Spatial and Temporal variation of Rainfall during South-West Monsoon period in Sri Lanka and its relationship with some of the Global Teleconnections.

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Abstract

The inter decadal rainfall of south west monsoon (SWM) rainfall over Sri Lanka was examined in relation to the Northern Hemisphere macro scale circulation pattern, outgoing longwave radiation and sea surface temperature during the period 1961 to 2010. SWM rainfall data for 24 stations located all over the island are used in the analysis.

Using the monthly rainfall average for the monsoon season May to September climatological map (1961-1990) was generated using these twenty four rainfall stations. Anomalies in average rainfall for different decades were considered for the period 1961-2010. Namely 1961-1970, 1971-1980, 1981-1990, 1991-2000 and 2001-2010. In order to detect the trends over shorter time periods, the cumulative departure from the mean (CDM)[1] was created. Initially in order to discover whether there was an overall regional signal during the period 1961-2010, total rainfall in the SWM season (May to September) was analysed over fifty years, two 25 years and five 10 year periods by fitting a linear least square trend line to the annual deviation from the mean. Finally the study was focussed on anomalies in global circulation, outgoing longwave radiation and sea surface temperature[2] to identify the changes of characteristics of the main component of global monsoon circulation which have direct impact on SWM rainfall in Sri Lanka.

Over the last forty years (1961-2000) there was a decreasing trend in the decadal average of SWM rainfall received and this decreasing trend changes to an increasing trend in the final decade 2001-2010, at the stations along the South-West coastal belt of the island. This change was statistically significant in some stations. Key features of the SWM circulation also show the changes favorable for such changes.

Middle part of the up country of the island shows the same variation in the decadal average of SWM rainfall received. But the magnitude of the decrease is smaller than that of the coastal areas. The anomalous decrease in wind speed in South-West monsoon circulation, outgoing longwave radiation and sea surface temperature gives supportive evidences for this effect.

Introduction

Sri Lanka is an island located within the tropics, from 5°55'N to 9°51'N and 79°42'E to 83°53'E, just southeast of the southern tip of the Indian sub-continent, extending of 65,610 square kilometers. The highlands, mostly above 300 meters, occupy the south central part of Sri Lanka with numerous peaks (Piduruthalagala -2524 m, Kirigalpotte -2396 m), high plateaus and basins and are surrounded by an extensive lowland area. The climate of Sri Lanka is characterized as both tropical as well as monsoonal and is dominated by the Southwest and Northeast monsoons, on which the life and economy of the island is critically dependent. The significant anomalies in climate are mainly decided by the temporal and spatial variations of rainfall, which have a strong impact not only on agricultural activities but on the energy services in the country. Orography plays an important role in the rainfall distribution of Sri Lanka The central part of the southern half of the island is mountainous reaching more than 2.5 km, in height. These topographical features strongly affect the spatial patterns of winds, seasonal rainfall, temperature, relative humidity and other climatic elements, particularly during the monsoon season.

There is no climate variable that will impose greater influence on the society than changes in monsoon rainfall which exists as the life blood of about two-thirds of the world's population. Rainfall also plays an essential role in determining atmospheric general circulation and hydrological circle, in linking external radiative forcing and the atmospheric circulation. In order to predict the changes of the monsoon rainfall, it is crucial to determine the response of the monsoon rainfall to the recent global warming. Global climate is changing mainly due to rapid increase of emission of greenhouse gases through the anthropogenic activities. Third Assessment Report (AR3) of

Intergovernmental Panel for Climate Change (IPCC) documented that the global temperature had increased by about 0.6^{0}C for the period 1900 – 2000. Subsequently, in 2007, Fourth Assessment Report (AR4) of the IPCC and in 2013 Fifth Assessment Report (AR5) of IPCC has documented that the global temperature had increased by about 0.74^{0}C for the period 1905 – 2006 and 0.85^{0}C for the period 1880 – 2012 respectively. Comparison of temperature trends according to the above mentioned three reports, clearly revealed that the rapid increase of increasing trend of temperature during the recent past. In addition AR4 and AR5 indicated the strong possibility of changing climate pattern with the climate change.

Literature provides evidence that Sri Lanka also has continued to experience climate change[2,3]. It was found that there is a higher probability in changing rainfall pattern in Sri Lanka during the recent past, related to climate change. Therefore comprehensive analysis for the rainfall and the analysis of atmospheric condition are needed to identify the trend and the reasons.

