Spatio-temporal variation of extreme indices derived from observed and reanalysis products for detection of climate change across India

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Abstract Id. : 5837

Sessions : HS2.4.7 on Hydrological change: Regional hydrological behaviour under transient climate and land use conditions

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Outline

- Introduction
- Objective
- Methodology
- Results and Discussions
- Conclusions

Introduction

- Globally, hydrological extreme events are on the rise over the past 50 years
- IPCC (AR5, 2013) : warm temperature extremes have been increasing and cold temperatures extremes have been decreasing
- Precipitation extremes are also found to have increased (*Alexander, 2016*)

Fig. 1 Hydrological extreme events

Sources
a) https://www.theatlantic.com/photo/2018/08/devastating-monsoon-floods-in-kerala- india/568171/
b) https://www.skymetweather.com/content/weather-faqs/what-is-the-impact-of-el-nino-on-indian-monsoon/
c) http://www.indusscrolls.com/extreme-rainfall-events-in-india-linked-to-man-made-emissions-study/
d) https://blog.ucsusa.org/kristy-dahl/extreme-heat-and-wildfire-in-california

Introduction

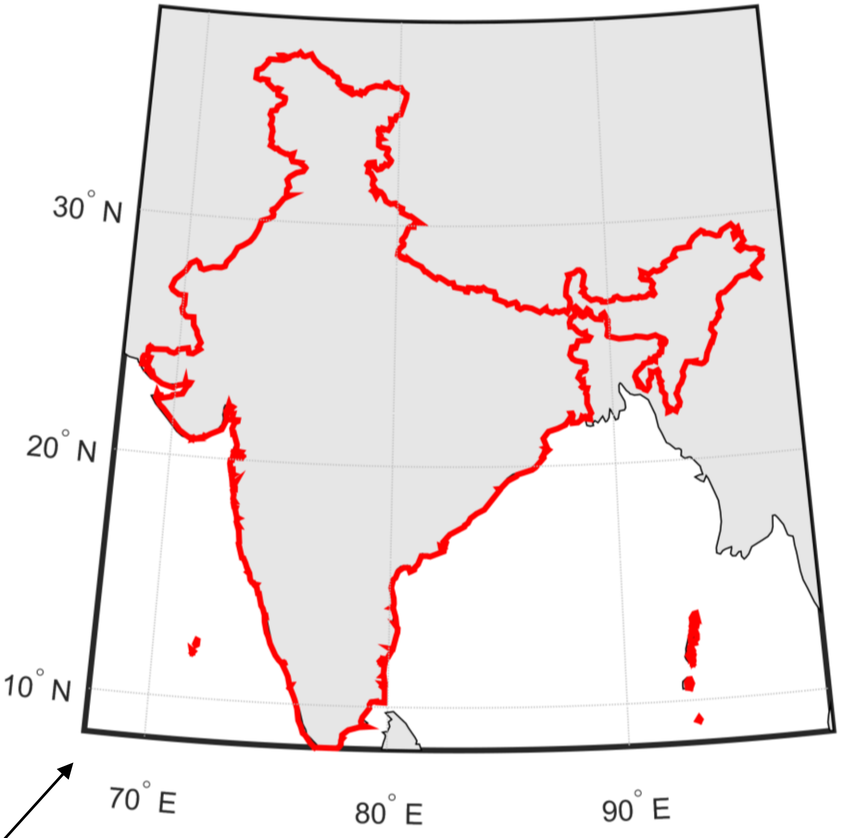
- Alexander, (2016) and Zhang et al., 2011 reviewed global observed changes in temperature and precipitation extremes and investigated how indices of extremes evolved over time .
- 70% of the **global** land area, showed **decrease** in the annual occurrence of **cold nights** and a **increase** in the annual occurrence of **warm nights**, Precipitation has widespread significant trend but it is spatially heterogeneous (Alexander et al., 2006; Donat et al., 2013).
- **In India**, **moderate rainfall events decreased** over central India and Western Ghats while **heavy rainfall events have increased** (Goswami et al., 2006; Ghosh et al., 2011; Krishnamurthy, 2011).
- All India: Decrease in annual average and increase in extreme temp. and precip. (Jain and Kumar, 2012; Kumar et al., 2010; Rajeevan et al., 2008; Roy and Balling, 2004) .
- Increase in mean temperature over India, contributed by increase in max. temp (Kothawale and Rupa Kumar, 2005; Arora et al., 2005; Kumar et al., 1994).
- For India as whole, the frequency of **hot days and nights** showed **increasing** trend while **cold days and nights** showed **decreasing** trends (Kothawale et al., 2010).

