooling Degree-Days (*CDD*) are meteorological parameters designed to reflect the demand of energy needed to heat or cool building or structure. These parameters are derived from daily temperature observations. The heating or cooling requirements for a given structure at a specific location are considered to be directly proportional to *HDD* or *CDD* at that location. The definitions for *HDD* and *CDD* in this study follow those of the Ministry of Housing and Urban-Rural Development in the Mainland (2005) which defines HDD as the annual total of the differences between a reference temperature of 18.0 °C and the daily mean outside temperature for days with daily mean outside temperature below 18.0 °C and CDD as the annual total of the differences between a reference temperature of 26.0 °C and the daily mean outside temperature for days with daily mean outside temperature above 26.0 °C.

(c) Analysis of extreme value

The time-dependent Generalized Extreme Value (GEV) distribution, commonly used to estimate the distribution of the extreme values (Coles, 2001), was used in this study for determining the long term trends of variation of probability of occurrence of extreme weather events. The maximum of a sequence of observations (such as annual maxima data), under very general conditions, is approximately distributed as GEV distribution which comprises of three asymptotic classical extreme value models, namely Gumbel, Frechet, and Weibull (Fisher and Tippett 1928; Jenkinson 1955; Gumbel 1958). The corresponding cumulative distribution function and probability density function (pdf) of the GEV is given by :

$$F(x;\mu,\sigma,\xi)=\begin{cases}\exp\{-\exp(-\dfrac{x-\mu}{\sigma})\}, & \xi=0, x>0\\ \exp\{-[1+\xi(\dfrac{x-\mu}{\sigma})]^{-1/\xi}\}, & \xi\neq 0, 1+\xi(x-\mu)/\sigma>0\end{cases} \quad [1.1]$$

$$f(x;\mu,\sigma,\xi)=\begin{cases}\dfrac{1}{\sigma}\exp\{-[\dfrac{x-\mu}{\sigma}+\exp(-\dfrac{x-\mu}{\sigma})]\}, & \xi=0, x>0\\ \dfrac{1}{\sigma}[1+\xi(\dfrac{x-\mu}{\sigma})]^{-1/\xi-1}\exp\{-[1+\xi(\dfrac{x-\mu}{\sigma})]^{-1/\xi}\}, & \xi\neq 0, 1+\xi(x-\mu)/\sigma>0\end{cases} \quad [1.2]$$

where μ, σ and ξ are the location, scale and shape parameters respectively. When ξ approaches 0, the distribution becomes the Gumbel type with the following cumulative distribution function:

$$F(x;\mu,\sigma,\xi)=\exp\left\{-\exp\left(-\frac{x-\mu}{\sigma}\right)\right\}, \quad -\infty<x<\infty \quad [2]$$

For $\xi < 0$ and $\xi > 0$, the distributions are known as Frechet and Weibull respectively.

To obtain the parameter μ, σ and ξ, the GEV distribution is fitted to the annual extreme values. Given the sample size is larger than 25, the method of maximum likelihood method (Cox and Hinkley 1974; LeDuc and Stevens 1977; Kharin and Zwiers 2005) is adopted for the fitting in the non-stationary GEV distribution in Equations [1.1].

Suppose $x_1,\ldots, x_n$ are the annual maxima of the set of observations, the likelihood $\boldsymbol{L}$ is the product of the densities of Eq [1.2] for $x_1,\ldots, x_n$. Mathematically,

$$L(\mu,\sigma,\xi)=\frac{1}{\sigma^n}\prod_{i=1}^{n}\left(1+\xi\left(\frac{x_i-\mu}{\sigma}\right)^{-\left(\frac{1}{\xi}+1\right)}\right)\exp\left\{-\sum_{i=1}^{n}\left(1+\xi\,\frac{x_i-\mu}{\sigma}\right)^{-\frac{1}{\xi}}\right\} \quad [3]$$

The estimates of μ, σ and ξ, say μ_0, σ_0 and ξ_0, which maximize the likelihood $\boldsymbol{L}$ are called the maximum likelihood estimators.

Under the influence of climate change and urbanization effect (Leung *et al* 2004), the extreme values of different meteorological elements may exhibit trends with respect to time, i.e. a time-dependent GEV distribution (Kharin and Zwiers 2005; Feng *et al* 2007). For this study, the GEV parameters μ, σ and ξ were assumed as time-dependent quantities which vary linearly with time ($\boldsymbol{t}$) as

$$\begin{aligned} \xi(\boldsymbol{t}) &= a+b\boldsymbol{t} \\ \mu(\boldsymbol{t}) &= a_1+b_1\boldsymbol{t}, \\ \sigma(\boldsymbol{t}) &= a_2+b_2\boldsymbol{t}, \end{aligned} \qquad [4]$$

The standard likelihood ratio test was conducted to determine whether the trend estimated from the fitting of a time-dependent GEV distribution was significant against the null hypothesis of a time-independent GEV distribution with constant μ, σ and ξ. Assuming L_0 and L_1 are the log likelihood of the time independent (constant μ, σ and ξ) and the alternative time-dependent GEV distributions respectively, the null hypothesis is rejected at 5 % significant level when

$$D = 2(L_1-L_0) > \chi^2(v, 0.95) \qquad [5]$$

where v is the difference in the number of estimated parameters (Cole 2001) between the two test models. For the χ^2 distribution with v=1, the $\chi^2(v, 0.95) = 3.84$. Details of the maximum likelihood method and the likelihood ratio test are documented in Kharin's study (Kharin & Zwiers 2005).

After fitting the GEV distributions with the annual extreme values and determining the relevant parameters, the N-year return values X_N can be estimated from the cumulative distribution function as :

$$
X_N = \begin{cases} \mu - \dfrac{\sigma}{\xi}\left[1 - \left\{-\ln\left(1 - \dfrac{1}{N}\right)\right\}^{-\xi}\right] & \textit{for} \quad \xi \neq 0 \\ \mu - \sigma \ln\left[-\ln\left(1 - \dfrac{1}{N}\right)\right] & \textit{for} \quad \xi = 0 \end{cases} \qquad [6]
$$

RESULTS

(a) Trends in cold days, very hot days and hot nights

Figure 1.1(a), 1.1(b) and 1.1(c) show the variations of the annual number of cold days, very hot days and hot nights from 1885 to 2008. The annual number of cold days decreased by 1.2 days per decade and hot nights increased by 1.5 nights per decade from 1885 to 2008. They were statistically significant at 5% level. On the other hand, the annual number of very hot days did not show any significant trend from 1885 to 2008.

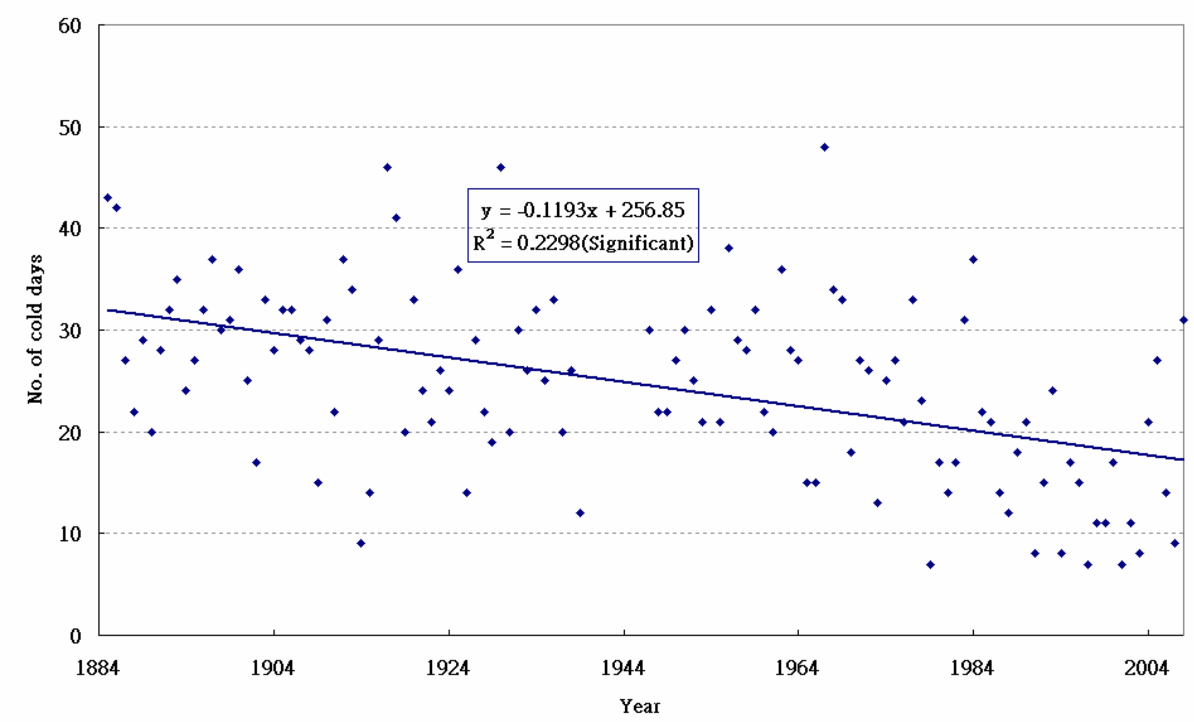

Figure 1.1(a). Annual number of cold days (1885-2008)

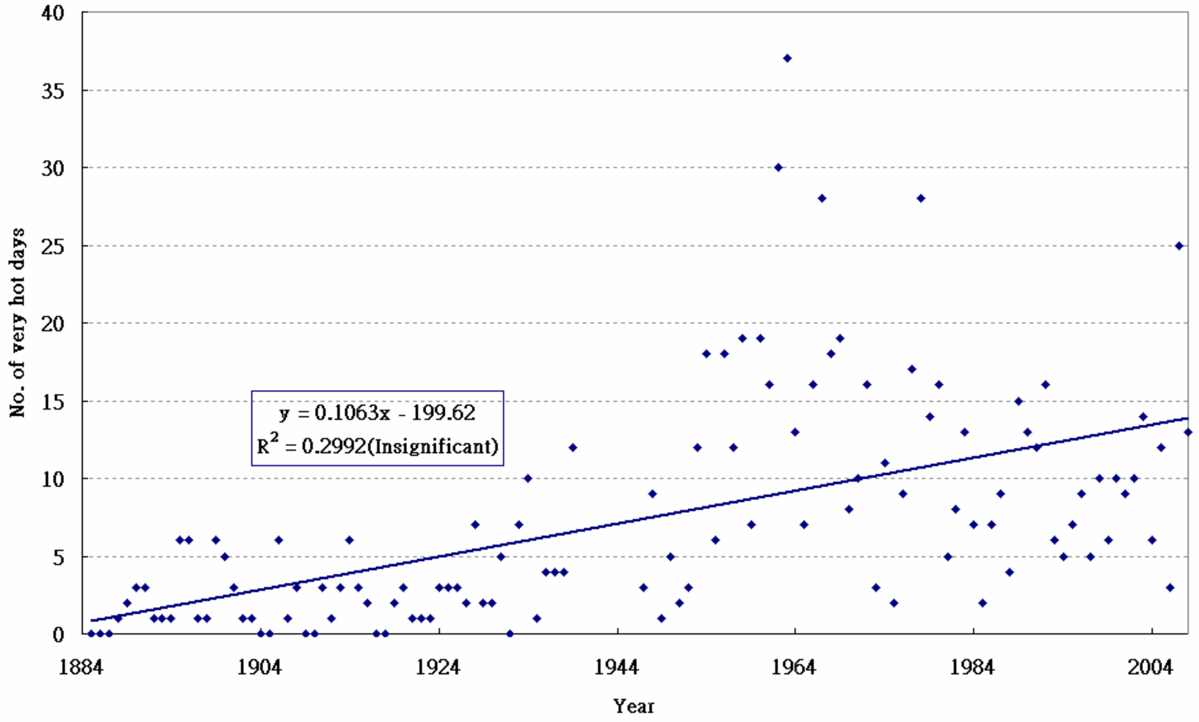

Figure 1.1(b). Annual number of very hot days (1885-2008)

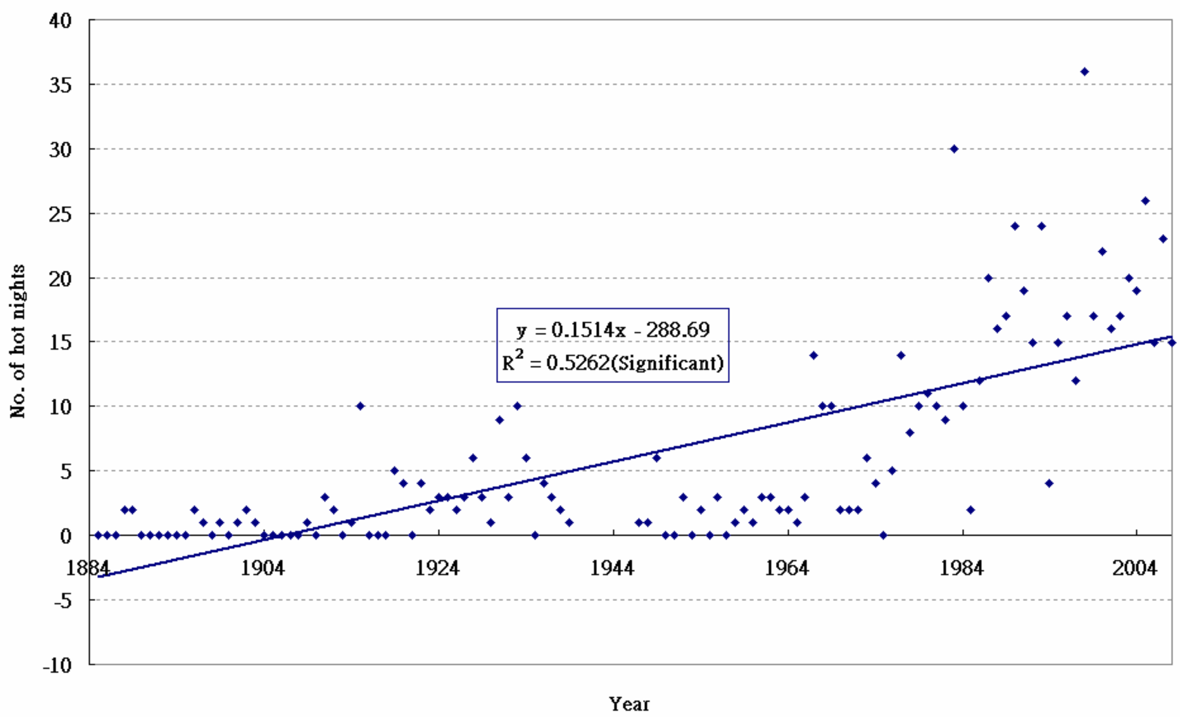

Figure 1.1(c). Annual number of hot nights (1885-2008)

(b) Trends in annual temperature extremes

Four annual temperature extremes based on T_{min} and T_{max} data were analysed in this study:

annual lowest T_{min} (LT_{min}), annual highest T_{min} (HT_{min}), annual lowest T_{max} (LT_{max}) and annual highest T_{max} (HT_{max}).

