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Long term climatology and trends of heat waves over India during the recent 50 years (1961-2010)

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सार – इस शोध पत्र में भारत की मुख्य भूमि के 103 स्टेशनों से ग्रीष्म ऋतु (मार्च से जुलाई) के दौरान के विगत 50 वर्षों (1961–2010) के ऊष्ण लहर या लू के आँकड़ों का उपयोग करते हुए ऊष्ण लहरों (HWs) तथा अति ऊष्ण लहरों या भीषण लू (SHWs) के विभिन्न सांख्यिकीय पहलुओं जैसे कि दीर्घ अवधि जलवायु, दशकीय विविधता और दीर्घ अवधि प्रवृतियों की जाँच की गई है। ऊष्ण लहरें / भीषण ऊष्ण लहरें ऐन्सो (ENSO) से जुड़ी हैं जो विश्व के मौसम को प्रभावित करती है, उसकी भी यहाँ जाँच की गई है। ऐसा पाया गया है कि देश के अनेक भागों (उत्तर, पश्चिमोत्तर, मध्य और पूर्वोत्तर प्रायद्वीप) में प्रत्येक ऋतु में औसतन 8 या उससे कम ऊष्ण लहरों वाले दिनों में ऊष्ण लहरें महसूस की गई। देश के उत्तर, पश्चिमोत्तर और मध्य भागों में मुख्य रूप से भीषण ऊष्ण लहरों का अनुभव किया गया है। पिछले चार दशकों की तुलना में अभी हाल के दशक 2001–2010 के दौरान समूचे देश में ऊष्ण लहरों / भीषण ऊष्ण लहरों वाले दिनों की संख्या में बढ़ोतरी देखी गई है जो देश और भूमंडल के लिए भी सबसे अधिक गर्म दशक रहा है। इस विश्लेषण अवधि के दौरान भारत में ऊष्ण लहरों वाले दिनों में महत्वपूर्ण रूप से बढ़ोतरी का रूख देखा गया है। उत्तर पश्चिमोत्तर तथा मध्य भारत के लगभग 25 स्टेशनों के आँकड़े ऊष्ण लहरों वाले दिनों में महत्वूपर्ण रूप से बढ़ोतरी के रूख को दर्शाते हैं और पश्चिमोत्तर भारत के 5 स्टेशन भीषण ऊष्ण लहरों वाले दिनों में महत्वपूर्ण रूप से वृद्धि के रूख को दर्शाते हैं। यद्यपि कुछ स्टेशनों पर ऊष्ण लहरों वाले दिनों (उत्तर भारत के 2 स्टेशन तथा पूर्वीतट के 3 स्टेशन पर) और भीषण ऊष्ण लहरों वाले दिनों (पूर्वीतट के 2 स्टेशन पर) में महत्वपूर्ण रूप से गिरावट की प्रवृत्ति देखी गई है। सामान्यतः ऊष्ण लहरों/भीषण ऊष्ण लहरों वाले दिनों की बारंबारता, स्थायित्तव और आवृत्त क्षेत्र अलनीनों वर्षों के बाद के वर्षों (अलनीनों +1) के दौरान औसत से अधिक पाए गए हैं।

ABSTRACT. Using HW information of 103 stations from Indian main land during the hot weather season (March to July) for the last 50 years (1961-2010), various statistical aspects of heat waves (HWs) and severe heat waves (SHWs) such as long term climatology, decadal variation, and long term trends were examined. The link of HWs/SHWs with ENSO phenomena, which has known impact on the weather world over was also examined. It was observed that many areas of the country (north, northwest, central and northeast Peninsula) have experienced HW days of $\geq$8 HW days on an average per season. The SHW were mainly experienced over north, northwest and central parts of the country. Compared to previous four decades, there was noticeable increase in the HW/SHW days over the country during the recent decade 2001-2010, which is also the warmest decade for the country as well as for the globe. Significant long term increasing trends in HW days was also observed over India during the analysis period. About 25 stations from north, northwest and central India showed significant increasing trend in the HW days and 5 stations mainly from northwest India showed significant increasing trend in SHW days. However, few stations have shown significant decreasing trend in HWs (2 stations from north India & 3 stations from east coast) and SHWs (2 stations from east coast). In general, the frequency, persistency and area coverage of the HW/SHW days were found to be more than average during years succeeding El Nino (El Nino +1) years.

Key words – Heat waves, Decadal variation, Climate change, Long term trends, Climatology, ENSO.

1. Introduction

According to a recent IPCC report (IPCC, 2007), during the 100-year period (1906 to 2005), the mean annual global (land + ocean) surface air temperature has increased by about 0.74 °C and during the same period, the global averaged annual land surface air temperatures have increased much faster than the global averaged annual sea surface temperatures. The report also noted significant changes in the frequency and intensity of extreme weather events like HWs, droughts, floods and hurricanes over various parts of the world. During the last decade, several cases of severe heat waves (SHWs) have occurred over various global regions (Stott *et al*., 2004;

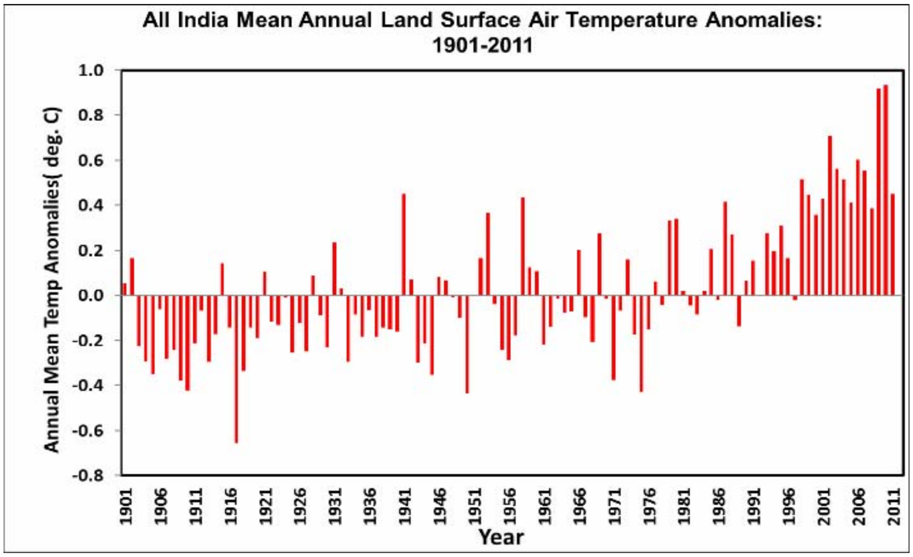


Fig. 1. Annual mean land surface air temperature anomalies averaged over the country as a whole (All India) for the period 1901-2011. The period of 1971-2000 was used for computing the anomalies. (*Source* : IMD, 2012)

Trigo *et al*., 2005; Barripedro *et al*., 2011). A recent study (Perkins *et al*., 2012), based on the analysis of multiple indices derived from the latest HadGHCND daily maximum temperature, minimum temperature and average temperature for the period 1950-2011, found increasing global trends in the intensity, frequency and duration in the observed summer time heat waves and annually calculated warm spells. The study also observed that in some regions, the non-summer warming events are driving the trends in the annual events. The changes in the frequency or intensity of these extreme events have profound impact on human society and the natural environment (Parker *et al.,* 1994; Easterling *et al.,* 2000; Meehl and Tebaldi, 2004; Coumou and Rahmstorf, 2012). The heat stress and exacerbated underlying conditions associated with HWs can cause an increase in the human deaths. In the United States, 3,829 of the 8,015 heat-related deaths recorded during the period 1979-1999 were attributed to weather conditions (Donoghue *et al*., 2003). The European summer HW of 2003, which was the hottest summer on record in Europe since at least 1540, had significant societal and environmental impact across the Europe (García-Herrera *et al*., 2010). France was hit especially hard. The HW led to health crises in several countries and combined with drought to create a crop shortfall in parts of Southern Europe. This extreme episode was directly associated with approximately 40,000 extra death particularly of elderly people in various parts of Europe, which corresponds to 20 times the excess mortality recorded during the 1995 Chicago, USA HW. Chase *et al*., (2006) on examining the 2003 Europe HW in the global context by analyzing the daily temperature anomalies for all parts of the globe for the 25-year period (1979-2003) found regular occurrence of extreme warm anomalies equally, or more, unusual than the 2003 HW. However, such events were rarely observed in summer and directly over Europe, where many residents do not have the air conditioning facility. Chase *et al.*, (2006) also found natural variability in the form of El Niño and volcanism to be of much greater importance than any general warming trend in causing extreme regional temperature anomalies.

The WMO statements on global climate during recent two years (WMO, 2011 & 2012) indicate that the global temperatures are continuing to increase. Whereas the year 2010 was warmest year along with 2005 since 1880, the available observations till date showed that the year 2011 was the world's 10th warmest year and warmest year with La Nina on record. The 2010 Northern Hemisphere summer was marked by exceptional HWs that impacted most of the United States, Kazakhstan, Mongolia, China, Hong Kong, North Africa and the European continent as a whole, along with parts of South Asia, Canada, Russia, Indochina, South Korea and Japan. During July, 2011 number of deaths related to severe HW events were reported from various parts of USA with Oklahoma and Texas reporting their warmest months ever on record. A new statistical analysis by Hansen et al, 2012 has found that the extreme anomalies in the surface temperatures such as those observed in Moscow in 2010 and Texas and Oklahoma, USA in 2011 were a consequence of global warming. These studies therefore indicate that the impact of the global warming on the extreme events like HWs is likely to continue. Therefore,

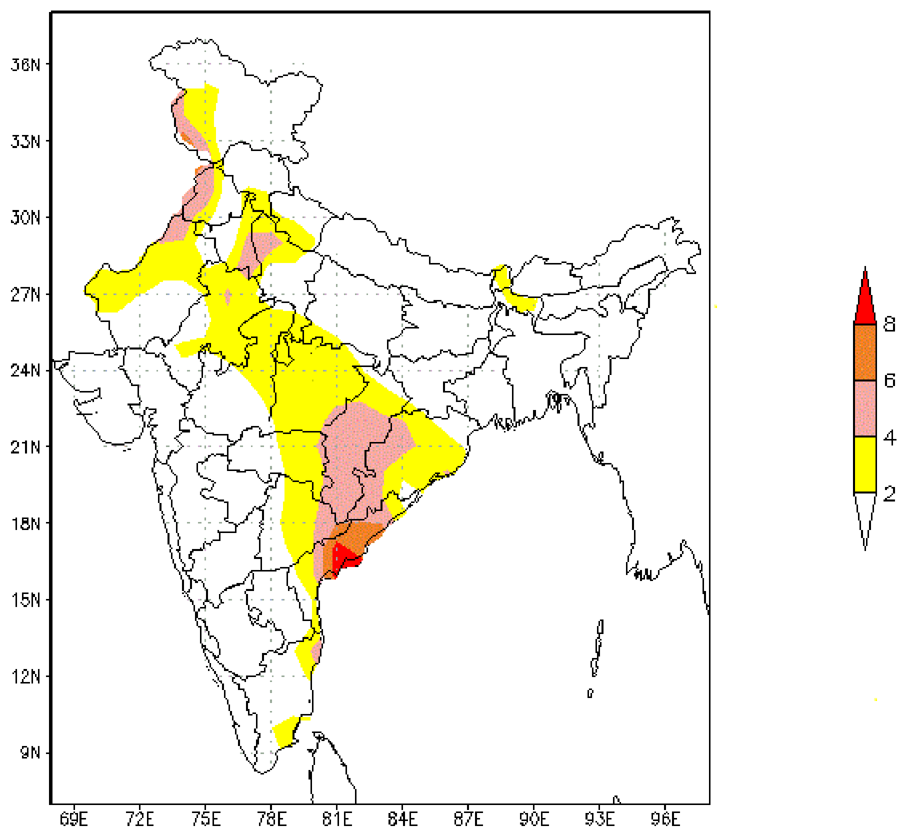


Fig. 2. Composite maximum temperature anomaly map over India for the HW period of 9-15th May, 2002 based on the data of 103 stations used in this study

more studies particularly in the regional level are necessary to examine impact of global warming on the extreme weather and climate events.

