MAUSAM, **64**, 3 (July 2013), 467-474

551.524(540.51)

Analysis of extreme high temperature conditions over Gujarat

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(*Received 7 July 2011, Modified 22 May 2012*)

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सार – भूमंडलीय उष्णन का एक परिणाम यह है कि इसके कारण विभिन्न पैमाने/तीव्रता पर विश्व के विभिन्न भागों में चक्रवात, भारी वर्षा, बाढ़, सूखा और लू आदि जैसी प्रतिकूल घटनाओं की बारम्बारता में वृद्धि हुई है। इस क्षेत्र की सामाजिक–आर्थिक समृद्धि के लिए जलवायु परिवर्तन और प्रतिकूल मौसम की घटनाओं का घटना चिंता का मुख्य कारण है। मार्च से मई 2010 की अवधि के दौरान गुजरात में मध्यम से भीषण लू की स्थिति बनी रही जिनमें गुजरात के अधिकांश जिलों में लू वाले दिनों को रिकॉर्ड किया गया। यह अध्ययन गुजरात में अधिकतम चरम तापमान की स्थितियों की दशकीय जलवायु का विश्लेषण करने के लिए किया गया। इस अध्ययन में किए गए दशकीय विश्लेषण से पता चला है कि पहले के तीन दशकों की तुलना में 70 प्रतिशत से अधिक स्टेशनों में मध्यम लू के दिनों की संख्या और प्रचण्ड लू के दिनों की संख्या अधिक रही है। अहमदाबाद, बड़ोदा, राजकोट, बनासकांठा (डीसा), साबरकांठा (इडर) के जिलों में पिछले दशक (2001–2010) में चली मध्यम लू में वृद्धि का पता चला है। भारत मौसम विज्ञान विभाग के विभिन्न स्टेशनों जैसे बड़ोदा, डीसा, कांडला और इडर में पिछले दशक में अधिक अधिकतम तापमान रिकॉर्ड किया गया है। गुजरात के समुद्री तट से दूर के पाँच स्टेशनों की ग्रीष्म ऋतु की अधिकतम तापमान की विसंगतियों से भी पिछले दशक में उच्च सकारात्मक विसंगति (4 डिग्री से. तक) का पता चलता है। इस शोध पत्र में मई 2010 की प्रचंड लू के दौरान सिनॉप्टिक स्थिति का विश्लेषण भी किया गया है।

ABSTRACT. One of the fallouts of the global warming is the increase in frequency of extreme events like cyclones, heavy rainfall, flood, droughts and heat waves etc, across different parts of the world on varying scale/intensity. Climate variability and occurrence of extreme weather events are the major concerns for socio-economic well being of the region. During the period March to May 2010, Gujarat experienced moderate to severe heat wave condition with record number of days with heat waves in most of the districts of Gujarat. This study was undertaken to analyze the decadal climatology of extreme high temperature conditions over Gujarat. The decadal analysis carried out in the study indicated that the number of moderate heat wave days and severe heat wave days are highest in the last decade as compared to earlier three decades in more than 70 per cent of the stations. The districts of Ahmedabad, Baroda, Rajkot, Banaskantha (Deesa) and Sabarkantha (Idar) show increase in moderate heat waves in the last decade (2001-2010). Various IMD Stations like Baroda, Deesa, Kandla and Idar have recorded all time highest temperatures in the last decade. The summer maximum temperature anomalies of five non coastal stations of Gujarat also indicate a high positive anomaly (upto 4 °C) prevalent in the last decade. The paper also analyses the synoptic condition during the severe heat wave of May, 2010.

Key words – Extreme, Temperature, Gujarat, Heat wave, Global warming.