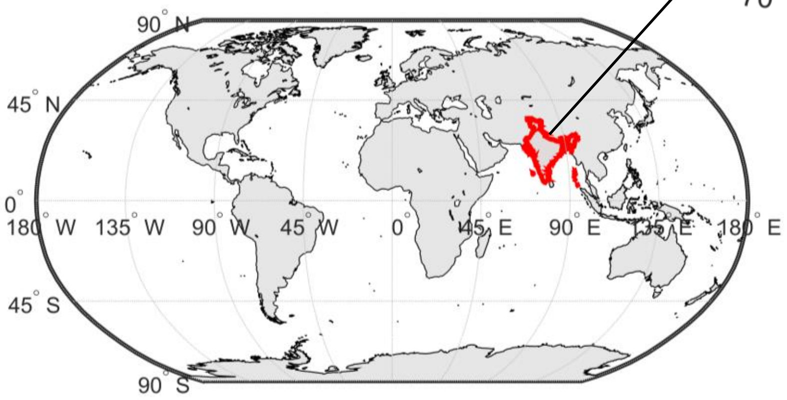
Objective

To investigate the spatio-temporal trends in extreme hydrological indices in the context of climate change

Study Area

- India lies between 8°N- 37°N (latitude) and 67°E - 98°E (longitude)
- Total of 3481 NOAA grid intersection points.





Data
(Gridded Rainfall and Temperature)

REFERENCED DATA

1. India Meteorological Department (IMD) daily precipitation (1971-2017) and Maximum and Minimum Temperature (1971-2013)

Spatial resolution = Precipitation (0.25° lat. x 0.25° lon.), Temperature (1° lat. x 1° lon.)

Temporal resolution = Daily

http://www.imdpune.gov.in/index.html

2. Climate Prediction Center (CPC), National Oceanic and Atmospheric Administration (NOAA) daily precipitation and Temperature at spatial resolution (0.5° lon x 0.5° lat) for 1979-2017 .

https://www.esrl.noaa.gov/psd/

PROJECTED GENERAL CIRCULATION MODEL (GCM)

Second Generation Canadian Earth System Model (CanESM2/RCP8.5) for the future (2006 to 2100)

spatial resolution = 2.74° lat x 2.81° lon

Temporal resolution = Daily

Source: Canadian Centre for Climate Modelling and Analysis (CCCma)

http://climate-modelling.canada.ca/data/cgcm4/cgcm4.shtml

Methodology

- Quality check for missing values
- Regridding of GCM datasets (using Inverse Distance Weighting method)
- Bias correction of GCM datasets (Quantile based Bias Correction method)
- Identification of extreme events and selection of suitable indices (ETCCDI)
- Analysis of trends of hydrological extremes (Mann-Kendall test and Regression analysis)

Only for GCM data

Regridding and Bias Correction of GCM datasets

- GCM data are regridded to 1° x 1° resolution using **Inverse Distance Weighting (IDW)** method.

- Out of several bias correction method, we have used Conditional Quantile based Bias Correction (CQBC) method. This method has been previously applied to GCM soil moisture data (Chanda and Maity, 2017).

$$\tilde{X}_m = \bar{X}_{o,q} + \left(X_m - \bar{X}_{m,q}\right) * \frac{S_{o,q}}{S_{m,q}} \quad (1)$$

Where, $\tilde{X}_m$ is the corrected GCM value for raw GCM value X_m, $\bar{X}_{m,q}$ and $\bar{X}_{o,q}$ are the parameters for the concerned quantile range. $\bar{X}_{m,q}$ is the sample mean of GCM values for quantile interval q and the ratio of standard deviation of observed $\left(S_{o,q}\right)$ and GCM $\left(S_{m,q}\right)$ data of quantile interval gives correction factor.

