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Decadal variation in the heat and cold waves over India during 1971-2000

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सार – इस शोध–पत्र में 1971–2000 की अवधि में भारत के सभी मौसम वैज्ञानिक उपखडों में प्रतिदिन की उष्ण लहर और शीत लहर की स्थितियों से संबंधित सूचना का उपयोग करते हुए उष्ण लहर (एच.डब्ल्यू.)/भीषण उष्ण लहर (एस.एच.डब्ल्यू.) और शीत लहर (सी.डब्ल्यू.)/भीषण शीत लहर (एस.सी.डब्ल्यू.) के विभिन्न अभिलक्षणों में दशकीय परिवर्तनों की जाँच की गई। 1991–2000 के दशक में इन दोनों उच्च आवृत्ति वाले तापमान की चरम घटनाओं (उष्ण और शीत लहरों) की आवृत्ति, अवस्थिति और स्थानिक विस्तारों में उल्लेखनीय वृद्धि का पता चला है। ये परिवर्तन 1991–2000 की अवधि के दौरान रिकार्ड किए गए अब तक के सबसे अधिक दशकीय मापक्रम भूमंडलीय उष्णता के क्षेत्रीय प्रभाव को व्यक्त कर सकते हैं। इन परिवर्तनों का एक भाग वनों की कटाई, शहरीकरण आदि जैसे स्थानीय कारकों से भी प्रभावित हो सकता है। अधिकांश उपखंडों में एच.डब्ल्यू./एस.एच. डब्ल्यू. की सक्रियता पूर्ववर्ती (1971–1980) और उत्तरवर्ती (1991–2000) दशकीय अवधियों की तुलना में मध्यमावधि दशकीय अवधि (1981–1990) में अपेक्षाकृत कम थी। सत्तर से अस्सी तक और तत्पश्चात् नब्बे तक के दशक से उत्तरी भारत में सी. डब्ल्यू./एस.सी.डब्ल्यू. की सक्रियता में वृद्धि हुई है। अन्य क्षेत्रों में सी.डब्ल्यू./एस. सी.डब्ल्यू. की सक्रियता में परिवर्तन अन्य दो अवधियों की तुलना में न्यूनतम सक्रियता वाले मध्यमावधि की अवधि समेत एच.डब्ल्यू/एस.एच.डब्ल्यू. के अनुरूप ही थे। संपूर्ण आँकड़ा अवधि के दौरान तीन उपखंड़ों नामतः केरल, लक्षद्वीप तथा अंडमान निकोबार द्वीपसमूह में कभी भी किसी तरह की उष्ण/शीत लहरों की स्थितियाँ नहीं बनी।

ABSTRACT. Using information regarding daily heat wave and cold wave conditions over all the meteorological sub-divisions of India for the period 1971-2000, the decadal changes in the various characteristics of heat wave (HW)/severe heat wave (SHW) and cold wave (CW)/severe cold wave (SCW) were examined. A significant increase was noticed in the frequency, persistency and spatial coverage of both of these high frequency temperature extreme events (heat and cold waves) during the decade (1991-2000). These changes might be the manifestation of regional impact of highest ever decadal scale global warming recorded during the period (1991-2000). A part of these changes might also be caused by local factors such as deforestation, urbanization etc. The HW/SHW activity over most of the subdivisions were relatively less during the intermediate decadal period (1981-1990) as compared to that during the preceding (1971-1980) and succeeding (1991-2000) decadal periods. The CW/SCW activity over North India showed increase from the decade of seventies to eighties and then to nineties. For other areas, the changes in the CW/SCW activity were similar to that of HW/SHW with the intermediate period having minimum activity compared to the other two periods. During the entire data period, three sub-divisions, namely Kerala, Lakshadweep and Andaman & Nicobar Islands did not experience any heat/cold wave conditions at all.

Key words – Decadal variation, Heat and Cold waves, Extreme events, Regional impact.

1. Introduction

Changes in the frequency or intensity of extreme weather and climate events have profound impact on human society and the natural environment (Easterling *et al.* 2000). Such events can adversely affect the life, health and well being of human society. One of the reasons for the observed changes in the climate is its natural variability. In recent years, the human influence on the global and regional climates has added one more dimension to the climate change problem.