In tune with the global warming trend, the temperatures over India have also shown noticeable warming trend. As per the recent India Meteorological Department (IMD) report on annual climate over India (IMD, 2012), during the recent 111 years (1901-2011), the linear trend per 100 years in the annual mean land surface air temperature anomalies averaged over India was 0.59 °C. This is shown in Fig. 1**,** which is a re-plotted figure from the IMD report. As seen in this figure, the annual mean land surface air temperature anomaly averaged over the country as a whole in 2010 was 0.93 °C and the year was warmest among all the years during the entire 111 years of data. Noticeably, all the warmest 7 years in the country including 2010 have occurred during the recent decade (2001-2010) making the decade warmest ever in the record. The other 6 years in the decreasing order of the annual mean surface air temperature anomaly are 2009 (0.92 °C), 2002 (0.71 °C), 2006 (0.60 °C), 2003 (0.56 °C) and 2007 (0.55 °C). It may be mentioned that in 2010, the country as a whole also experienced warmest pre-monsoon season (March-May) on record since 1901 with the mean temperature anomaly averaged over the country during the season being 1.8 °C. The linear trend per 100 years in the mean land surface air temperature anomalies during the pre-monsoon season averaged over India was 0.59 °C. Associated with this warming trend, severe HW events that killed thousands of the people have occurred in the country. For example, during a typical intense heat wave over southeastern coastal state of Andhra Pradesh during the period 9-15th, May 2002, more than 1000 people were killed. A map of composite daily maximum temperature anomalies associated with this Heat Wave event is given in Fig. 2. The composite average maximum temperature anomalies of ≥ 6 °C were observed over many areas of coastal Andhra Pradesh. About 200 people were also killed in other parts of the country associated with other HW events in the same month. In the subsequent year (2003) also, more than 1000 people mostly poor and elderly were killed in this coastal state in association with the HWs during the period May to June. In May 2010 during a HW event, more than 250 persons were killed in north India.

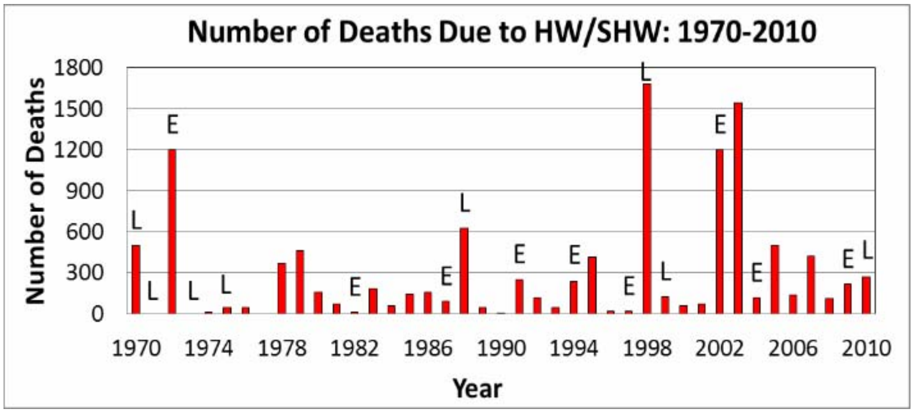


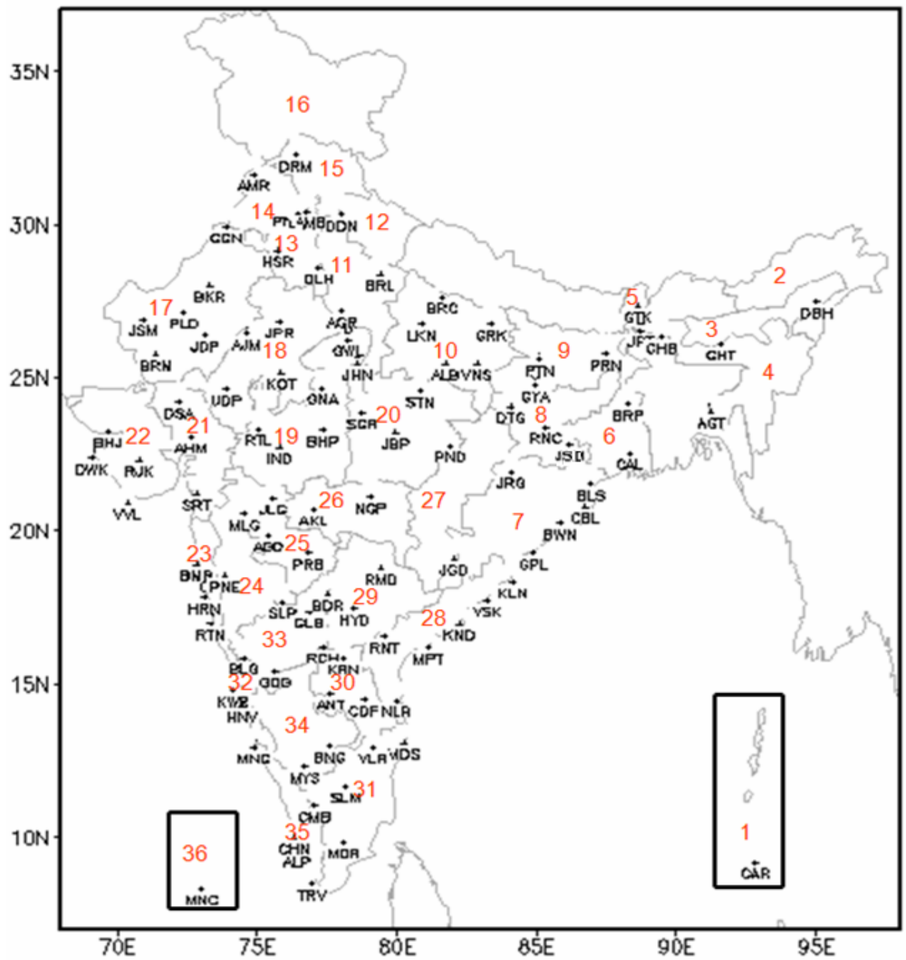
Fig. 3. Number of deaths reported in India annually in association with HW/ SHWs for the period 1970-2010. The data were collected from media reports and IMD's reports on annual disaster weather events. The vertical bars corresponding to EL Nino (La Nina) years are labeled as E (L)

Fig. 3 shows the loss of human lives due to heat waves in India during the period 1970-2010. The data regarding deaths related to the HW events were collected from reports of Disastrous weather events published by India Meteorological Department and various media reports. Highest number (1681) of deaths related to HW was reported in 1998 followed by 2003. As seen in this figure, though there is slight increase in the number of yearly deaths related to HWs during recent years, no noticeable trend is visible in the time series. However, the recent decade (2001-2010) registered the highest number of deaths due to heat wave events compared to previous 3 decades. Chaudhury *et al.*, (2000) observed mortality associated with HW/SHW to be more during years followed by El Nino events than El Nino years. This is reflected in the Fig. 3 also as the number of deaths related to HWs in years following El Nino years (1983, 1988, 1995, 1998, 2003, 2005 & 2010) were more than that during the El Nino years. However, the year 1973 (year following El Nino year 1972) was an exception as the number of deaths associated with HWs were less in 1973 than 1972.

In India, the HW conditions are generally experienced during the period from March to July. There have been earlier studies on the HWs over India (Raghavan 1966; Natarajan 1964; Bedekar *et al.*, 1974; Subbaramayya and Surya Rao 1976; Chaudhury *et al.*, 2000; De 2001 & De *et al.*, 2005; Pai *et al.*, 2004) which provided some idea about climatological characteristics of HWs over India. Pai *et al.* (2004) using daily sub-division scale HW information over all the meteorological subdivisions of India (country was divided into 35 sub-divisions at that time) for the period 1971-2000, examined the decadal changes in the various characteristics of HW (SHW) over the country. The study revealed a significant increase in the frequency, persistency and spatial coverage of HWs during the decade (1991-2000). However, in the present study, the main aim is to use station wise HW(SHW) information from a network of uniformly distributed stations over a longer period [*i.e.*, for the recent 50 years period (1961-2010)] to examine the long term climatology and trends in the frequency, persistency and spatial coverage of HWs/ SHWs over India. The decadal variations of the HW features have also been examined. As the ENSO phenomena in the Pacific is known to impact weather and climate over various parts of the world, the impact of this phenomena on the HWs over India was also examined.

2. Data and methodology

There is no universal definition of a HW. In general, a HW over a region refers to a prolonged period of excessively hot weather (above certain threshold temperature value) over the region, which may be accompanied by high humidity. Different definitions are used in different countries. In United States of America (USA), though the definition of HW slightly varies from region to region, the most commonly used definition of a HW is the period of at least three consecutive days above 32.2 °C (90° F). In Australia, HW is declared if there are five consecutive days at or above 35 °C (95° F), or three consecutive days at or over 40 °C (104° F). Denmark declares HW if for a period of at least 3 consecutive days, average maximum temperature exceeds 28 °C across more than 50% of the country.



No.	Sub-division Name	No.	Sub-division Name
1	A & N islands	19	West Madhya Pradesh
2	Arunachal Pradesh	20	East Madhya Pradesh
3	Assam & Meghalaya	21	Gujarat region,DNH & Daman
4	Naga.,Mani.,Mizo.& Tripura	22	Saurashtra ,Kutch & Diu
5	Sub-HimalayanW.B.& Sikkim	23	Konkan & Goa
6	Gangetic West Bengal	24	Madhya Maharashtra
7	Orissa	25	Marathawada
8	Jharkhand	26	Vidarbha
9	Bihar	27	Chattisgarh
10	East Uttar Pradesh	28	Coastal Andhra Pradesh
11	West Uttar Pradesh	29	Telangana
12	Uttarakhand	30	Rayalaseema
13	Haryana,Chandigarh & Delhi	31	Tamil Nadu & Pondicherry
14	Punjab	32	Coastal Karnataka
15	Himachal Pradesh	33	North Interior Karnataka
16	Jammu & Kashmir	34	South Interior Karnataka
17	West Rajasthan	35	Kerala
18	East Rajasthan	36	Lakshadweep

Fig. 4. Locations of 103 stations over India used in this study. Boundaries of the 36 meteorological sub-divisions of the country are shown in the map along with the sub-division numbers. The names of the sub-divisions corresponding to the sub-division number are also listed for easy geographical reference

TABLE 1

Definition of HW/SHW used in this study (IMD, 2002)

1. Heat wave need not be considered till maximum temperature of the stations reaches at least 40 °C for plains and at least 30 °C for Hilly regions
2. When normal maximum temperature of a station is less than or equal to 40 °C
    a. Heat wave : Departure from normal is 5 °C to 6 °C
    b. Severe heat wave : Departure from normal is 7 °C or more
3. When normal maximum temperature of a station is more than 40 °C
    a. Heat wave Departure from normal is 4 °C to 5 °C
    b. Severe heat wave Departure from normal is 6 °C or more
4. When actual maximum temperature remains 45 °C or more irrespective of normal max. temperature Heat wave should be declared.
5. For Coastal stations if the maximum temperature of 40 °C is reached "Heat wave" may be declared.

