Interdecadal Oscillations and the Warming Trend in the Area-Weighted Annual Mean Temperature of Pakistan

Muhammad Afzaal[1], Muhammad Athar Haroon[1], Qamar ul Zaman[1]

Abstract

The assessment of change in temperature of the country is very much essential in the global warming context. The availibity of accurate and reliable long term temperature records becomes imperative for the purpose mentioned above. In the partial fulfillment of the need the area-weighted annual temperature time series for Pakistan is prepared for the period 1901 – 2007, by merging the Climate Research Unit (CRU) and Pakistan Meteorological Department (PMD) observed datasets. For this purpose, some statistical analysis has been done on both the datasets to evaluate the agreement between the two datasets. The datasets were found to have correlation of 0.86 for the period 1960 – 2000, besides other similarities of variance, mean, standard deviation etc. After the reconstruction of long term temperature time series spectral analysis has been carried out to identify the variations over the time span in terms of frequency. This analysis revealed that there are inter decadal oscillations of the period of 14 – 50 years and inter annual oscillations of the period 5 – 6 years in the time series. Linear trend analysis showed that there is a clear indication of warming in Pakistan. The increasing rate of temperature has been found to be 0.06°C per decade. Total change in temperature is calculated to be 0.64°C, with warming and cooling episodes in last 127 years.

Key Words: Global Warming, Area-Weighted Temperature, Spectral Analysis

Introduction

In response to global warming, Pakistan is also facing Change in its climate, especially, in the temperature which seems to be risen considerably. Such change can be seen in northern areas of Pakistan warming trend is rapidly invading the glaciated areas [Rasul et al, 2008]. Climate has intrinsic variability and has been changing in past decades, even, before we started measuring the climate parameters. The threat of climate change can be coped with by identifying its effects on different socio-economic sectors of the country. Substantial efforts have been made to establish reliable and accurate records of surface air temperatures of the region [Sing, N. et al, 1996]. It is very important to prepare a long term time series to identify the changes in temperature and the way it behaved in terms of inter annual to inter decadal oscillations.

The major part of Pakistan is arid to semi arid with large spatial variability in the temperature [Q. Z. Chaudhary, et al 2004]. A study on climatic normal of Pakistan, 1931 – 1960 and 1961 – 1990, revealed that there was cooling over Northern Pakistan and southeastern Pakistan due to the increase in monsoon cloudiness and rainfall [Kruss et al, 1992]. Analysis of reconstructed long term temperature time series from 1876 – 1993 yielded the presence of large variability in temperature of the country and warming since the beginning of last century with total change of 0.2°C [N. Sing et al, 1996]. In this paper the time series of area-weighted annual mean temperatures of Pakistan has been prepared and analyzed for the period from 1901 to 2007, to detect the changes in temperature during last century and trends of recent climate events. Spectral analysis has also been carried out to identify the low and high frequencies present in the time series. The purpose of this study is to provide a reliable long term area weighted temperature records of the country for further research.

Data and Methodology

Long term temperature records of Pakistan are available for 20th century. The real time data generated by Pakistan Meteorological Department (PMD) along with the Climate Research Unit (CRU) data, named as CRU TS 2.0, are used. The CRU data-set comprises 1200 monthly grids of observed climate, for the period 1901-2000 covering the global land surface at 0.5 degree resolution.

[1] Pakistan Meteorological Department

Thirty-Eight synoptic stations of PMD, for which long term temperature data is available, have been used in this study. The spatial distribution of the stations is displayed in Fig 1.