According to the rainfall and the wind pattern, Sri Lanka can be divided into four seasons namely, First inter-monsoon (March – April), Southwest monsoon (May – September), Second inter-monsoon (October – November) and Northeast monsoon (December – February) according to the rainfall pattern. Highest total area average rainfall is receiving during the Southwest monsoon and second intermonsoon periods and the both periods brining about 60% of the total rainfall. The rainfall receiving in these two periods are vital to the economy of Sri Lanka, because 40-45% of power demand of Sri Lanka is fulfilled by hydro power and which are directly determined by the reservoirs of the highlands mainly recharge during these two seasons. Lowest rainfall is receiving during the first intermonsoon. (National Atlas of Sri Lanka, 1988)

Data and Methodology

The meteorological data required for the study were obtained from Sri Lanka Meteorological Department. It is maintaining 20 meteorological stations and daily records of Rainfall, Temperature, Relative Humidity, Wind speed and Wind direction etc. are available. In addition there were about 35 agriculture meteorological stations and 350 rainfall stations in the island under the supervision of Sri Lanka Meteorological Department. The distribution of rainfall observational centers is satisfactorily represents the whole island and the prevailing distribution is established according to the World Meteorological Organization standards. The total of 24 stations used in the study are listed in Table 1.

Station	Latitude	Longitude
Colombo	79.86	6.9
Ratnapura	80.4	6.68
Kurunegala	80.37	7.46
Kandy	80.63	7.33
Nuwara Eliya	80.76	6.96
Badulla	81.05	6.98
Batticaloa	81.7	7.71
Puttalam	79.83	8.03
Anuradhapura	80.38	8.35
Hambantota	81.13	6.12
Ratmalane	79.88	6.81
Mannar	79.91	8.98
MahaIlluppallama	80.46	8.12
Katunayake	79.88	7.17
Ampara	81.66	7.28
Bataata	80.91	6.1
Welimada	80.9	6.9
Angamedilla	80.91	7.85
Galle	80.22	6.03
Clyde	80.03	6.58
Kurunduoya	80.83	7.07
Vauniya	80.5	8.75
Mahalewaya	81.13	6.13
Ambalantota	81.02	6.12

Table 1: Latitudes and Longitudes of selected stations

Monthly rainfall for the period of May to September was collected from the 24 rainfall stations throughout the country and averaged. Missing values in the monthly rainfall series were estimated using Krigging interpolation. Climatological map (1961-1990) was generated using data gathered from 24 rainfall stations and it is shown in the Fig. 1. More rain is confined in the southwest region in Sri Lanka in this season.

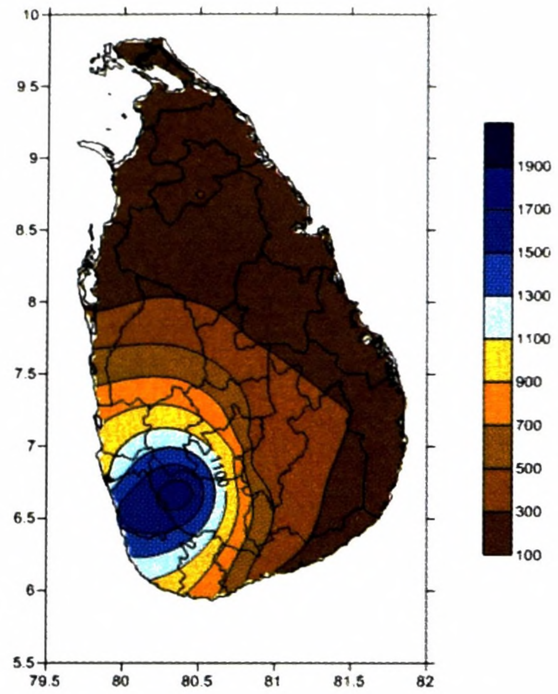

Fig. 1. Rainfall Climatology in Sri Lanka (1961-1990)

Analysis of the temporal changes in the southwest monsoon decadal average rainfall trend (SWDART) was carried out by calculating percentage differences for five considered decades. For instance, to calculate SWDART for the decade 1961-1970, the decadal average rainfall during the and 1961-1990 were compared. For this, the decadal average rainfall during the southwest monsoon for the periods mentioned was separately calculated for all the stations considered for the study. Subsequently, the percentage change in the decadal average rainfall trend was calculated using: {((Rainfall (1961-1970) – (Rainfall (1961-1990))/ Rainfall (1961-1990))} ×100%

This percentage can be positive or negative and accordingly to whether there is an increase or decrease trend in the average decadal rainfall

According to Figure 2 there was significant anomaly in temporal trend of southwest decadal average rainfall can be visible in Sri Lanka. In General the decade 2000-2010 shows considerable change when compared with the other decades. Apparent change can be identified in the southwest, southern and southeastern areas.

In order to discover whether there was an overall regional signal during the period 1961-2010, total rainfall in the south-west monsoon period (May to September), (SWDART) were analysed for the period of fifty years, two twenty five years periods and five ten year periods by fitting a linear least squares trend line to the annual deviation from the mean. To detect trends over short time periods, the cumulative departure from the mean (CMD) was also calculated using the following formula.

$$CMD = \sum_{n=1}^{n} (x_i - \bar{x})/\bar{x}$$

During 1961-2010, there were overall negative trends in south-west total rainfall except for a few stations. These approximately equal negative trends suggest a consistent pattern of change in smaller time periods. Therefore the analysis was repeated using two 25 year periods 1961-1985 and 1986-2010 and using 5 ten year periods.

