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Homogeneity Assessment of Trinidad and Tobago's Surface Air Temperature Data

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Abstract: *A homogeneity assessment of the annual mean maximum and minimum surface air temperature data series for Trinidad (Piarco International Airport, 1946-2011) and Tobago (A.N.R Robinson International Airport, 1970-2011) was undertaken to determine whether the data series are suitable in their current form for use in climate change studies. Four statistical change point detection tests were employed, namely, the standard normal homogeneity test, the Buishand range test, the Pettitt test and the Von Neumann ratio test. Statistically significant (p < 0.01) change points were detected by all four tests in the four data series. It is concluded that the available surface air temperature data at these two stations are inhomogeneous thereby rendering the data unsuitable, in their current form, for use in climate change studies. The data must first be homogenised before they could be used to reliably detect changes and trends in the broader-scale climate. It is recommended, therefore, that the stations' histories be constructed using all the relevant available metadata and that at least two reference stations be established to assist with the data homogenisation process.*

Keywords: *Surface air temperature, climate change, change point detection tests, homogeneity assessment*

1. Introduction

Long-term climate data are indispensable in hydrology and climate change studies. However, the analysis of climate time series to detect changes and trends is more reliable when homogenised datasets are used (WMO, 2011). Homogenisation is the process of adjusting a climate dataset to remove artificial non-climatic changes. A climate data time series is homogeneous if the variations exhibited by the series are caused solely by the weather and climate (Conrad and Pollak, 1950).

Unfortunately, most long-term climate data series are affected by a number of factors not related to the broader-scale climate, such as changes in station location; local land use and cover, instrument types, exposure, mounting and sheltering; observation practices; and calculations, codes and units (WMO, 2011). Some changes may cause sharp discontinuities (such as a change in instrument or station location), while others may cause gradual biases (such as the increasing urbanisation in the vicinity of the station). In both cases, the related time series become inhomogeneous, and these inhomogeneities may affect the accurate assessment of climatic trends. Thus, homogeneity assessments must first be undertaken before a climate time series could be reliably used to distil and identify changes in the broader-scale climate (WMO, 2011).

The objective of this study therefore was to perform a homogeneity assessment of annual mean maximum and minimum time series collected at the two main meteorological stations in Trinidad and Tobago (T&T) to determine whether the surface air temperature data are suitable in their current form for use in climate change studies.

2. Statistical Methods

The homogeneity assessment procedure employed by the European Climate Assessment project (Wijngaard et al. 2003), appropriate for detecting inhomogeneities in climate time series and endorsed by WMO (2003), was used. The procedure comprises four complementary statistical tests, namely, the standard normal homogeneity test (Alexandersson, 1986), the Buishand range test (Buishand, 1982), the Pettitt test (Pettitt, 1979), and the Von Neumann ratio test (Von Neumann, 1941). The null hypothesis of each of these four tests is that the series is independent and identically distributed (random). Under the alternative hypothesis, a step-wise shift in the median (Pettitt test) or in the mean (the standard normal homogeneity and the Buishand range tests) is present. The Von Neumann ratio test assumes under the alternative hypothesis that the series is not randomly distributed and complements the other three tests because of its sensitivity to departures of homogeneity that are of a nature other than strict step-wise shifts. Whereas the first three tests are location-specific and thus capable of locating the year in which a break is likely, the Von Neumann ratio test does not give information on the year of the break.

Wijngaard et al. (2003) further explained that although the three location-specific tests have many characteristics in common, they are also different. For example, the Pettitt and Buishand range tests are more sensitive to breaks in the middle of the series whereas the standard normal homogeneity test detects breaks near the beginning and the end of a series relatively easily. The standard normal homogeneity and the Buishand range tests assume the series values are normally distributed while the Pettitt test does not, since it is based on the ranks of the series values rather than the values themselves. Thus, the Pettitt test is less sensitive to outliers and departures from normality than the other tests.

According to the Wijngaard et al. (2003) procedure, depending on the number of tests rejecting the null hypothesis, the data series can be placed in one of three categories. If zero or one test rejects the null hypothesis at the 1% level, the data series belongs to class 1 ('useful') and is deemed sufficiently homogeneous for trend and variability analyses. If two tests reject the null hypothesis at the 1% level, the data series belongs to class 2 ('doubtful'), so the results of trend and variability analyses should be regarded critically from the perspective of possible inhomogeneities. If three or four tests reject the null hypothesis at the 1% level, the data series belongs the class 3 ('suspect') and is deemed unsuitable for use in trend and variability analyses.

3. Data Used

The annual mean maximum and minimum surface air temperature data series used in the analysis were collected at the Piarco International Airport in Trinidad and the A.N.R. Robinson International Airport in Tobago for the periods 1946-2011 and 1970-2011 respectively.

