

Chapter 4

Heat and Cold Waves Over India

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1 Introduction

During the period 1901–2012, almost the entire globe has warmed with a rise of about 0.84 °C in the annual surface air temperature averaged over the globe (land + ocean) leading to significant changes in the frequency and intensity of extreme weather and climate events, such as heat waves (HWs) and cold waves (CWs), droughts and floods, hurricanes, tornadoes and thunderstorms, over various parts of the world (IPCC 2013). Changes in the extreme weather and climate events pose significant threats on our environment as well as on the life, health and well-being of the human society (Easterling et al. 2000; Meehl and Tebaldi 2004; Balbus and Malina 2009; Coumou and Rahmstorf 2012). The HWs and CWs are one of the less-known forms of extreme weather as they are not visible as other forms of severe weather. However, these abnormal temperature events can impose severe physiological stress on the human body as the body operates best within a fairly normal temperature range. There is a marked relationship between human mortality and thermal stress. During unusually cold/hot episodes, deaths from different causes can rise significantly with the elderly at greater risk than others (WMO 1996). In USA, 3829 of the 8015 heat-related deaths recorded during the period 1979–1999 were attributed to weather conditions (Donoghue et al. 2003). In 2003, Europe witnessed the hottest summer on record since 1540, which had huge adverse impacts (García-Herrera et al. 2010).

In India, manifold increase in the human deaths was observed during various heat waves (HWs) of 1995, 1998 and 1999 (De 2001). Similarly, an intense cold wave over North India during the first to third week of January 2003 caused deaths of more than 900 people of which 813 were from Uttar Pradesh (De et al. 2005). Figure 1 shows the deaths caused by HWs and CWs during the period 1971–2010. In Fig. 1, time series of deaths due to both HWs and CWs does not show any

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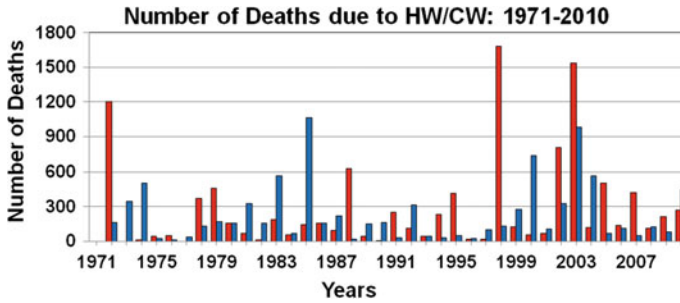


Fig. 1 Number of deaths in India annually due to HW/CWs for the period 1971–2010 obtained from media reports and IMD’s annual disaster weather reports. The red (blue) bars corresponds to deaths due to HW/SHWs (CW/SCWs) (color figure online)

noticeable trends. However, number of deaths due to heat wave events was the highest during the recent decade (2001–2010) compared to the previous three decades.

The heat (cold) waves represent rise (fall) of maximum (minimum) temperature at a given place by a certain amount from its climatological value. In India, the HWs are generally observed during March to July, and CWs are observed during November to March with each of these extreme events mostly experienced during the middle 3-month period of the respective seasons; hot weather season of April–June (AMJ) and cold weather season of December to February (DJF), respectively. Due to significant impact of HWs and CWs on the human health and observed changes in their frequency, intensity and persistency over various parts of the globe, there have been many studies on these extreme temperature events over India and their impact on human mortality (Raghavan 1966, 1967; Rai Sircar and Datar 1963; Natarajan 1964; Bedi and Parthasarathy 1967; Bedekar et al. 1974; Subbaramayya and Surya Rao 1976; Chaudhury et al. 2000; De 2001; De et al. 2005; Pai et al. 2004, 2013). However, each of these studies used different threshold temperature values to describe the HWs and CWs.

Here, we describe various characteristics such as frequency, persistency and spatial coverage of HWs and CWs in the country during the seasons of AMJ and DJF, respectively, and the associated decadal variations. In addition, trends in the frequencies of these extreme temperature events and changes associated with the two ENSO phases (El Nino and La Nina) have been also highlighted.

2 Definition of HW and CW

There is no universal definition for HW or CW. Different definitions of HW and CW are used in different countries. However, a HW (CW) over a region represents an interval of hotter (colder) than normal weather over the region. The criteria used

Table 1 Criteria used in this study for defining heat and cold waves

Criteria for declaring heat wave based on maximum temperature (T_{\max})
Heat wave over a station is declared only when the actual T_{\max} of the station is ≥ 40 °C for plains and ≥ 30 °C for Hilly regions. However, when the T_{\max} is ≥ 40 °C for coastal stations and ≥ 45 °C for other stations, conditions are declared as heat wave
The following criteria are used for defining severity of the heat wave
When normal $T_{\max} \leq 40$ °C and
i. if (actual T_{\max} – normal T_{\max}) is 5–6 °C: heat wave
ii. if (actual T_{\max} – normal T_{\max}) is ≥ 7 °C: severe heat wave
When normal $T_{\max} > 40$ °C and
i. if (actual T_{\max} – normal T_{\max}) is 4–5 °C: heat wave
ii. if (actual T_{\max} – normal T_{\max}) is ≥ 6 °C: severe heat wave
Criteria for declaring cold wave based on minimum temperature (T_{\min})
When the T_{\min} is ≤ 10 °C for coastal stations, conditions are declared as cold wave
The following criteria are used for defining severity of the cold wave over all the stations
When normal $T_{\min} \geq 10$ °C and
i. if (actual T_{\min} – normal T_{\min}) is –5 to –6 °C: cold wave
ii. if (actual T_{\min} – normal T_{\min}) is ≥ -7 °C: severe cold wave
When normal $T_{\min} < 10$ °C and
i. if (actual T_{\min} – normal T_{\min}) is –4 to –5 °C: cold wave
ii. if (actual T_{\min} – normal T_{\min}) is ≥ -6 °C: severe cold wave

for defining the HW and CW are given in the Table 1, which signify increase (decrease) in the daily maximum (minimum) temperature at a station by a certain threshold compared to a climatological value. In this study, we have used the base period of 1971–2000 for computing the climatological values. HW (CW) of relatively higher intensity is classified as severe HW (severe CW) or SHW (SCW).

3 Data and Methodology

The HW/SHW information of 103 stations uniformly distributed over the country for the AMJ season was derived from the daily maximum temperature data for the period 1961–2010. Data for at least 90 % of days were available in 95 out of 103 stations. For deriving CW/SCW information, daily minimum temperature data of 86 stations uniformly distributed over the country for DJF season for the period 1971–2010 were used. Data for at least 90 % of days were available in 90 out of 86 stations. Both the above data sets were obtained from the archive of the Climate Services Division, IMD, Pune.

