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Relationship between Winter Temperature in Hong Kong and East Asian Winter Monsoon

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Abstract

A regime shift in the regional winter temperatures in southern China and Hong Kong occurred in the winter of 1986/1987. In Hong Kong, this regime shift is characterized by a positive step-change of more than 0.8°C in the mean winter temperature after the transition. This regime shift coincides well with an abrupt fall in winter monsoon strength in 1986/1987. In turn, the weakening of the winter monsoon coincides with a change in the phase of the Arctic Oscillation from the negative to the positive.

1. Introduction

The interannual variability of the winter monsoon has been described by Chang and Lau (1980) using the 1978-1979 Winter Monex dataset. It has also been noted by a number of authors including Ding (1990, 1994), Zhang *et al.* (1997), Chen *et al.* (2004). Furthermore, Huang *et al.* (2004) reviewed the relationship between winter monsoon variability in the time scales of ENSO, Chang and Li (2000) examined the inherent interaction between summer and winter monsoons in relation to the time scales of the tropospheric biennial oscillation (TBO), Chang (2005) also pointed out that the winter monsoon was affected by the decadal variations in the Pacific and Indian Oceans.

Hong Kong is strongly influenced by the East Asian Winter Monsoon, and falls in surface temperature in Hong Kong has been used as one of the criteria in the definition of monsoon surge (Lau and Chang 1987). In this regard, Lam (1979) investigated the synoptic patterns associated with winter monsoon surge arrivals in Hong Kong during the 1978-1979 Winter Monex.

Leung *et al.* (2004) showed that there was a statistically significant trend in winter temperatures in Hong Kong, and suggested local urbanization as a reason for the warming. Liang and Wu (1996) also found a warming in winter temperatures in Guangdong. Using NCEP re-analysis data, Wu and Chan (2005) showed that winter temperature anomalies over southern China were negatively correlated with the strength of the East Asian Winter Monsoon. The warming in winter temperatures in Hong Kong may thus also be related to the falling strength of the East Asian winter Monsoon as part of the regional phenomena. This possible relationship is examined from the perspective of regime shifts.

Gong *et al.* (2001), as well as Jhun and Lee (2004) among others have suggested that the strength of the East Asian Winter Monsoon is modulated by the Arctic Oscillation which reflects the strength of the polar vortex (Thompson and Wallace 1998). The link between the two is also briefly examined.

2. Data and Methodology

2.1. Data

Annual mean winter temperatures (December to February, DJF) for southern China were computed from monthly mean temperatures between 1958 and 2001 available from the National Climate Centre (NCC) of China Meteorological Administration (CMA). Annual mean winter temperatures in Hong Kong between 1958 and 2005 were computed using the hourly temperature data recorded at the Hong Kong Observatory Headquarters. The start year of 1958 was chosen to match with that of southern China. The locations of these stations are given in Figure 1.

It is customary to use monsoon indices to represent the strength of the monsoon, and to use more than one such index (Wang and Fan 1999). The data for computing the various monsoon indices are described in Section 2.2.1 below.

The values of the Arctic Oscillation (AO) index are obtained from http://www.cgd.ucar.edu/cas/jhurrell/indices.html.

2.2. Methodology

2.2.1 *Representation of Monsoon Strength*

For the present study, the Unified Monsoon Index (UMI) proposed by Lu and Chan (1999), the winter monsoon index (WMI) defined by Youn (2005), and a winter monsoon index (EAWMI) devised for this study as described below are used.

UMI is selected because it represents the strength of the 1000 hPa northerly winds averaged over the South China Sea (7.5-20°N, 105-120°E) from December to January (DJF). A larger UMI value represents stronger northerlies and thus a stronger winter monsoon, and vice-versa. UMI are calculated from the monthly the upper-air reanalysis data of the National Centers for Environmental Prediction - National Center for Atmospheric Research (NCEP-NCAR) for 1958-2005 (Kalnay *et a*l. 1996).

WMI, defined as the standardized SLP difference between (40°N, 135°E) and (45°N, 95°E) averaged for DJF, is selected because it can be taken to represent the intensity of winter outbreaks of cold air masses on the Asian continent, the more negative the index the stronger the winter monsoon. Trenberth's monthly gridded northern hemisphere sea-level pressure (SLP) data on a 5-degree latitude/longitude grid (Trenberth and Paolino 1980) available from http://dss.ucar.edu/datasets/ds010.1/data were used as they are considered a better choice than NCEP-NCAR reanalysis data (Hurrell 2001).