Figure 1.2(a), 1.2(b), 1.2(c) and 1.2(d) show the variations of LT_{min}, HT_{min}, LT_{max} and HT_{max} from 1885 to 2008 respectively. All of them had statistically significant rising trend with rising rates of about 0.1 ^{o}C per decade.

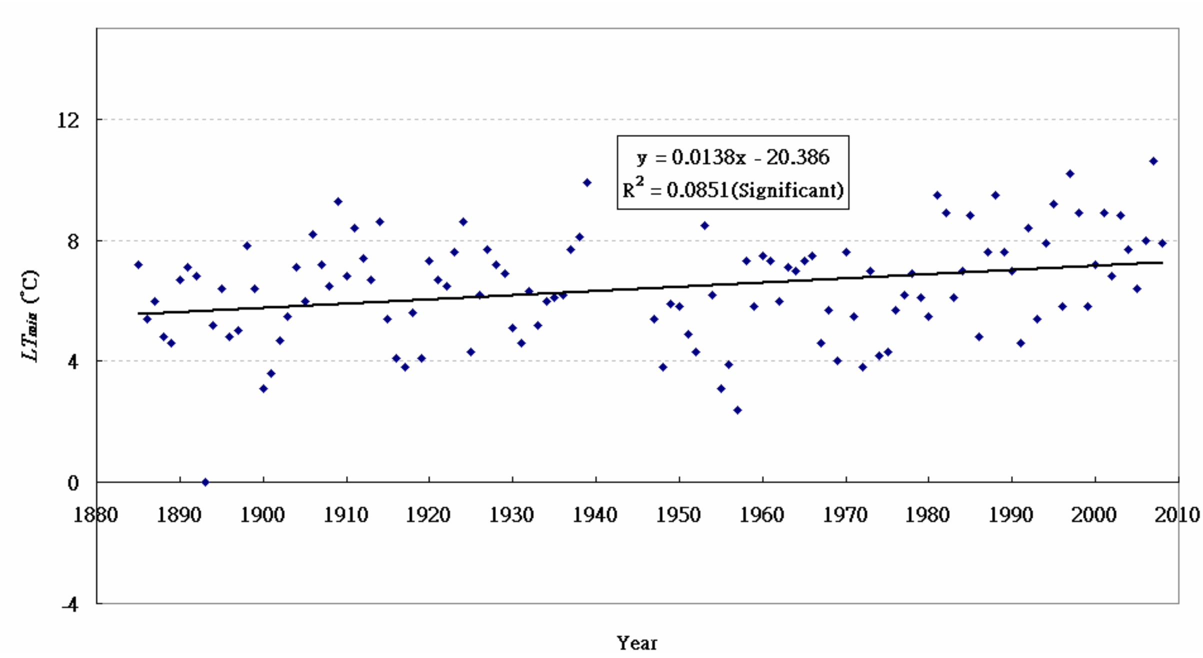

Figure 1.2(a). Time series of LT_{min} (1885-2008)

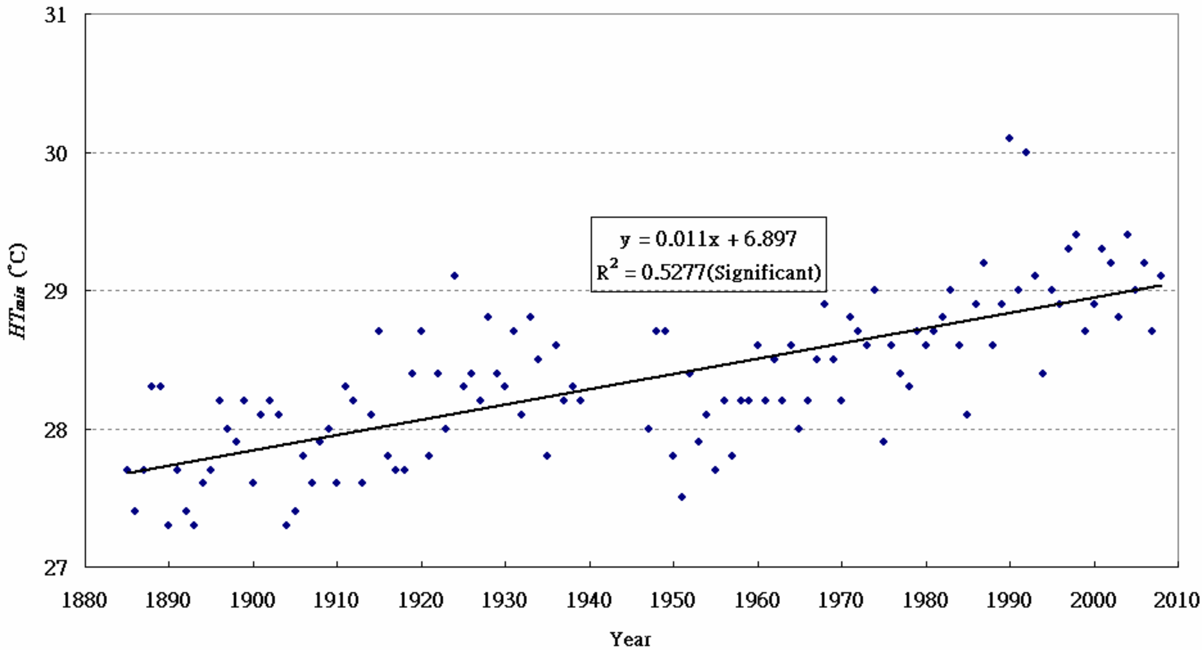

Figure 1.2(b). Time series of HT_{min} (1885-2008)

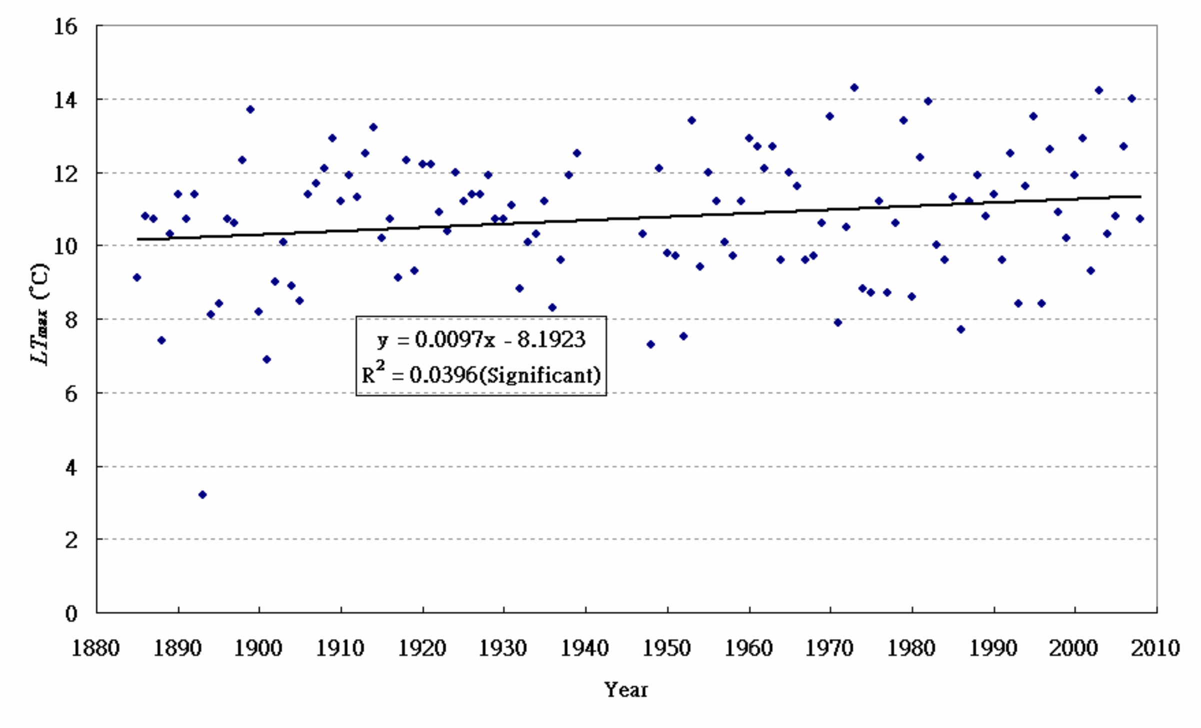

Figure 1.2(c). Time series of LT_{max} (1885-2008)

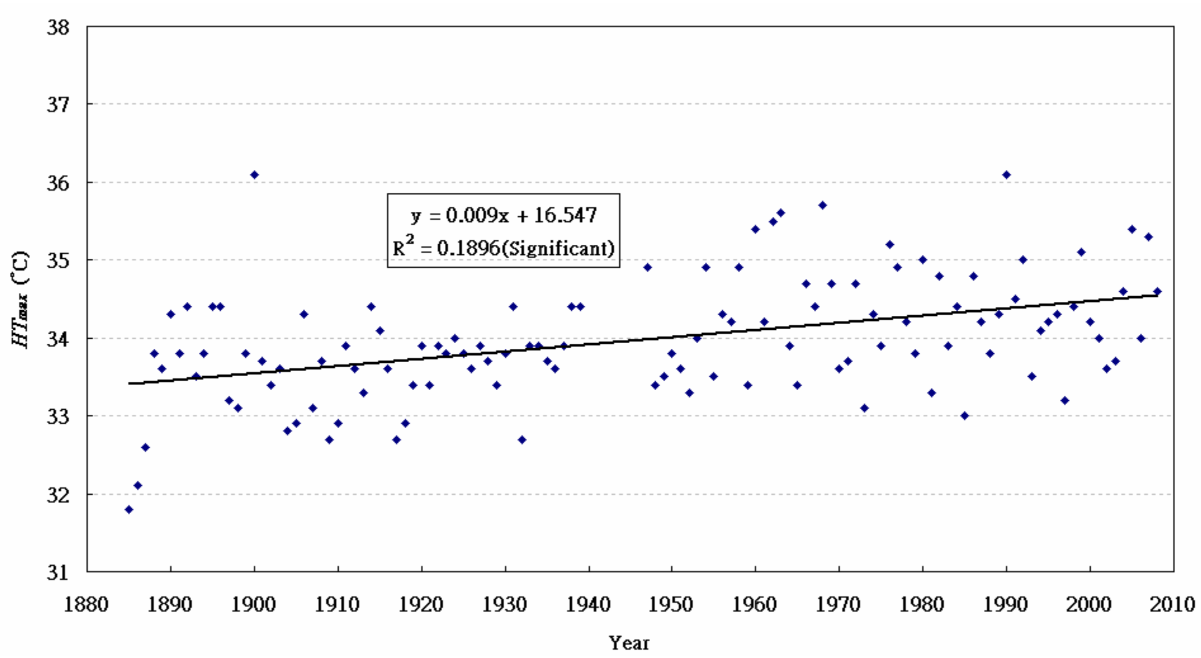

Figure 1.2(d). Time series of HT_{max} (1885-2008)

Table 1 summarises the results of the likelihood ratio tests for the significance of time-dependency of the three parameters μ, σ and ξ for the GEV distributions of LT_{min}, HT_{min}, LT_{max} and HT_{max} from 1885 to 2008. It showed that the GEV distributions of extreme values of these three temperature parameters had significant time dependency.

Table 1. Significance of time-dependency of μ, σ and ξ for the GEV distributions of LT_{min}, HT_{min}, LT_{max} and HT_{max} from 1885 to 2008

Weather elements	**Significance of time-dependency**		
	μ	σ	ξ
LT_{min}	Yes	No	Yes
HT_{min}	Yes	No	Yes
LT_{max}	Yes	No	No
HT_{max}	Yes	No	No

Figure 1.3(a), 1.3(b), 1.3(c) and 1.3(d) show the long term trends of the 5-year, 10-year, 50-year and 100-year return values of LT_{min}, HT_{min}, LT_{max} and HT_{max} from 1885 to 2008 respectively. The rates of increase of the return values for fixed return periods for LT_{min}, HT_{min}, LT_{max} and HT_{max} ranged from about 0.1 to 0.3 °C per decade. All trends were statistically significant at 5% level.

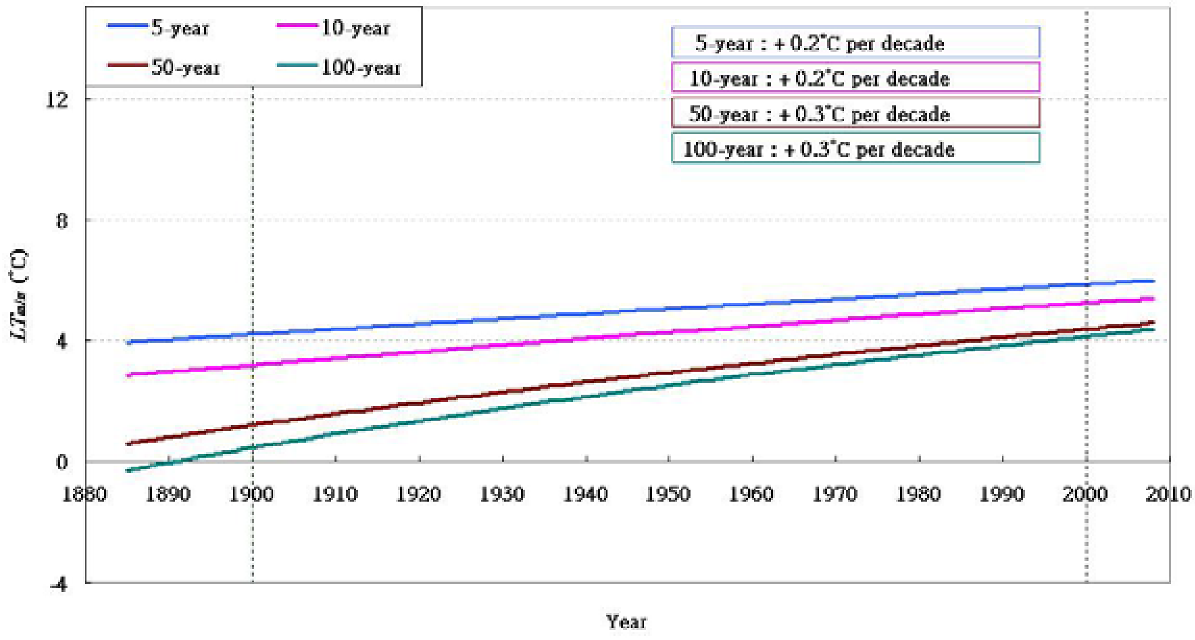

Figure 1.3(a). Long term trends of the return values for LT_{min} with return periods of 5-year, 10-year, 50-year and100-year respectively (1885-2008)