1. Introduction

Extreme positive departures from the normal maximum temperature result in heat wave during the summer season (De *et al*., 2005). These are called heat waves, because the spells of hot weather are often seen to move from one region to another (Chaudhury *et al*., 2000). Generally heat waves develop in the northwestern parts of India and from this area they progress to neighboring sub-divisions of the country. On some occasions, heat waves also develop *in situ.* Over India, heat waves are prominent extreme temperature events occurring during the pre-monsoon season (April to June) [Kalsi & Pareek (2001)]. During the period 1901 to 2010, around 23 severe heat wave conditions have occurred in India, resulting in death of 8869 persons and a damage of 144 million US dollar (EMDAT, 2011). One of the predicted outcomes of the global warming is the increase in frequency of extreme events, including heat waves, etc. across different parts of the world on varying scale/intensity (Srivastava *et al*., 2001; Ray *et al*., 2009; Manton, 2010). Hence, understanding the pattern and frequency of heat waves is essential for better forecasting and management of the extreme temperature conditions.

TABLE 1

Decadal frequency of MHW and SHW for IMD and Part time observatories (P/T)

Stations	Moderate Heat Wave (MHW)				Severe Heat Wave (SHW)			
	1971 to 1980	1981 to 1990	1991 to 2000	2001 to 2010	1971 to 1980	1981 to 1990	1991 to 2000	2001 to 2010
Ahmedabad	27	22	22	36	0	0	1	0
Baroda	17	14	15	37	0	0	0	3
Surat	42	46	25	32	9	5	5	8
Rajkot	5	2	21	33	1	0	1	1
Bhuj	35	40	36	22	1	1	7	2
Deesa	13	3	13	31	0	0	0	11
Naliya	8	22	21	19	8	3	10	19
Bhavnagar	16	24	18	22	0	2	0	0
Veraval	0	0	0	0	11	8	9	31
Kandla (P/T)	24	10	10	25	4	3	4	19
V V Nagar (P/T)	19	1	6	30	0	0	1	2
Porbandar	6	4	4	9	17	11	29	30
Idar (P/T)	8	10	15	67	0	0	1	21

Gujarat is one of the states of India, having strong impact of heat waves. The study of Chaudhury *et al*., (2000) shows that during the period 1978-1999, there were seven heat waves in Gujarat, causing death of 34 persons, mostly occurring during the period March to May. In Gujarat the day temperatures are more or less uniform over the plains except during winter, when temperatures tend to increase southwards. May is the hottest month with mean maximum temperature of 40.1 °C in the planes of Gujarat region. Gujarat region is warmer than the sub-division Saurashtra and Kutch in summer. The increase in maximum temperature in the period from January to May ranges from 5 °C to 14 °C at individual stations of Gujarat state as one moves from south to north.

During the period March to May 2010, Gujarat experienced moderate to severe heat wave condition with record number of days with heat waves in most of the districts of Gujarat.

In this context, the current study was undertaken to analyse the decadal climatology of extreme high temperature conditions over Gujarat and also understand the synoptic conditions for the heat wave in May, 2010.

2. Data and methodology

Maximum temperature data for summer months (March, April, May) for the period (1969 To 2010) was analyzed for all IMD (full time, manned by IMD) and Part time (manned by local authorities) observatories in Gujarat.

Heat wave is considered only when the maximum temperature of a station reaches at least 40 °C for Plains and at least 30 °C for Hilly regions.

IMD has adopted the following three categories:

(*i*) *First category* - When normal maximum temperature of a station is less than or equal to 40 °C, heat wave (HW) may be considered ,if the maximum temperature departure from normal is 5 °C to 6 °C and severe heat wave (SHW) may be considered if the departure from normal is 7 °C or more.

(*ii*) *Second category* - When normal maximum temperature of a station is more than 40 °C than heat wave (HW) may be considered if maximum temperature departure from normal is 4 °C to 5 °C and severe heat wave if the departure from normal is 6 °C or more.

(*iii*) *Third category* - When actual maximum temperature remains 45 °C or more irrespective of normal maximum temperature, heat wave should be declared.

As per the above criterion heat waves days & severe heat wave days were calculated moderate for each station during the 42 year period (1969-2010).

