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# Analysis of Variability of Bright Sunshine Hours And Temperature in Tea-growing Areas in Sri Lanka

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## ABSTRACT

The importance of a study of climate variability in tea-growing areas is enormous as climate variability profoundly influences the yield, quality and management aspects of tea. Information on climate change and variability, especially on a regional basis, is important for planning, decision and policy-making in crop production activities. Temperature (minimum, maximum, and diurnal), and data on the sunshine hours, from four different locations were analysed on an annual basis, in order to identify their temporal and spatial variability.

Significant changes were found with respect to maximum and minimum temperatures and sunshine hours. Moreover, these changes were found to be different among locations. Maximum and minimum temperatures showed a significant warming trend at Talawakelle and Badulla. Diurnal temperatures shows a significant increasing trend only at Badulla. At Talawakelle, Hantana and Ratnapura, decreasing trends were observed with respect to sunshine hours.

For most of the climatic variables considered, the change was with respect to the mean, but not with respect to the variance.

It is important to note that the change in the above-mentioned climatic parameters was not consistent across locations, so that detailed analysis needs to be carried out at regional level.

**Key words:** Climate variability, sunshine hours, temperature

## INTRODUCTION

Climate variability and occurrence of extreme weather and climatic events have received increased attention during the last few years (Meehl *et al.*, 2000). There is sufficient evidence for climate change, based on global analyses and more detailed regional analyses (Parker *et al.*, 1994).

As shown by many studies (Jones and Briffa, 1992; Hansen and Lebedeff, 1987; Jones 1994; Parker *et al.*, 1994), the trends of climate change vary regionally and with location. Studying these trends in the Sri Lankan context is very important because Sri Lanka is an agricultural country, with about 35% of the population engaged in Agriculture (Central Bank Report, 2003).

According to the literature (see Recent Climatic Changes in Sri Lanka, 2000), an increasing trend in the annual maximum temperature of 0.029°C per year in Sri Lanka was observed during 1961-1990. The same study reported that the annual minimum temperature also showed an increasing trend of 0.008° C per year. In addition, in the same study, large spatial and temporal variations in temperature trends have been reported as occurring in Sri Lanka.

Therefore, a study of climate variability at the regional level is important, as agricultural crops are highly vulnerable to local climate change.

Some studies (Basnayake *et al.*, 2003; Fernando and Chandrapala, 1995), conducted on this aspect, have shown significant trends in major climatic parameters like temperature and rainfall.

Tea (*Camellia sinensis* L. (O.) Kuntze) is one of the most economically-important perennial crops in Sri Lanka, contributing about 1.3% of the GDP (Central Bank Report, 2003). As tea is a frequently-harvested crop, climate variability profoundly influences the quantity and quality of the tea yield.

Temperature, sunshine hours and rainfall are the main parameters that influence the yield of tea (Devanathan, 1992). Temperature largely controls the rate of development and duration of expansion of leaves, shoots and roots, when other factors are not limiting (Carr and Stephens, 1992). The number of hours of sunshine is also directly correlated with the yield of tea (Devanathan, 1975). Sunshine hours per day are more important than solar radiation intensity for the potential tea yield, as tea is a $C_3$ crop (Carr and Stephens, 1992). In fact not only for tea, but pragmatic planning for any crop needs a thorough understanding of the climate, and in particular climate variability.

Information on climate variability is useful in allowing decision-makers and resource managers to better anticipate, and plan for, potential impacts of climate variability. Further advances would serve the industry by providing improved knowledge, enabling more scientifically-based decisions across a broad spectrum of the climate-sensitive tea sector.

Thus, the needs exists to focus on long-term changes in climatic parameters in tea-growing areas, on a regional basis.

The objective of this paper is therefore to investigate the patterns of change of air-temperature (maximum, minimum and diurnal), and bright sunshine hours (BSH), in major tea-growing areas.

## METHODOLOGY

Four locations, representing all the major tea-growing climate and elevation groups, were considered for the study. A station index of the selected locations is presented in Table 1.