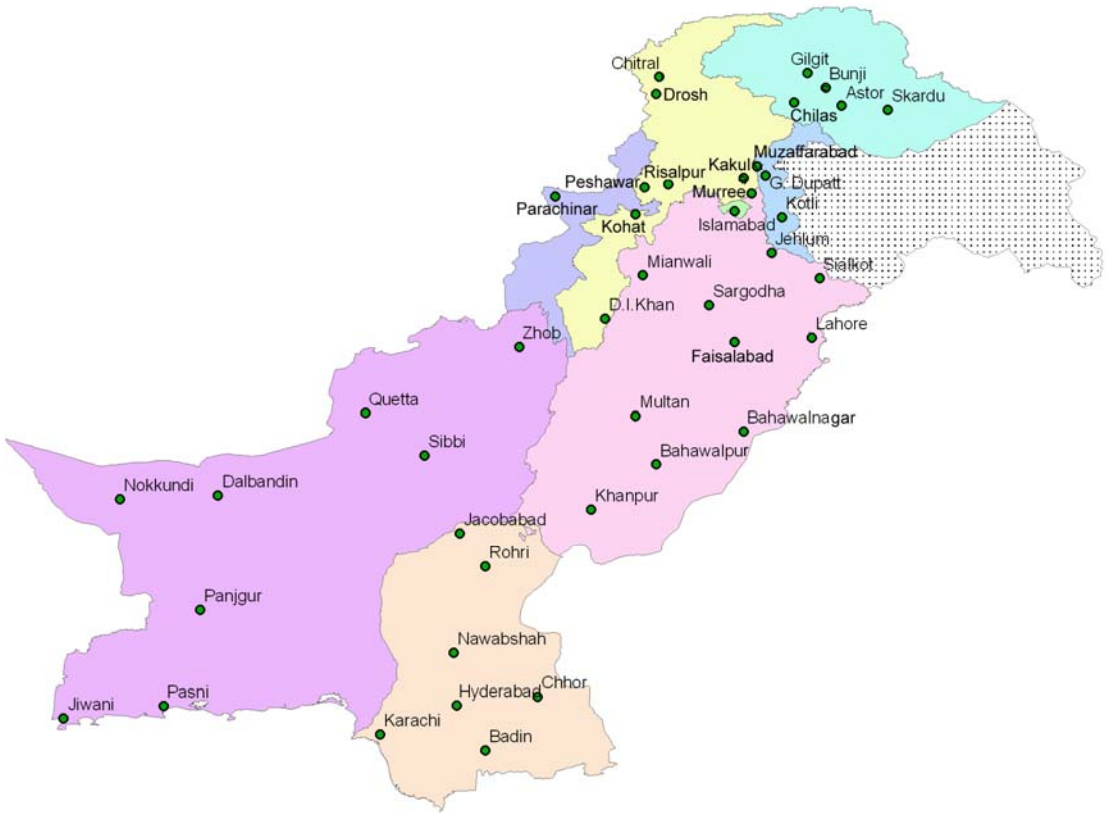

Fig 1.Spatial Distribution of Synoptic Stations of PMD

Area-weighted temperatures have been calculated for each station by the following equation (1), given by S. L. Grotch [S. L. Grotch, 1987].

$$T_{awy} = \frac{\sum T_{iy} \cos \Phi_i}{\sum \cos \Phi_i} \qquad (1)$$

Where

T_{awy} is the area-weighted temperature for the year 'y',

T_{iy} is the temperature of station/grid-point 'i' for the year 'y' and

Φ_i is the latitude of station/ grid-point '*i*'.

The area-weighted annual temperatures are given in Fig. 7. The annual anomaly has been calculated with respect to base period of 1961 - 1990.

After the calculation of area-weighted temperatures for each station, all Pakistan temperatures were calculated by taking the average over the country. The data quality is assured before calculating the temperatures at each station. In this way a time series of annual area-weighted temperature anomaly has

been obtained from 1960 – 2007. The temperature anomalies from 1901 to 1959 have been reconstructed using CRU data aforementioned. For this purpose, area-weighted anomalies of CRU and PMD have been compared from 1960 to 2000. Parameters of univariate statistics have been calculated for both datasets for comparison using Matlab 7. The same software has been used to plot figures.