The criteria (IMD, 2002) used by India Meteorological Department (IMD) for defining the HW and Severe HW (SHW) conditions over India since 2002 are given in the Table 1. It is seen in Table 1 that the HW/SHW conditions signify certain amount of rise of daily maximum temperature at a station with respect to normal climatological value computed for the period 1971-2000. For this study, we used criteria given in the Table 1 for defining HW/SHW conditions over the stations. The daily maximum temperature data of 103 stations uniformly distributed over the country for the period 1961-2010 was used. The Fig. 4 shows the locations of these stations on an India map. The boundaries of the 36 meteorological sub-divisions are also indicated in the map. Each of these sub-divisions has been given a number which is shown in the map. The names of all the 36 sub-divisions are listed side by for quick geographical reference. The daily station temperature data for the period 1969-2010 which is readily available in the electronic format were obtained from the National Data Center (NDC) of IMD, Pune. The data for the period 1961-68 were manually gathered into a spreadsheet from Indian Daily Weather Report (IDWR) logs.

Out of the total 103 stations, 95 stations had daily maximum temperature data available for at least 90 percentage of the total number of days during the period. It has been found that approximately 99% of the temperature values fall within the range of mean $\pm$ 3 S.D (Karl Pearson's Correlation Formula). Any outliers (*i.e.*, values beyond 3 SD from the mean) or abnormally large difference in the maximum temperature between two consecutive days in the data set were scrutinized by taking current weather into consideration and were accordingly assimilated into the data. In order to derive the station wise HW/SHW information, at first, daily normal of the maximum temperatures for all of the stations were computed for all the days of the hot weather season using all the data available during the period 1971-2000. Using these daily normal maximum temperature data, daily anomalies were computed and using the criteria given in the Table 1, days that satisfied the HW/SHW conditions for each station were identified. This formed the basic information for examining various climatological features and trends in the HW/SHW conditions over India in this study. The climatological features of HW/SHW days were examined by preparing monthly and seasonal (March to July) maps of mean number of HW/SHW days. For this purpose, data for the entire data period (1961-2010) were used. The climatological features of the duration of station wise longest HW/SHW days spell were also examined. To examine the link between ENSO and spatial distribution of the HWs over India, composite spatial maps of mean number of HW (including SHW) days during the hot weather season (March to July) were prepared for El Nino and La Nina years. During the period 1961-2010, there were 11 El Nino years (1963, 1965, 1972, 1982, 1987, 1991, 1994, 1997, 2002, 2004 & 2009.) and 9 La Nina years (1964, 1970, 1971, 1973, 1975, 1988, 1998, 1999 & 2010). The composite seasonal maps were also prepared for years succeeding El Nino years and those succeeding La Nina years separately.

The decadal variation in the all India HW/SHW days for the hot weather season (March-July) was examined. For this, the all India HW/SHW days for each season was computed as the sum of seasonal HW/SHW days of all the 103 stations used in the study and then computing decadal average for each of the 5 decades. The decadal variation in the spatial distribution of the HW/SHW days over the country was also examined by preparing the seasonal maps of the average HW/SHW days for each of the five decades (*i.e.*, 1961-70, 1971-80, 1981-90, 1991-2000 and 2001-10) in the data period.

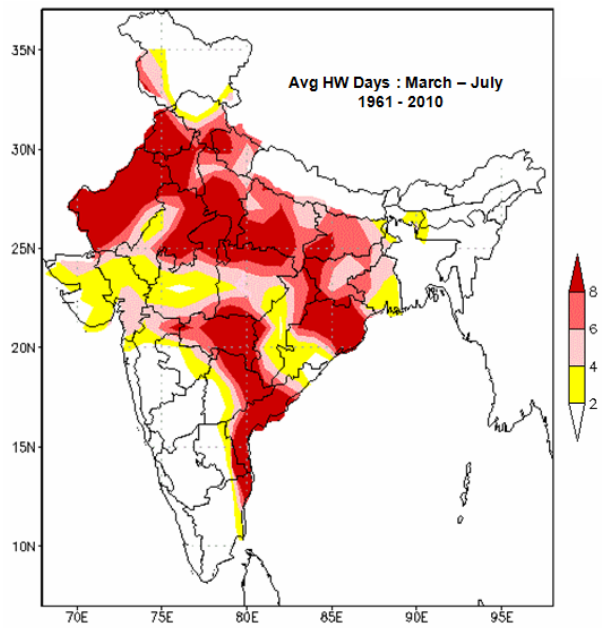


Fig. 5(a). Seasonal climatology map of number of HW days during the hot weather season (March - July) over India. The climatology was computed by averaging the number of HW days for the period (1961-2010)

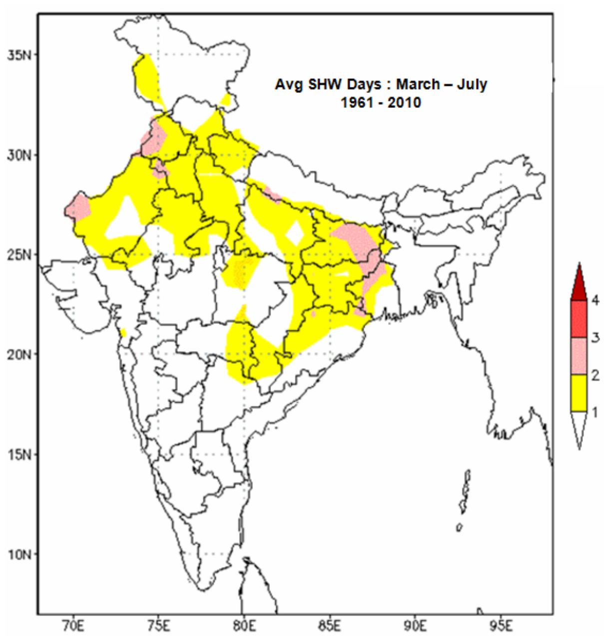


Fig. 5(b). Seasonal climatology map of number of SHW days during the hot weather season (March - July) over India. The climatology was computed by averaging the number of SHW days for the period (1961-2010)

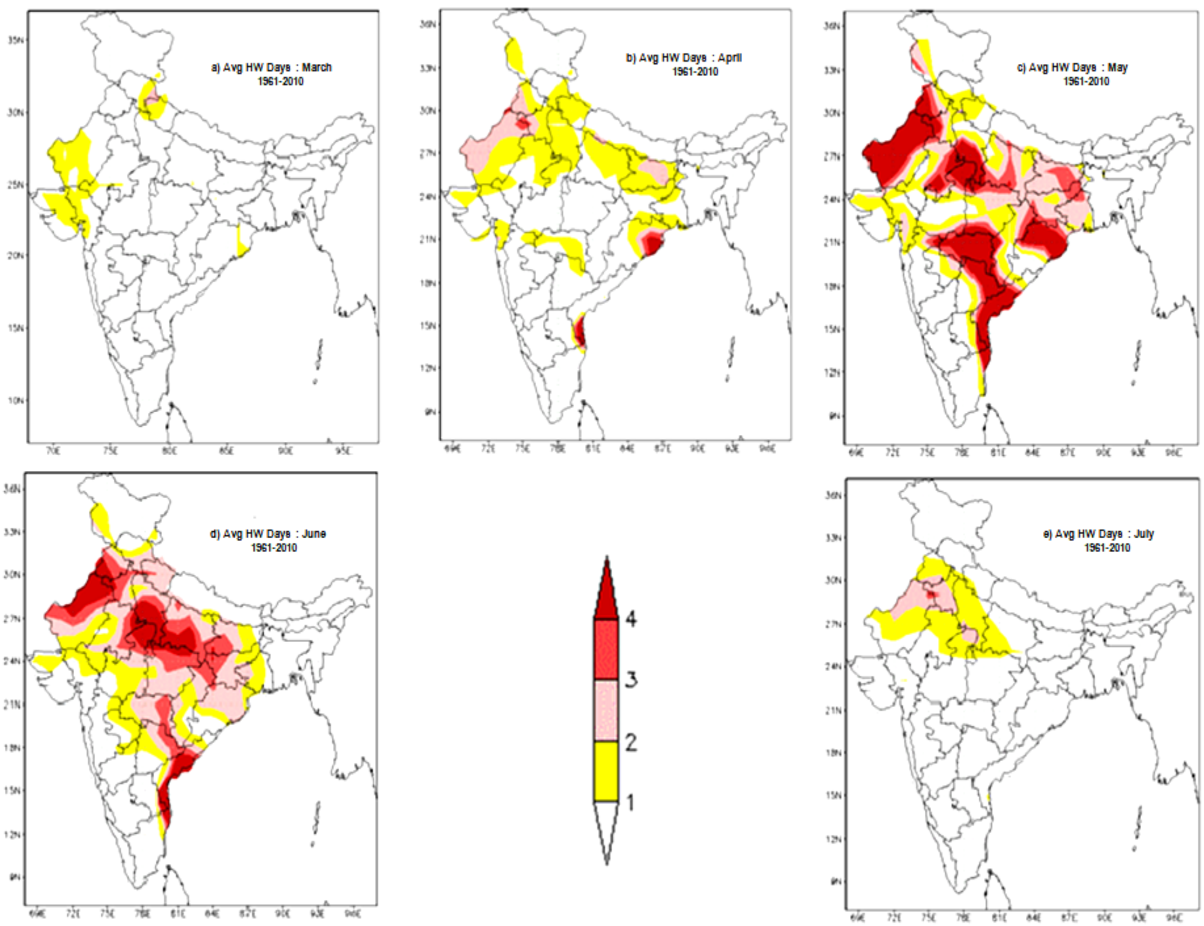
The ENSO link and long term trends in the year to year variation of all India HW/ SHW days have been discussed. The long term trends in the station wise average number of HW/SHW days during the hot weather season were examined using data for the entire period. The trend and the year to year changes in the number of stations affected by HW/SHW in each year during the entire data period (1961-2010) was also examined to study the changes in the area coverage of HW/SHW events. For computing trends, simple linear regression method was used. The significance of the linear trends was tested using student's *t*-test.

3. Results

3.1. *Monthly and seasonal climatology of HW/SHW days (1961-2010)*

Monthly and season wise spatial variation of the average number of HW days experienced over India during the hot weather season (March-July) during the period 1961-2010 are discussed here. Fig. 5(a) shows the spatial variation of seasonal climatology of HW days experienced over the country expressed as average HW days per season. It is seen from Fig. 5(a) that except over northeast India and large parts of Peninsula (South of ~21° N & west of 80° E), most areas of the country have experienced on an average ≥ 2 HW days. Many areas of West Rajasthan, Punjab, Haryana, northern parts of East Rajasthan, Madhya Pradesh, Chattisgarh, Vidarbha, western Uttaranchal, East Uttar Pradesh, western parts of Jharkhand & Bihar, Gangetic West Bengal, northern parts of Orissa, Telangana, Coastal Andhra Pradesh, eastern parts of Rayalaseema and north Tamil Nadu on an average have experienced ≥ 8 HW Days. Fig. 5(b) is same as Fig. 5(a) but for average SHW days per season. It is seen that average SHW days of 1-3 days were mainly experienced over northwest, north and eastern parts of the country.

