Forecasting of Seasonal and Monthly Rainfall in Sri Lanka Using Climate Predictability Tool (CPT)

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PREFACE

Seasonal weather forecasting has become more important for many sectors for their future planning in taking proactive adaptation and mitigation measures for anticipated weather extreme conditions. In realizing the importance of this issue, the 13th Governing Board meeting held during 04-05 November 2007 recommended the collaborative project title "Seasonal Climate forecasting using Climate Predictability Tool (CPT)" and consequently it was approved by the Standing Committee meeting held in New Delhi, India in December 2007. This project has been collaborating with Sri Lanka Meteorological Department, International Centre for Theoretical Physics (ICTP) of Italy, Seoul National University of South Korea and Bangladesh Meteorological Department.

In the initial phase of the project, work has been carried out for developing June-July-August (JJA) forecast for Sri Lanka. As a part of this collaborative project, a comprehensive training programme was conducted in Sri Lanka during 12-23 May 2008 for Meteorologists and Research Assistants of the Sri Lanka Meteorological Department to foster the research activities on seasonal weather forecasting and to make use of knowledge for issuing operational forecasts for the stakeholders in the country. Results of the initial phase of the project were presented in an international training activity organized by ICTP, Trieste, Italy during 04-15 August 2008.

The authors wish to acknowledge the Director of SMRC for the encouragement given in conducting this research on seasonal weather forecasting for SAARC member states. They also wish to acknowledge Director General of Meteorology of Sri Lanka Meteorological Department for providing necessary data and nominating collaborative scientist for the project. Authors also wish to thank International Centre for Theoretical Physics (ICTP), Trieste, Italy in particular Dr. Jin Ho Yoo for providing valuable guidance and data for the study. Thanks are also due to Prof. In-Sink Kang and his team of Seoul National University (SNU) of South Korea for providing CGCM data for making seasonal forecasts for Sri Lanka.

Authors
December 2008

Acronyms

AGCM	Atmospheric General Circulation Model
CCA	Canonical Correlation Analysis
CGCM	Couple General Circulation Model
CPT	Climate Predictability Tool
DJF	December-January-February
DODS	Distributed Oceanographic Data System
ENSO	El Nino and Southern Oscillation
EOF	Empirical Orthogonal Function
GHG	Greenhouse Gas
ICTP	International Centre for Theoretical Physics
IMD	Indian Meteorological Department
IRI	International Research Institute
JJA	June-July-August
LPA	Long Period Average
MOS	Model Output Statistics
NWP	Numerical Weather Prediction
PCR	Principal Components Regression
SAARC	South Asian Association for Regional Cooperation
SNU	Seoul National University
SMRC	SAARC Meteorological Research Centre

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SUMMARY

Sri Lanka is a tiny tropical island located in the Indian Ocean having an agricultural based economy, for which tea, coconut, rubber and paddy are the most important cash crops to maintain its economy in a sustainable manner. Floods and droughts are the major extreme events, which affect the crop production in the country, out of which floods associated with monsoon rains are much more prominent in almost every year. Southwest monsoon, which contributes heavy downfalls over the western and southwestern areas, is important as it is responsible for feeding hydro catchments of many reservoirs over the highlands. Rivers carry away this monsoon rains towards northeast by nourishing minor tanks in the dry zone, which in turn cater the demand for the farmers in the region. It is regarded that the rice bowl of Sri Lanka is located in the dry zone and paddy crop is cultivated with both rain and irrigated water from the minor tanks.

Therefore, a reliable seasonal weather forecasting technique is presented for taking proactive adaptation measures for sustainable management of agriculture, water resources and other vulnerable sectors in Sri Lanka. Climate Predictability Tool (CPT), developed by International Research Institute of University of Columbia is made use of making seasonal weather forecasts for Sri Lanka. It uses Canonical Correlation Analysis, in which predictors and predictands are involved in making forecasts using Model Output Statistics technique. The model is trained with 27 years of rainfall data retrieved from Meteorological observatories in Sri Lanka and sea surface temperature data of Coupled General Circulation Model of Seoul National University. The CPT has shown some potential to predict June-July-August seasonal mean-rainfall and month of June mean-rainfall over Sri Lanka as a whole and over the selected districts in the western and southwestern parts of Sri Lanka. Results reveal that the forecasted June-July-August seasonal mean-rainfall is slightly overestimated especially over the individual districts, except Kandy and Nuwara Eliya, due to fairly higher rainfall received during the southwest monsoon in 2008. Forecast for the month of June is somewhat acceptable as the model is able to catch-up excess rainfall received over individual districts. Climate Predictability Tool seems to be a better tool for predicting southwest monsoon rains in Sri Lanka.

1. Introduction

In a broader context, climate prediction is very much important, as the climate is changing owing to natural and anthropogenic activities. Climate change has been aggravated in the recent past and projected to be even worsening in the future especially due to anthropogenic inputs to the living climate system. In view of this, climate change has a greater bearing on seasonal weather and therefore a suitable technique is desired for making seasonal weather forecasts for the benefits of stakeholders in various sectors such as agriculture, water resources, energy, etc.

Sri Lanka has an agricultural based economy in which Tea, Rubber and Coconut are the main cash crops for maintaining the economy in a sustainable manner. Rice is the staple food for the people in the country and sometimes, annual production may not be sufficient due to havocs triggered by the meteorological hazards such as floods and droughts.

Seasonal weather forecasting is conventionally done using statistical methods, in which several parameters are used with multiple or even multivariate regression techniques. With the new development of computing resources, seasonal weather forecasting is now tested using numerical methods for which meso-scale or limited area models are run for several months with the initial and boundary data from Global Circulation Models. No proper technique had been utilized in Sri Lanka for seasonal prediction, however ten parameter multiple regression model has been tested in the recent past for forecasting southwest monsoon rainfall. Therefore reliable and user-friendly seasonal weather forecasting technique is an utmost urgency for the Department of Meteorology in Sri Lanka.

To comply with the above requirements, the Climate Predictability Tool (CPT), developed by the International Research Institute (IRI) for Climate and Society of University of Columbia, USA is made use of for making seasonal weather forecasts for Sri Lanka. CPT is a powerful tool for making efforts to forecast seasonal climate in the tropical and sub-tropical areas in the world. This has been tested in many African countries for making seasonal weather outlook for their countries. It is hoped that this method could be utilized in other countries in the SAARC region for making seasonal climate forecasts until the dynamical methods are properly tested and adopted.

2. History of Long Range Forecasting

In India, long-range weather forecasts of southwest monsoon rainfall has been issued since the establishment of the India Meteorological Department (IMD). After experiencing the serious famine in 1877, H.F. Blanford was involved in forecasting of monsoon rainfall by analyzing the snow cover over Himalayas. In 1886, an operational long-range forecast of monsoon rainfall, covering entire India and Burma, was issued by H.F. Blanford. However, Gilbert Walker, who was the Director General of IMD during 1904-1924, developed the first objective statistical model, which correlates monsoon rainfall and antecedent global atmospheric, land and ocean parameters. In 1988, sixteen-parameter power regression and parametric model were introduced operationally, which was developed by Gowariker el al. (1989, 1991). However, none of the models was able to forecast monsoon rainfall in 2002, which was an all-India drought year, as a result new operational model was developed by Rajeevan et.al. (2004) with ten parameters. With the revised version, an early forecast for the southwest monsoon rainfall is made available in April with an update forecasts in July.

In United states, extended and long range forecasts were made by the Extended Forecast Section of United States Weather Bureau during 1940s (Namias 1947). The 5-day circulation forecast was made well before the advent of Numerical Weather Prediction (NWP) with the use of constant absolute vorticity trajectories and other semi-quantitative applications of Rossby (1939). 5-day mean patterns were estimated with extrapolation of recent movements of troughs and ridges (Namias and Clapp, 1944). Subjective methods were employed in estimating temperature and precipitation from the predicted height anomaly patterns and latter statistical methods were developed (Klein, 1949, 1965 and Klein *et. al.* 1959) to objectively relate mean temperature anomaly and precipitation to the mean circulation. With the advent of NWP, daily forecasts were issued for 3-5 days based on subjectively modified model outputs (Shuman and Hovermale 1968). As the model physics improved, it began to show acceptable skills even in long range forecasting and therefore, forecasts of mean circulation, temperature and precipitation anomalies for 6-10 days were issued (Andrew 1977). After the long period of testing the first 90-day seasonal outlook was issued by the U.S. Weather Bureau for the summer of 1974.

There are several other related studies on Asian summer monsoon and associated rainfall and other features especially after 1970s. Some of the studies were conducted by Madden and Julian (1971 and 1972); Keshavmurti (1973); Bhalme and Parasanis (1975); Krishnamurti and Bhalme (1976); Murakami (1977); Yasunari (1979, 1980 and 1981); Krishnamurti and Aydanuy (1980); Sikka and Gadgil (1980); Krishnamurti and Subramanyam (1982); Sing and Kriplani (1985); Singh *et al.* (1986); Pant and Rupa Kumar (1997); Devkota *et al.* (2006).

Dynamical models may be the best suitable tool for making seasonal forecasts provided that the initial and boundary conditions are accurate enough. Due to the lack of data coverage over the vast ocean area, initial and boundary conditions are not much accurate and therefore global dynamical models do not have the credibility to simulate the salient feature of the mean monsoon and its variability. There are many global modeling centres, which produce global forecasts in adequate lead-time and therefore accurate and reliable forecasts may be developed in the future through improved data assimilation techniques. In the mean time, empirical / statistical methods need to be developed for generating seasonal weather forecasts to cater the demand.

3. Geography and Climate of Sri Lanka

Sri Lanka is a tropical island, 65,610 km^2 in area. It is situated in the North Indian Ocean, just southeast of the southern tip of the Indian sub continent, lies between 6 °N and 10 °N latitude and between 80 °E and 82 °E longitude. The coastline, which is about 1585 kilometers in length, is irregular, comprising sandy beaches, extensive lagoons and estuaries, mangroves, coastal marshes and dunes. The continental shelf, 26000 square kilometers in extent, is on the average 20 kilometers wide and 20 to 65 meters deep. It is narrowest at Kalpitiya where the width is only two kilometers while on the northeast it is continuous with peninsular India. The near-shore zone is characterized by the occurrence of reef, which are of three types, namely coral, sandstone and crystalline rock (boulder).