**Table1. Station index of the selected locations**

| Location | Climatic zone | Altitude (m) | Longitude | Latitude | Period of data collected |
|---|---|---|---|---|---|
| Talawakelle | Up-country wet zone | 1382 | $80^0 40^1$ E | $6^0 55^1$ N | 1976-2005 |
| Ratnapura | Low-country wet zone | 29 | $80^0 40^1$ E | $6^0 41^1$ N | 1976-2005 |
| Badulla | Up-country intermediate zone (Uva) | 1120 | $81^0 07^1$ E | $6^0 57^1$ N | 1976-2005 |
| Hantana | Mid-country intermediate zone | 762 | $80^0 38^1$ E | $7^0 26^1$ N | 1976-2005 |

Daily air temperatures (minimum, maximum and diurnal), and daily bright sunshine hours recorded by the Campbell Stocks Sunshine recorder at the Talawakelle and Hantana locations, were obtained from the agro-meteorological stations maintained by the Tea Research Institute under the supervision of the Department of Meteorology. Data for the other two locations (Badulla and Ratnapura) were obtained from the Department of Meteorology. Data obtained were screened for outliers, and missing values were estimated using a linear interpolation method (Schatzman, 2002).

In order to facilitate the study of variability through the series, each series was divided into five-year periods, and based on these sub-periods different aspects of climate variability were studied.

### Homogeneity of variance

Bartlett's test was used to determine the homogeneity of variances. The Bartlett test statistic, which is usually considered as a generalization of the F- test statistic, is specifically designed to test the equality of variances across groups.

### Most pronounced period and commencement of change

The non-parametric procedure, the Mann-Kendall (M-K) rank correlation test, was used to determine the interval in which the trend was most pronounced and the critical point of the commencement of climate change for the significant period.

In this procedure, for each element $x_i$, the number of $n_i$ elements $x_j$ preceding it ($i > j$) so that rank ($x_i$) > rank ($x_j$) is calculated. The test statistic calculated here is $t = \sum n_i$ The distribution of $t$ is assumed to be asymptotically Gaussian with:

$$E(r_s) = \mu = \frac{n(n-1)}{4} \text{ and } \mathrm{var}(t) = \sigma^2 = \frac{n(n-1)(2n+5)}{72}.$$

Two-sided $H_0$ is rejected for high values of $|u(t)|$: where

$$u(t) = [t - E(t)]/\sqrt{\mathrm{var}(t)}.$$

When $u(t)$ is significant (P<0.05) for a particular period, that significant period can be considered as the period with significant change. The sign of the $u(t)$ indicates increasing or decreasing change. The backward computation of $u(t)$ series is called $v(t)$. The intersection of these two series determines the starting point of change for a particular series.

### Simple linear regression analysis

The simple linear regression analysis was done to determine any significant relationship in temperature (maximum, minimum and diurnal), and bright sunshine hours, with time. Regression coefficients were used to determine the positive or negative trends. This was also used to confirm the results from the Mann-Kendall (M-K) rank correlation test.

## RESULTS AND DISCUSSION

### Annual maximum temperature (AMaxT)

The mean values of maximum temperatures for the five-year periods in the four locations, and the percentage drop/increase in each period relative to the previous period, are presented in Table 2.

ANOVA revealed that there were significant differences (P<0.01) among the six sub-periods only at Badulla and Talawakelle. The maximum temperatures at both locations show increases of temperature between contiguous sub-periods. However, at Ratnapura and Hantana increases, as well as drops in maximum temperature, were observed relative to the previous periods. At Badulla, significant increases in maximum temperature occurred in between the last four sub-periods (1986-2005) and the first two sub-periods (1976-1985). At Talawakelle, significant increases occurred in-between the 1976-1995 and the 1996-2005 periods.

According to Table 2, trends in AMaxT are subjected to large spatial variation. Regression analysis of the Badulla and Talawakelle data indicate significant warming trends (p<0.01). However, such warming trends could not be detected at Ratnapura and

Hantana. At Ratnapura the indication was of significant decreasing trends at the 10% significance level.

The results of the Bartlett's test showed homogeneity of variance between the periods at Talawakelle, Badulla and Hantana. However, the variances were not homogenous during the sub-periods at Ratnapura, at the 10% significance level. In other words, some sudden extreme events would have occurred at Ratnapura during the study period. However, there was no clear direction of continuous increment or decrement of variance. This cannot, therefore, be considered as a long-term change in variance. Overall, this non-significance of change in variance proves that there was no such significant increment or decrement in occurrence of extreme events, during the study period (1976-2005).

