Evaluation of Projected Minimum Temperatures for Northern Pakistan

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Abstract

Pakistan has agriculture based economy, mainly dependant on the Indus water system originates from glaciated northern mountains of Himalaya-Karakoram- Hindukush ranges. These glaciers possess a treasure of solid water which melts with high temperature and makes this precious resource available in rivers during needy times. Recent climate studies have shown a non-significant increasing trend for annual mean temperature over the mountainous areas of the Upper Indus Basin in Pakistan. This study aimed at investigation of the recent trend of global warming for this region and to test the reliability of future data generation by a statistical downscaling model "SDSM". The period under study was 1991-2009 and the analysis was carried on mean minimum (night) temperatures. The Northern parts of Pakistan were chosen as the study area that lie along northwest of the upper Indus basin. A correlation has been processed among modeled and observed data to evaluate the satisfaction between the two datasets. For all the studied stations, very high correlation observed between the two data sets and correlation coefficient (R^2) was found as 0.92, which encourage the way forward. A state of art downscale modeling systems known as SDSM (statistical down scale model) developed by Wilby and Dawson (2007) was applied for evaluation of projected minimum temperature. On the monthly scale, model under estimated temperature from 0.7°C to 1.08◦C for summer season and over estimated from 1.97°C to 3.23°C for winter season. The strong correlation suggested that SDSM can be used with reasonable level of confidence to obtain future projections of night time temperature.

Keywords: SDSM, Correlation coefficient, Indus basin, projected minimum temperature, Northern Pakistan.

Introduction

Pakistan is an agriculture dependant country with varying geography as well as the climatic conditions. On the east it is connected with plains of Indian Punjab and in the west its borders joins with deserts of Iran. Rasul et al., (2008) stated "In the northern parts of the country Himalaya-Karakorum-Hindukush together makes the largest mountain chain on the earth".

They are custodian of the third largest ice reserves after the Polar Regions. They possess a treasure of solid water which melts with high temperature in summer and makes this precious resource available in rivers during dry spells. The environment has given the operational control of this water tank in terms of temperature after the strong buildup of greenhouse gases (Rasul et al., 2006).

Climate change effects are expected to be greatest in the developing world. One of the high priorities for narrowing gaps between current knowledge and policymaking needs is the quantitative assessment of the sensitivity and vulnerability of climate change, especially in terms of agro-economic indicators in the developing countries like Pakistan. To pursue such assessment, the most fundamental requirement is the availability of the reliable estimation of future climate projection on the regional level. This can be achieved by different models and it is possible by the validation of climate model. Climate models are the main tools available for developing projections of climate change in the future (Houghton et al., 1995, 2001). In comparison with other downscaling methods the statistical method is friendlier to use and has the ability to provides local or station information (Wilby et al., 2002).

The year 2009 was ranked among the top 5 warmest years since the beginning of instrumental records about 1850, while the decade from 2000 to 2009 has been the warmest on record (WMO, 2010). The major assessment of temperature change is that all land areas will warm more than the global average (with the exception of Southeast Asia and South America in June, July and August; JJA), with amplification at high latitudes (IPCC, 2007).

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Chaudhry et al., (2009) have shown a non-significant increasing trend for annual mean temperature over the mountainous areas of the Upper Indus Basin in Pakistan. On the basis of long-term data sets since the late 19th century, analyses of the temperature data show significant increasing trends in annual temperature for North Western Himalayan region (Bhutiyani et al., 2009). Bhutiyani et al., (2007) conclude that their study confirmed that the North Western Himalayan region has 'warmed' significantly during the last century at a rate, which is higher than the global average. The rise in air temperature has been primarily due to rapid increase in the maximum as well as minimum temperatures, whereby the maximum temperature has increased more rapidly leading to bigger Diurnal Temperature Range (DTR).