One of the weather elements that have important effect on the human health is the temperature. The human body operates best within a fairly normal temperature range. An abnormal heat or cold can impose severe physiological stress. There is a marked relationship between human mortality and thermal stress. During unusually hot episodes, deaths from different causes can rise by more than 50% above normal with the elderly at greater risk than others (WMO 1996). During various heat waves in recent years (1995, 1998 & 1999), it is estimated that the number of excess deaths in India rose manifold (De 2001).

The thermal conditions that cause physical discomfort can be described in different ways. The

TABLE 1

Criteria used for declaring Heat wave and Cold wave by India Meteorological Department between January 1989 and March 2002

Nomenclature	Departure from normal temperature
(A) Criteria for Heat Wave/ Severe Heat Wave	
(a) *When normal maximum temperature of station is 40° C or less*	
Normal	-1° C to 1° C
Above normal	2° C
Appreciably above normal	3° C to 4° C
Markedly above normal/ Moderate heat wave	5° C to 6° C
Severe heat wave	7° C or more
(b) *When normal maximum temperature of station is more than 40°C (The term moderate heat wave will not be used)*	
Normal	-1° C to 1° C
Above normal	2° C
Heat wave	3° C to 4° C
Severe heat wave	5° C or more
(c) *When normal maximum temperature of station is 45° C or more for two days or more*	
The condition may be declared as heat wave	
(B) Criteria for Cold Wave/ Severe Cold Wave	
(a) *When normal minimum temperature of station is 10° C or more*	
Normal	1° C to -1° C
Below normal	-2° C
Appreciably below normal	-3° C to -4° C
Markedly below normal/ Moderate cold wave	-5° C to -6° C
Severe cold wave	-7° C or less
(b) *When normal minimum temperature of station is less than 10° C (The term moderate cold wave will not be used)*	
Normal	1° C to -1° C
Above normal	-2° C
Cold wave	-3° C to - 4° C
Severe cold wave	-5° C or less

description of heat and cold waves is one among them. Table 1 gives description of heat and cold waves that is used for defining abnormal thermal conditions by India Meteorological Department (IMD) between 1989 and 2002 (IMD 1988). The definitions of heat/cold waves used by IMD were evolved over past several decades. It is seen in Table 1 that the heat (cold) wave conditions signify certain amount of rise (fall) of temperature at a given place with respect to normal climatological value. In India, the heat wave conditions are generally experienced during the period from March to July and cold wave conditions are experienced during the period from November to March. There have been some earlier studies on the heat and cold waves over India (Raghavan 1966 & 1967, Rai Sircar and Datar 1963, Natarajan 1964, Bedi and Parthasarthy 1967, Bedekar *et al.* 1974, Subbaramayya and Surya Rao 1976). In these studies the threshold temperature values used to describe the heat and cold waves were however different. Nevertheless, these studies provided some idea about climatological characteristics of heat and cold waves over India. After these studies, relatively little work has been done on these high frequency extreme temperature events particularly in respect of their changes over long time periods. In this study, the changes in the frequency, persistency and spatial coverage of heat and cold waves over all the 35 meteorological subdivisions of India that have occurred during the last three decades have been examined.

2. Data and methodology

The main data used in this study are the meteorological sub-division (hereafter sub-division) wise information on the daily heat wave and cold wave conditions over India for the period 1971-2000. Since March 2002, IMD has adopted revised criteria for describing heat and cold waves and India has been divided into 36 sub-divisions. However, in this study we have used earlier position of India being divided into 35 sub-divisions. Fig. 1 shows the map of these 35 sub-divisions and their names. The criteria used in this study for defining heat and cold waves are same as that given in Table 1. The base period of the normal maximum/minimum temperatures used in these criteria is 1931-60. IMD adopted these criteria with effect from 1 January 1989. Slightly different criteria were used earlier to this.

The required data regarding heat and cold waves for the period January 1989 onwards were taken from Indian Daily weather Reports (IDWRs). Prior to this period, the information about heat and cold waves were taken from daily weather charts using the criteria given in the Table 1. Both the IDWRs and weather charts were obtained from the Office of Deputy Director General of Meteorology (Weather Forecasting), IMD, Pune.