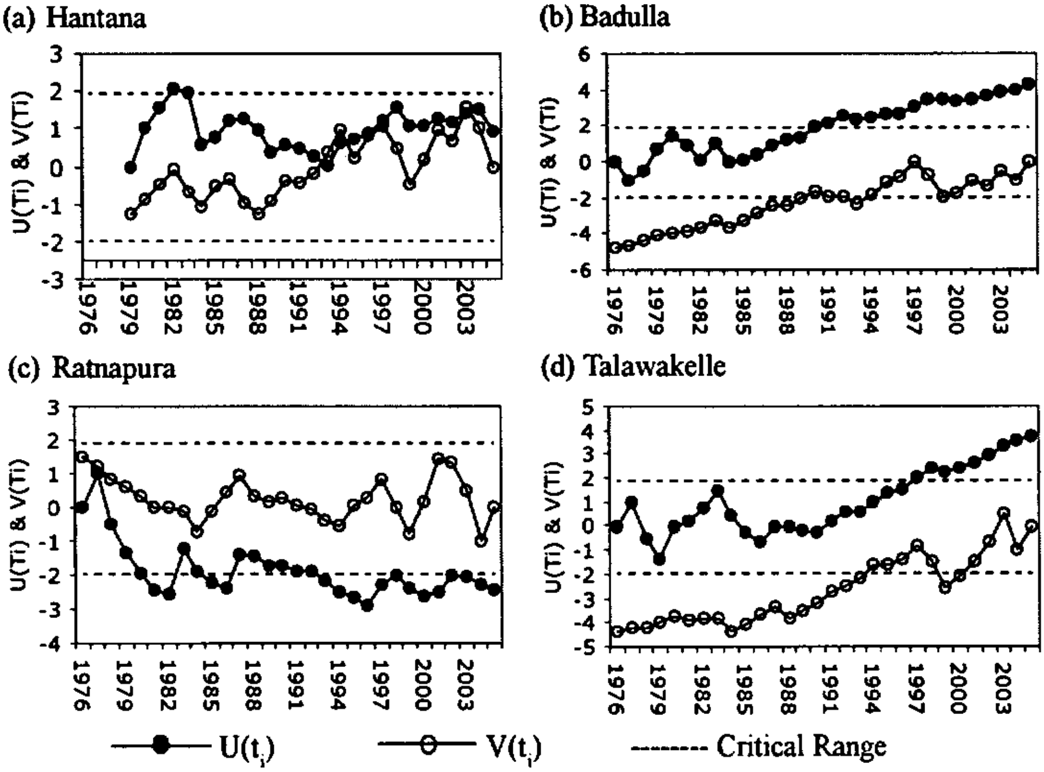
Based on the results, the conclusion is that the mean annual maximum temperature change in the tea-growing areas is due to the change in mean, but not in variance.

**Table 2. Mean annual maximum temperature (MAMaxT) during five-year periods, percentage drop/increase (%D/I) with respect to the previous five-year period, and coefficient of variation.**

| Period | Talawakelle | | | Ratnapura | | | Badulla | | | Hantana | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | %D/I | CV% | Mean | %D/I | CV% | Mean | %D/I | CV% | Mean | %D/I | CV% |
| 76-80 | 23.54 | – | 1.30 | 32.30 | – | 0.44 | 28.88 | – | 1.16 | 26.75 | – | 0.79 |
| 81-85 | 23.56 | 0.08 | 3.13 | 31.82 | -1.49 | 2.10 | 28.90 | 0.07 | 1.64 | 27.96 | 4.52 | 5.80 |
| 86-90 | 23.68 | 0.51 | 2.01 | 32.06 | 0.75 | 1.55 | 29.44 | 1.87 | 1.06 | 27.66 | -1.07 | 2.81 |
| 91-95 | 23.98 | 1.27 | 0.80 | 31.76 | -0.94 | 0.72 | 29.52 | 0.27 | 0.88 | 27.72 | 0.22 | 2.80 |
| 96-00 | 24.38 | 1.67 | 2.36 | 31.80 | 0.13 | 1.68 | 29.88 | 1.22 | 2.04 | 27.90 | 0.65 | 2.36 |
| 01-05 | 24.76 | 1.56 | 1.16 | 31.90 | 0.31 | 0.86 | 29.96 | 0.27 | 0.69 | 27.42 | -1.72 | 3.40 |
| Results for the ANOVA F Test(Pr<F) ,the Bartlett's Test (BT) of homogeneity of variance, estimated trend coefficients (b) in regression analysis and their significance levels | | | | | | | | | | | | |
| Pr<F (ANOVA) | 0.0015 | | | 0.3726 | | | 0.0004 | | | 0.7363 | | |
| BT | 0.1455 | | | 0.0634 | | | 0.3334 | | | 0.3780 | | |
| b (Pr<F) | 0.05(<0.01) | | | -0.02(0.08) | | | 0.05(<0.01) | | | -0.004(0.86) | | |

To confirm these results, the M-K rank correlation test was applied to the temporal series of mean annual maximum temperature. Plots of $U(t_i)$ and $V(t_i)$ for maximum temperature are shown in Fig. 1.

