Time series homogenization

Case of monthly temperature series of the northern part of Madagascar

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ABSTRACT. The statistical technique for detecting jumps in the temperature series based on the regression model is favorable for homogenizing the climate data of the northern part of Madagascar. Thus, we will present the results of the homogenization of the series of maximum and minimum temperatures corresponding to the Antsiranana climate station. The homogenization of the temperature series is carried out at the monthly and daily scales.

RÉSUMÉ. La technique statistique pour la détection des sauts dans les séries de températures basée sur le modèle de régression est favorable pour homogénéiser les données climatiques de la partie Nord de Madagascar. Ainsi, nous allons présenté les résultats de l'homogénéisation des séries des températures maximales et minimales correspondant au station climatiques d'Antsiranana. L'homogénéisation des séries de températures est réalisée aux échelles mensuelle et quotidienne.

KEYWORDS : homogenization, hydrology, climatology, tests, trend, jumps.

MOTS-CLÉS : homogénéisation, hydrologie, climatologie, tests, tendance, sauts.

1. Motivations and introduction

The statistical characteristics of the recordings in a measuring station can undergo all kinds of artificial disturbances which do not reflect the real variations of the climate: displacement of stations, replacement of measuring instruments, change of hours of observations or modification of the immediate environment of the measuring instrument. As a result, decisions may be made based on data that contains errors. Meteorological network data are used in most climate variability research. The reliability of these data should be verified before using them in this area. Indeed, the need for long series of reliable climate data is increasingly felt in various areas. For example, climate change studies require the creation of comprehensive databases with which the climate signal can be adequately analyzed, tracked over time and predict future changes with minimal uncertainty of error. It is also very important to find robust techniques for detecting these artificial biases so that the data used is as close as possible to the observations that would have been made without disturbing the measurement conditions. The process of detection and correction of non-climatic breaks is called homogenization.

2. Data

The data used for this study come from the General Directorate of Meteorology, series of temperatures (minimum and maximum) at the time step per day from January 1st, 1950 to December 31st, 2008 from the five weather stations located in the Northern region of Madagasca (table: 1 and the tables:4 to 8)

Country	Number ID	Station Name		Longitude	Beginning	End
Madagascar	10111	Antsiranana	12° 21’04” S	49° 17’39” E	1950	2007
Madagascar	21011	Antalaha	14° 59’56” S	50° 19’12” E	1991	2004
Madagascar	20511	Sambava	14° 16’43” S	50° 10’29” E	1950	2008
Madagascar	30511	Nossy Be	13° 19’05” S	48° 18’33” E	1950	2007
Madagascar	67295	Vohemar	13° 22’22” S	49° 59’56" E	1950	2006

Table 1. *Characteristics of the base station and its neighbors*

3. Methodology

Various homogenization techniques([2], [3], [4], [6]) have been developed to accommodate different types of factors such as the variable to be homogenized, the spatial and temporal variability of the data depending on where the stations are located, the length of the series and the number of missing data (Aguilar et al., [1]).

The method we used in this study is based on linear regression models that look for both jumps and trends. These are models in which the conditions of normality, independence and heteroskedasticity of the data are assumed, and which are solved by standard least squares techniques. Multiple regression is based on the application of several regression models to homogenize temperature series (Vincent, [11]). When the residues are independent, the applied model fits the data well. If not, adjust with another model. The discontinuity determination in the basic series is identified with the following model:

$$y_i = \begin{cases} \tau + \beta_1 x_{i1} + \ldots + \beta_k x_{ik} + e_i + & i = 1 \ldots p \\ \tau + \delta + \beta_1 x_{i1} + \ldots + \beta_k x_{ik} + e_i & i = p+1 \ldots n \end{cases}$$