For this study, statistics of various features of heat and cold waves such as number of heat/cold wave days, frequency of heat/cold wave spells; duration of most frequent heat/cold wave and duration of longest heat/cold wave etc., were prepared for all the 35 sub-divisions of

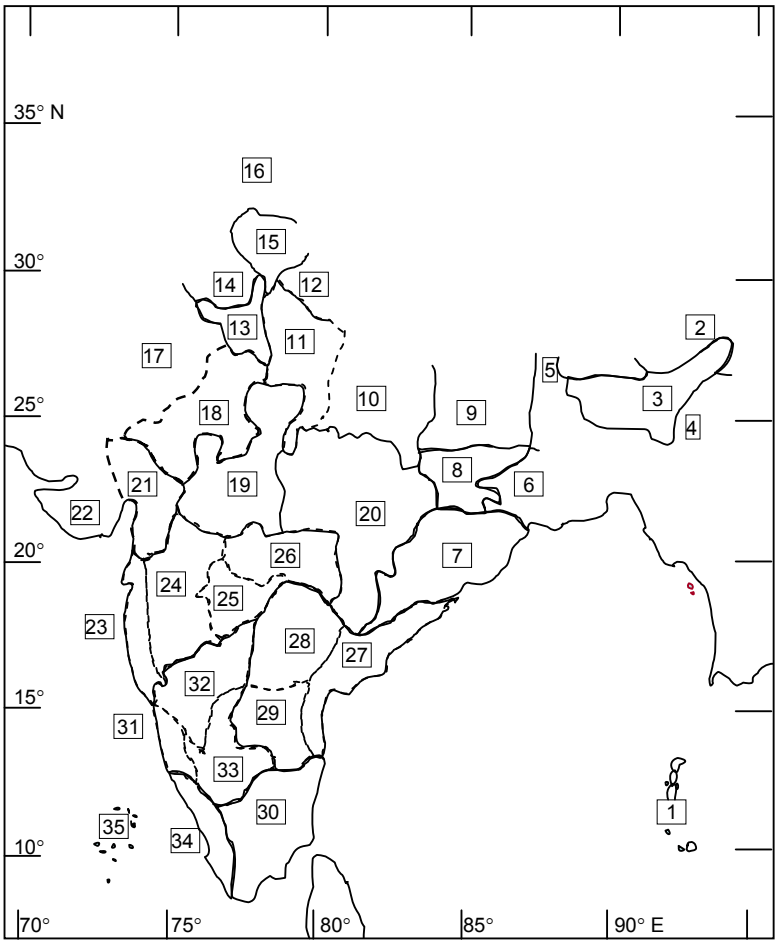

Fig. 1. 35 meteorological sub-divisions of India

India for three decadal periods *i.e.*, 1971-80, 1981-90 and 1991-2000. The number of sub-divisions affected by heat/cold waves in each year during the entire data period (1971-2000) was also examined to study the changes in the spatial coverage of these events. Decadal changes in the statistical features of heat and cold waves are highlighted. Statistical features of heat (cold) waves and severe heat (severe cold) waves are also discussed separately.

3. Results

3.1. *Heat Wave (HW) / Severe Heat Wave (SHW)*

3.1.1. *Frequency of HW / SHW spells*

A HW (SHW) spell is the duration in days during which HW (SHW) conditions are continuously experienced over a given sub-division. This duration can vary from one day to several days. The HW (SHW) event of one day duration is called HW (SHW) spell of 1 day, the event of 2 days duration is called HW (SHW) spell of 2 days and so on. In a given hot weather season, there can be HW (SHW) spells of various durations. The total number of all such HW (SHW) events or spells during a given period provides an idea about the frequency of HW (SHW) events or spells that have been experienced by a given sub-division during that period.

