Homogenization of Sea Surface Temperature at Xiao Changshan marine station in the east of the Bohai Sea using the PMT method

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Abstract: Using the PMTred algorithm (penalized maximum T test) and the detailed metadata archive, the monthly mean sea surface temperature (SST) datasets from 1960 to 2011 have been detected and adjusted. Results show that the SST time series has serious problems of inhomogeneity. The changes in observation instruments and observation system are the main causes of the discontinuity. For the monthly SST time series, the negative adjustments have the high proportion, which may be greatly due to the SST decreasing after automation. It is found that the annual mean SST trends have changed obviously before and after adjusted. The increasing trend of annual mean SST after adjustment is higher than before, by up to 0.252 °C/10 yr.

1. Introduction

Long time observation series is fundamental and essential for the describing climate change. However, these observation series without effect of non-climatic factors are rare [1]. These non-climatic factors including station relocation, instrument change, environment changes and so on may introduce artificial discontinuities or inhomogeneities, in the time series [2, 3]. Such discontinuities can lead to misinterpretations of the studied climate. In order to avoid errors and obtain homogeneous climate time series, non-natural irregularities in climate data series must be detected and removed [2, 3, 4]. In recent years, methods considering effects of inhomogeneity on meteorological elements have been well developed in China, e.g., surface air temperature (SAT), precipitation, pressure and so on. Homogenized meteorological elements datasets have been constructed [5-9]. But, like many long-term climate data series, the oceanographic element time series along coast of China Seas also contains discontinuities or breakpoints caused by relocations or instruments changes. There are few scientists focusing on the homogenization of oceanographic climate series along coast of China. It may due to the lower density of the marine stations, the complex geography of the coast and the limited metadata, etc [10].

Sea surface temperature (SST) is one of the most important variables used to quantify climate change and elements for the oceanic environment as well [11-15]. In this study, we take the SST time series of Xiao Changshan marine station in coast of the Baihai Sea as an example to examine the homogeneity in this station and then adjust it in detail.

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. Section 4 analyses the detected change points and the
related causes. Section 5 presents the observed trends from the raw time series and the homogenized time series. Finally, a summary is given in section 6 to complete this article.

2. Data sources
The SST data in Xiao Changshan marine station from January 1960 to December 2011 is collected and processed by the National Marine Data and Information Service (NMDIS) of the State Marine Administration (SOA) of China. NMDIS employed a variety of quality control (QC) procedures on the data including checks for physically unreasonable values, unreasonably long consecutive occurrences of the same values, daily maximum temperature less than minimum temperatures, and so on. In addition, few monthly missing data are reconstructed by regression analysis method.

Xiao Changshan marine station is located in the Xiao Changshan Island of Dalian city (Figure 1). This island is dominated by gravels, no large coastal projection. The observational environment conforms to the specification for offshore observations in China [16]. The station history data file (i.e. metadata) which used to verify the veracity of statistically detected change points is checked and stored by NMDIS, including the time of relocation, environment change, algorithms for calculating a daily mean, observing procedures and so on [16]. This station experienced a transformation from artificial observation system to automatic observation system in 2001 and totally four temperature instruments have been used from 1960 to 2011. The station location and environment are almost no significant change. Thus, in the paper, we mainly consider the effect of the observational system and instrument change on the homogeneity of the SST series. In addition, the homogenized monthly mean SAT time series from National Meteorological Information Center (NMIC) are used to construct reference time series.

3. Change point detection method of SST series
After comparatively analysing the performance of several homogenization methods for time series [17], the RHtests V4 software package [18] is used in our study. This package includes the PMTred algorithm, which is based on the penalized maximum t (PMT) test. The PMTred algorithm deal with multiple change points using a recursive testing algorithm and account for the first order autocorrelation, and thus have the word “red” in their names [19, 20]. 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 [21]. 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.

The reference meteorological stations are chosen by the following conditions:

1. The horizontal distance between candidate marine station and reference meteorological stations should be within 350km;
2. The correlation coefficient between monthly SST time series and the SAT time series should be 0.7 or higher;
3. The urban heat island effect of the meteorological station is minor or insignificant.