TABLE 2

Year-wise frequency of MHW and SHW days in the last decade (2001-2010)

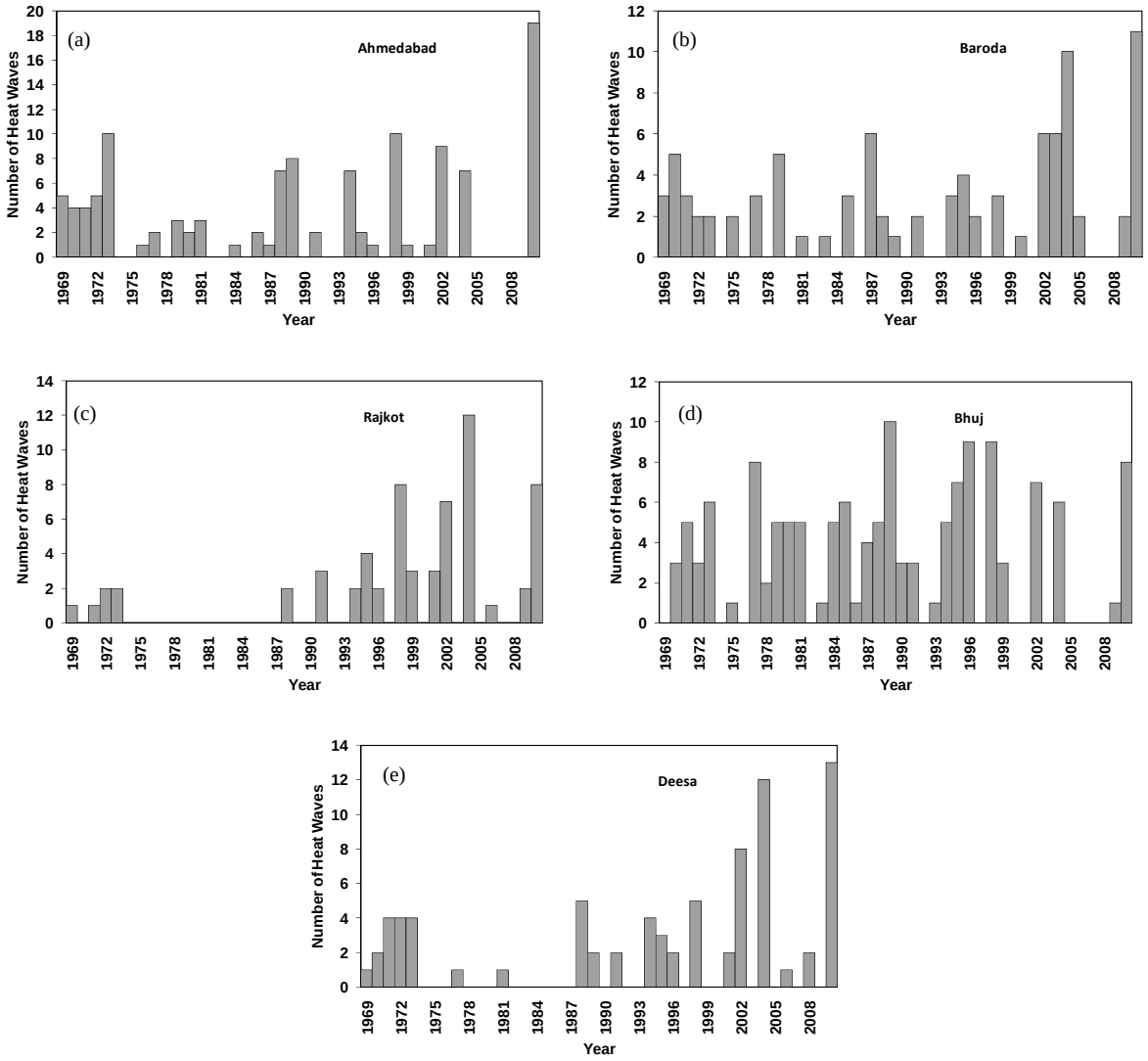
Stations	2001		2002		2003		2004		2005		2006		2007		2008		2009		2010	
	SHW	MHW	SHW	MHW	SHW	MHW	SHW	MHW	SHW	MHW	SHW	MHW	SHW	MHW	SHW	MHW	SHW	MHW	SHW	MHW
Ahmedabad	0	1	0	9	0	0	0	7	0	0	0	0	0	0	0	0	0	0	0	19
Baroda	0	0	1	6	0	6	1	10	0	2	0	0	0	0	0	0	0	2	1	11
Surat	0	1	2	5	1	3	1	7	0	3	0	0	0	4	0	0	0	3	4	6
Rajkot	0	3	0	7	0	0	0	12	0	0	0	1	0	0	0	0	0	2	1	8
Bhuj	0	0	0	7	0	0	0	6	0	0	0	0	0	0	0	0	0	1	2	8
Deesa	0	0	1	4	0	2	2	11	0	0	0	0	0	0	0	2	0	0	5	13
Naliya	0	3	1	0	5	3	6	4	2	2	0	0	0	2	0	2	2	3	3	0
Bhavnagar	0	3	0	2	0	0	0	5	0	1	0	0	0	0	0	0	0	0	0	11
Veraval	1	0	3	0	2	0	6	0	5	0	1	0	2	0	0	0	9	0	2	0
Kandla	0	0	2	1	1	5	2	4	3	0	0	2	0	5	0	0	2	5	9	3
V V Nagar	0	0	1	4	0	3	0	5	0	1	0	0	0	0	0	0	0	6	1	11
Porbandar	2	2	4	1	3	1	7	0	0	0	0	1	0	0	1	1	8	3	5	0
Idar	0	3	2	12	0	14	11	7	0	9	0	0	0	2	0	2	0	5	7	15