Fig. 2 shows the sub-division wise distribution of the total number of HW (SHW) events or spells during the hot weather season (March-July) for three decadal periods, *viz*., 1971-80, 1981-90 and 1991-2000. In all the three maps of Fig. 2, sub-divisions that had experienced ≥15 spells are shown by shaded areas. It is seen that during the period 1971-80, coastal Andhra Pradesh (21) and Orissa (18) are the only two sub-divisions, which had experienced ≥15 HW spells. These subdivisions had also

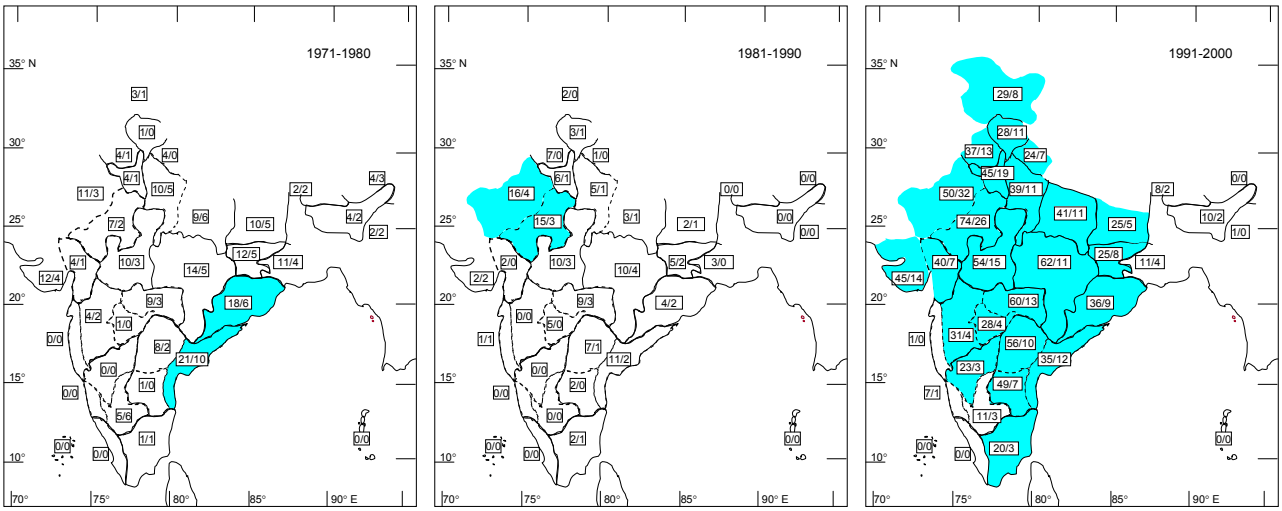

Fig. 2. Total number of HW (SHW) spells experienced by 35 meteorological sub-divisions of India during the hot weather season (March - July) for the decades 1971-80, 1981-90 and 1991-2000. The sub-divisions that have experienced the number of HW spells of ≥15 are shown as shaded areas

TABLE 2

Highest number of HW/SHW spells and days experienced by any sub-division each year and the corresponding sub-divisions during the period 1971-2000

Year	Highest number of		Highest number of	
	HW spells [sub-division number (s)]	SHW spells [sub-division number (s)]	HW days [Sub-division number (s)]	SHW days [Sub-division number (s)]
1971	1 (17)	-	1 (17)	-
1972	7 (7, 8 & 33)	6 (33)	18 (6)	13 (27)
1973	5 (27)	-	6 (20 & 27)	-
1974	1 (10, 19, 20 & 21)	1 (10 & 21)	2 (19 & 20)	1 (10 & 21)
1975	4(27)	1 (20 & 26)	4 (20 & 27)	1 (20 & 26)
1976	2(17, 18 & 27)	2 (17, 18 & 27)	6 (27)	6 (27)
1977	6 (22)	3 (22)	14 (22)	8 (22)
1978	2 (7 & 27)	1(27)	6 (27)	5 (27)
1979	4(2, 3 & 7)	4 (3)	9 (3)	5 (3)
1980	2(20)	1 (27)	7 (27)	1 (27)
1981	1 (22 & 23)	1 (22 & 23)	2 (23)	2 (23)
1982	3(13 , 19 ,20 & 27)	2 (7)	6 (20)	2 (7)
1983	-	-	-	-
1984	5 (17)	2 (17 & 18)	7 (17)	2 (17 & 18)
1985	1(12, 15, 16, 27 & 30)	-	1 (12,15, 16, 27 & 30)	-
1986	2(17 & 26)	2 (17 & 26)	3 (17 & 20)	3 (17 & 20)
1987	1 (12 & 14)	-	1 (11 & 14)	-
1988	3 (14)	-	5 (17)	-
1989	4(18)	1 (17, 18, 19, 20, 26 & 28)	11 (19)	3 (17)
1990	6 (17 & 18)	-	9 (17)	-
1991	10 (26)	2 (17, 18, 21 & 22)	16 (19, 20 & 26)	4 (17 & 21)
1992	6 (17)	-	10 (17)	-
1993	10 (26)	3 (17)	24 (18)	6 (13 & 17)
1994	11 (17)	4 (17)	25 (18)	5 (18)
1995	9 (18)	6 (17)	23 (17)	11 (17 & 20)
1996	11 (22)	4 (26)	23 (18)	6 (26)
1997	5 (7)	2 (27)	14 (27)	6 (27)
1998	12 (17, 21 & 29)	7 (18)	35 (17)	18 (18)
1999	14 (16)	7 (17)	41 (16 & 20)	13 (17)
2000	7 (13 & 17)	3 (13 & 17)	22 (17)	5 (17)