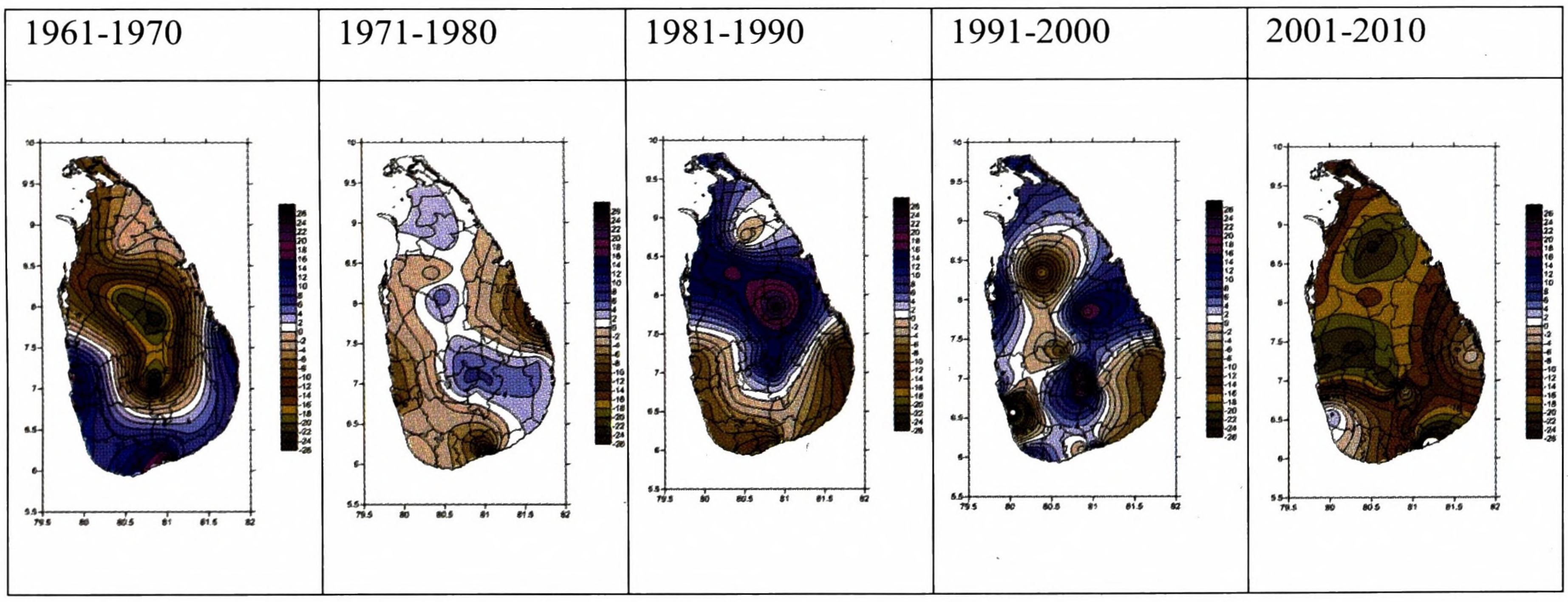

Fig. 2.-Rainfall anomaly in south-west monsoon period (May-September) in Sri Lanka during different decades in the period of 1961-2010

