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Urbanization-induced Regional Climate Change on the Western Plain of Taiwan for the Period 1964~1999

WEN-ZER LIN [a,*], HSIAO-CHUNG TSAI[b], CHUNG-HO WANG[c], WEI-HSIEN TENG[d]
[a] Research Center for Environmental Changes, Academia Sinica, NanKang,
Taipei, TAIWAN 11517, R.O.C.
[b]Department of Civil Engineering, National Taiwan University,
Taipei, TAIWAN 10617, R.O.C.
[c]Institute of Earth Science, Academia Sinica, NanKang,
Taipei, TAIWAN 11517, R.O.C.
[d]Department of Architecture, National United University,
Miaoli, TAIWAN 36017, R.O.C.
http://www.rcec.sinica.edu.tw

Abstract: Time-series study on anomaly of urban heat island intensity (referred as UHI) for four urban-rural pairs in the western Taiwan has been performed from 1964-1999 to evaluate the effect due to rapid urbanization. The monthly average changes are 0.003 °C, -0.0002 °C, -0.001 °C, and -0.002 °C for Taipei-Tamshui, Taichung-Chinchuankang, Tainan-Tainan Airport, and Kohsiung-Shiaokang Airport, respectively for the past 36 years. The negative tendency for the southern part of western Taiwan indicates that rural sites are developing rapidly during the study period. The Mann–Kendall trend test is applied to annual surface temperature records of these four stations. Results clearly show that significant regional climate changes are observed for all four stations. The apparent climate changing is estimated to begin at around 1980. Seasonal analyses on monthly averages of maximum daily UHI intensity suggest that regional warming is strongest in summer for Tainan-Tainan Airport pair whereas in winter and spring for other station pairs.

Key-Words: Regional climate change, UHI intensity, Urbanization, Mann–Kendall trend test

1. Introduction

Regional or local climate is generally much more variable than that on a hemispheric or global scale because variations in one region are usually compensated by opposite variations elsewhere. Nonetheless, a proportion of the 0.5 °C warming seen over the last century for the earth surface may be directly related to urbanization influences [11, 15]. Climate variability patterns result from interactions among the atmospheric circulation, land and ocean surfaces [7]. Ichinose [6] pointed out that urbanization in past four decades has weakened the daytime penetration of sea wind around a big city thus resulting regional warming. Taiwan is located at the rim between the world of largest landmass and largest ocean. Its subtropical to tropical oceanic setting characterizes a climate of high temperature and rainfall with strong monsoons. Taiwan has created an "economic miracle" that has caught the attention of the world, but its energy usage per person also reaches to the highest level among countries with population over 10 millions. Urbanization has been rapidly increased in Taiwan since 1972 along with highly developed industry and large density of population that have turned the Western Plain of Taiwan into a mega-suburb with countless cities, small towns, factories, and roads. As a result, a regional scale heat-island effect that is clearly visible through remote sensing [15]. This study explores the urbanization effects of four big cities of western Taiwan by analyzing their time series temperature data. Under similar circumstances city development degree in Taiwan can be expected to continue into the near future. Nevertheless the pressing need for urban studies that is called for trying to detect urban climatic effects and to determine the consequences of urbanization in Taiwanese cities is unquestioned. Our main goals are: (1) to examine the diurnal cycle change patterns of four urban-rural pairs; (2) to document the urbanization effect by analyzing monthly average maximum UHI intensities in the West Plain of Taiwan. In this study the large-scale climatic change factors of these cities are firstly eliminated [2, 21]; then monthly variations and long-term trends are performed for four urban-rural station pairs using the Mann-Kendall test. Results from the study are further compared with other urban climate studies such as [2, 9, 11].

