



Asia-Pacific Network for Global Change Research

Development and Application of Climate Extreme Indices and Indicators for Monitoring Trends in Climate Extremes and their Socio-Economic Impacts in South Asian Countries

Final report for APN project: ARCP2008-10CMY-Sheikh

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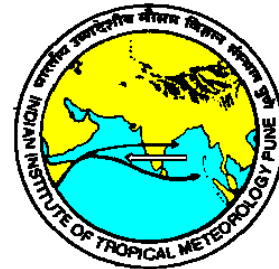
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**Project Reference Number: [ARCP2008-10CMY-Sheikh](#)
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Overview of project work and outcomes

Non-technical summary

Under this two-year APN project, two activities were held, one during 2008 and the other during 2009 in Kathmandu, Nepal. A good network of meteorological stations over the participating South Asian countries (Bangladesh, India, Nepal, Pakistan and Sri Lanka) was used to develop the climate extreme indices over the region using all the 27 ETCCDMI (Expert Team on Climate Change Detection and Monitoring Indices) core climate indices. The participating countries, after having converted the time series data of the key climate variables temperature (maximum and minimum) and daily rainfall totals into high quality metadata by passing it through homogeneity and quality control testing, used it for analysis. Trend graphs, histograms and spatial pictures were prepared to see trends in climate extremes and study their behavior over different parts of South Asia. A comprehensive report in this regard was prepared. In the first meeting held during 21-25 April, 2008, it was decided to average out the trends of all indices for all stations over South Asia and develop a picture for the region as a whole and see the position of the respective countries in its perspective. Five research papers were further decided to be prepared based on the outcome of these results. These research papers included: (i) Indices of temperature and rainfall extremes over South Asia (ii) Impact of altitude on extremes (iii) Extremes in climatic zones (iv) Impact of urbanization on extremes and (v) On the Relationships between Climate Extremes and Synoptic Large-scale Modes for their publication in international climate journals. These papers met with extensive discussions during the second meeting of the project held in Kathmandu, Nepal during the period 15-19 June, 2009 and received suggestions for their modification and improvement. So far the first research paper has been submitted to the International Journal of Climatology for publication and the other four are in the process of being completed.

Objectives

The main objectives of the project were:

1. to prepare and archive metadata of meteorological stations for each participating country and to build/enhance the capacity of the scientists of the participating countries for monitoring climate extreme trends
2. to study the linkage of climate extreme indices trends to global warming, the extreme weather phenomena worldwide and the natural forcing phenomena like ENSO, IOD and NAO etc.
3. to consolidate the results for research studies for their publication in international climate journals and to increase awareness of policy makers in the South Asia region, on the issues related to vulnerabilities associated with climate extremes and possible adaptation measures.

Amount received and number years supported

The Grant awarded to this project was:

US\$ 44,600 for Year1, 2007-2008

US\$ 38,000.00 for Year 2, 2008/2009

Activity undertaken

The official term of this project was from July, 2007 to June, 2009. During the year-1 of this project (ARCP2007-19NMY-Sheikh) work on collection and digitization of climate data and compilation of core climate extreme indices using an expanded network of stations was completed. First activity of the project was a week long meeting held in Kathmandu, Nepal during 21-25 April, 2008 wherein the results obtained by the participating countries met with extensive discussions and received suggestions for their modification and improvement. Additional analysis was also

decided to be carried out on South Asia region as a whole and then see the position of different participating countries in its context. Further on the advice of resource persons, five research papers were decided to be prepared for their publication in international climate journals.

The second meeting of the project was held again in Kathmandu, Nepal during the period 15-19 June, 2009. Work done on all the research papers were shared with the participants and resource persons and extensively discussed for their improvement. Some modifications / changes in the analysis and text were suggested by the resource persons. Dr. Michael Manton, one of our resource persons of the project could not make himself available in the meeting and on his advice Mr. Dean Collins of Bureau of Meteorology (BoM), Australia joined the meeting as a resource persons. Dr. Sultan Hameed was the other resource person from the Stoney Brook University, New York, USA.

Results

A total of 210 stations for temperature and 265 for precipitation (Bangladesh: Temperature (26), Precipitation (20); India: Temperature (121), Precipitation (146); Nepal: Temperature (20), Precipitation (56); Pakistan: Temperature (32), Precipitation (32) & Sri Lanka: Temperature (11), Precipitation (11)) were analyzed using all the 27 ETCCDMI (Expert Team on Climate Change Detection and Monitoring) core climate extreme indices to draw the trend changes over the stations, respective countries and over the region as a whole. Both temperature and precipitation indices are generally seen to show rising trends over the South Asia region. Detailed results are elaborated under Section 3.0 (Results and Discussion).

Relevance to APN's Science Agenda and objectives

The climate extreme Index (CEI) was first introduced in early 1996 (Karl et al 1996) with the goal to summarize and present a complex set of multivariate and multidimensional climate changes in United States so that the results could be easily understood and used in policy decisions made even by non-specialists in the field. This is the first tool developed as a framework for quantifying observed changes in climate extremes. The transfer of knowledge to the participating South Asian countries through this project falls well within the domain of APN science Agenda that supports the identification of existing methods and development of new methodologies and tools for improving the effectiveness of user communities. Sound scientific results on the trends in the core climate extreme indices and their linkages with various important climate phenomena worldwide will help greatly in the policy making processes and help the policy-makers adopt the most appropriate adaptation measures.

Self evaluation

The project activities went extremely well and the project objectives set forth were achieved successfully. The work done for South Asia region as a result of this project will certainly lead towards complementing the picture already developed for SEA/TEA and Oceania region done under a similar project in 2004 by the Bureau of Meteorology Research Centre, Australia and the work carried out over other parts of the globe.

The project proved highly useful for the South Asia Region lying in tropics, sub-tropics and partly in temperate regions, which often is subjected to climatic extremes like floods, droughts, tropical cyclone etc. This two-year project greatly enhanced the capacity building of the scientists of the participating countries in the analysis of climate extremes and strengthened the collaboration among the developing and developed countries and institutions within the South Asia region. The project is thus evaluated to be of immense importance for the region and will open up new vistas for

future research helping policy makers to take appropriate adaptation measures in the region to counteract the adverse effects of climate extremes.

Potential for further work

The work on the socio-economic impacts of the climate extremes is still a gap to be filled-in appropriately and requires at least a year long extension in the project. Sharing of the results through physical interaction with the policy makers also is a demand of the project to help them use the results more effectively and in a meaningful way.

Publications

- i. Siraj ul Islam, Nadia Rehman and Muhammad Munir Sheikh, Future change in the frequency of warm and cold spells duration over Pakistan simulated by the PRECIS Regional Climate Model, *Climatic Change*, Volume 94, Numbers 1-2 / May, 2009 DOI: 10.1007/s10584-009-9557-7
- ii. Saraju K. Baidya, M.L. Shrestha, M. Munir Sheikh, Trends in Daily Climatic Extremes of Temperature and Precipitation in Nepal, *SOHAM (Society of Hydrology and Meteorology) Journal*, Vol. 5 No. 1, March 2008.
- iii. Muhammad Munir Sheikh, Naeem Manzoor, Muhammad Adnan, Javeria Ashraf, Sultan Hameed, Michael Manton, Ahsan Uddin Ahmed, Md. Nazrul Islam, Rupa Kumar Kolli, Jayashree V. Revadekar, Madan Lal Shrestha, Saraju Kumar Baidya, G.H.P. Dharmaratna, K.H.M.S. Premalal; 2008. A report titled: "Trends in Extreme Daily Rainfall and Temperature Indices over South Asia" on the 1-year concluded project (APN2005-10-NSY) sent to APN in December, 2008.
- iv. Muhammad Munir Sheikh, Naeem Manzoor, Muhammad Adnan, Javeria Ashraf and Arshad Muhammad Khan, contribution as co-authors in chapter 3 of the book titled: *Global Environmental Changes in South Asia: A Regional Perspective*, 2010 published by Capital Publishing Company, New Delhi, India (ISBN: 81-85589-73-9).

References

The main references used in building up of this project and in the studies are listed below:

1. Alexander LV, Zhang X, Peterson TC, Caesar J, Gleason B, Klein Tank AMG., Haylock M, Collins D, Trewin B, Rahimzadeh F, Tagipour A, Ambenje P, Rupa Kumar K, Revadekar JV, Griffiths G, Vincent L, Stephenson D, Burn J, Aguilar E, Brunet M, Taylor M, New M, Zhai P, Rusticucci M, Vazquez-Aguirre JL. 2006. Global Observed Changes in daily climate extremes of temperature and precipitation, *Journal of Geophysical Research*, 111, D05109, DOI: 10.1029 / 2005JD006290.
2. Easterling DR, Meehl GA, Parmesan C, Changnon SA, Karl TR and Mearns LO. 2000. Climate Extremes: Observations, Modeling, and Impacts, *Science* 22 September 2000: Vol. 289. No. 5487, pp. 2068-2074 DOI: 10.1126/ science. 289. 5487.2068.
3. Easterling DR, Evans JL, Groisman PYa, Karl TR, Kunkel KE and Ambenje P. 2000. Observed Variability and Trends in Extreme Climate Events: A Brief Review. *Bulletin of the American Meteorological Society*, 2000.

