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台灣地區現代氣溫上昇現象與全球溫暖化比較的研究*

A Study of the secular temperature increase in Taiwan compared with global warming*

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摘　要

本文藉台灣中央氣象局的五個氣象站的月均溫與年均溫資料，來分析台灣地區現代（1897-1997）氣溫變化趨勢，並與同期的世界氣溫變化趨勢進行比較。

本文首先檢定各站氣象資料序列的一致性程度，然後以低通濾波、趨勢分析、頻譜分析、主成分分析等統計方法，來探討台灣地區的現代氣溫變化趨勢。

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分析結果顯示在現代（1897-1997），五個氣象站的所錄得的氣溫均有明顯的上昇趨勢，其中以夏季氣溫的上昇最爲強烈。

五個氣象站的氣溫資料在透過主成分分析後，可降維爲一個由筆者命名爲「全台灣氣溫序列」（all Taiwan temperature series）的主成分，此主成分所代表的台灣地區現代（1897-1997）的氣溫上昇趨勢是甚爲明顯的，達1.14℃，較同時期全球氣溫的上昇值高出0.60℃，約爲全球氣溫上昇值的兩倍。

在台灣地區的現代氣溫上昇趨勢中，有些時期的氣溫變化週期與艾尼紐／南方振盪及準二年振盪（QBO）具有遙相關。

Abstract

Monthly temperature data of five meteorological stations under the Central Weather Bureau of Taiwan were analysed over the longest available observation period (101 years, 1897-1997), aiming to detect recent temperature changes in Taiwan and to compare the observations with global warming. After testing the homogeneity of the data series, different statistical methods, such as low-pass filtering, trend analysis, spectral analysis, and principal component analysis, were applied to analyse recent temperature changes in Taiwan. As a result, temperatures have strikingly increased at all five stations over the secular period. Season-wise, the strongest increase was observed during summer.

An "All-Taiwan Temperature Series" was constructed to have a long and reliable area mean temperature time series for whole Taiwan applying principal component analysis. Notably to see is the strong and significant temperature increase of 1.14 °C over the period 1897-1997, whereas the global temperatures show an increase of only 0.60 °C over the same period. Most strikingly to note that temperatures in Taiwan have increased double compared with global warming.

Over the whole observation period also some regular fluctuations of temperature were detected which can be related to the teleconnection El Niño/Southern Oscillation phenomenon and the quasi-biennual-oscillation.

Introduction

Global change has reached a critical magnitude with a serious impact on society, human welfare and quality of life to human being. Taking into account the complex nature of the glob-

al change issue, climate change must be regarded as the influenced factor of it. A large amount of studies give clear evidence of the fact that climatic change has rapidly developed over the past 100 years showing, on a global scale, an increase of surface temperature between 0.3 and 0.6 °C (HOUGHTON et al., 1990 and 1992). Due to its great societal impact, the change of temperature needs more attention in regional as well as seasonal scales.

So far, only some studies have been carried out about recent climate changes in Taiwan (CHENG et al., 1993, 1995 and 1996; LIU et al., 1996; TSUANG et al., 1996; WU et al., 1994). Therefore the question remains open whether climate change has occurred in Taiwan or not and whether it corresponds with global warming or not. This study deals with the change of temperature in order to verify its magnitude in annual and seasonal respects. The aims of the study are as follows:

(1) to detect temporal characteristics of recent temperature changes in Taiwan;

(2) to compare the temperature trends in Taiwan with global warming.

Data

Monthly temperature records were analyzed for five stations under the Central Weather Bureau of Taiwan over the longest period available covering a 101 years unbroken period from 1897 to 1997 (Table 1, Figure 1).

Table 1: Stations under study with their latitude, longitude and elevation

表一　本研究所選用測站的空間位置與海拔高度

No.	Station	Latitude North	Longitude East	Elevation m
1	Taipei	25.03	121.50	5
2	Tainan	23.00	120.20	14
3	Taichung	24.15	120.68	84
4	Hengchun	22.00	120.73	22
5	Penghu	23.57	119.55	11

In order to detect the annual and seasonal characteristics of temperature trends, the corresponding means were computed. Seasons were defined as follows:

- winter: December — February
- spring: March — May

- summer: June — September
- autumn: October — November.