The correlation coefficients of the SST time series of Xiao Changshan marine station with each SAT time series of the neighbouring meteorological stations are calculated. SAT time series of Zhuanghe, Wa Fangdian and Changhai meteorological stations (Table 1, Figure 2) which highly correlated with the candidate SST time series are chosen (the correlation coefficients are 0.77, 0.74, 0.79, respectively, exceeding 99% confidence level). In addition, there are also similar evolution characters between the annual mean SST time series and selected SAT time series (Figure 3).

| Name       | Code | Latitude | Longitude |
|------------|------|----------|-----------|
| Zhuanghe   | 54584| 39°72'   | 122°95'   |
| Wa Fangdian| 54563| 39°63'   | 122°02'   |
| Changhai   | 54579| 39°27'   | 122°58'   |

Figure 2. Distribution of the reference meteorology stations (blue dot) of Xiao Changshan ocean station (red dot).
The homogenous nearby meteorological stations with high correlation coefficients with the SST time series are chosen to construct reference series by correlation coefficient weighted average method. The formula is shown as follows:

\[ \bar{y}_i = \frac{\sum_{j=1}^{n} \rho_{ij} y_j}{\sum_{j=1}^{n} \rho_{ij}^2} \]  

where \( i \) denotes the time, \( j \) represents the number of the reference meteorological stations, \( \rho_{ij} \) is the correlation coefficient between SST series of Xiao Changshan and the SAT series of the reference meteorological stations, \( y_j \) is the monthly mean SAT time series of each reference station and \( \bar{y}_i \) means the calculated reference SAT series.

Combined with the detailed metadata of Xiao Changshan 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).

4. Statistics of Detected Change Points and the Related Causes

The result of PMT test on SST time series at Xiao Changshan marine observational station shows that there are 5 tested suspicious discontinuities in the raw SST time series, that is, October 1964, September 2000, December 2001, January 2005 and February 2009 (Table 2). Consequently, the station historical records are used to verify the rationality of these tested discontinuities. According to metadata (Table 3), 3 tested discontinuities (October 1964, December 2001, January 2005) are supported by metadata and identified to be significant documented change point in the monthly mean series. 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 [18]. Table 4 lists the three detected change points and the adjustment value in different periods. This result shows that the negative correction values have the high proportion, about -0.67 °C and -0.52°C. The latter is
linked tightly to the SST decreasing after automation [21]. The homogenization adjusts the warming bias resulting from the less observation times in the earlier time using artificial observation system. Finally, we obtain the homogenized time series of monthly mean SST in Xiao Changshan station.

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 |
|---------------------|----------------------|-------------------------|-------------|
| October 1964        | 6.245                | 3.473-4.034             | Yes         |
| September 2000      | 4.345                | 3.381-3.937             | Yes         |
| December 2001       | 5.929                | 3.245-3.756             | Yes         |
| January 2005        | 6.092                | 3.279-3.802             | Yes         |
| February 2009       | 4.109                | 3.378-3.920             | Yes         |

Table 3. The observational instruments changes from the metadata of Xiao Changshan ocean observation station.

| No | time                  | Instrument                      | Observational system |
|----|-----------------------|---------------------------------|-----------------------|
| 1  | Jan. 1959-Dec.1964    | Analytik Jena 16 Mercury Thermometer | artificial system    |
| 2  | Jan. 1965-Dec. 2001   | SWY1-1 Thermometer              | artificial system    |
| 3  | Jan. 2002-Jun.2004    | YZY4-1 Themohaline Sensor       | automatic system     |
| 4  | Jul. 2004 till now    | SWL1-1 Thermometer              | automatic system     |

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

| No | Break points | Adjustment range |
|----|--------------|------------------|
| 1  | Nov. 1965    | -0.67°C          |
| 2  | Feb. 2002    | -0.52°C          |
| 3  | Jul. 2004    | 0.1°C            |

5. SST variation before and after homogeneous adjustment

The annual mean SST time series at Xiao Changshan marine observational station before and after adjustment are shown in Figure 4. 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 0.157 °C /10 yr. Compared to unadjusted time series, the warming rates of the homogenized SST time series are notably larger, about 0.252 °C/10 yr. This result shows that the inhomogeneous time series appears to underestimates the warming trend during the past 52 years. Furthermore, the correlation coefficients between the adjusted annual mean SST series and annual mean SAT series of Zhuanghe, Wa Fangdian and Changhai are much higher than before, by up to 0.86, 0.83 and 0.86.
6. Conclusion
In this study, we homogenized the SST time series of Xiao Changshan 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 non-climatic factors causing the inhomogeneity of the SST time series have been analyzed. 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 0.252 °C/10 yr implying that the inhomogeneous series underestimates the warming trends during the past 52 years.

The density of marine observational stations in China is very sparse. SST reference series are difficult to develop by the traditional method. Therefore, in the present study, we try to use SAT time series and PMTred algorithms to detect the inhomogenities in the SST time series of Xiao Changshan marine station. Some meaningful results have been obtained. However, we have to point out that due to the limited metadata, biases located in the reference time series, biases in homogenization methods and the subjective judgements, etc., there must be some uncertainty in the homogenized time series. In other words, although homogenized data always reflects actual climate changes better than the original data does, it still cannot reflect the “real” climate changes. In order to eliminate the uncertainty and more closer to the “real” one, there is still much work should to be done, including collection of more high quality metadata, using multiple detected methods and then deciding the result by averaging and so on [22]. Our work is only the beginning and much hard work is needed for the oceanographic element homogenization.

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