

# Detecting climate rationality and homogeneities of sea surface temperature data in Longkou marine station using surface air temperature

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**Abstract:** This study presents a systematic evaluation of the climate rationality and homogeneity of monthly sea surface temperature (SST) in Longkou marine station from 1960 to 2011. The reference series are developed using adjacent surface air temperature (SAT) on a monthly timescale. The results suggest SAT as a viable option for use in evaluating climate rationality and homogeneity in the SST data on the coastal China Seas. According to the large-scale atmospheric circulation patterns and SAT of the adjacent meteorological stations, we confirm that there is no climate shift in 1972/1973 and then the climate shift in 1972/1973 is corrected. Besides, the SST time series has serious problems of inhomogeneity. Three documented break points have been checked using penalized maximum T (PMT) test and metadata. The changes in observation instruments and observation system are the main causes of the break points. For the monthly SST time series, the negative adjustments may be greatly due to the SST decreasing after automation. It is found that the increasing trend of annual mean SST after adjustment is higher than before, about 0.24 °C/10 yr.

## 1. Introduction

Long term instrumental data are essential in order to study climate change and variability since these are the most reliable records of the climate of the past. However, the value of these datasets strongly depends on the homogeneity of the underlying time series. But, these observation series suffer from inhomogeneities caused by several non-climatic factors[1]. These non-climatic factors include station relocation, instrument change, environment changes and so on, most of which introduce artificial discontinuities or inhomogeneities in the time series [2, 3]. So, the establishment of climate data set is a complex process and two steps are needed. The first step is the basic step called quality control (QC). The second step is the inhomogeneity test and adjustment in order to remove and correct non-natural irregularities in climate data series. According to the Specifications of Near-shore Observations of China (GB/T14914-2006, China) [4], the QC includes logic test, range test, statistical test, spike test, gradient test and so on. The basic logic test in the quality control in the first step contains: checks for physically unreasonable values, unreasonably long consecutive occurrences of the same value, the internal consistency test, check whether the maximum value is less than the average value and the minimum value. The first step can pick out and correct most dubious value in these observation data. However, there are still some suspicious values which are difficult to detect in the first step. These suspicious values show inconsistent with the local climate characteristics, called climate in-rationality values. Therefore, the climate rationality needs to be analyzed before the inhomogeneity test and adjustment.



Sea surface temperature (SST) is one of the most important variables used to quantify climate change and elements for the oceanic environment as well [5-7]. In our work, the SST in Longkou marine station which is located on the coast of the Bohai Sea is taken as an example to examine the climate rationality and homogeneity. The first aim is to check the climate shift in some years by comparing the SST time series with adjacent SAT time series from China Meteorological Administration (CMA). Subsequently, synoptic conditions over the China Seas before and after the climate shift points are examined using National Centers for Environmental Prediction-National Center for Atmospheric Research (NCEP/NCAR) reanalysis. Then, the penalized maximal T test (PMT), which was developed by X L Wang (2008), as well as the metadata is used in our work to homogenize the SST data in Longkou station.

The rest of the paper is organized as follows. Section 2 briefly introduces the data sources. Section 3 describes the methods used in our study. And analyze the check of climate rationality in Longkou station. Section 4 analyses the check of climate rationality and inhomogeneity test and adjustment. Section 5 presents the observed trends from the raw data and the adjusted data. Finally, a summary is given in section 6 to complete this article.