The reference data of the global temperature anomalies were taken from JONES (1999).

Methods

Detecting the temporal characteristics of temperature changes in Taiwan, various statistical methods of time series analyses were applied; all methods are approved by climate change scientists.

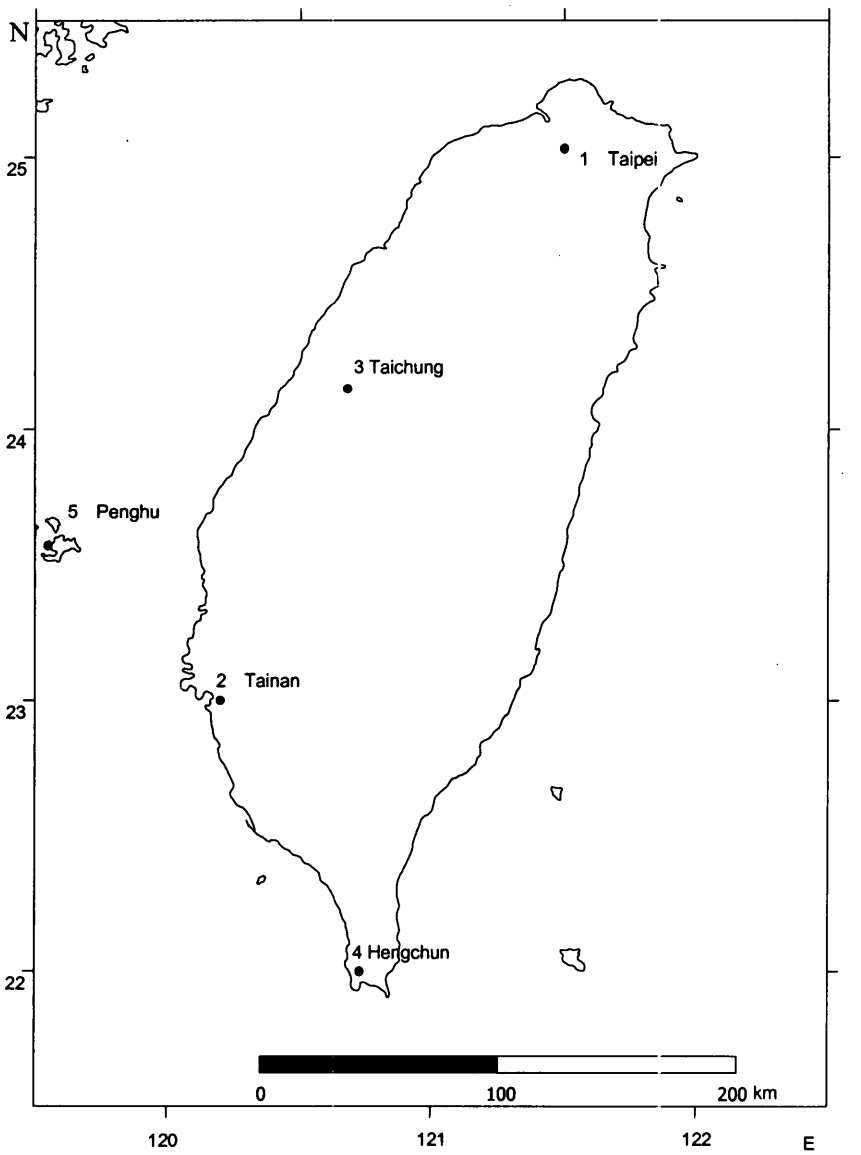

Figure 1 : Map of Taiwan showing the location of the stations under study

圖一 本研究所選用測站的空間分布圖

· Test of homogeneity

Data series were first checked for any inhomogeneities which may be caused by station moves, or the alteration of instruments or even changing of observation methods. Such reasons may cause irregular trends and superpose the real features of temperature trends. To study the station history is commonly considered as the most reliable method for homogeneity test. As a strong statistical approach, the homogeneity test of data series was carried out by applying the ABBE-test, emphasized by the World Meteorological Organisation (1966). Finally, the data series were also plotted in graphs for a visual check of outliers or typing errors.