4. Groisman PYa, Knight RW, Easterling DR, Karl TR, Hegerl GC and Razuvaev VN. 2005. Trends in Intense Precipitation in the Climate Record, American Meteorological Society, Vol.18, Issue 9 pp. 1326–1350.
5. Haylock M and Nicholls N. 2000. Trends in extreme rainfall indices for an updated high quality data set for Australia, 1910-1998. International Journal of Climatology, 20, 1533-1541
6. Intergovernmental Panel on Climate Change (IPCC), Third Assessment Report (TAR, 2001).
7. Klein Tank AMG, Peterson TC, Quadir DA, Dorji S, Zou X, Tang H, Santhosh K, Joshi UR, Jaswal AK, Kolli RK, Sikder AB, Deshpande NR, Revadekar JV, Yeleuova K, Vandasheva S, Faleyeva M, Gomboluudev P, Budhathoki KP, Hussain A, Afzaal M, Chandrapala L, Anvar H, Amanmurad D, Asanova VS, Jones PD, New MG and Spektorman T. 2006. Changes in Daily Temperature and Precipitation Extremes in Central and South Asia", J. of Geophysical Research, Vol. 111, D16105, Doi:10.1029/2005JD006316, 2006.
8. Manton MJ, Della-marta PM, Haylock MR, Hennessy KJ, Nicholls N, Chambers LE, Collins DA, Daw G, Finet A, Gunawan D, Inape K, Isobe H, Kestin TS, Lefale P, Leyu CH, Lwin T, Maitrepierre L, Ouprasitwong N, Page CM, Pahalad J, Plummer N, Salinger MJ, Suppiah R, Tran VJ, Trewin B, Tibig I and Yee D.. 2001. Trend in Extreme Daily Rainfall and Temperature in Southeast Asia and South Pacific: 1961-1998, Int. J. Clim. Vol. 21, pp 269-284.

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The Resource persons Dr. Sultan Hameed, Professor, Stony Brook University, USA; Mr. Dean Collins of Bureau of Meteorology, Australia and Dr. Michael Manton from Monash University, Australia deserve our full appreciation for the best contributions they made for the project in transferring their expertise to the scientists of South Asian countries. The Team Leaders and the other scientists from the participating countries also deserve our appreciation for their wholehearted efforts in making this project a success. The role of respective meteorological organizations in the participating countries is also acknowledged for their support in providing the raw and digitized daily climate data.

Technical Report

Preface

The two-year APN project: "Development and Application of Climate Extreme Indices and Indicators for Monitoring Trends in Climate Extremes and Their Socio-economic Impacts in South Asian Countries" proved to be a useful source in quantifying the trends in statistical based climate extremes such as warm days, warm nights, cool days, cool nights, very wet days and extremely wet days etc. over South Asia region (Bangladesh, India, Nepal, Pakistan and Sri Lanka). The results drawn on individual country basis as well as on South Asia region as a whole and for some key regions are extremely useful in devising strategies to minimize the adverse impacts of climate extremes.

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1.0 Introduction

The Intergovernmental Panel on Climate Change (IPCC) projected in its Third Assessment Report (TAR 2001) that over the period 1990 to 2100; the average global temperature would increase by 1.4 to 5.8 °C and would be subject to increase in frequency and intensity of extreme climate events (floods, droughts, extreme temperatures etc.). Later a study: "Extreme Weather on the rise" released by World Meteorological Organization (WMO) in 2003 said that the world was experiencing record number of extreme weather events such as droughts and tornadoes. Laying the blame firmly at the feet of global warming, the Agency warned that the number of extreme events could continue to increase. Citing examples, the WMO said that 562 tornadoes that hit the United States in May, 2003 was a record far higher than the previously recorded monthly peak of 399 in June, 1992. The South Asia region was a no exception to that and witnessed too a good number of weather extremes in the recent past. A catastrophic cyclonic storm in Bangladesh left 100,000 people dead in 1991. Pakistan faced the previous century's worst flood in Jhelum River in 1992. There was a severe urban storm flooding in Lahore, the Capital city of Punjab Province, during August 1996, the wettest month on record with 437 mm of rainfall occurring during a 3-day period from 23-25 August. Dokriani glacier in the Himalayas, India retreated at a record pace of 66 feet in 1998 despite a severe winter in that year. In 1999, a severe cyclonic storm hit the coastal areas of Pakistan and India and brought in its wake, huge devastation to the coastal areas of both the countries. Pakistan faced the history's worst drought during the period 1998-2001. A record level of 620 mm of rainfall fell in Islamabad, Pakistan one in just 10 hours brought in its wake huge urban storm flooding in the famous Lai Nullah flowing through the twin cities of Rawalpindi and Islamabad and caused catastrophic losses to life and property. A pre-monsoon heat wave that hit India in 2003 caused the peak temperatures to reach 45 to 49 °C and killed more than 1400 people. In Sri Lanka, heavy rains from the Tropical Cyclone 01B during May, 2003 exacerbated the already wet conditions, caused flooding and landslides and resulted in more than 300 fatalities. In the year 2004, Pakistan received very low monsoon rains leaving Tarbela Dam on Indus River some 60 feet below its Maximum Conservation Level (MCL) of 1550 SPD (Survey of Pakistan Datum) which previously had not come across such a situation. Starting on July 15, 2004, Bangladesh faced the worst ever flood in its history, and broke the record of flooding in 1988. Two third of the country went under water.

Such a situation with regard to the climate extremes which occurred mostly during the last decade of the previous century, the warmest decade ever recorded, over the globe and particularly in the South Asia region provided a sufficient basis for a substantial research activity to be initiated aiming at analyzing the daily climate data to assess trends and changes in climate extreme indices and study their impacts on different socio-economic sectors. The idea of initiating such a project for south Asia was fostered also by the general consensus within the climate community that any change in the frequency and intensity of climate extremes would have profound impacts on different socio-economic sectors.

The project was thus a need for the South Asia region and was jointly initiated by GCISC and PMD in line with the project already completed for SEA/TEA and Oceania region by the Bureau of Meteorology Research Centre, Australia in 2004.

2.0 Methodology

2.1 Project Aims

Extreme weather and climate extremes have received attention in the last few years, due to the often large loss of human life and increasing costs associated with them (Karl and Easterling, 1999). These can have major impacts on society, the economy and the environment (Manton M.J. et al. 2001). The purpose of this APN project is to get a set of indices and indicators to monitor the trend of climate extremes over the South Asia region and to help the individual participating countries to (i) assess the expected corresponding changes on water resources, agricultural production, biodiversity, human health etc; (ii) prepare a set of recommendations for appropriate adaptation measures and (iii) conduct research using the outcome of the project results. This information is a prerequisite requirement to add to the understanding of the national policy makers in the region to develop appropriate adaptation strategies leading towards the mitigation of adverse impacts of climate extremes.

2.2 Data used and selection criteria for meteorological stations used

High quality time series data of key climate variables (daily rainfall totals and maximum and minimum temperature) of 265 precipitation and 210 temperature stations were used across South Asia from a network of meteorological stations in the participating countries. All the 27 ETCCDMI (Expert Team on Climate Change Detection and Monitoring Indices) core climate indices were used to monitor their trends. The selection criteria of stations followed Manton et al. 2001 and used the guidelines: The records are as long as possible and include preferably the standard reference period of 1971-2000 and not more than 20% of the daily values are missing in each year; the stations are of high quality, preferably non-urban stations and well maintained; the station, in most cases, has a documented history of changes such as those involving instrumentation and observational practices etc. and the station has been located at a single site during the period of record. Daily temperature data for the period 1971-2000 and daily precipitation data for the 1961-2000 periods are used. These periods represent the most common periods over which participating countries had digitized data available.

2.3 Quality control and homogeneity testing of the data used

In the process of preparing datasets for the model RCLimDex (Model used for developing climate extreme indices), outlier data was identified by using 3 (sigma) SD levels. A large number of suspect data for Tmax and Tmin was thus identified for different stations. The obvious ones were immediately sorted out as per instructions provided in the manual of RCLimDex (for example, when Tmin was found greater than or equal to Tmax, the data were replaced by default -99.9). A record of all such suspect data was maintained for future reference and potential data checking with the respective meteorological organizations.

All the data sets were checked for the homogeneity and quality control for the outliers, such as, $T_{max} < T_{min}$, sudden jumps in the series, and repeated values. Exploratory data analysis was done for each station individually which allowed identification of some outliers and gave an indication of potential in homogeneities and missing values in the data sets. Some of the major gaps were removed by possible available documentations in the meteorological organizations.

2.4 Analytical or statistical techniques employed

27 climate extreme indices based on those recommended by ETCCDMI (Alexander et al. 2006) are used, of which, 16 related to temperature and 11 to precipitation. A full description of the indices is provided in Table 1.