2. Methodology and Site Selection

To make our spatial coverage uniform, one north, one central and two south stations were selected for our study (Fig. 1). The four largest cities in Taiwan were chosen to evaluate the urbanization effects that would show respective results for four different climatic, geographic and socioeconomic sections in Taiwan. The results may provide useful insights about the urbanization effect on these regions and potential future impacts. The rural sites were chosen with criteria of less developed and proximal to the corresponding city station for temperature comparison. Temperature data were retrieved from Central Weather Bureau (CWB) for four city stations (Taipei, Taichung. Tainan, and Kaohsiung) and one rural site (Tamshui); whereas temperature records of other three rural sites (Chinchuankang, Tainan Airport, Shiaokang Airport) were collected from Taiwan Air Force due to the availability of their long term meteorological records. For the agreement of temperature records for all city-rural pairs, the study period covers from 1964 to 1999. Table 1 lists geographical coordinates and attitude of the eight stations (i.e. four urban-rural pairs) in the study. Among the studied stations, Taipei has a typical monsoon type with cool/wet winters and hot/humid summers. Taichung is the third largest city of Taiwan with a basin feature as Taipei, but its climate is much similar to other two southern coastal cities (Tainan and Kaohsiung) where sea-land wind prevails in these areas. The four urban-rural pairs have suffered a common trend of buildings increasing and vegetation-covered area decreasing in all four cities. And the recent population increase and unorganized settlement in major cities and suburban areas of Taiwan have underlined the importance of regional climate studies. Similar to other subtropical countries, Taiwan also encounters many problems resulting from rapid urbanization although urban and non-urban planning are employed by local government, cities with surrounding rural region still develop to a higher level even massively extending to neighboring mountain area.

3. Temperature Data Analyses

3.1. Diurnal cycle change in UHI intensity

In order to find the magnitude and approximate time of the maximum UHI effect in Taiwan we compute the diurnal UHI intensity and apply the Mann–Kendall trend test for four city-rural pairs. Generally, the UHI intensity is calculated after sunset [12, 18]. The variability of sunset time between seasons is small in Taiwan because of its low latitude, but temperature contrast is evident due to geographical differences between stations. To eliminate part of the geographical effect on temperature, the anomalies from 36 years average values (1964–1999) are calculated for the temperature series of each urban-rural pair. Diurnal UHI change between each urban-rural pair are computed for the studied period (1964-1999) as well as the earlier decade averages (1964–1973) and the latest decade averages (1990-1999) for comparison (Fig. 2). Sea-land wind effect is not considered in the data computation.

Fig. 2 illustrates in the northern Taipei-Tamshui pair, the diurnal UHI (peak value) emerges in about 1pm in the early 1964–1973 decade but shifted to around 8pm in the last 1990~1999 period. That means the maximum UHI undergoes an apparent change from daytime (about 12am) to night (about 7pm). Diurnal temperature minimum also shows an upward movement from the early decade to the last period, especially during the night. Both phenomena clearly suggest the existence of a stronger nocturnal heat island effect in the latter period (1990~1999). This timing-shifting is good agreement with the results of Jonsson [8] and Lin [13] who evaluated subtropical urban climate for the latest decade and pointed out that a urbanization process can significantly change the city diurnal cycle pattern. The diurnal pattern of Taichung-Chinchunkang Airport pair shows similar pattern with its mean maximum peak emerging in about 12 am (Fig. 2b). Both the daily maximum and minimum display increasing trends toward the latter period that agreed with other studies [3, 4, 8, 12]. The Tainan-Tainan Airport pair represents a reversed pattern (Fig. 2c). Its maximum temperature emerges in the afternoon (about 1pm), whereas the minimum in the morning (about 7am) during the early decade (1964-1973); but the maximum temperature occurs earlier (about 4am) and minimum in the afternoon (about 4pm) during the latter decade (1990-1999). The major reason for this opposite observation is because Tainan city has been in faster growth rate (urbanization) than its neighboring Tainan Airport area during the recent period. In Kaohsiung-Shiaokang Airport pair, the diurnal cycle pattern is greatly different from other three pairs (Fig. 2d), because it emerges more significant negative value in daytime from 1964~1999. Part of the reason may be due to the close proximity between the Kaohsiung city and Shiaokang Airport (4.25 km apart) thus showing the same feature. Negative UHI intensity in daytime can be found in other cities [11], but is more common at large cities in Taiwan [13, 14]. It is noted that no negative UHI during daytime (assuming 9:30am~4:30pm) is observed in Taipei-Tamshui pair, because the geographic distance is large (15.5km) and Tamshui is heavily influenced by sea-land wind thus the negative UHI effect is reduced. Sea-land wind effect seems causing smaller variation in diurnal UHI when comparing that with other three pairs. In short, it is apparent that the patterns of maximum UHI intensity in Taiwan are comparable with other Asian cities [17].

