Adaptation and Impact Assessment to Climate Change of the Plantation Sector in Sri Lanka

Foundation for Environment, Climate and Technology, SRI LANKA

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http://www.climate.lk/
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NRMS	- Natural Resources Management Services
IRI	- International Research Institute for Climate and Society
UoP	- University of Peradeniya

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Acknowledgement

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We thank the University of Peradeniya and the Mahaweli Authority for supporting this work. Mr. S.B. Rajakaruna, Ms. Asoka Amerasekera and Ms. K.P. Renuka of NRMS helped administer the project. Data was obtained from the Sri Lanka Department of Meteorology, Department of Agriculture, Department of Irrigation and the Mahaweli Authority of Sri Lanka. We thank Mr.Chanaka Wickremasinghe, Mr. K.B.Jayasundera and Ms.Sudharma Jayasinghe for assistance in processing them.

We thank Ann Binder, and Sandy Vitelli for providing the facilities and making the arrangements for the visit of Dr. Sarath Peiris and Dr. Neil Fernando to IRI. We thank Zeenas Yahiya, Madhura Weerasekera, Shaky Sherpas and Jason Rodriguez for helping finalize this report.

Summary

This report documents the work undertaken by the IRI, FECT, NRMS and University of Peradeniya as part of the overall project. Separate reports were prepared by the Tea Research Institute, Coconut Research Institute and the Department of Meteorology in Sri Lanka. The work at IRI, FECT and NRMS has proceeded satisfactorily. The work was in the domain of climate and climate change, crop-climate impact analysis and contributions to synthesis. We have contributed significantly in terms of research output and in capacity building, which were the goals of the AIACC project.

Administrative Arrangements

Four research assistants were recruited for project work – all of them have been trained in climatic data analysis. Managerial, administrative, accounting, data, programming, documentation and GIS services, and office space and utilities were provided through NRMS and FECT.

Publications

Three journal articles have been prepared with one provisionally accepted. We have published one full-length conference paper and three conference abstracts. Lessons learnt from the project were published in two issues of the TIEMPO magazines from the University of East Anglia. One of these pieces was highlighted in the SciDev.Net website that is sponsored by the project sponsors, TWAS.

Communication of Findings

We have presented our work on climate change and related issues in Universities, Mahaweli Authority, to post-graduate students in meteorology at the University of Colombo and post-graduate students in oceanography and water resources management at the University of Peradeniya. Three feature articles on climate change and data issues were highlighted in several Sri Lankan newspapers. The results were presented to NOAA in the Annual progress reports from IRI and written up as a web feature on the IRI website. The website SciDev.net highlighted our work on Coconut Yield Predictions.

Capacity Building

Two research assistants, (Heli Bulathsinhala and Kusalika Ariyaratne) obtained their M.Sc. supported by this project. Two other research assistants (Irugal Bandara and Manjula Siriwardhana) obtained extensive training in climatic data analysis, scientific reporting and project management.

The IRI hosted Dr. Sarath Peiris for three weeks, Dr. Neil Fernando for a week where advanced research was carried out on crop-climate interactions.

Photos: Pix: Left: CRI, FECT and IRI partners visited a coconut plantation at the field research station of the Coconut Research Institute in Puttalam District in North-West Sri Lanka, in May, 2004. Left: A bunch of coconuts that is being deflowered at the research station and Right: Project scientists observing it.

Summary of Science

Quality Control: The quality of the monthly temperature data at the main stations of the Sri Lanka Department of Meteorology and Agriculture were evaluated based on station histories, comparison with neighbors, and internal consistency of the data. The Global Historical Climatology Network (GHCN) has previously carried out such quality control for 11 Sri Lankan stations. We have used 15 stations, each of which was of a longer duration than used in the GHCN analysis. The data that failed to pass the quality control based on multiple checks and consistency of statistical relationships of mean temperature among the different stations were discarded. We have constructed an estimate for the temperature record for each station based on its best-correlated neighbors alone. The comparison of the actual and estimated temperature brings out shifts in mean and shifts in variance and we have implemented a technique to adjust the data for shifts in mean and variance. There have been several relocations of stations and changes of instrumentation that causes these shifts. Overall, the dataset resulting from this work is more comprehensive while meeting all the standards used in the GHCN work. The techniques were applied to stations of the Department of Agriculture as well.

Interpolation Techniques: Simple spatial temperature interpolation procedures do not capture regional variations due to rapid elevation change in-between the stations such as in Sri Lanka. A topographically informed interpolation gives realistic interpolations for temperature. Elevation data at 1-km resolution was used in the interpolation. Simple lapse rate theory was used to bring in the elevational dependency into the interpolation. This procedure was used to produce realistic annual and monthly spatial climatologies for temperature. We also present climatological values for lapse rates for mean, maximum and minimum monthly temperature in Sri Lanka.

Climate Change Assessments: We have undertaken quality assessment for 18 stations each of which had a longer duration than used in the GHCN analysis and had fewer missing records. The GHCN quality checks lead to all data prior to 1950 from Trincomalee, Batticaloa and Colombo; and data from Hambantota prior to 1921 are being discarded. The present quality control leads to a much smaller set of data being discarded. Our estimates of changing temperature show modest differences in estimates of the warming trend for most stations for the period from 1960-2001 but larger differences for earlier periods. There is a trend of 2.6 ^{o}C/100 years of warming trend in annual average maximum temperature and 1.7 ^{o}C/100 years for annual average minimum temperature from 1961-2000. These warming trends vary both seasonally and regionally. The regional differences are presented as maps here.

Fine-Scale Climatology Construction: We have constructed high-resolution climatologies for Sri Lanka for rainfall, minimum, mean and maximum temperature and solar radiation. For temperature we undertook topographically informed interpolation schemes. All these climatologies were based on quality-evaluated data.

Future Climatology Construction: We have used the trend assessments for each station and the topography informed interpolation scheme to construct possible future climatologies for Sri Lanka annually, seasonally and also monthly. Here we show the projected temperature change for the year 2025 and 2050.

Yield Prediction

The national coconut production in a given year is decided by the number of factors such as bearing extent of coconut, age of bearing palms, use of fertilizer and other agronomic practices, pest and disease damage, and distribution of rainfall in the previous year. Assuming that the above factors can be grouped into two main factors namely climate and technology. The climate effect was estimated by regressing production data. The technology effect was estimated from the historical log-linear trends. The Regression model that integrates both climate and technology effects developed to predict ANCP with high fidelity (R^2=0.94). The Coconut Research Institute has operationalized the prediction scheme and the predictions are provided at http://www.cri.lk/yield.html.

Pix: Project meeting at the Coconut Research Institute with officials from the Department of Meteorology, Coconut Research Institute, Tea Research Institute, Sri Lanka Association for the Advancement of Science and Natural Resources Management Services held on 29 July, 2002, Project staff associated with IRI's work attended this meeting and shown at the Right (L-R, Z. Yahiya, S. Razick, K. Ariyaratne, H. Bulathsinhala, C. Wickramsinghe).

1. Introduction

This report documents the work undertaken by the IRI, FECT, NRMS and University of Peradeniya as part of the overall project. Separate reports were prepared by the Tea Research Institute, Coconut Research Institute and the Department of Meteorology in Sri Lanka. The work was in the domain of climate and climate change, crop-climate impact analysis and contributions to synthesis. We have contributed significantly in terms of research output and in capacity building, which were the goals of the AIACC project.

The following activities were carried out under this project.

Data Collection

1. Monthly mean temperature data for 16 stations for the Department of Meteorology and for 20 stations from the Department of Agriculture, for the 30 years were obtained. This data was digitized and checked.
2. Since there was inadequate coverage especially in the area of plantation crops by the existing Department of Meteorology stations, we have improved coverage by incorporating the data from the Department of Agriculture.
3. The available weekly data were converted to monthly data, and the analysis of monthly data for 19 Agriculture Department stations for the period 1975 - 1996 was completed.
4. Monthly minimum and maximum temperature data were obtained from the AIACC project for 16 stations.

Quality Control of Climate Data

5. Quality control of the minimum, maximum and mean temperature data was carried out in a systematic manner for 16 stations. Stations that were moved were identified. Outliers were identified and consistency among stations was checked.
6. An algorithm and computer program was developed to estimate temperature for a given station from that of its neighbors for data infilling.
7. Alternative temperature chronologies were constructed for each station as a means of checking the consistency and reliability of the stations.
8. The quality of the temperature observations of the different stations was ranked and periods of suspect data were demarcated.
9. A complete set of quality evaluated data was re-constructed after the quality control.
10. Quality control of the rainfall data was carried out in a systematic manner for 16 stations. Stations that were moved were identified. Outliers were identified and consistency among stations was checked.
11. Three technical reports on the quality control work were prepared.

Estimating Current Climate

12. **Mapping of Rainfall Data:** Quality controlled rainfall data were used to prepare more precise maps of rainfall at annual, seasonal and monthly time scales.

13. **Mapping of Temperature Data:** Previous attempts to map spatial data were poor particularly in the highland tea areas, as they do not take account of elevation differences in interpolation. We developed an algorithm and computer program to take account of elevation in our mapping. Digital elevation data was obtained from the IRI. As a means of testing these interpolation schemes, we obtained additional data from Irrigation Department.