where y_i is the value of the base series at time i, x_{ik} is the value of the reference series k at time i. There are n observations and k reference series. The jump location, p, is determined by adjusting the model for all possible positions and selecting the one with the smallest sum of residual squares. The choice of the jump position is valid according to the Fisher test. The estimate of the jump amplitude is given by δ and its significant threshold is calculated according to the Student statistic (Vincent, [11]). A two-phase regression model can detect a change in mean and / or trend in a series (Solow, [10]). Either the adjusted model represents a series in which there is a one-point discontinuity p:

$$y_i = \begin{cases} \tau_1 + \lambda_1 i + e_i + & i = 1 \ldots p \\ \tau_2 + \lambda_2 i + e_i + & i = p+1 \ldots n \end{cases}$$

where y_i is the value of the base series at time i, τ_1 and τ_2 are the means before and after the change, λ_1 and λ_2 are the trends before and after the change and p is the position of the change. The model residuals are represented by e_i. The location of the jump is determined by least squares. Several changes have been made:

– Easterling and Peterson [6] apply the technique iteratively to detect several jumps and evaluate the significant thresholds by a multiple permutation procedure [8];

– Lund and Reeves [7] provide a revised Fisher statistic;

– Wang [13] proposes a model in which the slopes are equal before and after the break. We retained the improved version by Xiaolan Wang based on the maxima t test with penalty [14] and the maximum F test with penalty [16], nested in a recursive test algorithm [15].

This method has been used successfully in many studies on the analysis of extremes of precipitation and temperature around the world (Vincent et al., [12], Aguilar et al., [5]; Meehl et al, [9])

4. Homogenization process

It is almost impossible to be 100% sure of the quality of the past data, an assessment of homogeneity is always recommended. The best recommended technique is to go through the following four steps below:

– Metadata analysis and quality control.
– Creating a series of reference times.
– Detection of change points (jumps).
– Data adjustment.

4.1. Quality control

It is applied to detect and identify errors made in the process of recording, handling, formatting, transmitting and archiving data.[1]

4.2. Quantiles-Match (QM) adjustment

It aims to adjust the series so that the empirical distribution of all segments of the trend-removed basic series match (Wang [15]); the value of the adjustment then depends on the empirical frequency of the values to be adjusted. As a result, the shape of the distribution is often adjusted, although the tests are supposed to detect jumps in averages; and the QM adjustment takes into account the seasonality of the change. Also, the annual cycle, the delay autocorrelation of 1, and the linear trend of the base series were estimated while explaining all the identified hops (Wang [15]); and the predicted trend for the base series is preserved in the QM adjustment algorithm.

The homogenization of the monthly temperatures is performed by adjusting the monthly temperature data observed before the date of the jump by correction factors. These correction factors are calculated taking into account the position of the jumps and their amplitudes obtained from the QM algorithm. The figures (figure: 1) and (figure: 2) represent the raw monthly temperature data observed and the linear trend jumps by multiphase regression model from 1960 to 2007 .

4.3. Homogenization of monthly series

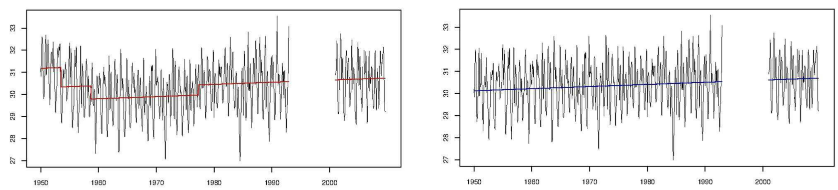

Figure 1. *Non-homogeneous and homogeneous series of maximum monthly temperatures, Antsiranana station*

The process of homogenization allowed us to retain three jumps in the series of maximum temperatures (figure: 1) and four jumps in the series of to one minimum temperatures (figure: 2).

Seg	Date	Amplitude	correction factors
1	1953 07	-0.88	-0.9892
2	1958 09	-0.5979	-0.1025
3	1977 04	0.4595	0.4281

Table 2. *Maximum temperature correction factors*

The tables (table: 2) and (array: 3) present respectively the estimated parameters of the regression model correction to n phase(s) corresponding to the detected jump in the series of monthly maximum and minimum temperatures.