3.2. UHI time series and Mann-Kendall trend

Lack of homogeneity in data series always creates a big problem for researchers who study time series analysis. For example, changes in instrumental exposure, station location, and the method of estimating daily and monthly averages are factors to affect climate data quality. In this study, we adopt the sequential version of Mann-Kendall rank statistic [19] to identify the probable regional climatic change in our data series. This test is regarded as the appropriate method for analyzing climatic changes using climatological time series data [1, 5], because it is non-parametric, rank order based, insensitive to missing values, and often used to evaluate whether there is a significant trend in data series over a period of time. The important parameters including u(t) representing a forward sequential statistic and u'(t) a backward sequential statistic, both are calculated in the Mann Kendall test to evaluate signals of climate changes in our annual temperature time series.

Fig. 3 shows results of the Mann Kendall test for the annual surface temperature at four urban-rural pairs. Clearly, significant regional climate changes are observed for all stations in this study. Taipei–Tamshui pair has a significantly warming trend in 0.003 ^{o}C / month (Fig. 3a). Although a minor cooling trend in -0.0002 ^{o}C average every month is found at Taichung–Chinchuankang Airport pair, the warming is evident after 1986 (Fig. 3b). Similar cooling trend is also observed for Tainan–Tainan Airport pair in -0.001 ^{o}C / month (Fig. 3c) and Kaohsiung-Shiaokang Airport pair in -0.002 ^{o}C /month(Fig. 3d). The cooling trend suggests that the rural areas of Tainan Airport and that of Shiaokang have been developing more quickly than their corresponding urban stations. Our findings are in good agreement with Aesawy and Hasanean [1] who studied six southern Mediterranean stations toward either warming or cooling direction. The beginning year of the change occurs in 1982 for Taipei–Tamshui, in 1981 for Taichung–Chinchankang Airport and in 1980 for Tainan–Tainan Airport; but shows much earlier for the Kaohsiung-Shiaokang Airport (out of studied period). Hence the regional climate change roughly begins in around 1980, a period well corresponded with the history record that Asian nations such as Taiwan, China (Hong-Kong), Malaysia, and South Korea all starting to booming economically.

3.3. Time series on monthly average of daily maximum UHI

To express the UHI effect more efficiently, regional and seasonal time series (1964–1999) were constructed using average UHI values from all large urban-rural stations. We assumed that the urban and rural sites respond in the same fashion to climate forcing mechanisms, and that the rural sites are also affected by urbanization, the time series trend term represents a linear estimate of the urban temperature bias associated with urban growth. It is apparent that the urban effect is concentrated in temperature minimums, as in each season the trend accounts for a significant portion of the total variation in urban temperatures. Fig. 4 illustrates the time series of max. daily UHI anomaly and monthly averages for four city-rural pairs. Positive trend are observed in Taipei-Tamshui pairs (Fig. 4a) whereas a little negative trends in other three pairs.

Shown in Fig. 4b its neighborhood was developed gradually after Chinchuankang airport have been built and hence first emerged a negative anomaly since 1974, and its value of slope (-0.0002) is very small meaning that both Taichung (city) and Chinchuankang airport (rural area) have a similar development condition. There is a slight oscillation variation and negative trend of anomaly in Tainan-Tainan airport pair (Fig. 4c) that can be suggested Tainan airport area where have developed promptly during the period investigation. It is worth to note a significantly decreasing (negative) trend, comparing other two negative pairs, found in Kaohsiung-Shiaokang pair (fig. 4d) due to neighboring Shiaokang airport rapid development. Monthly average of max. daily UHI shows strongest value in summer of Tainan-Tainan airport whereas others three pairs have the high peaks in spring (March). However, these variations are relatively small due to effects from northeast monsoon and sea-land wind. Reflected an effect of regional warming in Taiwan linear equations in Fig. 4a~4d was analyzed from 1964-1999. This observation agrees very well with the extensive study of urban temperature biases in the USA [6]. There is less study for urban bias in the regional temperature maximum series. Only in the warm season does the trend represent a significant fraction of the temperature variation. The comparatively minor influence of temperature maximum is consistent with previous work showing that the temperature maximum is substantially less affected by urbanization than the minimum [12]. Our results for temperature maximum in Taiwan, however, do not match those presented by [10] who considered temperature trends over the entire USA carrying a small but significant inverse relationship between population and urban bias in temperature maximums. The discrepancy between ours and [10] may be due to a number of factors, such as differences in geographic scope, time period of analysis, and methodological approach.