Because the East Asian Winter Monsoon is closely related to the subtropical high (SH) and the East Asian Trough (EAT) (Wu and Wang 2002), it is appropriate to define a winter monsoon index incorporating parameters representing these systems. A winter monsoon index, EAWMI, is therefore constructed as the leading principal component of the SH intensity index, western point index, ridge position index, the EAT position index as well as the circulation index over Eurasia (e.g., Zhao

1999). This principal component accounts for some 60% of the variability in the winters between 1958/1959 and 2004/2005. A larger EAWMI corresponds to a stronger, northward displaced and westward extended SH, an eastward shift in the EAT and predominantly zonal flow above the Eurasian continent. The climatic indices for computing EAWMI come from the National Climate Center (NCC) of the China Meteorological Administration (CMA).

To facilitate the comparison among the monsoon indices, values of WMI and UMI are multiplied by -1. Therefore the convention taken in the present study is that larger the value of the monsoon index, the stronger would be the winter monsoon.

2.2.2. *Identification of Regime Shifts*

Long-term climate variability can be interpreted in terms of the regime shift. A regime shift is characterized by an abrupt transition from one quasi-steady climatic state to another, and its transition period is much shorter than the lengths of the individual epochs of each climatic state (Yasunak and Hanawa 2002). An example is the Pacific Decadal Oscillation (PDO) regime shift in 1977 from a cold to warm phase (Hare and Mantua 2000).

The regime detection algorithm used here is the sequential t-test analysis developed by Rodionov (2004). In brief, this approach determines the existence of a regime shift without fixing the number of observations. Rather, tests are performed for sequential observations. The sequential algorithm does not require a priori hypothesis about the timing of regime shift. This method was applied by Rodionov and Overland (2005) to detect regime shifts in the Bering Sea ecosystem. In the present study, only those regime shifts significant at the 5% level are considered.

4. Results

4.1. Regime Shifts in Winter Temperatures

Figure 2 is the time series of the mean winter temperature in southern China and at the Hong Kong Observatory Headquarters. A regime shift is found in both series in the winter of 1986/1987, marking an abrupt transition from a relatively cool epoch (1958/1959 to 1985/1986 hereafter called cool period for short) to a warmer epoch (after 1986/1987 hereafter called warm period for short). For both series, the shifts in the mean values between the two epochs are greater than 0.8^{o}C. Thus, in addition to the effects of local urbanization (Leung *et al.* 2004), the warming in Hong Kong's winter temperatures may also be a result of regional influences.

4.2. Regimes Shift in the Winter Monsoon

The regime shifts in mean winter temperatures in southern China and Hong Kong coincide with regime shifts in the strength of the winter monsoon from high to low indices as characterized by the WMI and EAWMI (Figure 3a and 3b), signifying a weakening of the winter monsoon. This shift is not apparent in the UMI (Figure 3c). It may therefore be surmised that regime shifts in mean winter temperatures in southern China as well as Hong Kong are related to the regime shift in the winter monsoon. Some model simulations also suggest that a weakening of winter monsoon is associated with global warming (Hu *et al.* 2000, IPCC 2001).

Of the three winter monsoon indices, EAWMI seems to have the strongest relationship with Hong Kong's mean winter temperatures, being the only index to give statistically significant correlations (at the 5% level) with mean winter temperatures before as well as after the regime shift (Table 1).

4.3. Winter Monsoon and the Arctic Oscillation

EAWMI and WMI are correlated with the Arctic Oscillation index to examine the relationship between winter monsoon and Arctic Oscillation, all series first being subjected to a Gaussian filter (Hanna and Cappelen 2003) to remove oscillations shorter than 10 years.

The resulting correlation coefficient is r = -0.83 and r = -0.74 for EAWMI and WMI, respectively, both statistically significant at the 5% level. Figure 4 shows that the regime shift in the winter monsoon corresponds very well with a phase change in the Arctic Oscillation from the negative to the positive in the mid-1980s noted by Overland *et al.* (1999). Phase change in the Artic oscillation has also been attributed to the influence of global warming by some investigators, for example, Schindell *et al.* (1999).

5. Conclusions

Regime shift analysis shows that a regime shift occurred in the mean winter temperatures in southern China and Hong Kong in 1986/1987. In the case of Hong Kong, following the regime shift the mean winter temperatures were approximately 0.8^{o}C higher than that before the transition. This regime change coincides well with a weakening of the winter monsoon strength as represented by the East Asian Winter Monsoon Index and the Winter Monsoon Index. Furthermore, the weakening in the winter monsoon appears to occur concurrently with a change in phase of the Arctic Oscillation from negative to positive.