4. Results and Discussion

Time series plots of the four data sets are shown in Figures 1 to 4. Table 1 shows the homogeneity test results for the annual mean maximum temperature time series for Trinidad. The test statistics for the first three tests all exceed their corresponding critical test statistic, indicating the presence of a statistically significant ($p < 0.01$) change point (1987). The Von Neumann ratio test, unlike the other three tests, yields a statistically significant result when the test statistic is less than the critical test statistic and therefore confirms the results of the other three tests. This implies that the annual mean maximum temperature time series in its current form is inhomogeneous and unsuitable for use in trend and variability analyses.

Similarly, the results for the other three time series in Tables 2, 3 and 4 show that all four tests detected the presence of statistically significant ($p < 0.01$) change points and, by so doing, signal that these three time series are also inhomogeneous and thus unsuitable for use in their current form for trend and variability analyses.

It is important to note that the homogeneity assessment above using the absolute tests detects only the most obvious inhomogeneities arising from an abrupt shift in the mean/median due to, for example, the recalibration or change of an instrument, relocation of the instrument to a new site or the construction of a heat source such as a building or car park near to the site of the instrument.

Table 1. Homogeneity test results for annual mean maximum temperature in Trinidad, 1946-2011

Test	Test statistic	Critical test statistic (1%)	Change point	Result
Standard normal homogeneity	42.19	11.79	1987	Reject
Buishand range	3.17	1.80	1987	Reject
Pettitt	988	469	1987	Reject
Von Neumann ratio	0.54	1.43	-	Reject

Table 2. Homogeneity test results for annual mean minimum temperature in Trinidad, 1946-2011

Test	Test statistic	Critical test statistic (1%)	Change point	Result
Standard normal homogeneity	47.0	11.79	1987	Reject
Buishand range	3.4	1.80	1987	Reject
Pettitt	1014	469	1980	Reject
Von Neumann ratio	0.32	1.43	-	Reject

Table 3. Homogeneity test results for annual mean maximum temperature in Tobago, 1970-2011

Test	Test statistic	Critical test statistic (1%)	Change point	Result
Standard normal homogeneity	15.78	11.08	1986	Reject
Buishand range	2.14	1.75	1986	Reject
Pettitt	315	225	1986	Reject
Von Neumann ratio	0.96	1.30	-	Reject

Table 4. Homogeneity test results for annual mean minimum temperature in Tobago, 1970-2011

Test	Test statistic	Critical test statistic (1%)	Change point	Result
Standard normal homogeneity	22.66	11.08	1995	Reject
Buishand range	2.39	1.75	1994	Reject
Pettitt	416	225	1994	Reject
Von Neumann ratio	0.58	1.30	-	Reject

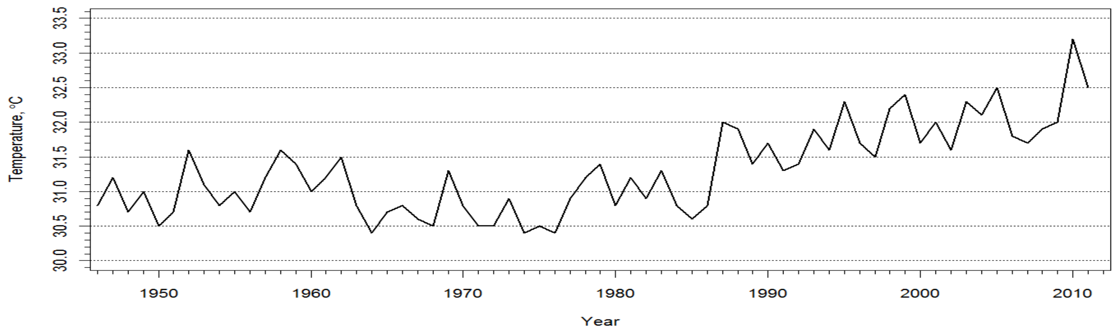

Figure 1. Time series plot of annual mean maximum surface air temperature in Trinidad, 1946-2011

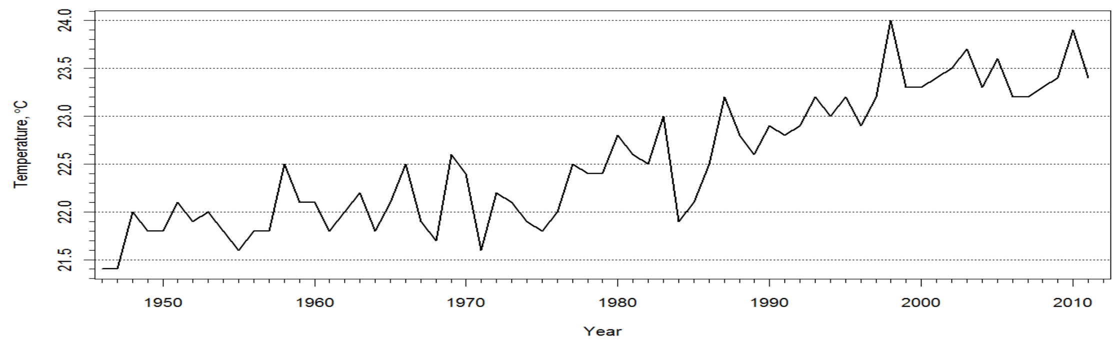

Figure 2. Time series plot of annual mean minimum surface air temperature in Trinidad, 1946-2011