4. Conclusion

From four urban-rural stations pairs of time series study on the anomaly of UHI intensity for the 1964–1999 periods has been performed to investigate the influence of rapid urbanization on the local climate change in western Taiwan. The city diurnal cycle patterns are distinctively different for the urban-rural pairs in Taiwan, depending on the development history and geographic location. Trends with 0.003 ^{o}C, -0.0002 ^{o}C, -0.001 ^{o}C, and -0.002 ^{o}C in monthly average are found for Taipei-Tamshui, Taichung-Chinchuankang, Tainan-Tainan Airport, and Kohsiung-Shiaokang Airport, respectively. The shift towards cooler side in three out of four pairs suggest rural sites have been developing more quickly than their city counterparts in southern Taiwan since 1960. The Mann–Kendall trend test is applied to the annual surface temperature records and results show a significant regional climate change occurred for the four stations. The general beginning year for the change in regional climate trend is estimated to be around 1980 in Taiwan.

Seasonal analyses on monthly averages time series of maximum daily UHI intensity show that the regional warming is strongest in summer in Tainan-Tainan Airport pair whereas in winter and spring in other three stations. It has been realized that regional warming is not only due to the increase of urbanization but also to other possible climatic factors such as global warming etc.[16, 21]. Understanding the variability on regional scales is a prerequisite for appropriate city planning by local government and related experts. The results presented in this study will be helpful in the comprehension of regional climate change through rapid urbanization and serves as important scientific basis to formulate a better strategy to remediate the unfavorable climate warming.

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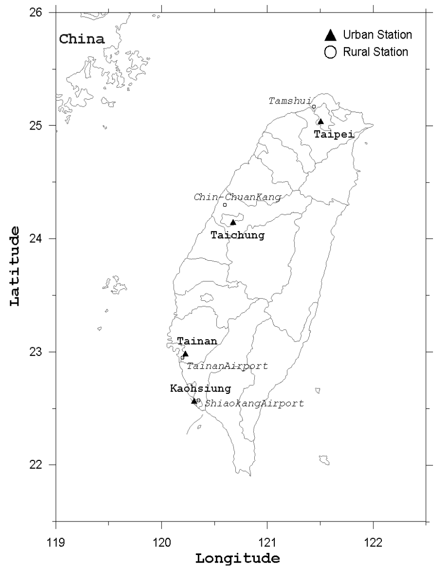

Fig. 1 Locations of four urban-rural pairs meteorological observatories and stations selected in Taiwan for this study.

Table 1. Geographical coordinates and attitude of the eight stations selected in the study

Station	Longitude	Latitude	Location
Taipei[a]	121.506	25.039	Urban
Tamshui	121.440	25.166	Rural
Taichung[b]	120.676	24.148	Urban
Chinchuankang	120.600	24.300	Rural
Tainan[c]	120.227	22.986	Urban
Tainan Airport	120.200	22.950	Rural
Kaohsiung[d]	120.308	22.568	Urban
Shiaokang Airport	120.349	22.573	Rural

a: Taipei-Tamshui distance : 15.56km.
b: Taichung-Chinchuankang Airport distance: 18.52 km.
c: Tainan-Tainan Airport distance: 4.85 km.
d: Kaohsiung and Shiaokang Airport distance: 4.25km.