According to Pakistan's agroclimatic classification two-third of Pakistan's area lies in semi-arid to arid zones (Chaudhry et al., 2004). Hence, majority of the people depend on arid and semi-arid areas to support their livelihoods through agro-pastoral activities. The greatest and most unpredictable risks in the mountain areas are expected to come from more frequent extreme events, such as forest fires, floods, avalanches, and landslides (IPCC, 2001). Increasing temperatures may have a positive impact on agriculture in the mountain areas, for instance through shortening of growing period for the winter season crops (Hussain and Mudasser, 2007).

Current study of future scenario generation for temperature data may help providing a research platform in the diversified fields of meteorology of Pakistan. The results obtained in this study project the theme that the future temperatures may not be increasing all the time for every region. The comparison of results shows that the model has firm grip on downscaling capability for production of seasonal temperature data (Kazmi et al., in press).

Difficulties remain in reliably simulating and attributing observed temperature changes at smaller scales. On these scales, natural climate variability is relatively higher, making it harder to distinguish changes expected due to external forcing (IPCC, 2007). Global climate circulation model (GCM) is already available for all the important meteorological parameters but the resolution is rather coarse. Murphy (1998) stated that although it can be employed for a number of impacts assessment studies like risk of drought or flooding on large catchments, but for the impact assessment studies like agricultural crop modeling we need point to point inputs. The purpose of this study is to evaluate these projections for future study of climate where point to point data would be required.

Ferro et al., (2005) reported that "night temperatures (Tmin) seem to be increasing at much high rates than the day temperatures". The lowest Tmin are expected to be warmer by more than 5°C over most parts of India, the highest maximum temperatures shown an increase of 2°C. Even during the recent study period it was also observed that the night temperatures are increasing more rapidly than the maximum temperatures not only over India, but also across several regions of the world.

Table 1: List of stations incorporated in the study, with location & elevation information and the correlation coefficient between SDSM and Observed Tmin.

S.No	Station	Latitude °N	Longitude °E	Altitude above mean sea level (Meters)	R^2value (SDSM VS Obs)
1	Kohat	33.57	71.43	510	0.921
2	Peshawar	34.02	71.58	359	0.86
3	Muzaffarabad	34.25	74.04	701	0.90
4	Cherat	33.82	71.88	1301	0.77
5	Chitral	35.85	71.83	1499	0.80
6	Kakul	34.18	73.25	1308	0.91
7	Balakot	34.38	73.35	980	0.84

8	Gupis	36.17	73.4	2155	0.60
9	Astore	35.34	74.9	2167	0.89
10	Skardu	35.3	75.68	2317	0.87
11	Drosh	35.57	71.78	1464	0.84
12	D.I.Khan	31.82	70.92	173	0.83
13	Gilgit	35.92	74.33	1459	0.83
14	Ghari Dupatta	34.12	73.62	812	0.80
15	Kotli	33.52	73.9	613	0.87

Data and Methodology

Real time meteorological data of mean minimum temperature (Tmin) on monthly/annual basis for the period 1991-2009, for 15 meteorological stations of Azad Jammu Kashmir (AJK), Northern Areas and the north western province Khyber Pakhtunkhwa (KPK) of Pakistan were utilized for the study. This data was obtained from the data archive of Pakistan Meteorological Department (PMD).

Future data (for A2 scenario) as generated by the Statistical Downscaling Model SDSM (recently produced at PMD) for different parameters, period and location, was incorporated.

SDSM is user-friendly software designed to implement statistical downscaling methods to produce high-resolution monthly climate information from coarse-resolution climate model (GCM) simulations. The software also uses weather generator methods to produce multiple realizations (ensembles) of synthetic daily weather sequences. Additionally, the software performs ancillary tasks of predictor variable pre–screening, model calibration, basic diagnostic testing and statistical analyses of climate data. SDSM is a software package (with multiple versions available), and accompanying statistical down scaling methodology, that enables the construction of climate change scenarios for individual sites at daily time–scales, using grid resolution GCM output. The software performs five basic tasks involving statistically down scaling GCM output, namely: screening of candidate predictor variables; model calibration; synthesis of current weather data; generation of future climate scenarios; diagnostic testing and basic statistical analyses.