Table 1: Extreme climate indices used in this study

Code	Indicator name	Definition	UNITS
FD0	Frost days	Annual count when TN (daily minimum temperature) <	Days
SU25	Summer days	Annual count when TX (daily maximum temperature) > 25°C	Days
TR20	Tropical nights	Annual count when TN (daily minimum temperature) >	Days
GSL	Growing season length	Annual count between first span of at least 6 days with TG > 5°C and first span after 1 st July of 6 days with TG < 5°C, where TG is daily mean temperature (TX + TN)/2	Days
TXx	Max Tmax	Annual maximum value of daily maximum temp	°C
TNx	Max Tmin	Annual maximum value of daily minimum temp	°C
TXn	Min Tmax	Annual minimum value of daily maximum temp	°C
TNn	Min Tmin	Annual minimum value of daily minimum temp	°C
TN10p	Cool nights	Percentage of days when TN < 10th percentile	Days
TX10p	Cool days	Percentage of days when TX < 10th percentile	Days
TN90p	Warm nights	Percentage of days when TN > 90th percentile	Days
TX90p	Warm days	Percentage of days when TX > 90th percentile	Days
WSDI	Warm spell duration indicator	Annual count of days with at least 6 consecutive days when TX > 90th percentile	Days
CSDI	Cold spell duration indicator	Annual count of days with at least 6 consecutive days when TN < 10th percentile	Days
DTR	Diurnal temperature range	Annual mean difference between TX and TN	°C
ETR	Extreme temperature range	Annual difference between highest TX and lowest TN	°C
R10	Number of heavy precipitation days	Annual count of days when rainfall ≥ 10mm	Days
R20	Number of very heavy precipitation days	Annual count of days when rainfall ≥ 20mm	Days
RX1day	Maximum 1-day precipitation amount	Annual maximum 1-day precipitation	mm
Rx5day	Maximum 5-day precipitation amount	Annual maximum consecutive 5-day precipitation	mm
R95p	Very wet days	Annual total PRCP when daily rainfall > 95 th percentile	mm
R99p	Extremely wet days	Annual total PRCP when daily rainfall > 99 th percentile	mm
PRCPTOT	Annual total wet-day precipitation	Annual total precipitation in wet days (daily rainfall ≥ 1mm)	mm
SDII	Simple daily intensity index	Annual total precipitation divided by the number of wet days (defined as daily rainfall ≥ 1.0mm) in the year	mm/day
R95PT	Annual contribution from very wet days	(R95p/PRCPTOT) x 100	%
CDD	Consecutive dry days	Maximum number of consecutive days with rainfall <1mm	Days
CWD	Consecutive wet days	Maximum number of consecutive days with rainfall ≥ 1mm	Days

The Rnn index (Annual count of days when precipitation is greater than a user defined threshold) is not used as because of diversified rainfall patterns, no threshold can be fixed for the whole region. The Ice Days index (ID0) (Annual count of days when maximum temperature is less than 0°C is also not considered because this extreme is rare in tropical, subtropical and most temperate parts of South Asia. However, two additional indices which are not included in the standard definitions of indices are used. These are: Extreme Temperature Range (ETR) and annual contribution from very wet days (R95PT) and not directly calculated by RclimDex (Alexander L.V. et al, 2006) are

included in the analysis with the definitions given below and also described above in Table 1:

$$\text{ETR} = \text{TXx} - \text{TNn}$$

and $\text{R95PT} = (\text{T95P}/\text{PRCPTOT}) \times 100$

Spatial averages, temporal trends and frequency distribution analysis form the basis of this study. Geographical patterns of trends in each index (Manton et al. 2001) are determined by calculating trends for all stations across the region. Significant changes are determined using the Mann-Kendall (non-parametric) Test at the 5% level of significance. Temporal time series are calculated for the South Asia region as a whole using simple averages calculated over all available station series, rather than an area-weighted average method. Similar studies have estimated that regional trends calculated using simple averages agree to within 10% of trends calculated using more complex area-weighted methods (Klein Tank et al. 2006).

Frequency distributions of regionally-averaged temperature (precipitation) indices are determined for the periods 1971-1985 (1961-1980) and 1986-2000 (1981-2000). The Mann Whitney (non-parametric) test is then applied to these distributions to test the significance of the shift in means. This method does not assume a distribution for the residuals and is robust to the effect of outliers in the series (Alexander et al. 2006).

3.0 Results & Discussion

Sixteen temperature indices are used to assess changes in temperature extremes in the South Asia region. These can be grouped into absolute, percentile-based, threshold and durational indices (Alexander et al. 2006) and indices are either discussed individually or in groups. The number of stations showing positive and negative trends for each index is shown in Table 2, along with the number of stations with significant trends given in parenthesis. Table 3 shows long-term regional averages for the temperature indices over two periods: 1971-1985 and 1986-2000. The p-value is also given for the significant shift in mean between the periods. Besides trends worked out in extreme daily temperature and precipitation indices across South Asia, the project also focuses on some specific regions individually, in particular the island of Sri Lanka, the Tropical region (5°N to 23.5°N), Eastern Himalayas (Nepal), Greater Himalayas (northern Pakistan above 35°N) and Thar Desert, spanning the border between Pakistan and India.

Table 2: Number of stations showing positive (+) and negative (-) trends in climate extreme indices over South Asia. Figures in parentheses () show number of stations with significant changes at 95% level. The South Asia (SA) average trend values are also provided (units given in Table 1). Asterisks denote significant trends at 95% level.

Index	Bangladesh		India		Nepal		Pakistan		Sri Lanka		Average Trend over SA
	+	-	+	-	+	-	+	-	+	-	
TXx	13 (2)	12 (1)	88 (33)	32 (5)	18 (4)	2 (0)	18 (6)	14 (1)	10 (4)	1 (0)	0.01
TXn	12 (0)	13 (0)	68 (32)	49 (14)	13 (4)	6 (0)	15 (2)	16 (4)	8 (6)	1 (0)	-0.02 *
TNx	13 (0)	12 (1)	59 (22)	60 (14)	13 (0)	6 (0)	5 (0)	24 (4)	10 (3)	1 (0)	-0.01
TNn	12 (0)	12 (2)	75 (28)	42 (13)	13 (2)	7 (1)	24 (5)	7 (0)	10 (4)	1 (0)	0.01
TX10p	0 (0)	6 (2)	30 (8)	90 (47)	2 (0)	17 (9)	12 (2)	18 (2)	2 (1)	9 (8)	-0.14 *
TX90p	6 (2)	1 (0)	80 (37)	39 (15)	17 (13)	3 (1)	17 (4)	15 (4)	10 (7)	1 (1)	0.16 *
TN10p	2 (1)	5 (1)	24 (10)	97 (65)	6 (0)	14 (8)	15 (2)	16 (5)	1 (0)	10 (8)	-0.19 *
TN90p	4 (1)	3 (0)	83 (43)	37 (13)	16 (3)	4 (0)	15 (3)	16 (3)	10 (8)	1 (0)	0.11 *
CSDI	3 (0)	4 (1)	26 (5)	94 (53)	9 (1)	11 (6)	18 (1)	12 (4)	2 (0)	9 (2)	-0.17 *
WSDI	5 (0)	2 (0)	76 (24)	43 (10)	16 (7)	4 (1)	15 (2)	17 (1)	9 (5)	2 (0)	0.10
SU25	22 (4)	2 (0)	78 (35)	43 (6)	17 (11)	3 (0)	20 (5)	11 (5)	9 (2)	2 (0)	0.20 *
TR20	12 (0)	13 (0)	68 (32)	49 (14)	13 (4)	6 (0)	15 (2)	16 (4)	8 (6)	1 (0)	0.04
DTR	18 (3)	7 (0)	53 (24)	68 (35)	15 (3)	4 (1)	17 (8)	15 (6)	4 (2)	7 (2)	0.00
FD0	0 (0)	1 (0)	8 (1)	5 (2)	1 (0)	4 (1)	10 (1)	16 (6)	1 (1)	0	0.03
ETR	13 (1)	11 (0)	61 (16)	60 (16)	11 (4)	8 (2)	12 (1)	19 (1)	5 (0)	6 (1)	0.01
GSL	0	0	0	3 (0)	0	0	9 (0)	4 (0)	0	0	1.25
CDD	2 (0)	17 (1)	54 (2)	89 (9)	13 (0)	42 (5)	10 (0)	21 (1)	8 (5)	3 (0)	-0.51 *
CWD	9 (1)	10 (0)	86 (4)	57 (3)	25 (9)	30 (4)	19 (1)	13 (1)	2 (0)	9 (1)	0.01
RX1day	10 (0)	8 (1)	77 (3)	66 (1)	22 (2)	32 (2)	20 (2)	11 (0)	4 (0)	7 (0)	0.08
RX5day	10 (0)	10 (0)	77 (5)	63 (0)	28 (2)	27 (1)	22 (2)	8 (0)	5 (0)	6 (0)	0.07
R95p	12 (0)	8 (0)	78 (9)	64 (1)	32 (2)	23 (2)	21 (3)	11 (2)	3 (0)	7 (1)	0.62
R99p	11 (0)	9 (1)	81 (4)	61 (1)	25 (1)	30 (2)	18 (2)	12 (1)	5 (0)	6 (0)	0.20
R10mm	16 (0)	4 (0)	74 (6)	66 (5)	29 (5)	23 (2)	23 (7)	8 (1)	1 (0)	10 (4)	0.09 *
R20mm	14 (1)	6 (0)	64 (4)	80 (2)	28 (5)	27 (2)	23 (4)	8 (1)	2 (0)	9 (1)	0.05 *
PRCPTOT	14 (2)	5 (0)	73 (6)	69 (2)	33 (2)	23 (0)	22 (7)	10 (1)	2 (0)	9 (4)	2.97 *
SDII	10 (1)	8 (3)	60 (2)	80 (15)	24 (6)	31 (10)	19 (0)	13 (0)	8 (1)	3 (0)	-0.02 *
R95PT	10 (0)	10 (1)	81 (7)	62 (3)	30 (2)	25 (3)	19 (1)	13 (1)	7 (0)	4 (1)	0.02