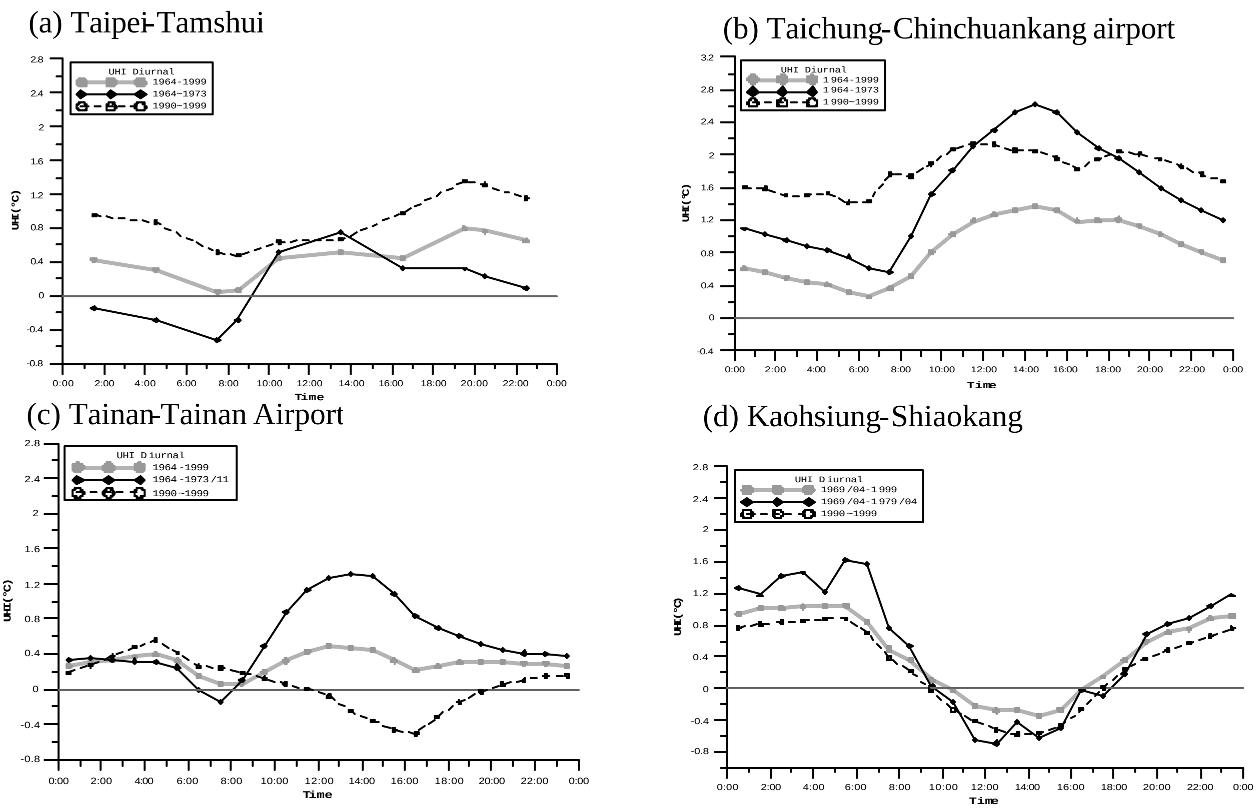

Fig. 2. Diurnal variability of the four pairs chosen in this study. Solid line represents 1964~1973, dot line from 1990~1999 and gray line from 1964~1999.