· Gaussian low-pass filter

The monthly data series were smoothed with the Gaussian binominal low-pass filter in order to suppress the short-term fluctuations or high-frequency oscillations. This filter emphasized by the World Meteorological Organisation is applied over 10 years referring to annual and seasonal temperature data.

· Trend analysis computation

In order to detect trends of the temperature series and to compare the results with global warming linear regression equations (least squares) were computed individually for the time series of each station. The regression coefficients are given in ° C and their statistical significance was tested with the help of the trend-to-noise ratio (t/n). Additionally, a non-parametric, non-linear trend test after MANN was applied to detect every trend in the time series no matter what form it has. The computed MANN ' s Q-values together with the t/n-ratios can be taken as measures of significance of the linear trend; values >1.96 can be regarded as significant trend at a 95 %-level of confidence (for details see SCHAEFER, 1996). Lower values express a less significant level of confidence:

t/n-ratio, Q-values	2.58	1.96	1.65	1.28	1.04	0.84	0.67
Level of confidence	99%	95%	90%	80%	70%	60%	50%

Linear trends as well as non-linear trends were computed for the annual and seasonal temperature means over the period under study.

· Power spectrum analysis

Spectral methods were applied on the time series in order to study any temperature cycles

or periodicities (for details see SCHAEFER, 1996):

(1) the Autocorrelation Spectral Analysis (ASA) according to BLACKMAN and TUCKEY (1958),

(2) the Maximum Entropy Spectral Analysis (MESA) with the algorithms according to JUNK (1982).

Both methods can be combined in order to achieve reliable results on significance and spectral resolution of power spectrum.

· Principal component analysis

An "All-Taiwan Temperature Series" (ATTS) was constructed to have a long and representative area mean temperature time series for whole Taiwan applying principal component analysis (PCA). This temperature series can be compared and discussed with global temperature anomalies according JONES (1999). PCA is a useful and commonly applied tool in climatology: A large data matrix can be reduced to some important factors (Principal Components, PCs) which can be physically interpreted (SCHAEFER, 1996; 1998). Aim of constructing an area mean temperature time series of Taiwan is to calculate an objective temperature series which can be regarded as representative for whole Taiwan enabling to analyse trends, variabilities and periodicities.

Results

· Test of homogeneity

Firstly, the station history was studied; the site of each station is shortly described as follows:

Taipei station was established in 1896 within the Central Weather Bureau complex located at the fringe of Taipei. Due to the high urbanisation over recent decades, the land surface is fully cemented and densely-crowded by buildings and therefore more influenced by the urban heat island effect. Under the extension scheme (1992-1997) of the Central Weather Bureau complex, the station has been transferred to the campus of the Taipei Normal College.

Taichung station, located in Taichung city, was established in 1896, while Tainan station, in Tainan city, was set-up in 1897. Both stations were initially situated at the fringe of the town, but now they are also surrounded by highly commercialized and residental buildings.

Penghu station is set up at the biggest of the Penghu Islands that are located in the middle

of the Taiwan Strait, about 56 km off the main Taiwan island. Penghu Islands are still a rural environment and have also little variation of the relief, so that the station truly represents all of the Penghu islands. Weather recordings have, however, changed from manual to automatic readings in 1982. Hengchun station has since 1896 its original site east of Hengchun town which is located on the southern tip of Taiwan.

From a careful check of the station history, no inhomogeneities of the data series under study were observed. Temperature records of all five stations represent unbroken time series and the visual check of the plotted graphs of data series showed no inhomogeneities. According to the statistical ABBE-test of homogeneity all data series are homogeneous over the whole observation period.

· Annual and seasonal trends

In order to study the long-term trends and variabilities of annual and seasonal temperatures, the linear trends were computed for each of the five stations. Additionally, the non-linear trend test by MANN was also applied.