- The bias correction is applied to the data from 2006 to 2100 using parameters derived from the quantile based comparison of the GCM and reference datasets of the period 1979-2005.

Identification of Extreme Events and Selection of Suitable Indices

Table. 1. Extreme precipitation and temperature indices

ETCCDI Tank et al.(2009) http://www.clivar.org/organization/etccdi/etccdi.php

Hydrological variables	Index name and Definition
Temperature extremes	TX90,TX95,TX99 Number of days on which max daily temperature TX>90th , 95th and 99th percentile, respectively TX1, TX5, TX10 Number of days on which max daily temperature TX<1st, 5th , 10th, respectively
	TN90, TN95, TN99 Number of days on which min daily temperature TN>90th , 95th and 99thpercentile, respectively TN1, TN5, TN10 Number of days on which min daily temperature TN<10th , 5th and 1st percentile, respectively
Precipitation extremes	R90, R95, R99 Number of days on which precipitation R>90th , 95th and 99th percentile, respectively R90p, R95p, R99p Precipitation depth from days having greater than 90th , 95th and 99th percentile of daily precipitation series
	R1, R5, R10 Number of days on which precipitation R<1st , 5th and 10th percentile, respectively R1p, R5p, R10p Precipitation depth from days having greater than 1st , 5th and 10th percentile of daily precipitation series

Analysis of Trends of Hydrological Extremes

- **Mann-Kendall test (***Kendall, 1975; Mann, 1945***)**

The expression for M-K test statistic S is

$$S = \sum_{i=2}^{n} \sum_{j=1}^{i-1} sign(X_i - X_j) \quad (2)$$

where, n is the length of the data series X_i and X_j are the sequential data in the series

$$sign(X_i - X_j) = \begin{cases} -1 & for(X_i - X_j) < 0 \\ 0 & for(X_i - X_j) = 0 \\ 1 & for(X_i - X_j) > 0 \end{cases}$$

$E[S] = 0$

When n>=10, statistics is normally distributed

$$Var(S) = \frac{n(n-1)(2n+5) - \sum_{p-1}^{q} t_p(t_p-1)(2t_p+5)}{18} \quad (3)$$

Where, t_p = number of ties for the pth value and q = number of tied value

Analysis of Trends of Hydrological Extremes

To test for monotonic trend at significance level of $\propto$ the null hypothesis of no trend is rejected if the absolute value of standardized test statistics Z is greater than $Z_{1-\propto/2}$ obtained from the standard normal cumulative distribution tables

Standardized test statistic Z is computed by

$$Z = \begin{cases} \dfrac{s-1}{\sqrt{Var(S)}} \; if \; S > 0 \\ 0 \; if \; S = 0 \\ \dfrac{s+1}{\sqrt{Var(S)}} \; if \; S < 0 \end{cases}$$

- **Regression Analysis (***Sen, 1968; Jain and Kumar, 2012; Sonali and Kumar, 2012***)**

$$y = \beta_0 + \beta_1 X \qquad (4)$$

Where, y is dependent variable and X is independent variables, β_0 (intercept) and β_1(slope of fitted straight line) are parameters.

Results and Discussions
Spatial variation of the significant trend in daily precipitation

At **Annual** Scale
R95p: 13 %
R5p: 20%

At **Seasonal** Scale
R95p: Nil
R5p: 21%

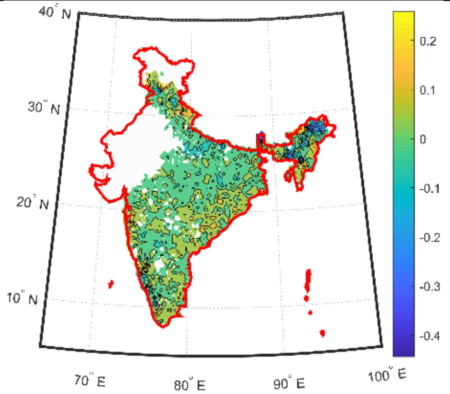


Fig. 1. a. Spatial Variation of Trend in R95 (for daily annual precipitation)