14. **Mapping Solar Radiation Data:** We have worked under the guidance of Prof. T.D.M.A Samuel of the University of Peradeniya to produce maps of solar radiation climatology using a scheme that he devised and calibrated for Sri Lanka to use daily sunshine hours to estimate solar radiation.

Climate Change Assessment

15. The observed and re-constructed annual maximum and minimum temperatures were analyzed separately after careful quality control as even a few outliers and erroneous data can bias results – unfortunately most climate change assessments for the region so far has been carried out without this kind of careful assessments. Trend values were taken by the linear best-fit method for all 18 stations. The sensitivity of these trend values was evaluated against the window used for the trend estimate. Seasonal, monthly and regional trend estimation was undertaken. Significance tests were applied to these trend estimates using standard IPCC procedures – these accounted for variance changes and missing data. We find that linear trend estimation is a rather crude measure of the temperature changes in Sri Lanka so careful assessment is essential for reliable estimates of change.

16. These climate change estimates were mapped to obtain a spatial representation of temperature trends. Thereafter, we have used a new algorithm to use the trends in different stations to construct scenarios of likely climatology in twenty years, based on the assumption that current trends shall continue. This of course is only as good as any other method that is being used for such estimation. Interpolation techniques were devised to take account of topography in scenario construction.

Crop-Climate Interactions

17. Collaboration with Dr. Sarath Peiris to develop the skill of the national coconut yield production and for the development of additional lead time to predictions.

18. Collaboration with Dr. Neil Fernando for economic valuation of climate impacts on coconut sector.

2. Quality Control of Climate Data

INTRODUCTION

It is a testament to the dedication of observers and meteorologists that a reasonably high quality of data collection is maintained in Sri Lanka in spite of many limitations. Now there is particular interest in detecting climate change where estimates of the warming trend are only of the order of 0.004 ^{o}C per year (IPCC, 2003). Minor errors in temperature data can throw off such estimates of climate change substantially. Hence, it is important to undertake careful assessments of data quality. In addition, there is a need to salvage all available information out of historical data that may not be entirely precise. Thus one needs techniques for reconstruction of missing data, for adjustment for relocation of stations and for adjustment where possible for poor instrument calibration.

Quality assessment of mean temperature data at a near equatorial location such as Sri Lanka is challenging given the limited seasonal variability. Annual temperature in stations other than those in the hills ranges between 22 and 29 ^{o}C. The inter-annual variation at all station is less than 2 ^{o}C.

The data of the Sri Lanka Department of Meteorology and its predecessors has been subjected to internal quality assessments. Data from 11 out of the 19 Department of Meteorology stations have been incorporated into the Global Historical Climate Network (GHCN) database (Peterson and Vose, 1997). Quality control has been carried out based on a set of globally applicable guidelines and suspect portions of the data have been omitted.

This analysis while systematic was based on a limited set of data that was available in the global archives. A more complete data record is available through Sri Lanka's Department of Meteorology and the Department of Agriculture. In addition, we can use the station histories to interpret relocations and replacements, and calibrations of instruments.

Here we attempt to build a reliable and complete set of station mean temperature data for Sri Lanka. We shall also estimate values for the data does not pass quality control or where the data is missing.

DATA AND METHODOLOGY

Temperature observations are available starting from 1869 for 19 Sri Lanka Department of Meteorology stations (figure 1). We have undertaken quality assessments of the monthly mean, maximum and minimum temperature data for all Sri Lanka Department of Meteorology, and Department of Agriculture observatories. Here we report on the evaluation of annual mean temperature data for 15 Department of Meteorology stations (figure 2). The methodology utilized is as follows

Exploratory data analysis was carried out on the time series to check for errors in transcription and data entry. The annual temperature time series for the different stations was constructed and its histograms, mean, variance and extreme values were examined. The time series was examined for mean temperature values that exceeded 3 times the inter-quartile range. Such data were removed unless a similar anomaly was replicated in neighboring stations

An average "All Sri Lanka Temperature" (ASLT) series was constructed. A cross-correlation was constructed of the mean temperature records of the 15 stations and the ASLT. In addition, correlation tables were constructed for parts of the record (1869-1894, 1895-1919, 1920-1949 and 1950-2000). When the correlations were lower, even smaller intervals were tested to see whether there was any correlation.

The temperature variation at each station was reconstructed based on the data at the five stations that had the highest correlation during the years from 1900-2000.

The reference time series (Peterson and Easterling, 1994, Easterling *et al*., 1996, Eischeid, 1995) for each station was constructed using the following steps:

1. A time series of the standardized anomaly was computed for each station by subtracting the mean and normalizing by the standard deviation.
2. The cross-correlation table of the different standardized anomalies was used to pick out the five stations that had the best correlation for a particular station.
3. The following formulas were used to estimate a "reference time series" of standardized anomalies for each station from these five best-correlated stations.
4. The standardized anomaly reference time series was converted to a reference time series by using the mean and standard deviation.

Years that showed significant discrepancies between the observed and reconstructed data was identified as suspect. Data were identified as suspect based on a comparison of the observed and reconstructed data and the lack of any relationship between the observed and reconstructed data.

Site-change effects were estimated using the cumulative sum technique (Rhoades and Salinger, 1993, Easterling and Peterson, 1995) by the difference between the target station and weighted mean of neighboring stations. An extension of the procedure can be used to adjust the observed data for shifts in mean and variance.

OUTCOMES AND DISCUSSION

Exploratory Data Analysis

Outliers: The outliers in the time series and histograms were identified and the data was checked from the various sources, such as the Department of Meteorology archives, the GHCN archives, reports of the Colombo Observatory, the Department of Meteorology and the reports to the Colonial office. In most cases, the data from the different stations were consistent but there were exceptions, which were corrected for. Even after these corrections, there were still outliers which were beyond a threshold of thrice the Inter-Quartile-Range of the distribution and which were identified as suspect. These were Jaffna and Ratnapura (1896), Galle and Hambantota (1901), Nuwara Eliya (1997) and Anuradhapura, Batticaloa, Badulla, Galle, Hambantota and Diyatalawa (1998).

The standardized error (figure 3) shows higher values up to 1889 and thereafter it has also increased considerably in recent years since 1977. This deterioration of the quality of data is partially due to the lack of proper calibration of the data in the war zone stations in North. In recent years, the data quality has begun to improve perhaps due to the reduction in intensity of conflict.

Cross-Correlation

The correlations between each time series and the ASLT for the entire record length from 1869-2000 ranged between 0.35 and 0.70. The stations that had the lowest correlations below 0.4 were Jaffna, Puttalam and Nuwara Eliya. The correlations for Kandy, Ratnapura and Hambantota were between 0.4 and 0.5. Based on an inspection of the data (figure 2), correlation analysis was carried out for periods that seemed to show homogeneity.

The correlation with ASLT may be taken as a measure of data quality. Accordingly listed below are the stations which had correlation of temperature with ASLT below 0.3.

Jaffna	1869-1894 (-0.1), 1981-2000
Puttalam	1894-1905 (-0.23)
Batticaloa	1869-1880 (0.10), 1895-1905 (-0.16)
Hambantota	1869-1880 (0.28), 1895-1905 (-0.15)
Rathnapura	1869-1880 (-0.30)

Comparison of Data with Reference Time Series and Reconstruction of Data

The comparison of annual temperature at each station and reconstruction, help identify shifts in locations of the stations, calibration errors, and declines in quality of the data. As an example, the reconstruction and observations of the Kandy station show similarity after 1955 (figure 4). In the period prior to that a shift in mean is seen in the in-between 1919 and 1953. Again, the period prior to 1919 also shows a shift in mean. This station was moved in 1894, 1896, 1921 and 1953. Kandy is nestled in a mountain plateau and small shifts can be influential. In particular, the shift in 1921 and 1953 are particularly significant in terms of change in elevation. Thus the data between 1921 and 1953 should be subjected to adjustment of mean and variance. The procedure of Rhoades and Salinger (1993) was adopted to adjust for the shift in means and the adjusted time series is provided in figure 5.

There have been many displacements of stations over the last 140 years. Some of the stations or instruments were moved and observations continued to be made. In other cases, instruments were replaced with new ones. The reconstruction has been undertaken for all stations. The data reconstruction brings out shifts in mean in Mannar (1900-1935), Kandy (1921-1954), Ratnapura (1911-1920), Colombo (1930-1968) and Nuwara Eliya (1950-1975) and shifts in variance at Galle between 1902 and 1913.

Outcomes

The examination of the quality and consistency of mean temperature data using station histories, exploratory data analysis techniques, correlation techniques and reconstruction techniques reveal that the twentieth century records are of excellent quality. However, the data quality in the nineteenth century of several stations was relatively poor. In addition, there has been deterioration in data quality in the last decade, which may be related to the civil conflict in Sri Lanka.

In comparison with the globally available data sets for Sri Lanka, we have used more stations, fewer missing data and longer records. The GHCN quality checks lead to all data prior to 1950 from Trincomalee, Batticaloa and Colombo data and data from Hambantota prior to 1921 being discarded. The present quality control leads to a much smaller set of data being discarded. In addition, a reconstruction of the missing data has been presented based on the relationships in the temperature data among the different stations.