The highlands, mostly above 300 meters, occupy the south central part of Sri Lanka with numerous peaks (Pidurutalagala -2524m, Kirigalpotte - 2396m), high plateaus and basins and are surrounded by an extensive lowland area. The central part of the island is the source of the major rivers of the country, numbering over a hundred, which flow across the lowlands into the Indian Ocean. Long parallel ridges cut by these rivers, their height increasing gradually from the coast characterize the topography of the southwest. The northern and north-central parts of the island form one greater pain and the maritime districts consist of similar level or undulating stretches.

The island is subject to two monsoons, the southwest (May to September) and northeast (December to February). For the most parts, Sri Lanka is hot and humid. Despite the relatively small size of the country, there is considerable variation in climate over time and space. Rainfall shows seasonal fluctuation, depending on the monsoon and on convectional and cyclonic effects. The mountain mass, positioned across the line of direction of the two monsoons, intercepts the moisture-laden winds, causing them to deposit their moisture on the windward side. Consequently, the western littoral receives rain throughout the year while the rest of the low country remains dry except during the northeast monsoon from December to February, when it rains especially in the north and east. Rain in the inter-monsoon periods is caused by thermally-driven convection and occurs mainly in the afternoon or evening, often accompanied by thunder. The annual average rainfall varies from below 1000mm over the northeast and southwest of the island to over 5000mm on the southwestern slopes of the central hills (Fig. 2). Variability of rainfall in southwest monsoon season is comparatively lower than that of northeast monsoon season (Fig. 3(a) and 3(b)). The standard deviation of rainfall in southwest and northeast monsoon seasons, during the period 1961-90, is 62.4mm and 199.6mm respectively. On the basis of rainfall distribution, the island is divided into two major distinct areas, the wet and dry zones. The wet zone covers about a quarter of the island in the southwest, extending southward from Chilaw and up to Kandy and Nuwara Eliya in the east. The rest of the island (3/4) mainly consists of the dry and intermediate zones, having only a single rainy season and an average annual precipitation of about 1425mm (in the dry zone). The region between the wet and dry zones is referred to as the intermediate zone (Fig. 1). These are mainly dry and suited for irrigated agriculture. Large forests of many valuable hardwoods are located here.

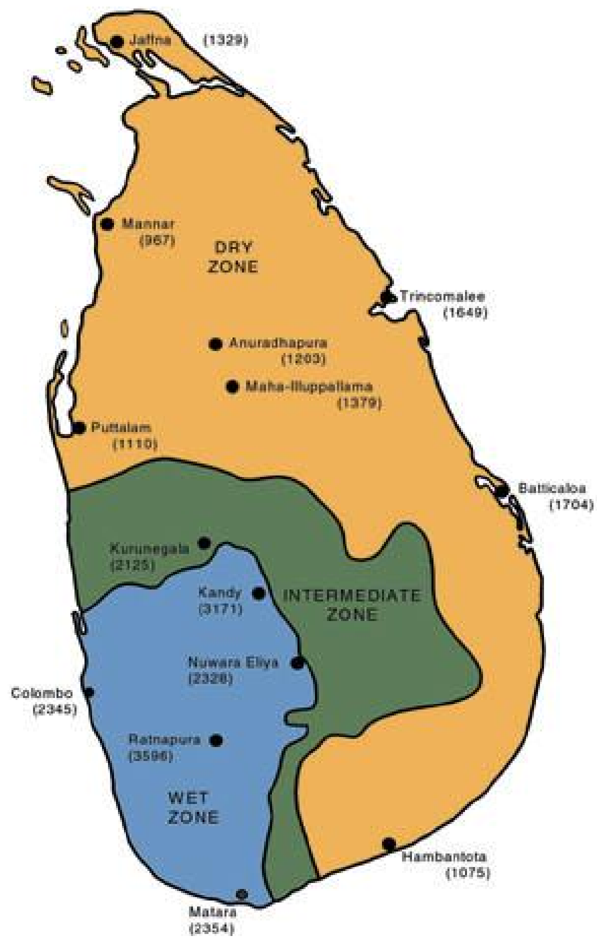
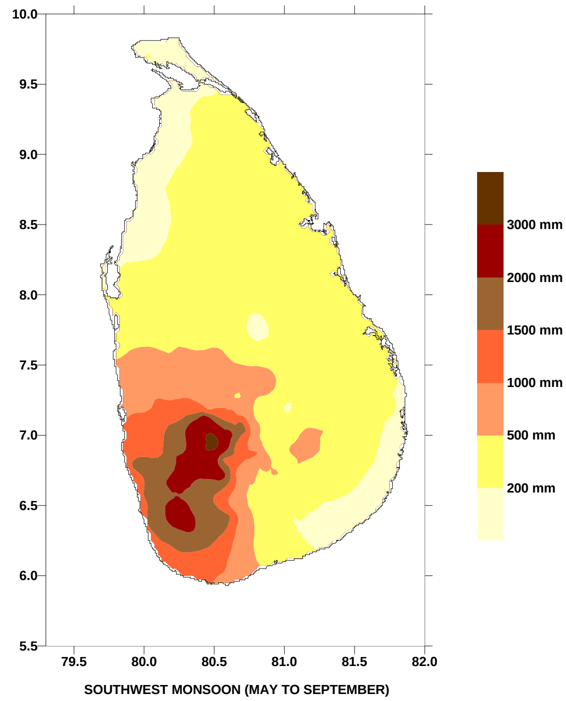
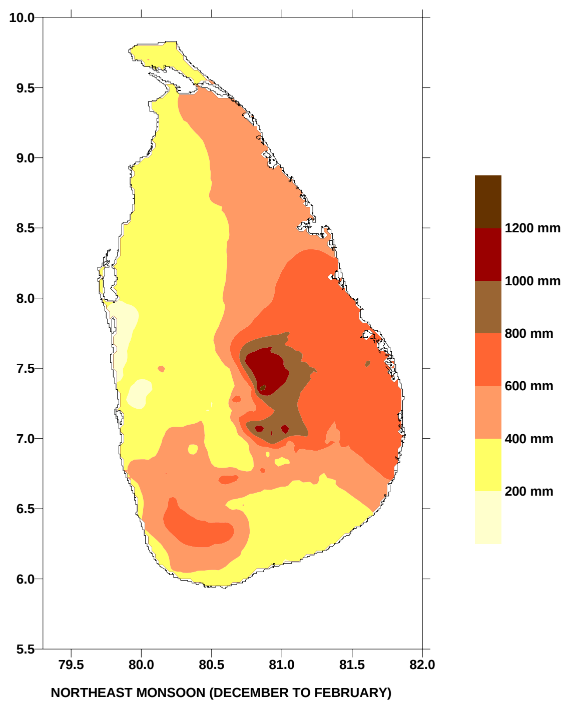


Fig. 1. Map showing Wet, Dry and Intermediate Zones of Sri Lanka.



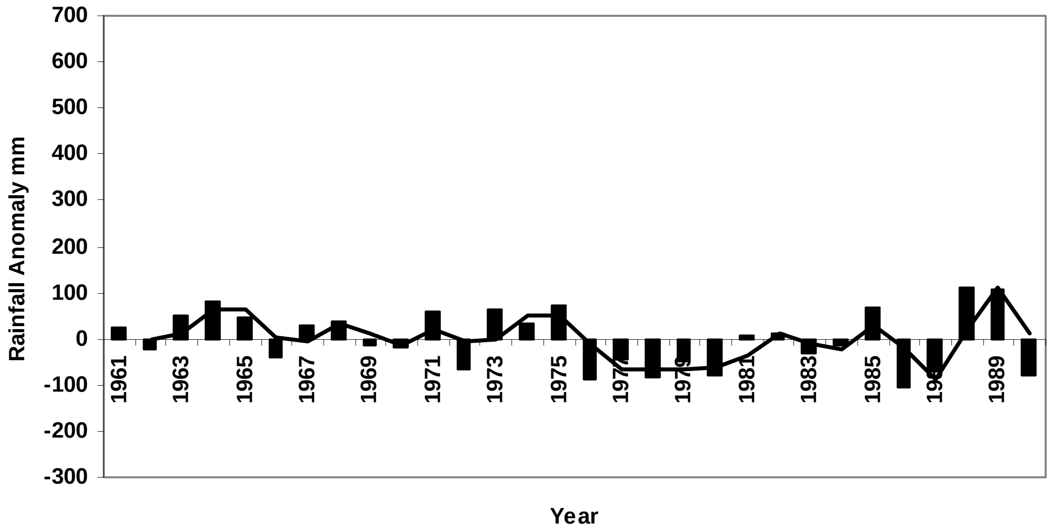
(a)



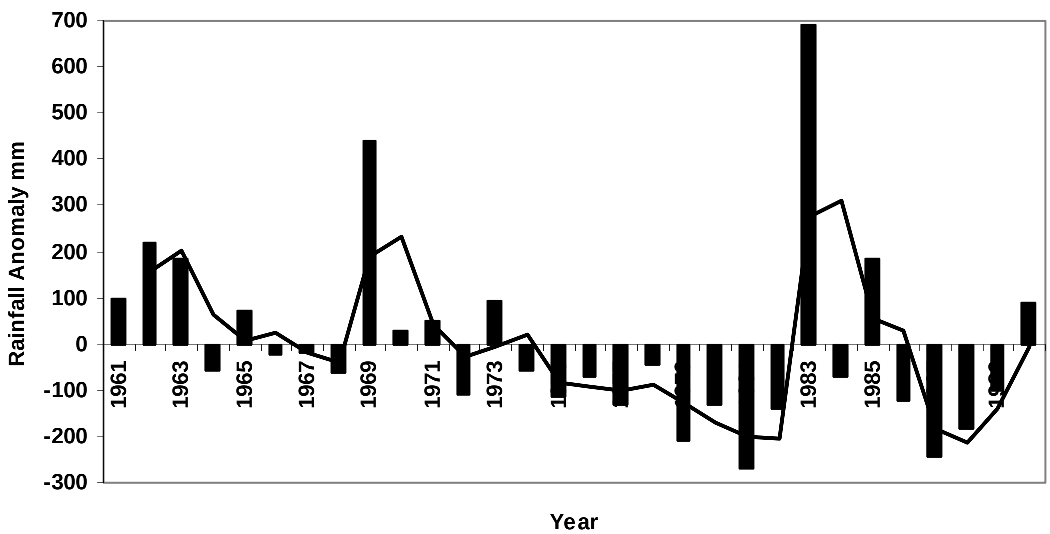
(b)

Fig. 2. Spatial distribution of (a) southwest and (b) northeast monsoon rainfall over Sri Lanka.