**Figure 1: Temporal series of $U(t_i)$ and $V(t_i)$ obtained from the M-K rank correlation test for Max $T^0$ in selected locations.**




The $U(t_i)$ series of maximum temperatures at Talawakelle and Badulla exceeded the critical range (± 1.96) from year 1997 and 1990, respectively, indicating the starting points of significant changes. This confirms the ANOVA test results for maximum temperatures.

Both locations exceeded the upper boundaries of the critical range, confirming the warming trends from regression analysis. At Ratnapura, the lower boundary of the critical range was exceeded for several years. These results indicate an increase of maximum temperatures at Talawakelle and Badulla. The $U(t_i)$ series of maximum temperatures at Hantana was within the critical range for the period considered. This confirms the results obtained from regression analysis.

**Annual minimum temperature (AMinT)**

ANOVA revealed that there were significant ($P<0.01$) differences in AMinT between periods only at Talawakelle (Table 3). AMinT at Badulla was significant at the 10% significance level ($P=0.08$). However, unlike with maximum temperatures, at all locations, increases as well as drops of minimum temperatures were observed relative to the previous periods. The percentage increase, or drop, is higher with minimum temperatures than with maximum temperatures.

Regression analysis indicates a significant (P<0.01) positive trend only at Talawakelle and Badulla. The rate of increase of minimum temperatures is almost double in Talawakelle than in Badulla. However, the rate of increase in maximum temperature is the same in both locations.

Bartlett's test confirmed that there was heterogeneity in variance between periods at Hantana. At Hantana this was due to the high CV during 1981-1985. After 1990, the CV remained continuously at a low level. At Talawakelle, Bartlett's test was significant at the 10% significance level (P=0.06). This may be due to a comparatively higher CV in the 1986-90 and the 1991-95 periods. This can be used to get some insight about the occurrence of extreme events in Hantana and Talawakelle during particular periods.

Based on the results, it can be concluded that the change with respect to minimum temperature is due to both mean and variance in Talawakelle. However, this is only due to change in the mean at Badulla, and due to variance at Hantana. This clearly indicates the spatial variation of the climatic parameters with respect to local climate change.

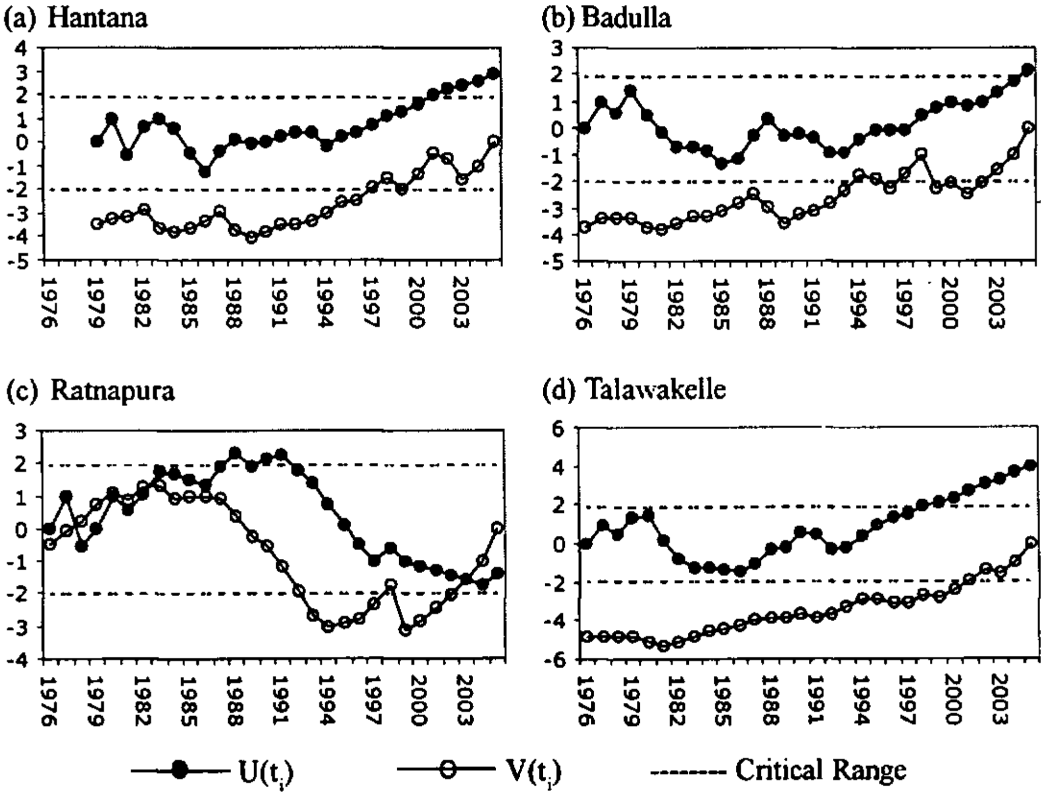
**Table 3. Mean AMinT during five-year periods, percentage drop/increase (%D/I) with respect to the previous five-year period, and coefficient of variation.**