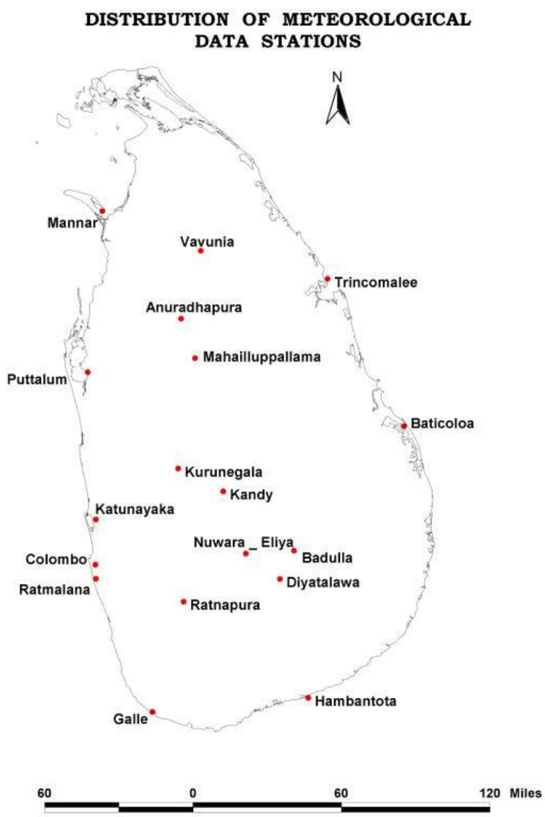


Fig.1. *Location map of the surface temperature observation stations of the Department of Meteorology. The analysis for the stations with short records (Pottuvil, Kankesanturai, Ratmalana and Katunayake) is not reported here.*

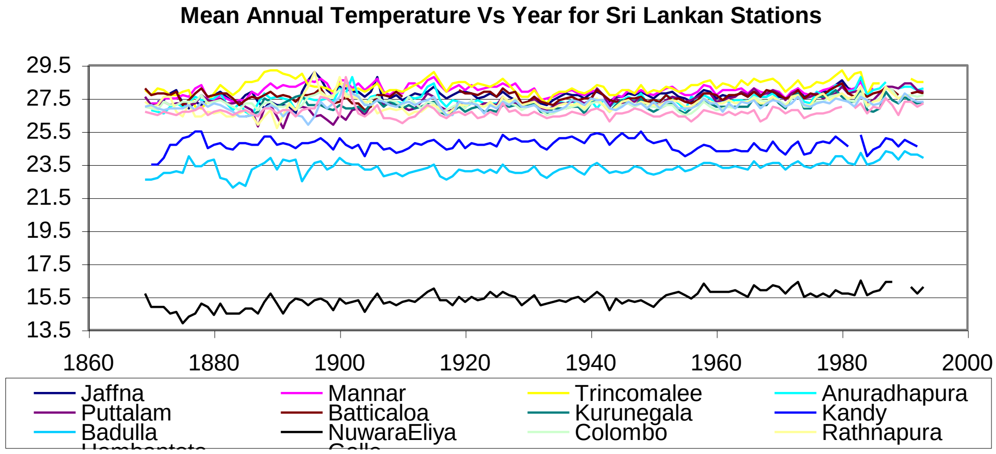


Fig.2. *The variation of the mean annual temperatures for the main Department of Meteorology stations in Sri Lanka with long records.*

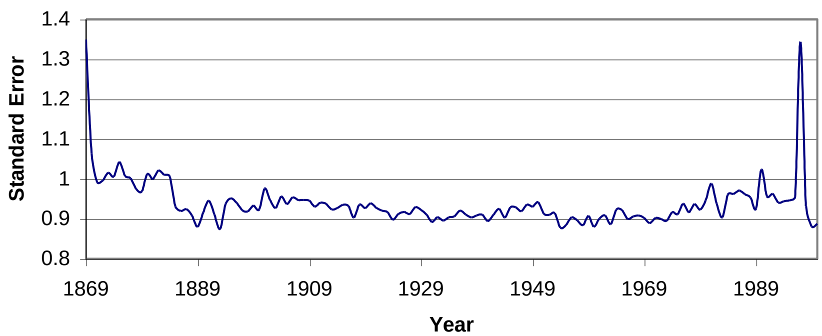


Fig.3.*Thestandard error of the annual temperature anomalies for all stations in Sri Lanka. Inconsistencies in the anomalies from one station to another could reflect either dramatic spatial contrasts in temperature variability or the accuracy of observations in this ensemble of stations. Given that there is high correlation between stations in the last fifty years; one can safely assume that spatial consistency of temperature anomaly patterns is to be expected within Sri Lanka. Hence, the standard error computed from the temperature anomalies for each year is a reflection of the quality of data. This measure shows that the data quality has improved very much in the last century but has begun to deteriorate lately.*

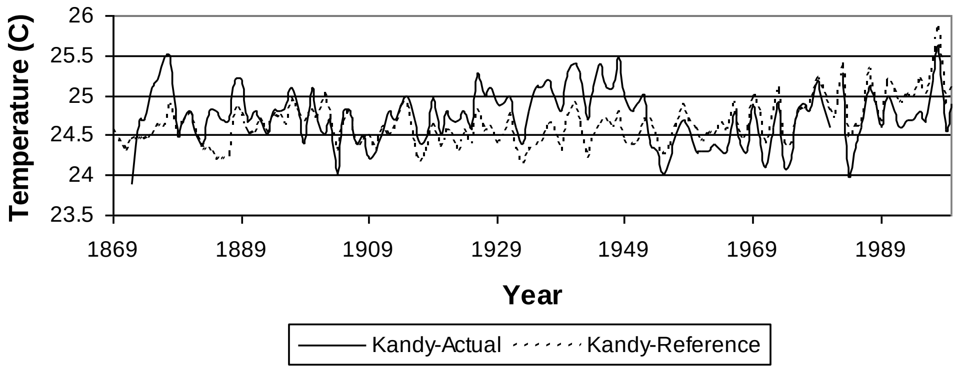


Fig.4. *Shows the mean annual temperature as observed at Kandy and a reference temperature estimate based entirely on other stations that are highly correlated with Kandy in the last fifty years. The discrepancies between the two time series are due to shifting of the Kandy stations in 1920's and 1950's.*

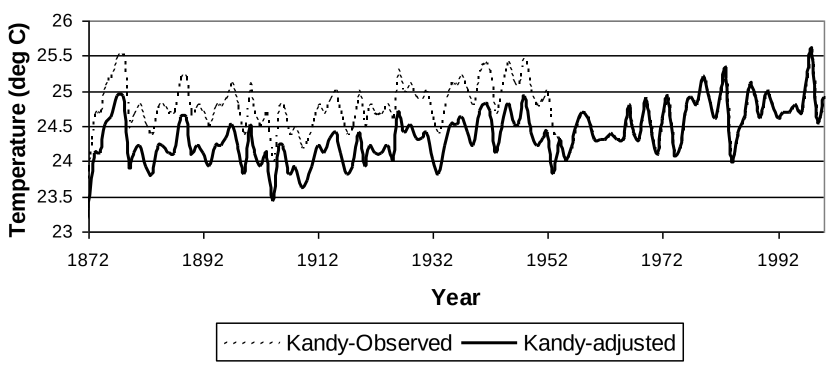


Fig.5. *Shows the mean annual temperature as observed at Kandy and a temperature reconstruction for the present location at Katugastota based on the on other stations that were highly correlated with Kandy in the last fifty years*

3. Interpolation of Temperature Data

INTRODUCTION

Sri Lanka has rapid changes in topography and there are sharp changes in surface temperature over short distances. Relative to other tropical regions, Sri Lanka has a relatively good network of meteorological observatories (figure 1). Yet, even with this network, simple interpolations lead to misleading results. For example, the striking drop in temperature near the Knuckles mountain range in Central-Eastern part of Sri Lanka (between Matale and Aralaganvila in figure 1) is not brought out (figure 2) as there are no observations for this mountain range. The interpolation technique may be improved using simple meteorological theory. A simple application of a lapse rate, $T_s = T + \Gamma * se$ Where; T_s is the corresponding station temperature at its sea level, Γ is the lapse rate to account for the influence of elevation on temperature and *se* is the elevation of the station may be used to guide the spatial interpolation. This method can be called topographically informed temperature interpolation (Willmot and Matsura, 1995). As high resolution topographical data is available globally, one can use this technique to develop high-resolution temperature climatologies elsewhere too.

DATA AND METHODOLOGY

Quality evaluated maximum and minimum temperature data for the period from 1961 to 1990 for 18 Sri Lanka Department of Meteorology stations, and for the available data for 19 Department of Agriculture observatories were used. Digital Elevation Model (DEM) data at a resolution of 90 *m* for Sri Lanka was obtained. The methodology is as follows;

a) Monthly and annual minimum, maximum and mean temperature was estimated for each station based on the record from 1960-1990.
b) For each station, the climatological temperature values were plotted as a function of elevation. One or two stations that were extreme outliers were discarded.
c) The lapse rate (Γ) was estimated as the gradient of best fit of the temperature-elevation plots for minimum, maximum and mean values respectively. Since there was a tailing off of the lapse rate near coastal locations, two different lapse rates were computed (Γ for the regions away from the coast defined as above elevation of 100 *m* and Γ_{coast} for the coastal stations defined as elevation below 100 *m*. (figure 3)
d) Using this lapse rate, a "reduced" temperature value at zero elevation ($T_{h=0}$) was estimated using the formula $T_{h=0} = T_{h=se} + se * \Gamma$.
e) Reduced temperatures on a grid of 1-km were estimated using inverse distance weighing interpolation from the reduced temperature values for the available stations.
f) The gridded reduced temperature values were renormalized to the appropriate elevation using the DEM elevation at the grid point. Temperature climatology maps were plotted as the temperature values on this fine-scale grid.