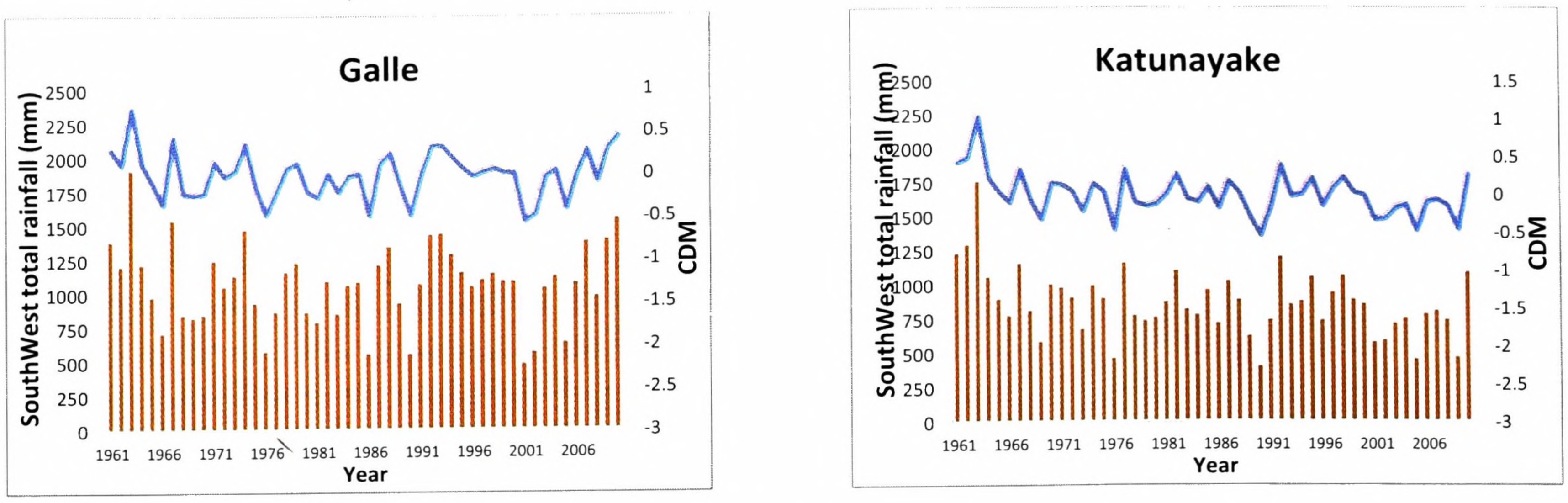

Fig. 3: Trends in total rainfall for whole fifty years in the south-west monsoon period (May to September) from 1961 to 2010 for two stations. Left hand panels show total rainfall series (bars-left axis) with the cumulative departure from the mean as a line. (Right axis), with a least squares fitted estimate of trend.

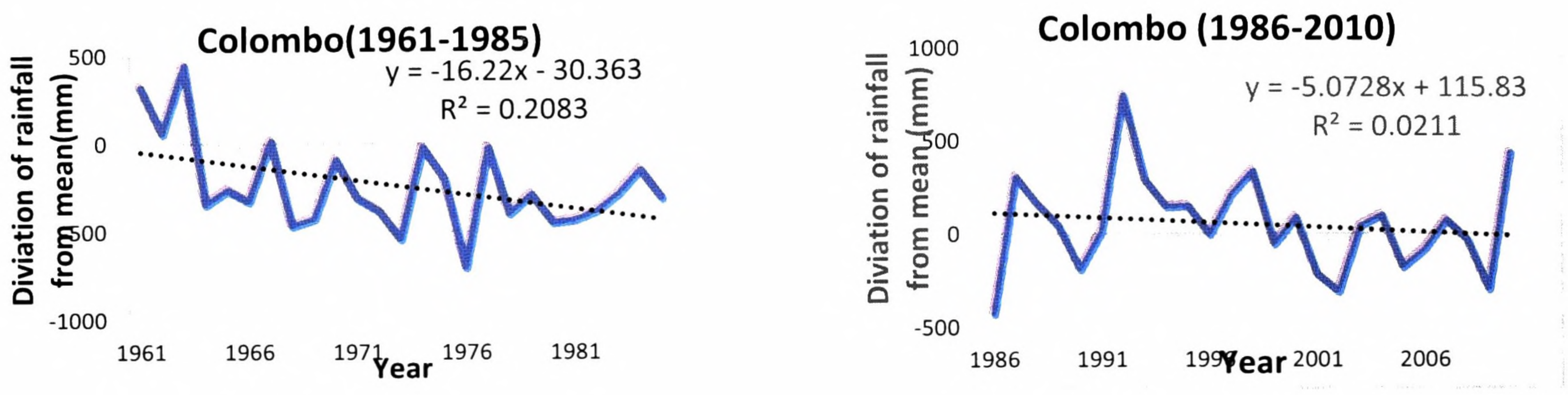

Fig. 4: Trends in total rainfall for twenty five year blocks in the south-west monsoon period (May to September) from 1961 to1985 and from 1986 to 2010 for Colombo. Left hand panel shows deviation from mean rainfall, with a least- squares fitted estimate of trend.