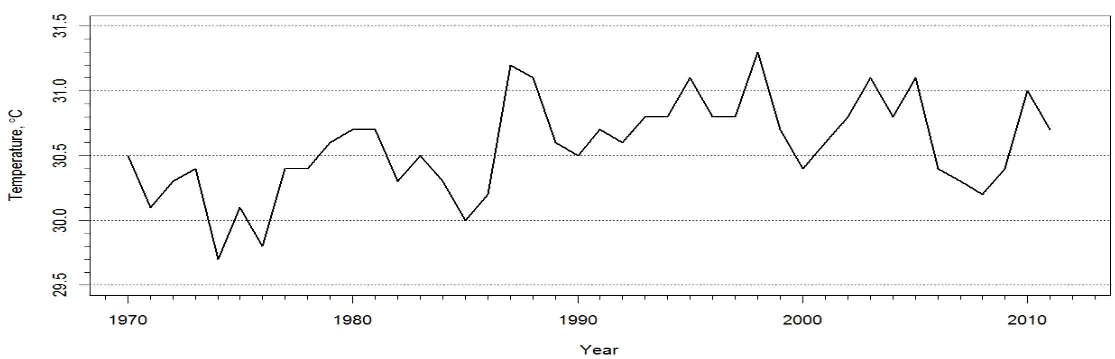

Figure 3. Time series plot of annual mean maximum surface air temperature in Tobago, 1970-2011

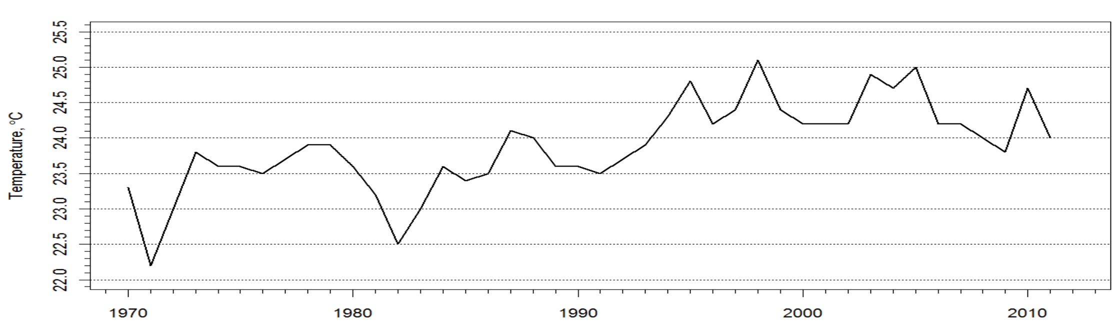

Figure 4. Time series plot of annual mean minimum surface air temperature in Tobago, 1970-2011

There may be, however, other inhomogeneities present in the two data series due to a gradual but constant degradation of a sensor (instrument drift), or gradual land-use and land cover changes around the instrument site. For this reason, it has long been recommended (e.g. Conrad and Pollak, 1950; Peterson et al., 1998) that it is more effective and reliable to apply homogeneity tests relatively, that is, testing with respect to a neighbouring reference station that is supposedly homogeneous. A reference station is one that is ideally sited and would have experienced all of the broad climatic influences of the station whose data are to be homogenised but none of its artificial biases (WMO, 2003).

Szentimrey (2006) emphasised the deficiency of absolute homogenisation methods thus: "The main problem of the application of absolute methods is that the separation between the climate change signal and the inhomogeneity is essentially impossible." More recent research has demonstrated that absolute homogenisation, where only the station time series is used, can make the data series more inhomogeneous because it is difficult to distinguish small inhomogeneities from climate variability (Venema, 2012).

Unfortunately, neighbouring reference stations are not available for the two stations whose data series have been assessed. It is therefore virtually impossible to reliably homogenise the data series at these two stations at the current time. This highlights the need for the establishment of other temperature measuring stations close enough to these two stations and in other parts of Trinidad and Tobago to make it possible to reliably detect a climate change temperature signal.