RESULTS AND DISCUSSION

We have used this methodology to produce maps of monthly and annual minimum, mean and maximum temperature for Sri Lanka. This methodology of using the topographically informed interpolation provided realistic estimates of temperature in the hilly areas. The average lapse rate in Sri Lanka (0.0064 °C/m) is consistent with the average environmental lapse rate value elsewhere for all months. However, in the coastal region, the lapse rate was inconsistent. It ranged from -0.0012 to 0.039 and was quite sensitive to the outliers.

CONCLUSIONS

The monthly lapse rates show consistency throughout the year and with standard estimates for the environmental lapse rates. The lapse rates for coastal areas were inconsistent as may be expected from the multiple processes of temperature variations at the coast. We find based on temperature data available for a few stations that were not used in the study and from anecdotal evidence that the temperature climatologic maps show fidelity to observations.

These maps are similar to previously produced spatial climatologies for Sri Lanka such as in the National Atlas of Sri Lanka (Somasekeram, 1988), and Arjuna's Atlas (Somasekeram, 1997). However, the maps that have been produced provide a finer scale rendering of the climatology and a more realistic rendering in the mountainous areas.

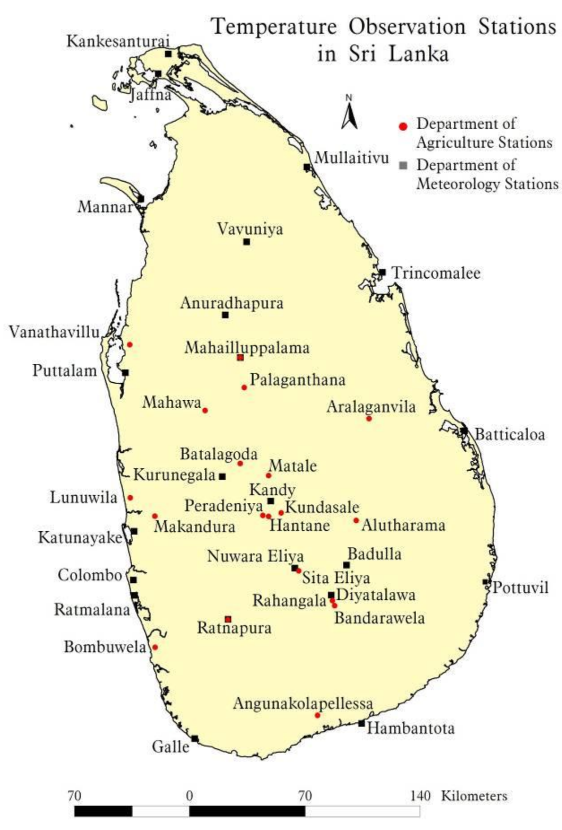


Fig.6. *Location map of the temperature stations used in the interpolation analysis.*

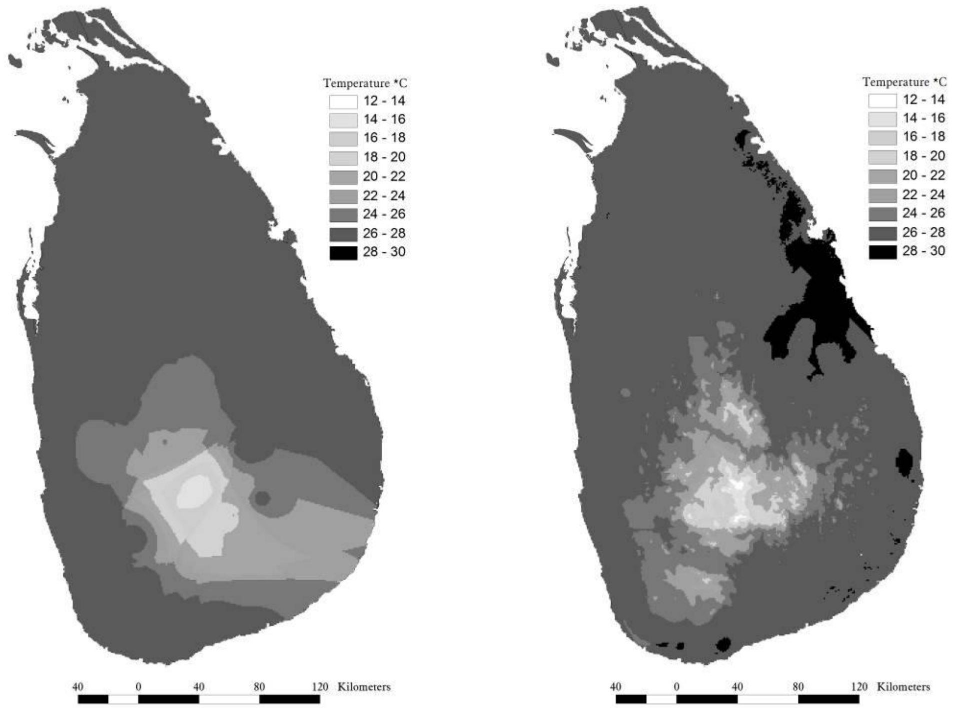


Fig. 7. *Left: Simple spatial interpolation of the annual average station temperature for the whole island. Right: Topographically informed annual average temperature climatology map for Sri Lanka.*

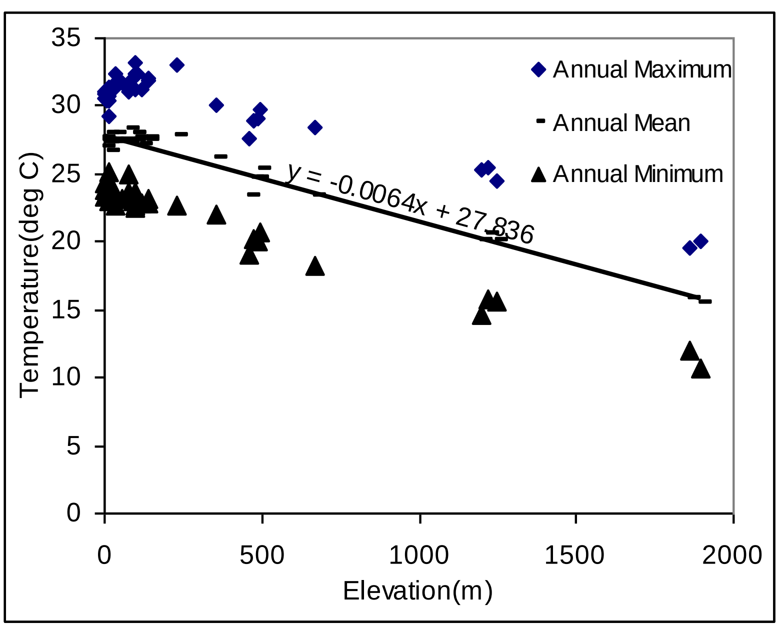


Fig.8. *Plots of average annual temperature versus elevation of the mean, minimum and maximum temperature.*

4. Climate Change Assessments

INTRODUCTION

Proper adaptation to climate change (IPCC, 2001) requires precise estimates of its magnitude, and descriptions of its temporal and spatial variation at several scales. Analyses of historical variations of instrumental temperature records are important for the investigation of regional effects of global warming. Such analysis is particularly important in locations with long and dense historical data such as in Sri Lanka. Assessments of rainfall and temperature trends have been provided previously (Rupa Kumar and Patil, 1996, Chandrapala *et al.*, 1996, Domroes, 1996).

Homogeneity of climate data is desirable and even critical when datasets are used to study questions related to climate fluctuations and changes. Climate data homogeneity (true homogeneity) exists when variations in the data are the result only of variations in weather and climate. But meteorological time series have from time to time changes of non – meteorological origin such as replacement of measuring devices, shifting observation sites, changes of vegetation or construction in the vicinity of a station, urbanization, and changes in the time of day of observation. Discontinuities may arise due to an abrupt change occurring at the observation station; on the observing platform, or in the way the data are processed. These changes include instrument changes, station relocations or changes in averaging methods for time averaged quantities. Before one can reliably use such climatic data for analysis of long-term climate change, adjustments are needed to compensate for the non – climatic discontinuities.

Quality control has been carried out based on a set of globally applicable guidelines and suspect portions of the data have been omitted. The period 1960-2001 gives good correlation among neighboring stations largely because of better data quality. However, the data quality in the Northern stations has some uncertainty.

The trends were analyzed by using linear best fit for the observed and quality controlled data, as there is no significant or pre-recognized pattern in the climate data. The trend values are greatly affected by the period, which is used for the analysis.

DATA

The mean, maximum and minimum temperature records for the last 100 years were obtained from the Sri Lanka Department of Meteorology (Fig.1) for stations that have long records.