Behaviour of Trends in extreme temperature and precipitation indices over South Asia are discussed below:

3.1 Temperature indices over South Asia

An increase in the warmest day temperature of the year (TXx) is seen at most stations across India, Nepal and Sri Lanka, whereas the changes are more mixed over Pakistan and Bangladesh. The percentages of stations showing an increase are around 56%, 73%, 90%, 52%, and 99% respectively for Pakistan, India, Nepal, Bangladesh and Sri Lanka. Many of the warming trends over Nepal are significant, compared to non-significant changes in the upper Himalayan parts of Pakistan. Southern and central parts of India below about 18°N have stronger increases in TXx relative to other parts. The northwestern parts of India and adjoining northeastern part of Pakistan (the monsoon dominated region) show decreasing trends at most stations. The coldest night temperature of the year (TNn) also shows increasing trends at most

stations over India, Nepal, Pakistan and Sri Lanka but mixed trends are seen over Bangladesh. The Greater Himalayan region of Pakistan shows a decreasing trend though non-significant at most stations, whereas over Nepal, a non-significant increasing trend is most common. These changes are shown in Fig. 1 (a & b).

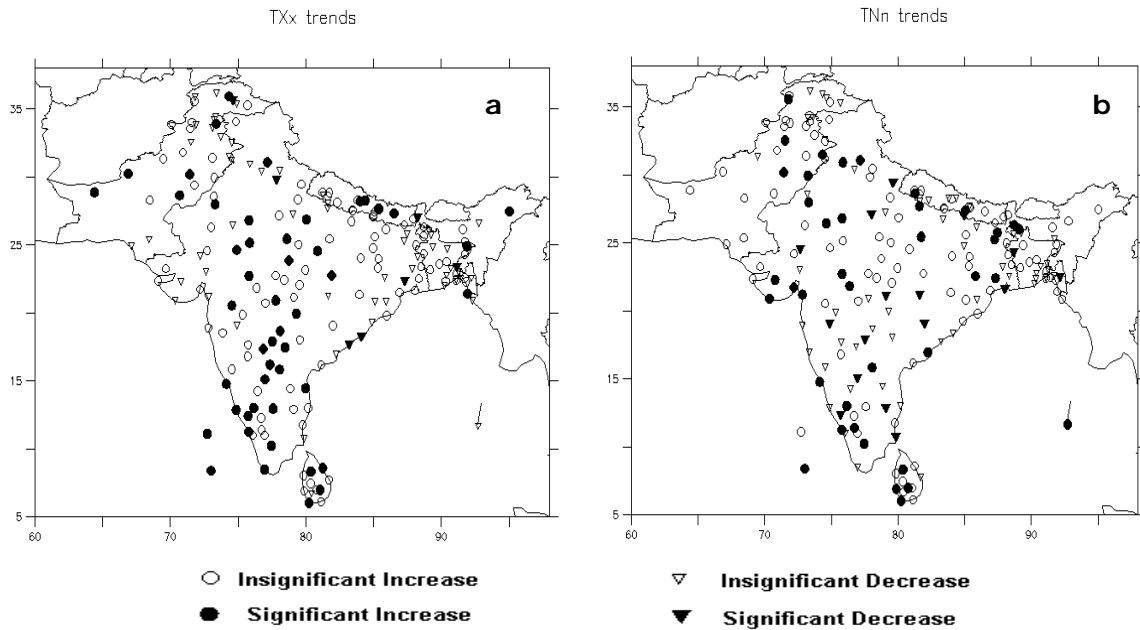


Fig. 1: Trends in (a) TXx and (b) TNn during the period 1971-2000

TXx and TNn both show a very little increasing trend averaged across the region. Consequently there is virtually no trend in the regionally-averaged ETR. Frequency distribution analysis shows a shift toward higher TNn values in the later part of the period i.e. 1986 to 2000, compared to the period 1971-1985. However, shifts in the mean are non-significant for both TXx and TNn. These changes are shown in Fig. 2 (a & b).

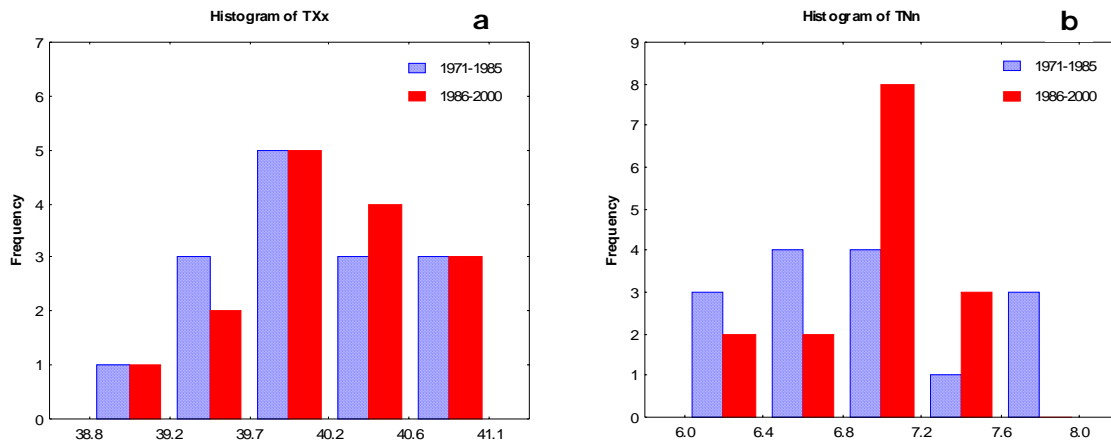


Fig. 2: Frequency analysis for (a) TXx and (b) TNn averaged over South Asia

The indices of coldest day temperature of the year (TXn) and warmest night temperature of the year (TNx) have both increased in Nepal at around 68% of stations, whereas mixed changes are found over Pakistan for TXn but a decrease in TNx at around 83% of stations. This suggests quite a different picture of temperature changes over Nepal and Pakistan. Further, a significant decrease is observed in TNx at almost all stations in the Greater Himalayan region including the Karakoram Range, the abode of glaciers. India and Bangladesh show mixed results for both indices as shown in Fig. 3 (a & b).

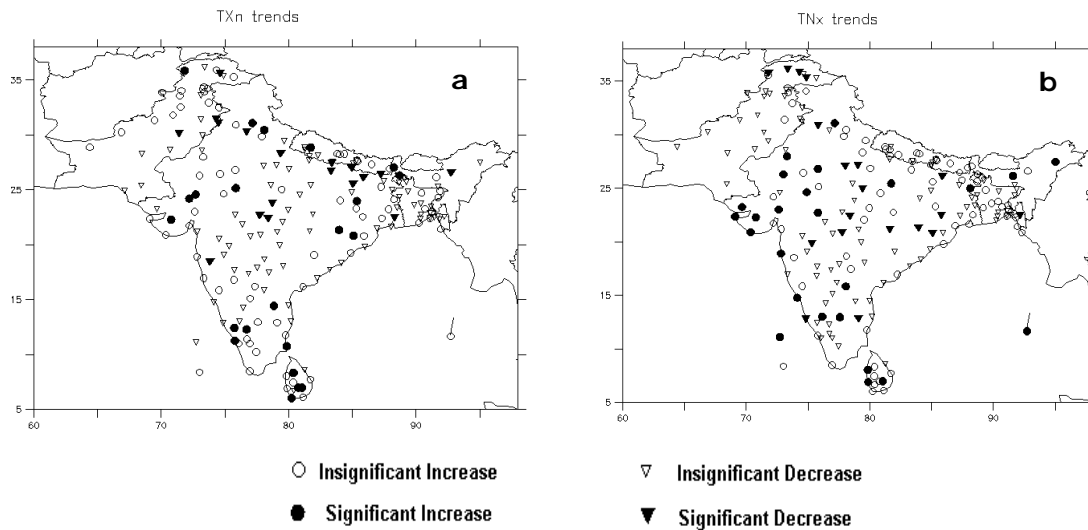


Fig. 3: Trends in (a) TXn and (b) TNx during the period 1971-2000

The frequencies of cool nights (TN10P) and cool days (TX10P) have generally decreased across the region whereas their warm counterparts i.e. warm nights (TN90P) and warm days (TX90P) have mostly increased. Over the Greater Himalayan part of Pakistan above 35°N, the percentage of warm nights has decreased, while over Nepal it has increased. The daytime trends (TX10P and TX90P) generally have the same sign as their nighttime counterparts. This suggests that the eastern Himalayas have warmed more than the western Himalayas. The regional trends show strong increases in the percentages of warm days and nights, and strong decreases for percentages of cold days and nights. These changes are shown in Fig. 4 (a-d).