## 2. Data sources

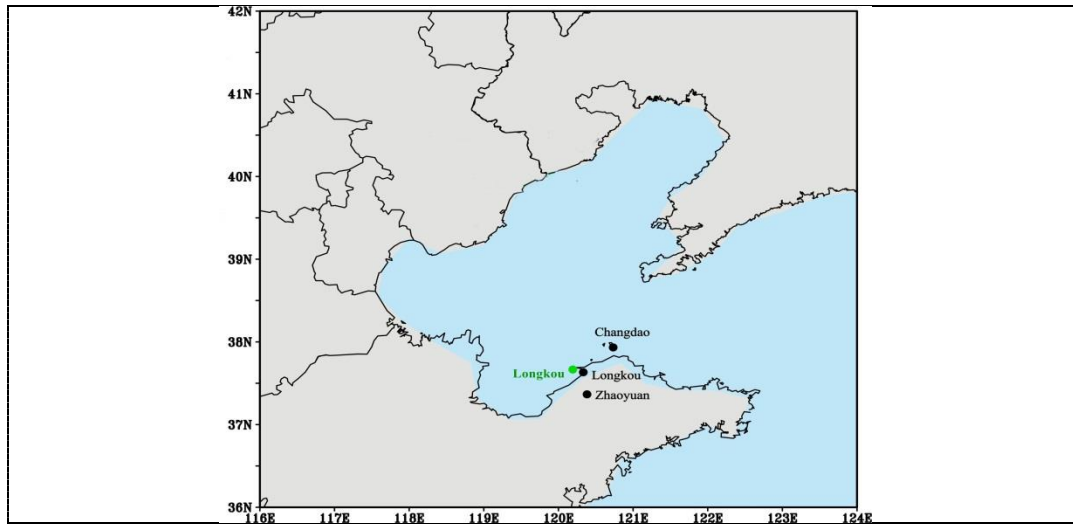
Long marine station is located in the coast of the Bohai Sea (Figure 1). The SST data in Longkou marine station from January 1960 to December 2011 is collected and processed by the (NMDIS) of the State Marine Administration (SOA) of China. The station history data file (i.e. metadata) which used to verify the veracity of statistically detected change points is also checked and stored by NMDIS, including the time of relocation, environment change, algorithms for calculating a daily mean, observing procedures and so on [4]. The homogenized monthly mean SAT time series from National Meteorological Information Center (NMIC) are used to construct reference time series. The monthly 2.5x2.5 gridded NCEP-NCAR reanalysis data[8] is used to provide air temperature, wind, sea level pressure and geopotential height which can reflect the background of large-scale atmospheric circulation. Data are provided by the NOAA/OAR/ESRL PSD, Boulder, Colorado, USA from their Web site at <http://www.cdc.noaa.gov/>.

## 3. Change point detection method of SST series

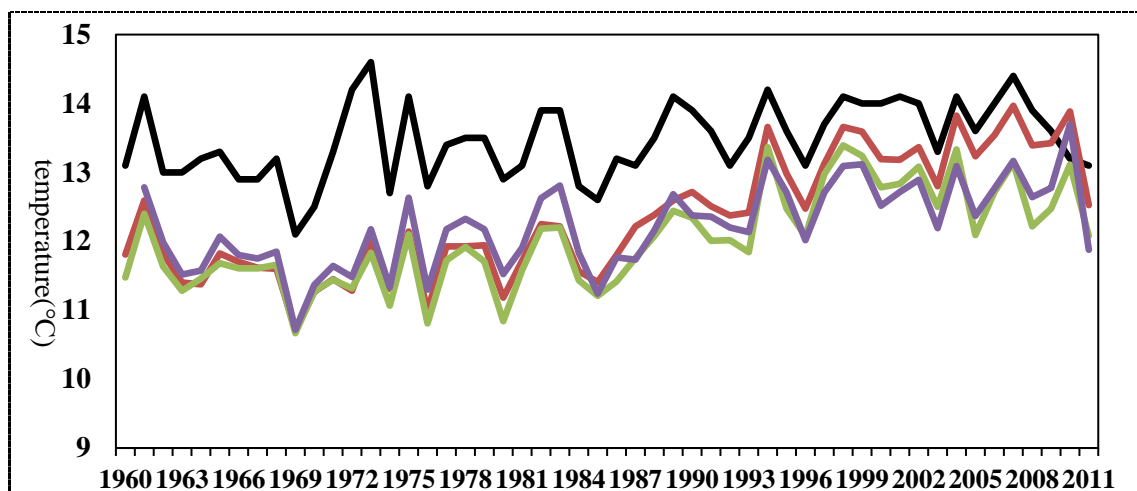
Much of research on homogenization techniques has been completed in recent years. The homogeneity tests applied were: Standard Normal Homogeneity Test (SNHT) [9]; the Maronna and Yohai bivariate test [10]; the Easterling and Peterson test [11] and PMT test [12]. After comparatively analyzing the performance of several homogenization methods for time series of SAT across China [13], we use the RHtest version 4 software package [14] to detect and adjust inhomogenities in this study. This package includes the PMF method and PMT method.