As far as the long-term trend of the annual temperature is concerned, all five stations show remarkably increasing temperatures over the 101 years observation period (Table 2). Annual temperatures increase between 0.92 °C and 1.36 °C indicating a much larger magnitude compared to the global annual mean of 0.60 °C (see also Table 5). The large annual temperature increase in Taiwan is underlined by the high significance at a 95 % level of confidence expressed by t/n ratios distinctly >1.96 . Consequently, the computed trends of the annual temperature increase are linear at all stations. The trend values of the non-linear MANN test are also very high (>1.96) indicating positive and significant trends of annual temperature at all stations.

Table 2: Trend computations of annual temperatures in Taiwan (1897-1997).

表二 台灣地區五個測站年均溫的趨勢分析（1897-1997）

Station	Trend [°C]	t/n	MANN's Q
Taipei	1.27	2.54	8.27
Tainan	1.36	2.55	8.07
Taichung	1.16	2.42	7.56
Hengchunn	0.92	2.12	6.21
Penghu	1.02	2.21	6.71

As far as the secular trends for the individual seasons are concerned, the observations differ (Table 3). Though positive trends of warming consistently prevail, seasonal differences must nevertheless also be taken into consideration. It can be followed that the largest temperature increase occurs over the secular time series in summer showing, at the same time, the highest significance. Ranking second, autumn also demonstrates a large increase of temperature though the trends at the various stations are less significant than in summer. From the magnitude of warming, spring ranks third and winter forth with the lowest (but still positive) trend at a however lesser significant level.

Such observations clearly explain that summer (and autumn) are the largely controlling season(s) for the annual temperature increase in Taiwan. Seasonal observations are, however, controversial for Taiwan compared with global warming observations that clearly identify winter warming as the main reason for the annual temperature increase.

Concerning the seasonal trends only the trends for the summer temperatures are linear (t/n-values >1.96); however, the trends for all seasons are significantly positive because of the high values of MANN ' s Q (>1.96).

Table 3: Trend computations of seasonal temperatures
at five selected stations in Taiwan (1897-1997)

表三　台灣地區五個測站各季氣溫的趨勢分析（1897-1997）

Station	Trend [°C]	t/n	MANN's Q	Station	Trend [°C]	t/n	MANN'sQ
Winter				Summer			
Taipei	1.05	1.27	3.94	Taipei	1.33	2.27	7.11
Tainan	0.84	0.97	2.89	Tainan	1.56	2.74	8.93
Taichung	0.92	1.07	3.37	Taichung	1.20	2.31	7.35
Hengchun	0.57	0.81	2.43	Hengchun	1.04	2.26	6.93
Penghu	0.62	0.79	2.23	Penghu	1.50	2.54	8.19
Spring				Autumn			
Taipei	1.30	1.67	4.99	Taipei	1.51	1.75	5.49
Tainan	1.63	1.87	5.34	Tainan	1.30	1.69	5.46
Taichung	1.19	1.58	4.58	Taichung	1.40	1.65	5.03
Hengchun	0.96	1.45	4.24	Hengchun	1.14	1.93	6.08
Penghu	1.21	1.72	4.91	Penghu	1.37	2.04	6.47

Periodicities

In order to detect any periods or quasi-periods during the whole period, two methods of power spectrum (ASA, MESA) were applied. Some periods were detected which can be related to the well-known teleconnection El Nino/Southern Oscillation-phenomenon (ENSO), with periods between 3.0 and 8.0 years. In addition, also the signals of the Quasi-Biennual-Oscillation (QBO) with periods of 2.0 to 2.7 years were detected in the series. Notably, the 11-year sunspot-cycle cannot be found in the temperature series of Taiwan.

Construction of an All-Taiwan Temperature Series

PCA was applied to construct an "All-Taiwan Temperature Series" for annual and seasonal temperatures. The time series of annual and seasonal temperatures at all five stations were taken to build the data matrix (101*5): 101 cases which correspond to the temperature values, and five variables, corresponding to the five stations. After standardization of the values the correlation matrix was built and applied for PCA. All stations are well correlated ($v \geq 0.8$) and therefore only one PC was extracted that explained about 90 % of the total variance. The first PC describes the inter-annual temperature variability over Taiwan. The PC-values were constructed applying a multiple regression equation. After a back-transformation of the standardized PC1-values, the annual temperature values were taken as All-Taiwan Annual Temperature Series.