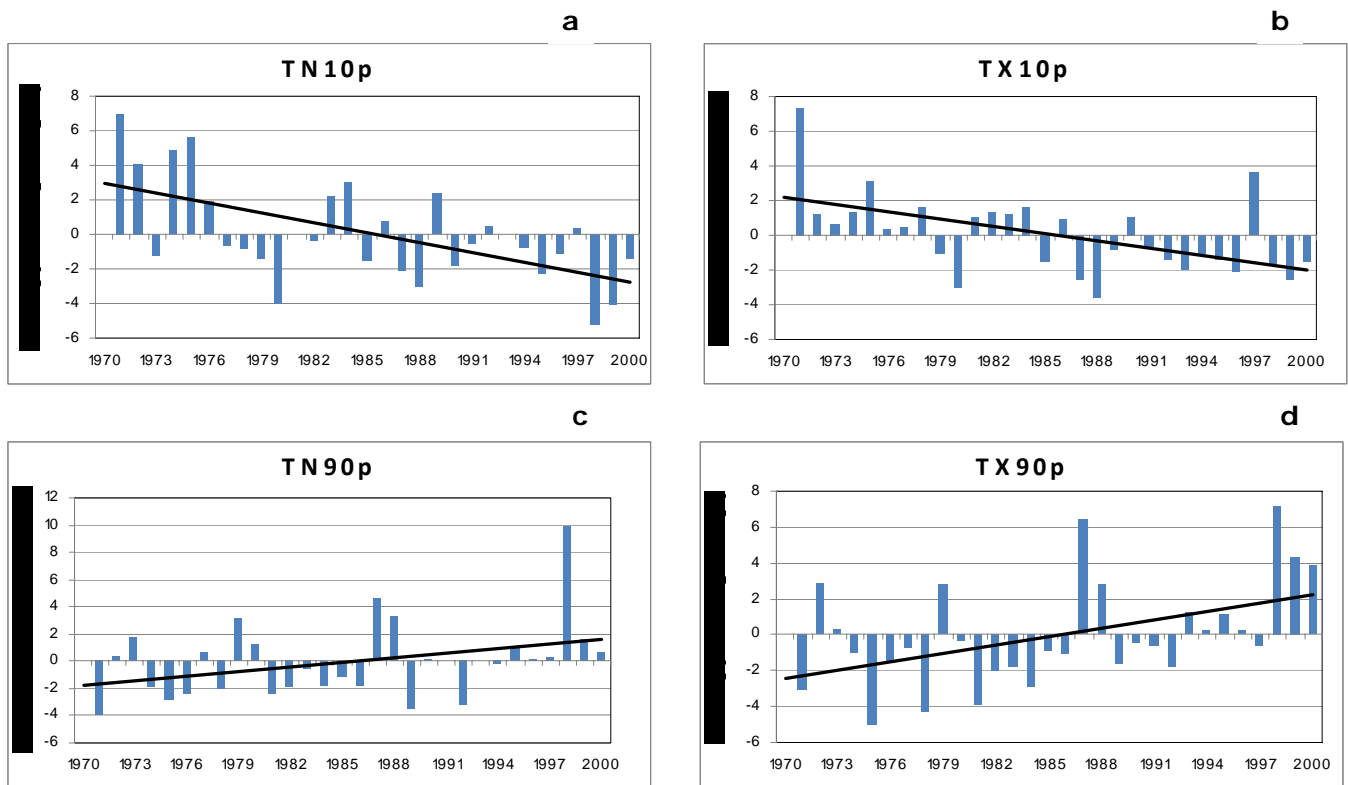


Fig. 4: Trends in (a) TN10P (b) TX10P, TN90P and TX90P averaged over South Asia. Frequency distribution analysis shows a significant increase in TX90P but non-significant increase in TN90P. TX10P and TN10P show significant decreases for the period 1986-2000 compared to 1961-1985. This picture for South Asia is consistent with global analyses showing the annual percentage of warm nights (cold

nights) to have increased (decreased) over the past few decades (Alexander et al. 2006).

The frost days index (FDO) is defined as the annual count of days when daily minimum temperature is less than 0°C. Only a few stations over the region actually record frost. Generally FDO shows increasing trends over the Greater Himalayas in Pakistan and decreasing trends over the western border of Pakistan. Mostly decreasing trends are found over northwestern parts of India for the few stations for which FDO could be calculated.

The annual count of days when daily maximum temperature exceeds 25°C (SU25) is seen to have increased at most stations across the region. The percentage of stations showing positive trends over Nepal (85%) is higher than Pakistan and India both around 65%. Around 92% and 82% of stations show warming trends over Bangladesh and Sri Lanka respectively. Nepal has increasing trends for 19 stations, with 8 significant, whereas Pakistan has increasing trends over 20 stations, with 5 significant. The Greater Himalayan region has a significant decreasing trend at three stations and only one with a significant positive trend. The southern tip of India and Sri Lanka show significant increasing trends at most stations. The regional average of SU25 has increased significantly over the whole period of analysis (1971-2000).

The frequency of tropical nights (TR20) has increased at most stations over Nepal, Sri Lanka and the southern tip of India below around 15°N. Nepal has increasing trends at 13 stations, with 4 significant, whereas the Greater Himalayan region has a decreasing trend at 5 stations, with 4 significant. Sri Lanka has increasing trends at 8 out of 9 stations, with 6 significant. Despite these coherent changes at the sub-regional level, TR20 shows no trend when averaged across South Asia.

Generally, the cold spell duration index (CSDI) displays decreasing trends across the region, contrary to the warm spell duration index (WSDI), showing increasing trends, except over Pakistan where some 53% of stations show a decreasing trend. These changes are shown in Fig. 5 (a & b). The regional average of CSDI has significantly decreased, whereas for WSDI it has a slight increasing trend.

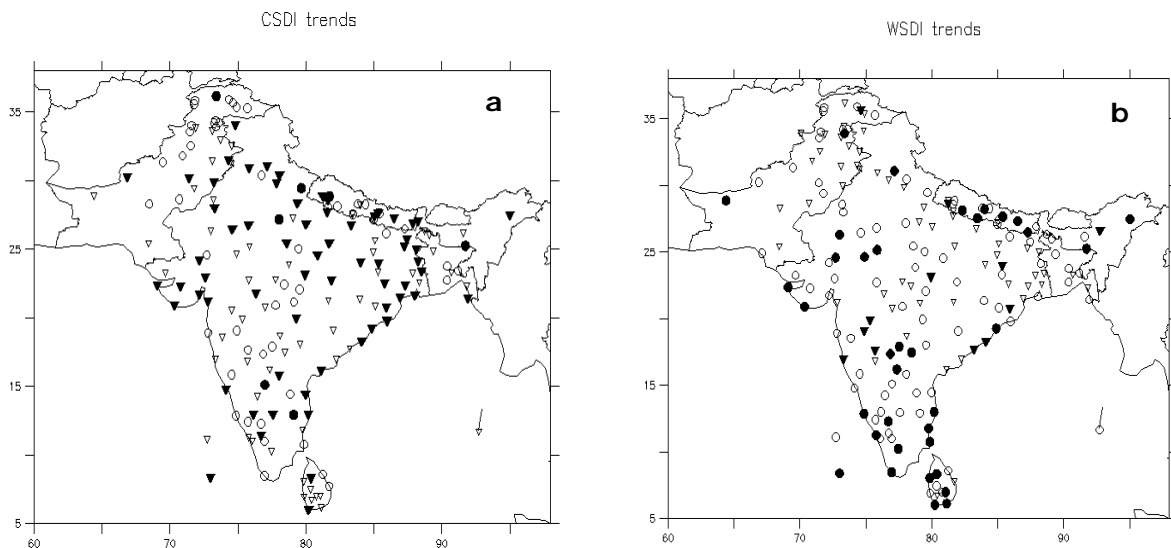


Fig. 5: Trends in (a) CSDI and (b) WSDI during the period 1971-2000

The standard definition of growing season length (GSL) could be calculated only for a few northern stations in South Asia. The climate of the remaining stations is too warm throughout the year for the daily mean temperature to fall below the required threshold. Generally there are increasing trends in GSL over northern Pakistan and along the western border. In contrast, two stations in northwestern India show non-significant decreases.