The daily real time data of mean minimum temperature for the specified stations was scrutinized and compiled on monthly and annual basis. The same approach was applied for the generated data as well. Both the data sets were analyzed on monthly and annual basis in order to investigate the general trend on individual as well as comparative basis. For individual analysis the ordinary linear trend was incorporated while to compare the two data sets statistical based application “scatter plot” incorporated.

“A statistically test gives a clue for making quantative decisions about a process or processes” (Storch and Zwiers, 1999). The above data sets analyzed by using statistically technique (linear Regression and co-efficient of co-relation). In scientific studies the correlation generally measured as co- relation co-efficient “R^2” that portray the strength of a linear relation between two random variables. If the value of R^2 is near 0 it indicates no linear relationship and results in a highly scattered graph. But the value of R^2 is near +1 or -1 it indicates a strong relationship the data lies so close that the regression is linear. Correlation shows the relationship between two variables but regression takes this one step further, it predicts or estimates a score for one variable based upon other variable.

Result and Discussion

It was observed that the night temperatures are increasing in the Northern Areas of Pakistan. This result was concluded through detailed analysis of past records of different meteorological stations of the area. It was revealed in the study that in most parts of the region Tmin are increasing, except for a few stations.

Secondly a comparison was made between the real time data and the SDSM generated data. The comparative study projects that the generated/modeled data has very high correlation with the observed one. A few important stations are being discussed here.

Muzaffarabad (34.25°N, 74.04°E) is taken as first station for discussion, located in AJK adjacent to the eastern boundary of KPK. The station lies in the Jhelum Basin over the sub-mountainous plains on the foothills of Himalayas from where two important rivers Neelan and Jhelum are flowing. The Indus is flowing from its left in the Hazara valley of KPK; whereas Jhelum River starts its journey from the area, which is under discussion. Therefore the meteorological elements such as temperature and precipitation are important for the hydrological and agricultural computations. Hence in this study it has been tried to find coefficient of correlation between observed and model data regarding minimum temperature. The future data for Tmin from SDSM was compared with the observed one with R^2 = 0.90 that is a reliable output as given in Figure 1(a). For any scientific based comparison the value of the correlation coefficient greater than 0.49, is considered reliable (Faheem, M., 2000). Due to the significant value of correlation between both data sets the results are very optimistic.

Regression line is used to estimate the score for an individual variable based on the other variable. For linear regression, the base fit line has been plotted between the two variables depicted in scatter plot. The best fit line is defined as the line for which the data lie very close to the line. The equation of regression line is given below:

$$Y = 1.06x - 1.07$$

The slope of the line is a positive value which means that there is an increasing trend of temperature. Regression result is 95% for Muzaffarabad, which means almost 95% points (data), lie very close to the line.

For river basin the mean annual cycle of Tmin from SDSM and Meteorological station observations are shown in Figure 1(b) .The highest value of Tmin found in June, while the minimum value Tmin is observed in January. The Meteorological stations recorded temperature is higher for the months of September to February as compared to model data. The predictors which used by the model are surface airflow strength, meridional velocity, 500 hPa geo potential height (GPH), surface specific humidity and mean temperature at 2m height above the ground. This difference is because of the fact that meteorological stations are located in valleys and don't represent the temperature in high mountains.