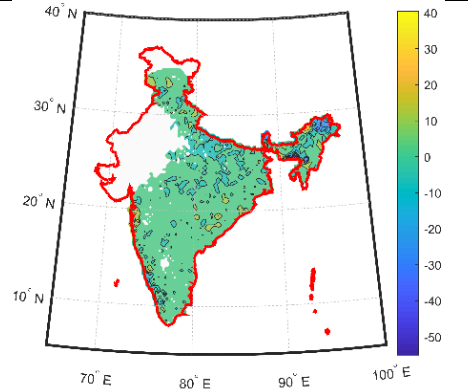


Fig. 1. b. Spatial Variation of Trend in R95p (for daily annual precipitation)

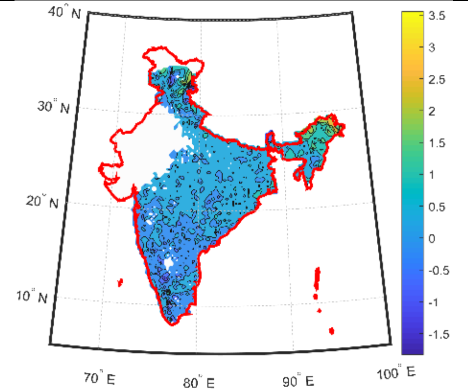


Fig. 1. c. Spatial Variation of Trend in R5 (for daily annual precipitation)

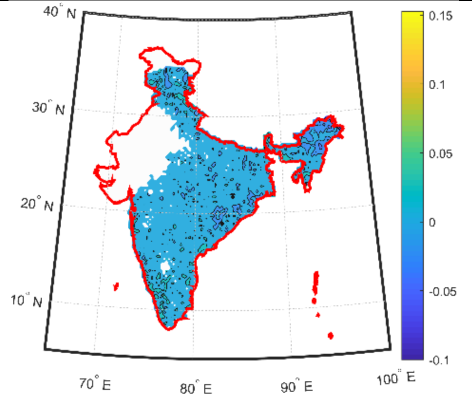


Fig. 1. d. Spatial Variation of Trend in R5p (for daily annual precipitation)

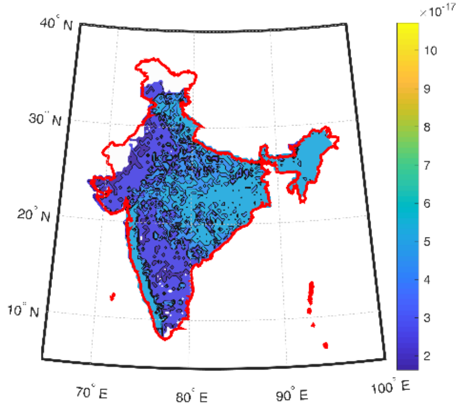


Fig. 1. e. Spatial Variation of Trend in R95 (for daily seasonal precipitation)

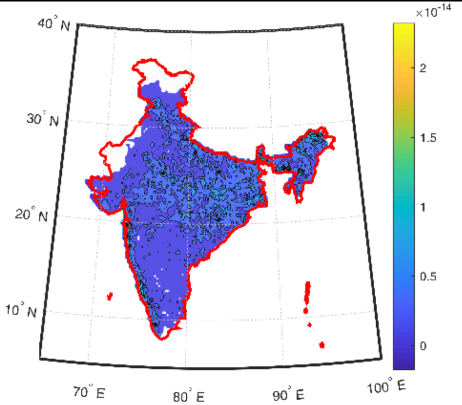


Fig. 1. f. Spatial Variation of Trend in R95p (for daily seasonal precipitation)

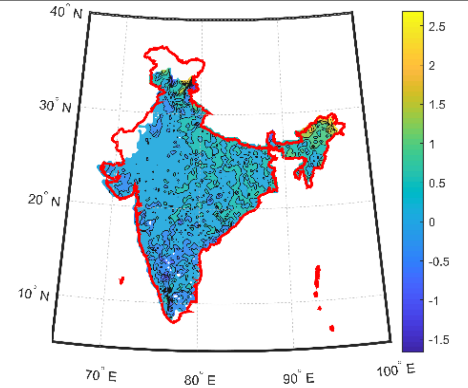


Fig. 1. g. Spatial Variation of Trend in R5 (for daily seasonal precipitation)