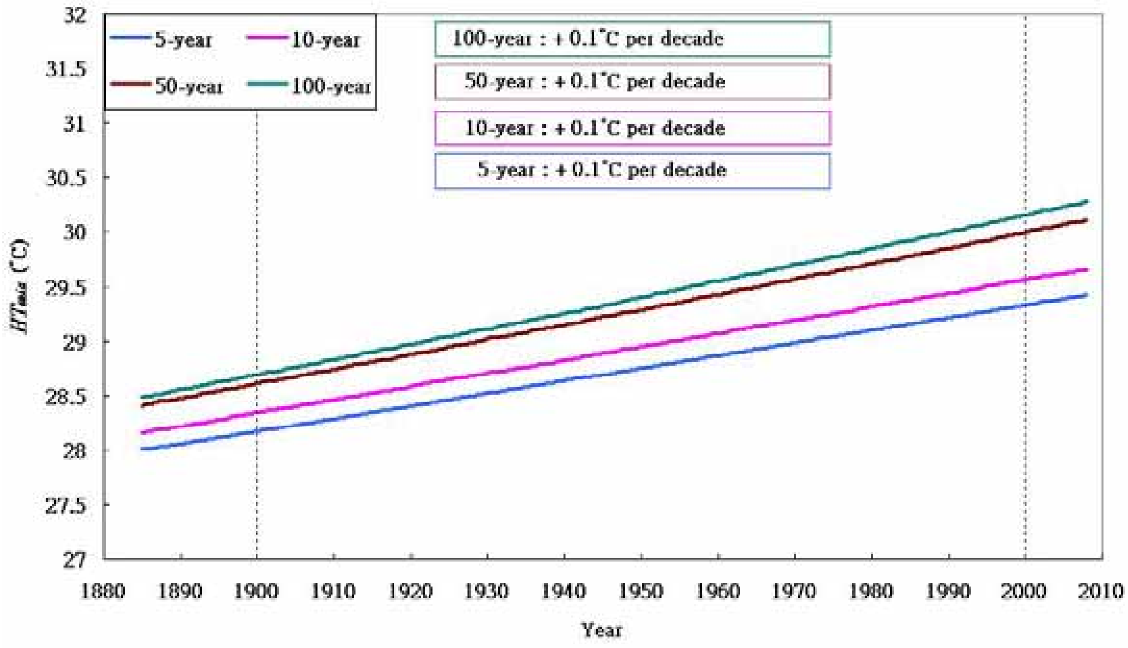

Figure 1.3(b). Long term trends of the return values for HT_{min} with return periods of 5-year, 10-year, 50-year and 100-year respectively (1885-2008)

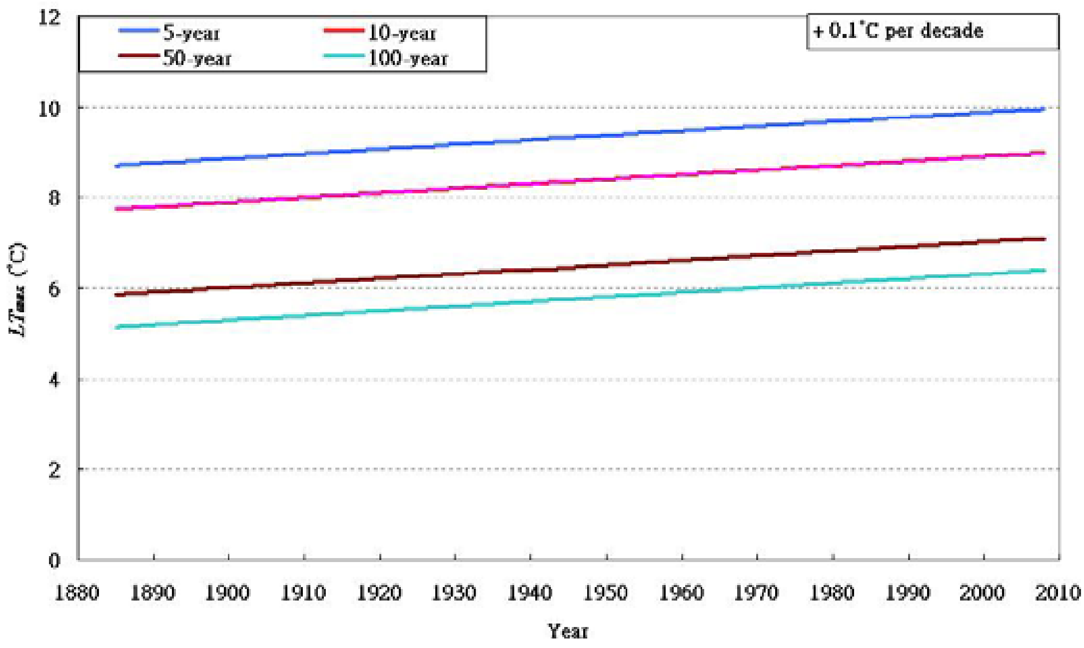

Figure 1.3(c). Long term trends of the return values for LT_{max} with return periods of 5-year, 10-year, 50-year and 100-year respectively (1885-2008)

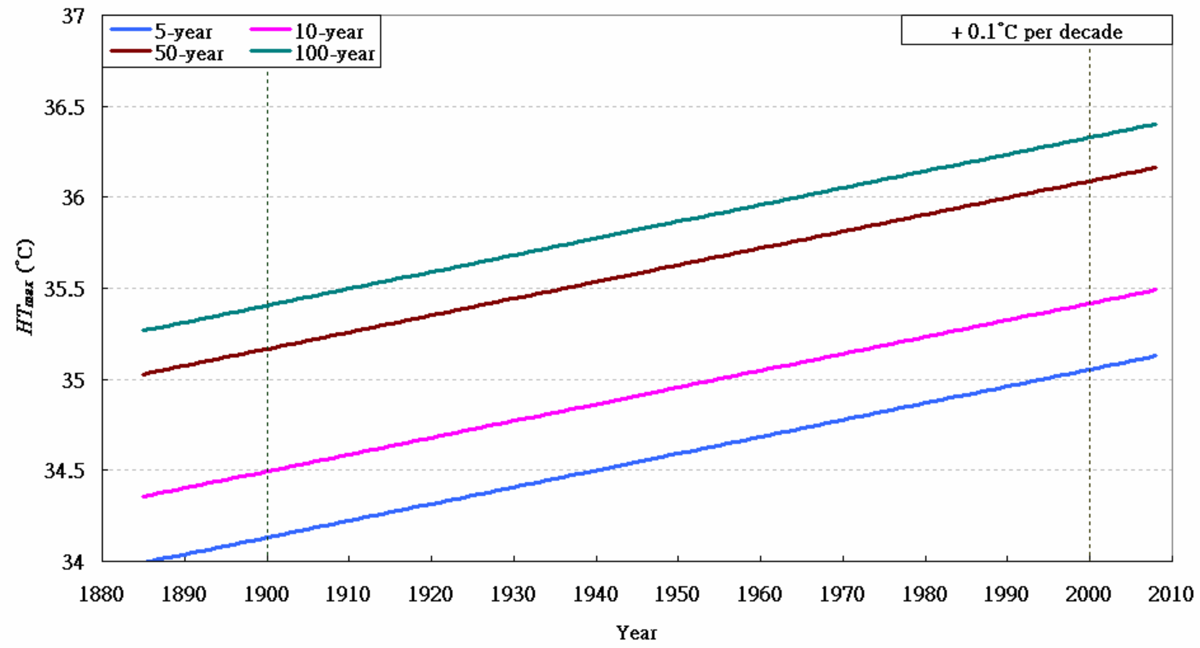

Figure 1.3(d). Long term trends of the return values for HT_{max} with return periods of 5-year, 10-year, 50-year and 100-year respectively (1885-2008)

Figure 1.4(a), 1.4(b), 1.4(c) and 1.4(d) show the plots of return values against return periods in 1900 and in 2000 for LT_{min}, HT_{min}, LT_{max} and HT_{max} respectively. The GEV pdf for extreme values of these four temperature parameters in these two years are also shown in the figures. All the four GEV pdf in 2000 were at higher temperature range than in 1900. The return period for a $T_{min} \leqq 4.0^{o}C$ lengthened from 6 years in 1900 to 163 years in 2000. On the other hand, the return periods for a $T_{min} \geqq 30.0^{o}C$ and a $T_{max} \geqq 35.0^{o}C$ shortened from > 100 and 32 years in 1900 to 51 and 4.5 years in 2000 respectively.

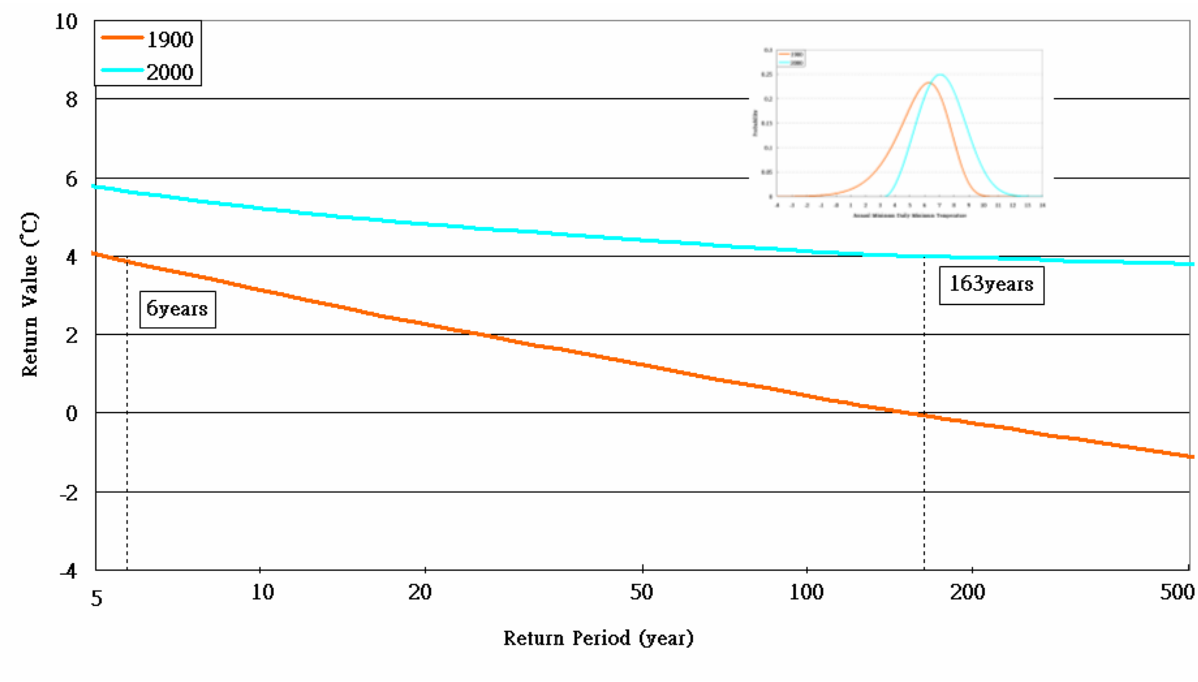

Figure 1.4(a). Return periods for LT_{min} in 1900 and 2000 (the insert shows the GEV pdf for LT_{min} in 1900 [brown line] and 2000 [blue line])

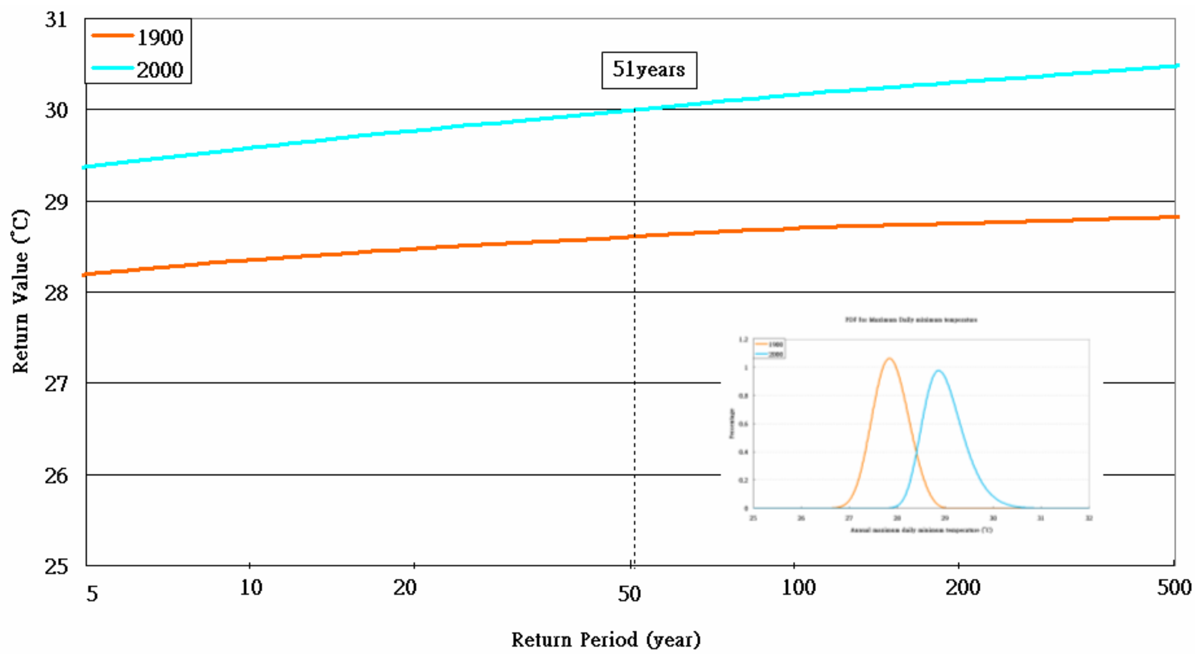

Figure 1.4(b). Return periods for HT_{min} in 1900 and 2000 (the insert shows the GEV pdf for HT_{min} in 1900 [brown line] and 2000 [blue line])

