Homogeneity study of fixed-point continuous marine environmental and meteorological data: a review

Jinkun Yang, Yang Yang¹, Qingsheng Miao, Mingmei Dong and Fangfang Wan
National Marine Data and Information Service, Tianjin 300171, China
¹yang03034101@126.com

Abstract. The principle of inhomogeneity and the classification of homogeneity test methods are briefly described, and several common inhomogeneity methods and relative merits are described in detail. Then based on the applications of the different homogeneity methods to the ground meteorological data and marine environment data, the present status and the progress are reviewed. At present, the homogeneity research of radiosonde and ground meteorological data is mature at home and abroad, and the research and application in the marine environmental data should also be given full attention. To carry out a variety of test and correction methods combined with the use of multi-mode test system, will make the results more reasonable and scientific, and also can be used to provide accurate first-hand information for the coastal climate change researches.

1. Introduction
Long time series of marine climate data is the marine environment changes and climate change and sea-air interaction and other areas of research basis. Fixed-point continuous observation of the marine environment and meteorological data is the most important. However, due to the observed data in the observation process is inevitably subject to many subjective or objective aspects of the impact [1, 2], including station migration, instrument failure or change, system upgrades, observation personnel replacement, observation frequency or time changes, statistical analysis methods changes, etc., so that the observed data not only record the real environmental climate change, but also hidden some inhomogeneous changes. And these changes will directly affect the development of data assimilation system and forecasting mode and other business and research work to improve the quality and level [3]. Many foreign experts have done a lot of research work on climate sequence homogeneity testing and revision, and have made significant progress [4-8].

In recent years, our researchers have been engaged in the research of the homogeneity of climate data, established homogeneous data set [9-14]. The homogeneity of data such as air pressure, precipitation, wind speed and relative humidity still remain at some experimental levels. The research on the homogeneity of marine hydrological environment data is starting later, and many related fields are still based on the original observation data, which leads to considerable uncertainty in the research conclusions [15-16].

Using the homogeneous data to conduct scientific research is more conducive to a true and reliable assessment of the marine environment historical climate trends and variability, especially for the climate and extreme events research [2, 17]. Therefore, it is an important problem to study all kinds of materials, especially the homogeneous test and revision method of hydrological data in the marine environment.
2. Overview of data homogeneity

The concept of homogeneity was first proposed by Conrad [18] in 1950, and he believed that the uniform time series should contain only weather and climate change. However, most long-term sequences are affected by many non-climatic factors that do not reflect the real changes. Mitchell [19] pointed out in 1953 that site migration, changes in instruments, observation techniques and surroundings were major non-climatic factors affecting homogeneity. These factors may lead to false, discontinuous trends that lead to blurred or even distorted climate change facts [20]. So it is very important to have a homogeneous approach to the data.

2.1. Inhomogeneous generation principle

\( \{y_i\}_{i=1,2,\cdots,n} \) represented a sequence of a element, the so-called homogeneous sequence, that is, the sample \( \{y_i\} \) taken from the same population, and thus have a common mathematical expectations \( E(y_i)=\mu \), and inhomogeneous sequence is the sample \( \{y_i\} \) taken from different populations, the typical performance such as follow:

\[
\begin{align*}
\sum_{i=m+1}^{n} y_i - \mu &= \sum_{i=1}^{m} y_i - \mu + \Delta \\
\mu &= \mu + \Delta \\
\end{align*}
\]

The above equation indicates that the sequence \( \{y_i\} \) changes significantly before and after the m-point, \( \Delta \) indicating a systematic deviation from the mathematical expectation due to a significant change in the observed value after the m-point. The m-point becomes the discontinuity of the sequence [21].

2.2. Classification of homogeneous test methods

There are so many methods of homogeneity test. Li et al. [1] and Li [22] summed up them developed over the past few decades, which is roughly summarized as the following two categories:

- Direct method: including the metadata application, instrument parallel comparison and statistical research;
- Indirect methods: including the use of single station data, construct reference sequence, subjective adjustment and objective statistics.

At present, there are two main trends in the development of data homogeneity test methods. First, do not rely on the reference sequence for single station to be seized data homogeneity test, including the maximum penalty F test [23-25], F test [26], T test [27], U test [27] and bias test [26]. Second, through the multi-station or homogeneous data set as a reference sequence for the data to be tested homogeneity test, including the maximum penalty T test [23-25], standard normal test [4], two regression tests [28], continuous T test [29] and anomaly anomaly [29] and so on.