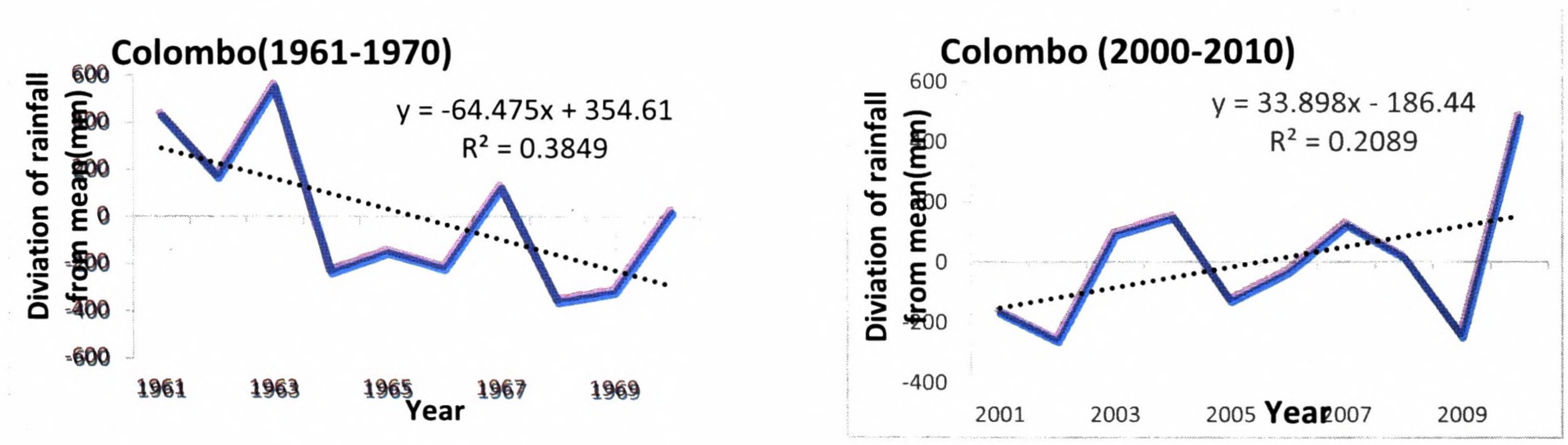

Fig. 5: Trends in total rainfall for five year blocks in the south-west monsoon period (May to September) from1961 to 2010 for five ten year periods. Left hand panel shows deviation from mean rainfall, with a least- squares fitted estimate of trend

The results of the analysis of seasonal trend are summarised in Table 2 which shows increases (+) and decreases (-). During the decade 1961-1970, there were large negative trends in SWDART in all the stations except one. But this was significant at few stations in the south-west monsoon regime of Sri Lanka, which are in the costal belt of the island. Middle part and up country of island also experience this negative trend. Smaller negative trend in WSDART almost identical to the previous decade was experience in the next three decades1971-1980, 1981-1990and 1991-2000, but the magnitude was comparatively small and some of them are not statistically significant. But in the decade 200-2010, Whole Island experience positive trend in south-west monsoon total rainfall. From these records combine to give decrease in trend of south-west monsoon rainfall received to the island during the four decades 1961-2000, and in the last ten years which is the first decade of the twenty second century shows increase trend in WSTR. But more detailed study should be carried out.

Discussion

Geographical location of Sri Lanka towards the southern tip of the Asian continental land mass and the northern area of the Indian ocean closer to the Bay of Bengal, in general and the Indian sub – continent in particular, plays a crucial role in its meteorological settings. Also relatively small extent of the land mass and its insularity (no part of the Island is farther than 110 km from the coast) maritime influence is felt over much of the Island. South-West monsoon season over Sri Lanka has been influenced by the Indian principal rainy season.

When comparing the wind vector anomaly at the surface level there is an anomaly with decreasing magnitude with decades in the Indonesia region which creates a favorable situation to reduce the strength of Inter Hemispherical Low level jet stream, but on the other hand, during the last decade 2001-2010 there is a sign of developing that anomaly again.

Station	**Trends in Decadal Rainfall**				
	1961-1970	**1971-1980**	**1981-1990**	**1991-2000**	**2001-2010**
Colombo	**-64.480**	-2.340	-1.27	-28.100	33.900
Ratmalana	***-87.740***	-1.380	-13.220	-22.350	**47.940**
Katunayaka	***-70.110***	-15.900	**-40.960**	-0.850	26.800
Galle	**-73.590**	-26.000	-5.420	**-26.080**	***98.600***
Clyde	-73.890	-24.800	-50.430	-1.07	***139.100***
Ambalantota	-8.770	**-20.020**	-10.320	2.660	4.380
Mahalewaya	**-26.780**	-18.100	-7.130	-0.344	10.600
Rathnapura	-33.860	-63.400	8.780	32.330	62.490
Badulla	**-13.120**	-8.880	14.370	9.050	14.980
Kurunegala	***-23.860***	**-49.080**	-21.460	9.960	***38.190***
Kandy	**-22.760**	-20.400	-10.640	-7.230	14.410
Nuwaraeliya	-17.140	-14.890	7.870	-1.530	17.350
Batticaloa	1.940	-4.500	5.880	10.230	-7.170
Anuradhapura	-8.664	-6.690	0.602	6.300	1.740
Hambantota	-32.000	-16.510	2.070	1.649	10.500
Mahailluppallama	-5.188	-1.120	6.004	9.255	-4.250
Welimada	-2.108	-3.049	7.356	47.290	4.112