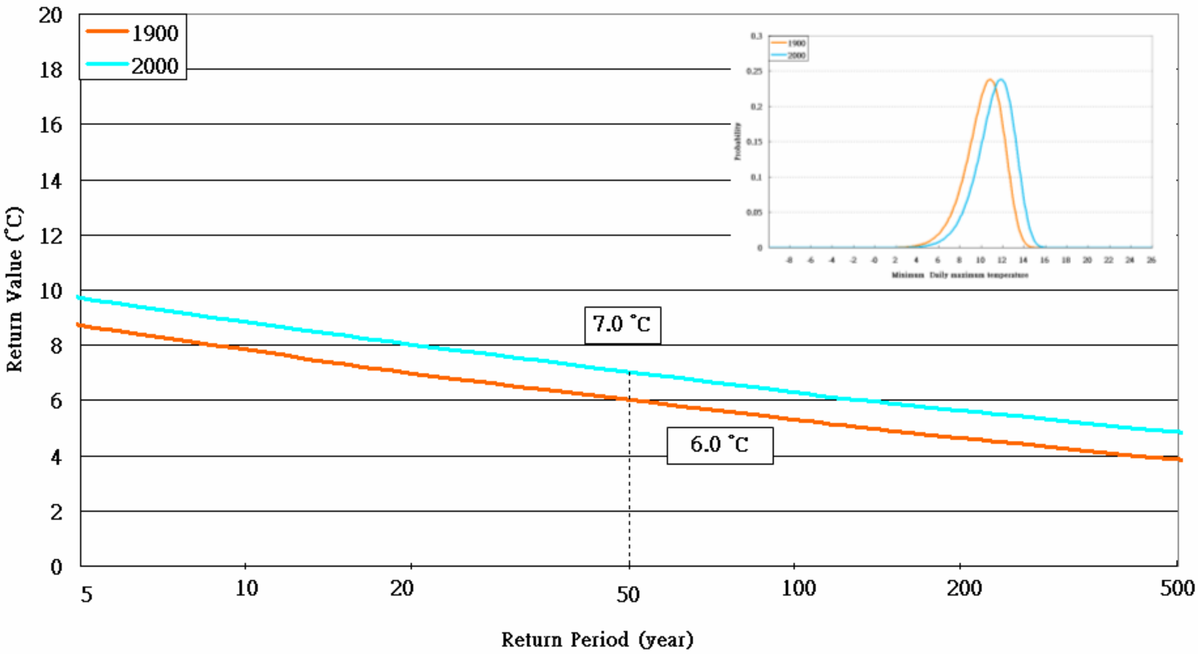

Figure 1.4(c). Return periods for LT_{max} in 1900 and 2000 (the insert shows the GEV pdf for LT_{max} in 1900 [brown line] and 2000 [blue line])

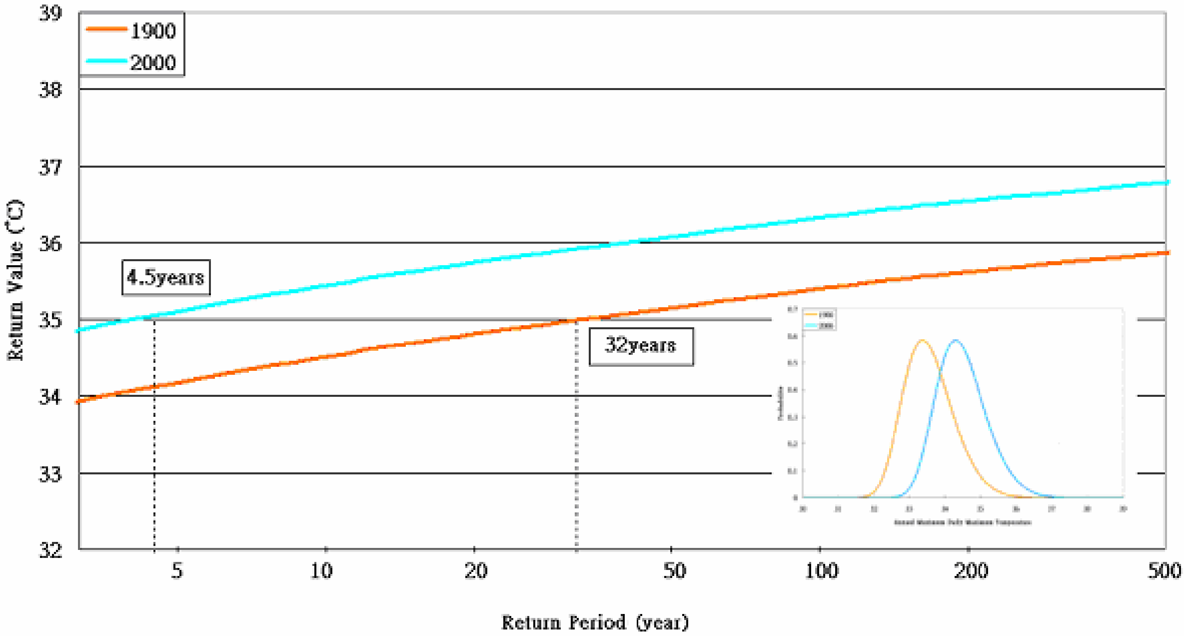

Figure 1.4(d). Return periods for HT_{max} in 1900 and 2000 (the insert shows the GEV pdf for HT_{max} in 1900 [brown line] and 2000 [blue line])

(c) Trends in *HDD* and *CDD*

Variations of the *HDD* and *CDD* from 1885 to 2008 are shown in Figure 1.5(a) and 1.5(b) respectively. The figures showed that *HDD* decreased by about 12 ^{o}C per decade and *CDD* increased by about 14 ^{o}C per decade. Both trends were significant at 5% level.

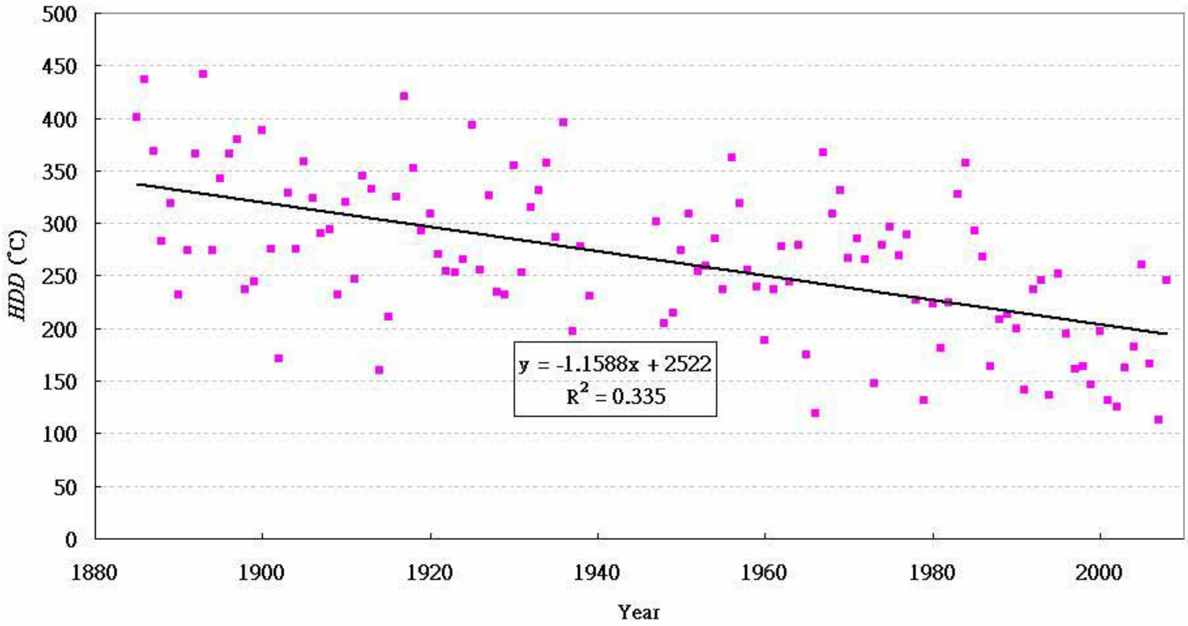

Figure 1.5(a). Time series of Heating Degree-Day (1885-2008)

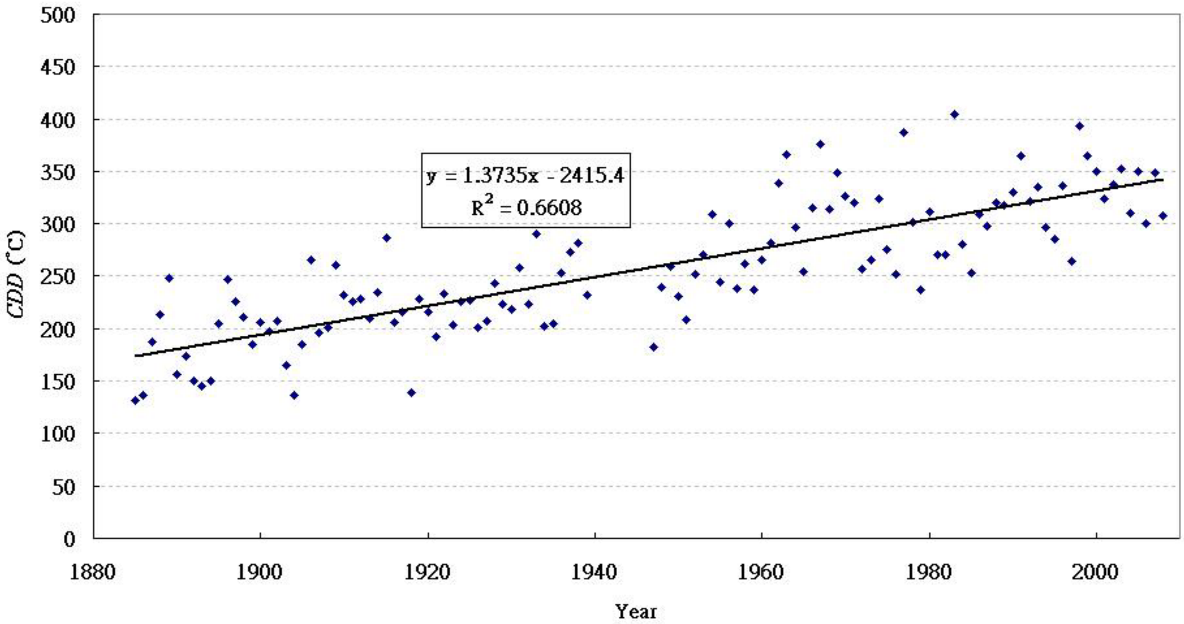

Figure 1.5(b). Time series of Cooling Degree-Day (1885-2008)

(d) The trend in the annual number of days with hourly rainfall exceeding 30 millimetres

Figure 2.1 shows the long term trend of the annual number of days with hourly rainfall exceeding 30 millimetres at the Hong Kong Observatory Headquarters from 1885 to 2008. The annual number of these rainy days increased at a rate of about 0.2 days per decade from 1885 to 2008. The trend was significant at 5% level.

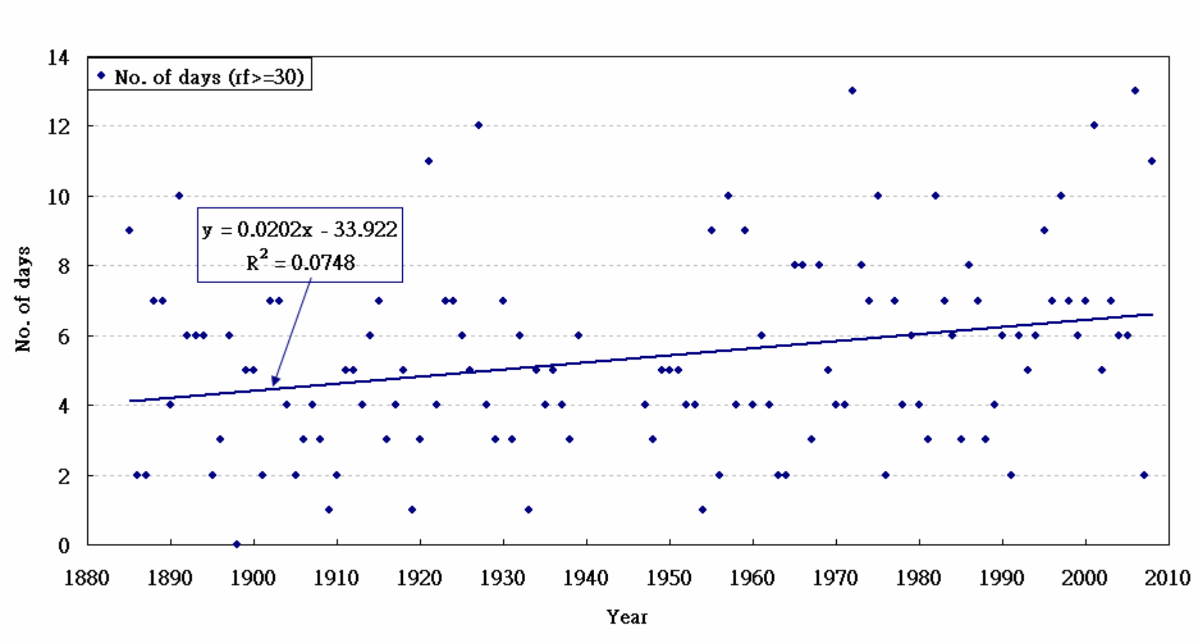

Figure 2.1. Annual number of days with an hourly rainfall exceeding 30 mm (1885-2008)

(e) Trends in the annual extreme rainfall

Results of the trend analyses for the variation of the annual maximum 1,2,3,4,6,12 and 24-hourly rainfall from 1885 to 2008 indicated that only the annual maximum 1 and 2-hourly rainfall had significant increasing trends at 5% level and the increasing trend for the annual maximum 3-hourly rainfall was marginally insignificant at 5% level. Figure 2.2(a), 2.2(b) and 2.2(c) show the variation of the annual maximum 1, 2 and 3-hourly rainfall from 1885 to 2008. The rates of increase were about 1.7, 2.1 and 1.7 millimetres per decade respectively.