| Period | Talawakelle | | | Ratnapura | | | Badulla | | | Hantana | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | %D/I | CV% | Mean | %D/I | CV% | Mean | %D/I | CV% | Mean | %D/I | CV% |
| 76-80 | 13.20 | – | 1.42 | 23.00 | – | 1.06 | 18.60 | – | 1.86 | 19.15 | – | 1.11 |
| 81-85 | 12.72 | -3.64 | 1.17 | 23.24 | 1.04 | 0.65 | 18.48 | -0.65 | 0.71 | 19.94 | 4.13 | 12.35 |
| 86-90 | 13.30 | 4.56 | 2.55 | 23.40 | 0.69 | 0.85 | 18.72 | 1.30 | 1.58 | 19.14 | -4.01 | 7.36 |
| 91-95 | 13.26 | -0.30 | 3.94 | 23.06 | -1.45 | 1.13 | 18.66 | -0.32 | 1.35 | 19.44 | 1.57 | 2.35 |
| 96-00 | 13.62 | 2.71 | 0.96 | 22.88 | -0.78 | 1.49 | 18.96 | 1.61 | 2.23 | 19.90 | 2.37 | 0.79 |
| 01-05 | 13.98 | 2.64 | 1.55 | 23.14 | 1.44 | 0.39 | 18.98 | 0.11 | 1.26 | 20.34 | 2.21 | 2.22 |
| Results for the ANOVA F Test(Pr<F) ,the Bartlett's Test (BT) of homogeneity of variance, trend coefficients(b) in regression analysis and their significance levels | | | | | | | | | | | | |
| Pr<F (ANOVA) | <0.0001 | | | 0.2350 | | | 0.0771 | | | 0.6834 | | |
| BT | 0.0557 | | | 0.2541 | | | 0.4297 | | | <.0001 | | |
| b (Pr<F) | 0.04(<0.01) | | | -0.004(0.55) | | | 0.02(0.002) | | | 0.03(0.28) | | |

Time-series plots with $U(t_i)$ and $V(t_i)$ for minimum temperature, obtained from M-K rank correlation tests, are shown in Fig. 2.

At Talawakelle, Badulla and Hantana, the series exceeded the critical range after 1997, 2004 and 2000, respectively. At all three locations, the excess was from the upper boundary, indicating an increase in minimum temperature. However, at Ratnapura, the excess was for a few years from the lower boundary, indicating a drop in the minimum temperature during this period.

**Figure 2. Temporal series of $U(t_i)$ and $V(t_i)$ obtained from the M-K rank correlation test for minimum temperatures at selected stations.**



## Annual diurnal temperature (MATDif)

The results from the ANOVA reveal that there were significant changes of diurnal temperature between periods at Badulla, at the 10% significance level (P=0.063) (Table 4).

According to the regression analysis, the diurnal temperatures showed an increasing trend over time at Badulla only (P<0.01).