METHODOLOGY

The following analysis was carried out:

a) Quality control was carried out as described in earlier sections.
b) The observed and re-constructed maximum and minimum temperatures were separately graphed as a function of year. The trend values were taken by the linear best-fit method for all 18 stations. These trends were mapped over the Sri Lankan station map.

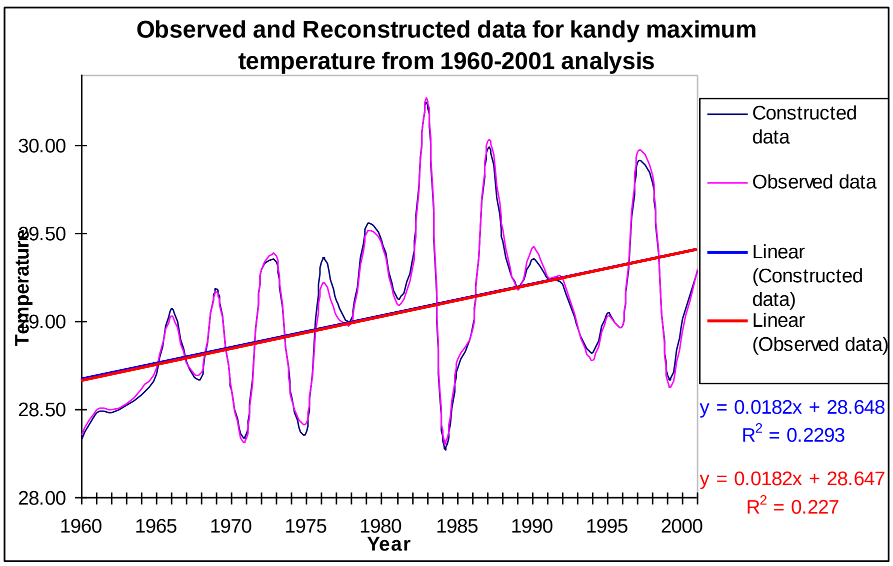
c) The same analysis was done for separate months for all the stations in order to get the seasonal trends over Sri Lanka.

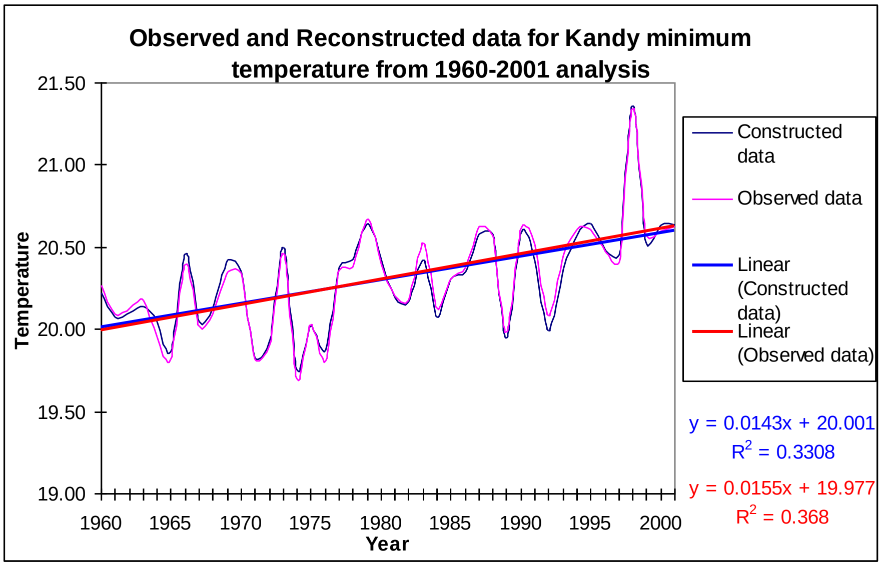
RESULTS

Quality Control

The mean and median differs by less than 0.1°C for all the stations other than Trincomalee in maximum temperature. The standard deviation is less than 0.5 other than few stations such as Anuradhapura, Badulla Trincomalee and Vavunia for maximum temperature and Vavuniya for minimum temperature.

The correlation values with neighboring stations always give a value higher than 0.85 for all stations. So we have used data from best-correlated five stations in order to reconstruct the data. The climate change trend is reliable as both reconstructed data from other stations and stations observations give similar results in most cases. Data from Kandy is shown as an example. The maximum temperature values for Trincomalee always show extreme values and the value for this station is suspect.





Trend Estimation

The climate change trend is towards warming in all of Sri Lanka. The average warming trend for maximum temperature is 2.6°C/100 years and for the minimum temperature is 1.7°C/100 years. This means that the daytime temperature is heating up faster than nighttime and the warming trend is changing from station to station and from season to season.

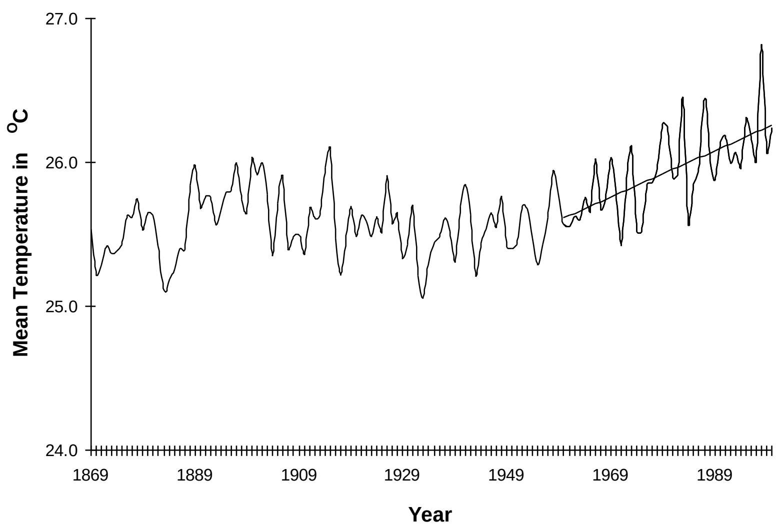


Fig.9. *The variation of annual average mean temperature in Sri Lanka during the period 1869-2000 and the trend line for the period 1960-2000.*

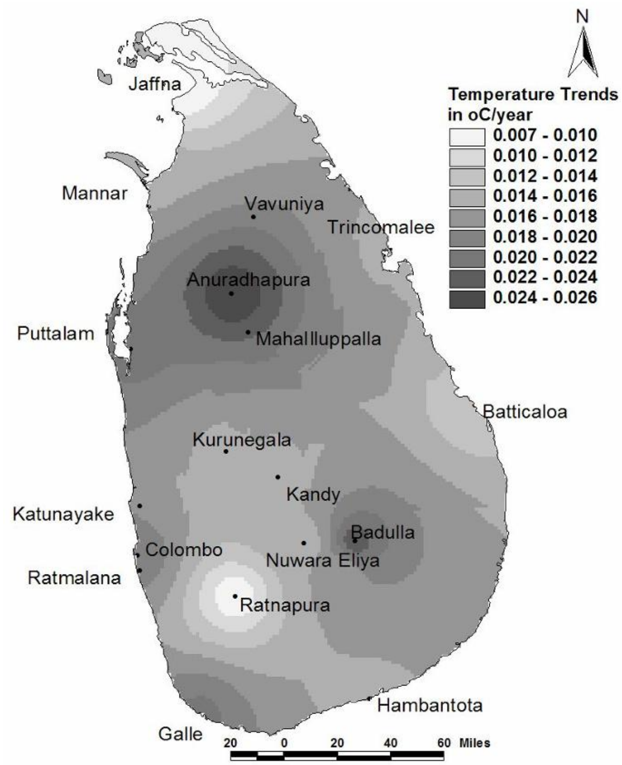


Fig.10. *Warming trends observed in the stations were estimated at each point and the inverse distance weighing method was used for interpolation. The annual average mean temperature trend for Sri Lanka is shown. The trend values ranges between 0.7 to 2.6 °C/100 years.*