3. Several commonly used homogeneity test methods

Here are a few commonly used homogeneity test methods and advantages and disadvantages for a brief introduction.

3.1. Standard normal homogeneity test (SNHT)

The widely used SNHT method developed by Alexandersson [4] is a maximum likelihood test method, that uses the data of adjacent stations to construct the reference sequence. The homogeneity test was performed on the ratio or difference sequence of the test sequence and the reference sequence.

\[
T_0 = \max_{1 \leq v < n} \{T_v\} = \max_{1 \leq v < n} \{v z_1^2 + (n - v) z_2^2\}
\]

\[
z_1 = \frac{1}{v} \sum_{i=1}^{v} z_i, \quad z_2 = \frac{1}{n - v} \left( \sum_{i=1}^{n} z_i \right)
\]

(2)
This method is a more commonly used method at home and abroad, but this method needs to rely on the reference sequence, and the selection of the reference sequence has a great impact on the test results. How to choose a good reference sequence is one of the difficulties of homogenization [30].

3.2. Two-phase regression (TPR)

The two-phase regression method was proposed by Solow [28] in 1987, refined by Easterling and Peterson et al. [6] in 1995, and later called E-P technology. This method is applied to the homogenization test of ground temperature. The basic principle is to use the difference of target and reference sequence as the detection sequence, and linear regression before and after the possible discontinuity. When the residual of the two linear regression reaches the minimum value, The time point is the discontinuity of the data (inhomogenous point).

The TPR is one of the most classical methods. It is an effective method to detect the mean and trend turning point in the sequence to be tested. This method has a better detection effect on the discontinuities caused by human [31]. This method is also suitable for Chinese sounding data sequence. It is also proved by Zhai [32] for homogenization of high temperature in Guangzhou and Beijing.

3.3. Penalized Maximal F test (PMFT)

The PMFT method is based on the Penalized Maximal T test (PMT), which empirically considers the problem of statistical deviation caused by the first-order autocorrelation of the time series and embeds the regression test algorithm. Which can be used to test and correct one or more mutations in the sequence point. Through the application of the experience of the penalty function, making the false alarm rate and test the non-uniform distribution of the problem greatly reduced [2, 23-25, 33].

Using this method to carry out the homogeneity of the sequence test does not require the reference sequence, but must have complete and detailed metadata information as a support in order to accurately determine the breakpoint, whether it is a real inhomogenous point. In addition, according to a large number of studies, the single station test method can not completely test the heterogeneity of climate sequence [29]. Because it can not remove the change trend of climate change itself. It will lead to breakpoint judgment on the phenomenon of missing [34]. And the method is affected by the segmentation test, the minimum sequence length that can be verified is 20 [25].

3.4. Penalized Maximal T test (PMT)

PMT and PMFT are the two different test methods of RHtest sequence homogeneity test system, based on the statistical method of good application such as SHNT and TPR [23-25]. The system has obtained a lot of researchers trial and recognized. The PMT is also for the normalized sequence to be tested. Unlike the PMFT, the PMT requires a reference sequence for homogeneity.

\[
P_t = \max_{1 \leq k \leq n-1} \left[ \frac{n-2}{\sum_{i \leq k} (X_i - \mu_1)^2 + \sum_{k+1 \leq i \leq n} (X_i - \mu_2)^2} \left( \frac{k(n-k)}{n} \right)^{\frac{1}{2}} \left| \mu_1 - \mu_2 \right| \right]
\]

(4)

The PMT method eliminates the effect of different sample lengths on the test results, which is much improved compared with SNHT. The use of homogeneous reference sequences can effectively improve the judgment of true non-climatic breakpoints [24].

4. Research on application of homogeneity method in China

In early 1980s, foreign scholars had done a lot of research on the homogeneity of climate data [35-39]. The homogenization study in China started late, and the sounding observations were initiated in the 1990s and were experimental studies for a small number of stations [32, 40]. In recent years, many scholars have devoted to the study and analysis of homogeneity of ground observation elements such
as air temperature, air pressure, precipitation and wind speed [32-33, 41-44]. A series of tentative studies have been carried out, especially the breakthrough in the study of the uniformity of temperature data (1951~2004). The establishment of this data set provides high quality air temperature data reflecting the real climate change in recent 50 years [45]. However, the study of the homogeneity of hydrological and meteorological elements in the marine environment has just started and needs to be developed vigorously.