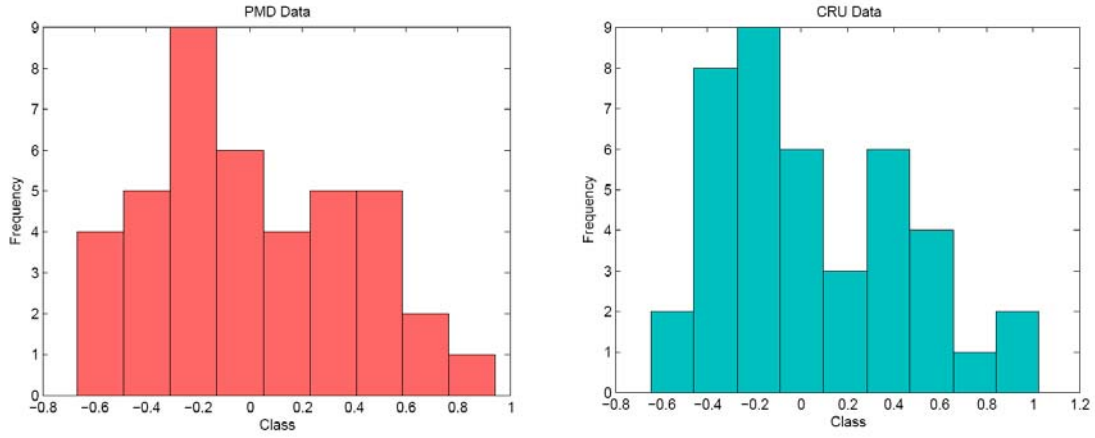

Fig. 2: Histograms represent Normal Distribution of the data

Fig. 2 shows the histogram of both the datasets. It can be seen that mode of the datasets are normally distributed. The Mode for both is almost same. Mode, Median and Mean is the measures of central tendency. The central tendency of both CRU and PMD lie very close to each other. However, mean of the datasets is different. This may be due to the fact that Mean is very much sensitive to the outliers. The Range, Standard Deviation and Variance are the measure of dispersion of the data set. From Table 1, it can be seen that the three parameters of dispersion of both the datasets lie close to each other. Furthermore, Skewness and Kurtosis can be used to describe the shape of the distribution. Both the datasets have positive Skewness which means the data are spread out more to the right of the mean value. Both the datasets have the value of Kurtosis less than three, which means that the distribution of the data is little bit flat near the Mean and have long tails. A low Kurtosis is due to the presence of extreme deviations which occur time to time. Pearson product moment correlation coefficient or simply the correlation coefficient (r) was calculated. It is a measure of association between the two data sets having value '+1' or '-1'.The value of the correlation coefficient between the considered datasets for the period is ≈ +0.9, which shows a strong agreement between both the datasets.

Table 1: Statistics of CRU and PMD Datasets (1960 – 2000)

	Max	Min	Range	Mean	Median	STD	Variance	Skewness	Kurtosis
CRU	0.94	-0.55	1.49	0.05	-0.07	0.39	0.16	0.48	2.21
PMD	0.85	-0.57	1.43	0.01	-0.06	0.38	0.14	0.33	2.03

Student's T-Test at 5% significance level has been used to compare the Mean of both the datasets. The test yielded the significance of 0.635806 and H=0 which means that null hypothesis cannot be rejected. The difference in means of two datasets lie in 95% confidence interval [-0.12949 0.210766]. F-Test has also been used to compare the variance of the two datasets. The F calculated from the datasets, 1.081937, is less than critical F, 1.692797. This means that variances are identical at 95% confidence level.

Statistical analysis of the two datasets provide sufficient evidence that the annual mean temperatures over Pakistan regenerated by CRU are reasonably well in accordance with that of observed by Pakistan Meteorological Department. After the confirmation of the reasonable agreement between CRU and PMD

data the area-weighted temperature anomalies over Pakistan have been reconstructed backward from 1960, using linear regression. Spectral Analysis has been made on the time series of Pakistan area-weighted annual temperature anomaly to describe the variance contained in the time series in terms of frequency or wavelength. For this purpose spectral analysis technique has been used to determine the power of prominent frequencies present in the time series. Power Spectral Density (PSD) has been estimated using Welch's Method [P.D. Welch, 1976]. This method is improved one among many other methods for spectral analysis [H. V. Storch et al, 1999]. It is not the purpose of this study to analyze the statistical methods, so, the above method has been used as a tool.

Results and Discussion

It is obvious from the above Fig. 3 that there is a high interannual variability in the temperature and it is difficult to explain the variability in terms of frequency.