Table 1. Correlation with winter temperature in Hong Kong for different periods. Correlation coefficients significant at the 5% level are in bold.

Periods	WMI	UMI	EAWMI
Cool period (1958/1959-1986/1987)	**-0.54**	**-0.71**	**-0.44**
Warm period (1987/1988-2004/2005)	-0.08	-0.24	**-0.49**

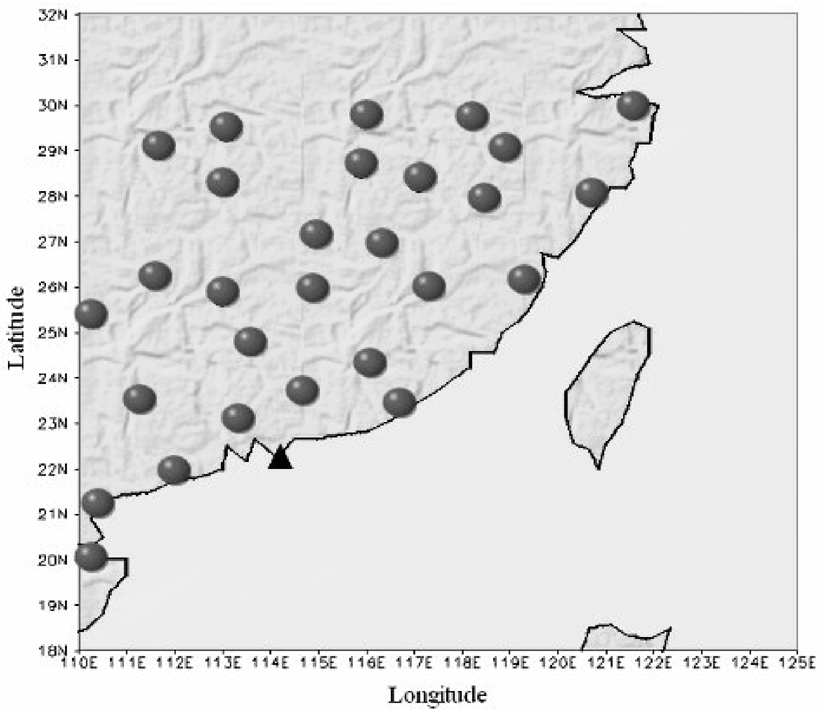

Figure 1. Locations of the Hong Kong Observatory (solid triangle) and the 28 land stations in southern China (buttons).