Climate Prediction Center (CPC), USA, uses the Oceanic Nino Index (ONI) [3-month running mean of ERSST.v3b Sea surface temperature (SST) anomalies in the Nino 3.4 region (5°N–5°S, 120°W–170°W)] a threshold of ± 0.5 °C for defining El Nino/La Nina events. The events are declared when the threshold is met for a minimum of 5 consecutive overlapping 3-month seasons. In this study, for HW (CW) case, a reference year was classified as an El Nino/La Nina year, when any of

the three 3-month seasons of March to May, April to June and May to July (November of previous year to January of reference year, December of previous year to February of reference year and January to March of reference year) is part of the 5 consecutive overlapping seasons. As per this definition, for HWs during the period 1961–2010, 14 years (1963, 1965, 1966, 1969, 1972, 1982, 1983, 1987, 1991, 1992, 1997, 1998, 2002 and 2010) satisfied the El Nino criteria and 12 years (1964, 1971, 1973, 1974, 1975, 1976, 1985, 1988, 1989, 1999, 2000 and 2008) satisfied the La Nina criteria. Similarly for the CWs case, during 1971–2010, the 13 years (1973, 1977, 1978, 1983, 1987, 1988, 1992, 1995, 1998, 2003, 2005, 2007 and 2010) satisfied El Nino criteria and 15 years (1971, 1972, 1974, 1975, 1976, 1984, 1985, 1989, 1996, 1999, 2000, 2001, 2006, 2008 and 2009) satisfied the La Nina criteria. Differences in the spatial distribution of HWs/CWs associated with the El Nino and La Nina events were examined by preparing composite spatial maps of frequency of HWs/CWs for the respective El Nino/La Nina years.

The nonparametric Mann–Kendall test (Gilbert 1987) was employed to test the monotonic increasing or decreasing trends in the frequency and spatial coverage of the HWs/CWs. The Mann–Kendall test assumes the trends to be monotonic and thus no seasonal or other cycle is present in the data.

4 Heat Wave (HW)/Severe Heat Wave (SHW)

4.1 Climatology and Decadal Variation

Frequency of the HW/SHW Days

Figure 2a, b, respectively, depicts the spatial variation of mean number (frequency) of HW and SHW days over the country expressed as days per season for the AMJ season. Most areas of the country except north-east India and large parts of Peninsula have experienced on an average ≥ 2 HW days (Fig. 2a). This region hereafter called the core HW zone (CHZ) covers states of Punjab, Himachal Pradesh, Uttarakhand, Delhi, Haryana, Rajasthan, Uttar Pradesh, Gujarat, Madhya Pradesh, Chhattisgarh, Bihar, Jharkhand, West Bengal, Orissa and Telengana and met subdivisions of Marathwada, Vidharbha, Madhya Maharashtra and coastal Andhra Pradesh. Many areas of west Rajasthan, Punjab, Haryana, Vidharbha, coastal Andhra Pradesh, northern parts of East Rajasthan, Madhya Pradesh, Orissa, Telengana and southern parts of Uttar Pradesh and Chhattisgarh have experienced on an average ≥ 8 HW days. As shown in Fig. 2b, mean SHW days of 1–3 days were mainly experienced over isolated areas of north and eastern parts of the CHZ.

The decade wise spatial distribution of mean HW days for the AMJ season shows (Fig. 3a–e) that in all the 5 decades, on an average, ≥ 8 HW days/season were experienced by many areas from eastern parts of Peninsula, north and north-west India, and some areas of Central India. The overall decadal mean

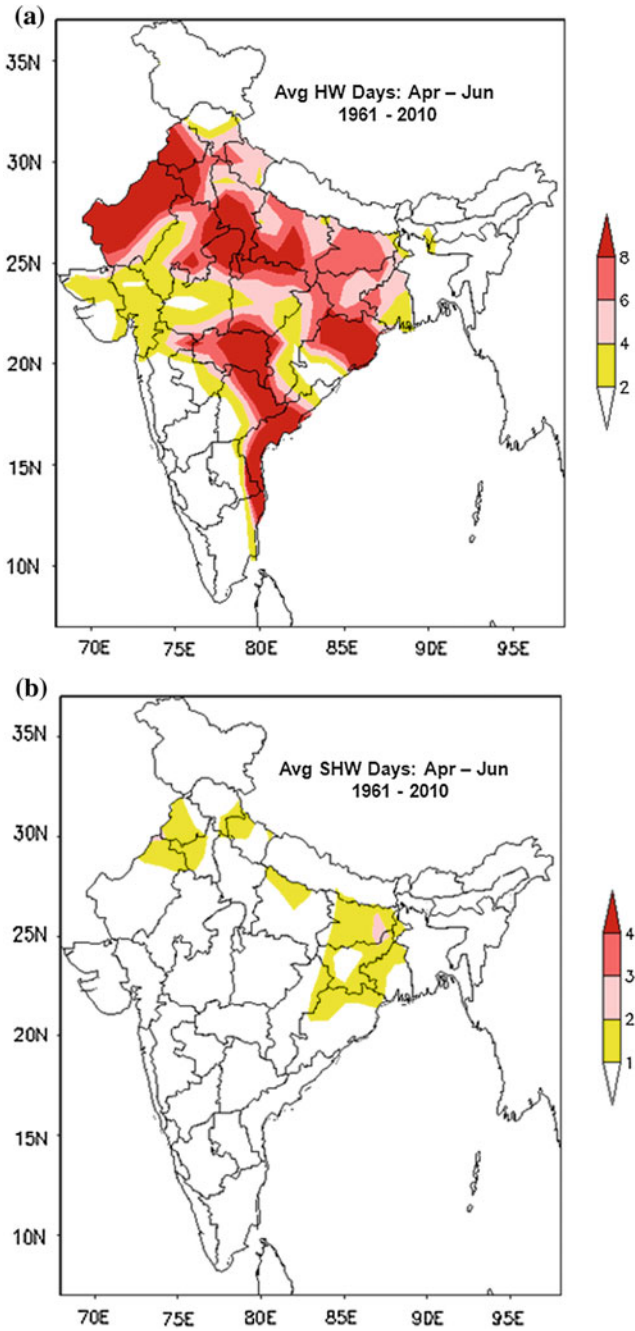


Fig. 2 a Average number of HW days over India during the hot weather season (AMJ) (1961–2010). b Same as a but for the SHW days