TABLE 3

Highest temperatures recorded in observatories of various stations during the period and all time high

Stations	(1970-2010)		All Time	
	Highest Temp.	Date	Highest Temp.	Date
Ahmedabad	47.5	12th May 1970	47.8	27th May 1916
Baroda	**46.2**	**5th May 2004**	**46.2**	**5th May 2004**
Surat	44.5	22nd April 1970	45.6	15th April 1952, 1st May 1956, 10th June 1901
Rajkot	47.9	13th May 1977	47.9	13th May 1977
Bhuj	46.6	30th May 1995	46.6	30th May 1995
Deesa	**47.3**	**22nd May 2010**	**47.3**	**22nd May 2010**
Naliya	43.5	15th April 1996	44.6	22nd May 1959
Bhavnagar	47.3	10th May 1988	47.3	10th May 1988
Veraval	**43.4**	**5th May 2004**	44.2	21st May 1959
Kandla	**45.9**	**4th May 2002**	**45.9**	**4th May 2002**
Vvnagar	47.5	11th May 1970	47.5	11th May 1970
Porbandar	**44.4**	**5th May 2002**	45.5	3rd May 1990
Idar	**48.5**	**22nd May 2010**	**48.5**	**22nd May 2010**

Bold lettered ones are for the decade 2001-2010



Figs. 1(a-e). Number of heat wave conditions in different years in Gujarat state for five stations during last 40 years (a) Ahmedabad (b) Baroda (c) Rajkot (d) Bhuj (e) Dessa

3. Results and discussion

3.1. *Study of decadal pattern*

The total number of heat wave & severe heat wave days in the four decades for IMD stations are shown in Table 1. The decadal analysis indicates that the number of moderate heat wave days & severe heat wave days are highest in the last decade (2001-2010) as compared to earlier three decades in more than 70% of the stations. The districts like Ahmedabad, Baroda, Rajkot, Banaskantha (Deesa), Sabarkantha (Idar) show increase in moderate heat waves in the last decade & coastal districts like Junagadh (Veraval), Kutch (Kandla) and Porbandar indicate appreciable increase in severe heat wave days in the last decade (2001-2010). Observatories in Bhuj, Naliya and Surat do not indicate any increase in the last decade. It is necessary to mention that Bhuj & Naliya observatories have been shifted after Bhuj earthquake & thus the normal of these stations could have changed & may have also affected the calculation of extremes (Heat waves). In coastal stations like Veraval & Porbandar the normal maximum temperatures are 32-33 °C, therefore as soon as the threshold of 40 °C is crossed and a departure of 7-8 °C from normal is realized severe heat wave conditions are declared. If we look at the Table 1, no severe heat wave conditions were recorded in Idar in the first two decades (1971-1980 & 1981-1990) and only one