Annual mean diurnal temperature range (DTR) has increased over Bangladesh and Nepal but decreased over India and Sri Lanka, with mixed changes over Pakistan. The increase in DTR is especially strong over almost all stations in the Greater Himalayan region, indicating that daytime temperatures have increased more than nighttime temperatures. The DTR increase is also high in the southern tip of India below 20°N, with many stations observing significant changes (Fig. 6). This is probably related to the strong rainfall decline in this region.

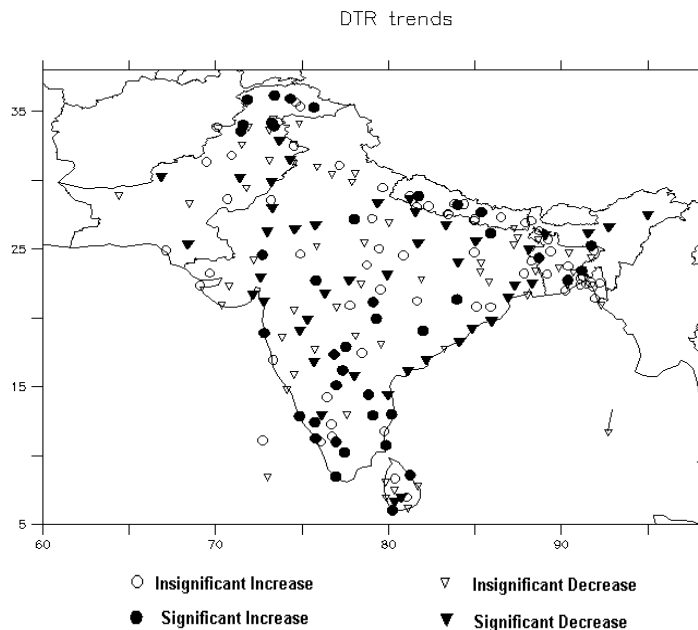


Fig. 6: Trend in Diurnal temperature range during the period 1971-2000

Table 3: Frequency distribution analysis for temperature indices for two periods: 1971-1985 and 1986-2000. P-value is for shift in mean with asterisks (*) denoting significant shifts at 95% level.

Indices / Periods	Mean (1971-1985)	Mean (1986-2000)	p-value
TXx	40.02	40.19	0.33
TNn	6.89	6.87	0.98
ETR	32.88	33.13	0.55
TNx	28.13	28.08	0.55
TXn	17.84	17.68	0.31
TN10p	11.24	8.77	0.04*
TN90p	8.94	10.72	0.12
TX10p	11.37	9.24	0.01*
TX90p	8.58	11.42	0.01*
FDO	4.06	4.33	0.58
SU25	293.99	297.77	0.04*
TR20	189.69	189.80	0.92
CSDI	7.16	4.93	0.21
WSDI	5.67	7.77	0.29
DTR	11.15	11.15	0.63
GSL	360.97	361.22	0.00

3.2 Precipitation indices over South Asia

Eleven precipitation indices were used to investigate changes in extreme precipitation indices in the South Asian region. The spatial distribution of stations over the region is quite uniform over India and Pakistan. However, the density of stations for smaller countries of Bangladesh and Nepal are higher by a factor of around three compared to Pakistan and India. Changes in the precipitation indices are discussed here separately or in appropriate groupings. The number of stations showing positive and negative trends for each precipitation index is shown in Table 2, and the long-term regional averages for the periods 1961-1980 and 1981-2000 are given in Table 4.

The consecutive dry days (CDD) index has generally decreased across the region except in Sri Lanka. The decrease is stronger over Nepal and Bangladesh with around 76% and 89% of stations showing a decline. In contrast, consecutive wet days (CWD) have increased over most of India and Pakistan but changes are more mixed than for CDD. Sri Lanka shows significant increases in CDD along the west coast. Similar trends in CDD are seen for the islands of the Aegean Sea and Cyprus (Kostopoulou and Jones 2005), indicating that southern Mediterranean areas, and especially the islands, are becoming more prone to drought and desertification (Brandt and Thornes 1996). These changes are shown in Fig. 7 (a & b). The regional average of CDD has dropped significantly whereas there is virtually no trend in CWD.

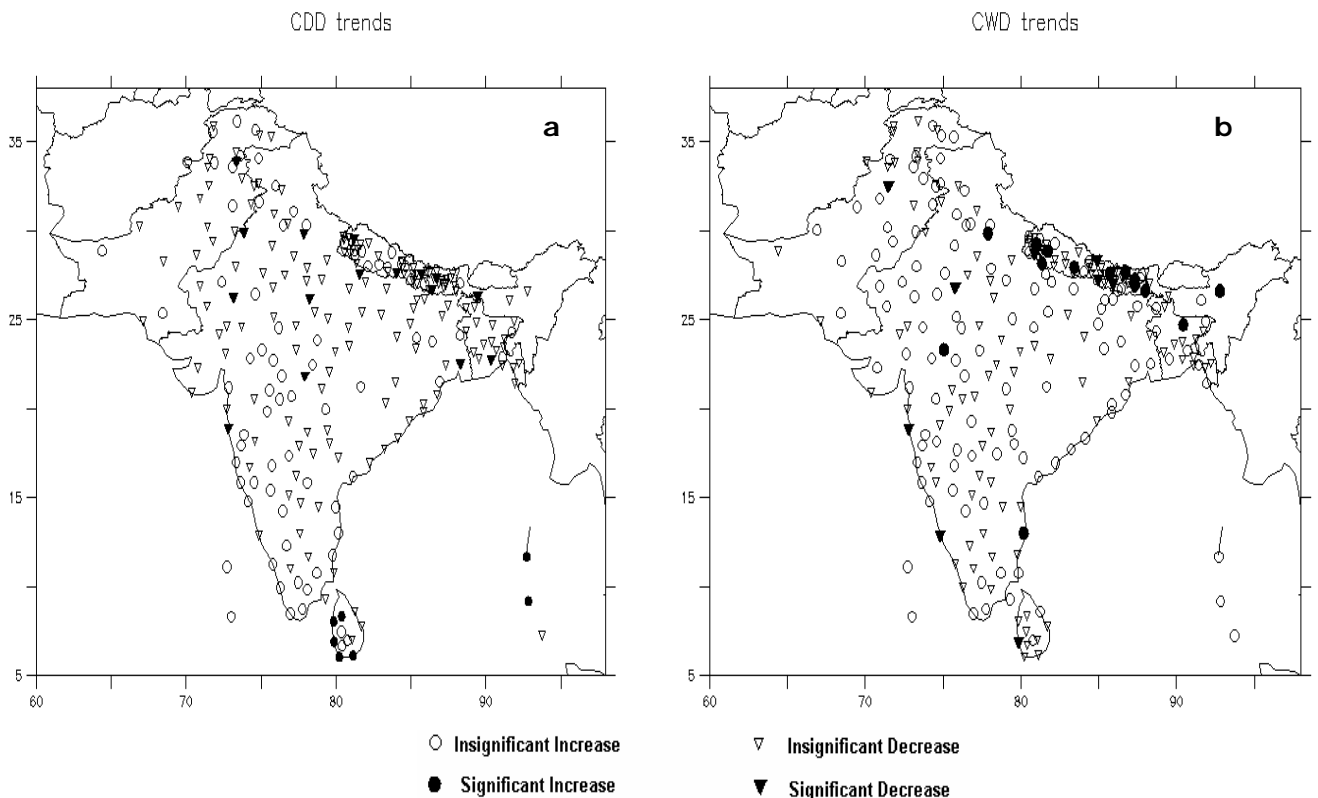


Fig. 7: Trends in (a) CDD and (b) CWD for the period 1961-2000

A simple measure of daily rainfall intensity (SDII) is defined as annual total wet day precipitation divided by the number of wet days. SDII has increased in many parts of the world e.g. parts of Europe, South Africa, USA and Australia (Kostopoulou and Jones 2005). In this study, SDII is seen to have decreased over much of India and Nepal, whereas over Bangladesh and Pakistan, it has increased at around 70% of stations. Changes in total precipitation (PRCPTOT) are mixed across the South Asia region, with some important sub-regional consistencies. Most stations on the east coast of India and in Bangladesh show increases, while declines are most common in

southern India and Sri Lanka. South Asia as a whole shows an increase in PRCPTOT and a decrease in SDII index, suggesting that the number of wet days have increased across the region resulting in lower daily rainfall intensity. Frequency distribution analysis shows a significant increase in PRCPTOT during the period 1981-2000 compared to 1961-1980 whereas an insignificant decrease is observed in SDII in the later half of 1961-2000.

The annual count of days with daily precipitation greater than 10mm (R10mm) has increased in many parts of the world (Alexander et al. 2006; Osborn et al., 2000). There are mixed changes in R10mm across South Asia but some sub-regional consistencies are evident. Stations in Pakistan and northwestern India mostly show an increase in the number of heavy precipitation days, as do stations in Bangladesh and on India's east coast. However, southern India and Sri Lanka show consistent patterns of decline. Similar results are obtained for the R20mm index. Regionally-averaged, the trend is positive for both indices. The number of heavy precipitation days is seen usually decreased during El Niño years and increased during La Niña years. However, the relationship with El Niño appears weaker during the 1990s, the warmest decade of the previous century as shown in Fig. 8 (a & b).