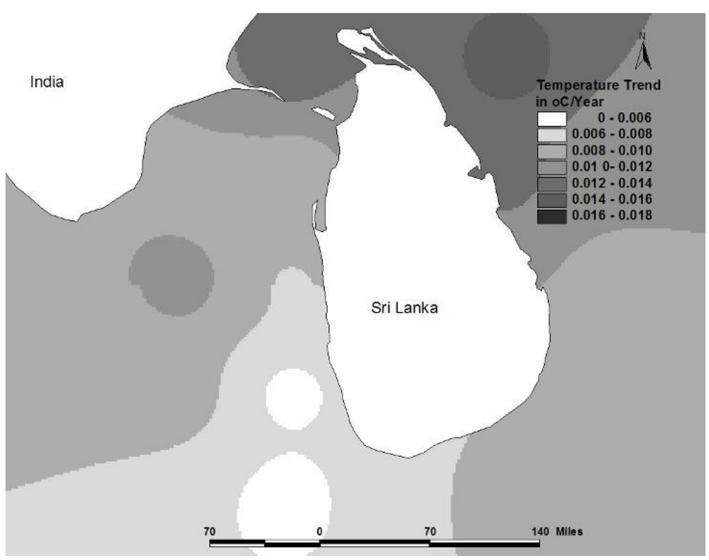


Fig.11. *Annual average Sea Surface temperature trend around Sri Lanka*

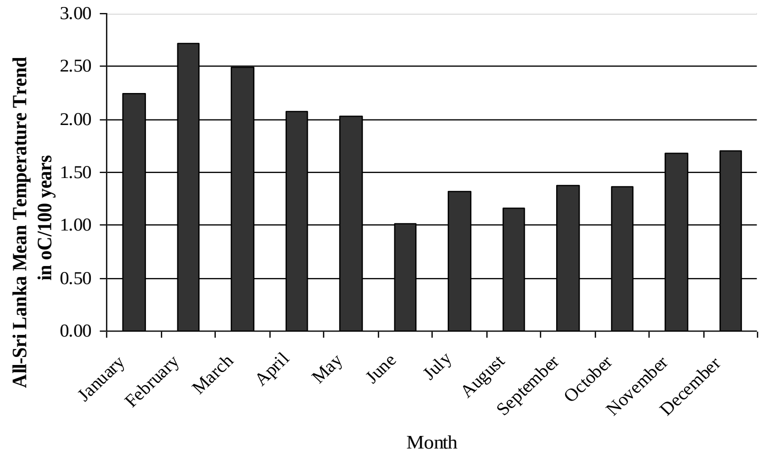


Fig.12. *Monthly variation of All-Sri Lanka mean temperature trend for the period 1960-2000*

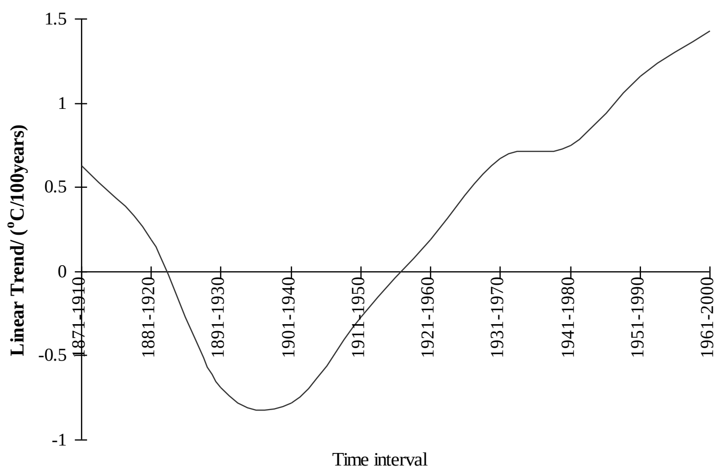


Fig.13. *Variation of annual average mean temperature trend for Sri Lanka with the time interval*

Outcomes

The reconstructed temperature data shows that observed data was consistent with that of the neighboring stations from 1960-2001 and thus estimates of climate change trends are reliable. There are some discrepancies between observed and reconstructed data before 1960 for the maximum temperature at Trincomalee.

All of the stations of the Sri Lanka Department of Meteorology show a consistent and significant warming trend. The warming trend has accelerated in recent years. The warming is stronger during the daytime. There is spatial variation by 50% in the warming trends with lower rate of warming at high elevations and increased warming towards the east of the Island.

The trends for mean surface temperatures show a trend of 2.6 ^{o}C/100 years on average in annual average maximum temperature and 1.7 ^{o}C/100 years for annual average minimum temperature. This means that the warming trend for maximum temperature is twice that for minimum temperature. These increasing trends of temperature show significant seasonal variation.

5. Estimating Fine-Scale Climatologies

Rainfall in Sri Lanka

Seasonal variation of rainfall was constructed. Rainfall data for 179 stations were obtained for the period from 1961 to 1990 as shown in the map (Fig.14). The data was subject to quality control in order to identify the suspicious data and stations. The Inverse-Distance-Weighing method was used for interpolation.

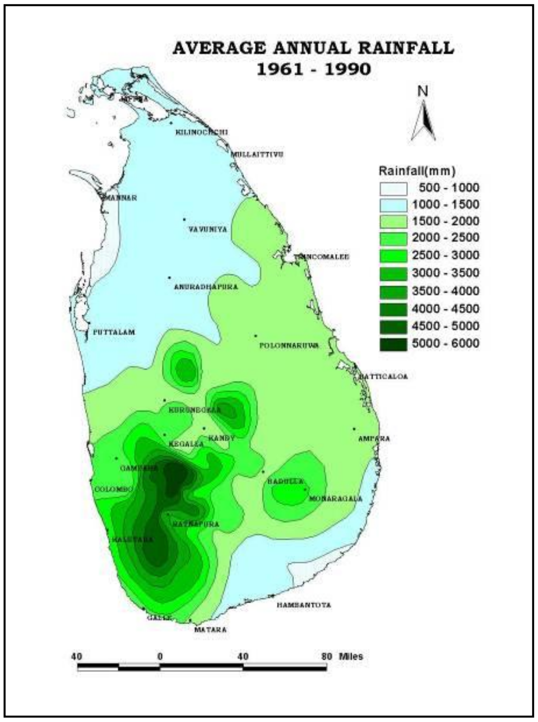


Fig.14. *Average Annual rainfall variation of Sri Lanka*

Mapping of Temperature Climatology:

Previous attempts to map spatial data are poor particularly in the highland tea areas as they do not take account of elevation differences in interpolation. We developed an algorithm and computer program to take account of elevation in our mapping. Digital elevation data was obtained from the IRI. As a means of testing these interpolation schemes, we obtained additional data from Irrigation Department.

Temperature data for Sri Lanka are available in 18 Sri Lanka Meteorology Department stations and 19 Sri Lanka Agriculture Department stations for more than 100 years. These data are available separately for maximum temperature, minimum temperature and mean temperature in annual and monthly basis. All the available data were tabulated and subjected to quality control; Annual average maximum and minimum temperature were mapped over Sri Lanka by using Inverse-Distance-Weighing method in order to get regional variation of temperatures. The seasonal variations were also identified by mapping monthly temperature values. The seasonal and regional distributions of temperatures are shown in the figures (Fig.15).

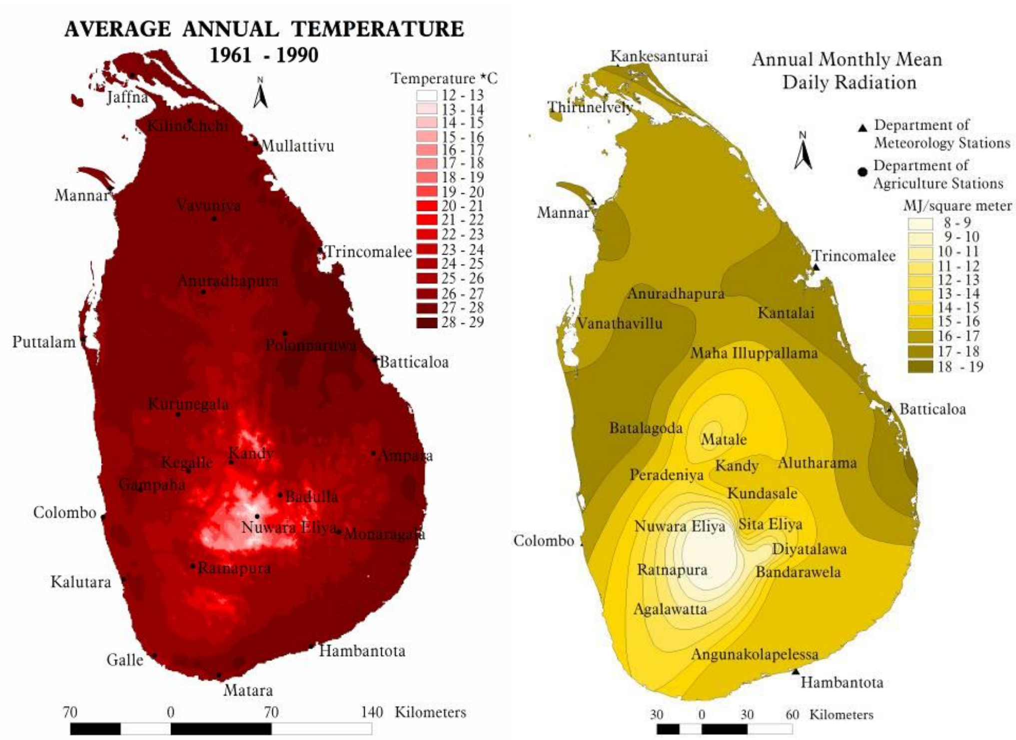


Fig.15. *The seasonal and regional distributions of temperatures*

Solar Radiation Climatologies: We have worked under the guidance and with the data of Prof. T.D.M.A Samuel of the University of Peradeniya to produce maps of solar radiation climatology using a scheme that he devised and calibrated for Sri Lanka to use daily sunshine hours to estimate solar radiation.

6. Future Climatological Scenarios under Present Trends

We have used the trend assessments for each station and the topography informed interpolation scheme to construct possible future climatologies for Sri Lanka annually, seasonally and also monthly. Here we show the projected temperature climatology for 2025 and 2050 (Fig.16).