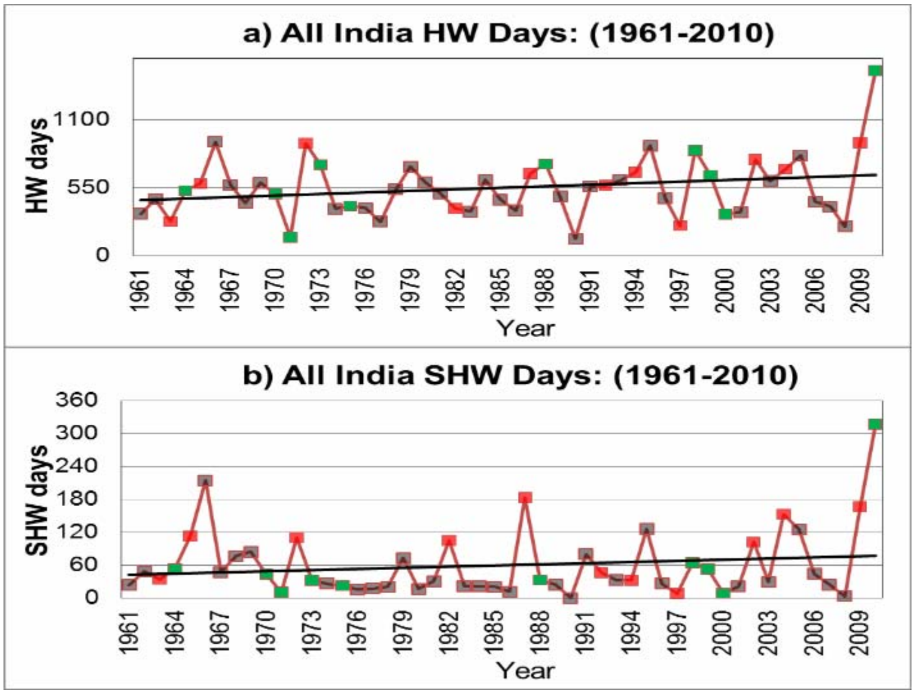
Figs. 6(a-e) show the monthly distribution of average HW days experienced during the period 1961-2010 for the 5 months of March to July respectively. As seen in the figures, west Rajasthan is the only region that experienced average HW days of ≥ 1 day during all the 5 months. Among the 5 months of the season, average number of HW days experienced and spatial coverage of HWs were relatively more during the months of May and June with many areas from northwest India, eastern parts of Peninsula and some areas of central India recording more than ≥ 4 HW days during these two months. Between these two months, May is slightly more prone to HWs than June in terms of average number of HW days and spatial coverage of HWs. The major difference between these two months was the relatively more spatial coverage of average HW days of ≥ 4 days over areas like west Rajasthan, Orissa, Vidarbha, Telengana and coastal Andhra Pradesh during May compared to June. The



Figs. 6(a-e). Monthly climatology maps of number of HW days for the 5 months of (a) March, (b) April, (c) May, (d) June and (e) July over India. The climatology was computed by averaging the number of HW days for the period (1961-2010)

monthly distribution of average SHW days showed that except for the months of May and June (about 1-2 days mostly over northwest, north and eastern parts of India), SHW were not experienced during most of the other months. Therefore, figures corresponding to the monthly distribution of SHW have not been shown here.

During May and June, the sun is located close to its northern most latitudinal position and northern parts of the country experience clear sky and dry weather. During the other 3 months (March, April and July), only few isolated pockets of the country experienced the HWs. The difference in the monthly spatial distribution of the HWs/SHWs is due the annual path of the sun and difference in the distribution of moisture over the country due the presence of two seas on either sides of the Indian Peninsula and arrival and advance of monsoon over the country from June onwards. In the beginning of the hot weather season (March to April), the thermal convective activity starts over the southern parts of the Peninsula and northeast India due to the presence of the moisture from the neighboring seas and this reduces the heating over that region. By June any way, the moisture level increases further due to the arrival of monsoon over the Peninsula. As a result the HW/SHW events are not frequently experienced over Peninsula except over northern parts of the east coast where intense prolonged HW/SHW events occur occasionally due to synoptic situations that opposes the sea breeze from the Bay of Bengal. However, during May and June, most parts of the north & northwest India remain dry and experience HW/SHW conditions till moisture reaches the region in association with the monsoon advance. In fact, arrival of the monsoon over north India signals the end of the hot weather season for the country. In years (like 1998 & 2002) when monsoon advance over north India was delayed, prolonged HW conditions were reported over many areas of north and northwest India.



Figs. 7(a&b). The year to year variation of all India (averaged over all the stations) (a) HW days and (b) SHW days during the hot weather season (March - July) for the period 1961-2010. The red (green) markers correspond to El Nino (La Nina) years

3.2. *ENSO and HW days*

Figs. 7(a&b) shows the year to year variation of the all India average HW days and SHW days for the hot weather season (March-July) for the period 1961-2010. Red (green) markers are used for the El Nino (La Nina) years. Trends in the time series are also shown. It is seen that both the time series show slight but insignificant increasing trends. The mean all India HW (SHW) days for the period 1961-2010 is 550 (60) days. It is seen that during 8 (7) of the 11 El Nino years, the all India HW (SHW) days were above its climatological value. Similarly during 5 (1) of the 9 La Nina years, the all India HW (SHW) days were above its climatological value. However, during 9 (5) of the 11 El Nino+1 (years succeeding El Nino event) years, all India HW (SHW) days were above its climatological value. On the other hand, during only 3 (2) of the 8 La Nina+1 (years succeeding La Nina event years, the HW (SHW) days were above its climatological value.

The composite spatial maps of mean HW days over India for the El Nino and La Nina cases are given in the Fig. 8(a). Similar composite maps for El Nino+1 and La Nina +1 cases are given in the Fig. 8(b). As seen in the Fig. 8(a), the composite maps of El Nino and La Nina cases nearly resemble to climatology map [Fig. 5(a)]. However, in the El Nino case, the areas of average number of HW ≥ 8 days extends slightly northward along the plains of Himalayas compared to the climatological distribution. On the other hand, in the La Nina case, the areas of average number of HW ≥ 8 days extends southward over parts of northwest and central India compared to the climatological distribution.

Fig. 8(b) shows that for El Nino +1 case, the areas of average number of HW days of ≥ 8 extends slightly both northward along the plains of Himalayas and southward over northwest and central India compared to climatological distribution. On the other hand, during the La Nina+1 case, the areas of average number of HW days of ≥ 8 shrink over north and central India compared to climatological distribution. In summary, among all the cases, the areas of average number of HW days of ≥ 8 is maximum during El Nino+1 case and minimum during the La Nina + 1 case compared to climatology.

Figs. 9(a&b) are same as Figs. 8(a&b) but for SHW days. It is seen that during El Nino as well as the El Nino+1 case, the areal coverage and frequency of SHW days are slightly more than the climatology. The La Nina case closely resembles to the climatology distribution but during La Nina+1 case, the areal coverage of SHW days are significantly less than the climatology.

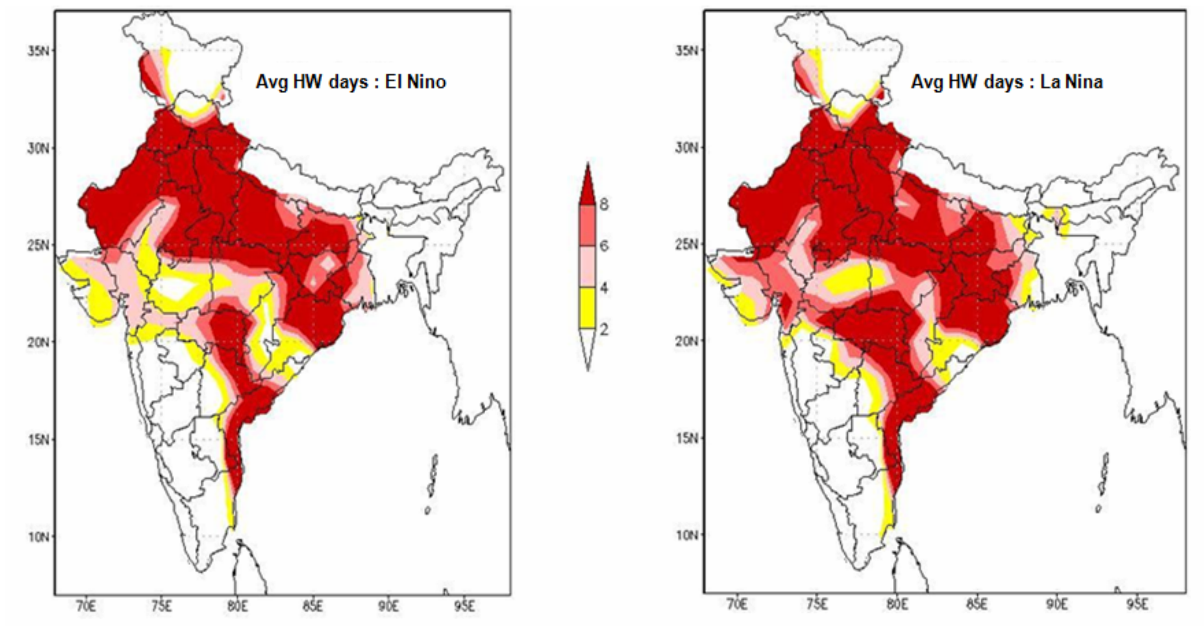


Fig. 8(a). Composite maps of average number of HW days during the hot weather season (March - July) over India for the El Nino case (11 years) and the La Nina case (9 years)

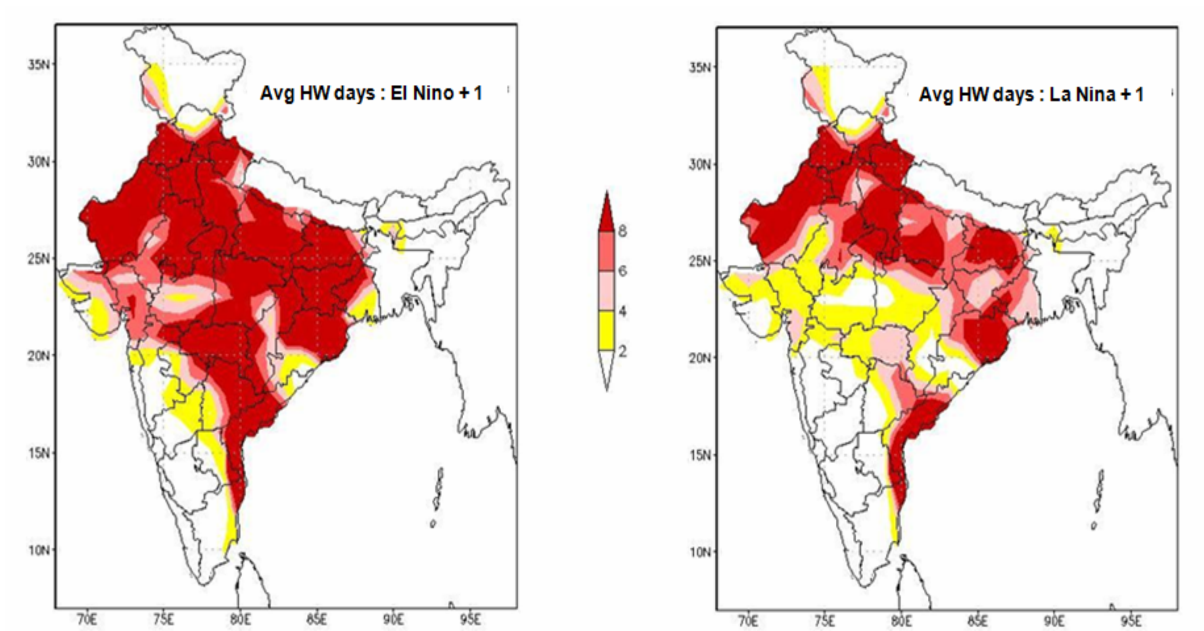


Fig. 8(b). Composite maps of average number of HW days during the hot weather season (March - July) over India for the El Nino+1 case (11 years) and the La Nina+1 case (8 years)