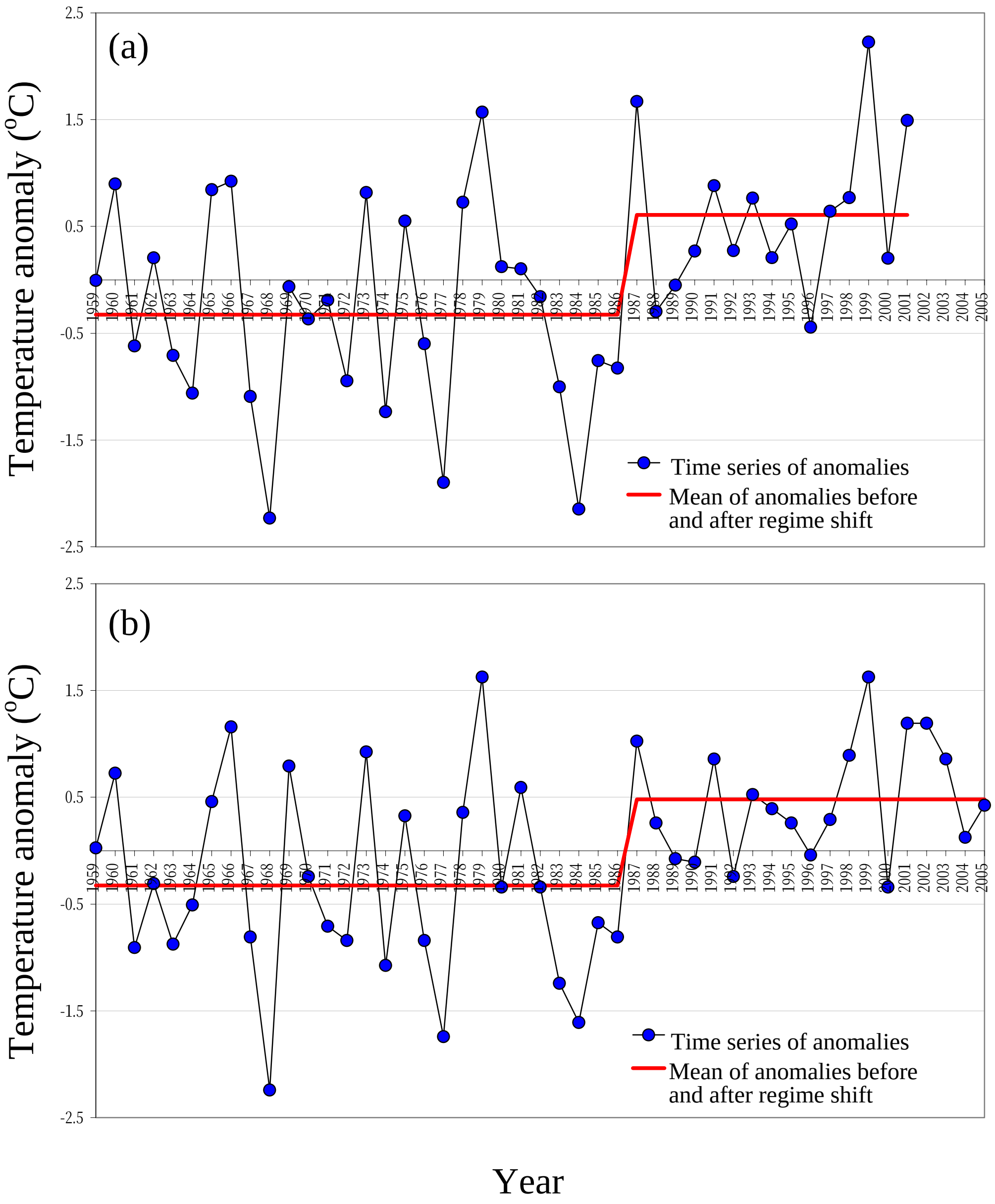

Figure 2. Time series of winter temperature anomalies in (a) southern China and (b) Hong Kong. The solid lines show the mean of the anomalies before and after the regime shifts. Anomalies in (a) are with reference to the long-term mean between 1958/1959 and 2000/2001, and in (b) between 1958/1959 and 2004/2005.