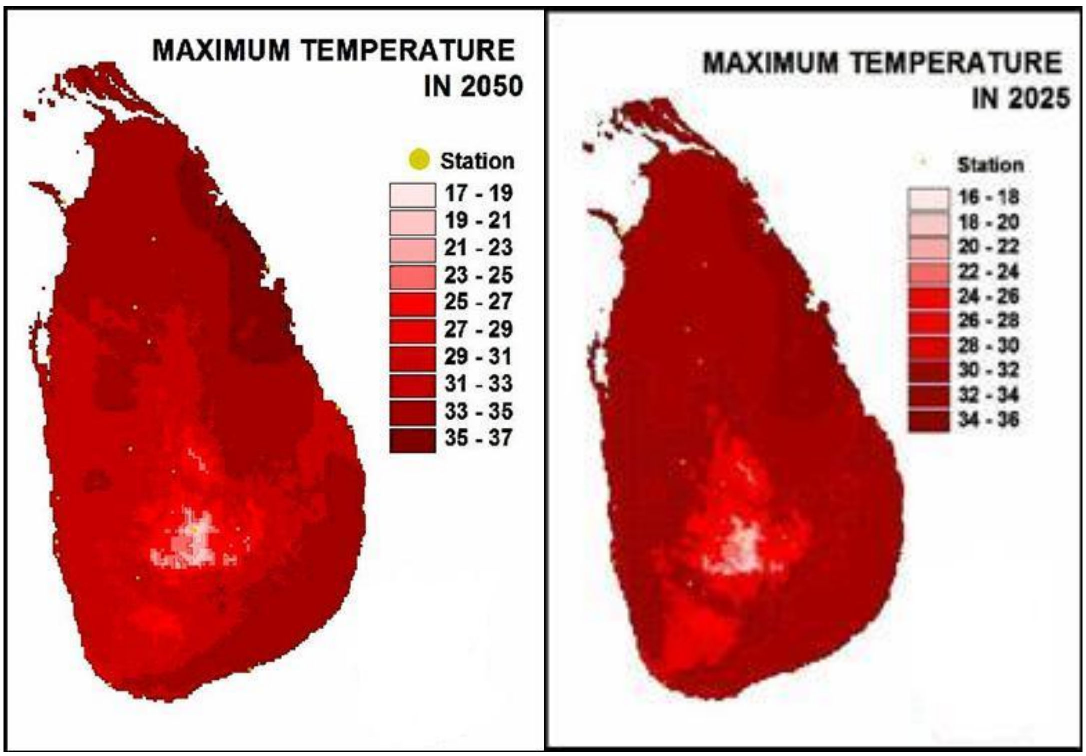


Fig.16. *A scenario of maximum temperature climatology in the year 2050 and 2025 based on trend extrapolation.*

7. Coconut Yield Prediction

Accurate forecasting of Annual National Coconut Production (ANCP) is important for national agricultural planning and negotiating forward contracts with foreign buyers. Climate and the long term trends (attributed to "technology") are major factors that determine ANCP. The climate effect was estimated by regressing production data that had been de-trended to remove the "technology effects" with quarterly rainfall in the year prior to harvest in principal coconut growing regions which are all in the low-lands. The technology effect was estimated from the historical log-linear trends. The regression model (Fig.17) that integrates both climate and technology effects developed to predict ANCP with high fidelity (R^2 = 0.94).

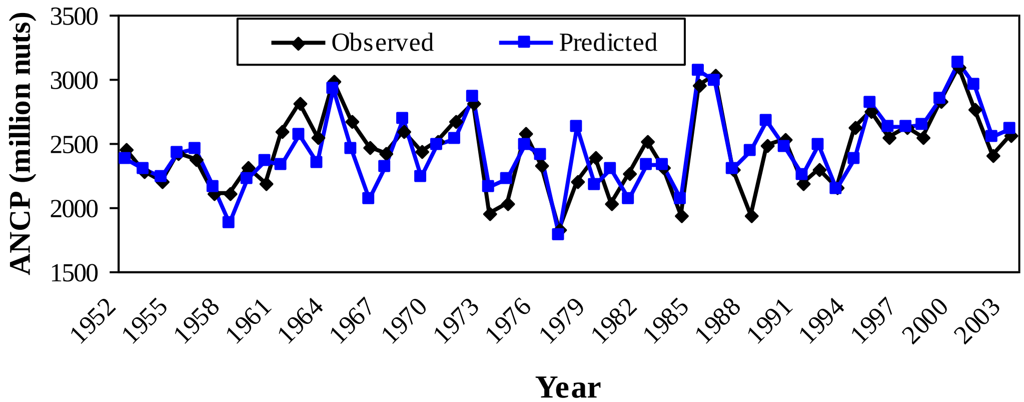


Fig.17. *The predicted and observed annual coconut production based on a model that accounts for technological change and seasonal climate (Peiris, Hansen and Zubair, 2006).*

8. Valuation of Climate Influences on Coconut Production

Coconut – Economic value for Sri Lanka

Sri Lanka is the 4th largest producer of coconut in the world. Coconut cultivation spans about 402 649 ha accounting for 21% of agricultural lands in the country. It contributes 2% to Sri Lanka's GDP, 2.5 % to export earnings, and 5% to employment. Of the national coconut production, the biggest single use (60% - 75%) is for domestic culinary consumption, followed by desiccated coconuts (DC), coconut oil and so on. Production and GDP values of coconut have fluctuated between US$ 115 million in 1950; US$ 177 million in 1986, and US$ 139 million in 2002. With a reproductive phase of 44 months, effects of weather are evident on all stages of development but the influence of weather depends on the stage of development. From a perspective of policy making, it is useful to quantify the impact of climate on the economy.

Valuation of climate on the economy of coconut

We have assessed the economic value of climate variability employing a percentile analysis on an array of 31-years national annual coconut production data. During 1971 to 2001 (31 years), national coconut production varied from 1821 million nuts (minimum in 1977) to 3096 million nuts (maximum in 2000) with a mean of 2435.90 million nuts (cv= 14%). Of the production array, 10% and 90% percentiles have been considered respectively as lower and upper production extremes. The 60% of production departures of each year of extremes with respect to the mean production of 10% to 90% percentile were attributed to climate variability because studies show that the 60% of the variation of coconut production is explained by climate. These production deviations were then valued multiplying by free-on-board (FOB) prices of fresh coconuts. Results show that the foregone income from coconuts due to low rainfall varied between US$ 32 million and US$ 73 million while the incremental income to the economy in crop glut extremes varied between US$ 42 million and US$ 87 million. Droughts lead economic losses estimated at US$ 32 million to US$ 73 million. In years of extreme crop surplus, the economy realises an income gain of US$ 42 million to US$ 87 million. Hence, with anticipated declines in rainfall due to climate change, coconut cultivation could be subjected to stress.

Production extreme	Year	Production (million nuts)	Change in Production (million nuts)	Foregone/incremental value (million US$)
Shortage	1973	1948	484	32
	1977	1821	611	49
	1984	1942	490	73
	1988	1937	495	54
Glut	1985	2958	526	42
	1986	3039	607	46
	1999	2828	396	59
	2000	2096	664	87

Table: Impact of extreme climate events on coconut production. Source: (Fernando, N, Zubair, L., Peiris, T.S.G., C.S. Ranasinghe and J. Ratnasiri., (2007)). US $ = approximately Rs.105 on 20 December 2004

9. Dissemination

We have presented our work on climate change and related issues in Universities, Mahaweli Authority, to post-graduate students in meteorology at the University of Colombo, to post-graduate students in oceanography at the University of Peradeniya and to post-graduate students in water resources management at the University of Peradeniya.

Presentations:

- Lareef Zubair, Climate Change Related Issues, Mahaweli Authority, Kandy and Colombo.
- Lareef Zubair, Janaki Chandimala and Manjula Siriwardhana attended the international conference on Sustainable Water Resources Management in the Changing Environment of the Monsoon Region, United Nations University, held in Colombo, Sri Lanka on 17th-19th November, 2004. Presentation by Manjula Siriwardhana on Climate Change Assessments for Sri Lanka from Quality Evaluated Data.
- December 2003: Using Climate Information for Water Resources and Disaster Management, Central Engineering Consultancy Bureau, Digana, Sri Lanka.
- January 2003: Climate and its Prediction for Water Resources Management, Ministry of Water Resources and Irrigation, Colombo.
- December 2003: Climate and its Predictions for Sri Lanka, Center for Environmental Studies, University of Peradeniya, Peradeniya, Sri Lanka.

Posters:

- Four posters were presented at the Workshop on Integrated Assessment Modelling, Taj Samudra Hotel meeting – initiating the training of the AIACC project team by New Zealanders. These posters were on the topics of project outline, data quality control, climatology and seasonal climate predictions. A3 versions of these posters were presented to members of each local participating institutions of this project.

Internet:

- Project partners at the Coconut Research Institute have operationalized the prediction scheme, and the predictions are provided at http://www.cri.lk/yield.htm

10. Capacity Building

The PI made arrangements at International Research Institute for climate and society, New York to host Dr. Sarath Peiris for three weeks. His work there led to a draft research paper on crop-climate interaction in collaboration with Dr. James Hansen. The PI was also able to host Dr. Neil Fernando for a week where we developed a draft on the valuation of climate impacts on coconut sector along with Dr. Peiris.