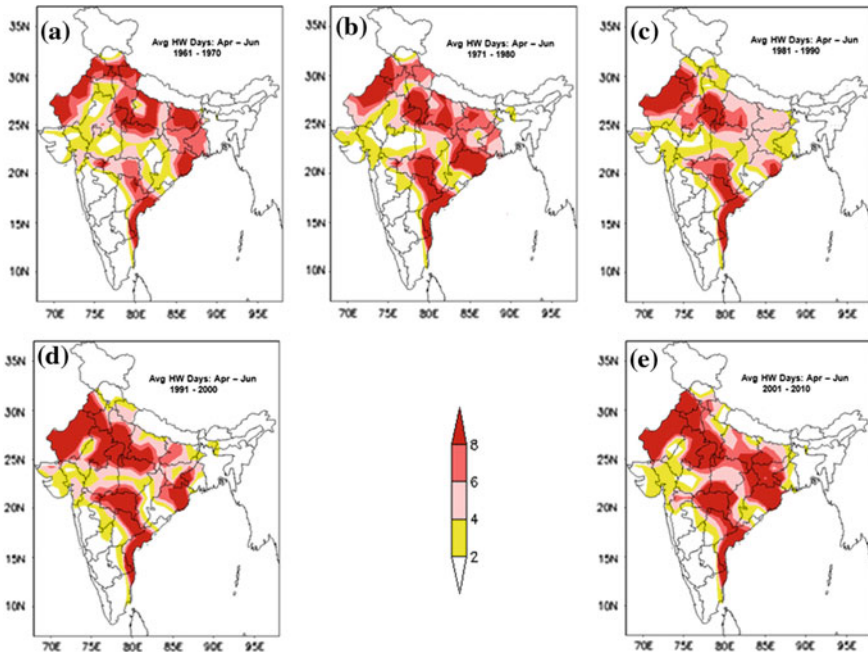


Fig. 3 Mean number of HW days over India during the hot weather season (AMJ) for the 5 decades viz. **a** 1961–70. **b** 1971–80. **c** 1981–90. **d** 1991–2000 and **e** 2001–2010

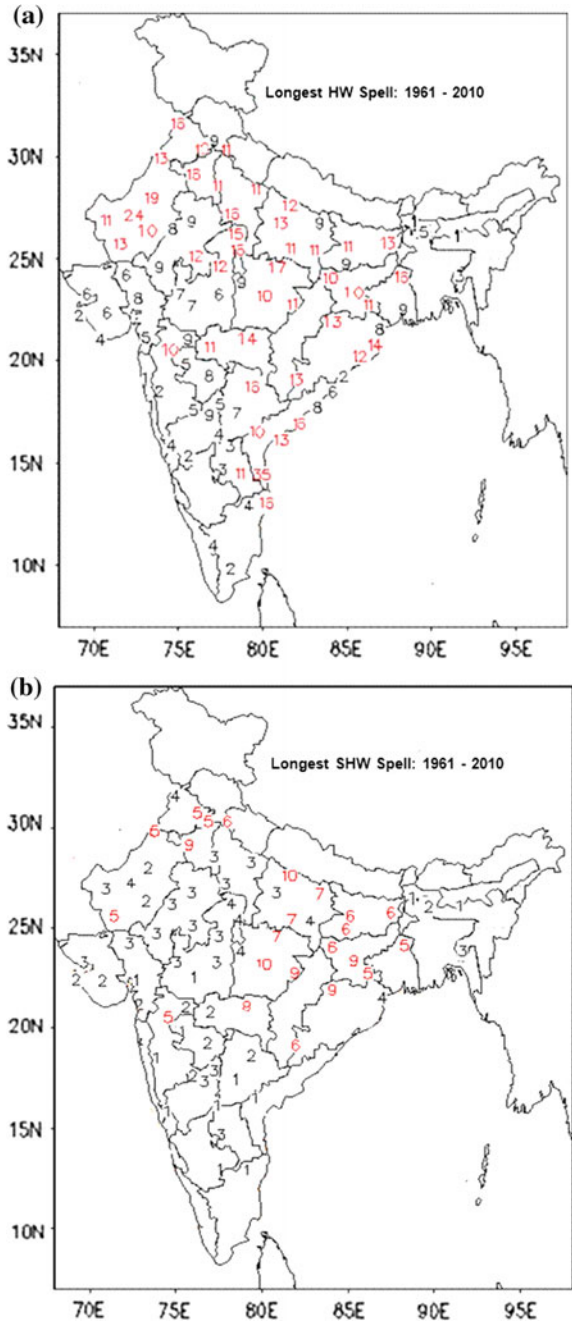
patterns of HW days during the last two decades were similar to that of middle decade (1981–90), but with areas of ≥ 8 HW days spread southwards over North India and northwards over the Peninsular. Among the 5 decades, the areas of ≥ 8 HW days over the north and north-west India during the recent two decades (1991–2000 and 2001–10) were slightly more and relatively south than that during the first two decades (1961–70 and 1971–80).

The decadal variation of the SHW days (figure not presented) showed increase in the frequency and areal coverage in the average SHW over north and eastern parts of CHZ during the recent two decades compared to previous three decades.

Persistency of HW/SHW Conditions

Duration of HW/SHW event is as important as its intensity as far as thermal stress on the human body. Therefore, it is interesting to know how many days these conditions are likely to persist or prevail once the conditions are set in. It was found that during all the decades and for most of the stations, most frequent HW/SHW spells were of about 1–2 days duration. However, few HW/SHW spells persisted for very long duration ($\geq 10/\geq 5$ days) in some stations. Fig. 4a, b depicts length of duration of the longest HW (SHW) spell in each station with duration ≥ 10

Fig. 4 a Station-wise duration of the longest HW spells during 1961–2010. The HW spells of ≥ 10 -day duration are shown using red colour. **b** Same as **a**, but for the SHW spells. The duration of SHW spells ≥ 5 days are shown using red colour (color figure online)



(≥ 5) days shown in red. Most of the stations north of 23°N and east of 78°E have experienced longest HW spells of duration ≥ 10 days (Fig. 4a) with 8 stations of central and the north-west India having longest HW spells of duration ≥ 15 days. Phalodi (West Rajasthan) among these 8 stations experienced the longest HW spell of duration of 24 days (17 May–9 June, 1994). Three stations from coastal regions of Andhra Pradesh and Tamil Nadu and 1 station each from West Bengal and Telengana have experienced longest HW spells of duration ≥ 15 days with Nellore (NLR) station from coastal Andhra Pradesh reporting the longest HW spell of 35 days duration (6 May–9 June, 1996). During the data period, all the stations together have experienced 38 HW spells of duration of ≥ 15 days. However, 20 of these HW spells were experienced in the last 2 decades compared to 18 spells experienced during the first 3 decades indicating increase in the persistency of HW conditions during the recent decades. Further, during only 23 years of the data period, duration of the longest HW spell was ≥ 15 days. Nellore alone has experienced 18 HW spells of ≥ 15 days duration. The longest HW spell during 4 of the five calendar decades, 1961–70 (30 days), 1981–90 (22 days), 1991–2000 (35 days) and 2001–2010 (22 days), was also experienced by Nellore. However, Bikaner had experienced longest HW spell of 19 days in the decade 1971–80. Thus, among all the stations, Nellore is most prone to longer HW spells.