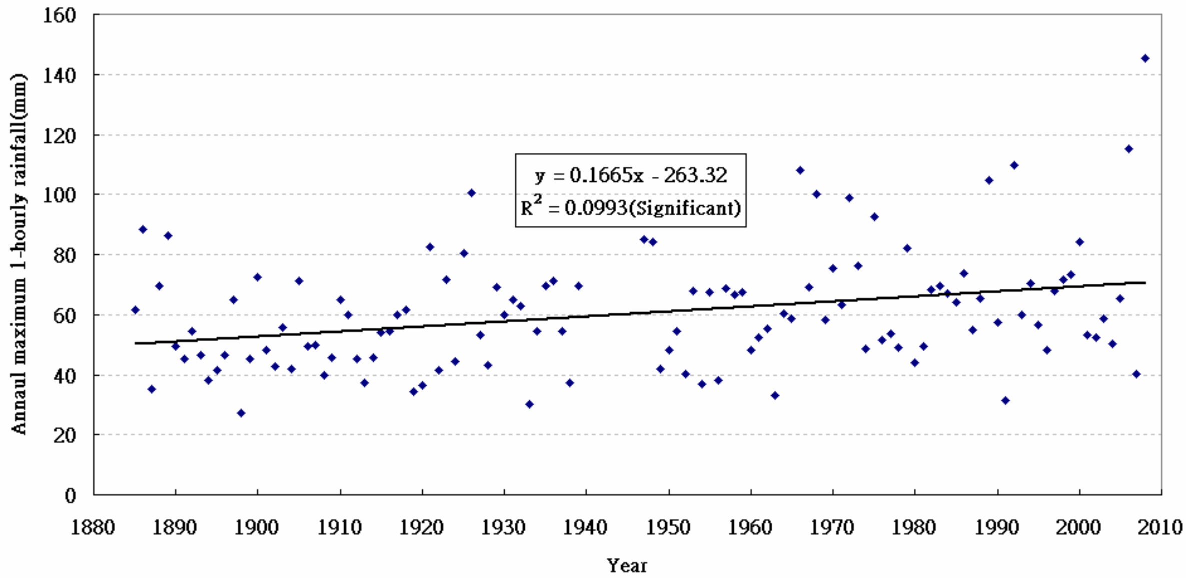

Figure 2.2(a). Time series of annual maximum 1-hourly rainfall (1885-2008)

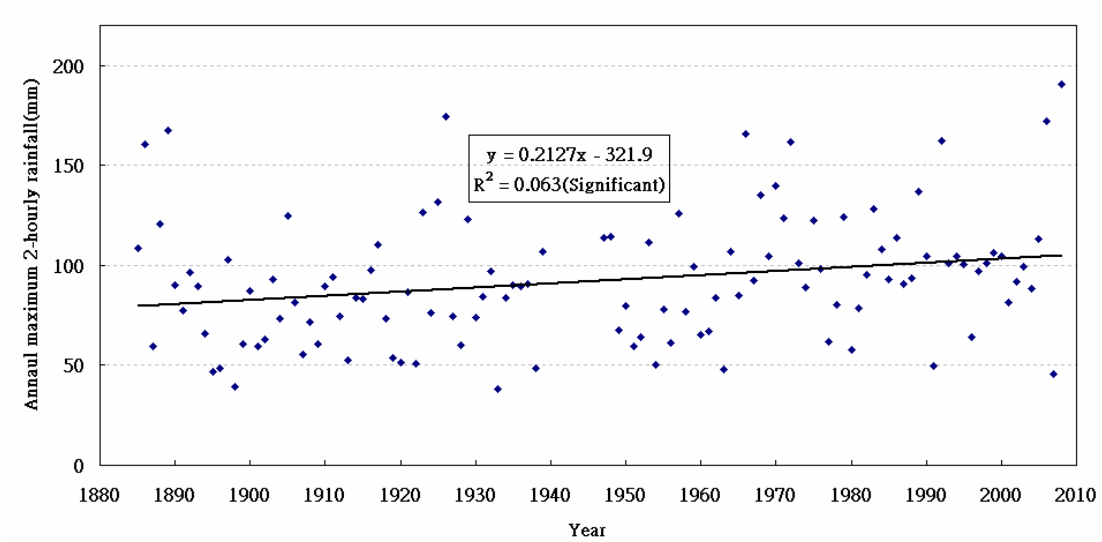

Figure 2.2(b). Time series of annual maximum 2-hourly rainfall (1885-2008)

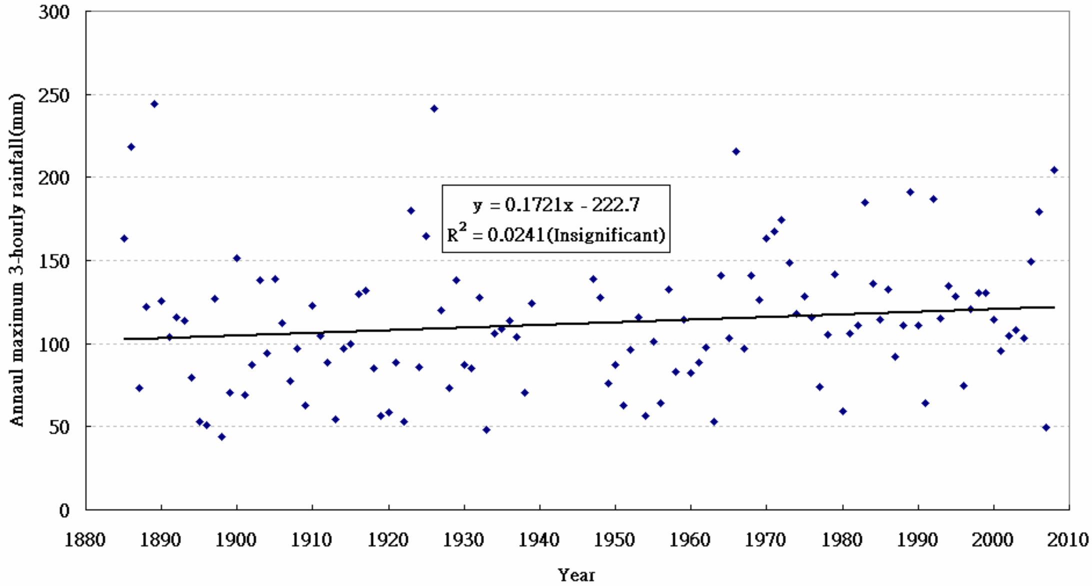

Figure 2.2(c). Time series of annual maximum 3-hourly rainfall (1885-2008)

Table 2 summaries the results of the likelihood ratio tests for the significance of time-dependency of the three parameters μ, σ and ξ for the GEV distributions of the annual maximum 1, 2 and 3-hourly rainfall from 1885 to 2008. It showed that the GEV distributions of the extreme values of these three rainfall parameters had significant time variations.

Table 2. Significance of time-dependency of the three parameters μ, σ and ξ for GEV distributions for the annual maximum 1, 2 and 3-hourly rainfall from 1885 to 2008

Weather elements	**Significance of time-dependency**		
	μ	σ	ξ
Annual maximum 1-hourly rainfall	Yes	No	No
Annual maximum 2-hourly rainfall	Yes	No	No
Annual maximum 3-hourly rainfall	Yes	No	No

Figure 2.3(a), 2.3(b) and 2.3(c) show the long term trends of the 10-year, 20-year, 50-year and 100-year return values of annual maximum 1, 2 and 3-hourly rainfall from 1885 to 2008 respectively. The return values for fixed return periods for the annual maximum 1, 2 and 3-hourly rainfall increased by 1.1, 1.8 and 2.0 millimetres per decade respectively,

significant at 5% level.

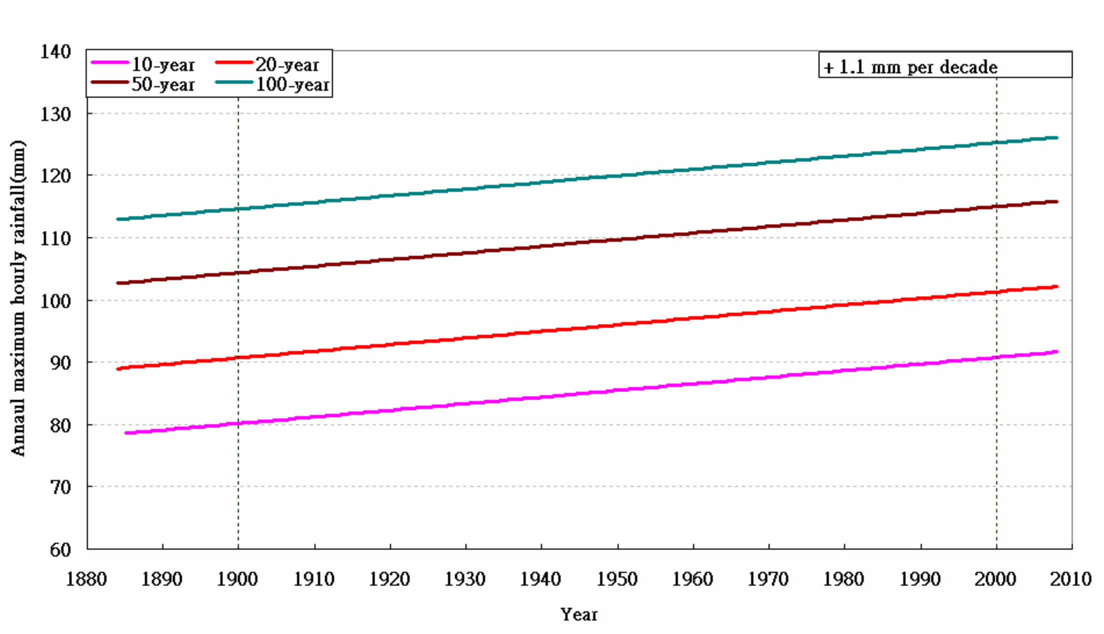

Figure 2.3(a). Long term trends of the return values for the annual maximum one-hourly rainfall with return periods of 10-year, 20-year, 50-year and 100-year respectively (1885-2008)

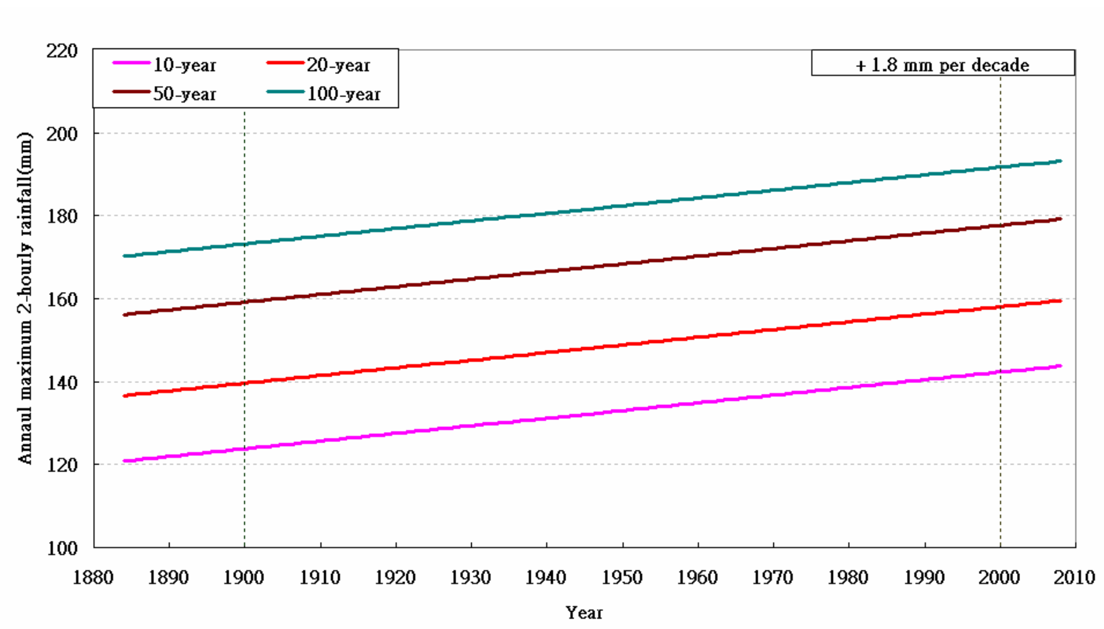

Figure 2.3(b). Long term trends of the return values for the annual maximum two-hourly rainfall with return periods of 10-year, 20-year, 50-year and 100-year respectively (1885-2008)

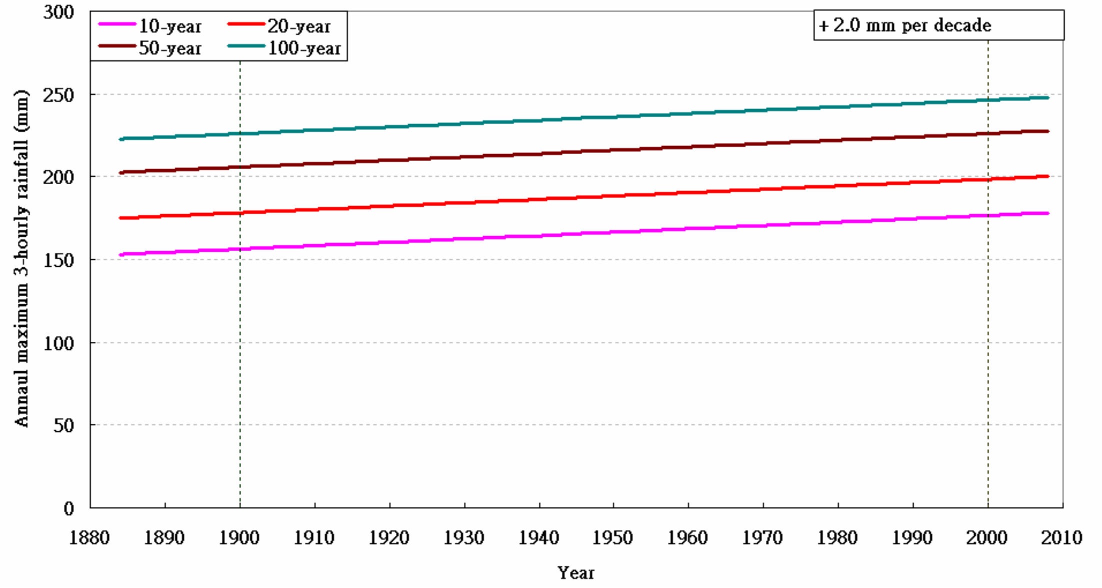

Figure 2.3(c). Long term trends of the return values for the annual maximum three-hourly rainfall with return periods of 10-year, 20-year, 50-year and 100-year respectively (1885-2008)

Figure 2.4(a), 2.4(b) and 2.4(c) show the plots of return values against return periods in 1900 and in 2000 for the annual maximum 1, 2 and 3-hourly rainfall respectively. The GEV pdf for the extreme values of these three rainfall parameters in these two years are also shown in the figures. All the three GEV pdf in 2000 were at higher rainfall range than in 1900. The return period for 1-hourly rainfall of 100 millimetres or above shortened from 37 years in 1900 to 18 years in 2000. For 2-hourly rainfall of 150 millimetres or above and 3-hourly rainfall of 200 millimetres or above, the return periods shortened from 32 years and 41 years to 14 years and 21 years respectively.