4.1. Application of homogeneity test on ground meteorological data
Yuan [46] et al. used the method of RHtest software and metadata combination to homogenize and correct the pressure monthly data, which from the 825 base station in China. And the results were remarkable. Founding that there are 400 inhomogeneous stations, and 425 stations existed systematic error. The long-term trend of spatial consistency of pressure data after homogeneous is better.

Li [47] et al. used the SNHT and t test method to homogenize the ground temperature data of Linhe station for a period of 52 years, and the breakpoints appeared in 1980 and 1995 respectively. It coincided with the time of station migration and building construction. Mainly in the season for the winter and summer obvious, followed by the spring and autumn.

Liu [41] et al. used SNHT method to test the average annual wind speed data of 690 stations in China from 1951 to 1990. Cao [33] et al. used the PMFT method and combined with the detailed historical information of the 701 meteorological observation stations, to test the average annual wind speed data in China from 1951 to 2006. The results of the two studies show that the homogeneity of the wind speed data in most stations in our country is in good condition. The instrument change and station migration are the main reasons for the inhomogeneous of the annual mean wind speed sequence. And the former is the most important reason.

Zhu [48] et al. used the PMT method and the PMFT method, selecting a homogenous neighbor station as a reference station, using the relevant system weights to construct the reference sequence on average, combined with metadata information. For nearly 64 years, China's more than 2,400 national terrestrial stations humidity was tested for homogeneity and correction. The results show that there are serious inhomogenous problems in the ground relative humidity data in China, 68% of the stations have breakpoints, artificial observation, automatic observation, relocation and time changes are the main reasons.

4.2. Application of homogeneity test on marine environmental data
At present, many scholars and experts have done a lot of research on the homogeneity test of meteorological observation data series. However, there are few studies on the homogeneity test of marine elements, such as sea level data and sea surface temperature data (SST). Most of the studies remain at the level of trial. And the method is relatively simple [2, 49].

Wang [49] et al. mainly used the trend and periodic signal, and the methods, such as significance test technique, the adjacent station synchronization data comparison, to diagnose and revise the homogeneity of sea level data in the western Bohai Sea. Li [2] et al. used method of PMFT and PMT to test and revise the monthly mean SST of six oceanic observatories with representative and complete data on the Bohai Rim. Although the two methods are different from the research object, the results are similar. Both of them are obviously inhomogeneity. Large distance migration of the station, the changes of the observation system and instrument, the change of zero point, the settlement of the ground and the change of the natural environment are the causes of the inhomogeneity of the data sequence. The long-term trend of the data sequence is more obvious and the linear correlation coefficient becomes larger.

5. Discussion and outlook
In this paper, the principle of inhomogeneity and homogeneity test method were briefly introduced. On this basis, the concrete process and advantages and disadvantages of several commonly used homogenization test methods are expounded in detail. Based on the sounding data, ground
meteorological data and marine environmental data, the application status and progress of different inhomogeneous testing methods are reviewed. At present, there are more than 10 kinds of homogeneity methods. Most scholars use one method to test one or several elements. A lot of literature shows that different homogeneity test methods have different results for the same sequence.

As of 2016, China has more than 120 marine observation stations, domestic and international research on the homogeneity of meteorological data is basically mature. In the marine environmental information research and application should also be given full attention. In order to be able to make full use of these more and more observational data, it is an important problem to be solved urgently in the production of homogeneous scientific and reasonable data sets. How to choose the homogeneity test method which is the most suitable for the hydrological and climatic data of China's marine environment, how to establish a multi-mode inspection system which is a kind of homogeneity test method is also the key direction and key problem of future research.