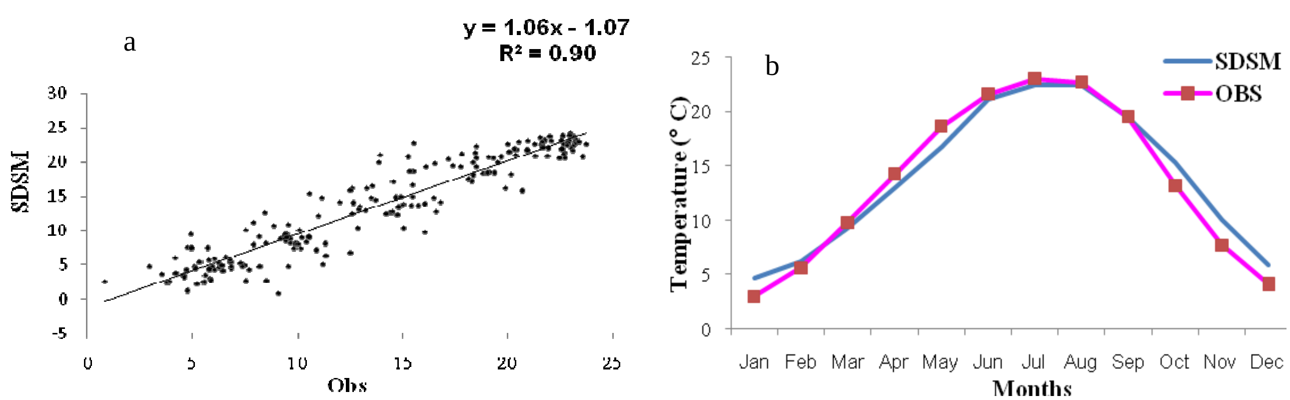

Figure 1: (a) Scatter plot between real time and modeled Tmin (annual) for the period 1991-2009, for Muzaffarabad; **(b)** Monthly Mean Temperature of Muzaffarabad from 1991-2009.

The second station Skardu (35.3°N, 75.68°E) is located in the northern areas of Pakistan. The station also lies in the upper Indus basin within the Karakoram Range. It is known for heavy snowfall in the region, its night temperature remains below freezing point for 6-7 months of the years. In the vicinity of the station some very large and significant glaciers such as Baltoro, Siachen and Biafo are located. Because of these features the temperature profile for this region has great importance regarding the climate change and global warming issues. Figure 2(a) exhibit the comparative study of correlation between real time and model generated Tmin is R^2 = 0.87 which is statistically significant on annual basis. Although, the area has a complex geographical features but SDSM has generated good results for future time period i.e., 1991-2009.

The equation of regression line ***Y = 1.12x - 1.37*** shows an increasing trend, as the slope of line is a positive value. Value of R^2 is shown as "0.87". The line shows that the value of Y change 1.12°C as the value of X goes up 1°C and error of estimation is 12%.

Figure 2(b) represents the annual change in monthly Tmin for Skardu of 19 years from 1991-2009. The difference between model and observed calculated Tmin on monthly basis reveals that the model overestimates in winter from October to March and underestimates in summer from June to August respectively. There is a good agreement of model and observed data during transition period. In winter (NDJF) model over estimate 2.6°C whereas in summer model underestimate -0.8°C.