Moreover, another important factor, alluded to previously, that adversely affects the quality of the temperature data, is the siting of the weather station. For a station's site to be considered representative of a larger area, it must satisfy certain specific siting requirements. Therefore, these two stations were investigated to determine whether they satisfy the World Meteorological Organisation-approved siting requirements, as described by Leroy (2010). According to the Leroy (2010) siting classification scheme, a site can be placed in one of 5 classes; class 1 is best whereas class 5 is worst. Classes 1 and 2 are considered compliant sites without any warming bias, while classes 3, 4 and 5 are considered non-compliant with varying amounts of warming bias.

To satisfy class 1, the measurement point must be situated at no less than 100 m from heat sources or reflective surfaces (buildings, concrete surfaces, car parks, etc.). More specifically, a source of heat should occupy no more than 10% of the surface within a circular area of 100 m surrounding the screen, make up no more than 5% of an annulus of 10 m-30 m, or covers no more than 1% of a 10 m circle.

To satisfy class 2, the measurement point must be situated at no less than 30 m from artificial heat sources or reflective surfaces (buildings, concrete surfaces, car parks, etc.). More specifically, a source of heat should occupy no more than 10% of the surface within a circular area of 30 m surrounding the screen, make up no more than 5% of an annulus of 5 m-10 m, or cover no more than 1% of a 5 m circle.

Both stations failed to meet classes 1 and 2 siting requirements, but met the class 3 requirements. To satisfy class 3 requirements, the measurement point must be situated at no less than 10 m from artificial heat sources or reflective surfaces (buildings, concrete surfaces, car parks etc.). More specifically, a source of heat should occupy no more than 10% of the surface within a circular area of 10 m surrounding the screen or make up no more that 5% of an annulus of 5 m. Class 3 station measurements are considered to have an additional estimated uncertainty of up to 1 °C. This fact again emphasises the need for properly sited reference stations to allow the detection of the inherent warming bias in the temperature measurements at these two stations. It is also important to note that the measurements at these two stations cannot be taken to be representative of any area beyond the micro-climate of the airports where they are located. The measurements may therefore be suitable for aviation, forecasts and warnings but not for climate change studies where accurate and reliable temperature data are needed to detect the small increase in temperature expected from climate change.

These results therefore underscore the need for adherence to the Global Climate Observing System (GCOS) climate monitoring principles 3 and 4 (WMO, 2011) at these two meteorological stations. The GCOS climate monitoring principle 3 states:

> "The details and history of local conditions, instruments, operating procedures, data processing algorithms and other factors pertinent to interpreting data (i.e. metadata) should be documented and treated with the same care as the data themselves."

The GCOS climate monitoring principle 4 states: "The quality and homogeneity of data should be regularly assessed as part of routine operations." WMO (2011) further emphasised the importance and relevance of homogeneous datasets thus:

> "Unlike observations taken solely to support the preparations of forecasts and warnings, the availability of a continuous, uninterrupted climate record is the basis for many important studies involving a diverse array of climatological communities. Homogeneous climate datasets are of utmost importance for meeting the needs of climate research, applications and user services."

In addition, there is an urgent need in Trinidad and Tobago for the establishment of class 1 temperature stations (reference stations) for the reliable detection a possible global warming signal in our climate.

The importance of metadata and proper station siting for detecting a global warming signal in a temperature data series was aptly summarised in a report by WMO (1993) thus:

> "A purely meteorological or climatological interpretation of data presumes the systematic elimination of all non-meteorological, non-climatological sources or error. Let us take the example of an increase in the mean air temperature observed over a period of twenty years. Is the change attributable to a change in thermometer, to a change from manual to automatic measurement, to the erection of new buildings near the weather station, to a change of observer, to instrument drift or to an actual warming trend or some other cause?"

The report goes on to add that climatologists cannot claim to have demonstrated the detection of the small change in temperature expected from global warming "with certainty unless their data is extremely accurate", and:

> "is free of all the types of errors mentioned above" and "shows how users could benefit from a precise description of the conditions under which measurements have been taken and of the historical background of the measuring facilities, as well as a listing of changes that have occurred in the surroundings of each station."

5. Conclusion

The major conclusion that can be drawn from this study is that the two major surface air temperature datasets available in Trinidad and Tobago are inhomogeneous and therefore unsuitable for use in climate change studies. These two datasets must first be homogenised before they could be used to reliably detect changes and trends in the broader-scale climate. Unfortunately, in the absence of suitable reference stations and the unavailability of metadata to undertake the homogenisation exercise, the creation of homogenised datasets is currently impossible. Additionally, the failure of the two meteorological stations to meet the World Meteorological Organisation-approved siting requirements implies that these two datasets have an additional inherent warming bias due to poor siting and should therefore be used with extreme caution. It is recommended that class 1 reference stations be established in Trinidad and Tobago to facilitate valid climate change studies to detect temperature trends and variability.

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