The figures (figure: 5) and (figure: 4) represent the distribution of the QM (Quantile-Match) adjustments of each segment applied, respectively, to the maximum monthly temperature series and minimum.

The analysis of the figures (figure: 1) and (figure: 2) also shows that the smallest correction ($0 < A_m \leq 0,1^{\circ}C$) made to the monthly temperature series is performed during all periods, while the largest correction ($A_m \geq 1,9^{\circ}C$).

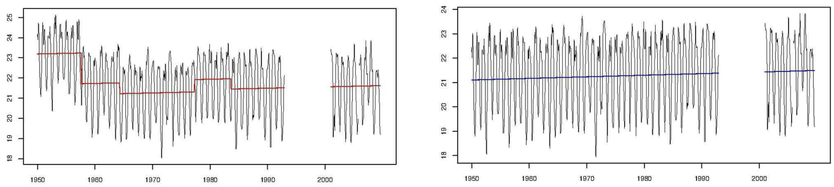

Figure 2. *Non-homogeneous and homogeneous series of minimum monthly temperatures, Antsiranana station*

Seg	Date	Amplitude	Correction factors
1	1957 08	-1.5242	-1.9416
2	1964 04	-0.5371	-0.5075
3	1977 04	0.6148	0.1057
4	1983 08	-0.5114	-0.4250

Table 3. *Minimum temperature correction factors*

The homogenization of the monthly series provides the date and the amplitude of the breaks detected. Although it is not possible to apply the correcting coefficients to the daily data, the dates of the breaks nevertheless make it possible to determine supposedly homogeneous periods..

5. Discussion

The use of the QM adjustment takes into account the seasonality of the change; it is possible for the winter and summer temperatures to be adjusted differently because they belong to different quantiles of the distribution. This is a strong point of the temperature homogenization method used in this article. In fact, the anthropogenic influence of the measurement process at the climate station does not have the same impact on the measurement carried out during the different periods of the year.

We calculated the annual average from the homogenized maximum and minimum daily temperature series. These series are subsequently compared with the series of homogenized monthly temperatures obtained during the treatment. This comparison allows us to verify the consistency between the homogenization of annual temperature series and the homogenization of the monthly temperature series.

For the comparison, we calculated the average temperature per station, during the period 1950 to 2007, using the two homogenized monthly series. The analysis of the result clearly shows the coherence between the homogenization of annual temperatures and monthly temperatures.

6. Conclusion

The process of homogenization allowed us to retain three jumps in the series of maximum temperatures (1953 with an amplitude of $-0.88^{\circ}C$, 1958 with an amplitude of $-0.60^{\circ}C$ and 1977 with an amplitude of $0.46^{\circ}C$) and four jumps in the series of minimum temperatures (1957 with an amplitude of $-1.53^{\circ}C$, 1964 with an amplitude of $-0.54^{\circ}C$, 1974 with an amplitude of $0.61^{\circ}C$ and 1983 with an amplitude of$-0.51^{\circ}C$).

From the positions of jumps and their amplitudes, we found the monthly correction factors corresponding to the 12 months of the year. The tables 2 and 3 present the values of these factors for the three hops identified from the annual minimum temperature series. The table analysis 2 and 3 shows that the monthly correction factors are not distributed according to a uniform law.Thus, the corrections made to the monthly temperatures differ from one month to another. This constitutes a strong point of the method of homogenization of the temperatures used. In fact, the anthropogenic influence of the measurement process at the climate station does not have the same impact on the measurement made during the different periods of the year.

The monthly correction factors were calculated for all the minimum and maximum monthly temperature series corresponding to the 5 stations selected in this study. We also adjusted the correction factors when the value of the mean absolute error is not equal to zero.