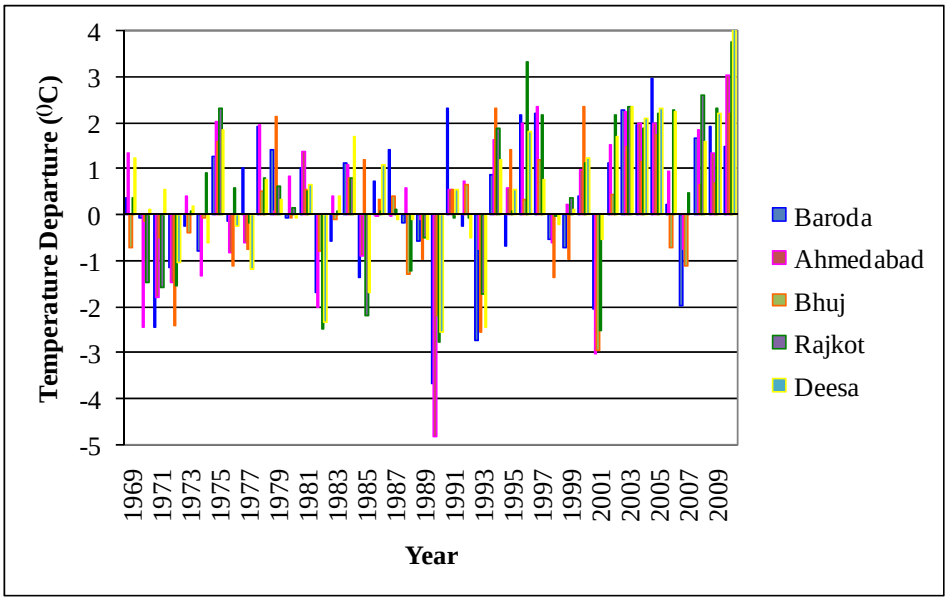


Fig. 2. Summer maximum temperature anomaly based on normal (1960-1990) for five stations of Gujarat

SHW was realized during1991-2000, while the decade 2001-2010 recorded a total of 21 SHW. Similarly in most of the coastal stations of Saurashtra and Kutch, like Veraval, Porbandar, Kandla and Naliya, significant increase in the SHW has occurred in the last decade (2001-2010). If we see the total heat wave days (MHW + SHW), then except for Bhuj and Surat it is highest in the last decade for all stations.

In the last decade maximum cases of heat wave days were recorded in 2010 followed by 2004 & 2002 for most of the stations (Table 2). Idar (District-Sabarkantha) recorded highest number of severe heat wave conditions in 2004, followed by 2010. The SHW prevailed from 13th to 23rd March 2004, when maximum temperatures were between 42 °C to 45 °C as against normal of 36 °C. During the period under study this is the longest continuous severe heat wave spell (11 days) realized in any station in Gujarat state. Next higher number of SHW of 9 days were recorded in Kandla (a coastal station in Kutch district) in two spells during March, 2010 (19th - 23rd) when temperatures crossed 40 °C and during May (22nd - 25th), when temperatures were between 43 °C and 44 °C. Third highest number of SHW days were again recorded in Idar in 2010, out of which 7 days of severe heat wave were realized in three spells when temperatures crossed 45 °C on 3 days in March (20th -22nd), on 2 days in April (16th and 17th) when temperature reached 47 °C mark and on 2 days in the month of May (21st and 22nd) when the maximum temperature were 47.7 °C & 48.5 °C respectively (Table 3).

Deesa also had SHW conditions on 5 days in 2010. This was the highest for Deesa during the period under study. During the period 19th to 21st March 2010, the temperature were between 43-44 °C and again in May SHW conditions prevailed on 21st and 22nd May (2 Days) when temperatures were 46.5 and 47.3 °C respectively.

Table 3 shows the highest temperatures recorded during the period under study and also the highest ever recorded temperatures. Fifty per cent of the stations have recorded highest temperatures in the last decade. Deesa (1901 to 2010) and Idar (1957-2010) recorded highest ever temperature on 22nd May 2010. In the last decade four stations have recorded all time high temperatures and six stations have recorded highest temperatures in the past 40 years. The results indicated a significant increase in high temperature extremes in the last decade over Gujarat.