Notes on significant of trend: Bold = $p < 0.10$ Bold Italic = $p < 0.05$

Table 2: Trend in rainfall from 1961-2010 for five decades

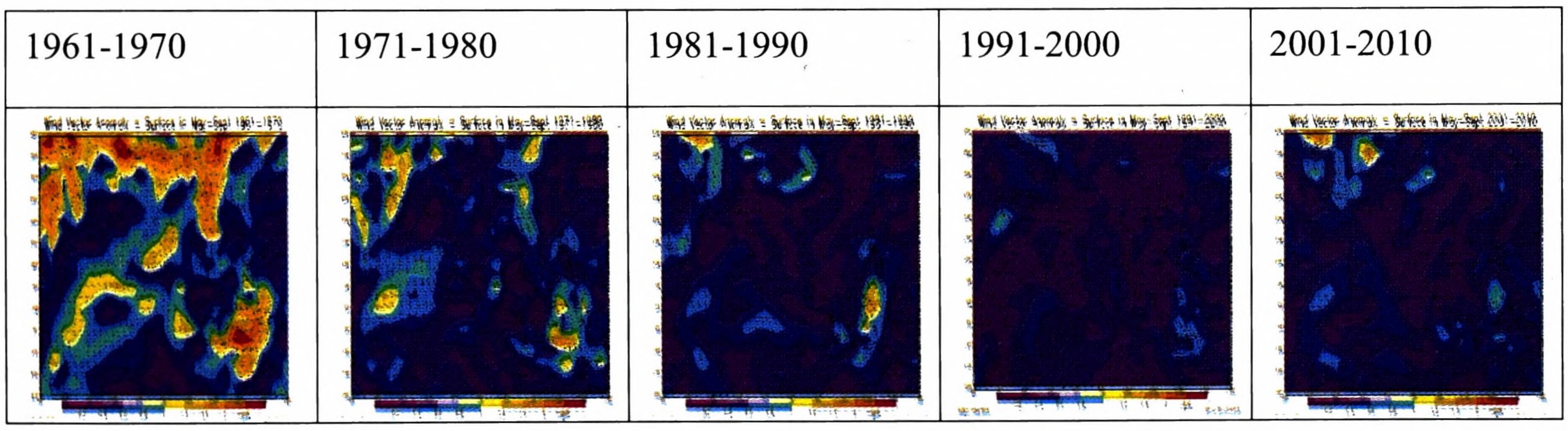

Fig. 6: Wind Vector Anomaly at the surface level in May-September

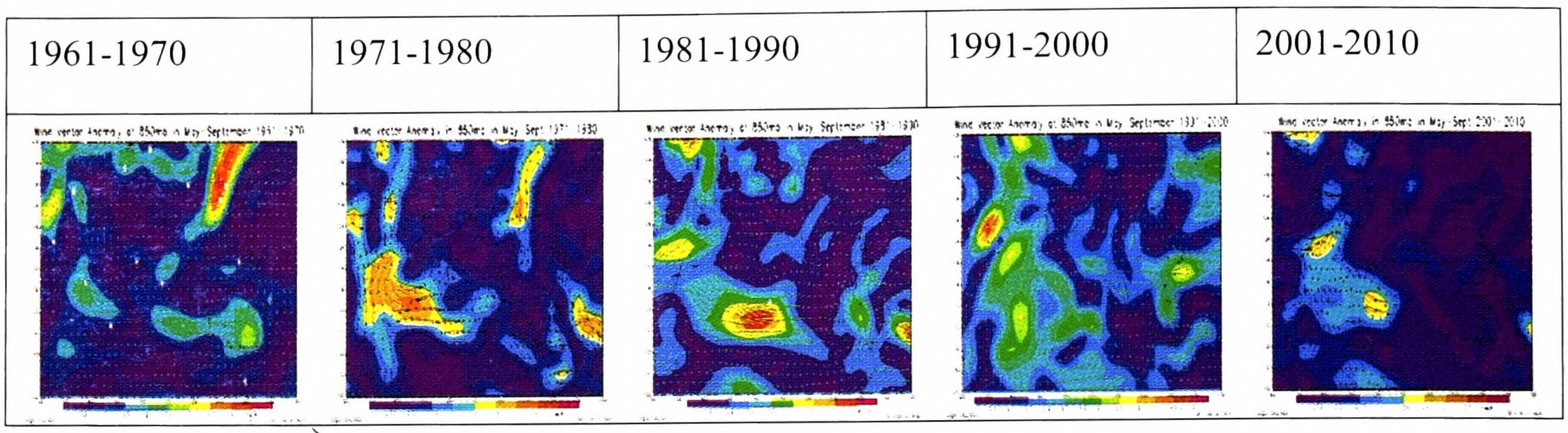

Fig. 7. Wind Vector Anomaly at the 850mb level in May-September

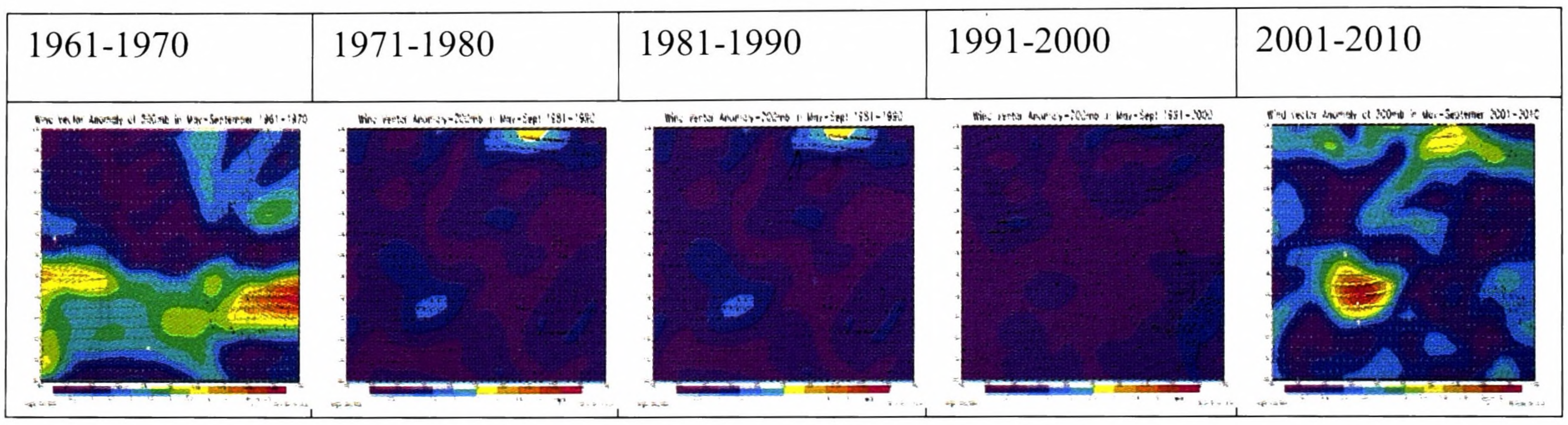

Fig. 8: Wind Vector Anomaly at the 200mb level in May-September

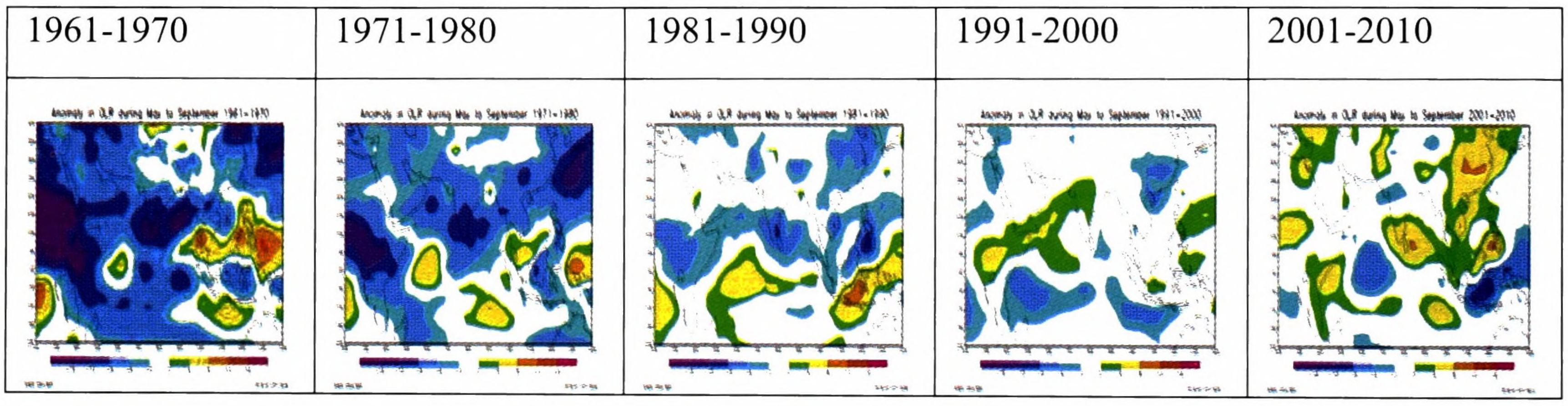

Fig. 9: Outgoing Longwave Radiation Anomaly in May-September

When comparing wind vector anomaly at the 850mb level there is no smooth change in anomaly. But it is clear that the core of the cross Equatorial flow has changed its position and speed with the decades. Its speed has increased and appears in the normal position in the last decade, 2000-2010.

Tropical easterly jets occur during summer monsoon months (May-September) in levels between 200 and 100mb. As in the above two wind vector anomalies tropical easterly jet gradually weakened with the decades and strengthened again in the decade 2000-2010, but in the south eastern Indian Ocean. These changes in essential key features of the southwest monsoon circulation can be the reason for the recent change in trend in the south west monsoon rainfall.