7. References

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Appendix 1

Extracts from station processing

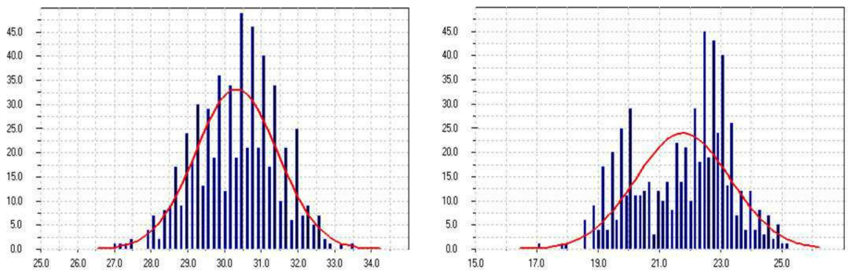

Figure 3. *Normal distribution of maximum and minimum temperature at* $[a; b] = 0.15\,^{\circ}C$ *from Antsiranana station*

Antsiranana Aero	Maximum temperature	Minimum temperature
Period	1950-2009	1950-2009
Length of Series	619	619
missing values	102	101
Arithmetic average	30.32	21.77
Standard deviation	1.11	1.55
Variance	1.24	2.39
Variance Coefficiente	3.67%	7.10%
Coefficient of Skew	-0.14	-0.32
Coefficient of Kurtosis	-0.36	-0.74
Maximum value	33.50 (1990.92)	25.10 (1953.17)
Minimal value	27 (1984.50)	17 (2007.58)
1st Quartile (25%)	29.50	20.40
Median	30.40	22.20
3rd Quartile (75%)	31.10	22.90
Kolmogorov-Smirnov test	$D = 0.05(p = 0.09, O.K.)$	$D = 0.11(p = 0.00, Non)$
Linear Regression Model	$y = 30.13 + 0.00 \times x$	$y = 22.30 - 0.00 \times x$
Coefficient of T-test b1	$T = 2.77 < 1.96(95\%)$	$T = -5.44 > -1.96(95\%)$
Trend / 10 years	$0.01(Nom)$	$-0.02\ (Non)$
Determination Index (Correlation)	$0.01(0.11)$	$0.05(0.21)$
Variance (Residual + Estimate = Total)	$1.22 + 0.02 = 1.24$	$2.27 + 0.11 = 2.38$
Correlation Coefficient Series	$r1 = 0.65 < r1(Tg_{95\%}) = 0.06\ (Non)$	$r1 = 0.81 < r1(Tg_{95\%}) = 0.06\ (Non)$
Report by Von Neumann	$V = 0.70 > V(Tg_{95\%}) = 1.87\ (Non)$	$V = 0.37 > V(Tg_{95\%}) = 1.87\ (Non)$
Statistics of Rank Spearman	$rs = 0.09, t = 2.35 < Tkrit_{97.5\%} = 1.96\ (Non)$	$rs = -0.21, t = -5.46 < Tkrit_{97.5\%} = 1.96\ (Non)$
Statistics of Rang Mann-Kendall	$t = 0.04 < Tkrit_{95\%} = 0.05\ (O.K.)$	$t = -0.16 < Tkrit_{95\%} = 0.05\ (Non)$
Confidence Interval of Arithmetic Mean.	$(30.24, 30.41)$	$(21.65, 21.89)$

Table 4. *Statistical parameters of maximum and minimum temperature of Antsiranana stationa*