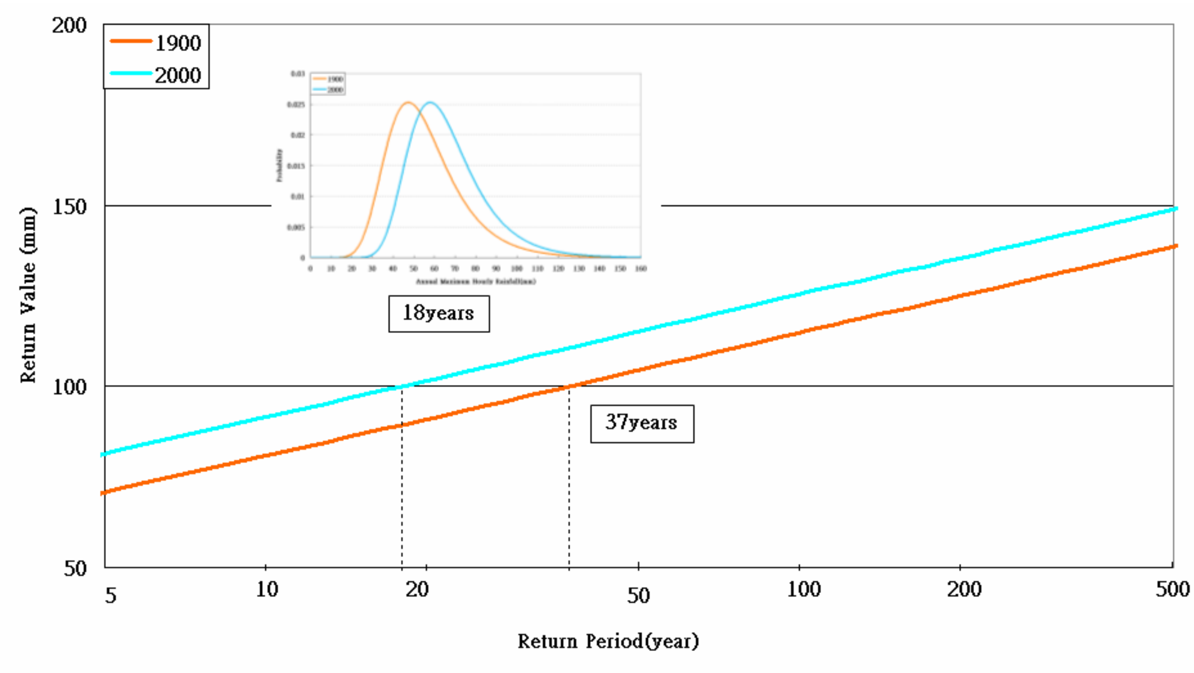

Figure 2.4(a). Return periods for annual maximum one-hourly rainfalls in 1900 and 2000 (the insert shows the GEV pdf for annual maximum one-hourly rainfalls in 1900 [brown line] and 2000 [blue line])

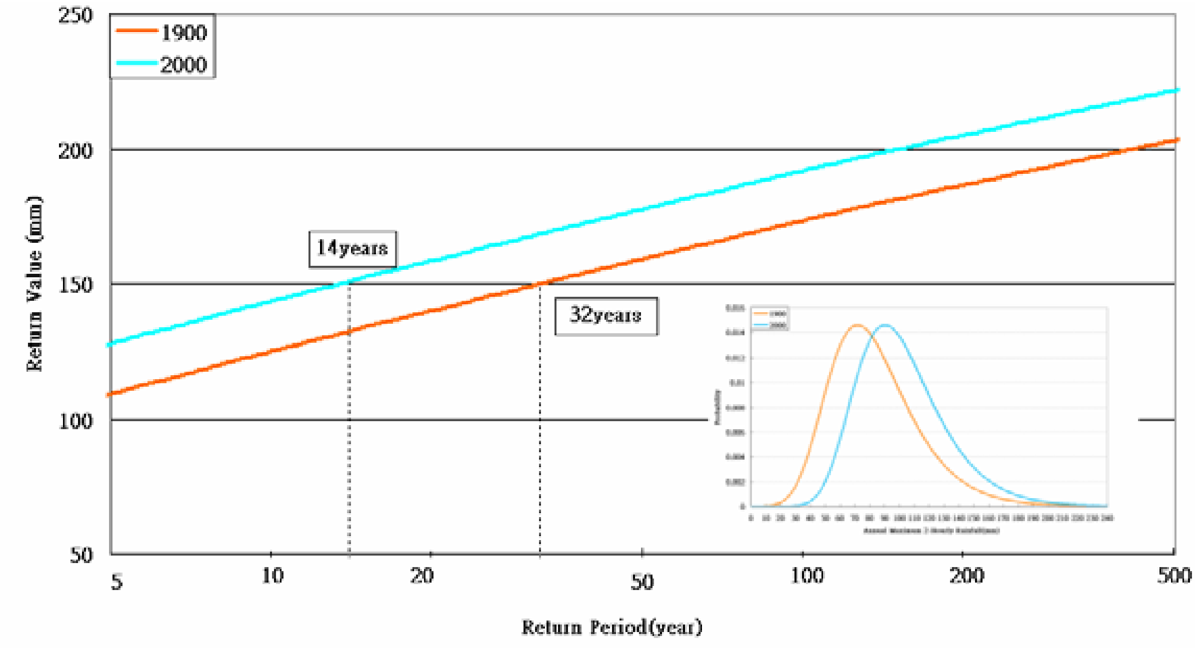

Figure 2.4(b). Return periods for annual maximum two-hourly rainfalls in 1900 and 2000 (the insert shows the GEV pdf for annual maximum two-hourly rainfalls in 1900 [brown line] and 2000 [blue line])

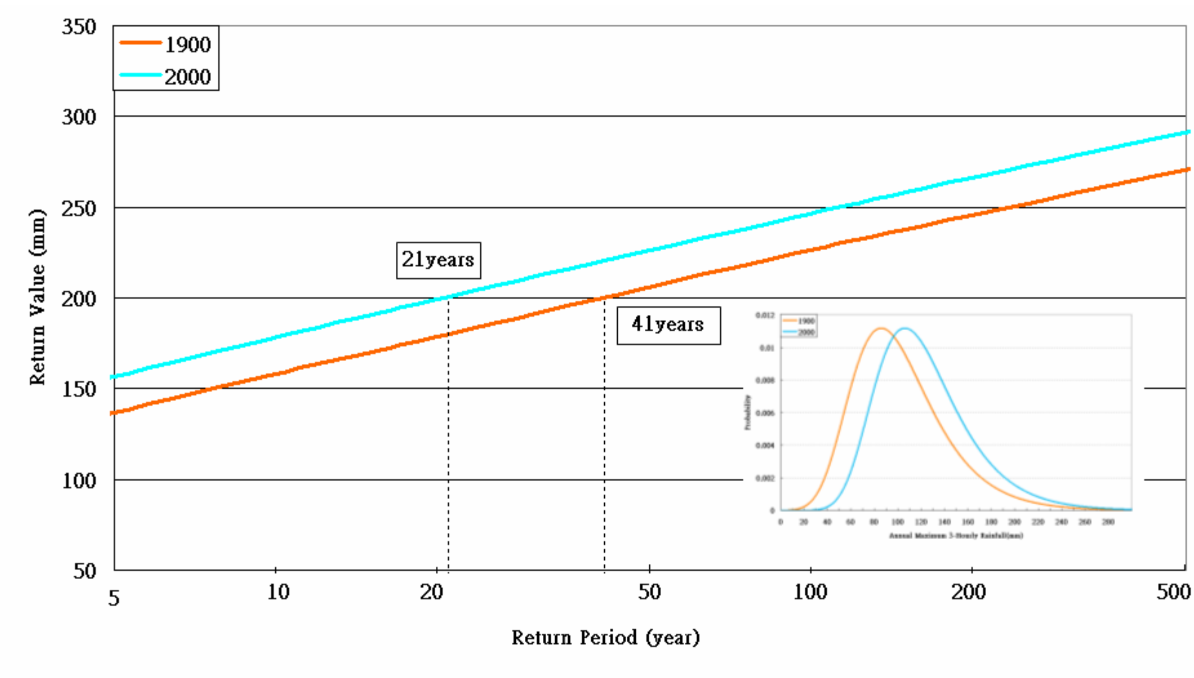

Figure 2.4(c). Return periods for annual maximum three-hourly rainfalls in 1900 and 2000 (the insert shows the GEV pdf for annual maximum three-hourly rainfalls in 1900 [brown line] and 2000 [blue line])

(f) Trends in the annual number of tropical cyclones within 100-300 km of Hong Kong

Figure 3.1(a) and 3.1(b) show the variations of the annual numbers of tropical cyclones of any intensity and annual numbers of typhoons passing within 100, 200 and 300 km of Hong Kong from 1961 to 2008 respectively. No significant trends (at 5% level) were observed.

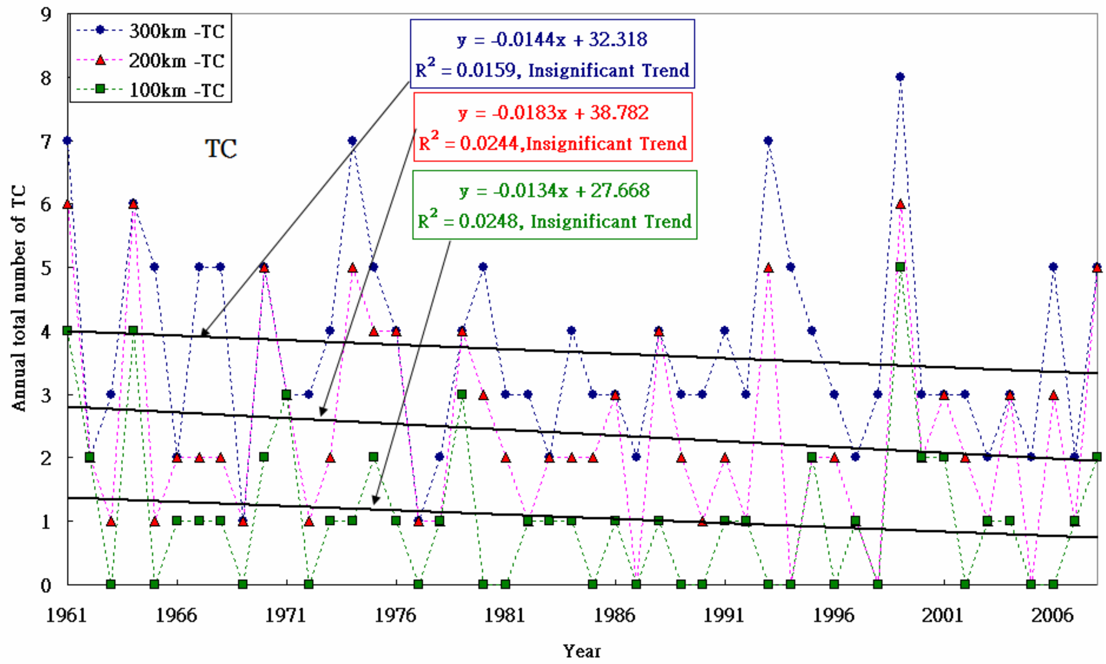

Figure 3.1(a). Time series of the annual number of tropical cyclones of any intensity passing within 100, 200 and 300 km of Hong Kong (1961-2008)

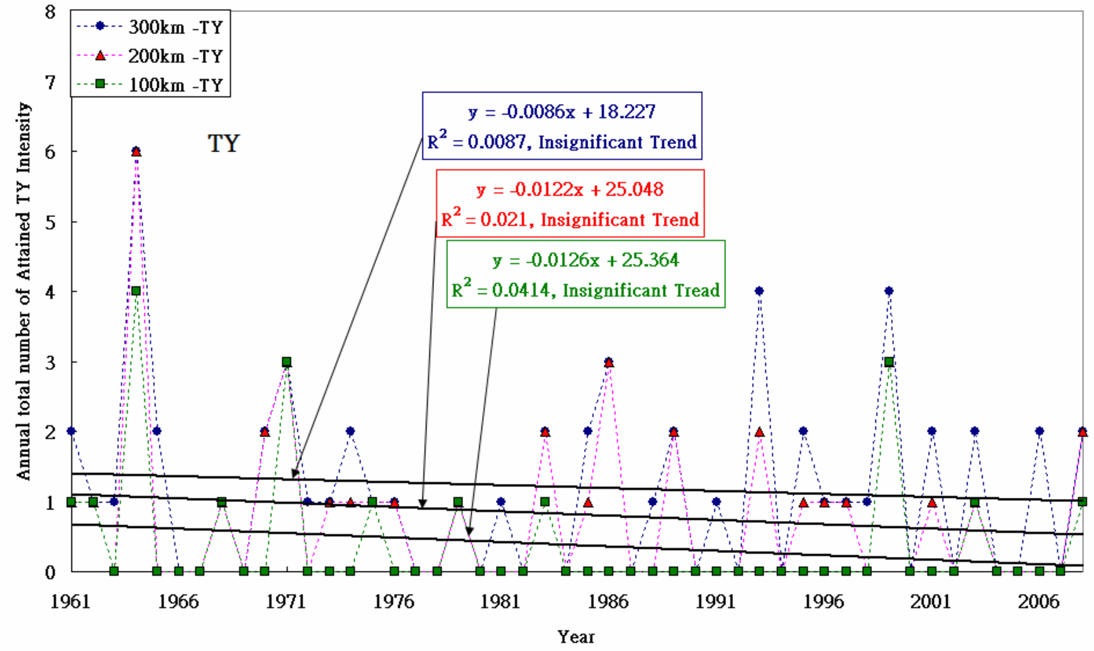

Figure 3.1(b). Time series of the annual number of typhoons passing within 100, 200 and 300 km of Hong Kong (1961-2008)

(g) Trends in winds at Waglan Island and Kai Tak

Figure 3.2(a), 3.2(b), 3.2(c) and 3.2(d) show the variation of the annual maximum U_{10} at Waglan Island, annual maximum U_g at Waglan Island, annual maximum U_{10} at Kai Tak and annual maximum U_g at Kai Tak respectively. Both annual maximum U_{10} and annual maximum U_g at Waglan Island decreased with time but the decreasing trends were insignificant at 5% level. On the other hand, annual maximum U_{10} and the annual maximum U_g decreased with time significantly at 5% level at Kai Tak. The rates of decrease were 1.9 and 2.5 m/s per decade respectively.