The stations which reported the longest SHW spell of ≥ 5 days were mostly belonged to north-west, east India and neighbouring Central India (Fig. 4b). Most of the stations from east Uttar Pradesh and east Madhya Pradesh reported longest SHW spells of ≥ 7 days. Bhariach (BRC) in 2005 (11th–20th June) and Jabalpur (JBP) in 2009 (19th June–28th June) experienced the longest SHW spell of 10-day duration each. However, it was noticed that no stations from coastal Andhra Pradesh (including Nellore) had reported SHW spell of ≥ 7 days. This shows that whereas Nellore is prone to very long duration HWs, it rarely experiences long duration SHWs. During the entire data period, 10 SHW spells of duration ≥ 7 days of were reported by various stations with 6 of these SHW spells (all of duration ≥ 9 days) being experienced in the recent decade 2001–2010.

Spatial Coverage of the HW/SHW

As the hot season progresses, the areal coverage of HW/SHW shows noticeable increase (Raghavan 1966). The spatial coverage of a HW/SHW varies from event to event as well as year to year. Whenever a station reports HW/SHW conditions, area surrounding the station also experiences similar conditions. Therefore, number of stations affected by the event can be used as the proxy for the spatial coverage of the event. Here, spatial coverage of the HW (SHW) per season was computed as the number of stations affected by at least one spell of the HW (SHW) during that season. During the data period, the spatial coverage of HW varied from a few stations to many stations covering large part/whole subdivision to a group of

subdivisions. During the total period (1961–2010), on an average around 55 (14) out of 103 stations used in the study were affected by HW (SHW). Highest (71) stations), and lowest (27 stations) spatial coverage of the HWs was in 1972 (1990). Highest (41 stations) and lowest (0) spatial coverage of SHWs was in 2010 (1990). However, no trends were observed in both the time series.

4.2 HW/SHW Days and ENSO

Composite seasonal spatial maps of mean HW days over India for the 14 El Nino years as well as that of 12 La Nina years for the April–May–June season during the data period were prepared. Noticeably, higher frequency and spatial coverage of HW days were observed over CHZ in the El Nino case compared to the La Nina case (see Fig. 5). In case of El Nino, the areas of ≥ 8 HW days in the composite map extend northward along the Himalayan plains and eastward over Jharkhand and Bihar compared to that in the climatological map (Fig. 2a). However, in case of La Nina, the areas of ≥ 8 HW days in the composite map showed shrink over central and north-west India compared to that in the climatological map.

The composite maps of SHW days (figure not shown) showed that the composite areal coverage and frequency of SHW days during the El Nino (La Nina) case were more (less) than the climatology. In terms of persistency, it was observed that most of the longest HW/SHW spells were pertaining to the El Nino years.

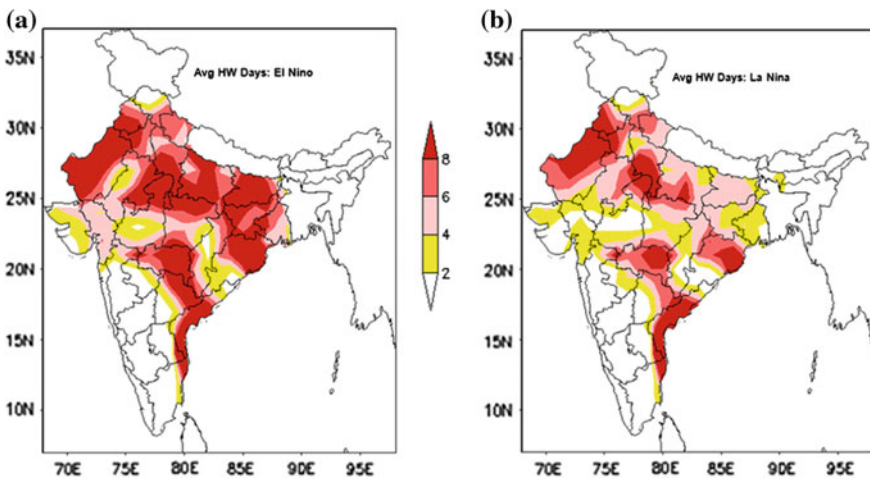


Fig. 5 Composite of average number of HW days during the AMJ season for the **a** 14 El Nino years and **b** 12 La Nina years

4.3 Trends in the Seasonal HW Days

Figure 6 shows the increasing (decreasing) trend in the station HW days using red rising arrow (blue falling arrow) with trends significant at 5 % or above level shown using filled arrows. About 20 stations from north India, north-west India, Central India and east coast showed significant increasing trends. These are also the stations that experience highest HWs during the season (Fig. 2a). However, 3 stations from the east coast (Kolkata Gopalpur, and Balasore) and 2 stations from North India (Ambala and Bhariach) showed significant decreasing trends. In case of SHW (Figure not shown), significant increasing trends were observed in 5 stations from north-west India (Amritsar, Hissar, Ganganagar, Phalodi and Jaipur). However, no stations showed significant decreasing trend. It was observed that even though the