It is known that Outgoing Longwave Radiation (OLR) is a measure of convective activity of a region. Deep Tropical Convection (DTC) plays an extremely important role in the general circulation of the atmosphere *via* its transport of heat and moisture from the tropics. Deep convection produces high clouds. Because a deviation of normal state of DTC may have a greater impact on general circulation, it is essential to understand the potential changes in OLR and Sea Surface Temperature (SST)[4]. Regions of deep convection have been linked to areas of warm SSTs[5]. When comparing changes in OLR anomalies, the intensity of OLR is seen to gradually increase. The anomaly is most prominent in the Indonesian region where tropical easterly jet occur during summer monsoon months May- September and in regions where the essential features of the southwest monsoon develop. But in the last decade there is a little reduction in OLR. These changes are also favorable for the changes in the recent change in trend of the south west monsoon rainfall[4].

1961-1970	1971-1980	1981-1990	1991-2000	2001-2010

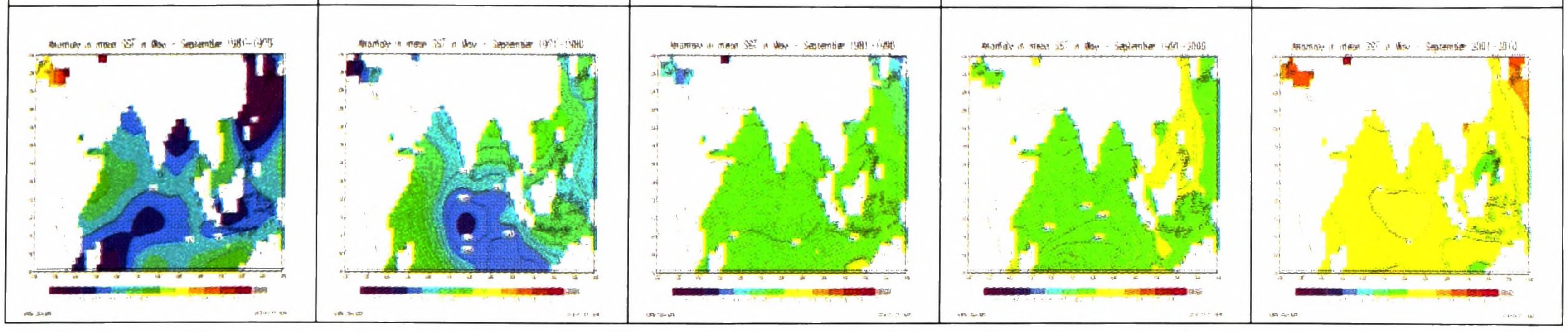

Fig. 10: Sea Surface Temperature Anomaly in May-September

SST in the region also changes gradually with decades and finally in the last decade it is increased. Since SST have been linked with OLR these observations also favorable for the changes in the recent change in trend of the south west monsoon rainfall.

Conclusions

Over the last forty years (1961-2000) there was a decreasing trend in the decadal average of South-West monsoon rainfall received and this decreasing trend changes to an increasing trend in the final decade 2001-2010, at the stations along the South-West coastal belt of the island (Table 1). Key features of the South-West monsoon circulation also shows the changes favorable for such changes in SWDART

Middle part of the up country of the island shows the same variation in the decadal average of South-West monsoon rainfall received. But the magnitude of the decrease is smaller than that of the coastal areas. This change was statistically significant in some stations in some of the decades.

The anomalous decrease in wind speed and the changes in the key features of South-West monsoon circulation gives supportive evidences for this effect. Decadal variations in OLR and SST are also favorable for the decreasing trend in SWDART. These changes in global circulation pattern may link with other global teleconnections EL Nino Southern Oscillations, Pacific decadal Oscillations, North Atlantic Oscillations etc. As such more comprehensive analysis is needed, much more is to be gained at this stage to confirm these changes in SWDART.

References

1. D. R. Archer and H. J. Fowler, Spatial and Temporal variations in precipitation in the Upper Indus Basin, global telaconnections and hydrological implications. *Hydrology and Earth Syst. Sci.*, 2004, **8 (1),** 47-61
2. N. B. P. Punyadewa and W. L. Sumathipala, 2004: Relationship between Rainfalls of Sri Lanka with Sea Surface Temperature (SST) in the Indian Ocean during La-Nina Condition. *Proc. Techn. Sess. Inst. Phys. Sri Lanka,* 2004, **20**, 43-54
3. N. B. P. Punyadewa and W.L. Sumathipala,: Variation of outgoing Longwave Radiation in the Indian Ocean and its relationship to rainfall of Sri Lanka. *Proc. Sri Lanka Assoc. Advmt. Sci.* 1997, **53**,
4. J. F. Dutton, C. J. Poulsen and J. L. Evans, The effect of global climate change on the regions of tropical convection in CSM1, *Geophys. Res. Lett.*, 2000, **27 (19)**, 3049-3052.
5. K. M. Lau, H. T. Wu and S. Bony, The role of large scale atmospheric circulation in the relationship between tropical convection and sea surface temperature. *J.Ch.* 1997, 10, 381-392.