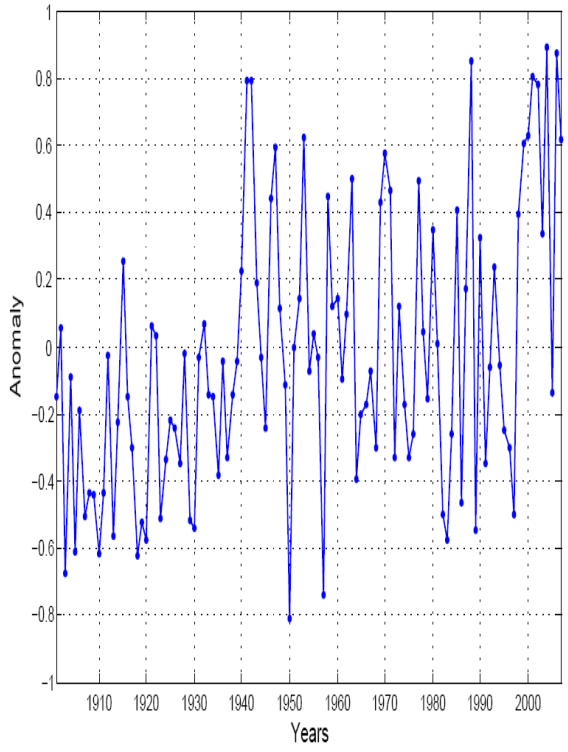

Fig. 3: Pakistan area-weighted annual temperature anomaly from 1901 – 2007

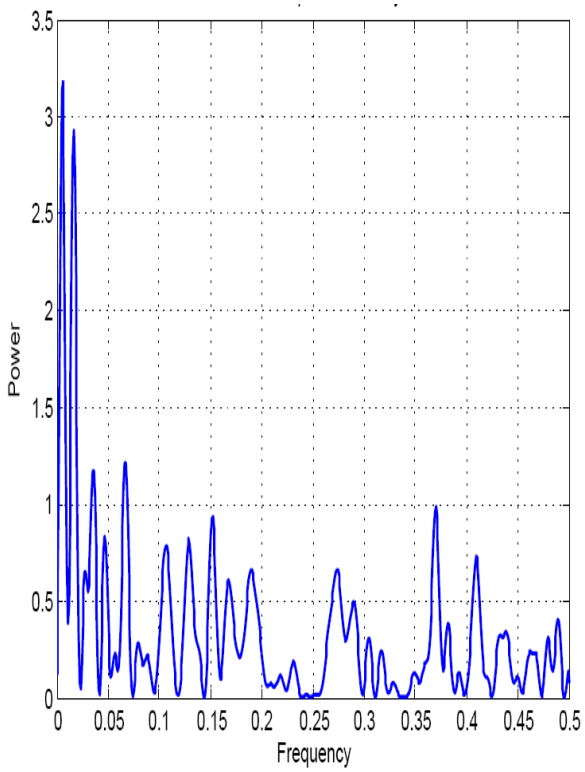

Fig. 4: Power Spectrum Density showing Noise in the data

Power Spectral Density (PSD) has been calculated which revealed that the data contains a lot of frequencies other than some dominant frequencies, which may be termed as noise. The Power Spectral Density plot is shown in Fig. 4. Therefore, some smoothing algorithm or a filter is required to expose its features and provide a good start for spectral analysis of the time series. The smoothing process provides a smoothed dataset which is the best estimate of the original data because the noise has been reduced.

Moving average filter smoothes data by replacing each data point with the average of the neighboring data points defined within the span. The span defines a window of neighboring points to include in the smoothing calculation for each data point. This window moves across the data set as the smoothed response value is calculated for each predictor value. A large span increases the smoothness but decreases

the resolution of the smoothed data set, while a small span decreases the smoothness but increases the resolution of the smoothed data set. The optimal span value depends on the data set and the smoothing method, and usually requires some experimentation to find. In this research paper span is taken as nine, because the value to be smoothed may have four neighboring point on either side. Fig. 5 shows the filtered time series.

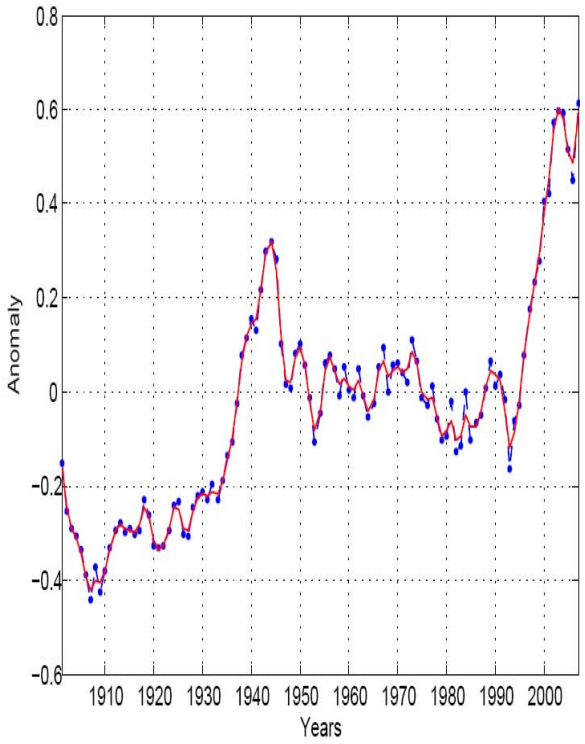

Fig. 5: Filtered Time Series of Area-Weighted Annual *Temperature Anomaly of Pakistan*