Variation in rainfall intensity and distribution are important because Sri Lanka is predominantly an agricultural country. The island may be divided into a large number of agro-ecological regions, according to these two factors and altitude. It is noteworthy that two stations with the same annual total rainfall intensity may have very different monthly distributions. Consequently stations with equal rainfall do not necessarily have identical climate condition.



(a)



(b)

Fig. 3. Temporal variation of All-Sri Lanka aerial rainfall (a) June-July-August (JJA) (b) December-January-February (DJF) with three year moving average.

Temperature also varies according to altitude. The mean annual temperature in the lowlands is 26-27 °C in the wet region and 29-30 °C in the dry zone, with a daily range of about six degrees. Temperature decreases with increase in altitude and in the mountain region the mean temperature ranges from 13 to 16 °C, with the night temperature occasionally dropping to around zero. In most parts of the country daily temperature ranges are more significant than the seasonal changes. Relative humidity generally ranges from 70% during the day to 95% at night. In the driest areas it may drop to 60%.

The influence of the sea makes the island free from temperature extremes experienced by large continental landmasses. Consequently, no deaths resulting from heat stress or extreme cold are reported. However, climate-related disasters such as floods landslides cause considerable damage, as do cyclones and extended droughts.

4. Climate Predictability Tool (CPT) & Methodology of Making Forecasts

The two techniques, which are used in the CPT, are Principal Components Regression (PCR) and Canonical Correlation Analysis (CCA). Each of these techniques can be used to address more than one kind of problem. This involves data that represent predictors, and data that represent what is to be predicted—i.e. predictands. Often, the predictor data is set up to occur earlier than the predictand data, with each spanning a historical period, so that predictive relationships become detectable and describable, and can be used for real-time forecasts. However, the predictor and predictand data can also be set up to occur at the same time, not staggered, so that the techniques describe diagnostic relationships between them, as may be desired for their own sake in climate research, perhaps preceding a study of predictive relationships.

The CPT is designed to use the prediction of a dynamical model (often called atmospheric general circulation model, or AGCM) as the predictor to make possible forecast of rainfall as a predictand. In an ideal world the prediction of the AGCM would be the best tool to use for the rainfall forecast, without needing to use CPT. However, today's best dynamical models are far from perfect. They have systematic errors. CPT cannot generate predictability where it does not exist. What it can do, however, is identify model errors that are characteristic, and correct the forecasts in such a way as to maximize their average accuracy over the long historical period for which there are samples of model forecast data along with the corresponding actually observed data. Thus, CPT *calibrates*, or *corrects*, model forecasts. This process is the same as what is commonly known as *model output statistics*, or *MOS*.

In this model correction design, and regardless of whether the CCA or the PCR tool is selected for the analysis, CPT does its job in the same basic manner. The way it works is that the predictand (the *y variable*) is related to the predictor (the *x variable*) linearly. The simplest case of a linear relationship is when there is one x and one y, such as the Southern Oscillation Index (SOI) for x, and the rainfall at a station (or the average rainfall over several stations) for y, and

$$y = bx + a \tag{1}$$

Here y is predicted by getting the value of the predictor, x, multiplying it by some factor b, and then adding a constant number a. In general, the prediction of y from x is not perfect: in some instances y is over-predicted while in others it is under-predicted. In *linear regression*, upon which both CPT techniques are based, a and b are determined such that the sum of the squared errors over all of the historical cases used to make the equation is minimised. Squared errors rather than the absolute value of the errors are minimized because this nicely fits the huge collection of linear statistical theory. A consequence of this is that possible large errors heavily govern the formation of the equation, while the possible small or moderate errors exert much less influence. While this has both advantages and drawbacks, regression techniques remain very widely used. This simple form of linear regression, y = bx + a, is the basis of the much more complex versions of linear regression used in the CCA and PCR tools provided by CPT. In particular, in both CPT techniques, x is extended from a single scalar variable to an entire set of variables, X, that can form patterns in space and/or time, and y can either remain a single scalar (or a single average value of several elements) as in PCR, or be a second set of variables having patterns, Y, as in CCA. It should be noted that in PCR, even though only one predictand element is treated at a time, the technique can be applied repeatedly to each such predictand element (e.g. rainfall at each station) and results can be presented together such as on a map. In handling each predictand element separately, the relationships among the predictand elements are not explicitly used in making an overall forecast as it is in CCA.

A number of different varieties of linear regression can be identified, and can be classified using various criteria. One criterion that helps to describe the two techniques used in CPT is the level of complexity of the predictor and predictand data. Three commonly recognized levels can be identified:

(a) *simple regression*: a single predictor and a single predictand

$$y = bx + a \tag{1}$$

(b) *multiple regression*: two or more predictors, and a single predictand

$$y = b_1 x_1 + b_2 x_2 + \dots\dots\dots + b_n x_n + a \tag{2}$$

(case of n predictors; a is the accumulated constant)

The PCR tool in CPT is in this category of regression, with the x's themselves being defined in a special way in order to need much fewer of them.

(c) *multivariate (pattern) regression*: two or more predictors, two or more predictands

Y = **BX** + a (3)

(**Y**, **B** and **X** are matrices; can be CCA)

The CCA tool in CPT is in this category of regression, with the x's and the y's themselves being defined in a special way in order to need much fewer of each.

The categorization above identifies the PCR technique as a kind of multiple regression that uses a set of predictors to predict one predictand element at a time, and the CCA technique as a kind of multivariate regression, using a set of predictors collectively to predict a set of predictands collectively, such that both predictors and the predictands possess patterns amongst themselves as well as in their linkages with one another. In both techniques, the prediction rules are determined by analyzing the set of predictors and predictands over a historical period. In climate diagnostics and prediction, often each case of corresponding predictors and predictand(s) come from one year for a specific season, so that there are as many cases as there are years. Short histories are less effective in identifying the best prediction rules, since every year contains extraneous or random variations; thus the more years that are available, the greater the likelihood that the consistent and robust relationships outweigh the random behaviors and appear clearly in the analysis results.

The CPT software was initially designed for use in forecast development by national meteorological services, especially in Africa (most commonly in the Southern African Regional Climate Outlook Forums), to simplify the production of seasonal climate forecasts. It can be used in any region, and for diagnostic research as well as forecasting. It can be used to perform CCA or PCR on any pair of data sets, for any application.

5. Data for the Study

Coupled Global Circulation Model (CGCM) data of Seoul National University (SNU) model (SNU Tier-1) is used as predictors to make seasonal weather forecasts for Sri Lanka. These data are provided through the International Centre for Theoretical Physics (ICTP) DODS server about one month prior to any season. Several global field variables are available viz. precipitation, sea surface temperature, surface temperature at 2m height, zonal winds of 850mb and 200mb, meridianal wind of 850mb and 200mb, geopotential height of 500mb, etc. Data is downloaded through GrAdsDODS by running a script file and then binary data is transformed into ASCII format using a FOTRAN code. Station data is collected from the database of Sri Lanka Meteorological Department and processed to obtain JJA seasonal rainfall as the predictands for the CPT. All-Sri Lanka and District-wise aerial precipitation was calculated for JJA season and transformed into a format (*.cptd), which suits for the CPT software.

6. Results and Discussion

6.1 Predictability of June-July-August (JJA) rainfall

Southwest monsoon onsets, on average, on 23rd May in each year and prevails until mid September in contributing heavy downfalls over the western slopes of the central highlands and adjoining western and southwestern parts of the island. This season is somewhat important as it is responsible for feeding hydro catchments of many reservoirs located over the highlands, which in turn contributes for generating hydropower. The Mahaweli, the longest river in the country, originates in the central highlands and flowing towards northeast by nourishing minor tanks in the dry zone. Therefore, JJA seasonal rainfall is important for many parts of the country for sustainable management of many sectors.

6.1.1 All-Sri Lanka forecast

All-Sri Lanka mean-rainfall is calculated with Kriging interpolation method using Surfer software, in which scattered rainfall station data is interpolated into pixel values, which in turn calculates aerial average of rainfall over the entire country. Sea surface temperature of SNU-Tier-1 Coupled General Circulation Model (CGCM) model data, during 1981–2008, is used as the predictors to make forecast for All-Sri Lanka during for JJA. The CPT is trained, with Canonical Correlation Analysis (CCA) technique, for the period of 27 years with a cross-validation window of 5 years. The domain of the predictor variables is selected as 24S°-45S° and 40E° to 75E°, which seems to be highly correlated with the predictand variables in Sri Lanka. The model is optimized with 4 no. of Empirical Orthogonal Functions (EOF) modes of X-predictors, 1 no. of EOF modes of Y-predictand and 1 no. of CCA modes. The goodness of the model is reported as 0.5770. Table 1 shows some statistics viz. Pearson's correlation, RMSE, Hit Score, Bias, etc. of the trained CPT model for All-Sri Lanka JJA mean-rainfall.

Table 1. Some statistics of the 27 years trained model for All-Sri Lanka JJA mean-rainfall.