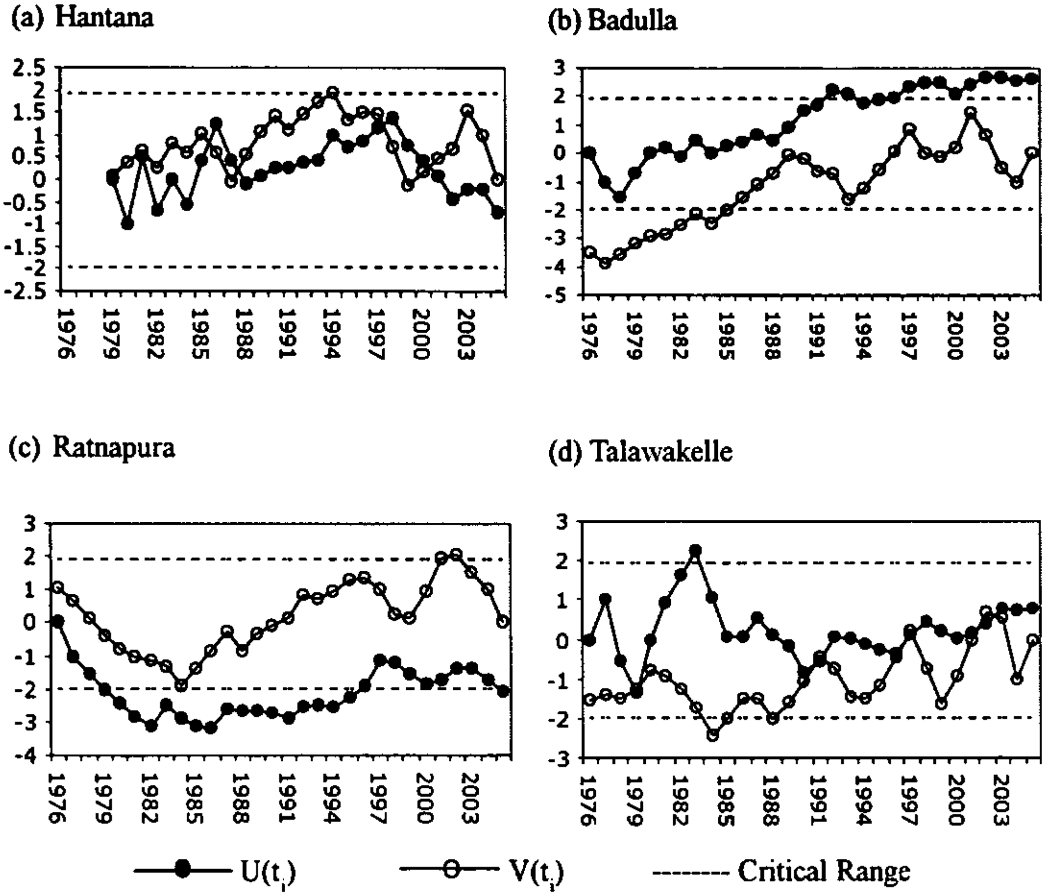
Bartlett's test confirmed the homogeneity of variance at all four locations.

**Table 4. Mean annual temperature difference (MATDif) during five-year periods, percentage drop/increase (%D/I) with respect to the previous five-year period, and coefficient of variance.**

| Period | Talawakelle | | | Ratnapura | | | Badulla | | | Hantana | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | %D/I | CV% | Mean | %D/I | CV% | Mean | %D/I | CV% | Mean | %D/I | CV% |
| 76-80 | 10.40 | – | 3.04 | 9.30 | – | 3.13 | 10.34 | – | 4.57 | 7.60 | – | - |
| 81-85 | 10.80 | 3.85 | 8.2 | 8.60 | -7.53 | 6.42 | 10.44 | 0.97 | 3.36 | 8.06 | 6.05 | 13.29 |
| 86-90 | 10.40 | -3.70 | 4.66 | 8.68 | 0.93 | 4.11 | 10.74 | 2.87 | 3.20 | 8.56 | 6.20 | 23.59 |
| 91-95 | 10.70 | 2.88 | 4.53 | 8.72 | 0.46 | 2.05 | 10.86 | 1.12 | 4.05 | 8.28 | -3.27 | 14.33 |
| 96-00 | 10.76 | 0.56 | 5.11 | 8.92 | 2.29 | 6.00 | 10.90 | 0.37 | 3.49 | 8.00 | -3.38 | 6.67 |
| 01-05 | 10.82 | 0.56 | 3.29 | 8.74 | -2.02 | 3.30 | 10.98 | 0.73 | 1.75 | 7.08 | -11.50 | 19.35 |
| Results for the ANOVA F test(Pr<F) ,the Bartlett's test (BT) of homogeneity of variance, trend coefficients (b) in regression analysis and their significance levels | | | | | | | | | | | | |
| Pr<F (ANOVA) | 0.6701 | | | 0.0979 | | | 0.0629 | | | 0.5779 | | |
| BT | 0.3928 | | | 0.3090 | | | 0.7116 | | | 0.2237 | | |
| b (Pr<F) | 0.009(0.44) | | | -0.01(0.14) | | | 0.03(0.002) | | | -0.04(0.22) | | |

The time-series plots with $U(t_i)$ and $V(t_i)$ for temperature differences are shown in Fig. 3. The temperature difference at Badulla exceeded the upper boundary of the critical range after 1991. At Ratnapura, the lower boundary of the critical range was exceeded for several years. At Talawakelle and Hantana, it was within the critical range indicating no trend.