The PMT test is a relative homogeneity test which relies on the reference series in a greater degree. In this condition, it is very important and necessary to create a homogeneous climatological reference series in the PMT test. Since the sparsity of the marine stations along the coast of the Bohai Sea, it is difficult to develop a SST reference series. In this study, we use homogeneous SAT series from neighbouring meteorological stations to construct a reference series for each marine station. This approach is considered to be proper and reasonable due to the fact that the variability of SST in the coastal zone of Circum Bohai Sea is the only inner sea of China and effect mainly by land climate. Meanwhile, SST series always reflect the similar regional-scale climate variability in the study region as the SAT series [15]. In particular, the interannual variation trend of the candidate and reference series is removed in order to obtain the anomaly series that more directly reflects the climate fluctuations in the homogeneity assessment. SAT time series of Longkou, Zhaoyuan and Changdao meteorological stations (Figure 2) which highly correlated with the candidate SST time series are chosen (the correlation coefficients are 0.7, 0.8, 0.8, respectively, exceeding 99% confidence level) (Table 1), with a distance limit of 300km and an altitude difference limit of 500m. In addition, there are also similar evolution characters between the annual mean SST time series and selected SAT time

series (Figure 3).



**Figure 1.** Distribution of the reference meteorology stations (black dot) of Longkou ocean station (green dot).



**Figure 2.** The time series of annual mean SST at Longkou marine station (black solid line) and the time series of annual mean SAT at meteorological stations Longkou (red solid line), Zhaoyuan (green solid line) and Changdao (purple solid line) from 1960 to 2011.

The reference series is constructed by correlation coefficient weighted average method with the three SAT series. The formula is shown as follows:

$$\bar{y}_l = \frac{\sum_{j=1}^n \rho_j^2 \times y_{jl}}{\sum_{j=1}^n \rho_j^2} \quad (1)$$

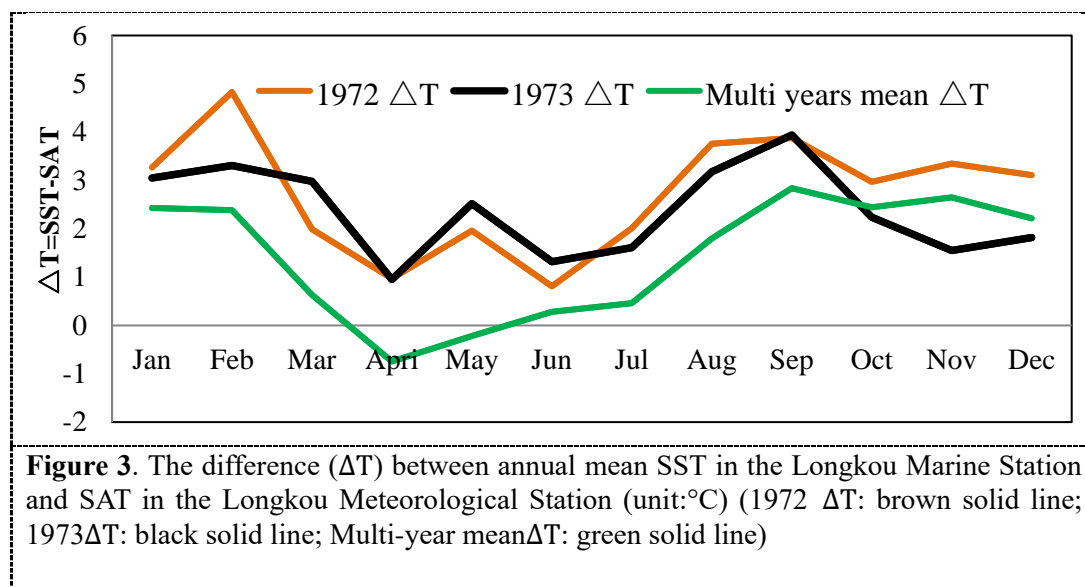
where  $i$  denotes the time,  $j$  represents the number of the reference meteorological stations,  $\rho$  is the cocorrelation coefficients between SST series of Longkou and the SAT series of the reference meteorological stations station,  $y$  is the monthly mean SAT time series of each reference station and means the calculated reference SAT series.