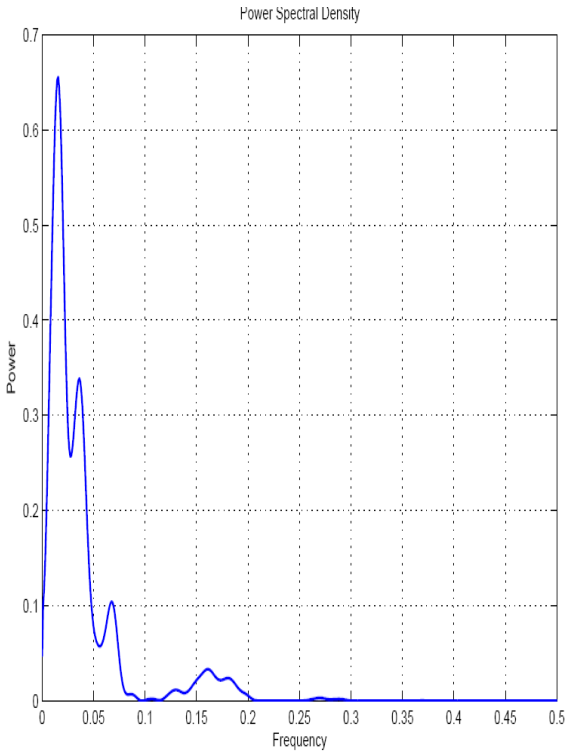

Fig. 6: Power Spectrum Density showing *Reduction in the Noise*

The power spectrum of a signal represents the contribution of every frequency of the spectrum to the power of the overall signal. Fig. 6 depicts the power spectrum of the smoothed time series of area-weighted temperature anomaly. It can be seen that the noise has been reduced and the dominant frequencies can clearly be identified in the signal. First dominant frequency lies at 0.02, second dominant frequency lies at 0.03 and the third one lies at 0.07. There is a band of high frequencies which lie at 0.16 – 0.18. The spectrum revealed the oscillations of interdecadal period of 50, 33 and 14 years while of interannual period of 5 - 6 years. The interannual oscillations might be related to the impact of El-Nino Southern Oscillation phenomenon on the temperatures of the region. The interdecadal oscillations may be associated with the changes in the ocean circulation or other global phenomena, which need to be investigated further.

There is warming trend in the temperature from the beginning of the time series as seen in Fig. 5. The temperature of Pakistan has been rising at the rate of 0.06°C per decade and the total change in temperature has been 0.64°C over the period, which is significant at 95% confidence level. The temperature has been rising from 1907 and lasted up to 1945 at the rate 0.2°C per decade. Then the temperature began to fall at the rate 0.03°C per decade up to 1993. However the average temperature in the later period remained 21.8°C while in the former period it remained 21.6°C, which clearly indicates the warming of 0.2°C in the country. After 1993, there is a sharp rise in temperature which lasted up to

the end of the time series i.e. 2007. The temperature has risen at the rate of 0.53C per decade in this period. The average temperature in the last decade remained at 22.3°C.