**Figure. 3. Temporal series of $U(t_i)$ and $V(t_i)$ obtained from the M-K rank correlation test for temperature differences at selected stations.**




## Annual bright sunshine hours (ABSH)

The results, shown in Table 5, indicate that there were significant differences ($P<0.01$) among the six sub-periods with respect to ABSH, at all locations except Hantana. The percentage drop/increase in ABSH is the highest compared to the other three variables. At Badulla and Hantana, this significance is due to the highest mean values of 5.24 and 6.95 hours per day, during the 1986-1990 and 1981-1985 periods, respectively. The ABSH shows a drop between contiguous sub-periods from1976 to 2005 at Talawakelle, Hantana and Ratnapura, except for the 2001-2005 sub-period at Ratnapura.

Bartlett's test confirmed the homogeneity of variance of sunshine hours at Talawakelle, Ratnapura and Passara. However, variances were not homogeneous at

Hantana owing to the high CV during 1981-1985. With respect to the BSH also, long-term changes in variance can be considered since the CV showed low values continuously after this period.

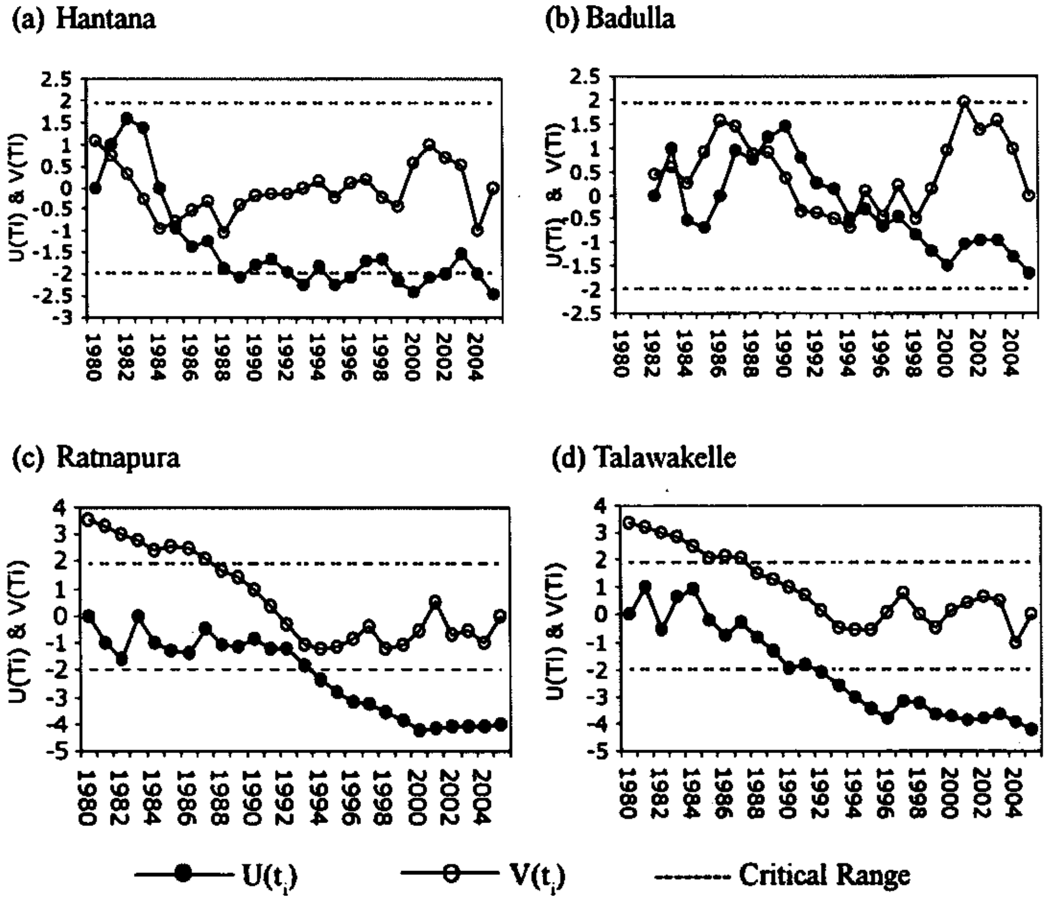
Regression analysis of BSH at Talawakelle, Ratnapura and Hantana indicates a decreasing trend (P<0.05). At Passara, it shows no trend (P=0.64).