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References
[1] Li Q X, Liu X N, Zhang H Z, et al. 2003 Homogeneity study of insitu observational climate series J. Meteorological science and technology 31(1) 3-10
[2] Li Y, Mu L, Wang G S, et al. 2016 The detecting and adjusting of the sea surface temperature data homogeneity over coastal zone of circum Bohai Sea J. Haiyang Xuebao 38(3) 27-39
[3] Zhang G J, He J H, Zhou Z J, et al. 2012 Homogeneity Study of Precipitation Data Over China Using RHtest Method J. Meteorological science and technology 40(6) 915-921
[4] Alexandersson H 1986 A homogeneity test applied to precipitation data. J. International Journal Climatology 6 661-675
[5] Jones P D, Bradley R S, Diaz H F, et al.1986 Northern Hemisphere surface air temperature variations:1851-1984 J. Journal of Climate and Applied Meteorology 25 161-179
[6] Easterling D R, Peterson T C 1995 A new method for detecting undocumented discontinuities in climatological time series J. International Journal Climatology 15 369-377
[7] Herzog J, Mulle W G 1996 Homogenization of various climatological parameters in the German weather service R. In:Proceedings of the first seminar for homogenization of surface climatological data 101-111
[8] Peterson T C, Easterling D R, Karl T R, et al. 1998 Homogeneity adjustments of in situ atmospheric climate data: A review J. International Journal of Climatology 18 1493-1517
[9] Li Q X, Liu X N, Zhang H Z, et al. 2004 Detecting and adjusting on temporal inhomogeneity in Chinese mean surface air temperature dataset J. Advance in Atmospheric Sciences 21(2) 260-268
[10] Li Q X, Li W 2007 Construction of the gridded historic temperature dataset over China during the recent half century J. Acta Meteorological Sinia 65(2) 293-300
[11] Li Q X, Peng J D, Shen Y 2012 Development of China homogenized monthly precipitation dataset during 1900-2009 J. Journal of Geographic Science 22(4) 579-593
[12] Cao L J, Zhao P, Yan Z W, et al. 2013 Instrumental temperature series in eastern and central China back to the nineteenth century J. Journal of Geophysical Research: Atmospheres 118(15) 8197-8207
[13] Xu W H, Li Q X, Wang X L, et al. 2013 Homogenization of Chinese daily surface air temperature and analysis of trends in the extreme temperature indices J. Journal of Geophysical Research: Atmospheres 118(17) 9708-9720
[14] Zhang L, Ren G Y, Ren Y Y, et al. 2014 Effect of data homogenization on estimate of temperature trend: a case of Huairou station in Beijing Municipality J. Theoretical and Applied Climatology 115(34) 365-373
[15] Fang G H, Wang K, Guo F Y, et al. 2002 Long-term changes and interrelations of annual
variations of the hydrographical and meteorological parameters of the Bohai Sea during recent 30 years. *J. Oceanological et Limnologia Sinica* **33**(5) 515-525

[16] Yan Z W, Yang C 2001 Influence of Inhomogeneity on the Estimation of Mean and Extreme Temperature Trends in Beijing and Shanghai[J] *Advances in Atmospheric Sciences* **18**(3) 309-322

[17] Xiao B S, Ma Y X, Zhao T B, et al. 2016 Long-Term Trends in Extreme Temperature over China Mainland Based on Homogenized Dataset *J. Meteorological monthly* **42**(3) 339-346

[18] Conrad V, Pollak C 1950 Methods in Climatology 2nd ed. *Cambridge:Harvard University Press* 459

[19] Mitehell J M 1953 On the causes of instrumentally observed secular temperature trends *J. J Meteor* **10**(4) 244-261

[20] Wu H, Zhang C Y, Wang L X, et al. 2013 Maximum Temperature Series in Eastern Forest Region of China in Recent 50 Years *J.Scientia Silvae Sinicae* **49**(8) 1-9

[21] Song C H, Liu X N, Li J M 1995 A Study of Testing Methods on Inhomogeneity of Temperature Sequences *J. Quarterly journal of applied meteorology* **6**(3) 289-296

[22] Li Q X 2011 Introduction to the Study on the Homogeneity of Climate Data *M. Beijing: China Meteorological Press* 11-12

[23] Wang X L 2007 Penalized maximal F-test for detecting undocumented mean-shifts without trend-change *J. Journal of Atmospheric and Oceanic Technology* **25**(3) 368:384

[24] Wang X L, Wen Q H, Wu Y 2007 Penalized maximal t test for detecting undocumented mean change in climate data series *J. Journal of Applied Meteorology and Climatology* **46**(6) 916-931

[25] Wang X L 2008 Accounting for autocorrelation in detecting mean shifts in climate series using the Penalized Maximal t or F Test *J. Journal of Applied Meteorology and Climatology* **47**(9) 2423-2444

[26] Wang S T, Wang B M, et al. 1982 Collation and statistical methods of meteorological data *M. Beijing: China Meteorological Press*

[27] Tu Q P, Wang J D, Ding Y G, et al. 1984 Probability statistics of Meteorological Application *M. Beijing: China Meteorological Press*

[28] Solow A 1987 Testing for climatic chang: An application of the two-phase regression mode *J. J Appl Meteorol* **26** 1401-1405

[29] Wu L H, Mao Y D, Hu D Y, et al. 2005 Sequence homogeneity test and correction system for surface climate data *J. Journal of Zhejiang Meteorology* **26**(4) 40-44.