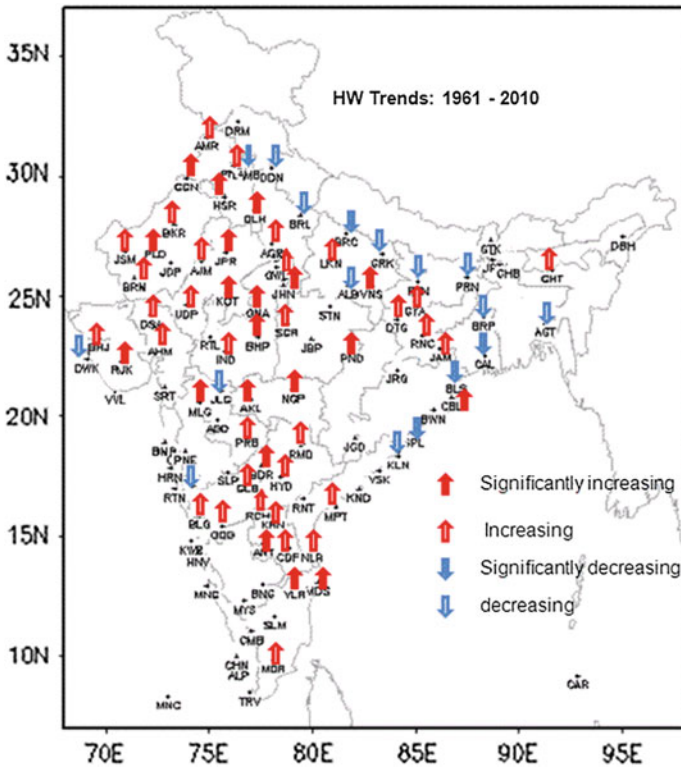


Fig. 6 Trends in the HW days of 103 stations during the AMJ season for the period 1961–2010. Nonparametric Mann–Kendall test was used to test the significance of the trends. Red rising (blue falling) arrows represent the increasing (decreasing) trends. Filled arrows represent the trends significant at 5 % level (color figure online)

day to day temperatures in the stations over the Peninsular India were not increasing above the HW/SHW thresholds, a general increasing trend was observed in the season averaged maximum temperatures over these stations.

4.4 Trends in the Total HW/SHW Days Over Core HW Zone (CHZ)

There are 71 stations in the CHZ. The time series of the total number of HW and SHW days over CHZ (Fig. 7a, b) for the period 1961–2010 shows slight but insignificant increasing trends. In Fig. 7, red (green) markers indicate El Nino (La Nina) years. The seasonal mean HW (SHW) days in the CHZ for the period 1961–2010 is 456 (39) days. In 9 (8) out of the 14 El Nino years, the HW (SHW) days in CHZ were more than its climatological value. Similarly, in 3 (1) out of the 12 La Nina years, the HW (SHW) days over CHZ were more than its climatological value. Decade wise, the HW (SHW) days over CHZ were less than normal during the first (middle) 3 decades with lowest decadal frequency of 393 (25) days in the central decade (1981–90). Among all the five decades, the highest decadal frequency of 536 (64) days was observed during the latest decade (2001–10).

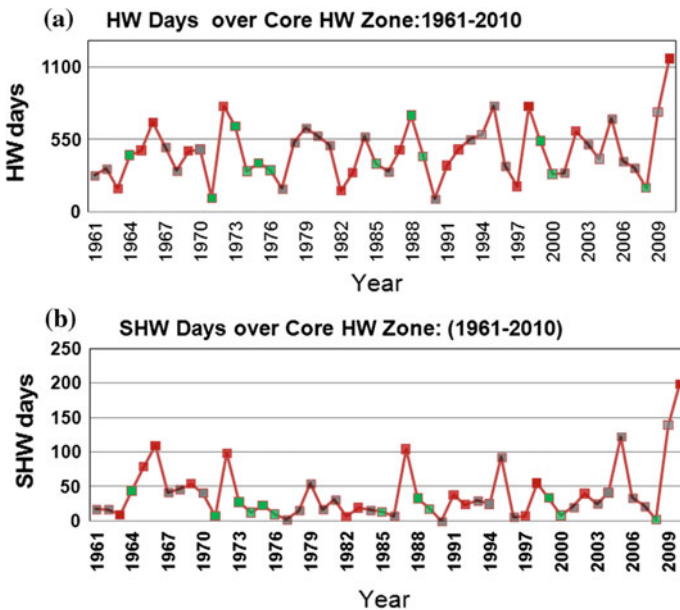


Fig. 7 Interannual variation **a** HW days and **b** SHW days in the core HW zone during the AMJ season for the period 1961–2010. The El Nino and La Nina years are indicated using red (green) markers (color figure online)

5 CW/SCW

5.1 Climatology and Decadal Variation

Frequency of the CW/SCW Days

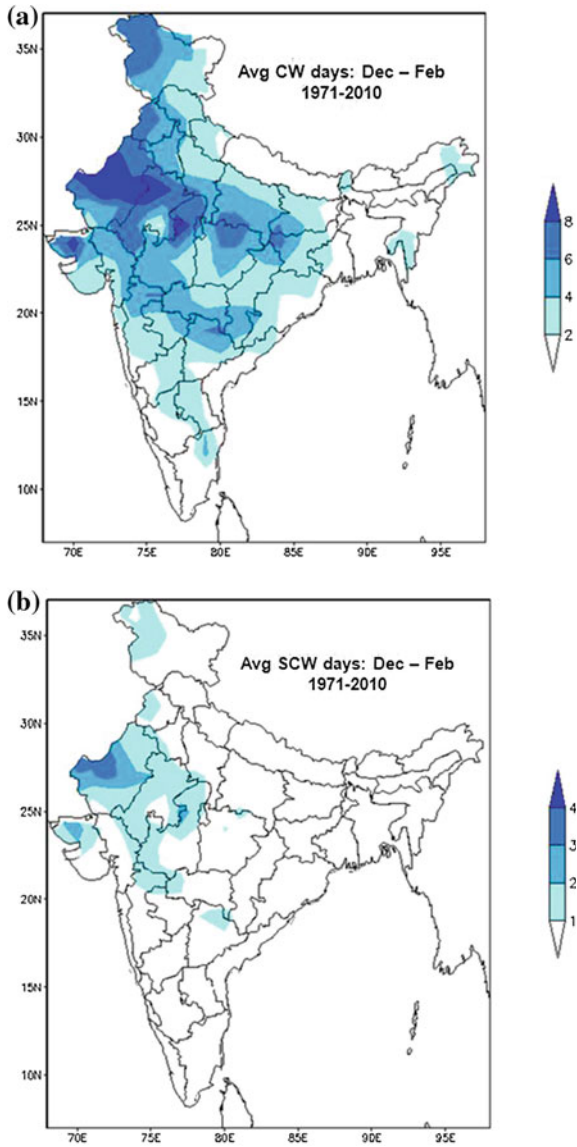
Figure 8a, b shows the spatial variation in mean number (frequency) of CW and SCW days, respectively, during the cold weather season (DJF) over the country. It is seen (Fig. 8a) that on an average ≥ 2 CW days per season were experienced by most of the areas except southern Peninsula and north-east India. This region hereafter called the core CW zone (CCZ) and nearly same as CHZ expect that CCZ includes Jammu and Kashmir and excludes coastal Andhra Pradesh. Many areas over north and north-west of CCZ experienced ≥ 6 CW days and 1–3 SCW days (Fig. 8b).