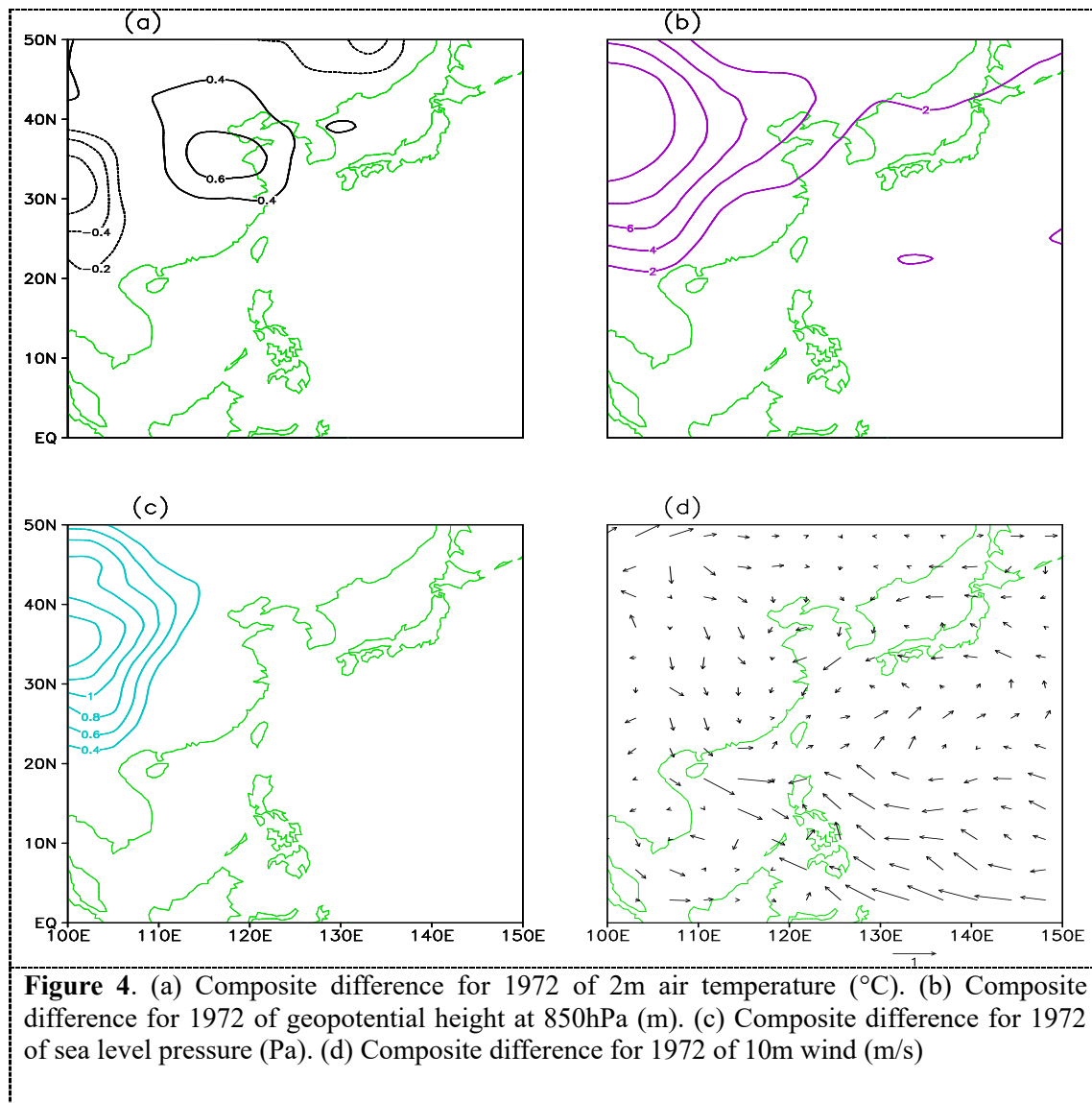
**Table 1.** The code and coordinate of the reference meteorological station.