All five stations are highly correlated and therefore the computed trends show comparable values: Over the whole period a highly increasing and significant linear trend of warming of 1.14 ° C can be detected (Table 4). Increasing trends can also be identified for the seasons, but only the trend of summer temperature is linear while the trends for the other seasons are, however, increasing and significant, but not linear (Table 4).

Table 4: Computed trends of "All-Taiwan Temperature Series" in °C (1897-1997)

表四 主成分：「全台氣溫序列」的年均溫與月均溫的趨勢分析（1897-1997）

	Trend	t/n	MANN's Q
Annual	1.14	2.54	7.98
Winter	0.79	1.09	3.55
Spring	1.16	1.73	5.08
Summer	1.13	2.61	8.38
Autumn	1.20	1.76	5.55

Global temperature anomalies

Annual as well as seasonal global temperatures have increased linear and significantly during the observation period (1897-1997) at a rate of about 0.6 °C (Table 5).

Table 5: Computed trends of the global temperature anomalies (1897-1997).

表五 全球(1897-1997)年均溫及月均溫的趨勢分析

	Trend [°C]	t/n	MANN's Q
Annual	0.60	2.77	9.13
Winter	0.60	2.43	7.48
Spring	0.64	2.70	8.89
Summer	0.56	2.67	8.72
Autumn	0.59	2.60	8.47

Annual and seasonal temperatures are also given in graphs along with the 10-year Gaussian binominal low-pass filtered curves and the linear trends of temperature, resulting from the regression analysis trends over the whole period (Figure 2). In the figure the annual and seasonal development of the All-Taiwan Temperature Series (ATTS) can be directly compared with the global trends (GTA). The annual and seasonal trends of ATTS show strongly increasing values that are more striking than the trends of the global temperature anomalies. Notably, the inter-annual variability of ATTS is distinctly greater than for GTA, especially in winter. A higher inter-annual variability expresses a higher statistical noise and a lower significance of the trends.

Discussion and conclusion

Monthly temperature data for all five stations in Taiwan can be taken as homogeneous over the 101-years observation period (1897-1997). The data series were analyzed for detecting temperature trends applying different statistical methods. For a comparison on global scale, the results of temperature change in Taiwan were compared with global temperature trends, showing similarities and differences between the temperature trends in Taiwan and on a global scale.