	Pearson's correlation	RMSE	Hit Score	Bias	Mean absolut e error	P value at 95% confidenc e level
All-Sri Lanka	0.5773	0.57	51.85	0.00	0.49	0.0000

6.1.1.1 Calibration and validation of the trained model (All-Sri Lanka)

In order for calibration of the trained model for All-Sri Lanka JJA mean-rainfall, the following simple linear type regression equation is utilized for observed and CPT model generated All-Sri Lanka JJA mean-rainfall data during the period 1991- 2006.

$$Y_{obs} = mX_{model} + c \qquad (4)$$

Where, Y_{obs} is the observed aerial mean-rainfall for All-Sri Lanka. X_{model} is the CPT generated mean-rainfall. m is the gradient of the regression and c is the intersect. Validation of CPT for all-Sri Lanka mean-rainfall is carried out for the year 2007 with the following equation.

$$Y_{proj} = mX_{model} + c \qquad (5)$$

Where Y_{proj} is the calibrated all-Sri Lanka mean-rainfall and X_{model} is the CPT-generated all-Sri Lanka mean-rainfall for JJA period. m and c are gradient and intersect of the above linear equation used from the calibration process. Fig. 4 shows the scatter plot of observed and CPT-generated All-Sri Lanka JJA mean-rainfall during the period of 1991-2006. Coefficients of the linear regression model for calibration are tabulated in Table 2 together with CPT-generated, calibrated and observed JJA mean-rainfall for 2008.

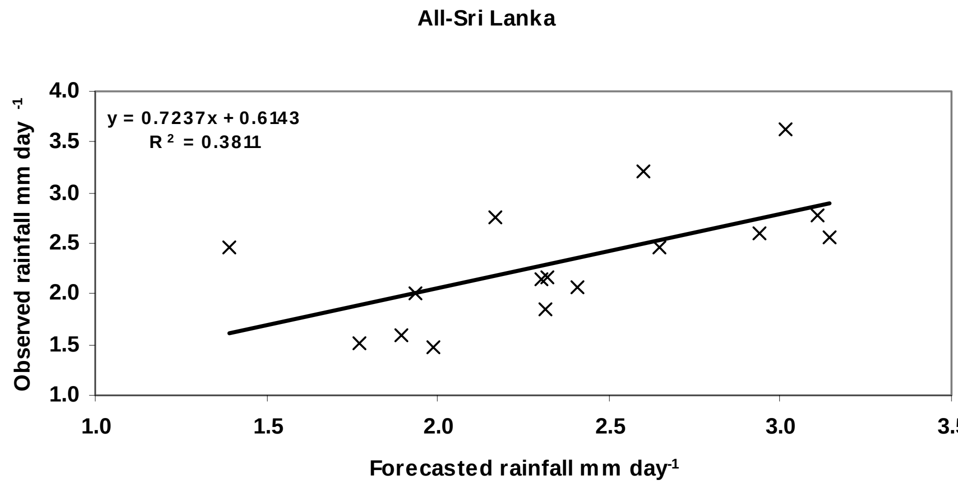


Fig. 4. Scatter plot of observed and CPT-generated All-Sri Lanka JJA mean-rainfall during 1991-2006 period.

Table 2. Coefficients of the linear regression model for JJA mean-rainfall for All-Sri Lanka with the forecast and observed rainfall of JJA 2008.

	m (Gradient)	c (Intersect) mm day^{-1}	CPT-Generated JJA mean-rainfall for 2008 mm day-1	Corrected JJA mean-rainfall for 2008 mm day^{-1}	Observed JJA mean-rainfall for 2008 mm day^{-1}
All-Sri Lanka	0.7237	+ 0.6143	2.10	2.13	3.25

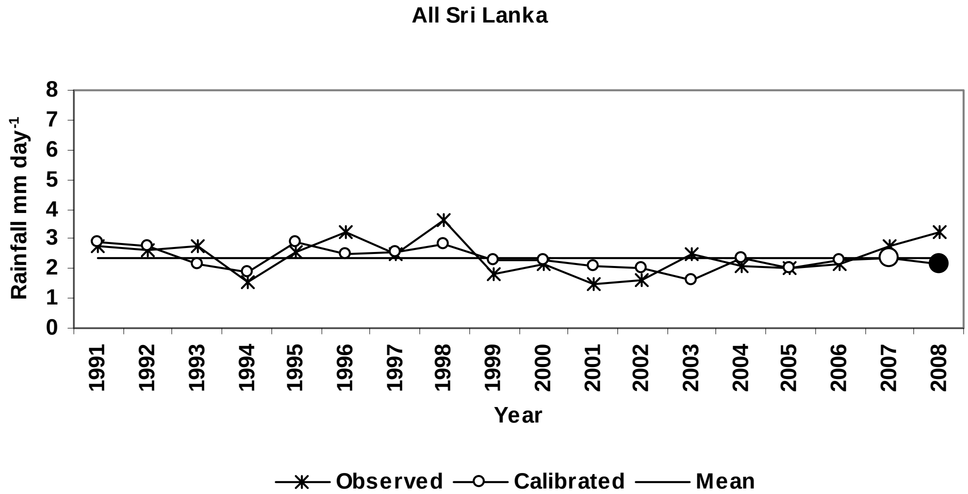


Fig. 5. Observed All-Sri Lanka mean-rainfall of JJA during 1991-2008 with calibration during 1991-2006, validation for 2007 and projection for 2008. Long Period Average (LPA) of observed All-Sri Lanka mean-rainfall from 1991-2008 is shown as Mean.

The Fig.5 shows the observed All-Sri Lanka JJA mean-rainfall during the period 1991-2008 together with the calibration during 1991-2006 and validation for the year 2007. It also shows the forecast (calibrated) for 2008-JJA season. Variability of the area averaged All-Sri Lanka rainfall during JJA season seems to be less as it reduces the noises of the signal with the spatial distribution. Another reason may be the southwest monsoon as a whole is less variable compared to the northeast monsoon season (Fig. 3(a) & 3(b)). It is also possible that JJA rainfall is mainly confined to the western, southwestern and western slopes of the central highlands. This effective area may merely represent 1/3 of the whole country. Nevertheless, when taking aerial average of JJA rainfall into whole country (All-Sri Lanka), the variance may have been flattened.

6.1.2 District level forecasts

Nine districts (Fig. 6), of which the southwest monsoon rainfall mainly confines, are selected to make forecast for JJA period. District mean-rainfall is calculated with Kriging interpolation method using Surfer software, in which scattered mean-rainfall station data is interpolated into pixel values, which in turn calculates aerial average of rainfall over each district in the country. Sea surface temperature fields (hindcast and forecast) of SNU Tier-1

CGCM model from 1981-2008 is used to train the model with Canonical Correlation Analysis (CCA) technique. Five-year period is set for cross-validation of the model. The domain of the predictor variables is selected as 24S°-45S° and 40E° to 75E°, which seems to be highly correlated with the predictand variables in nine districts in Sri Lanka. The model is optimized with 5 no. of Empirical Orthogonal Functions (EOF) modes of X-predictors, 2 no. of EOF modes of Y-predictand and 2 no. of CCA modes. The goodness of the model is reported as 0.6380. Some statistics of the trained model is given in Table 3.

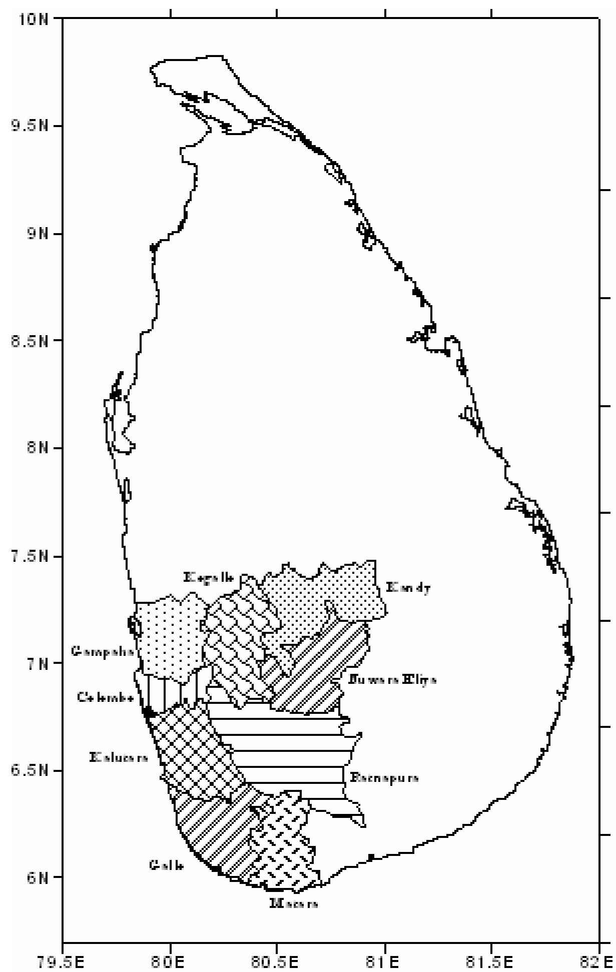


Fig.6. Map showing selected nine districts in Sri Lanka.

Table 3. Same as Table 1 but for nine selected districts in Sri Lanka.

District	Pearson's correlation	RMSE	Hit Score	Bias	Mean absolut e error	P value at 95% confidenc e level
Colombo	0.7460	1.33	51.85	-0.01	1.09	0.0000
Kalutara	0.7088	1.75	51.85	+0.01	1.44	0.0000
Galle	0.6600	1.86	48.15	+0.02	1.54	0.0000
Matara	0.5633	1.72	59.26	+0.03	1.38	0.0040
Gampaha	0.6166	1.32	48.15	-0.03	1.10	0.0000
Kegalle	0.6585	1.95	62.96	-0.05	1.56	0.0000
Ratnapura	0.6748	1.11	62.96	-0.04	0.92	0.0000
Kandy	0.4822	1.38	66.67	0.00	1.04	0.0120
Nuwara Eliya	0.5737	1.70	48.15	-0.02	1.35	0.0020