The number of heat waves in five non coastal stations of Gujarat in the past 40 years is shown in Fig. 1, except Bhuj all indicate an increasing trend. If we consider the Gujarat state as whole (five stations average), the average number of heat waves was 97 (92 heat wave and 5 severe heat wave) in last 40 years indicating an average of more than two heat waves every year. The average number of heat waves were very high (35) in the last decade for these five stations. This is also indicated in temperature departure of five stations of Gujarat (Fig. 2), which show high positive anomaly (upto 4 °C) prevalent in the last decade (2001-2010).

TABLE 4

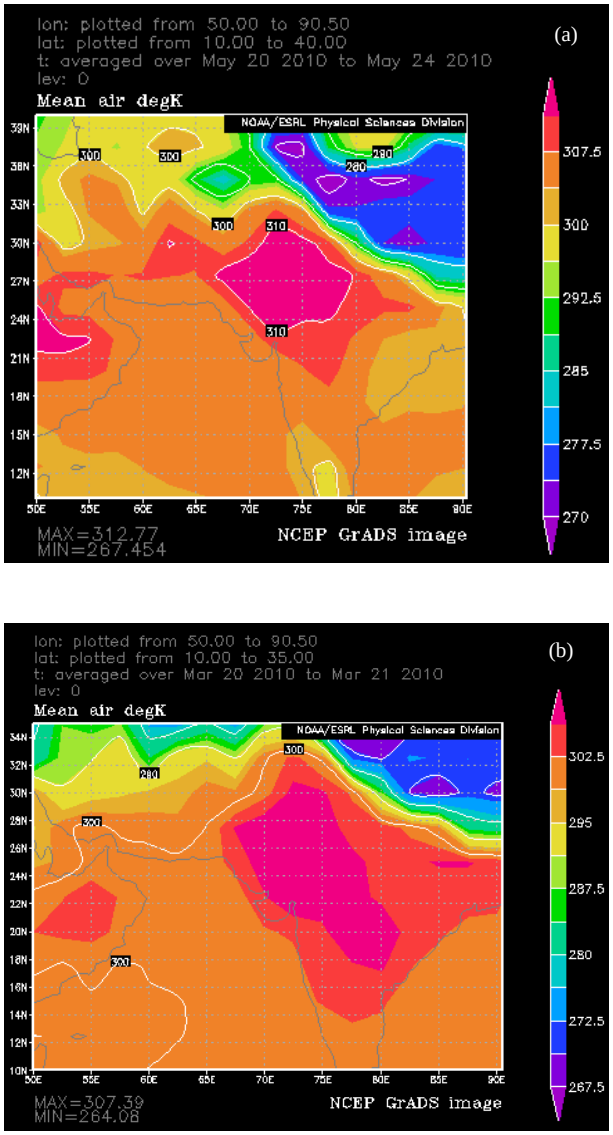
Cases of SHW days on continuous 5 or more days in the past 40 years

Stations	Temperature (°C)	Period	Days
Kandla (Coastal)	40.0 - 41.0	19th to 23rd March 2010	5
	42.0 - 44.0	20th to 25th May 2010	6
Porbandar (Coastal)	40.0 - 43.0	18th to 22nd March 2010	5
Deesa	45.2 - 47.3	20th to 24th May 2010	5
Idar	41.3 - 44.5	13th to 23rd March 2004	11

