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A study of changes in rainfall and temperature patterns at four cities and corresponding meteorological subdivisions over coastal regions of India

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ABSTRACT

Changes in the surface air temperature and rainfall, extreme events and their future projections at four Indian cities and corresponding meteorological subdivisions and homogeneous zones have been analyzed in this study based on observed gridded datasets from the India Meteorological Department (IMD) and climate projections from nine IPCC models. The cities include Howrah, Vishakhapatnam, Madurai and Kochi. Their corresponding meteorological subdivisions are Gangetic West Bengal, Coastal Andhra Pradesh, Tamil Nadu & Pondicherry and Kerala. When one considers the larger spatial scale, these cities and meteorological subdivisions are situated in the temperature homogeneous zones of North East, East Coast and West Coast. Similarly, North East and Peninsular India are the rainfall homogeneous zones where these four cities are situated. In this study, indication of change in any climate parameter is assumed to be strong if the same is found in a city and also in its meteorological subdivision and homogeneous zone. When the indications are of the same nature in a city and either in its meteorological subdivision or homogeneous zone, it is termed as weak. Comparison shows that the values of annual mean temperature and summer monsoon precipitation simulated by MIROC 3.2 (medres) and NCAR_CCSM3 models are close to the corresponding observed values at each of the four cities. Analysis shows similar trends in the annual mean observed temperature and monsoon precipitation in the selected four cities and their corresponding meteorological subdivisions and homogeneous zones. Based on IMD gridded datasets, the rise in annual mean temperature at 1% significant level during 1969–2005 in Kochi and its subdivision and homogeneous zone is a strong indication of warming. At Madurai such warming is weak. Whereas, at Howrah and Vishakhapatnam, there are no strong indications of warming based on the available IMD gridded data. So far as the future is concerned, the results show that in the coming 30 years, the projections of mean temperature rise at Vishakhapatnam, Madurai and Kochi at 1% significance are strong, whereas at Howrah it is weak. Extreme temperature events such as warm days & nights and cold days & nights have also been examined. There is strong projection of the decrease in the moderately cold events (T05p) at 1% significance at Madurai. At the same place, the projection of moderately warm events (T95p) is weak. At Kochi the projections of increase in low (T90p) and moderate (T95p) warm events at 1% significance are weak. There are no strong projections of increase/decrease of warm/cold events in Howrah and Vishakhapatnam.

1. Introduction

It is well known that Indian rainfall and surface temperature exhibit large temporal and spatial variations. Based on the long term observed datasets available from the India Meteorological Department (IMD), the entire country can be divided into six rainfall homogeneous zones (Parthasarthy et al., 1995) and seven temperature homogeneous zones (www.tropmet.res.in). Dash et al. (2002) examined the seasonal mean monsoon rainfall over India and its five homogeneous zones and showed large variability in the spatial distribution of rainfall over the country. Further, Dash et al. (2009, 2011) using gridded rainfall datasets prepared by IMD concluded that short spells of heavy intensity rain have risen and long spells of moderate and low intensity rains have decreased during the summer monsoon season in the past 50 years. However, all homogeneous zones do not exhibit similar changes in characteristics. There are regional disparities depending upon the climate types. Based on observational data, Dash et al. (2007) and Dash and Hunt (2007) have examined the changes in the characteristics of surface air temperatures during the last century over seven homogeneous regions in India. Dash and Mamgain (2011) further used IMD gridded temperature dataset to

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examine the changes in the number of warm days & nights, cold days & nights, Warm Spell Duration Index (WSDI) and Cold Spell Duration Index (CSDI) for the seven different temperature homogeneous regions of India. They also found differences in extreme temperature events occurring in different regions of India.

The connection between the global and regional climate changes is complex. Studies of the global variability of temperature trends show that in some regions (Orr et al., 2004) the trends may be significantly greater than global trends. In other regions local trends may also be less than global trends, or may even exhibit opposite behavior (e.g. in terms of precipitation). A study by Jones et al. (1990) on urbanization and related temperature variation indicates that the impact of urbanization on the mean surface temperature would be no more than 05 °C per 100 years. On the other hand, a study by Fujibe (1995) reports a rising trend of 2–5 °C per 100 years in minimum temperature at several large cities of Japan. It is understood that the observed warming is not only due to the increase of greenhouse gases but also due to urbanization (Nasrallah and Balling, 1993). De and Rao (2004) examined the trends in the climatic parameters in 14 urban cities in India, which have population in excess of 10 lakhs. Nine stations show increasing significant trends in annual and monsoon rainfall in the period 1951 to 2000 when rapid industrial development took place over these urban locations. Earlier Rupa Kumar and Hingane (1988) had reported the results of the analysis of long-term trends of surface air temperatures of six industrial cities in India. They concluded that three cities (Calcutta, Bombay and Bangalore) showed significant warming trends, two cities (Madras and Pune) did not show any significant trend and one city (Delhi) showed a significant cooling trend. Rao et al. (2004) examined the effect of urbanization on the meteorological parameters at fifteen Indian cities and found that radiation values, bright sunshine hours, wind speeds and total cloud amounts have a decreasing tendency during the last forty to fifty years whereas relative humidity and rainfall amounts show increasing tendency in some cities. Rao et al. (2005) further concluded that during summer, 60–70% of the coastal stations show increasing trends in the day time and night time temperatures. The spatial patterns of trend of rainfall and rainy days were analyzed by Das et al. (2013) using daily gridded (0.5° × 0.5°) rainfall data for the last 35 years (1971–2005). Results show that a statistically significant increasing trend of both rainfall and rainy days during the monsoon season was found over the east coast and Deccan Plateau region of India. Ghosh et al. (2009) analyzed the trend of summer monsoon rainfall all over India at a finer spatial resolution (1° × 1°) to identify the places that have a significant trend in terms of both rainfall amount and occurrence. Their analysis shows spatially varying mixed responses of global warming towards rainfall occurrence and amounts all over India. Rana et al. (2012) examined the rainfall trends in Delhi and Mumbai, the two biggest metropolitan cities of India, during the period from 1951 to 2004. Their analysis revealed that there is an insignificant decrease in long term southwest monsoon rainfall over Delhi and slight significant decreasing trend in the same parameter in Mumbai.