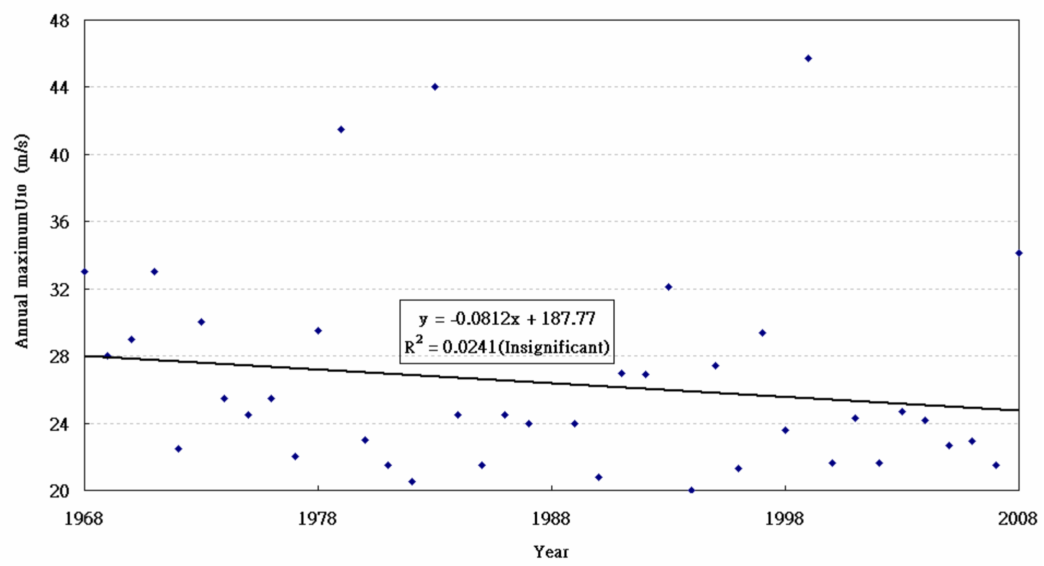

Figure 3.2(a). Time series of annual maximum U_{10} at Waglan Island (1968-2008)

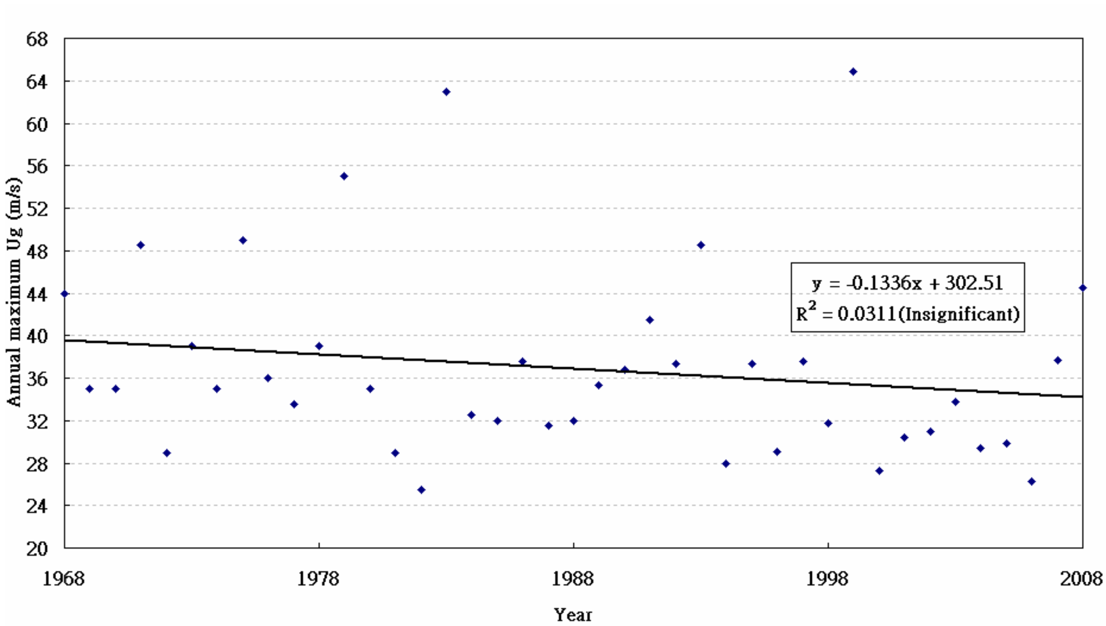

Figure 3.2(b). Time series of annual maximum U_g at Waglan Island (1968-2008)

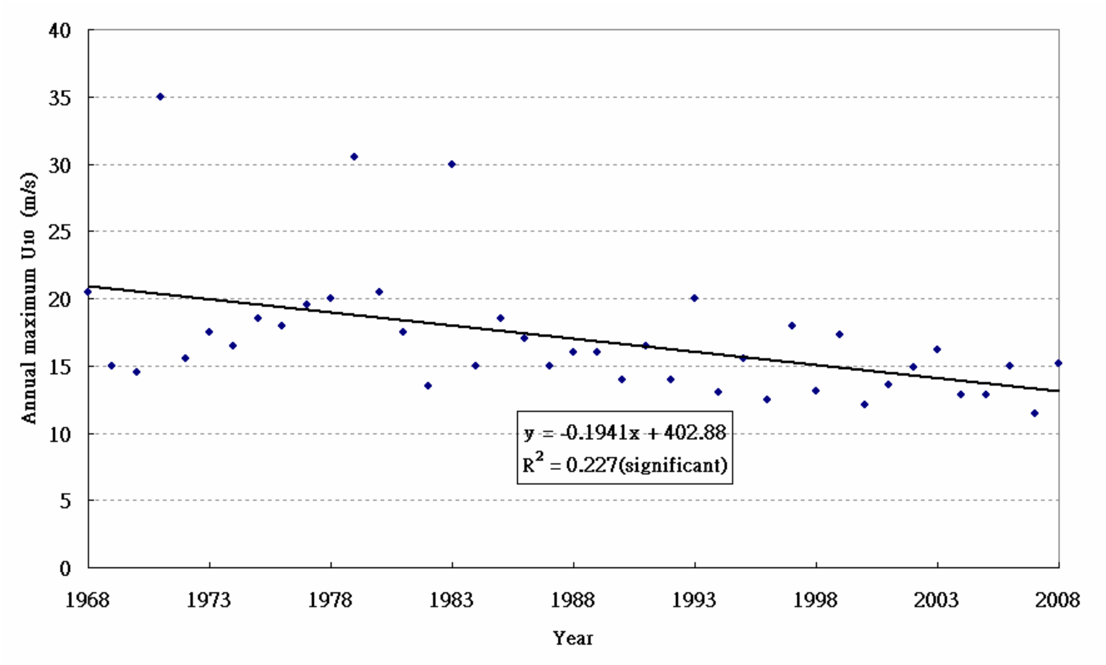

Figure 3.2(c). Time series of the annual maximum U_{10} at Kai Tak (1968-2008)

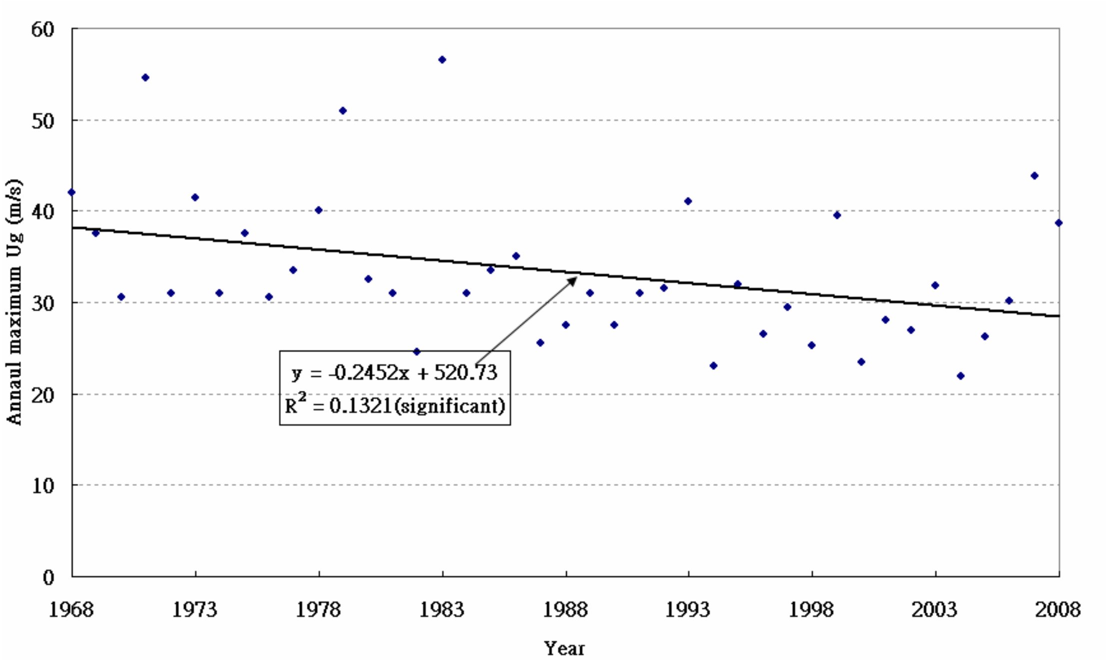

Figure 3.2(d). Time series of annual maximum U_g at Kai Tak (1968-2008)

Table 3 shows the results of the likelihood ratio tests for the significance of time-dependency of the three parameters μ, σ and ξ for the GEV distributions for annual maximum U_{10} and annual maximum U_g at Waglan Island and Kai Tak from 1968 to 2008. The time variations of the GEV distributions of the extremes values of these two wind parameters at Waglan Island were insignificant while those at Kai Tak were significant.

Table 3. Significance of time-dependency of the three parameters μ, σ and ξ for the GEV distributions for annual maximum U_{10} and annual maximum U_g at Waglan Island and Kai Tak from 1968 to 2008

Weather elements	**Significance of time-dependency**		
	μ	σ	ξ
Annual maximum U_{10} at Waglan Island	No	No	No
Annual maximum U_g at Waglan Island	No	No	No
Annual maximum U_{10} at Kai Tak	Yes	No	No
Annual maximum U_g at Kai Tak	Yes	No	No

Figure 3.3(a) and 3.3(b) show the long term trends of the 10-year, 20-year and 50-year return values of annual maximum U_{10} and annual maximum U_g at Kai Tak from 1968 to 2008 respectively. The return values for fixed return periods for annual maximum U_{10} decreased by about 0.9 m/s per decade and that for the annual maximum U_g decreased by about 2.2 m/s per decade. Both trends were statistically significant at 5% level.

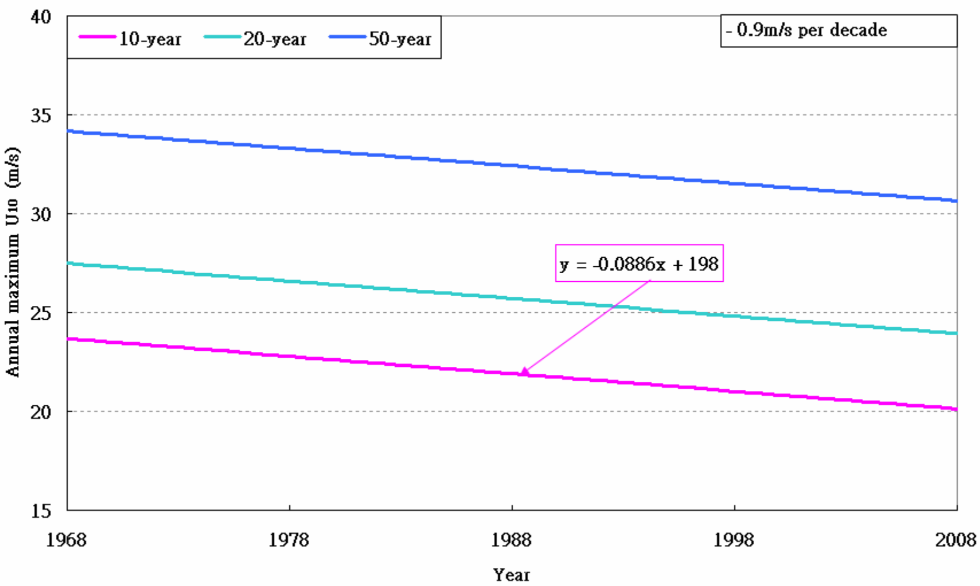

Figure 3.3(a).Long term trends of return values for the annual maximum U_{10} at Kai Tak with return periods of 10-year, 20-year and 50-year respectively (1968-2008)

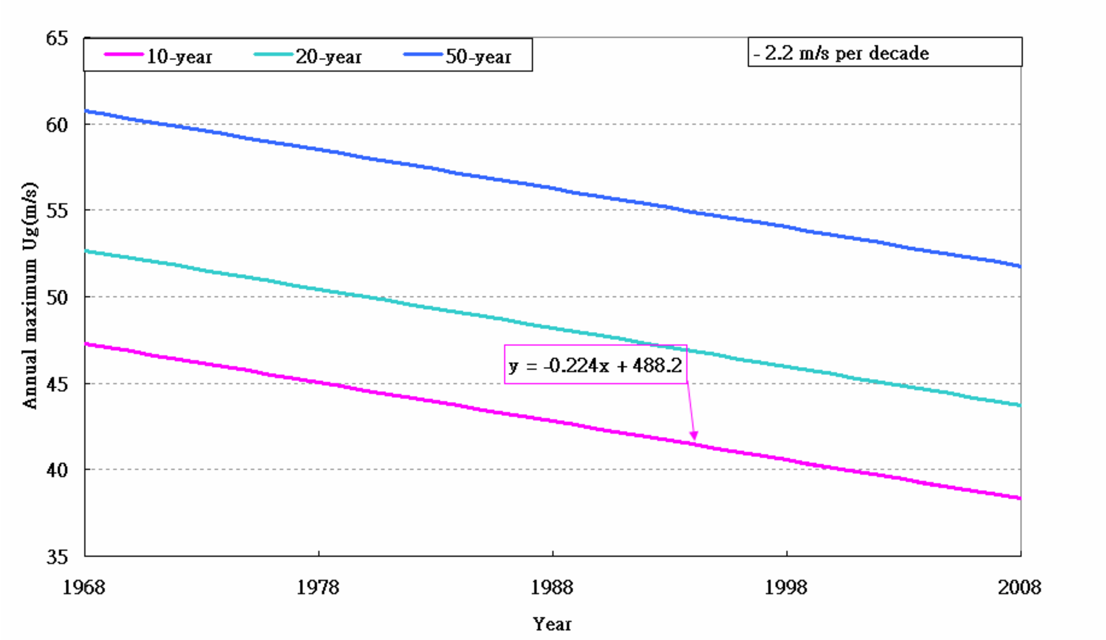

Figure 3.3(b). Long term trends of the return values for the annual maximum U_g at Kai Tak with return periods of 10-year, 20-year and 50-year respectively (1968-2008)

Figure 3.4(a) and 3.4(b) show the plots of return values against return periods in 2008 for annual maximum U_{10} and annual maximum U_g at Waglan Island respectively. The GEV pdf for the extreme values of these two wind speed parameters in 2008 are also shown in the figures. The return values of 50-year return period for annual maximum U_{10} and annual maximum U_g at Waglan Island in 2008 were 42.7 m/s and 60.7 m/s respectively.