Name	Code	Latitude	Longitude
Longkou	54753	37°63′	120°33′
Zhaoyuan	54755	37°23′	120°39′
Changdao	54751	37°93′	120°73′

#### 4. Analysis of Climatic shifts

It is known that in the same region SST series always reflect the similar regional-scale climate variability in the study region as the SAT series, with the relative stable difference between SAT and SST. However, in the figure 2, there is a sudden warming or climate shift during 1972/1973. Then, the difference ( $\Delta T$ ) between annual mean SST in the Longkou Marine Station and SAT in the Longkou Meteorological Station at 1972 and 1973 is shown in Figure 3. Comparing with the multi years mean  $\Delta T$ , it is obviously that the SST in 1972/1973 is much higher than normal which may be not consistent with the local climate background. Thus, synoptic analyses are undertaken to determine whether the apparent climate shift is evident in large-scale circulation patterns. Composites of 2m air temperature, geopotential height at 850hPa, sea level pressure and 10m wind are constructed for five years before and after the identified step changes. Composites constructed around 1972, i.e., 1973-1977 minus 1967-1971, are shown in Figure 4. Analysis of the 1972 change point reveals relatively higher temperature and geopotential height post-1972 but differences are weak and not significant over the Bohai Sea (Figure 4a and b). The relatively higher or lower sea level pressure and stronger or weaker wind at 10m post-1972, do not appear over the China Seas in the composite map shown in Figure 4c and 4d. The results indicate that there is no significant climate shift in this area. Therefore the sudden warming or warming climate shift at 1972/1973 may be not consistent with the large-scale atmospheric circulation. It is important to note that this warming shift at 1972/1973 should be adjusted. Referring to the SAT in Longkou, we give the adjustment about  $-1.58^{\circ}\text{C}$ .





## 5. Statistics of Detected Change Points and the Related Causes

Combined with the detailed metadata of Longkou station, the resulting change points from PMT method are synthesized and verified. In general, we retain one type of change points for adjustment: change points which are supported by metadata and are identified to be a significant documented change point in the monthly mean series. We consider a detected change point to be a documented one when metadata indicate a documented change within 1 year before or after the detected change point. In this case, the documented time of change is used to replace the estimated time of change when they are not identical (due to estimation error).

The result of PMT test on SST time series at Longkou marine observational station of which the unreal climate shift has been adjust is shows that there are 5 tested suspicious discontinuities in the raw SST time series, that is, January 1972, December 1983, December 1991, October 1993 and February 2002 (Table 2). Consequently, the station historical records are used to verify the rationality of these tested discontinuities. According to metadata, 3 tested discontinuities (January 1972, October 1991, February 2002) are supported by metadata and identified to be significant documented break points (Table 3).

SST time series which is identified to contain significant change points is adjusted to the latest segment of the data series, using the quantile-matching (QM) algorithm from RHtests V4 <sup>[14]</sup>. Table 4 lists the three detected change points and the adjustment value in different periods. The adjustment values are  $-0.73^{\circ}\text{C}$ ,  $-0.1^{\circ}\text{C}$  and  $-0.45^{\circ}\text{C}$ . The latter is linked tightly to the SST decreasing after automation [16-18]. The homogenization adjusts the warming bias resulting from the less observation times in the earlier time using artificial observation system. Finally, the homogenized time series of monthly mean SST in Longkou station can be obtained (Figure 5).

**Table 2.** Results of detected change points based on PMT method using a reference series and related statistical information.

Tested change point	Test statistic PTmax	95% confidence interval	significant
January 1972	7.33	3.76-4.36	Yes
December 1983	3.92	3.79-4.0	?
December 1991	5.93	3.23-3.77	Yes
October 1993	7.41	3.82-4.45	Yes
February 2002	4.11	3.38-3.92	Yes