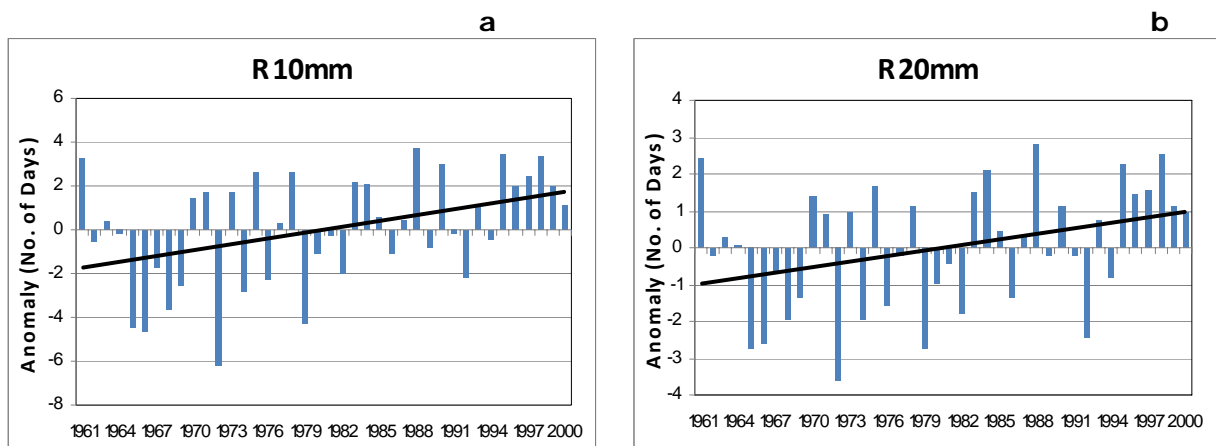


Fig. 8: Trends in (a) Rx1day and (b) Rx5day Precipitation averaged over South Asia

Changes in the indices of maximum one-day precipitation (RX1day) and five-day (RX5day) precipitation totals are not spatially coherent. Stations in Pakistan show a bias toward positive trends in these indices but generally results are mixed throughout South Asia, with spatial consistency only occurring at relatively small scales. This is possibly because these indices are based on only one extreme rainfall event per year on the average and consequently show more noise than other rainfall indices. When averaged over the whole of South Asia, both RX1day and RX5day show a slight increase over the period 1961-2000.

Changes in the contribution to annual rainfall from very wet days (R95PT) could have significant social impacts (Alexander et al. 2006). As for other extreme rainfall indices, this index only shows spatial consistency at short spatial scales, with very few significant changes observed across the dataset. Over the whole South Asia region, R95PT shows a weak increase over 1961-2000 but this trend is dominated by large inter-annual fluctuations. The frequency distribution analysis of precipitation indices is consolidated in Table 4. Most of the precipitation indices except CDD have increased in the second half of the period i.e. 1981-2000 compared to 1961-1980.

Table 4: Frequency distribution analysis for precipitation indices for two periods: 1961-1980 and 1981-2000. P-value is for shift in mean with asterisks (*) denoting significant shifts at 95% level.

Indices / Periods	Mean (1961-1980)	Mean (1981-2000)	p-value
CDD	88.96	75.93	0.00*
CWD	10.86	10.95	0.63
PRCPTOT	1344.45	1418.67	0.04*
SDII	16.61	16.35	0.14
R10mm	36.66	38.69	0.02*
R20mm	21.12	22.29	0.03*
RX1day	111.40	113.86	0.14
RX5day	212.83	214.94	0.69
R95p	349.10	369.99	0.06
R99p	109.93	115.45	0.21
R95PT	24.06	24.75	0.14

3.3 Trends in climate extremes over specific regions of South Asia

Changes in climate extremes are also computed to see their impacts over the specific regions of South Asia. These regions include: Sri Lanka, as an island country in the equatorial region; the Tropical region from 5°N to 23.5 °N; the Greater Himalayas above 35°N, comprising parts of the mountain ranges of Karakoram, Hindukush and Himalayas; the Eastern Himalayas comprising the whole of Nepal and the Thar Desert spanning the border between Pakistan and India. Fig. 9 shows the areas demarcated for the above regions. The trend changes worked out for the above regions both for temperature and precipitation are shown in Tables 5 & 6 respectively.

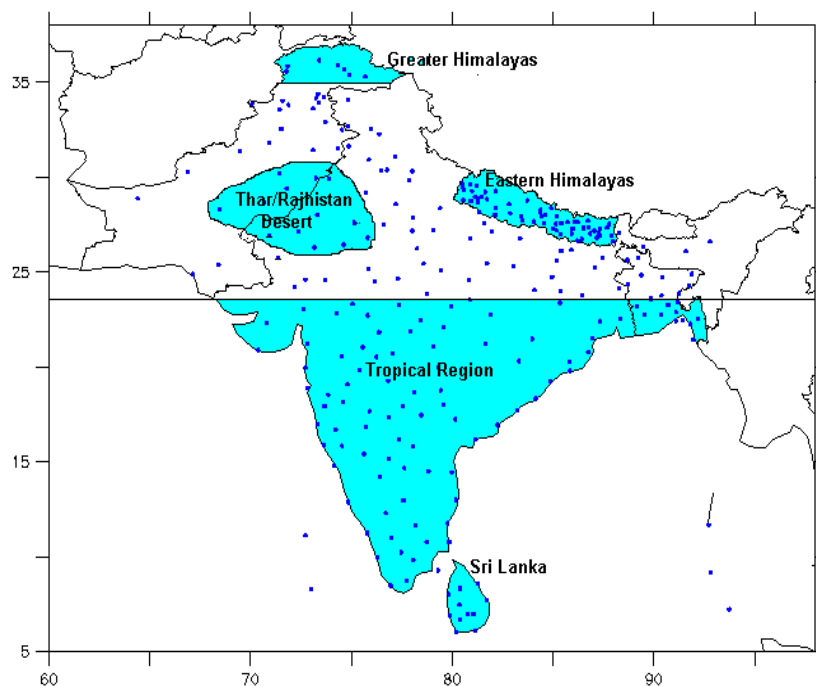


Fig. 9: Map showing the specific regions in South Asia

Table 5: Trends of Temperature Indices for specific regions over South Asia (units given in Table 1). Asterisks (*) denote significant trends at 95% level.

Index	Overall	Sri Lanka	Tropical Region (excluding Sri Lanka)	Greater Himalayan Region	Eastern Himalayan Region	Thar / Rajasthan desert region
CSDI	-0.17*	-0.08*	-0.16*	0.11	-0.38 *	-0.33*
WSDI	0.10	0.42 *	0.05	0.14	0.41*	0.09
DTR	-0.00	-0.01	-0.01	0.08*	0.02*	-0.02
ETR	0.01	-0.03	0.01	0.09	-0.08	0.05
SU25	0.20*	0.19	0.11	0.40	1.10*	0.39*
TN10p	-0.19*	-0.25*	-0.20*	0.15*	-0.29*	-0.29*
TN90p	0.12*	0.33*	0.11	-0.13	0.14	0.17*
TNn	0.01	0.04*	0.00	-0.01	0.02	0.05*
TNx	-0.01	0.01*	0.00	-0.01*	0.02	0.02
TR20	0.04	0.26	0.10	-0.43*	0.70*	0.17
TX10p	-0.14*	-0.24*	-0.14*	-0.03	-0.22*	-0.02
TX90p	0.16*	0.44*	0.14*	0.17*	0.41*	0.10
TXn	-0.02*	0.02	-0.01	-0.03	-0.04*	-0.01
TXx	0.01	0.04*	0.00	0.08	0.06*	0.05*

Table 6: Trends of Precipitation Indices for specific regions over South Asia (units given in Table 1). Asterisks (*) denote significant trends at 95% level.

Index	Overall	Sri Lanka	Tropical Region (excluding Sri Lanka)	Greater Himalayan Region	Eastern Himalayan Region	Thar / Rajasthan Desert Region
CDD	-0.52*	0.23*	-0.60*	-0.09	-0.25	-0.67*
CWD	0.01	-0.03	-0.00	0.01	0.01	-0.02
PRCPTOT	2.97*	-3.82	4.27*	6.05*	1.05	0.13
R10mm	0.09*	-0.12	0.10*	0.18*	0.04	0.01
R20mm	0.05*	-0.04	0.07*	0.10*	0.01	0.00
R95p	0.63	-0.66	1.02	2.06	-0.16	0.69
R99p	0.20	-0.60	0.34	1.09*	-0.31	0.09
RX1day	0.08	0.02	0.25*	0.34	-0.12	0.08
RX5day	0.07	-0.23	0.35	0.96	-0.28	0.04
SDII	-0.02*	0.02*	-0.02	0.02	-0.01	0.01

4.0 Conclusions

Changes in the frequency of extreme temperature events reflect global and regional warming. Extreme warm events have clearly become more common at most stations, while cold events have become less common. However, changes in the extreme values of day and night temperatures are not as clear, possibly because the records are too short to distinguish long-term trends from inter-annual variations. Trends and changes in the frequency distribution of regional averages are also generally consistent with a warming world. Spatial variations in the trends of temperature extremes indicate that warming is more pronounced in the eastern Himalayas compared to the Greater Himalayas, and that the Thar Desert seems to have warmed more than other parts of Pakistan and India.