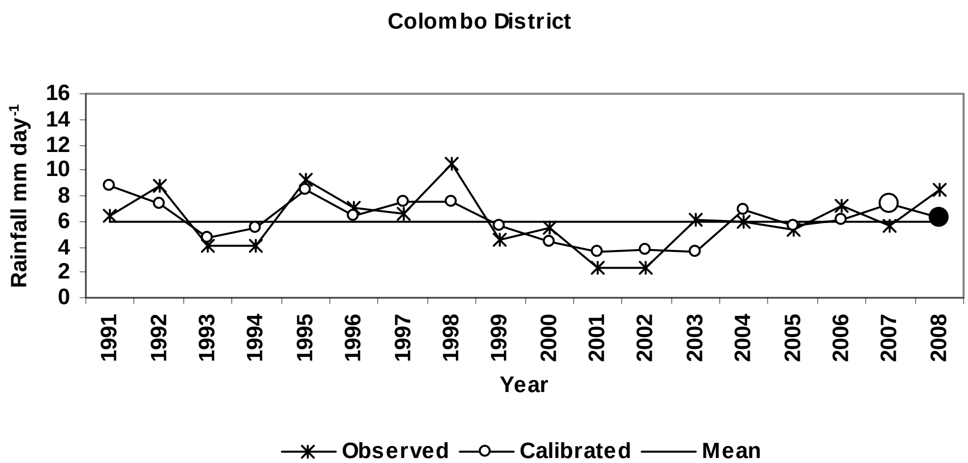
6.1.2.1 Calibration and validation of the trained model (District level)

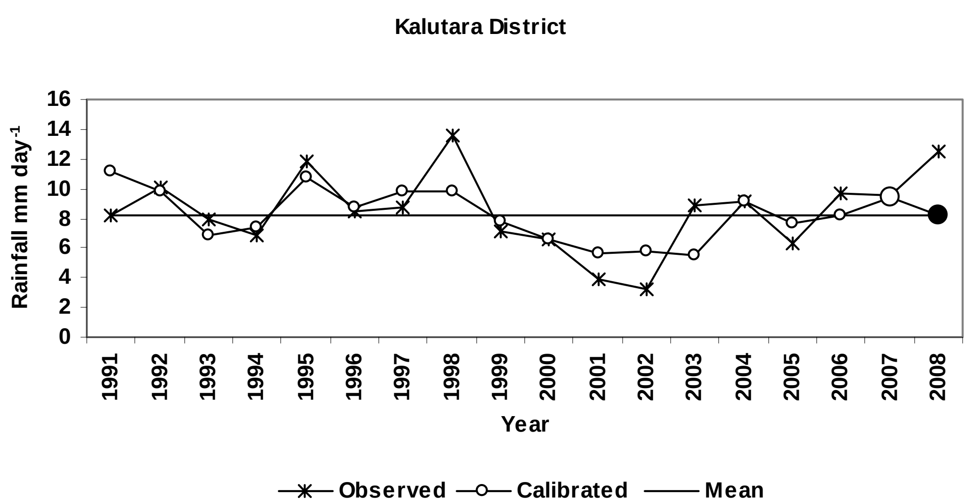
Calibration and validation of the trained model has been performed as in the section 7.1.1.1 and the gradient (m) and intersect (c) of the equation (4) were derived to obtain the district level forecast using equation (5). Coefficients of linear regression model for calibration of CPT generated district level JJA rainfall forecasts are tabulated in the Table 4. It also shows CPT generated, calibrated and observed JJA rainfall for 2008.

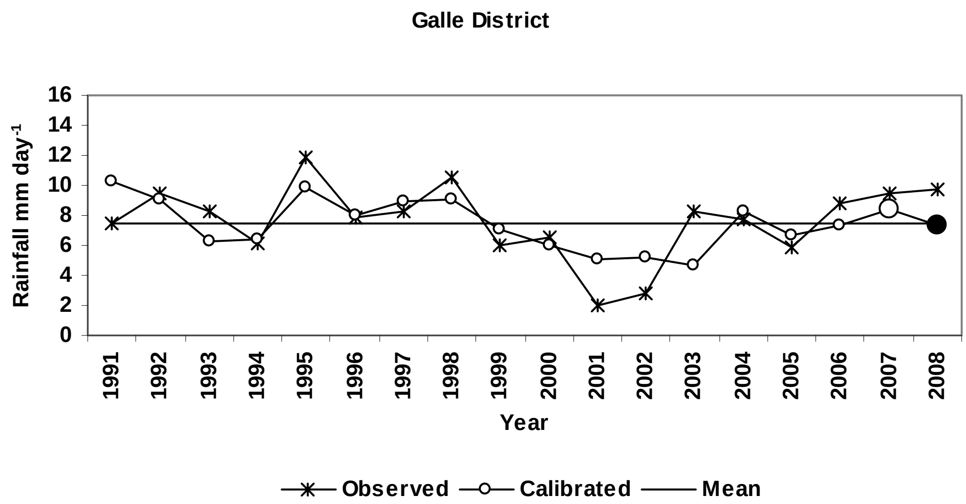
Table 4. Same as Table 2 but for nine selected districts in Sri Lanka.

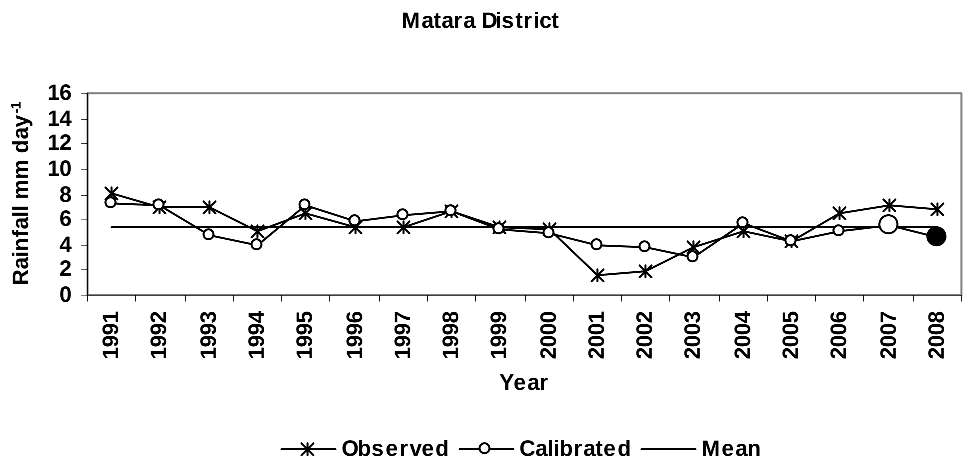
District	m (Gradient)	c (Intersect) mm day^{-1}	CPT-Generated JJA mean-rainfall for 2008 mm day^{-1}	Corrected JJA mean-rainfall for 2008 mm day^{-1}	Observed JJA mean-rainfall for 2008 mm day^{-1}
Colombo	1.0712	- 0.2216	6.05	6.25	08.52
Kalutara	0.8654	+ 0.9986	8.34	8.22	12.51
Galle	0.8475	+ 1.0996	7.30	7.29	09.61
Matara	0.8223	+ 0.7178	4.81	4.67	06.77
Gampaha	0.8284	+ 0.7776	4.67	4.63	06.92
Kegalle	0.8222	+ 1.3587	7.81	7.78	09.85
Ratnapura	0.7213	+ 2.0222	6.17	6.47	08.27
Kandy	0.6955	+ 0.9955	2.96	3.05	03.03
Nuwara Eliya	1.0318	- 0.2131	5.91	5.88	05.59

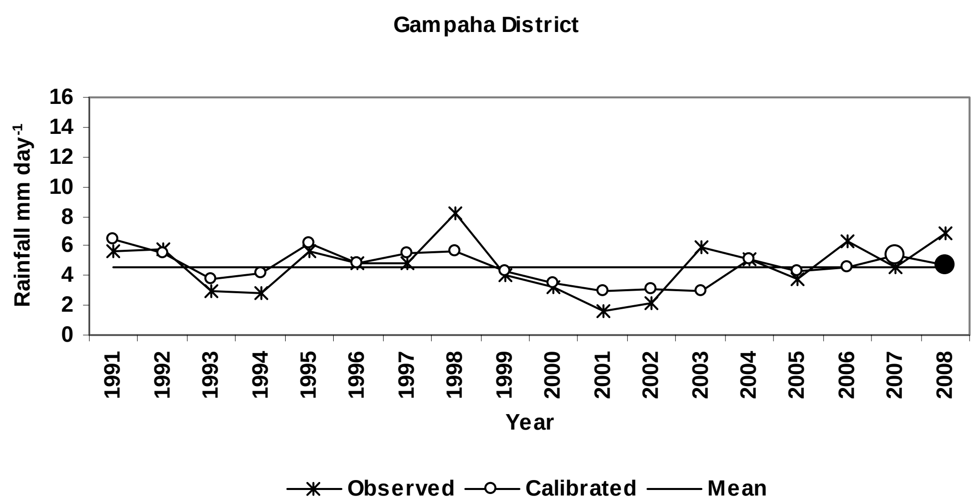
Calibrated JJA mean-rainfall during 1991-2006 is shown in Fig. 7 for nine districts in Sri Lanka. It also shows the observed JJA mean-rainfall during 1991-2008 together with validation for the year 2007. Results reveal that forecasted rainfall is overestimated except in Kandy and Nuwara Eliya districts, where the forecasts are within the acceptable range. These two districts received below normal rainfall over the Long Period Average (LPA) of 1991-2008. It appears that southwest monsoon in 2008 contributed excess rainfall for the country as a whole and rainfall is well above the LPA (Fig.7).