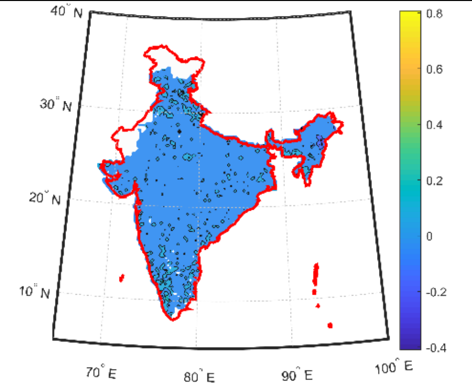


Fig. 1. h. Spatial Variation of Trend in R5p (for daily seasonal precipitation)

Significant Trends in Precipitation Extremes

Percentage of total no. of grid points

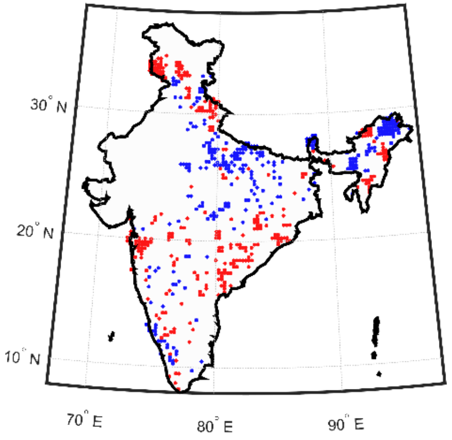


Fig. 2.a. Significant increasing (red dots) and decreasing (blue dots) trend in R95p of daily annual precipitation during 1971-2017. Level of significance is 5%.

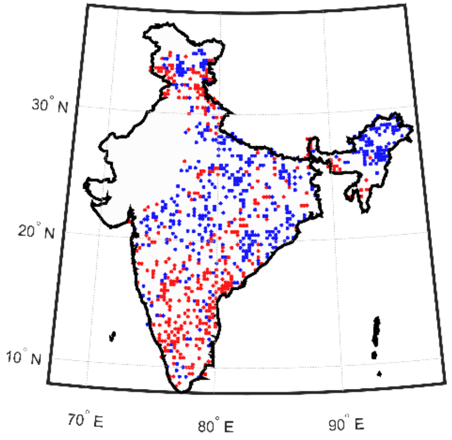


Fig. 2.b. Significant increasing (red dots) and decreasing (blue dots) trend in R5p of daily annual precipitation during 1971-2017. Level of significance is 5%.

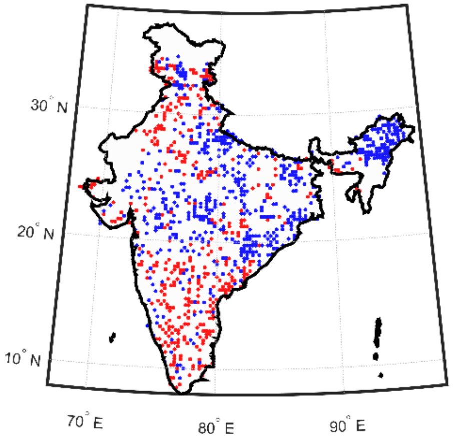


Fig. 2.c. Significant increasing (red dots) and decreasing (blue dots) trend in R5p of daily seasonal precipitation during 1971-2017. Level of significance is 5%.

Significant increasing trend

Significant decreasing trend

Significant Trends in Temperatures Extremes

Percentage of total no. of grid points

Index	IMD	CPC
Warm Days (TX95)	14 %	31 %
Cold Days (TX5)	42 %	39 %
Warm nights (TN95)	34 %	30 %
Cold nights (TN5)	39 %	32 %

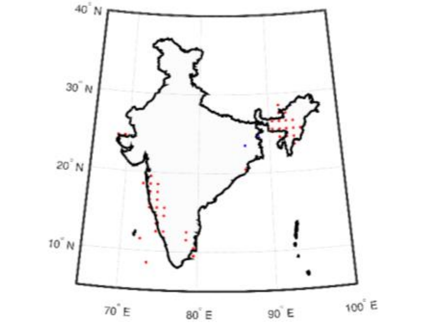


Fig. 3.a. Significant increasing (red dots) and decreasing (blue dots) trend in TX95 during 1971-2013 for IMD data. Level of significance is 5%.