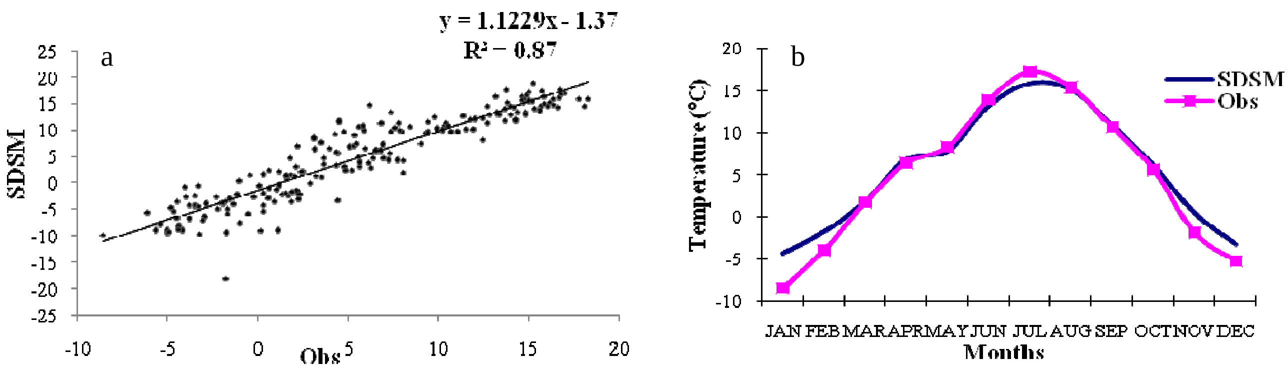

Figure 2: (a) Scatter plot between real time and modeled Tmin (annual) for the period 1991-2009, for Skardu; **(b)** Monthly Mean Temperature of Skardu from 1991-2009.

Gilgit (35.92°N, 74.33°E) is another station in upper Indus basin located near rivers Gilgit and Hunza. Due to its elevation1459 meters above mean sea level, the minimum temperature stays below zero for 4-5 months and snowfalls in winter. There are many glaciers such as Gulkin, Rakaposhi, Passau and Hispar. Due to climate change and global warming, glaciers of the specific region are receding and losing their ice mass at a faster rate. If the night time temperatures of the upper Indus basin increased then snow accumulation will decrease. It may create more disastrous situation in future because this area feeds the national life line river, Indus. According to Rasul et al., (2006) growing population augmented accelerated deforestation, which is considered the main driver behind the environmental heating among others. Snow and ice extent is shrinking much faster than ever before, as a whole, on the HKH mountainous terrain. In the present study it is revealed that the night temperature for this valley is also on increase. Secondly, the correlation between the observed and modeled Tmin is very optimistic, as R^2 = 0.83. These results further confirm the reliability on SDSM's future generation of temperature data. Therefore, it may be trusted for any climatic study in this immense important region.

Regression line ***Y = 1.812x - 3.0531*** is not a best fit line; points are scattered and not lie very near the line. For best fit line the sum of deviations from the lines for all the model values should be zero that is not possible for this line. Regression result is 84% for this station which mean that 84% of the model data depends upon the observed data in the Figure 3(a). The temperature variation showed by the model is 84% similar to the observed data.

Figure 3(b) reveals that the bias for winter and summer respectively for Gilgit. For Gilgit is among those few stations where the difference between model and observed data is more than 3°C however the projected Tmin has shown similar trend to that of the observed Tmin with a good association.

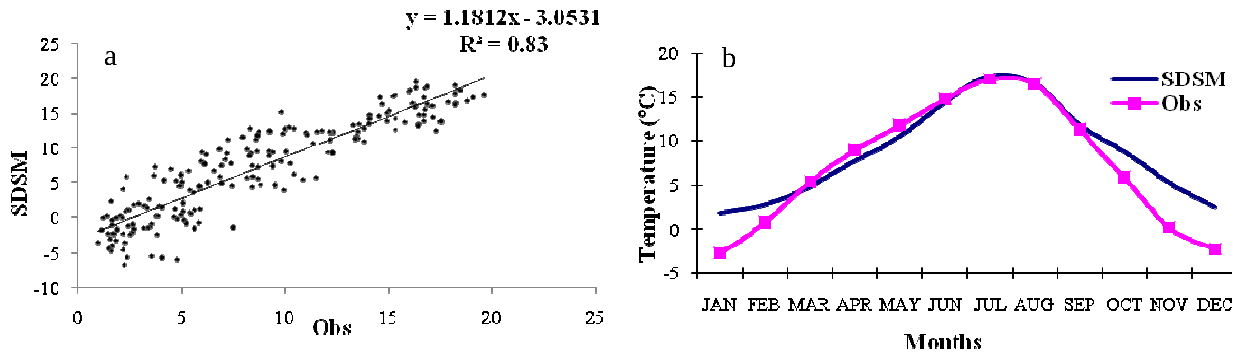

Figure 3: (a) Scatter plot between real time and modeled Tmin (annual) for the period 1991-2009, for Gilgit; **(b)** Monthly Mean Temperature of Gigit from 1991-2009.