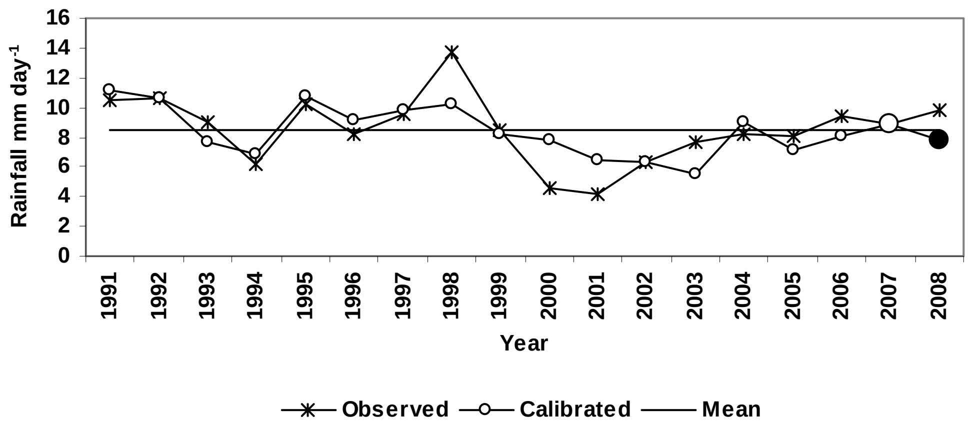



Galle District
Rainfall mm day-1
16
14
12
10
8
6
4
2
0
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
Year
Observed
Calibrated
Mean

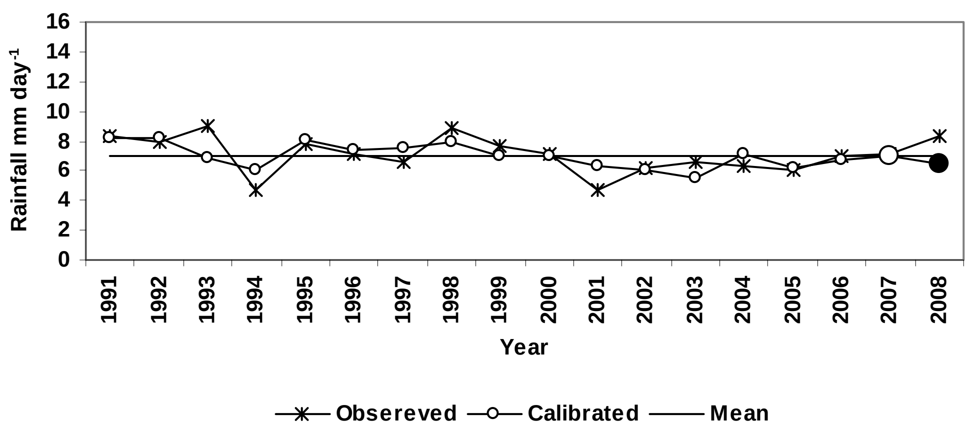

Matara District
Rainfall mm day-1
16
14
12
10
8
6
4
2
0
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
Year
Observed
Calibrated
Mean


Gampaha District
Rainfall mm day-1
16
14
12
10
8
6
4
2
0
1991
1992
1993
1994
1995
1996
1997
1998
1999
2000
2001
2002
2003
2004
2005
2006
2007
2008
Year
Observed
Calibrated
Mean

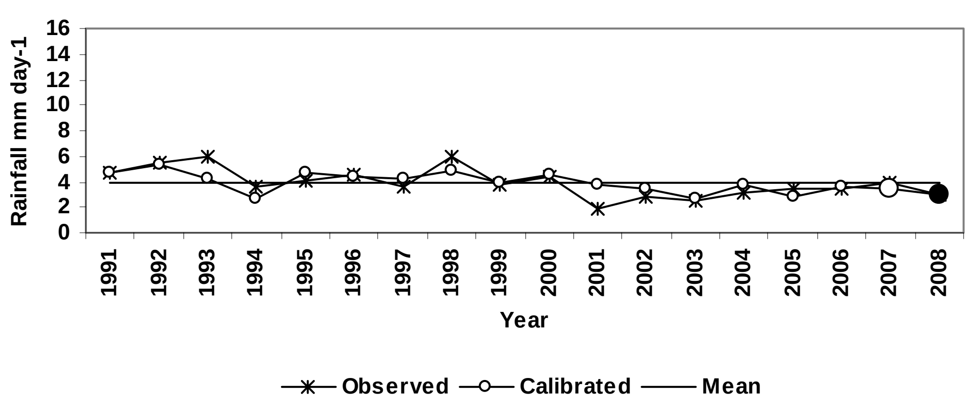
Kegalle District



Ratnapura District



Kandy District



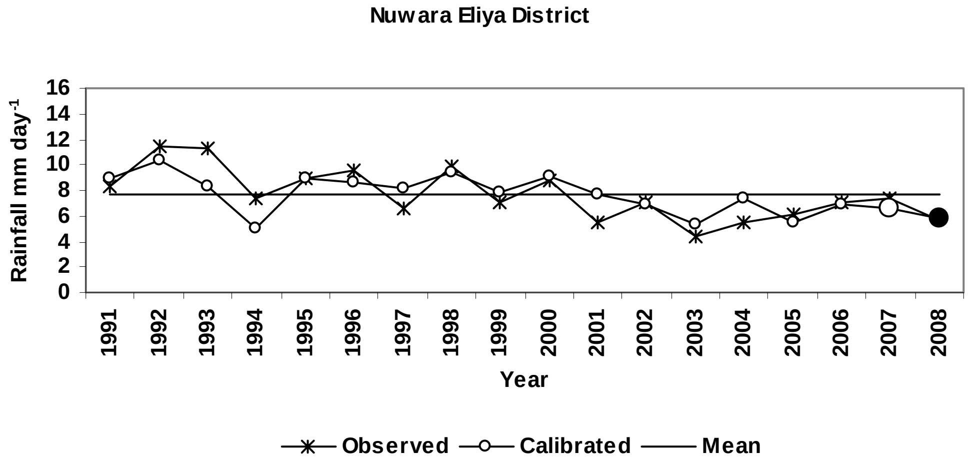


Fig.7. Observed district level mean-rainfall of JJA during 1991-2008 with calibration during 1991-2006, validation for 2007 and projection for 2008. Long Period Average (LPA) of observed district level mean-rainfall from 1991-2008 is shown as Mean.

JJA rainfall is varying over the districts owing to their physiographical changes. Districts, which locate on the windward side and well expose to southwestward are susceptible to receive substantial amount of rainfall during the JJA period.

6.2 *Predictability of June month rainfall*

Fairly high rainfall associated with low-level westerly monsoon jet stream is experienced at the onset and just after the onset of the southwest monsoon, especially over the southwestern parts of Sri Lanka. Therefore rainfall in June month is comparatively higher than other months in the season.

6.2.1 *All-Sri Lanka forecast*

Sea surface temperature of SNU-Tier-1 CGCM data, during 1981–2008, is used as the predictors to make forecast for All-Sri Lanka mean-rainfall for June month. The model is trained, with Canonical Correlation Analysis (CCA) technique, for the period of 27 years with a cross-validation window of 5 years. The domain of the predictor variables is selected as 15N°-13S° and 53E° to 73E°, which seems to be highly correlated with the predictand variables in Sri Lanka. The model is optimized with 6 no. of Empirical Orthogonal Functions (EOF) modes of X-predictors, 1 no. of EOF modes of Y-predictand and 1 no. of CCA modes.

The goodness of the model is reported as 0.7010. Performance of the tuned model is shown in Table 5.

Table 5. Some statistics of the 27 years trained model for All-Sri Lanka June mean-rainfall.

	Pearson's correlation	RMSE	Hit Score	Bias	Mean absolut e error	P value at 95% confidenc e level
All-Sri Lanka	0.7014	0.74	70.37	0.04	0.60	0.0000

6.2.1.1 Calibration and validation of the trained model (All-Sri Lanka)

Calibration and validation of the trained model has performed as in the section 7.1.1.1 and the gradient (m) and intersect (c) of the equation (4) were derived to obtain the All-Sri Lanka forecast using equation (5).

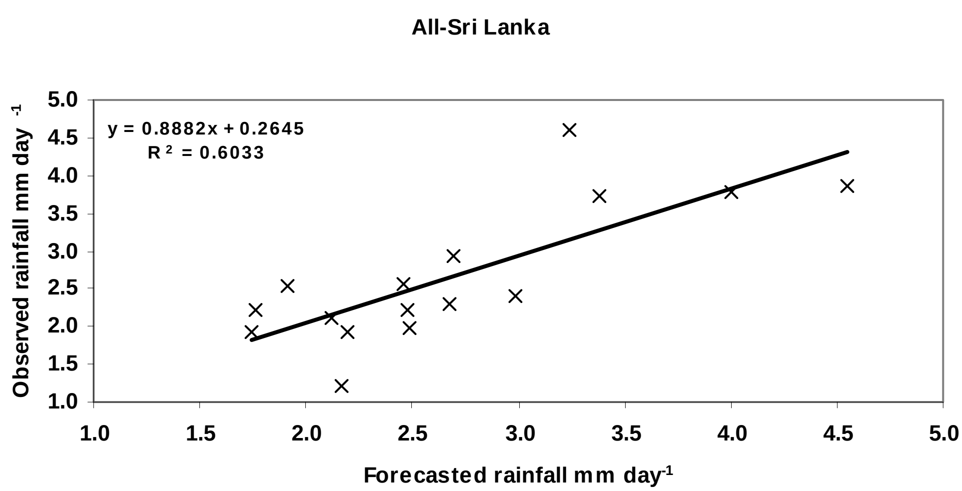


Fig. 8. Same as Fig. 4 but for June mean-rainfall.

Linear regression curve of the CPT generated and observed All-Sri Lanka June mean-rainfall is shown in Fig.8. The gradient (m) and intersect (c) together with CPT generated, calibrated and observed All-Sri Lanka June mean-rainfall are shown in Table 6.

Table 6. Coefficients of the linear regression model for June mean-rainfall for All-Sri Lanka with the forecast and observed rainfall of June 2008.

	m (Gradient)	c (Intersect) mm day^{-1}	CPT-Generated June mean-rainfall for 2008 mm day-1	corrected June mean-rainfall for 2008 mm day^{-1}	Observed June mean-rainfall for 2008 mm day^{-1}
All-Sri Lanka	0.8882	+ 0.2645	2.37	2.37	2.60

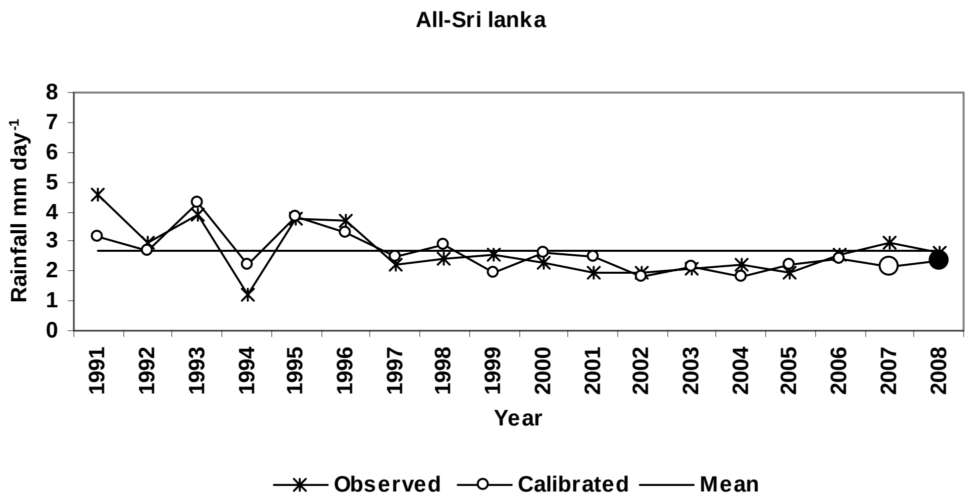


Fig. 9. Same as Fig. 5 but for June.