3.3. *Decadal Variation of HW/SHW days*

The decadal variation of the all India HW/SHW days for the five decades during the period 1961-2010 is shown in the Fig. 10. The all India HW days during the first two decades (1961-70 & 1971-80) was about 510 days/year which decreased to 470 days/year in the middle decade (1981-90) and then jumped to about 580 days/year and 670 days/year respectively in the last two decades (1991-00 & 2001-10). The decadal variation of all India SHW days indicate average SHW days of 74 days/year in the first decade decreasing significantly to 34 days/year in the next decade. During the subsequent 3 decades the all India SHW days showed increasing trend with about

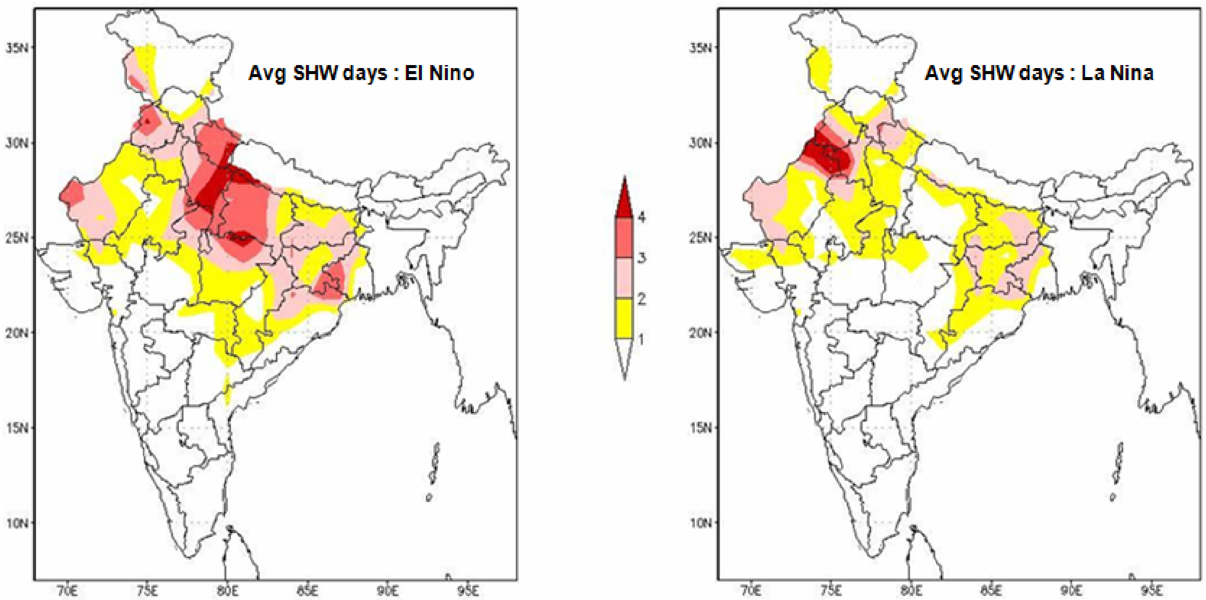


Fig. 9(a). Composite maps of average number of SHW days during the hot weather season (March - July) over India for the El Nino case (11 years) and the La Nina case (9 years)

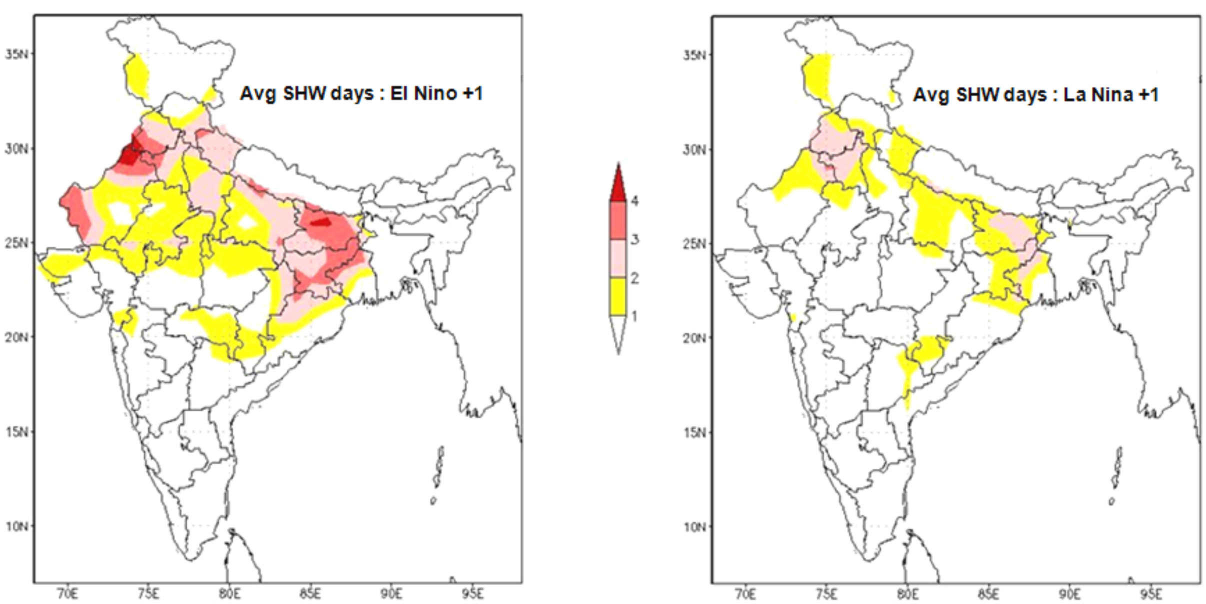


Fig. 9(b). Composite maps of average number of SHW days during the hot weather season (March - July) over India for the El Nino+1 case and (11 years) and the La Nina+1 case (8 years)

45 days/year & 48 days/ year in the two immediate decades (1981-90 & 1991-2000) and significant increase (98 days/year) in the last decade (2001-2010). The huge increase in the HW/days during the last decade is mainly caused by the increase in the HW/SHW events associated with the 3 El Nino years (2002, 2004 & 2009) of the decade.

The Figs. 11(a-e) show the spatial distribution of average number of HW days during the hot season (March-July) for the decades 1961-70, 1971-80, 1981-90, 1991-2000 & 2001-2010 respectively. As seen in the Figs. 11 (a-e), during all the 5 decades, many areas from eastern parts of Peninsula, north and northwest India, and some areas of central India have experienced average HW

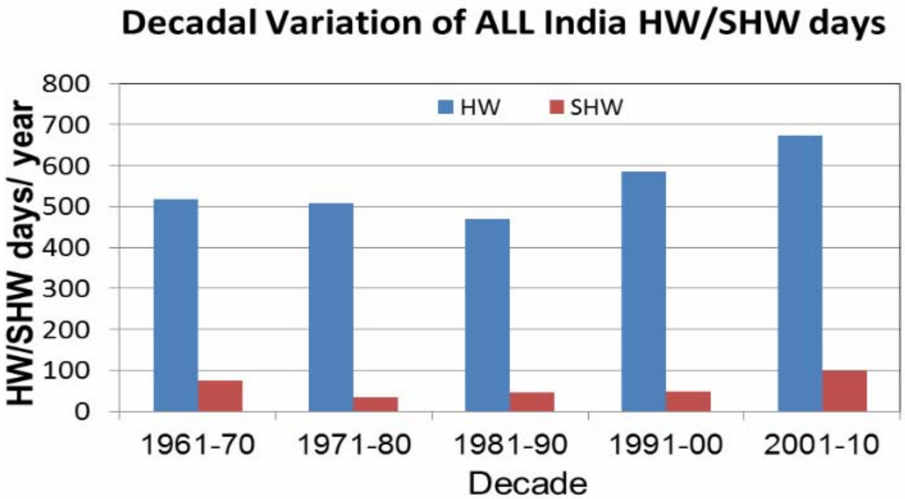
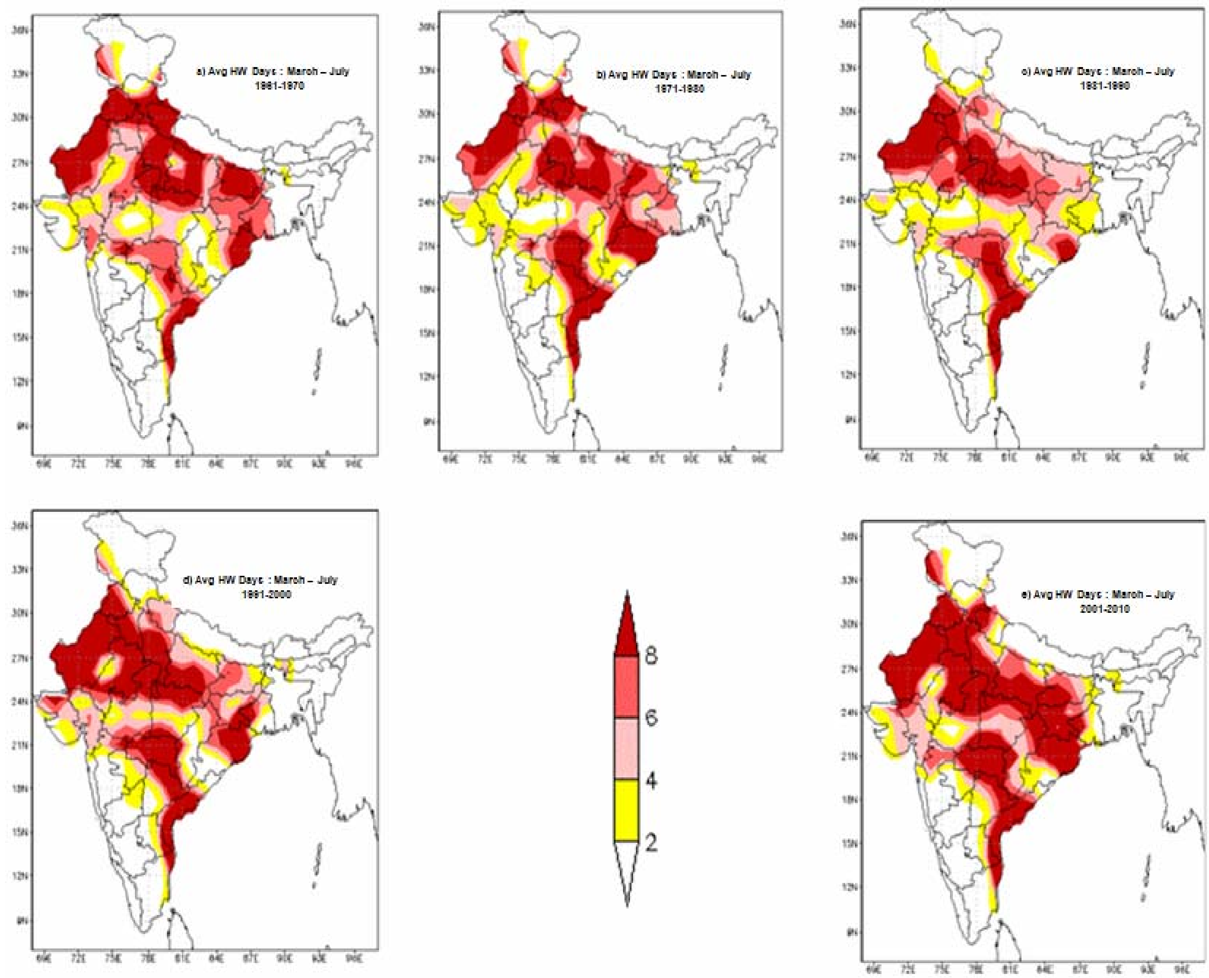
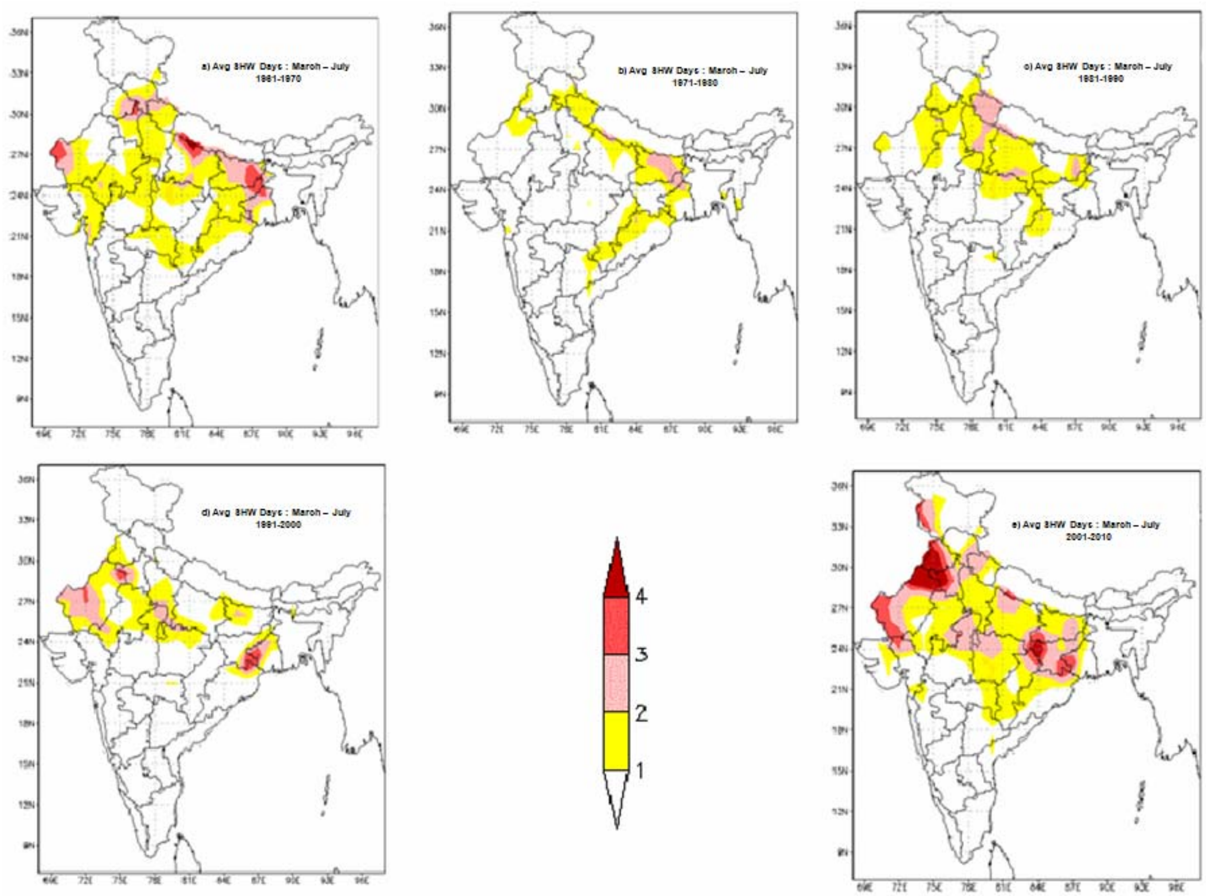