Today, surface temperature and rainfall data at reasonably good spatial and temporal resolutions are readily available from several sources. Gridded temperature and rainfall values prepared by IMD constitute a very good source of observed data. Daily temperature and rainfall are also available at several meteorological observatories of IMD (www.imd.gov.in). Simulations from various Intergovernmental Panel on Climate Change (IPCC) models are further available for projecting the future climate. Hence, it is very essential to examine in detail the current climate of the big cities using the new set of good quality data. Also the future projections of temperature and rainfall can be estimated based on model simulations. These scientific results may help the local bodies at the city level as guidelines to formulate their future growth plan. Section 2 in this paper analyses the climatology of the four cities and extreme temperature events occurring there based on observed data. Section 3 describes the validation of the IPCC model simulations. The future projected temperature and precipitation changes are discussed in Section 4. Section 5 describes the projected extreme temperature events into the future. The last Section 6 summarizes the conclusions.

2. Analysis of city level climatology and temperature extremes based on observed data

As mentioned earlier, two sets of observed data are available at each of the four cities. The first dataset is of IMD station observations recorded at particular meteorological observatories and the second set is prepared by IMD at regular grids for use in scientific applications. Rajeevan et al. (2006) have developed the high resolution (1° × 1° Lat × Long) daily rainfall dataset for the period 1951–2004 and subsequently Srivastava et al. (2009) developed the corresponding temperature dataset for the years 1969–2005. Fig. 1 depicts the locations of the four selected cities Howrah, Vishakhapatnam, Madurai and Kochi whose regional climates are examined here. Fig. 2(a)–(d) depicts the physical distances between the location of the four selected cities and the grids at which IMD datasets are available. Measurements show that the distances of Howrah, Vishakhapatnam, Madurai and Kochi from the corresponding nearest grids of IMD datasets are 20.18 km, 30.23 km, 18.79 km and 17.26 km respectively.

First of all, it is required to briefly mention the climates of these selected cities based on IMD datasets (http://www.imd.gov.in/section/climate). Howrah is an industrial city and a municipal corporation in the Howrah district of West Bengal. It is located at the coordinates 22°N and 88°E. It has a tropical wet-and-dry climate as per Köppen's climate classification. Howrah experiences extreme type of climates with hot and dry summer followed by humid monsoon and cold winter. The hot season commences from 1st week of March and lasts till the second half of June. In the month of April and May, temperature rises up to 35°. Winter tends to last for only about two and a half months, with seasonal lows dipping to 11 °C–14 °C between December and January. May is the hottest month while January is the coldest month. After rainy season, the humidity gradually decreases and the weather becomes dry towards the winter. Howrah gets maximum rainfall during south-west monsoon in the months of June, July, August and September. Vishakhapatnam is a major port and the second largest city in the state of Andhra Pradesh on the East Coast of India. It is geographically located at the coordinates 17°N and 83°E. It has a tropical savanna climate as per Köppen's climate classification. Since the city is located on the Bay of Bengal Coast, its humidity remains high throughout the year. There is little variation in the daily temperature at Vishakhapatnam throughout the year. May is the hottest month and January is the coolest one. Madurai, located at the coordinates 9°N and 78°E, is one of the oldest cities in the Indian peninsula. It has a dry and hot climate as per Köppen's climate classification. Kochi is a major port city located on the southwest coast of India, in the state of Kerala flanked by the Arabian Sea on the west and the Western Ghats on the east. It is located at the coordinates 9°N and 76°E. It has a tropical monsoon climate as per Köppen's climate classification. Kochi has little seasonal temperature variation, with moderate to high levels of humidity throughout. From June through September, the southwest monsoon brings in heavy rains as Kochi lies on the windward side of the Western Ghats. From October to December, Kochi receives lighter rain from the North East monsoon, as it lies on the leeward side. Summer months from March to May at Kochi are uncomfortable due to high temperature and humidity.

It is well known that climate change has large uncertainties. When one examines climate change at a particular location, for example in a city, large uncertainties may be noticed in the daily data series in terms of fluctuations or noise. While identifying the changes in any climatic parameter at a place, it is prudent to examine the corresponding changes in the same parameters observed in larger spatial area surrounding the place of study. The robustness of any change at a place depends on similar changes in the larger area surrounding that