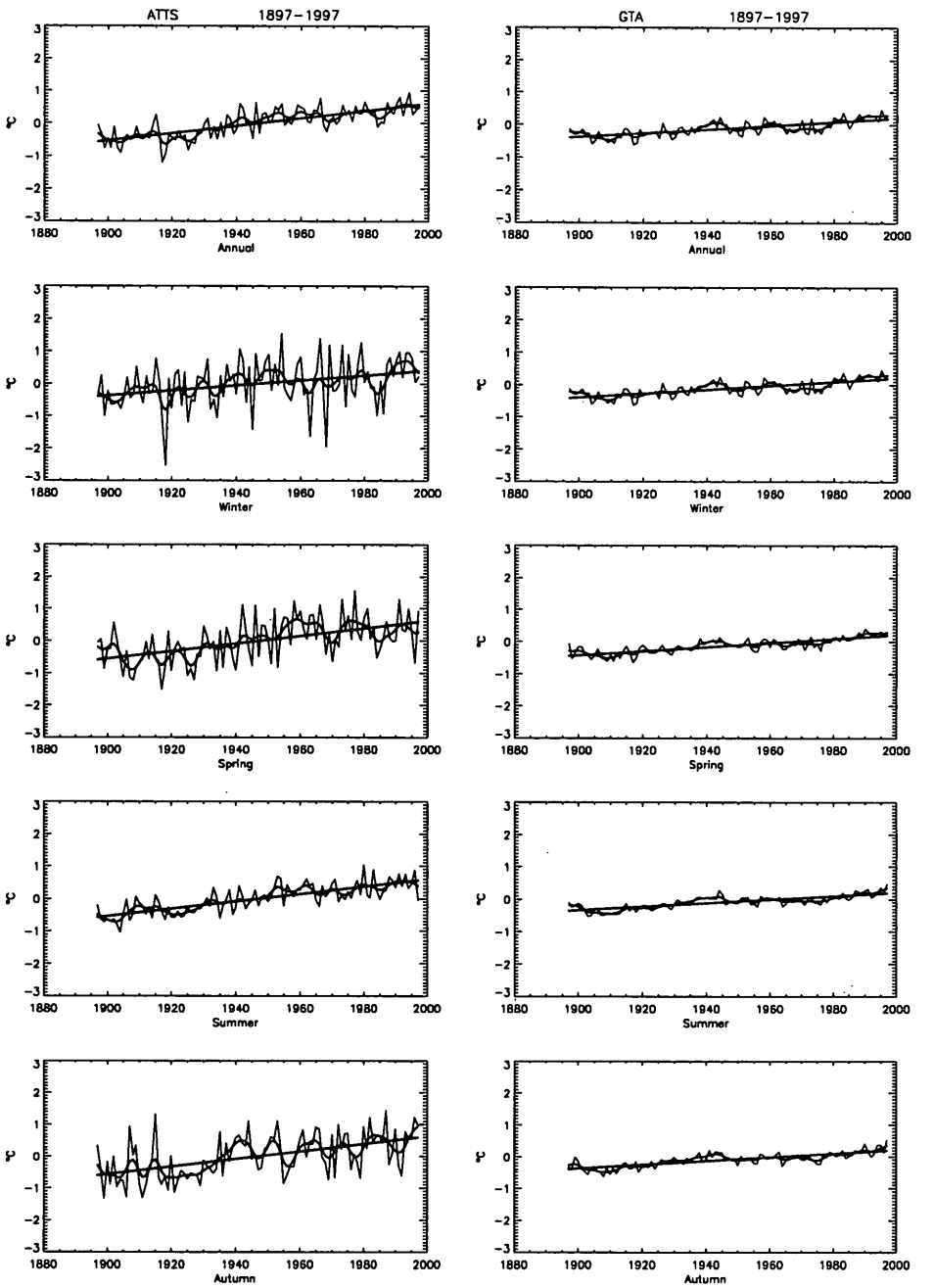

Figure 2: The "All-Taiwan Temperature Series" (left) and the global temperature anomalies (right); annual and seasonal means, respectively. Actual data (thin line) along with 10-years GAUSSian filtered values (smoothed curve) and the trend line (straight line).

圖二 「全台氣溫序列」（左）與全球氣溫變化（右）的月與年平均：實際數值（細線），10年高斯濾波值（平滑化曲線），趨勢線（直線）

Annual temperatures indicate strong warming trends at all stations in Taiwan, varying between 0.92 and 1.36 °C. The computed trends are distinctly higher than the observed global warming at a rate of 0.60 °C. The temperature series are well correlated expressing strong warming trends at all stations. These observations underline the homogeneity and reliability of the data series under study.

Opposite to the global temperature trends, the trend of annual warming in Taiwan is mainly due to the strong increase of summer temperatures. On a global scale the highest increasing trends were observed in winter.

The constructed "All-Taiwan Temperature Series" that explains about 90 % of the observed inter-annual variability can be taken as a reliable series to analyze recent temperature changes in Taiwan. ATTS shows strong increasing trends for the annual and seasonal temperatures validating the results of the analysis of all five stations. Annual temperature in Taiwan increased at a rate of 1.14 °C, while the global temperature shows an increase of only 0.60 °C. Temperatures in Taiwan therefore increased double compared with global warming.

The inter-annual variabilities at all five stations as well as of ATTS are remarkably higher than the global temperature anomalies, with the highest variability in winter and the lowest in summer.

Some periodicities were detected in the ATTS which can be related to the ENSO-phenomenon and QBO. As a result, temperatures in Taiwan are higher in El Nino-years, colder in La Nina-years. These relationships correspond with global observations though the 11-years sunspot-cycle cannot be found in the temperature series of Taiwan.

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