Fig. 10. Decadal variation of the all India (sum of all the stations) HW/SHW days (days/year) during the hot weather season (March - July) for the period 1961-2010



Figs. 11(a-e). Seasonal climatology maps of number of HW days during the hot weather season (March - July) over India for the 5 decades of (a) 1961-70, (b) 1971-80, (c) 1981-90, (d) 1991-2000 and (e) 2001-2010. The climatology was computed by averaging the number of HW days during the respective decades



Figs. 12(a-e). Seasonal climatology maps of number of SHW days during the hot weather season (March - July) over India for the 5 decades of (a) 1961-70, (b) 1971-80, (c) 1981-90, (d) 1991-2000 and (e) 2001-2010. The climatology was computed by averaging the number of SHW days during the respective decades

days of ≥ 8. Going through first to fifth decade, a noticeable shift in the areas of average HW days of ≥ 8 can be seen. During the first decade (1961-70), areas that experienced average HW days of ≥ 8 were mainly from west Rajasthan, Punjab, Uttaranchal and neighboring Haryana and along the areas close to plains of Himalayas. Areas of average HW days of ≥ 8 were also observed in coastal Andhra Pradesh, north Orissa and Gangetic West Bengal. However, in the next decade (1971-80), there was slight decrease in the areas of average HW days of ≥ 8 along the plains of Himalayas and increase over north Orissa and Telangana. In the third decade (1981-90), there was further decrease in the areas of average HW days of ≥ 8 over north India. Similar decrease was observed over north Orissa and Gangetic West Bengal. There was not much difference over coastal Andhra Pradesh and Telangana. However, as a whole, it appears that during the first three decades there was southward shift from one decade to the next in the areas of ≥ 8 HW days. During the final two decades the pattern remains nearly same as that of 1981-90, but with slight southward spread of areas of ≥ 8 HW days over north India and northward spread of areas of ≥ 8 HW days in the Peninsula from Andhra Pradesh area and in the east central India from Orissa and neighboring Gangetic West Bengal. By examining more clearly, it can be seen that there was some reduction in the areas of HW days of ≥ 8 particularly in the eastern parts of the country during the middle decade (1981-90) compared to the two decades each on either sides of it. This is in consistent with decrease in the subdivision wise HW days over India during the decade 1981-90 compared to other two decades (1971-80 & 1991-2000) reported by Pai *et al.* (2004). However, among various decades, the areas over the north and northwest India that experienced average HW days of ≥8 during the recent two decades (1991-2000 & 2001-10) were slightly more and relatively south than that during the first two decades (1961-70 & 1971-80). Between the recent two decades, the number of average heat wave days in the recent decade (2001-2010) is more as compared to

TABLE 2(a)

Details of station wise HW spells of duration ≥ 15 days experienced during the period 1961-2010. 11 El Nino years (2009, 2004, 2002, 1997, 1994, 1991, 1987, 1982, 1972, 1965 & 1963) and 9 La Nina years (2010, 1999, 1998, 1988, 1975, 1973, 1971, 1970 &1964)

Station Code	Year	Duration of spells in days	Period
Nellore (NLR)	1964	30	7 May to 5 June
Nellore (NLR)	1966	24	7 May to 30 May
Nellore (NLR)	1967	18	25 May to 11 June
Nellore (NLR)	1968	17	28 May to 13 June
Berhampur (BRP)	1972	16	6 May to 21 May
Nellore (NLR)	1976	18	18 May to 4 June
Chennai (MDS)	1976	15	19 May to June 2
Bikaner (BKR)	1978	19	5 May to 23 May
Gwaliar (GWL)	1978	15	10 May to 24 May
Jhansi (JHN)	1978	15	10 May to 24May
Nellore (NLR)	1978	15	18 May to 1 June
Nellore (NLR)	1981	15	14 May to 28 May
Hissar (HSR)	1984	16	22 May to 6 June
Agra (AGR)	1984	16	20 May to 4 June
Ramagundam (RMD)	1984	16	14 May to 29 May
Nellore (NLR)	1985	15	23 April to 7 May
Nellore (NLR)	1986	22	8 May to 29 May
Nellore (NLR)	1988	15	6 May to 20 May
Agra (AGR)	1991	17	24 June to17 July
Phalodi (PLD)	1992	17	7 June to 23 June
Nellore (NLR)	1993	18	28 April to 15 May
Bikaner (BKR)	1994	17	18 May to 3 June
Phalodi (PLD)	1994	24	17 May to 9 June
Nellore (NLR)	1994	17	4 May to 20 May
Amritsar (AMR)	1995	16	2 June to 17 June
Agra (AGR)	1995	16	29 May to 13 June
Satna (STN)	1995	17	30 May to 15 June
Nellore (NLR)	1996	35	6 May to 9 June
Nellore (NLR)	1997	28	16 May to 12 June
Bikaner (BKR)	1998	18	15 May to 1 June
Phalodi (PLD)	1998	20	13 May to 1 June
Kakinada (KND)	1998	16	27 May to 11 June
Nellore (NLR)	1998	19	27 May to 14 Jun
Chennai (MDS)	2003	15	17 May to 31 May
Nellore (NLR)	2007	16	9 May to 24 May
Chennai (MDS)	2007	16	9 May to 24 May
Nellore (NLR)	2008	22	1 May to 22 May
Jhansi (JHN)	2010	16	13 May to 28 May
Nellore (NLR)	2010	15	25 May to 8 Jun

TABLE 2(b)

Details of station wise SHW spells of duration ≥ 7 days experienced during the period 1961-2010

Station Code	Year	Duration of spells in days	Period
Bhariach (BRC)	2005	10	11 Jun to 20 Jun
Jabalpur (JBP)	2009	10	25 Jun to 4 July
Barmer (BRM)	2004	9	14 Mar to 22 Mar
Ranchi (RNC)	2005	9	12 Jun to 20 Jun
Jharsuguda (JRG)	2005	9	11 Jun to 19 Jun
Pendra (PND)	2009	9	19 Jun to 27 Jun
Barmer (BRM)	2010	9	14 Mar to 22 Mar
Gwalior (GWL)	1987	8	20 July to 27 July
Gorakpur (GRK)	1987	8	25 Jun to July 2
Bareilly (BRL)	1987	8	26 Jun to 3 July
Phalodi (PLD)	1987	8	21 Jun to 28Jun
Kota (KOT)	2004	8	17 Mar to 24 Mar
Nagpur (NGP)	2009	8	18 Jun to 25 Jun
Gorakhpur (GRK)	1966	7	7 Jun to 13 Jun
Jabalpur (JBP)	1969	7	25 Jun to 1 July
Varanasi (VNS), Satna (STN), Allahabad (ALB)	1982	7	5 July to 11 July
Gaya (GYA)	1982	7	3 July to 9 July
Jharsuguda (JRG)	1982	7	30 Jun to 6 July
Agra (AGR)	1987	7	18 July to 24 July
Allahabad (ALB), Varanasi (VNS)	1987	7	24 Jun to 30 Jun
Satna (STN), Gaya (GYA)	1987	7	25 Jun to 1 July
Bareilly (BRL)	2002	7	9 July to 15 July
Bikaner (BKR), Jaisalmer (JSM)	2004	7	16 Mar to 22 Mar
Udaipur (UDP)	2004	7	17 Mar to 23 Mar
Satna (STN), Gaya (GYA)	2009	7	25 Jun to 1 July
Daltonganj (DTG)	2009	7	20 Jun to 26 Jun

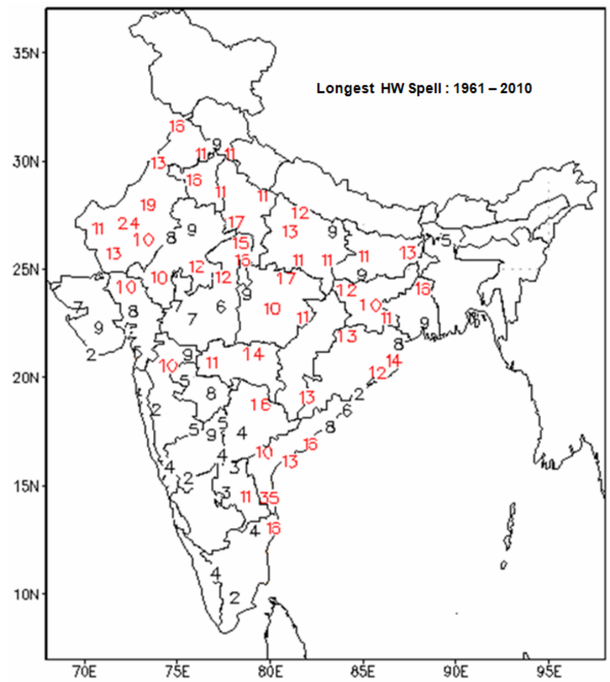
previous decade (1991-2000) and the difference is mainly observed over parts of north India, Orissa, Gangetic WB and coastal Andhra Pradesh (Fig. 11).