Month wise distribution of CW days showed (figures not given) that during December, CW days of ≥ 2 were experienced by most areas of Rajasthan, some northern parts of Gujarat and Madhya Pradesh and western parts of Jammu and Kashmir. During January, CW days of ≥ 2 were experienced by many areas of Punjab, Rajasthan, Madhya Pradesh, western part of J & K, southern parts of UP, northern parts of Maharashtra and some areas of Bihar, Jharkhand, Chhattisgarh and north Telengana. During February, the case was nearly similar to December except for reduced frequency of CW days over west J & K. During in all the 3 months, most of the Rajasthan experienced CW days of ≥ 2 days with some areas of ≥ 4 days. Month wise, SCW days were experienced mainly during January and February (about 1–2 days in an average and mostly over north and north-west areas of CCZ).

The decade wise spatial distribution of season average of CW days (Fig. 9a–d) shows overall decrease in the average CW days over the country going from 1971–1980 to 1991–2000 with systematic and noticeable decrease over north, north-west and north-east India and slight increase over some southern parts of Central India. However, during recent decade (2001–2010), there was slight increase in the spatial coverage and frequency of CW days compared to the previous decade (1991–2000). During 1971–1980, many areas of north and north-west India reported ≥ 6 CW days. However, during the subsequent decade (1981–90), the areas of ≥ 6 CW days were mainly restricted to north-west India. During subsequent decades, 1991–2000 and 2001–2010, the areas of CW days of ≥ 6 days showed further decrease over north-west India and an increase over southern parts of Central India. Decrease was also observed in the CW frequency over eastern parts of north-east India from about 2–6 days during the first two decades to less than 2 days during the recent two days.

The decadal variation of the average SCW days/season showed (figures not presented) relatively higher seasonal frequency of SCW days than its long-term

Fig. 8 a Average number of CW days over India during the DJF season computed using the CW information for the period of 1961–2010. **b** Same as **a**, but for SCW days



climatology during the first decade (1971–1980) over north and north-west area of CCZ. However, during the subsequent decades, an overall decrease in the average number of SCW days was observed over the region with lowest during 1991–2000 as in the case of CW days.

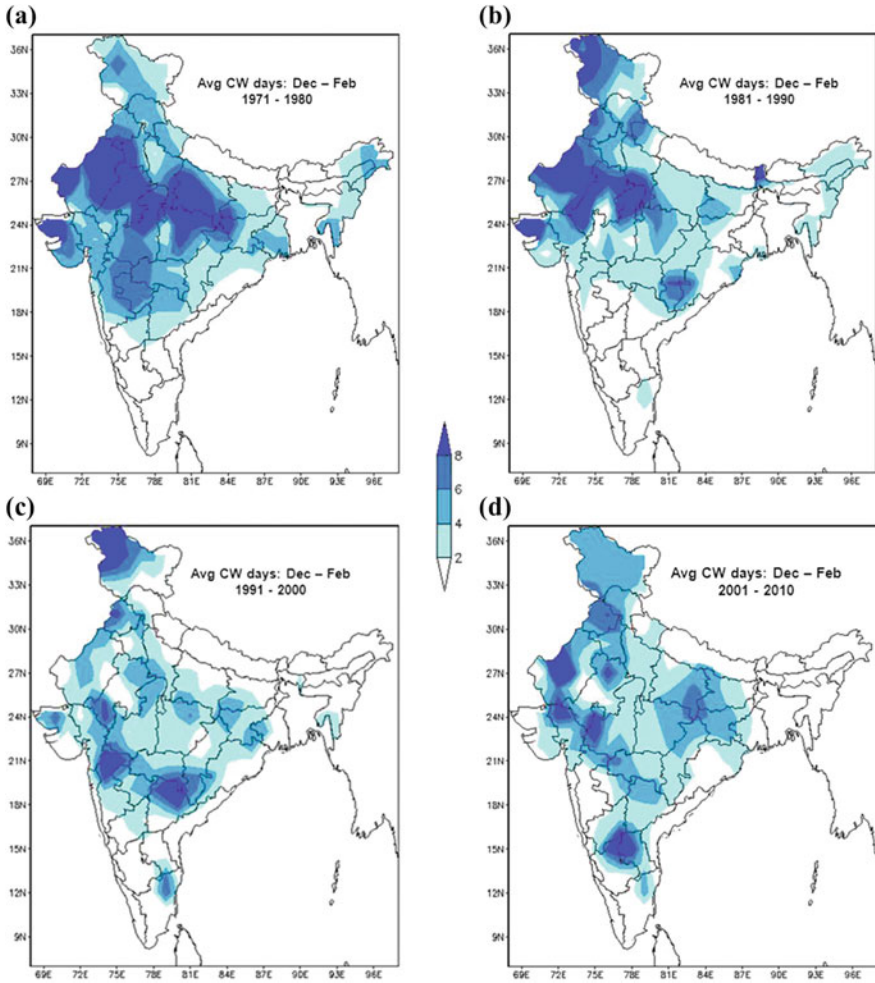
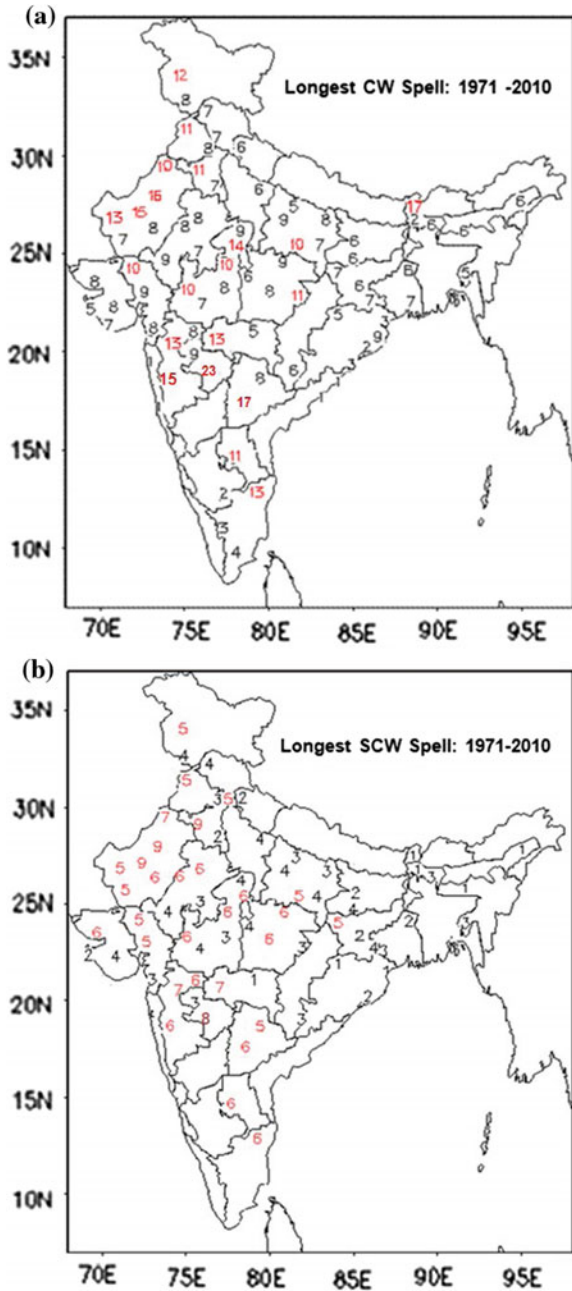