Forecasted All-Sri Lanka June mean-rainfall seems to be quite acceptable and well captured by the model (Fig.9). About normal (within 15% over the LPA) rainfall has been received during June month for the whole Sri Lanka.

6.2.2 *District level forecasts*

As in JJA forecasting, nine districts are selected to make forecast for June month. Sea surface temperature fields (hindcast and forecast) of SNU Tier-1 CGCM model from 1981-2008 is used to train the model with Canonical Correlation Analysis (CCA) technique. Five-year period is set for cross-validation of the model. The domain of the predictor variables is selected as 15N°-13S° and 53E° to 73E°, which seems to be highly correlated with the predictand variables in nine districts in Sri Lanka. The model is optimized with 7 no. of Empirical Orthogonal Functions (EOF) modes of X-predictors, 2 no. of EOF modes of Y-predictand and 2 no. of CCA modes. The goodness of the model is reported as 0.6420. Performance of the trained model is given in Table 7.

Table 7. Same as Table 5 but for nine selected districts in Sri Lanka.

District	Pearson's correlation	RMSE	Hit Score	Bias	Mean absolute error	P value at 95% confidence level
Colombo	0.6599	2.58	59.26	0.07	2.02	0.0000
Kalutara	0.7572	2.67	66.67	0.18	1.94	0.0000
Galle	0.6927	3.13	70.37	0.22	2.28	0.0000
Matara	0.6143	3.53	55.56	0.23	2.84	0.0000
Gampaha	0.4929	2.43	70.37	0.01	1.87	0.0020
Kegalle	0.6226	3.76	55.56	0.15	3.05	0.0000
Ratnapura	0.7403	2.78	70.37	0.17	2.06	0.0000
Kandy	0.5186	2.50	51.85	0.13	1.91	0.0060
Nuwara Eliya	0.6062	3.29	55.56	0.21	2.57	0.0020

6.2.2.1 Calibration and validation of the trained model (District level)

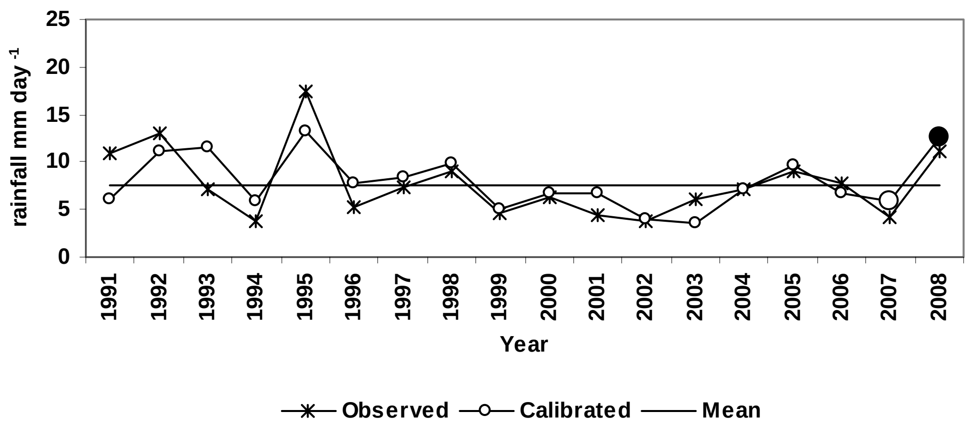
Calibration and validation of the trained model has performed as in the section 7.1.1.1 and the gradient (m) and intersect (c) of the equation (4) were calculated to obtain the district level forecast using equation (5). Coefficients for the linear regression model of calibration together with CPT-generated calibrated and observed district level June mean-rainfall for 2008 are listed in the Table 8.

Table 8. Same as Table 6 but for nine selected districts in Sri Lanka.

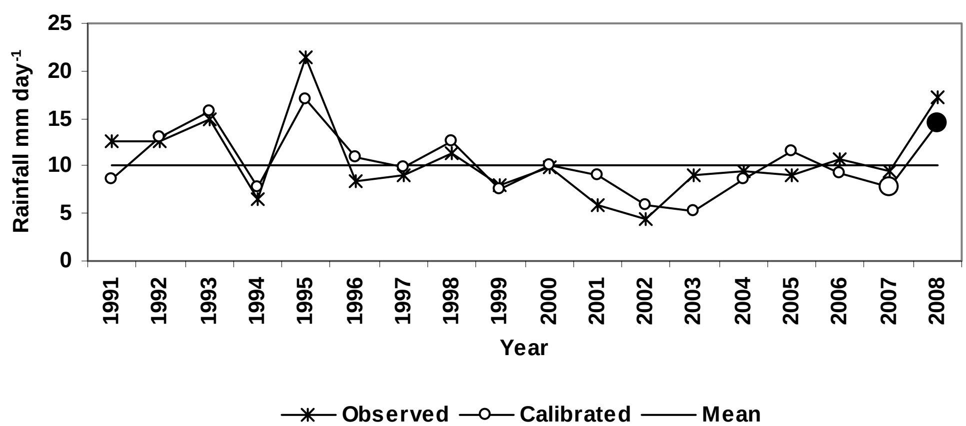
District	m (Gradient)	c (Intersect) mm day^{-1}	CPT-Generated June mean-rainfall for 2008 mm day^{-1}	Corrected June mean-rainfall for 2008 mm day^{-1}	Observed June mean-rainfall for 2008 mm day^{-1}
Colombo	1.0413	+ 0.1571	12.02	12.67	11.03
Kalutara	0.9666	+ 0.1354	14.89	14.46	17.13
Galle	1.0737	- 0.7490	11.93	12.07	10.93
Matara	0.6998	+ 1.3956	09.47	08.03	07.57
Gampaha	0.4561	+ 3.1506	08.04	06.82	08.83
Kegalle	0.7100	+ 2.5965	10.58	10.11	09.63
Ratnapura	0.8337	+ 1.1606	08.84	08.53	08.93
Kandy	0.7885	+ 0.6412	04.44	04.14	01.83
Nuwara Eliya	0.9604	+ 0.0152	08.36	08.05	04.50

Fairly heavy rainfall is received in several districts, which are considered in the present study, except Kegalle, Ratnapura, Kandy and Nuwara Eliya districts during the month of June 2008,. These districts received about or below normal rainfall over the LPA during 1991-2008. Fig.10 shows the observed, calibrated and validated mean-rainfall in nine selected districts. It reveals that the model is able to capture the excess rainfall received over five districts.