[30] Guo Y J, Li Q X, Ding Y H 2009 The effect of artificial bias on free air temperature trend derived from historical radiosonde data in China. *J. Meteorological monthly* **33**(6) 1309-1318

[31] Wei N, Sun X, Jiang C Y, et al.2012 Station Relocation Influence on Homogeneity of Temperature Series over Shanxi Province and Deviation Correcton *J. Meteorological monthly* **38**(12) 1532-1537

[32] Zhai P M 1997 Some gross errors and biases in China’s historical radiosonde data *J. Acta Meteorologica Sinica(in Chinese)* **55**(5) 563-572

[33] Cao L J, Ju X H, Liu X N 2010 Penalized Maximal F Test for the Homogeneity Study of the Annual Mean Wind Speed over China J. Meteorological monthly **36**(10) 52-56

[34] Chen Z, YANG X, Liu L K, et al. 2014 Comparative analysis of three methods detecting inhomogeneity of radiosonde temperature data in China *J. Journal of Meteorology and Environment* **30**(6) 141-146

[35] Quayle R G, Easterling D R, Karl T R, et al. 1991 Effects of recent thermometer changes in the cooperative station network *J. Bull. Amer. Meteor. Soc.* **72**(11) 1718-1723

[36] Chenoweth M 1992 A possible discontinuity in the U.S.historical temperature record *J. J.Climate* **5**(10) 1172-11792

[37] Peterson T C 2003 Assessment of urban versus rural in situ surface temperatures in the contiguous United States:No difference found *J. J.Climate* **16**(18) 2941-2959
[38] Wijingaard J B, Klein Tank A M G, Konnen G P 2003 Homogeneity of 20th century European daily temperature and precipitation series J. International Journal of Climatology 23(6) 679-692

[39] Della-Marta P M, Wanner H 2006 A method of homogenizing the extremes and mean of daily temperature measurements J. J. Climate 19(17) 4179-4197

[40] Zhai P M, Eskridge R E 1996 Analyses of inhomogeneities in radiosonde temperature and humidity time series J. J. Climate 9 884-894

[41] Liu X N 2000 The homogeneity test on mean annual wind speed over China J. Quarterly journal of applied meteorology 11(1) 27-34

[42] Wu B W, Wen H Y, Hui J 2008 The inhomogeneity test method of atmospheric pressure sequences based on $\Gamma$-distribution J. Journal of Applied Meteorological Science(in Chinese) 19(4) 496-501

[43] Guo Y J, Ding Y H 2008 Homogeneity and long-term trend analysis on radiosonde temperature time series in China during recent 50 years J. Journal of Applied Meteorological Science(in Chinese) 19(6) 646-654

[44] Li Q X, Peng J D, Shen Y 2012 Development of homogenized monthly precipitation dataset in China during 1900-2009 J. Acta Geographica Sinica(in Chinese) 67(3) 301-311

[45] Si P, Xu W H 2015 Homogenization of Tianjin daily surface air temperatures by sofeware pack RHtestV4 during 1951-2012 J. Climatic and Environmental Research(in Chinese) 20(6) 663-673

[46] Yuan F, Cao L J, Tang G L, et al.2015 Homogenization of monthly Pressure data at 825 Chinese Stations J. Progressus inquisitiones de mutatione climatis 11(5) 331-336

[47] Li J T, Li F P, Duan X L, et al. 2010 Analysis on Homogenization of Temperature Data of the Linhe Meteorological Station J. Meteorology Journal of inner Mongolia 6 14-17

[48] Zhu Y N, Cao L J, Tang G L, et al.2015 Homogenization of Surface Relative Humidity over China. J. Progressus inquisitiones de mutatione climatis 11(6) 379-386

[49] Wang H, Liu K X, Fan W J, et al. 2013 Data uniformity revision and variations of the sea level of the western Bohai Sea J. Marine science bulletin 32(3) 256-264