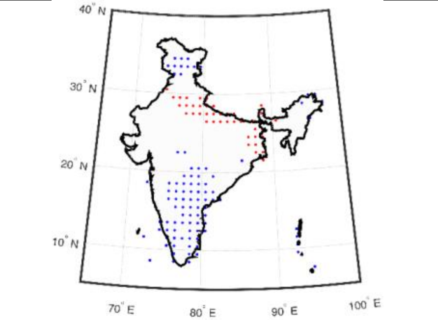


Fig. 3.b. Significant increasing (red dots) and decreasing (blue dots) trend in TX5 during 1971-2013 for IMD data. Level of significance is 5%.

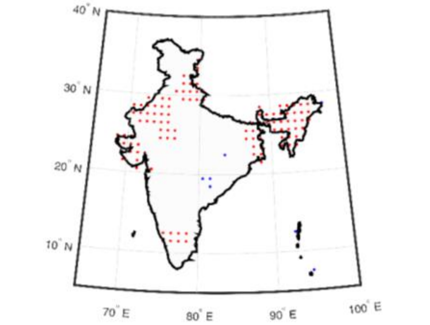


Fig. 3.c. Significant increasing (red dots) and decreasing (blue dots) trend in TN95 during 1971-2013 for IMD data. Level of significance is 5%.

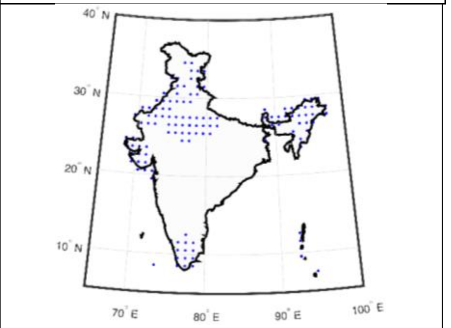


Fig. 3.d. Significant increasing (red dots) and decreasing (blue dots) trend in TN5 during 1971-2013 for IMD data. Level of significance is 5%.

Significant increasing trend

Significant decreasing trend

Spatial variation of the Future Significant Trend : Maximum Temperature

Three epochs:
2006-2040
2041-2070
2071-2100

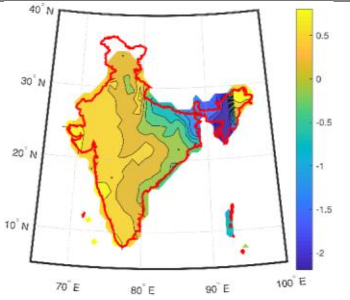


Fig. 4.a. Spatial variation of Trend in TX95 for first segment (2006-2040)

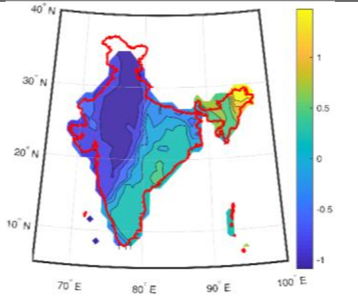


Fig. 4.b. Spatial variation of Trend in TX5 for first segment (2006-2040)

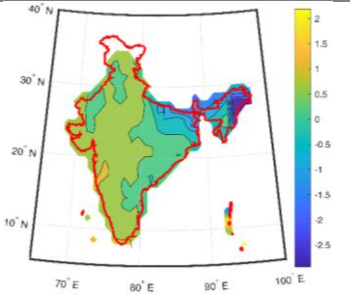


Fig. 4.c. Spatial variation of Trend in TX95 for second segment (2041-2070)

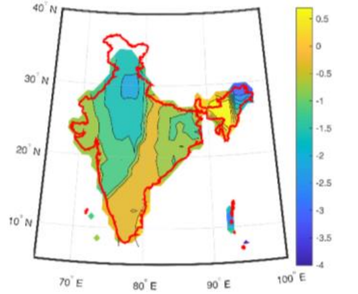


Fig. 4.d. Spatial variation of Trend in TX5 for second segment (2041-2070)