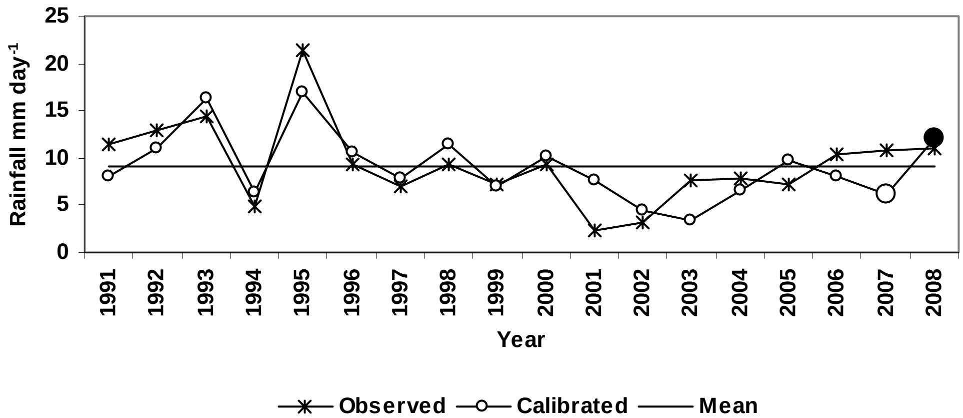
Colombo District



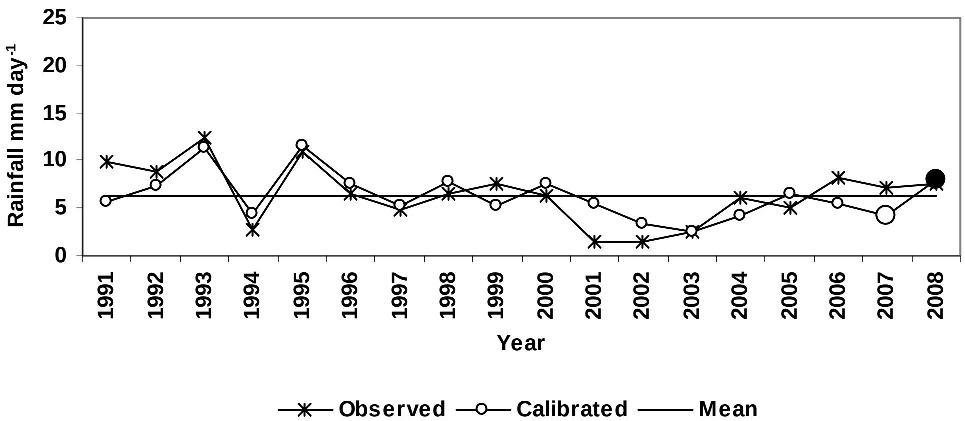
Kalutara District



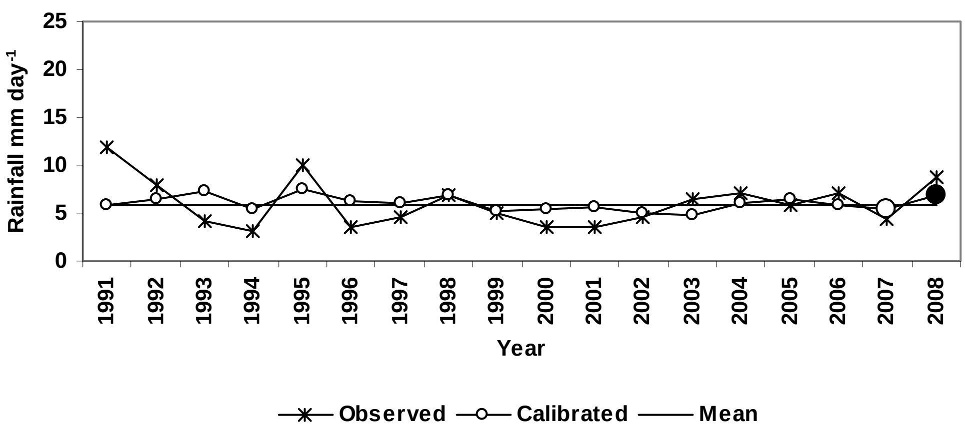
Galle District



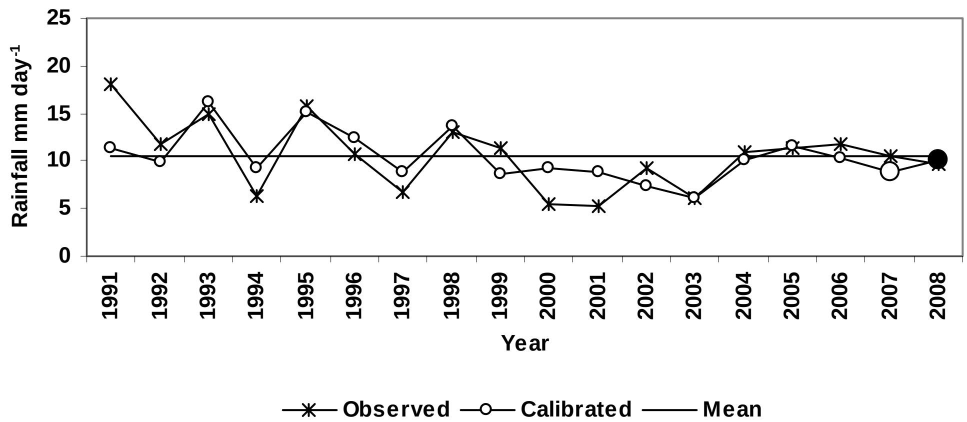
Matara District



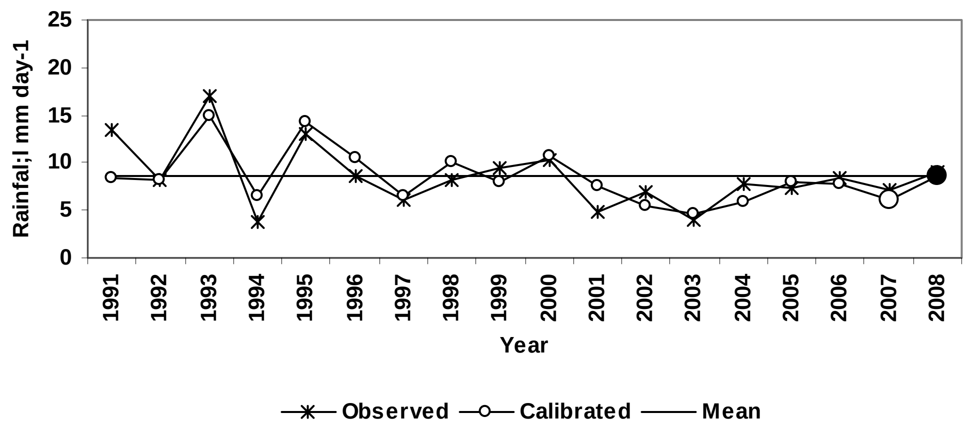
Gampaha District



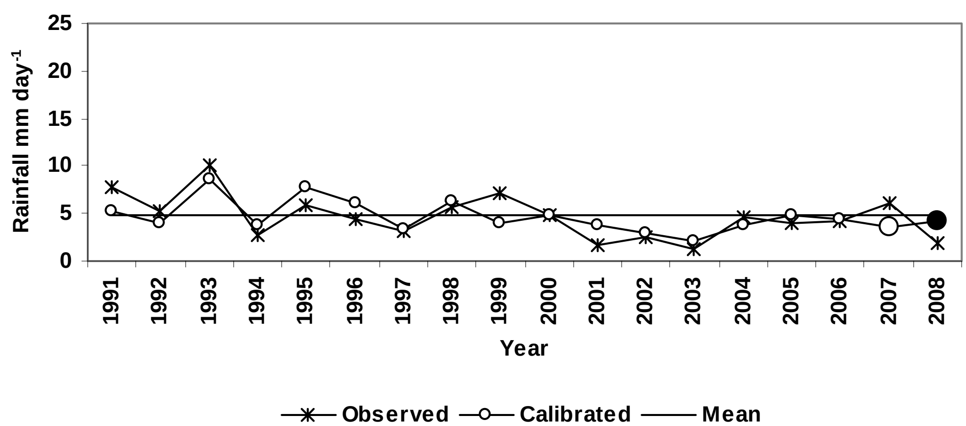
Kegalle District



Ratnapura District



Kandy District



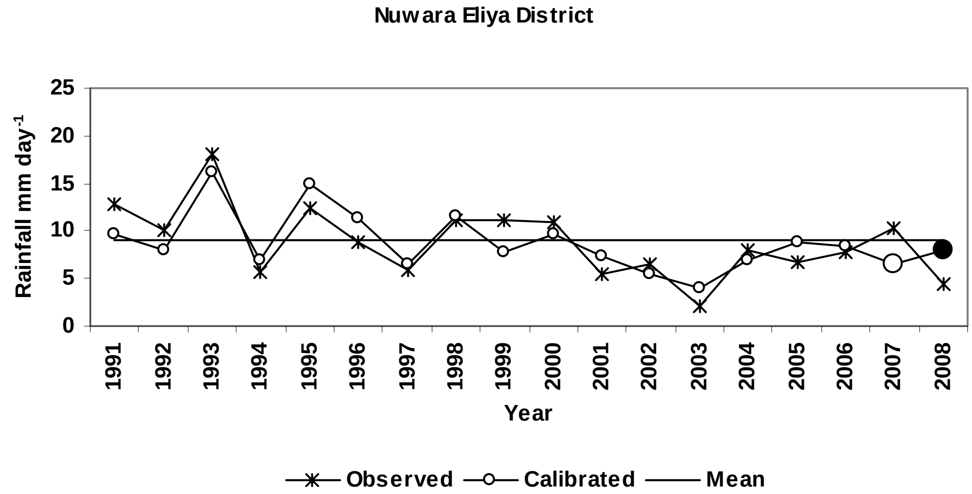


Fig. 10. Observed district level mean-rainfall of June during 1991-2008 with calibration during 1991-2006, validation for 2007 and projection for 2008. Long Period Average (LPA) of observed district level June mean-rainfall from 1991-2008 is shown as Mean.

7. Conclusions

In general, predictions are made in different time scales utilizing corresponding predictability sources. For an example, initial state of the atmosphere is of vital importance in predicting day-to-day weather forecasts in which predictability loses within a week or two due to chaotic nature of the atmosphere. For the climate change prediction, it is the Greenhouse Gas (GHG) forcing. In seasonal prediction, the source of predictability is mainly the Ocean variability with inter-annual time scale. Therefore, seasonal forecasts are conventionally done in detecting predictable signals of the concerned variables by avoiding associated noises. Empirical Orthogonal Functions (EOF) are typically used to filter out these noises and separate the predictability signals. These noises are associated in both predictors and predictands. One way of reducing noises of the predictands is to consider a larger spatial coverage of the concern variable by taking spatial average rather than considering a site specific value of the variable. Inter-annual variability of the predictand has a greater bearing on the predictability of such predictands using any predictor variable. In some parts of the world, especially over the tropical region, inter-annual variability is very much influenced by the ENSO events in which sea surface temperature over the eastern equatorial Pacific plays a crucial role. Inter-annual variability of the southwest monsoon rainfall over Sri Lanka seems to be less compared to the northeast monsoon rainfall and therefore JJA rainfall has higher predictability skills than the other seasons. When it comes to individual months predictability skill may not be that good due to intrusion of noises.

In the present study, sea surface temperature over the Indian Ocean region has shown some potential to predict JJA and June mean-rainfall over Sri Lanka as a whole and over the selected districts in the western and southwestern parts of Sri Lanka. However the same predictor variable doesn't correlate well in predicting July and August mean-rainfall over Sri Lanka (not presented in this report) and therefore, mean sea level pressure patterns over the Indian Ocean are selected. Results reveal that the forecasted JJA mean-rainfall is overestimated especially over the individual districts due to excess rainfall received during the whole southwest monsoon season. Forecast for the month of June is somewhat acceptable as the model is able to catch-up excess rainfall received over individual districts. On an average June and July months receive much higher rainfall than the other months in the season. Therefore inter-annual variability of these individual months is slightly higher than the other months. July mean-rainfall forecast seems not so accurate and it is overestimated over the most selected districts except Kandy and Nuwara Eliya. As mentioned before, this year received much higher rainfall throughout the season and the predictor variable (mean sea level pressure) is not able to cope up with these changes. August mean-rainfall forecast is somewhat reliable as the model is able to understand the decline effect of rainfall from the last year.

Developing accurate and acceptable seasonal forecasts is a challenging task with any conventional method as the end users are much keen on site specific locations. Seasonal forecasting using high resolution dynamical downscaling technique is very much costly as it consumes very high computing resources. Therefore, this study attempts to utilize Model Output Statistics (MOS) technique for CGCM field variables to develop regression based statistical interface for providing economical seasonal weather forecasts for Sri Lanka. Climate Predictability Tool (CPT) seems to be an affordable tool for any Meteorological service, especially in the developing nations. One of the drawbacks of this technique is tuning of the model at every use by changing the predictor variable to get the better correlation with the predictands.

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