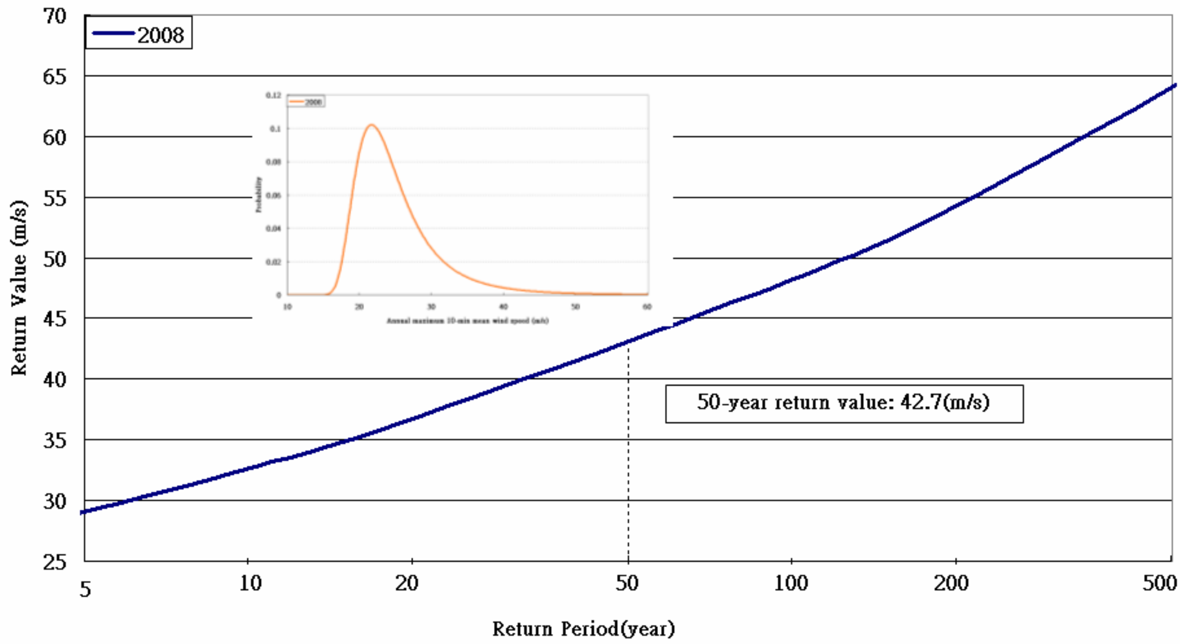

Figure 3.4(a). Return values for annual maximum U_{10} at Waglan Island in 2008 (the insert shows the GEV pdf for annual maximum U_{10} at Waglan Island in 2008)

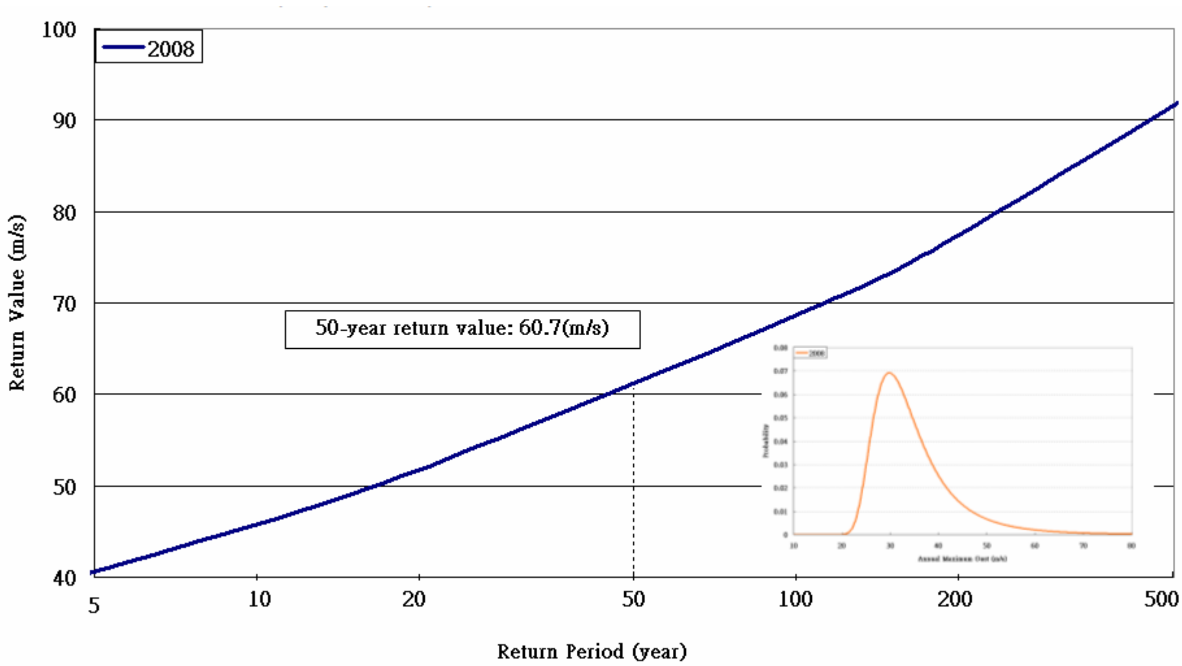

Figure 3.4(b). Return values for annual maximum U_g at Waglan Island in 2008 (the insert shows the GEV pdf for annual maximum U_g at Waglan Island in 2008)

Figure 3.4(c) and 3.4(d) show the plots of return values against return periods in 1968 and in 2008 for annual maximum U_{10} and annual maximum U_g at Kai Tak respectively. The GEV pdf for these two wind speed extremes in these two years are also shown in the figures. The two GEV pdf in 2008 were at lower wind speed range than in 1968. The return value of 50-year return period for annual maximum U_{10} decreased from 34.2 m/s in 1968 to 30.6 m/s in 2008. For annual maximum U_g, the return value of 50-year return period decreased from 60.8 m/s in 1968 to 51.7 m/s in 2008.

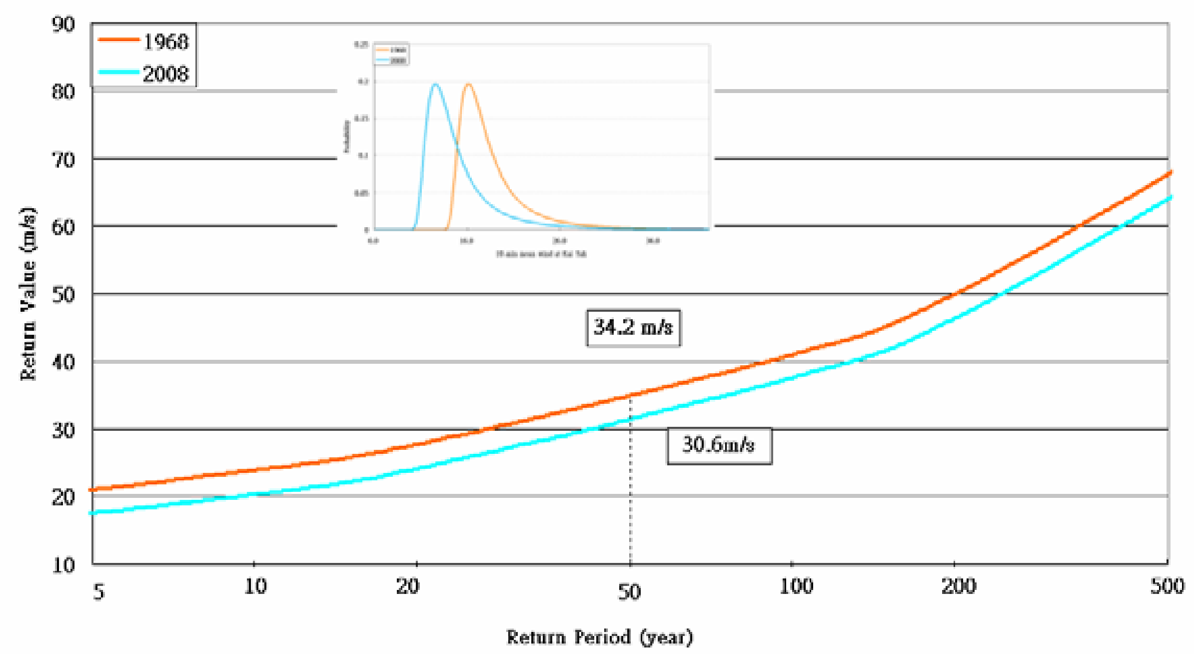

Figure 3.4(c). Return values for annual maximum U_{10} at Kai Tak in 1968 and 2008 (the insert shows the GEV pdf for annual maximum U_{10} at Kai Tak in 1968 [brown line] and 2008 [blue line])

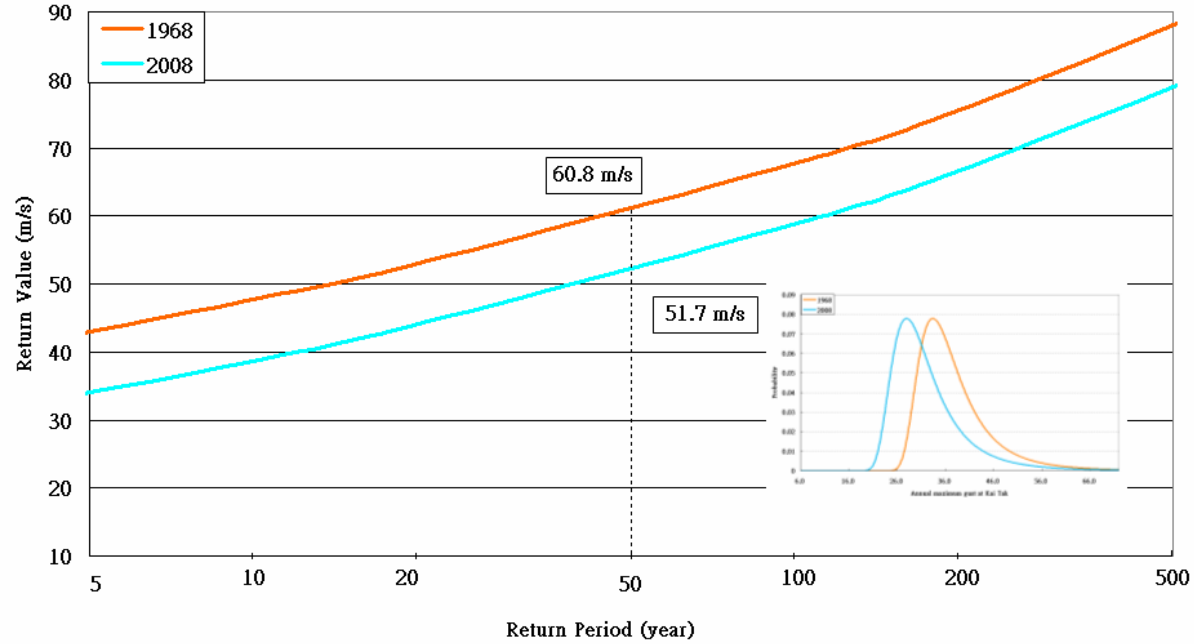

Figure 3.4(d). Return values for annual maximum U_g at Kai Tak in 1968 and 2008 (the insert shows the GEV pdf for annual maximum U_g at Kai Tak in 1968 [brown line] and 2008 [blue line])

CONCLUSIONS

Similar to the observations in previous analyses (Leung *et al* 2004; Lam 2006), this study found that the annual numbers of cold days and hot nights in Hong Kong increased from 1885 to 2008 with faster increasing rates after the World War II. The return period for T_{min} $\leqq$ 4.0 °C had lengthened from 6 years in 1900 to 163 years in 2000. On the other hand, the return periods for a T_{min} $\geqq$ 30.0 °C and a T_{max} $\geqq$ 35.0 °C shortened from > 100 and 32 years in 1900 to 51 and 4.5 years in 2000 respectively.

The *HDD* had decreased by 12°C per decade while the *CDD* had increased by 14°C per decade from 1885 to 2008.

There was also an observed increase in the frequency of occurrence of heavy rain days in Hong Kong since 1885. The annual number of days with an hourly rainfall exceeding 30 millimetres increased by 0.2 days per decade from 1885 to 2008 with faster increasing rate of 0.5 days per decade from 1947 to 2008. The return periods for 1, 2 and 3-hourly rainfall had decreased significantly from 1885 to 2008. The return period for 1-hourly rainfall $\geqq$ 100 millimetres had shortened from 37 years in 1900 to 18 years in 2000.

No significant trends in the annual number of tropical cyclones of any intensity and annual number of typhoons passing within 100, 200 and 300 killometres of Hong Kong from 1961 to 2008 were observed. No significant trends were also observed in the annual maximum 10-minute mean wind speeds on the hour and annual maximum 1-second gusts at Waglan Island from 1968 to 2008. On the other hand, the annual maximum 10-minute mean wind speed on the hour and annual maximum 1-second gust at Kai Tak showed significant decreasing trends and the return periods for extreme values of these two wind speed parameters there had lengthened in the same period. This phenomenon may be attributed to the effect of urbanization with the increasing number of high-rise buildings in urban areas.

REFERENCES

Coles, S.G. (2001). *An Introduction to Statistical Modeling of Extreme Values.* Springer-Verlag, London.

Cox, D.R., and D.V. Hinkley. (1974). *Theoretical Statistics*. Chapman and Hall, 511.

Feng, S., Nadarajah, S., and Hu, Q. (2007). "Modeling Annual Extreme Precipitation in China Using the Generalized Extreme Value Distribution." *Journal of the Meteorological Society of Japan*, 85, No.5, 599-613.

Fisher, R.A., and Tippett, L.H.C. (1928). "Limiting forms of the frequency distribution of the largest or smallest member of a sample.” *Proc., Cambridge Philosophical Society*, 24, 180-290.

Gumbel, E.J. (1958). *Statistics of Extremes*. Columbia University Press, 375.

Hui, Sam C.M., and Tsang, M.F. (1995). “Climatic Data for Sustainable Building Design in Hong Kong.” *Proc Joint Symposium 2005: New Challenges in Building Services*, Hong Kong SAR.

Jenkinson, A.F. (1955). “The frequency distribution of the annual maxima (or minima) values of meteorological elements.” Quart. J. Roy. Meteor. Soc., 81, 158-171.

Kharin, V.V., and Zwiers, F.W. (2005). “Estimating Extremes in Transient Climate Change Simulations.” Journal of Climate, 18, 1156-1173.

Lam, J.C. (1995). “Degree-day climate parameters for Hong Kong.” International Journal of Ambient Energy, 16,209-18.

Lam, C.Y. (2006). “On Climate Changes Brought About by Urban Living.” Hong Kong Meteorological Society Bulletin, 16(1/2), 15-20.

LeDuc, S.K., and Stevens, D.G.. (1977). “Maximum Likelihood Estimates for Parameters of the m^{th} Extreme Value Distribution.” Journal of Applied Meteorology, 16, 251-254.

Leung, Y.K., Yeung, K.H., Ginn, E.W.L., and Leung,W.M. (2004). “Climate Change in Hong Kong.” *Technical Note* No. 107, Hong Kong Observatory.

中華人民共和國住房和城鄉建設部 (2005) - 夏熱冬冷地區居住建築節能設計標準.

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