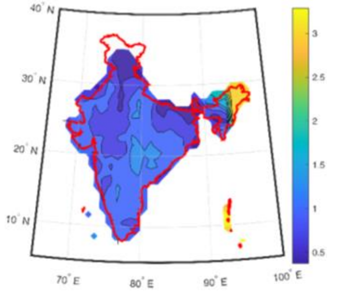


Fig. 4.e. Spatial variation of Trend in TX95 for third segment (2071-2100)

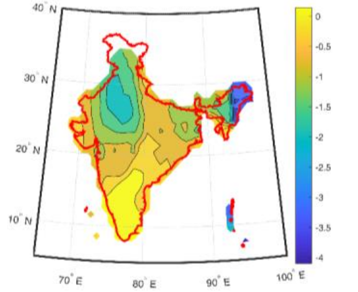


Fig. 4.f. Spatial variation of Trend in TX5 for third segment (2071-2100)

Future Significant Trends in Temperature Extremes: Maximum Temperature

Percentage of total no. of grid points

GCM with respect to IMD Historical		
Epochs	**TX95**	**TX5**
2006-2040	49 %	62 %
2041-2070	56 %	75 %
2071-2100	84 %	66 %

GCM with respect to CPC Historical		
Epochs	**TX95**	**TX5**
2006-2040	48 %	48 %
2041-2070	56 %	63 %
2071-2100	68 %	43 %

Significant increasing trend Significant decreasing trend

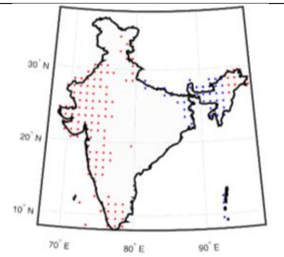


Fig. 5.a. Significant increasing (red dots) and decreasing (blue dots) trend in TX95 during 2006-2040.

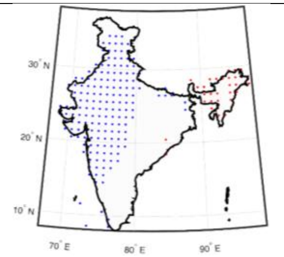


Fig. 5.b. Significant increasing (red dots) and decreasing (blue dots) trend in TX5 during 2006-2040.

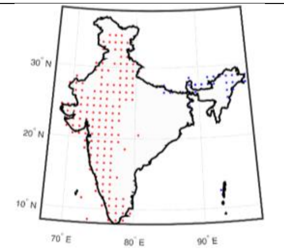


Fig. 5.c. Significant increasing (red dots) and decreasing (blue dots) trend in TX95 during 2041-2070.

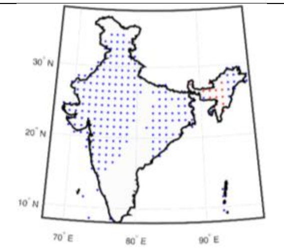


Fig. 5.d. Significant increasing (red dots) and decreasing (blue dots) trend in TX5 during 2041-2070.

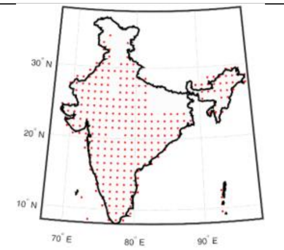


Fig. 5.e. Significant increasing (red dots) and decreasing (blue dots) trend in TX95 during 2071-2100.

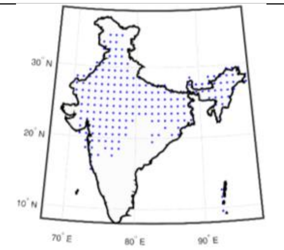


Fig. 5.f. Significant increasing (red dots) and decreasing (blue dots) trend in TX5 during 2071-2100.