Kohat (33.57 °N, 71.43 °E) having mild climate free from snow, located in the southern plains of Khyber-Pakhtunkhwa (KPK). The Kabul and Indus River runs in the vicinity therefore known as the major agricultural zone of the province. The present study shows that the said area has the same pattern of increasing night temperatures as observed for the highland stations.

The correlation coefficient R^2 for the observed and modeled Tmin is 0.92 much better as compared to the other northern studied areas as shown in Figure 4(a).

Here is the linear equation for regression is Y=1.157x-3.694 plotted on a rectangular coordinate system. It can be said that the regression line is best fit because all the points lie close to the line. Value of R^2 is 0.92 which is highly significant .The regression line result is 97% it mean the change in temperature trend for model data is similar to observed data up to level of 97%.

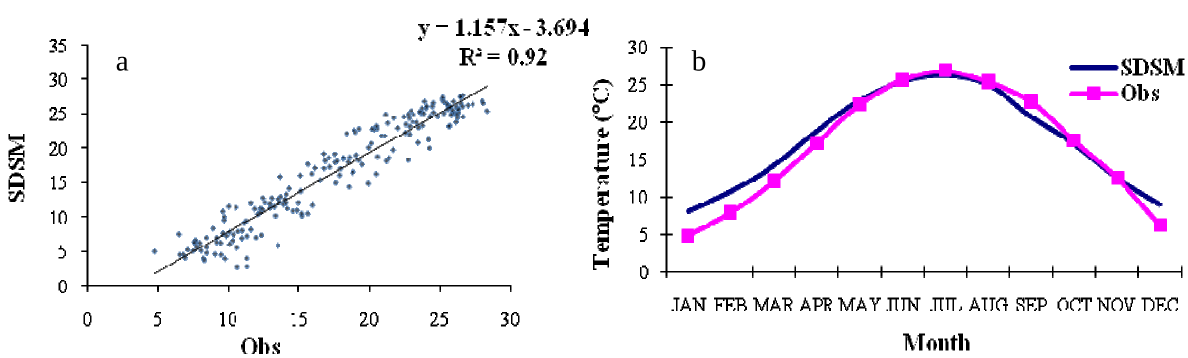

Figure 4: (a) Scatter plot between real time and modeled Tmin (annual) for the period 1991-2009, for Kohat; Monthly **(b)** Mean Temperature of Kohat from 1991-2009.

Figure 4(b) shows the monthly comparison for the two data sets i-e SDSM and observed data. The variation in temperature pattern is same as discussed early for the others stations. However the value of underestimation is less than the other stations that is -0.8. The figure 4(b) depicts a large difference for winter season as compared to the other one. Model and observed data show the same change in minimum temperature throughout the year. An over estimation has been observed for the months December, January, February and March while under estimations for the months July, August and September.

Conclusion

Many climatic studies have shown increasing trend for temperature projection in the northern areas of Pakistan. This study confirms the theory regarding the night temperatures as well. In the present study, the projection for minimum temperature of northern parts of Pakistan was tested against the real time values. It is revealed that the model has remarkably projected Tmin, for the study area. The correlation produced was above significant level for all the stations as R^2 ranged between 0.78 and 0.92, except for a single stations Gupis (with $R^2 = 0.60$) as shown in table1. The study area is the most important regarding the climate change projection with very complex topography. This validation recommends the reliability of SDSM products for climate based studies in the area. Keeping in mind these concerns, further studies are desired to have a clearer picture. The model utilized in this project has produced outstanding projection results in terms of downscaling. SDSM and observed data results are in very good accordance to each other especially when they are compared on monthly basis for minimum temperature.