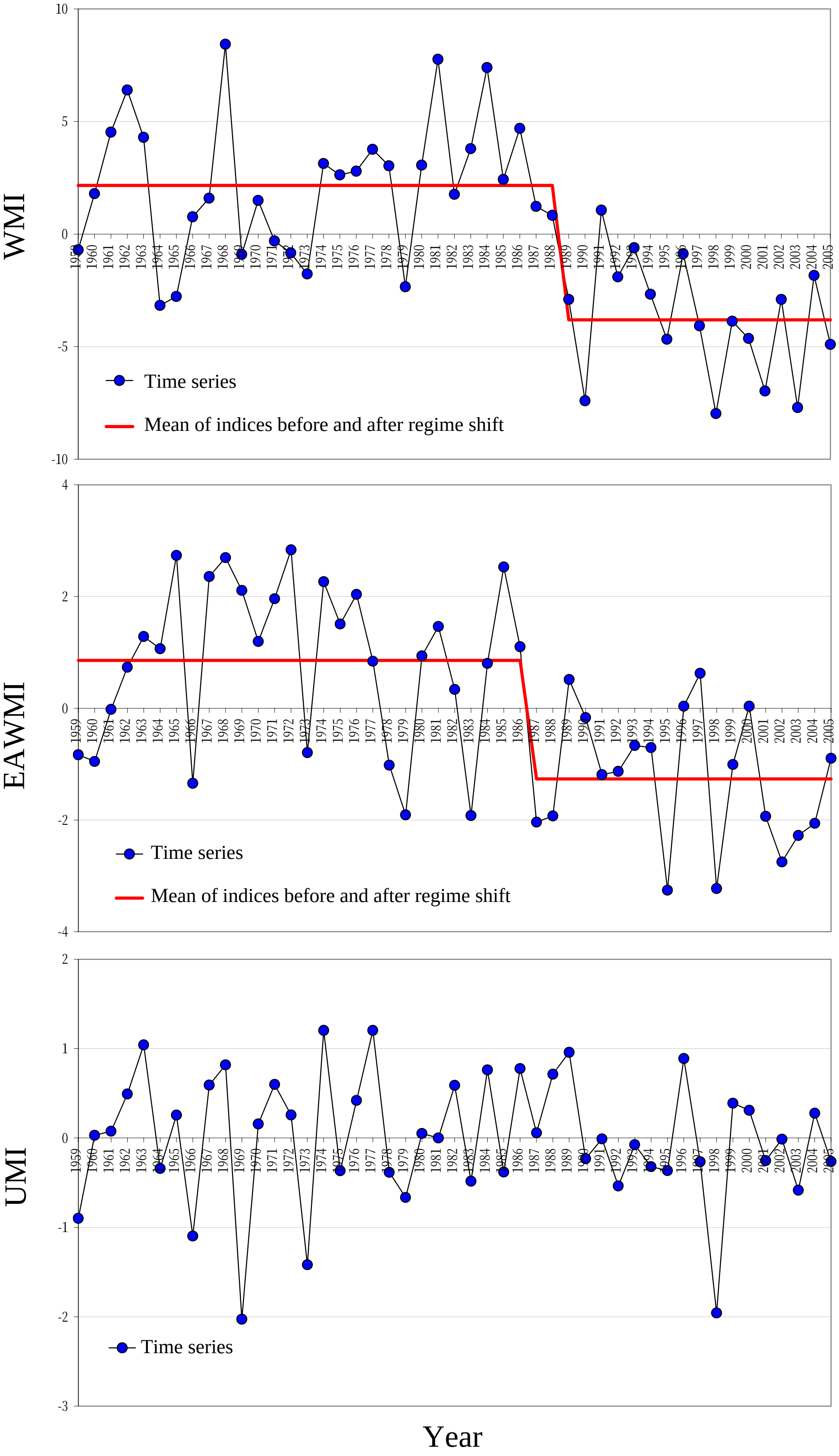

Figure 3. Time series of annual winter monsoon index of (a) WMI (b) EAWMI, and (c) UMI. The solid lines show the mean values before and after the regime shifts. No regime shift is detected in (c).

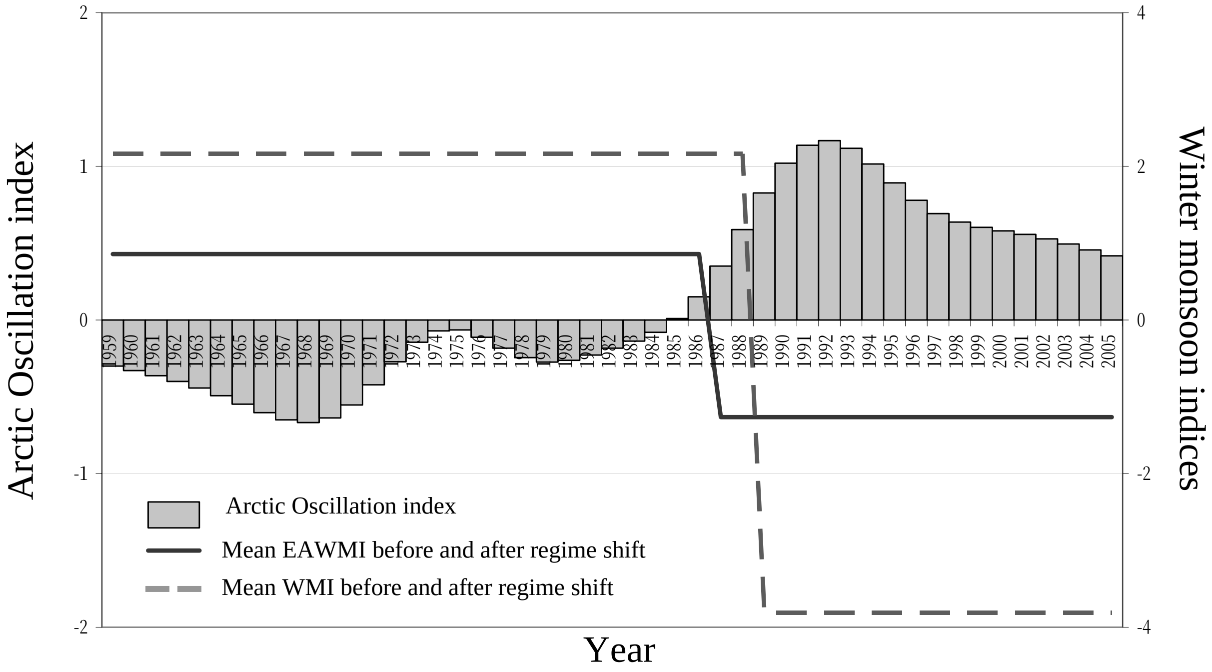

Figure 4. Histogram showing the temporal variations of Arctic Oscillation index Gaussian filtered to remove short-term oscillations of less than 10 years. Superimposed (solid and dashed lines) are the mean of winter monsoon indices before and after regime shift.

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