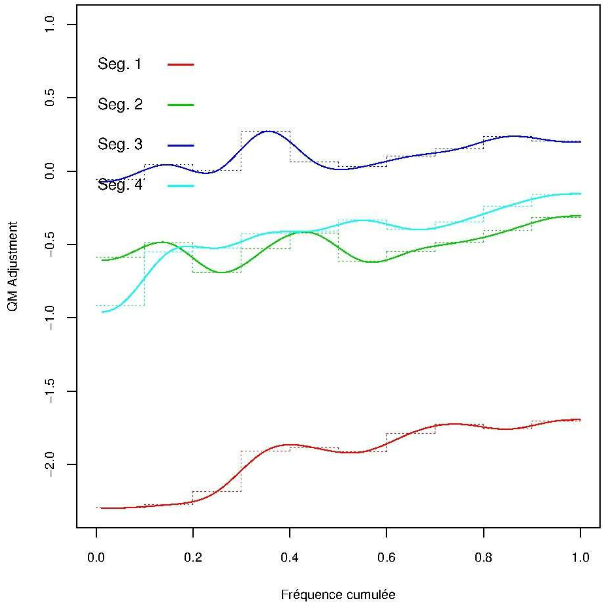

Figure 4. *Distribution of QM adjustments of minimum temperatures*

Vohemar Aero	Maximum temperature	Minimum temperature
Period	1950-2009	1950-2009
Length of Series	456	456
missing values	273	264
Arithmetic average	28.78	21.74
Standard deviation	1.64	1.52
Variance	2.69	2.32
Variance Coefficiente	5.70%	7.01%
Coefficient of Skew	-0.22	-0.35
Coefficient of Kurtosis	-1.04	-1.18
Maximum value	32.30 (1987.08,2001)	24.30 (1987.08)
Minimal value	25.10 (1984.50)	18.20 (1953.58)
1st Quartile (25%)	27.40	20.30
Median	29	22.10
3rd Quartile (75%)	30.20	23.05
Kolmogorov-Smirnov test	$D = 0.08(p = 0.00, Non)$	$D = 0.15(p = 0, Non)$
Linear Regression Model	$y = 28.56 + 0.00 \times x$	$y = 21.29 + 0.00 \times x$
Coefficient of T-test b1	$T = 1.77 < 1.97(95\%)$	$T = 4.13 < 1.97(95\%)$
Trend / 10 years	0.01	0.02 (out)
Determination Index (Correlation)	0.01 (0.08)	0.04 (0.19)
Variance (Residual + Estimate = Total)	$2.66 + 0.02 = 2.68$	$2.23 + 0.08 = 2.32$
Correlation Coefficient Series	$r1 = 0.78 < r1(Tg_{95\%}) = 0.08\ (Non)$	$r1 = 0.81 < r1(Tg_{95\%}) = 0.07\ (Non)$
Report by Von Neumann	$V = 0.44 > V(Tg_{95\%}) = 1.85\ (Non)$	$V = 0.38 > V(Tg_{95\%}) = 1.85\ (Non)$
Statistics of Rank Spearman	$rs = 0.06, t = 1.18 < Tkrit_{97.5\%} = 1.97\ (O.K.)$	$rs = 0.19, t = 4.22 < Tkrit_{97.5\%} = 1.97\ (Non)$
Statistics of Rang Mann-Kendall	$t = 0.02 < Tkrit_{95\%} = 0.06\ (O.K.)$	$t = 0.11 < Tkrit_{95\%} = 0.06\ (Non)$
Confidence Interval of Arithmetic Mean	$(28.62, 28.93)$	$(21.60, 21.88)$

Table 5. *Statistical parameters of maximum and minimum temperature of the Vohemar station*