Changes in indices of extreme precipitation are more mixed than those of temperature. Spatially consistent changes are only evident at relatively small scales. Nevertheless, most extreme precipitation indices show increases in the regional average, consistent with the findings that extreme precipitation has increased at the global level (Groisman et al. 1999, Osborn et al. 2000, Manton et al. 2001 and AR4 2007). However, the regional trends observed here are very weak and dominated by large inter-annual variations. El Niño years tend to have fewer rainfall extremes at the regional level, although this relationship appears weaker during the 1990s. Strong La Niña episodes tend to show the opposite influence, with positive biases in the extreme precipitation indices during these years.

5.0 Future Directions

The dominance of natural variability over background trends in rainfall extremes underlines the importance of investigating changes in extremes over as long a record as possible. Also, with 11 of the globe's 12 warmest years on record having occurred since the year 1995 (IPCC, 2007), it is important that the analysis of temperature extremes be updated to present. For these reasons, countries in South Asia should act to extend their digitized climate records both backwards and forwards in time.

Further the work on the socio-economic impacts of the climate extremes is still a gap to be filled-in appropriately in South Asian countries and this requires at least a year long extension in the project to share the results with the policy makers to help them use the project results more effectively and in a meaningful way.

References

1. Alexander LV, Zhang X, Peterson TC, Caesar J, Gleason B, Klein Tank AMG, Haylock M, Collins D, Trewin B, Rahimzadeh F, Tagipour A, Ambenje P, Rupa Kumar K, Revadekar JV, Griffiths G, Vincent L, Stephenson D, Burn J, Aguilar E, Brunet M, Taylor M, New M, Zhai P, Rusticucci M, Vazquez-Aguirre JL. 2006. Global Observed Changes in daily climate extremes of temperature and precipitation, *Journal of Geophysical Research*, **111**, D05109, DOI: 10.1029 / 2005JD006290.
2. Allan RJ and D'Arrigo RD. 1999. Persistent ENSO sequences: how unusual was the 1990-1995 El Nino? *The Holocene*, **9**, No. 1, 101-118. DOI: 10.1191/095968399669125102.
3. Brandt CJ, Thornes JB (eds) (1996) *Mediterranean desertification and land use*. London New York: Wiley, 554 pp.

4. Chen, J, Carlson BE, and Del Genio AD. 2002. Evidence for strengthening of the tropical general circulation in the 1990s, *Science*, **295**, 838-841, DOI:10.1126/science.1065835/.
5. De US, Dube RK and Prakasa Rao GS. 2005. Extreme Weather Events over India in the last 100 years J. Ind. Geophys. Union (July 2005) **Vol. 9**, No.3, pp.173-187.
6. Desert Meteorology (Thomas T. Warner, 2004), Cambridge University Press.
7. Dunbar RB, and Cole JE. 1999. Annual Records of Tropical Systems, PAGES Workshop Report Series, 99-1, PAGES, BERN Switzerland, 72 pp.
8. Easterling DR, Meehl GA, Parmesan C, Changnon SA, Karl TR and Mearns LO. 2000. Climate Extremes: Observations, Modeling, and Impacts, *Science* 22 September 2000: **Vol. 289**. No. 5487, pp. 2068-2074 DOI: 10.1126/ science. 289. 5487.2068.
9. Easterling DR, Evans JL, Groisman PYa, Karl TR, Kunkel KE and Ambenje P. 2000. Observed Variability and Trends in Extreme Climate Events: A Brief Review. Bulletin of the American Meteorological Society, 2000.
10. Fedorov AV and Philander SG. 2000. Is El Niño changing?" *Science* **288**: 1997-2002.
11. Gergis J. 2006. Reconstructing El Niño-Southern Oscillation (ENSO); evidence from tree-ring, coral, ice core and documentary palaeo archives, A.D. 1525-2002". PhD Thesis, School of Biological, Earth and Environmental Sciences, University of New South Wales, Australia.
12. Groisman PYa, Knight RW, Easterling DR, Karl TR, Hegerl GC and Razuvaev VN. 2005. Trends in Intense Precipitation in the Climate Record, *American Meteorological Society*, **Vol.18**, Issue 9 pp. 1326-1350.
13. Gruza G, Rankova E, Razuvaev V and Bulygina O. 1999. Indicators of Climate Change for the Russian Federation, *Climatic Change* **42**: 219-242, 1999.
14. Haylock M and Nicholls N. 2000. Trends in extreme rainfall indices for an updated high quality data set for Australia, 1910-1998. *International Journal of Climatology*, **20**, 1533-1541.
15. Intergovernmental Panel on Climate Change (IPCC), Third Assessment Report (TAR, 2001) and Fourth Assessment Report (AR4, 2007).
16. Klein Tank AMG and Können GP. 2003. Trends in indices of daily temperature and precipitation extremes in Europe, 1946-99. *J. Climate*, **16**, 3665-3680.
17. Klein Tank AMG, Peterson TC, Quadir DA, Dorji S, Zou X, Tang H, Santhosh K, Joshi UR, Jaswal AK, Kolli RK, Sikder AB, Deshpande NR, Revadekar JV, Yeleuova K, Vandasheva S, Faleyeva M, Gomboluudev P, Budhathoki KP, Hussain A, Afzaal M, Chandrapala L, Anvar H, Amanmurad D, Asanova VS, Jones PD, New MG and Spektorman T. 2006. Changes in Daily Temperature and Precipitation Extremes in Central and South Asia", *J. of Geophysical Research*, Vol. **111**, D16105, Doi:10.1029/2005JD006316, 2006.
18. Kostopoulou E and Jones PD. 2005. Assessment of Climate Extremes in the Eastern Mediterranean, *Meteorol Atmos Phys*. Vol. **89**, pp 69-85.

19. Manton MJ, Della-marta PM, Haylock MR, Hennessy KJ, Nicholls N, Chambers LE, Collins DA, Daw G, Finet A, Gunawan D, Inape K, Isobe H, Kestin TS, Lefale P, Leyu CH, Lwin T, Maitrepierre L, Ouprasitwong N, Page CM, Pahalad J, Plummer N, Salinger MJ, Suppiah R, Tran VJ, Trewin B, Tibig I and Yee D.. 2001. Trend in Extreme Daily Rainfall and Temperature in Southeast Asia and South Pacific: 1961-1998, *Int. J. Clim.* Vol. **21**, pp 269-284.
20. Osborn TJ, Hulme M, Jones PD and Basnett T. 2000. Observed trends in the daily intensity of United Kingdom precipitation, *International Journal of Climatology* **20**, 347-364.
21. Rasul GR, Chaudhry QZ, Zhao S and Zeng Q. 2004. A Diagnostic Study of Record Heavy Rain in Twin Cities Islamabad-Rawalpindi, *Advances in Atmospheric Sciences*, Vol. **21**, No. 6, 2004, 976-988.
22. Sheikh MM. 2001. Drought Management and Prevention in Pakistan, *Science Vision Quarterly*, **7** (3 & 4), COMSATS 1st Meeting on Water Resources in the South: Present Scenario and Future Prospects (November 1 & 2, 2001).
23. Trenberth KE and Hoar TJ. 1997. El Niño and Climate Change, *Geophys. Res. Lett.*, **24**, 3057-3060.
24. Vincent LA, Peterson TC, Barros VR, Marino MB, Rusticucci M, Carrasco G, Ramirez E, Alves IM, Ambrizzi T, Berlato MA, Grimm AM, Marengo JA, Molion I, Moncunill DF, Rebello E, Anunciação YMT, Quintana J, Santos JL, Baez J, Coronel G, Garcia J, Trebejo I, Bidegain M, Haylock MR and Karoly D. 2005. Observed Trends in Indices of Daily Temperature Extremes in South America 1960-2000, *Amer. Met. Soc.* Vol. **18**, pp 5011-5023.

Appendix

Conferences/Symposia/Workshops

Agenda/Program of the first APN Meeting (21-25 April, 2008) and of the second APN Meeting (15-19 June, 2009) is provided in the proceeding of the project.

Funding sources outside the APN

In-kind support was provided by Global Change Impact Studies Centre (GCISC) and Pakistan Meteorological Department (PMD).

Glossary of Terms

All acronyms and abbreviations are defined in the above text.

The participating countries, particularly India and Pakistan are not agreeable to share their Actual climate data; however, products are included in this report. Abstracts, Power Point Slides of the first meeting (21-25 April, 2008) and the final meeting (15-19 June, 2009) are not included in this report. However, the same will be included in the bound copies and will be sent shortly by courier.