Fig. 9 Average number of CW days over India during the cold weather season (DJF) for the 4 decades viz. **a** 1971–80. **b** 1981–90. **c** 1991–2000 and **d** 2001–2010

Persistency of CW/SCW Events

For most of the stations, the most frequent CW/SCW spells were of about 1–2 days duration with some individual CW/SCW spells persisted over some stations for a very long period ($\geq 10/\geq 5$ days). Figure 10a, b shows the station-wise duration of the longest CW (SCW) spell in the country. The durations of longest CW (SCW) spells of ≥ 10 (≥ 5) days are shown in red. Stations that experienced longest CW (SCW) spells of duration ≥ 10 (≥ 5) days were mainly from north, north-west and central parts of CCZ. Gangtok from Sikkim, however, has experienced the longest CW spell of 17 days (10–26 December 1986).

Fig. 10 a Duration of the longest HW spells during 1961–2010. The HW spells of ≥ 10 -day duration are shown using *red colour*. **b** Same as **a**, but for the SCW spells. The duration of SCW spells ≥ 5 days are shown using *red colour* (color figure online)



Spatial Coverage of the CW/SCW

Number of stations affected by at least one spell of the CW (SCW) during a season was computed for the all the 40 years (1971–2010). During the period, on an average around 48 (17) out of 86 stations used in the study were affected by CW (SCW). The spatial coverage of CW was the highest (67 stations) in 1971 and 1972 and was the lowest (8 stations) in 2009. Highest and lowest spatial coverage of SCW (47 and 2 stations, respectively) was in 1984 and 2009, respectively. Decreasing trends significant at the 95 % confidence level was observed in spatial coverage of CW and SCW.

5.2 ENSO and CW Days

Composite seasonal spatial maps of mean CW days over India for the 13 El Nino years as well as that of 15 La Nina years for the DJF season during the data period are shown in Fig. 11a, b. In the El Nino case, the composite map showed relatively reduced frequency of CW days over most areas of CCZ. However, in the case of La Nina, significantly more number of CW days were seen in most parts of CCZ. In the case of SCW also (Figures not presented), significant increase (decrease) in the frequency of the SCW days were observed in the northern and north-western parts of CCZ during La Nina (El Nino) years.

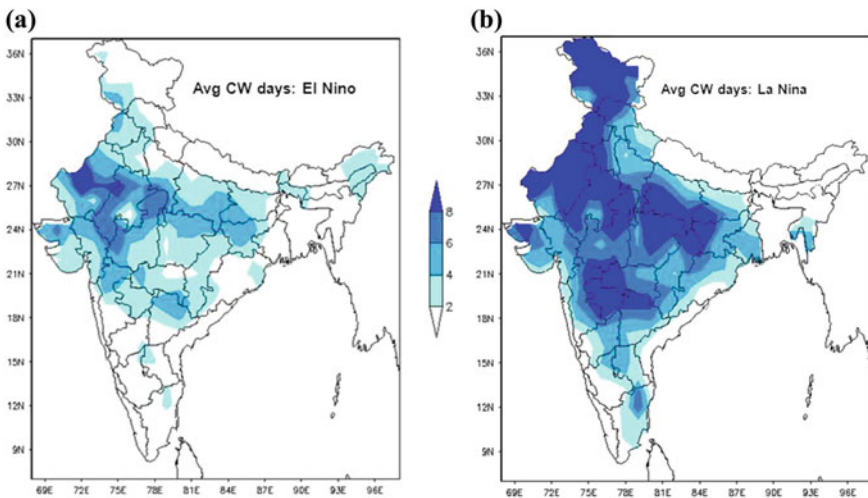


Fig. 11 Maps showing composite of average number of CW days during the AMJ season for the **a** 13 El Nino years and **b** 15 La Nina years

5.3 Trends in the Station-Wise Seasonal CW/SCW Days

In Fig. 12, red rising arrow (blue falling arrow) are used to represent stations with increasing (decreasing) trend in the CW days with filled arrows showing trends significant at the 95 % confidence level. Decreasing trends were observed in most of the stations (Fig. 12) north of about 18°N with significant trends observed in 23 stations (mostly from north and north-west parts of CCZ). On the other hand, two stations from south Peninsula (Ananthapur and Vellore) showed significant increasing trends. In case of SCW (figure not shown), decreasing trends were observed in many stations of CCZ with significant trends observed in 9 stations from north-western part and 4 stations from central part of CCZ. One station from south Peninsula (Ananthapur) showed significant increasing trend. The decreasing trends in the CW/SCW days was also corroborated by the increasing trends (figure not showed) in the season averaged (DJF) minimum temperature anomalies over

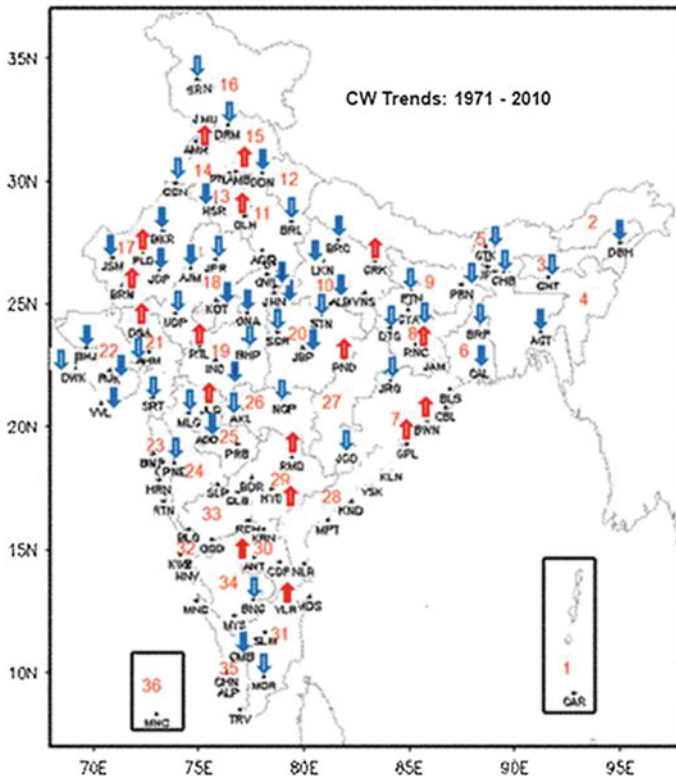


Fig. 12 Trends in the CW days of 86 stations during the DJF season for the period 1971–2010. Nonparametric Mann–Kendall test was used to test the significance of the trends. Red rising (blue falling) arrows represent the increasing (decreasing) trends. Filled arrows represent the trends significant at 5 % level (color figure online)