The Figs. 12 (a-e) are similar to Figs. 10 (a-e) but for the decadal variation of the spatial distribution of the average number of SHW days during the hot season (March - July). As seen in these figures, during the first 3 decades, the SHW days were mostly experienced in the northern parts of the country. During the last two decades, the highest number of SHW days were experienced in some areas of northwest, north and central India much south of areas that experienced SHW days during the first two decades. Among the various decades, areas that experienced SHW days of 2-4 were lowest during the decade 1971-1980 & highest during the decade 2001-2010 which is also the warmest decade for both the country and the globe. The average number of SHW days experienced in the recent decade (2001-2010) was also higher over most of the areas that experience SHW compared to the previous 4 decades.

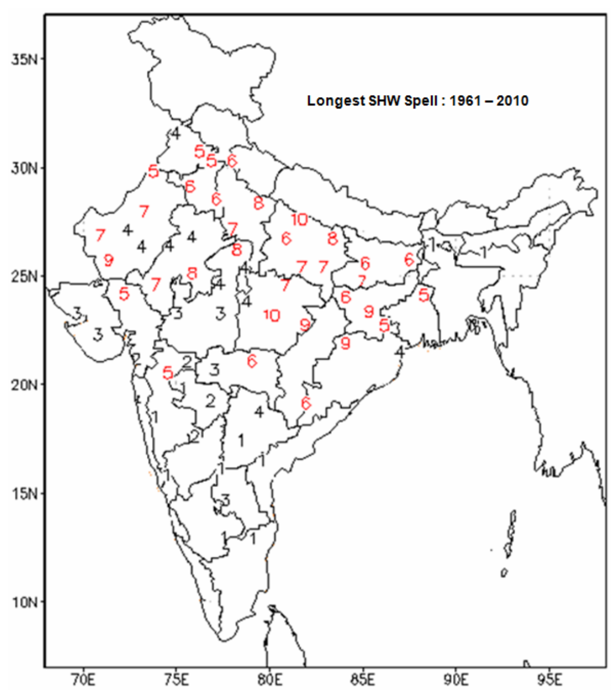
3.4. *Persistency of HW/SHW events*

When HW/SHW conditions start appearing over a station, it is interesting to know as to how many days these conditions are likely to persist or prevail. On examining this aspect it was found that during all the decades and for most of the stations affected by HW/SHW conditions, the duration of the most frequent HW/SHW spells were of about 1-2 days. This is expected as the HW/SHW conditions are very high frequency temperature extreme events. However, some individual HW/SHW spells were observed to have lasted for very long period (duration of 10-15 days) over some stations. The Fig.13a shows the map plotted with duration of the longest HW spell over each of the stations over the country. In this figure, the durations corresponding to spells of duration ≥10 days are shown in red. It is seen that in majority of the stations north of 20° N and along the east coast of Peninsula, the duration of the longest HW spells was ≥ 10 days. As seen in the Fig. 13(a), 8 stations from the northwest and north India had experienced longest HW spells of duration ≥ 15 days with Phalodi (West Rajasthan) experiencing longest HW spell of duration of 24 days (17 May to 9 June, 1994). Similarly, 4 stations from Andhra Pradesh and coastal Tamil Nadu and 1 station from West Bengal experienced longest HW spells of duration ≥ 15 days with Nellore (NLR) station from coastal Andhra Pradesh experienced longest HW spell of duration of 35 days (6 May to 9 June, 1996). Table 2(a) shows details of HW spells of duration ≥ 15 days experienced by various stations during the entire data period. Decadal wise number of HW spells of duration ≥15 days experienced by various stations during the decades 1961-70, 1971-80, 1981-90, 1991-2000 & 2001-2010 were 4, 7, 7, 15 & 6. Thus the total number of HW spells of duration of ≥15 days experienced by all the stations together during the entire data period was 39. It may also be noted that 21 HW spells of duration ≥15 days were experienced in the recent 2 decades compared to 18 HW spells of duration ≥15 days experienced during the first 3 decades indicating slight increase in the persistency of HW conditions during the recent decades. Further, out

(a)

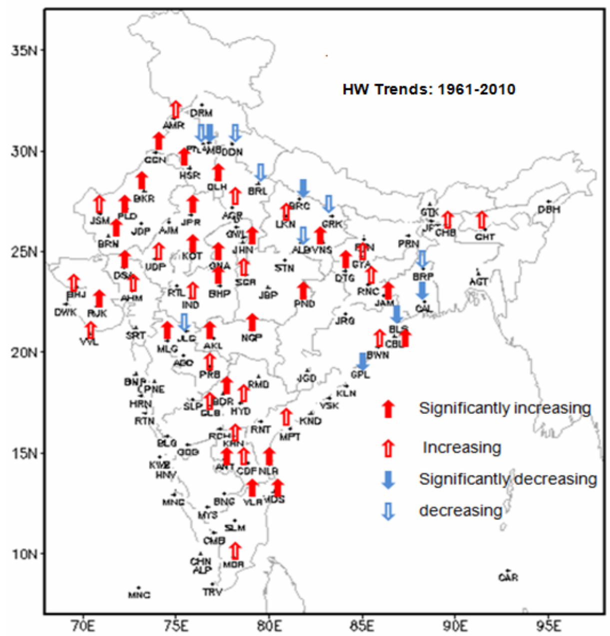


(b)

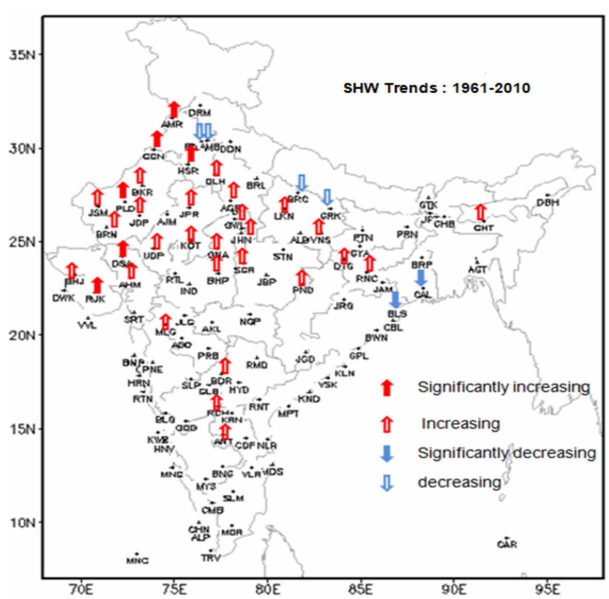


Figs. 13(a&b). Map showing the duration of the longest HW spell over each of the stations used in the study during the analysis period of 1961-2010. The duration of (a) HW spells ≥10 days and (b) SHW spells ≥5 days are shown using red colour

(a)



(b)



Figs. 14(a&b). Long term linear trends in the station wise (a) HW days and (b) SHW days during the hot weather season (March-July) over the 103 stations used in the study computed using data for the period 1961-2010. The trend was computed using simple linear regression. Increasing (decreasing) trends are shown using red up arrows (blue down arrows). The trends significant at 5% level are shown using filled arrows and other using open arrows

of 50 years, only during 25 years, the longest duration of HW spell by any station was ≥15 days. As seen in this table, out of the 39 cases of HW spells of ≥ 15 days reported by various stations, 18 cases were experienced by Nellore (NLR) alone. Of the 18 cases of HW spells of duration of ≥ 15 days experienced by Nellore, 4 cases were experienced during the decade 1981-90 and 6 cases each were experienced during the two decades each on either side of the decade 1981-90. Nellore also experienced longest HW spells during 4 of the five calendar decades 1961-70 (30 days), 1981-90 (22 days), 1991-2000 (35 days) & 2001-2010 (22 days). During the decade 1971-80, Bikaner had experienced longest HW spell of 19 days. Thus it is clear that among all stations used for this study, Nellore from coastal Andhra Pradesh is most prone for long HW spells.

The Fig. 13(b) shows the map plotted with duration of the longest SHW spell over each of the stations over the country. In this figure, the durations corresponding to spells of duration ≥5 days are shown in red. As seen in the Fig. 13(b), most of the stations that have experienced the longest SHW spell of ≥7 days are from north, northwest and central India. The details of SHW spells of duration ≥ 7 days experienced by any of the stations during the entire data period are shown in the Table 2(b). There were 31 such cases. It may be noticed that first 7 longest SHW spells (of duration ≥ 9 days) experienced by any of the stations in the study period was observed during the recent decade 2001-2010. The longest SHW spell of duration 10 days each was experienced by Bhariach (BRC) in 2005 (11^{th} to 20^{th} June) and Jabalpur (JBP) in 2009 (25^{th} June to 4^{th} July). Incidentally Nellore is not in the list. This means that though Nellore is prone to HWs of very long duration, SHW events of long duration is rare in Nellore. During the decades, 1961-70, 1971-80, 1981-90, 1991-2000 & 2001-2010, the numbers of SHW spells experienced by various stations were 2, 0, 14, 0 & 15 respectively.

In respect of ENSO link, it can be seen that most of the longest HW/SHW spells listed in the Tables 2(a&b) are pertaining to El Nino or El Nino+1 year.

3.5. *Long term trends in the station-wise seasonal HW/SHW days over India*

In order to examine the regional variation in the trends in the HW/SHW days during the hot weather season over India, linear trends in the station-wise HW/SHW days were computed. For computing linear trend, simple linear regression method was used. In the Fig. 14(a), stations with increasing (decreasing) trend are indicated using red up arrow (blue down arrow) for HW. However, filled arrows have been used for trends at

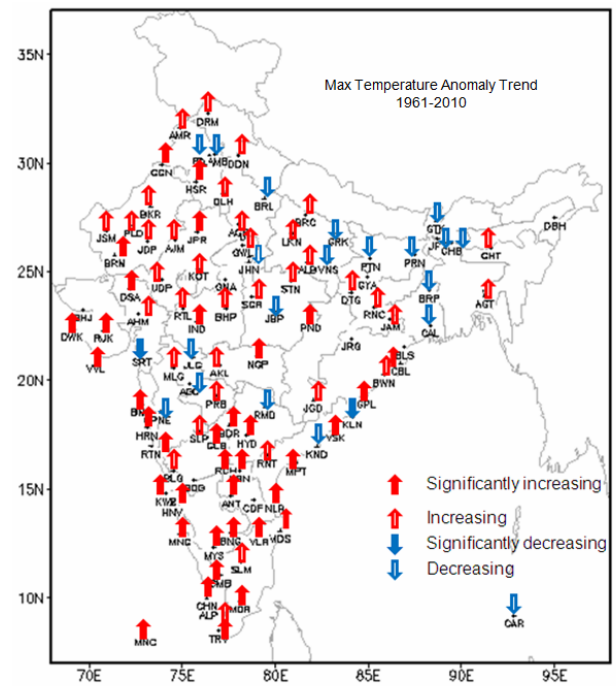


Fig. 15. Long term linear trends in the station wise maximum temperature anomaly over the 103 stations used in the study computed using data for the period 1961-2010. The trend was computed using simple linear regression. Increasing (decreasing) trends are shown using red up arrows (blue down arrows). The trends significant at 5% level are shown using filled arrows and other using open arrows

significant level of 5% or more. Significant increasing trend in the HW days, were observed in 25 stations spread over north India, northwest India, central India and east coast. As seen in the Fig. 5(a), these stations also experience highest average HWs during the season. On the other hand, only 5 stations (Gopalpur, Balasore & Kolkata from east coast of the country and Ambala and Bhariach from north India) showed significant decreasing trend. As seen, Island stations and stations from west coast, and northeast India, where HW days were experienced rarely, no significant trends were observed.