**Table 5. Mean annual bright sunshine hours (MABSH) during five-year periods, percentage drop/increase (%D/I) with respect to the previous five-year period, and coefficient of variance.**

| Period | Talawakelle | | | Ratnapura | | | Badulla | | | Hantana | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Mean | %D/I | CV% | Mean | %D/I | CV% | Mean | %D/I | CV% | Mean | %D/I | CV% |
| 76.80 | – | – | – | – | – | – | – | – | – | – | – | – |
| 81-85 | 6.10 | – | 9.63 | 5.78 | – | 9.89 | 4.60 | – | 9.56 | 6.96 | – | 23.36 |
| 86-90 | 5.74 | -5.90 | 7.55 | 5.70 | -1.38 | 7.13 | 5.24 | 13.91 | 5.97 | 5.90 | -15.23 | 6.23 |
| 91-95 | 5.26 | -8.36 | 6.93 | 4.86 | -14.74 | 12.31 | 4.76 | -9.16 | 5.68 | 5.82 | -1.36 | 2.55 |
| 96-00 | 5.22 | -0.76 | 8.72 | 4.36 | -10.29 | 10.46 | 4.76 | 0.00 | 2.82 | 5.80 | -0.34 | 3.45 |
| 01-05 | 5.10 | -2.30 | 5.37 | 4.90 | 12.39 | 2.89 | 4.84 | 1.68 | 4.03 | 5.80 | 0.00 | 4.88 |
| Results for the ANOVA F test (Pr<F) ,the Bartlett's test (BT) of homogeneity of variance, trend coefficients (b) in regression analysis and their significance levels | | | | | | | | | | | | |
| Pr<F (ANOVA) | 0.0078 | | | 0.0004 | | | 0.0269 | | | 0.1057 | | |
| BT | 0.6997 | | | 0.1718 | | | 0.2954 | | | <.0001 | | |
| b (Pr<F) | -0.05(<0.01) | | | -0.07(<0.01) | | | -0.005(0.64) | | | -0.05(0.02) | | |

Time series plots with $U(t_i)$ and $V(t_i)$ for BSH at four selected locations are shown in Fig. 4.

**Figure 4.** Temporal series of $U(t_i)$ and $V(t_i)$ obtained from the M-K rank correlation test for BSH at selected locations.




The $U(t_i)$ series of BSH at Ratnapura and Talawakelle exceeded the lower limit of the critical range after 1993 and 1990, respectively, indicating a significant drop of BSH. At Badulla, it was almost within the critical range. At Hantana, it was along the lower boundary of the critical range starting from 1988.

Here also we can conclude that the change is due to the mean and not to the variance, except Hantana.

## CONCLUSIONS

In the tea-growing areas of Sri Lanka, there was a significant climate change with respect to maximum, minimum and diurnal temperature, and bright sunshine hours. The periods in which significant changers commenced varied among the climate variables.

There was a significant warming trend of Max T° and Min T° at Talawakelle and Badulla. Only Badulla showed a significant warming trend of the day temperatures. Sunshine hours at Talawakelle, Ratnapura and Hantana showed a significant decreasing trend.

For most of the variables concerned, the change was with respect to the mean and not due to the variance.

Especially with respect to the parameters considered, climatic conditions varied, and thus adaptation options need to be suggested to mitigate the potential negative impacts owing to the above-mentioned changes.

The results have provided adequate evidence of changes of the climate parameters, namely maximum temperature, minimum temperature, diurnal temperature and bright sunshine hours. However, it is important to note that the changes in the above-mentioned climatic parameters was not consistent across locations. This indicates that detailed analysis need to be carried out at regional level. Most of the cultivation practices currently adapted appear to be based on the assumption that there is no such phenomenon as 'climate change'. However, the available evidence on climate change needs to be taken into consideration and agricultural practices re-scheduled accordingly.

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