most of the stations from the country (Chap. 2) for the period 1971–2010. Of the total stations, 38 stations showed significant increasing trends in the seasonal minimum temperature anomaly.

5.4 Trends in the Total CW/SCW Days Over CCZ

There are 63 stations in the CCZ. Decreasing trends at significant level of 95 % can be seen in both the time series of the total number of CW and SCW days over CCZ during the DJF season for the period 1971–2010 (Fig. 13a, b). Red (green) markers indicate El Nino (La Nina) years. The mean CW (SCW) days over the CCZ for the period 1971–2010 was 300 (52) days. In 5(4) out of the 13 El Nino years, and 8(6) of the 15 La Nina years, the CW (SCW) days over CCZ were above its climatological value. Decade wise, the CW (SCW) days over CCZ during the first decade was more than the normal value with higher decadal frequency of 464 (91) days during the first decade (1971–80) and that during the last 3 decades were below the normal value with lower decadal frequency of 213 (28) days during the third decade (1991–2000).

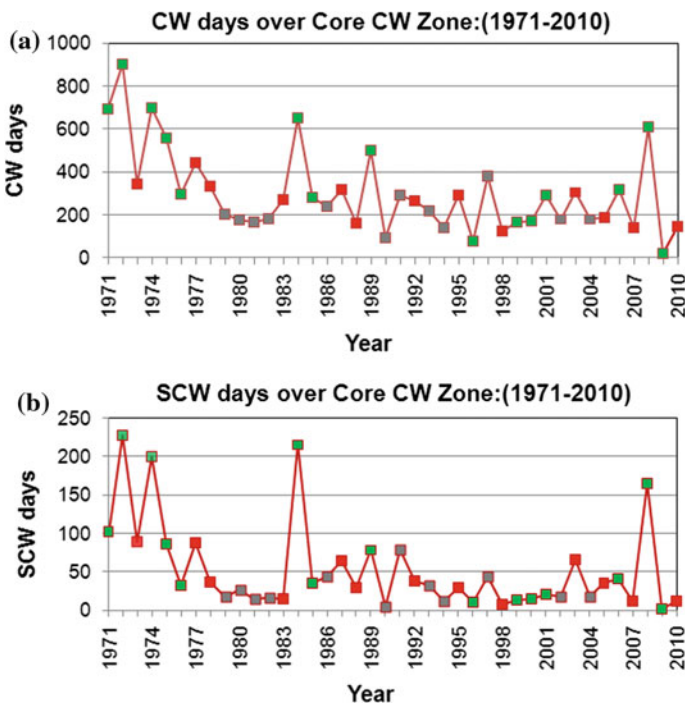


Fig. 13 Interannual variation **a** CW days and **b** SCW days in the core CW zone during the DJF season for the period of 1971–2010. The El Nino and La Nina years are indicated using red (green) markers (color figure online)

6 Conclusions

From the examination of various features of the HW (SHW) from 103 stations during the last five decades (1961–2010) and that of CW (SCW) from 86 stations during the last four decades (1971–2010), the following conclusions can be drawn.

1. During the hot weather season (AMJ), stations from the north, north-west, central, east India and north-east Peninsula (together called CHZ) are most prone for HW/SHW days with relatively highest frequency experienced during May. During the cold weather season (DJF), stations from CCZ that is nearly same as CHZ but includes Jammu and Kashmir and excludes coastal Andhra Pradesh are most prone for CW/SCW days with the highest frequency during January.
2. Appreciable increase (decrease) in the frequency and spatial coverage of HW/SHW days was observed over CHZ during the El Nino (La Nina) years. In case of CWs, the case was exactly opposite with decrease (increase) in their frequency and spatial coverage observed over the CCZ during the El Nino (La Nina) years.
3. Appreciable decadal variation was observed in the frequency, spatial coverage and area of maximum frequency both in the HW/SHW days and CW/SCW days. Decade wise, the all India frequency of HW days during the first 3 decades was less than normal with the lowest decadal frequency of 413 days during the middle decade (1981–90) and that during the last 2 decades were above normal value with the highest decadal frequency of 575 days during the latest decade (2001–10). The SHW days also showed similar decadal variation with the lowest (highest) frequency of 25 (67) during 1981–90 (2001–2010). However, above normal SHW days were also observed in the first decade (1961–70). In case of CWs, an overall decrease in the average CW/SCW days was observed from 1971–1980 to 1991–2000. But in the recent decade (2001–2010), there was slight increase in the area of coverage and frequency of CW days compared to the previous decade (1991–2000).
4. Significant increasing (decreasing) trends in the HW (CW) days were observed in many stations over CHZ (CCZ). However, insignificant increasing trend was observed in the total HW days of CHZ, and significant decreasing trend was observed in the total CW days of CCZ.
5. According to the latest IPCC report (IPCC 2013), the global averaged temperature during each of the last three decades has been warmer than any preceding decade since 1850 (Chap. 2). The observed increasing (decreasing) trend in the frequency of HW/SHW (CW/SCW) activity in recent decades, therefore, might be regional impact of the observed decadal scale global warming. Other possible reasons behind these changes are local factors such as deforestation and urbanization, which might have changed the exposure conditions of many of the stations used in this study. It may also be mentioned that the observed changes in the various characteristics of the HWs and CWs over India were in consistent with similar studies from various other parts of the world.

The latest projections from climate models (IPCC 2013) also suggest that increase (decrease) in the frequency, intensity and persistency of the HW (CW) are likely to continue due to the projected increase in the mean global temperatures. Therefore there is a need for proper operational service systems in the country for the advance warning of the heat and CWs, public information campaigns on dangers of these extreme temperature events, and social care networks to reach vulnerable sections of the populations.

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