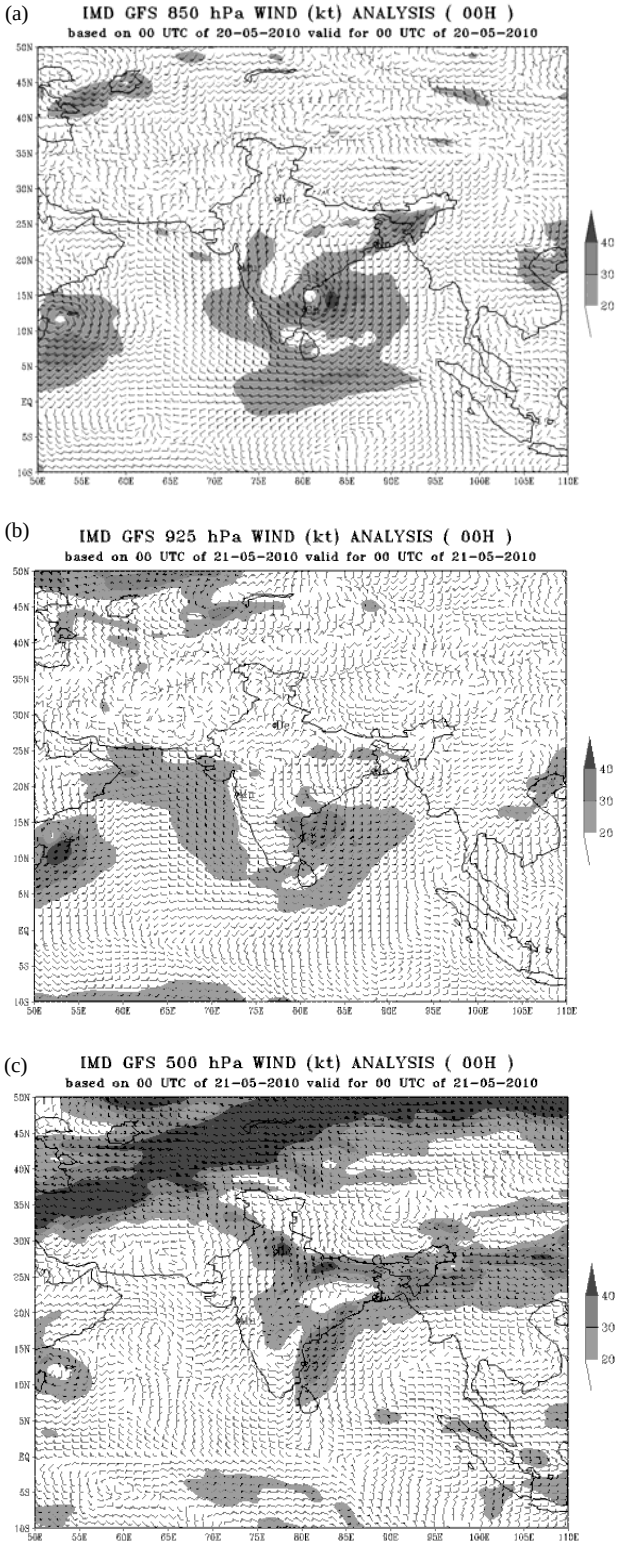
The damage potential of the heat waves depend upon the duration of the event therefore cases of five continuous days of SHW were also calculated. Table 4 shows the cases in the past 40 years when the SHW has prevailed for more than 5 continuous days. All cases of continuous SHW were found to be in the last decade (2001-2010), with 90% of the cases in 2010. Maximum frequency of heat waves over most parts of the state was found to be in the month of May. However, the frequency is higher in the month of April for coastal stations.

Climate variability and occurrence of extreme weather events are the major concerns linked to global warming. In a study (Hingane *et al*., 1985) authors had prepared an all-India mean series of seasonal and annual surface air temperature for a long term trend studies, using data for 1901-82. The analysis indicated a significant warming of 0.4 °C per hundred years in mean annual temperatures of the country as a whole. The gridded 30 years (Srivastava *et al*., 2008) moving averages of mean maximum temperature over Gujarat state (Ray *et al*., 2009) also indicated an increase by 0.11 °C during the period (1969-2005). The station wise analysis (1969-2008) further indicated that the increase is more over Saurashtra region as compared to that of the remaining parts. The heat wave conditions were also computed using different criteria but the results indicated an increase in heat waves in the last decade (1998-2008). De & Sinha Ray (2000) have also shown the impact of extreme weather and climate events on health in India mega cities. Some of the earlier studies have also indicated a relation between El-Nino and Heat waves (De & Mukhopadhyay, 1998; Chaudhury *et al*., 2000). De and Sinha Ray (2000) has shown the impact of extreme weather & climate events in Indian mega cities.