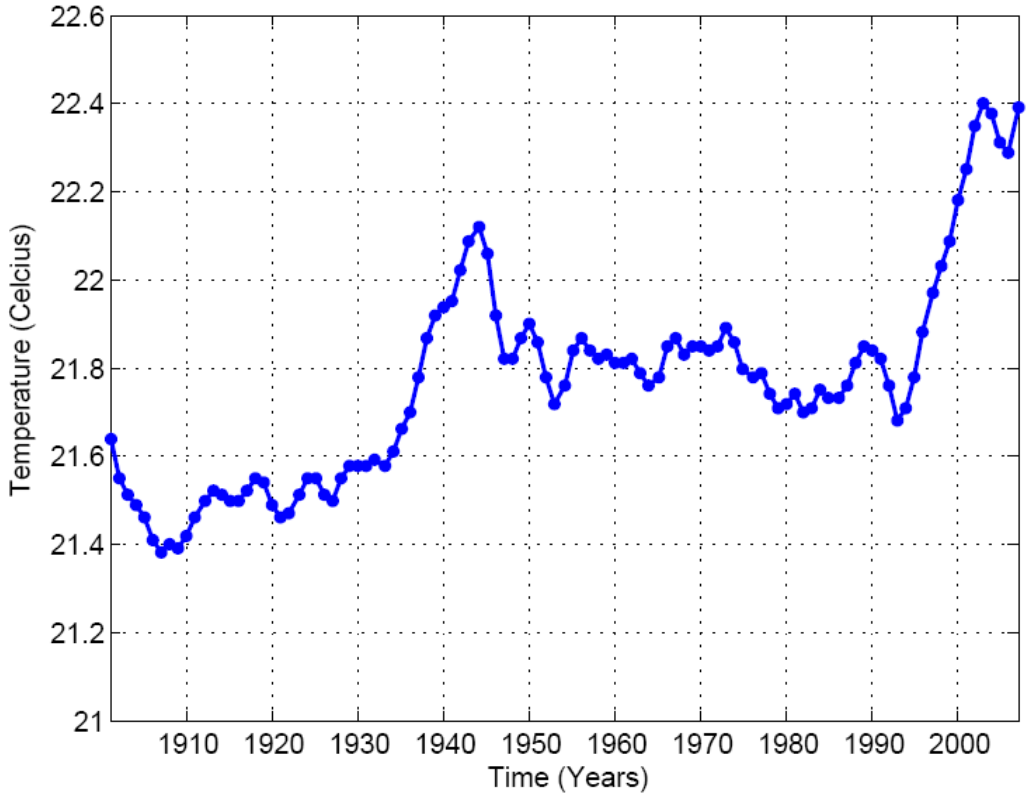

Fig. 7: Area-Weighted Annual Temperatures (°C) Over Pakistan

Conclusion

The univariate analysis of CRU and PMD observed temperature datasets for the period 1960 – 2000 showed that both the datasets are in good agreement with each other. The correlation between the two for the period is ≈ 0.86. On the basis of these results a time series of area-weighted annual mean temperature of Pakistan has been reconstructed for the period 1901 – 2007 by merging the mentioned datasets.

Spectral Analysis of time series revealed that there are interannual to interdecadal frequency in the temperature of Pakistan. The interannual oscillations of the period 5 – 6 years might be related to the impact of El-Nino Southern Oscillation phenomenon on the temperatures of the region, keeping in view the cycles of the phenomena. The interdecadal oscillations of the period 50, 33 and 14 years may be associated with the changes in the global phenomena like ocean circulations etc., which need to be investigated further.

Linear trend analysis of the temperature time series showed the clear indication of warming in the country. The temperatures have been rising at the rate of 0.06°C per decade and the total change in temperature has been 0.64°C over the period, which is significant at 95% confidence level, with cycles of increase and decrease over the time span.

References

1. **Ghulam Rasul, Qin Dahe, Q.Z. Chaudhry 2008:** Global Warming and Melting Glaciers along Southern Slopes of HKH Ranges. Pakistan Journal of Meteorology, Vol. 5 Issue 9 (July 2008). Pp 63-76.
2. **Chaudhary, Q.Z. and G. Rasul 2004:** Climatic Classification of Pakistan. Science Vision, Vol. 9 No. 1-2 (Jul-Dec, 2003) & No. 3-4 (Jan-Jun, 2004). Pp. 59-66.
3. **Kruss, P. O, K.A.Y.Khan, F.M.Q. Malik, M. Muslehuddin and A. Majeed 1992:** Cooling over monsoonal Pakistan. Proceedings of 5th International Meeting on Statistical Climatology. Environment Canada, Toronto, Pp 27.
4. **Singh, N. and Sontakke, N.A 1996:** Climate Variability over Pakistan and its relationship to variations over the Indian region. In: Climate Variability and Agriculture, Eds. Y.P.Abrol et al., Narosa Publishing House, New Delhi, Pp. 67-95
5. **Grotch, S.L 1987:** Some Considerations Relevant to Computing Average Hemispheric Temperature Anomalies. American Meteorological Society, Monthly Weather Review, Volume 115, Issue 7, Pp. 1305 – 1317.
6. **Welch, P.D 1976:** The Use of Fast Fourier Transform for the Estimation of Power Spectra: A Method Based on Time Averaging Over Short, Modified Periodograms. IEEE Trans. Audio Electroacoust, Vol. AU-15, Pp. 70 – 73.
7. **Storch H. V. and W.Zwiers F 1999:** Statistical Analysis in Climate Research, Cambridge University Press, Pp. 263 – 281.