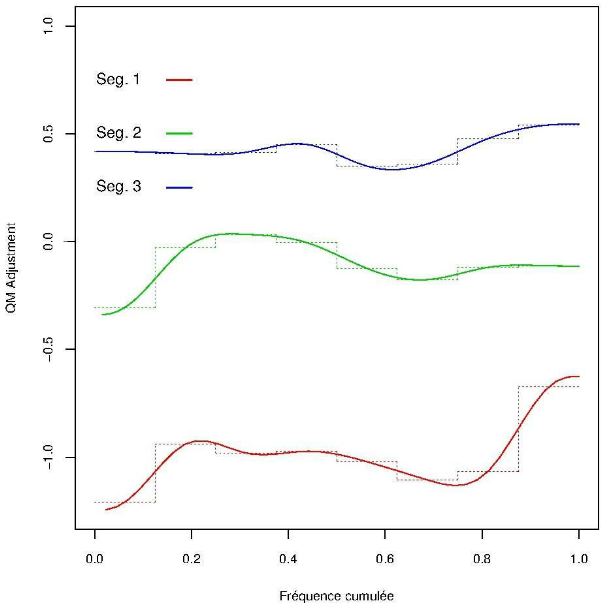

Figure 5. *The distribution of QM adjustments of maximum temperatures*

Antalaha Aero	Maximum temperature	Minimum temperature
Period	1991-2004	1991-2004
Length of Series	107	107
Missing values	61	61
Arithmetic average	28.63	21.10
Standard deviation	2.13	1.77
Variance	4.53	3.12
Variance Coefficiente	7.43%	8.37%
Coefficient of Kurtosis	-0.21	-0.15
Coefficient of Kurtosis	-1.35	-1.49
Maximum value	32.10 (1996)	23.70 (2002.08)
Minimal value	24.80 (1992.58)	18.10 (1992.50,1996.50)
1st Quartile (25%)	26.55	19.50
Median	28.90	21.30
3rd Quartile (75%)	30.50	22.80
Kolmogorov-Smirnov test	$D = 0.12(p = 0.11, O.K.)$	$D = 0.14(p = 0.03, Non)$
Linear Regression Model	$y = 28.47 + 0.00 \times x$	$y = 20.76 + 0.00 \times x$
Coefficient of T-test b1	$T = 0.59 < 1.98(95\%)$	$T = 1.43 < 1.98(95\%)$
Trend / 10 years	0.02	0.05
Determination Index (Correlation)	$0.00(0.06)$	$0.02(0.14)$
Variance (Residual + Estimate = Total)	$4.47 + 0.01 = 4.49$	$3.03 + 0.06 = 3.09$
Correlation Coefficient Series	$r1 = 0.82 < r1(Tg_{95\%}) = 0.15\,(Non)$	$r1 = 0.76 < r1(Tg_{95\%}) = 0.15\,(Non)$
Report by Von Neumann	$V = 0.36 > V(Tg_{95\%}) = 1.70\,(Non)$	$V = 0.48 > V(Tg_{95\%}) = 1.70\,(Non)$
Statistics of Rank Spearman	$rs = 0.07, t = 0.70 < Tkrit_{97.5\%} = 1.98\,(O.K.)$	$rs = 0.13, t = 1.36 < Tkrit_{97.5\%} = 1.98\,(O.K.)$
Statistics of Rang Mann-Kendall	$t = 0.03 < Tkrit_{95\%} = 0.13\,(O.K.)$	$t = 0.07 < Tkrit_{95\%} = 0.13\,(O.K.)$
Confidence Interval of Arithmetic Mean.	$(28.23, 29.04)$	$(20.76, 21.43)$

Table 6. *Statistical parameters of maximum and minimum temperature of Antalaha station*