**Table 3.** The number of shifts and the different causes leading to inhomogenization

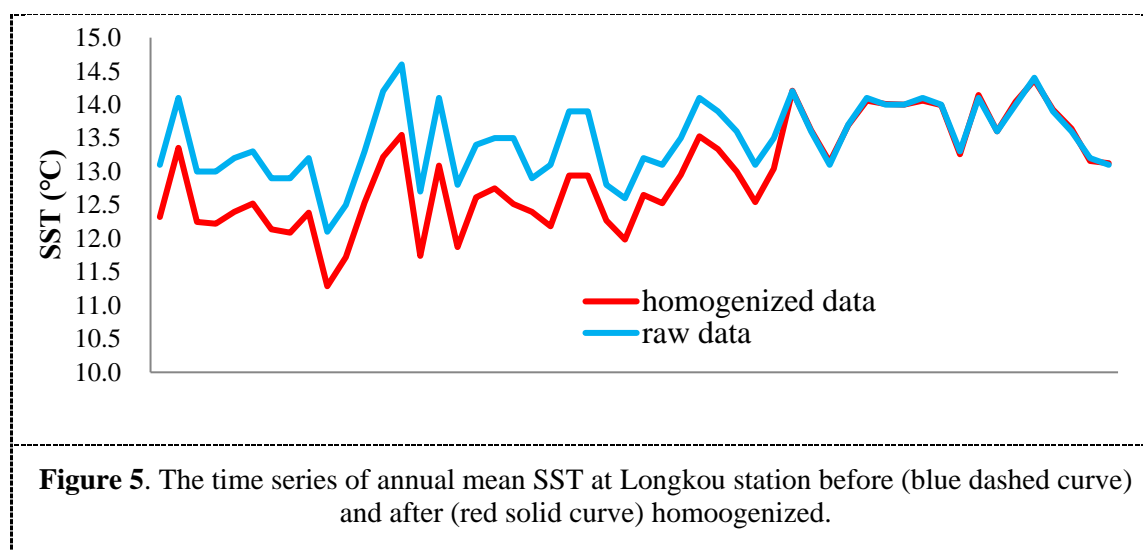
No	Name	Documented change points	Cause for inhomogenization		
			Station relocation	Instrument change	Artificial erros/Instru ment failure
1	Longkou	1972/01; 1991/10; 2002/02	1991/10	2002/02	1972/01

**Table 4.** Results of detected break points and the adjustment range

No	Break points	Adjustment range
1	Jan. 1972	$-0.73^{\circ}\text{C}$
2	Oct. 1991	$-0.1^{\circ}\text{C}$
3	Feb. 2002	$-0.45^{\circ}\text{C}$

## 6. SST variation before and after homogeneous adjustment

The annual mean SST time series of Longkou marine observational station before and after adjustment are shown in Figure 5. The linear SST trend from 1960 to 2011 is estimated by linear regression method. The linear trend of unadjusted annual mean SST time series is  $0.15^{\circ}\text{C}/10\text{ yr}$ . Compared to unadjusted time series, the warming rates of the homogenized SST time series are notably larger, about  $0.24^{\circ}\text{C}/10\text{ yr}$ . This result shows that the inhomogeneous time series appears to underestimates the warming trend during the past 52 years.



## 7. Conclusion

In this study, the climate in-rationality and non-climatic factors causing the inhomogeneity of the SST time series have been analyzed. We confirm that there is no climate shift in 1972/1973. The sudden warming during 1972/1973 is not consistent with the large-scale atmospheric circulation. It indicated that there are some climate in-rationalities during 1972/1973 which may be caused by artificial errors or instruments failure. And we need to adjust it first. The adjustment is 1.58°C. After that, we homogenized the SST time series of Longkou marine observational station over the period from 1960 to 2011, using PMTred algorithm to detect change points, and using the QM adjustment method conducted with SAT reference series to adjust the SST time series. The changes of instruments and observational system are the main causes for the identified inhomogeneities. The change of observational system causes a significant decrease in temperature in the new observational system.

We also assess the warming trend of the SST time series before and after adjustment. The correlation coefficient between the adjusted SST time series and time is much higher which means that the homogenized SST time series is improved well. The warming rate of SST series after adjustment is much larger than before, up to 0.24 °C/10 yr implying that the inhomogeneous series underestimates the warming trends during the past 52 years. The results also indicate that the use of SATs toward developing reference series is at least a viable option in assessing the homogeneity of SST.

## Acknowledgements

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