Future Significant Trends in Temperature Extremes: Minimum Temperature

Percentage of total no. of grid points

GCM with respect to IMD Historical		
Epochs	**TN95**	**TN5**
2006-2040	66 %	63 %
2041-2070	76 %	66 %
2071-2100	81 %	60 %

GCM with respect to CPC Historical		
Epochs	**TN95**	**TN5**
2006-2040	32 %	62 %
2041-2070	29 %	69 %
2071-2100	38 %	56 %

Significant increasing trend

Significant decreasing trend

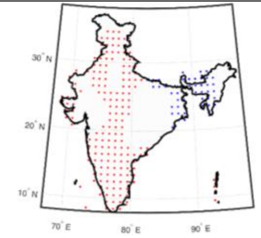


Fig. 6.a. Significant increasing (red dots) and decreasing (blue dots) trend in TN95 during 2006-2040. Level of significance is 5%.

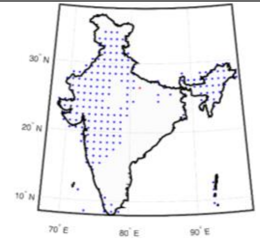


Fig. 6.b. Significant increasing (red dots) and decreasing (blue dots) trend in TN5 during 2006-2040. Level of significance is 5%.

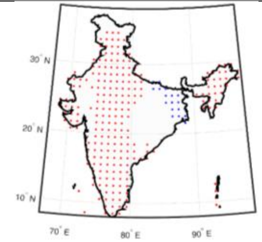


Fig. 6.c. Significant increasing (red dots) and decreasing (blue dots) trend in TN95 during 2041-2070. Level of significance is 5%.

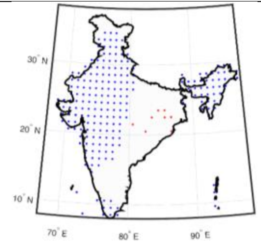


Fig. 6.d. Significant increasing (red dots) and decreasing (blue dots) trend in TN5 during 2041-2070. Level of significance is 5%.

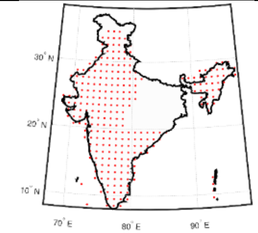


Fig. 6.e. Significant increasing (red dots) and decreasing (blue dots) trend in TN95 during 2071-2100. Level of significance is 5%.

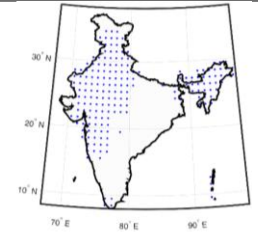


Fig. 6.f. Significant increasing (red dots) and decreasing (blue dots) trend in TN5 during 2071-2100. Level of significance is 5%.

Conclusions

- During the historical period (1971-2017), for daily annual precipitation, for R95p and R5p 13% and 20% of the locations examined have significant trend (either increasing or decreasing).
- For the seasonal analysis (monsoon: June to September), R95p has no significant trend anywhere in India, while for R5p, 21% of the locations have significant trend.
- Thus, the indices of low-extremes have undergone more substantial changes compared to indices of high-extremes both at the annual and seasonal scale during the historical period.
- 14% and 42% of all the locations have significant trend in *warm days* per year (TX95) and *cold days* per year (TX5) respectively during the historical period (1971-2013).
- 34% and 39% of all the locations are found to have significant trend in *warm nights* per year (TN95) and *cold nights* per year (TN5) respectively.
- On comparison of the analysis using IMD and CPC datasets, trends are in agreement for temperature extremes but spatially more extensive in case of CPC precipitation extremes.

Conclusions (contd.)

- All three epochs, 2006-2040, 2041-2070 and 2071-2100, show significant increasing trend in *warm days* (TX95) and significant decreasing trend in *cold days* (TX5) in most locations (49% to 84% of all locations).
- Most locations (varying from 60% to 81%) show an increasing trend in *warm nights* and a decreasing trend in *cold nights* in all epochs.
- Using CPC data as the reference, the corresponding figures are 43% to 68% and 29% to 69% respectively with similar sign of the trends as in case of IMD reference data.

Further Reading:

Kumar, S., Chanda, K., & Pasupuleti, S. (2020). Spatiotemporal analysis of extreme indices derived from daily precipitation and temperature for climate change detection over India. *Theoretical and Applied Climatology*, 1-15.

Selected References

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Thank you!