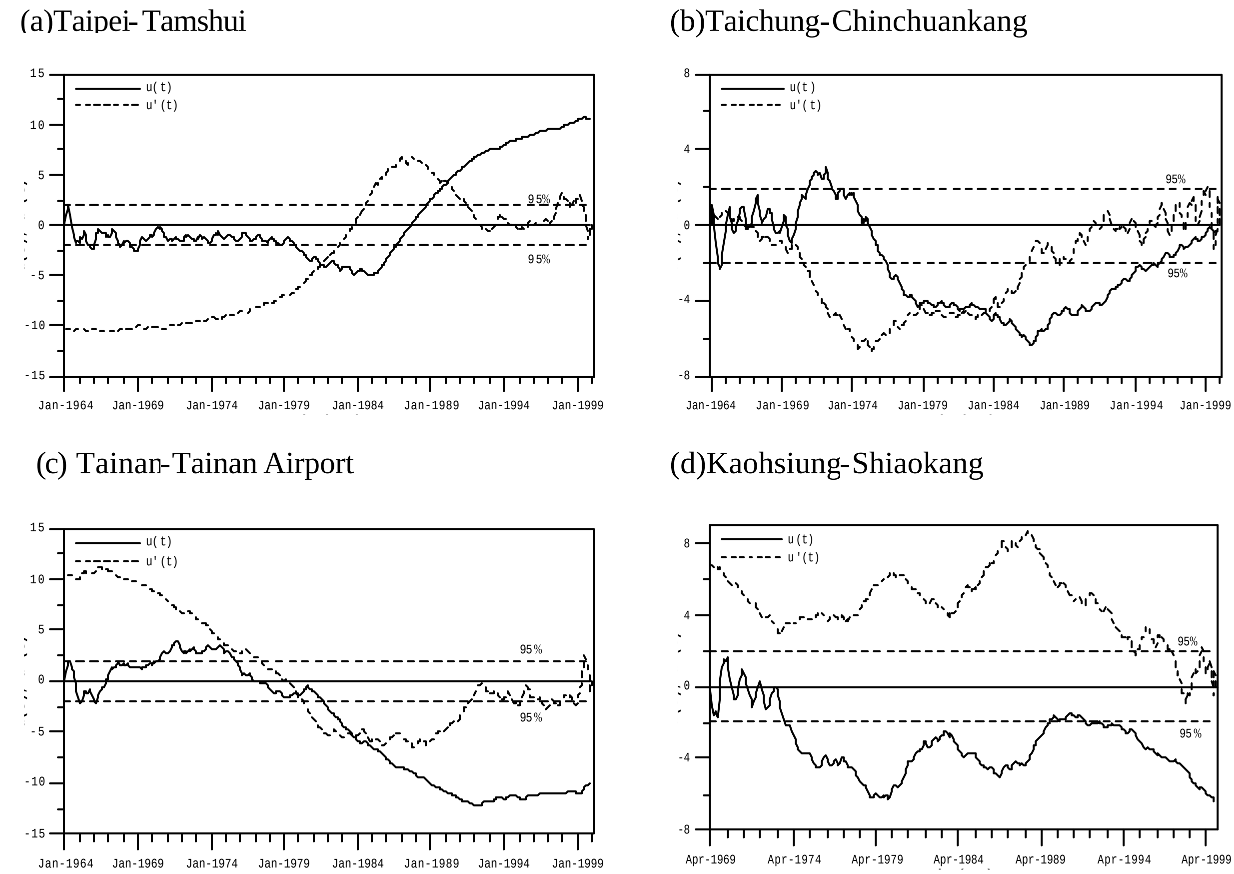

Fig. 3. Regional climate change in the annual temperature time series as derived from the sequential version of Mann Kendall test of four pairs from1964~1999. The beginning point of change is around 1980. Solid line represents u(t) and dash line u'(t) .

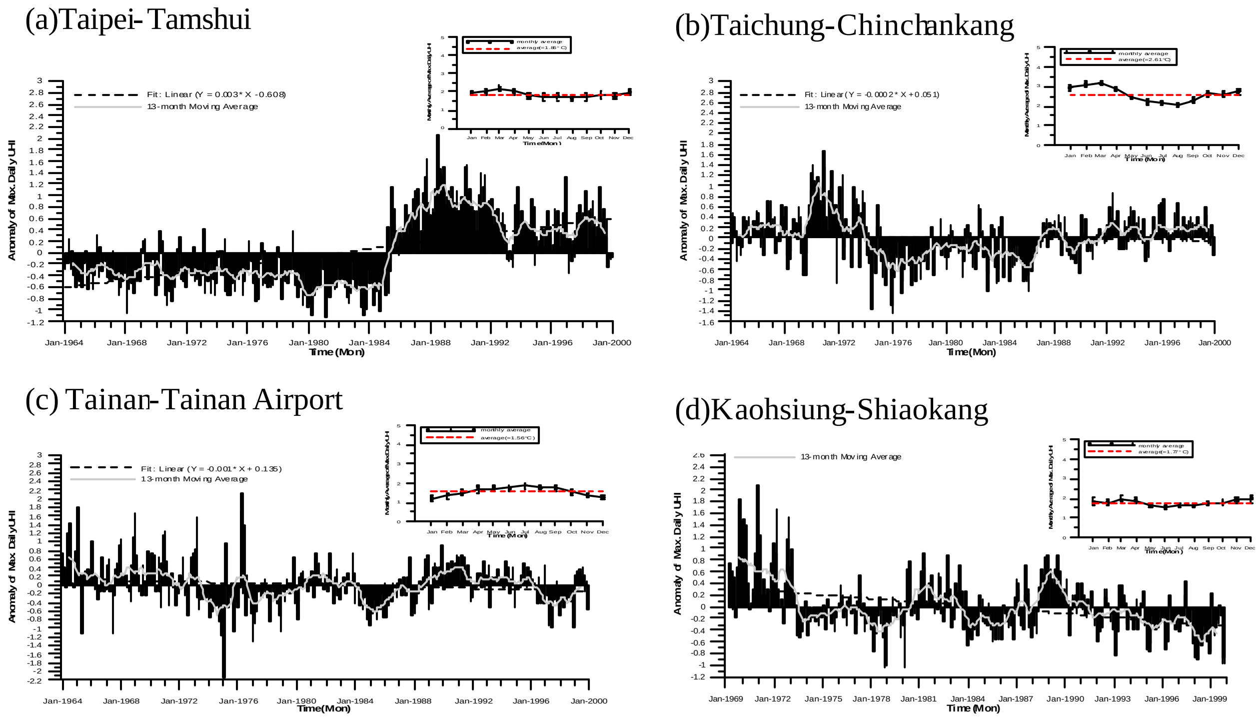

Fig. 4 Anomaly of max. daily UHI and its monthly average (upper right inset) for the four urban-rural pairs. The cover records are from 1976~1999.