During the period 1979-1998, it was seen that the maximum number of heat wave days and human lives lost were comparatively large during the years preceded by



Figs. 3(a&b). Mean air temperatures during severe heat wave episode (SHW) over Gujarat in 2010 (a) 20th May -24th May and (b) 20th March - 21st March



Figs. 4(a-c). Synoptic features during heat wave of May 20-25, 2010, (a) Low Level Northerly winds, (b) Hot dry winds blowing across the south-western Thar Desert and (c) Anticyclone over Pakistan and adjoining Gujarat at 500 hPa

warm ENSO years. In this study it was seen that in the past 40 years, the years with high number of heat wave days were either El-Nino years or years preceded by an El-Nino year. In the last decade also most of the heat waves have occurred in 2002, 2004 and 2010. The years 2002, 2004 and 2009 were El-Nino years and thus 2 El-Nino years and one year succeeding El-Nino year (2010) were years with maximum heat wave days in the last decade. This is in conformity with the findings of De & Mukhopadhyay (1998).

The study indicates an appreciable rise in extreme high temperature episodes over Gujarat in the last decade, as compared to earlier decades. More detailed study needs to be initiated to obtain a relation between El-Nino and temperature extremes during summer.

3.2. *Case study of severe heat wave condition (May 2010)*

During the period from March to May, normal temperature was quite high over the state. Moderate heat waves to severe heat waves prevailed over the region. Figs. 3(a&b) indicate the mean temperature distribution during the SHW period in May (20^{th} - 24^{th}) and in March (13^{th} - 15^{th}), 2010. A major part of North Gujarat region which includes districts like Banaskantha, Sabarkantha, Mehsana, Patan and Ahmedabad and Rajasthan was severely affected during the period.

Ahmedabad recorded 45 °C and more from 13^{th} to 15^{th} May and from 20^{th} to 25^{th} May, with the highest recorded being 46.8 °C on 22^{nd} May. In case of Ahmedabad it was the highest maximum temperature recorded in the last 30 years. The all time highest was 47.8 °C recorded on 27^{th} May in 1919. In the year 2010, heat wave prevailed on 19 days in summer season, which was the highest number of heat wave days recorded during the period under study (1969-2010). A record number of 5 days of heat wave in March, 4 days in the month of April and 10 days were recorded in May, 2010. In case of Deesa, highest temperature 47.3 °C was recorded on 22^{nd} May, 2010. It was the second highest maximum temperature recorded ever, with the all time highest being 47.4 °C, recorded on 3^{rd} June 1991. In the year 2010, moderate heat wave prevailed on 13 days and severe heat wave on 5 days (total 18 days). A record number of 6 days in March, 4 in April and 7 days were recorded in May. Rajkot in the year 2010 recorded MHW on 8 days and SHW on one day and Baroda recorded MHW on 11 days and SHW on one day (highest in 40 years).

During the period of heat wave (20^{th} to 25^{th} May), low level northerly winds were blowing over Gujarat region [Figs. 4(a&b)]. These brought hot dry air from

southwestern Thar Desert. The extreme high temperatures were also due to subsidence caused by an anticyclonic circulation over Pakistan and adjoining Gujarat Region at 500 hPa level [Fig. 4(c)].

4. Conclusions

(*i*) This study was carried out to analyze the decadal pattern of extreme temperature conditions over different weather stations of Gujarat.

(*ii*) The synoptic conditions of heat wave of May 2010 were also analyzed.

(*iii*) The decadal analysis indicated that the number of moderate heat wave days & severe heat wave days were highest in the last decade (2001-2010) as compared to earlier three decades. In the last decade four stations recorded all time high temperatures and six stations recorded highest temperatures in the past 40 years.

(*iv*) The results indicated a significant increase in high temperature extremes in the last decade over Gujarat.

(*v*) In the past 40 years, the years with high number of heat wave days were either El-Nino years or years preceded by an El-Nino year.

(*vi*) A record number of four heat waves prevailed in Gujarat in 2010. Ahmedabad, Deesa and Baroda observatories recorded highest number of heat wave days in the past 40 years.

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