Two research assistants were supervised during this grant, Mr. Heli Bulathsinhala and Ms. Kusalika Ariyaratne obtained their M.Sc supported by this project. Heli Bulathsinhala was awarded a M.Sc. by the University of Moratuwa in Water Resources Engineering and Kusalika Ariyaratne completed requirements for her M.Sc. at the Post-Graduate Institute of Science in University of Peradeniya. The above two research assistants and two other research assistants Mr. Irugal Bandara and Ms. Manjula Siriwardhana obtained extensive training in climatic data analysis, scientific reporting and project management.

Institutional capacity to conduct climate change research was established at the FECT. The sustenance of this capacity however is something that needs further grants.

11. Outputs

Journal Publications

- **Jan 2008:** Use of Seasonal Climate Information to Predict Coconut Production in Sri Lanka, International Journal of Climatology, 28 (1): 103-110.
- **Jan 2008:** Use of Seasonal Climate Information to Predict Coconut Production in Sri Lanka, International Journal of Climatology, 28 (1): 103-110.
- **May 2002:** Development of Meteorology in Sri Lanka, Journal of the Institution of Engineers, Sri Lanka. 15(2):14-18.
- **September 2003:** Saving Weather Data, TIEMPO, 49:16-22, University of East Anglia, UK.
- **Apr 2004:** Towards Developing Weather and Climate Prediction for Sri Lanka, Journal of the Institute of Engineers, Sri Lanka, XXXVII, 2:53-58.
- **July 2004:** Empowering the Vulnerable, TIEMPO, 52:3-6, University of East Anglia, UK, Also, highlighted in SciDev.net as "Communities facing climate change need local science."

Conference Papers

- **December 2004:** Peiris, T. S. G., Lareef Zubair, Piyasiri, C. H. (2004). Forecasting national coconut production – a novel approach. In Proceedings of the International Sri Lankan Statistical Conference Visions of futuristic methodologies. (Eds: Basil M. de Silva and Nitis Mukhopadhyay), 28-30, Post Graduate Institute of Science, University of Peradeniya, Sri Lanka.
- **November 2004**: Lareef Zubair with Upamala Tennakoon and Manjula Siriwardhana, *Climate Change Assessments for Sri Lanka from Quality Evaluated Data*, International Conference on Sustainable Water Resources Management in the Changing Environment of the Monsoon Region, United Nations University, Colombo, Sri Lanka.
- **December 2002**: with Heli Bulathsinhala, Quality Evaluation of Mean Historical Temperature Data in Sri Lanka, Sri Lanka Association for the Advancement of Science, 58th Annual Sessions, University of Colombo, Colombo, Sri Lanka.

News Articles

In multiple Sri Lankan newspapers on Climate Change in Sri Lanka and National Security

Theses

- Heli Bulathsinhala, Climate Forecasting for Water and Environmental Management in Sri Lanka, M.Sc., Civil Engineering, University of Moratuwa, Sri Lanka, March 2005, (Now Professional Engineer, Sri Lanka.)

- Kusalika Ariyaratne, Numerical Model for Simulating Shoreline Change, M.Sc, Oceanography, Post Graduate Institute of Science, University of Peradeniya, Sri Lanka, May 2005, (Now PhD candidate at Texas Tech University)

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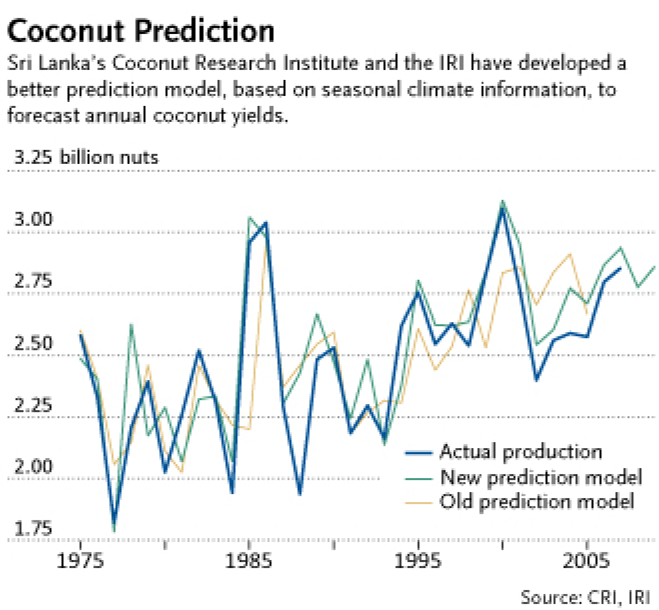
13. IRI Web Feature: Climate and Coconuts

By Francesco Fiondella and Jason Rodriguez

Millions of people in the tropics depend on coconuts for food, raw materials and livelihood. Coconuts are also a high value commercial crop. But like any crop, coconuts are at risk of drought and other prolonged events. By using climate science and better agricultural forecast models, the IRI has helped increase the resilience of coconut plantations to climate variability in one of the world's major producers, Sri Lanka.

"The uncertainty that characterizes agriculture - much of it due to climate variability- is among the greatest challenges facing farmers and others in the agriculture value chain in much of the world. Any information that reduces the uncertainty about future production or prices has immense value to them," says IRI research scientist James Hansen.



IRI's partners in this work have been the Coconut Research Institute of Sri Lanka (CRI), the Foundation for Environment, Climate and Technology (FECT), and the Sri Lanka Department of Meteorology. Together, the institutions have developed an improved prediction scheme that generates annual coconut production forecasts fifteen months in advance. The CRI has been using these forecasts since 2005 to help calculate projected coconut yields for the upcoming year. In a country such as Sri Lanka, more accurate projections are critical.

"Coconut cultivation sustains the livelihood of large numbers in the tropics and is the most important crop for food security after rice in Sri Lanka," says IRI scientist Lareef Zubair, who has been working with the CRI and other Sri Lankan colleagues since 2003.

"When we started out on this project, we were not sure whether we could provide an adequate prediction using climate information, as climate is one of many factors that affect production," Zubair says. "In addition, we had to assume that the climate and coconut data were of adequate quality."

Sri Lankans love their coconuts. The country has the highest annual per capita consumption of coconuts in the world- about 110 nuts. Sri Lankans dedicate about 400,000 hectares, more than a fifth of the agricultural land in the country, to grow the crop. These efforts produce on average 2.5 billion nuts every year, which account for 2% of Sri Lanka's gross domestic product, 2.5% of its export earnings and 5% of its workforce.

"One concern is about how coconut plantations can cope with climatic variability and adapt to climate change," says Neil Fernando, an agricultural economist at the CRI, with whom Zubair and Hansen collaborated. The work was funded through the Assessments of Impacts and Adaptations to Climate Change (AIACC) project from the Global Change System for Analysis, Research and Training (START).

CRI Experimental Station. L. Zubair/IRI.

Fernando and Zubair coauthored a paper in 2007 which calculated the economic impacts of climate variability on the Sri Lankan economy. In years of extreme crop shortage, income losses to the economy could be $32 million to $73 million. However, in years of extreme crop surplus, the economy could realize income gains between $42 million and $87 million.

Much like any agricultural commodity, coconuts are bought and sold months ahead of time via futures, or forward contracts. Accurate forecasting is critical for national agricultural planning and for negotiating forward-contract pricing with foreign buyers.

Coconut is a perennial crop with a longÂ development period of about 18 months. The long maturation period makes it vulnerable to severe or prolonged weather events, especially during Sri Lanka's two dry seasons (January to March, June to August).

"Extended dry spells can reduce yield," says Sanathanie Ranasinghe, the head of plant physiology at the CRI. "However, excessive cloudiness during the wet season can reduce photosynthesis, which can diminish the 'dry matter' production needed for nut growth".

"Coconut is quite different from short-season cereal and pulse crops that we've worked with," says Hansen. "We initially thought our ability to forecast rainfall would be the most important factor in forecasting coconut yields months before harvest. Instead, we learned that the history of weather as far as two years before harvest provides quite a bit of information about future yields."

Simply by monitoring rainfall during a dry season, growers are able to predict future yields up to 15 months in advance with good skill. If there's too little rainfall, then they can make management decisions, such as irrigating or increasing fertilizer use, to try to mitigate the impacts on yield.

"Seasonal climate forecasts allow us to extend the lead time of yield predictions from 15 months to 21 months," says Sarath Peiris, the head of the biometry division of the CRI. Growers don't have to wait until the dry season is upon them in order to adjust their yield predictions, he says.

Peiris and Fernando came to the IRI for three weeks of training in 2004 and have been in regular consultation since. Zubair has been to Sri Lanka to help scientists in the country's agricultural research institutions, meteorological services and other institutions on using the IRI's Data Library, and the use of monitored and forecast information.

The predictions are distributed to national policy makers and to the agricultural extension officers in the 12 coconut growing sub-regions, and through them, to 270 major coconut plantations in the country. The predictions have helped the government and growers make informed decisions during droughts. Users have started requesting predictions by season and by region, and the CRI scientists are now working towards this.

Sri Lankan coconut salesman biking to market. JC Gallard

"By investing modest resources, we helped them incorporate state-of-the art knowledge on climate variability into their prediction system," says Zubair, "and it turned out to have outcomes that were very useful for the end users."