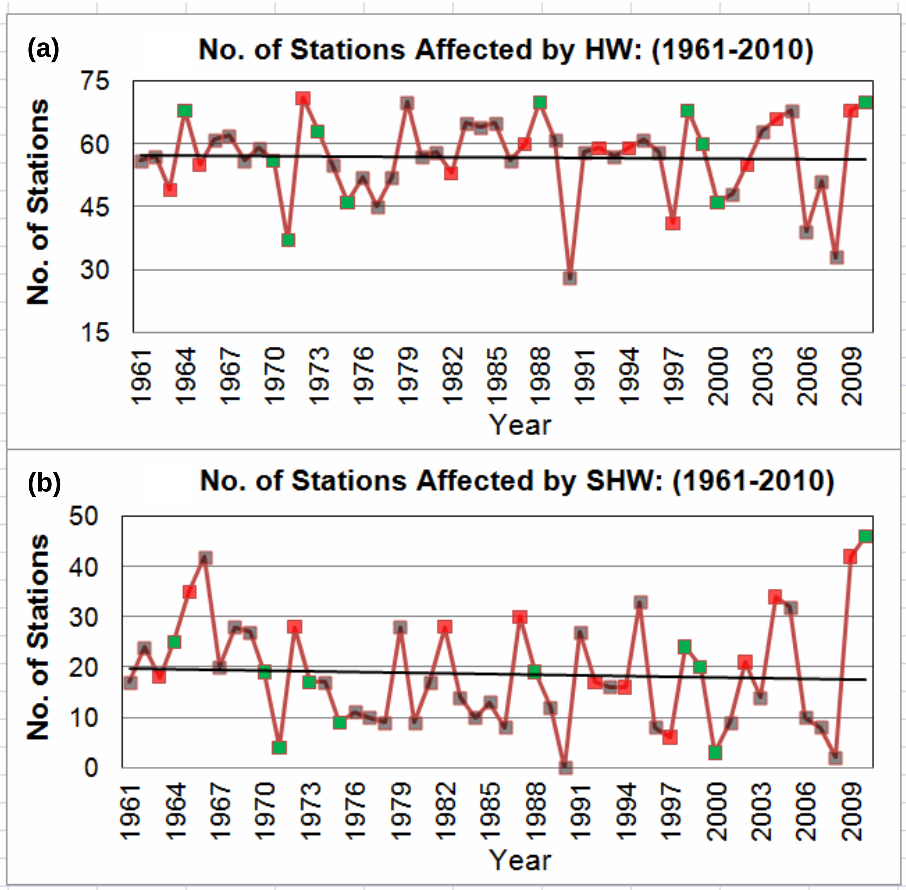
Fig. 14(b) is same as Fig. 14(a) but for SHW. Only 6 stations from northwest India (Amritsar, Hissar, Ganganagar, Phalodi, Deesa and Rajkot) showed significantly increasing trend and Balasore and Kolkata in the east coast showed significant decreasing trend.

In order to examine the trends in the magnitude of the heating conditions over the country, trend analysis of station wise maximum temperature anomalies averaged over the hot weather season (March to July) for the period 1961-2010 was carried out. The resultant trend map is given in the Fig. 15. It is seen that most of the stations show increasing trend. The significant increasing trends were however seen over many stations from Peninsular India both from interior and coastal areas that did not show any trends in the HW/SHW days. This indicates that though there is general increasing trend in the season averaged maximum temperature over the Peninsular India, the day to day temperatures are not increasing above the HW/SHW thresholds. Decreasing trends were observed over some stations along plains of Himalayas and southern parts of central India.

3.6. *Spatial coverage of the HW/SHW - Year to Year variation in the number of stations affected by the HW/SHWs*

The spatial coverage of a HW/SHW varies from wave to wave and in terms of area affected by the HW, it varies from a few stations to large part/whole sub-division to a group of sub-divisions. As the hot season advances up to the end of June, the waves tend to cover larger area (Raghavan 1966). In July, however, they nearly disappear from the country. Each year the area affected by the HW also varies. When a station experience HW conditions, area around that station will also experience HW conditions. Therefore, the number of stations affected by HW can be taken as the proxy for the spatial area affected by HW. Fig. 16(a) shows the year to year variation of the number of stations affected by the HWs during the hot weather season (March to July) for the period 1961-2010. As seen in the Fig. 16(a), on an average about 57 out of the 103 stations got affected by HWs. Highest number of stations (71) affected by HWs was in 1972, the lowest number of stations (28) affected by HWs was in 1990. During the recent decade (2001-2010), the highest (lowest) number affected by HWs was in 2010 followed by 2009 and 2005 (2008). The trend line fitted on the time series is nearly parallel to *x*-axis and hence indicates absence of any linear trend in the spatial coverage of HWs. Further, it is seen that the number stations affected by HWs was above average during about 50% of the El Nino or La Nina years and below average during the remaining years. On the other hand, the number of stations affected by HWs was more than average during all the 11 El Nino +1 years and less than average during 5 out of 8 La Nina+1 years, which is in consistence with the Fig. 8(b).

Fig. 16(b) shows the year to year variation of the number of stations affected by the SHW during the hot weather season (March to July) for the period 1961-2010. On an average 18 stations out of 103 stations got affected by SHWs. Highest number of stations affected by SHWs was in 2010 (46) followed by 2009 and 1966 (42 each) and no SHWs were experienced in 1990. The trend line fitted on the time series in this figure indicates absence of any trend in the spatial coverage of SHWs. The number of



Figs. 16(a&b). The year to year variation of number of the stations affected by (a) HW days and (b) SHW days during the hot weather season (March - July) for the period 1961-2010. The red (green) markers correspond to El Nino (La Nina) years

stations affected by SHWs was more than average during 7 out of 11 El Nino + 1 years and less than average during 5 out of 8 La Nina + 1 years.

4. Conclusions

During few months prior to arrival of southwest monsoon, large areas of India particularly from north and northwest region and northeastern parts of Peninsula experience disastrous HW/SHW events. This study examined climatology, decadal variation and long term trends of the station based on HW/SHW information such as the frequency, persistency and spatial coverage of HW/SHW over India. The study also examined the link between ENSO and the HW/SHW events over the country. The following conclusions can be drawn from the study.

(*i*) The climatology of HW days over the country based on station data showed that on an average ≥ 8 HW days per hot weather season (March- July) were experienced over many areas of north, northwest, central and northeast Peninsula. Relatively very few HW days per season were experienced over island stations and stations from western parts of the Peninsula and northeast India. Month wise, the highest area coverage and average frequency of the HW days were experienced in May and June. On an average SHW days of 1-3 days per hot weather season were mainly experienced over northwest, north and eastern parts of the country.

(*ii*) The relatively less number of HW incidences reported over island stations and stations from western parts of Peninsula and northeast could be an artifact of the definition of HW that is being used in this study. The HW defined in this study can be called as dry HW as the definition does not take into account humidity in the air and assumes that the heat stress is only caused by extreme temperatures which make it difficult for the body to cool itself through sweat and evaporation. However, the presence of humidity though cools the air, introduces an additional heat stress on the body by reducing the efficiency of the body's cooling mechanism as it blocks evaporation from the body. Therefore, when the HW definition used in the study is applied in the island stations and stations from regions like western parts of the Peninsula and northeast India where the humidity level during the hot weather season is high compared to stations from north and northwest India or northeastern parts of the Peninsula, it seems to fail in identifying the HW cases where the humidity plays larger role in the heat stress.

Therefore, to identify the HWs over regions having relatively higher humidity, a heat index similar to one used by National Weather Services (NWS) of USA may be necessary.

(*iii*) In majority of the stations north of 20° N and from east coast of Peninsula, the duration of the longest HW spell was ≥ 10 days**.** In some of these stations the duration of the longest HW spell was ≥ 15 days. The SHW spells of ≥ 7 days were mainly experienced by stations from north, northwest and central India.

(*iv*) Among all the stations, Nellore from coastal Andhra Pradesh was found to be the station most prone to HW both in terms of frequency (average HW days) and duration of the event. However, the station rarely experienced the SHW condition. Thus, though Nellore experienced frequent and long HW spells, the intensity of the event rarely crossed the SHW threshold level.

(*v*) The decadal variation of seasonal average of HW days over the country showed that during all the 5 decades, many areas from eastern parts of Peninsula, north and northwest India, and some areas of central India have experienced on an average ≥ 8 HW days per season. There was some reduction in the areas of ≥ 8 HW days per season particularly in the eastern parts of the country during the middle decade (1981-90) compared to the two decades each on either sides of it. The average number of HW days experienced and areas that experienced average HW days of ≥ 8 was relatively higher during recent 2 decades (1991-2000 & 2001-2010) compared to previous three decades. There was noticeable increase in the seasonal average of SHW days and area affected by SHW during the recent decade (2001-2010) compared to the previous 4 decades.

(*vi*) Increasing trends in the maximum temperature averaged over the season were observed over most of the stations used in the study except a few stations along plains of Himalayas, southern parts of central India and east India, which showed decreasing trends. The significant increasing trends in the seasonal averaged maximum temperature were observed mostly over stations from Peninsular India, which incidentally experience very few HW/SHW events. However, significant increasing trend in the HW days were observed mainly over 25 stations spread over north India, northwest India, central India, Tamil Nadu and Andhra Pradesh. On the other hand, only 5 stations (Gopalpur, Balasore & Kolkata from east coast of the country and Ambala and Bahriach from north India) showed significant decreasing trend. Over Island stations and stations from west coast, and northeast India, where HW days were experienced rarely, no significant trends were observed. Six stations from northwest India (Amritsar, Hissar, Ganganagar, Phalodi, Deesa and Rajkot) showed significantly increasing trend in the SHW days and 2 stations (Balasore and Kolkata) in the east coast showed significant decreasing trend. In general, the significant trend in HW/SHW days was mainly observed over stations where the season average of HW/SHW days is highest.

(*vii*) Year to year variation as well as decadal variation was observed in the all India HW/SHW days per hot weather season. Slight increasing trend (not significant) was observed in the all India HW/SHW days per hot weather season. This could be associated with the increase in the HW/SHW days observed during recent two decades. In general, all India HW/SHW days during the hot weather season were more than normal during El Nino+1 years and significantly less during La Nina + 1 years.

(*viii*) No noticeable long term trends were observed in the spatial coverage and persistency of the HW/SHW days over the country.

(*ix*) The composite analysis of HW/SHW days over the country in respect of ENSO events showed that during most of the extreme ENSO (El Nino & La Nina) cases, the areal coverage and frequency of the HW/SHW days were close to or slightly more than climatology. During the El Nino (La Nina) case, relatively more HW/SHW events occur over north India (northwest and central India) compared to climatological distribution. However, during the El Nino+1 case, relatively more HW/SHW days occur over most areas of the country which experience HW/SHW events climatologically. On the other hand during the La Nina+1 case, there is substantial decrease in the HW/SHW days over these areas except areas close to Himalayas. The persistency and area coverage of the HW/SHW spells are also highest during the El Nino +1 years and minimum during the La Nina +1 years. Co-incidentally, the deaths in the country related to HW/SHW days were also found to be high during the El Nino+1 years and low during La Nina+1 years.

(*x*) The observed increase in the frequency of the HWs over India is in tune with studies conducted in various other parts of the world. Further, the latest climate model projections (IPCC, 2007) indicate that rise in the frequency, intensity and duration of the HW are likely to continue. Therefore, there is need for proper early warning systems, improvement in the public information campaigns on dangers of HWs and use of social care networks to reach vulnerable sections of the populations.

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