Nosy Be Aero	Maximum temperature	Minimum temperature
Period	1950-2009	1950-2009
Length of Series	628	628
missing values	92	92
Arithmetic average	31.16	21.15
Standard deviation	1.12	1.92
Variance	1.24	3.69
Variance Coefficiente	3.58%	9.08%
Coefficient of Skew	-0.23	-0.48
Coefficient of Kurtosis	-0.45	-1.05
Maximum value	34.20 (2006.83)	24.60 (2008.08)
Minimal value	28.30 (1952.50,1956.50,1974.50)	16.70 (1968.50)
1st Quartile (25%)	30.40	19.40
Median	31.20	21.80
3rd Quartile (75%)	32	22.80
Kolmogorov-Smirnov test	$D = 0.06(p = 0.02, Non)$	$D = 0.15(p = 0, Non)$
Linear Regression Model	$y = 30.26 + 0.00 \times x$	$y = 20.95 + 0.00 \times x$
Coefficient of T-test b1	$T = 14.03 < 1.96(95\%)$	$T = 1.60 < 1.96(95\%)$
Trend / 10 years	0.03 (Non)	0.01
Determination Index (Correlation)	$0.24(0.49)$	$0.00(0.06)$
Variance (Residual + Estimate = Total)	$0.95 + 0.30 = 1.24$	$3.67 + 0.02 = 3.68$
Correlation Coefficient Series	$r1 = 0.66 < r1(Tg_{95\%}) = 0.06\,(Non)$	$r1 = 0.81 < r1(Tg_{95\%}) = 0.06\,(Non)$
Report by Von Neumann	$V = 0.68 > V(Tg_{95\%}) = 1.87\,(Non)$	$V = 0.38 > V(Tg_{95\%}) = 1.87\,(Non)$
Statistics of Rank Spearman	$rs = 0.49, t = 14.02 < Tkrit_{97.5\%} = 1.96\,(Non)$	$rs = 0.08, t = 1.88 < Tkrit_{97.5\%} = 1.96\,(O.K.)$
Statistics of Rang Mann-Kendall	$t = 0.31 < Tkrit_{95\%} = 0.05\,(Non)$	$t = 0.03 < Tkrit_{95\%} = 0.05\,(O.K.)$
Confidence Interval of Arithmetic Mean.	$(31.07, 31.25)$	$(21.00, 21.30)$

Table 7. *Statistical parameters of maximum and minimum temperature of Nossy Be station*

Sambava Aero	Maximum temperature	Minimum temperature
Period	1950-2009	1950-2009
Length of Series	566	566
missing values	154	159
Arithmetic average	28.75	20.51
Standard deviation	1.75	1.89
Variance	3.07	3.56
Variance Coefficiente	6.09%	9.19%
Coefficient of Skew	-0.05	-0.09
Coefficient of Kurtosis	-1.28	-1.29
Maximum value	32.30 (2007.08)	24.10 (1992)
Minimal value	24.80 (1984.50)	16.60 (1956.50,1959.67)
1st Quartile (25%)	27.10	18.77
Median	28.90	20.70
3rd Quartile (75%)	30.30	22.20
Kolmogorov-Smirnov test	$D = 0.10(p = 0.00, Non)$	$D = 0.10(p = 0.00, Non)$
Linear Regression Model	$y = 28.76 - 0.00 \times x$	$y = 19.94 + 0.00 \times x$
Coefficient of T-test b1	$T = -0.11 > -1.96(95\%)$	$T = 4.44 < 1.96(95\%)(O.K)$
Trend / 10 years	-0.00	$0.02\,(Non)$
Determination Index (Correlation)	$0.00(0.00)$	$0.03(0.18)$
Variance (Residual + Estimate = Total)	$3.06 + 0.00 = 3.06$	$3.43 + 0.12 = 3.55$
Correlation Coefficient Series	$r1 = 0.80 < r1(Tg_{95\%}) = 0.07\,(Non)$	$r1 = 0.83 < r1(Tg_{95\%}) = 0.07\,(Non)$
Report by Von Neumann	$V = 0.39 > V(Tg_{95\%}) = 1.87\,(Non)$	$V = 0.34 > V(Tg_{95\%}) = 1.86\,(Non)$
Statistics of Rank Spearman	$rs = -0.02, t = -0.48 < Tkrit_{97.5\%} = 1.96\,(O.K.)$	$rs = 0.22, t = 5.32 < Tkrit_{97.5\%} = 1.96\,(Non)$
Statistics of Rang Mann-Kendall	$t = -0.03 < Tkrit_{95\%} = 0.06\,(O.K.)$	$t = 0.14 < Tkrit_{95\%} = 0.06\,(Non)$
Confidence Interval of Arithmetic Mean.	$(28.60, 28.89)$	$(20.36, 20.67)$

Table 8. *Statistical parameters of maximum and minimum temperature of Sambava station*