Recommendations

It is recommended that other parameters such as precipitation, maximum temperature, relative humidity and solar radiation intensity may also be investigated by using SDSM to present the total picture of climatic conditions in that area.

References

Bhutiyani, M. R., V. S. Kale and N. J. Pawar, 2007: Long-Term Trends in Maximum, Minimum and Mean Annual Air Temperatures across the Northwestern Himalaya during the Twentieth Century, Climatic Change, Vol. 85, DOI: 10.1007/s10584-006-9196-1.

Bhutiyani, M. R., V. S. Kale and N. J. Pawar, 2009: Climate Change and the Precipitation Variations in the Northwestern Himalaya: 1866–2006, Int. Jr. of Climatol. published online in Wiley Inter Science (www.interscience.wiley.com) DOI: 10.1002/joc.1920

Chaudhry, Q. Z. and G. Rasul, 2004: Agroclimatic Classification of Pakistan, Science Vision, 9(3-4, Jan-Jun), 59.

Chaudhry, Q. Z., A. Mahmood, G. Rasul and M. Afzaal, 2009: Climate Change Indicators of Pakistan, Pakistan Meteorological Department, Technical Report No. PMD 22/2009

Faheem. M., 2000: Statistical Methods and Data Analysis, Kitab Markiz, Aminpur bazar, Faisalabad

Ferro, C. A. T., A. Hannachi and D. B. Stephenson, 2005: Simple Nonparametric Techniques for Exploring Changing Probability Distributions of Weather. J. Climate.

Houghton, J. T., L. G. Meira Filho, B. A. Callander, N. Harris, A. Kattenberg and K. Maskell . 1995: Climate Change 1995, Intergovernmental Panel on Climate Change (IPCC). Cambridge University Press, Cambridge.

Houghton, J. T., Y. Ding, D. J. Griggs, M. Noguer, P. J. V. Linden and D. Xioaosu. 2001: Climate Change 2001: The Scientific Basis Contribution of Working Group I to the Third Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press: Cambridge.

Hussain, S. S. and M. Mudasser, 2004: Prospects for Wheat Production under Changing Climate in Mountain Areas of Pakistan-An econometric analysis, Agriculture system, 94(2), 494-501, DOI:10.1016/j.agsy.2006.12.001.

IPCC 4th Assessment Report 2007: Climate Change 2007 (AR4).Online publication www.ipcc.ch/publications_and_data (24,Feb.2011)

IPCC Third Assessment Report 2001: Climate Change 2001 (AR3). Online publication www.ipcc.ch/publications_and_data (24,Feb.2011)

Kothawale, D. R. and K. R. Kumar, 2005: On the Recent Changes in Surface Temperature Trends over India. Geophys. Res. Lett., 2005.

Rasul, G. and Q. Z. Chaudhry, 2006: Global Warming and Expected Snowline Shift along Northern Mountains of Pakistan. Proc. of 1st Asia CliC Sympos. Yokohama, Japan.

Rasul, G., Q. Dahe and Q. Z. Chaudhry, 2008: Global Warming and Melting Glaciers along Southern Slopes of HKH Range. Pakistan Journals of Meteorology, 5(9), 63-76.

Storch H. V. and F. W. Zwiers, 2005: Empirical Distribution Function in Statistical Analysis in Climate Research, 1st edition, Edited by Syndicate of the University Press, Cambridge University Press, 81.

Wilby, R. L. and C. W. Dawson, 2007: User Manual for Statistical Downscaling Model (SDSM) version, 4.2.

Wilby, R. L., C. W. Dawson and E. M. Barrow, 2002: SDSM– A Decision Support Tool for the Assessment of Regional Climate Change Impacts.

WMO, 2010: WMO Statement on the Status of the Global Climate in 2009, WMO No. 1055.