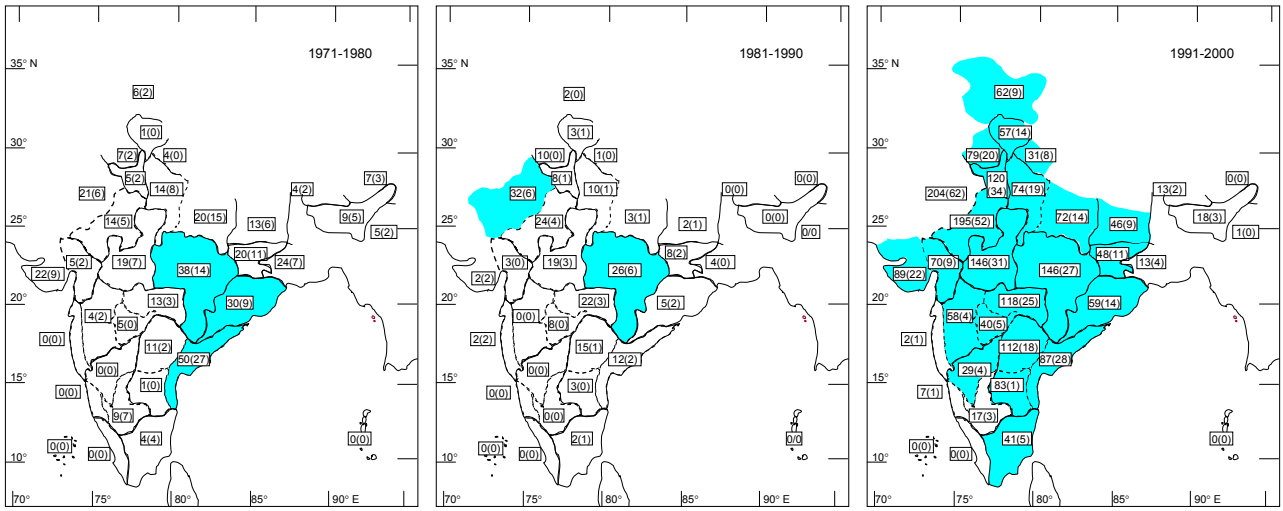

Fig. 3. Total number of HW (SHW) days experienced by 35 meteorological sub-divisions of India during the hot weather season (March - July) for the decades 1971-80, 1981-90 and 1991-2000. The sub-divisions that have experienced the number of HW days of ≥ 25 are shown as shaded areas

TABLE 3

Interannual variation of heat and cold waves experienced over the country

Year	Total number of HW (SHW)		Total number of sub-divisions affected by HW (SHW)	Total Number of CW (SCW)		Total number of sub-divisions affected by CW (SCW)
	Spells experienced by all the sub-divisions	Days experienced by all the sub-divisions		Spells experienced by all the sub-divisions	Days experienced by all the sub-divisions	
1971	1(0)	1 (0)	1(0)	39(0)	61(0)	14(0)
1972	55(40)	122(84)	14(14)	84(24)	143(30)	21(14)
1973	29(0)	42(0)	14(0)	35(19)	52(22)	12(12)
1974	4(2)	6(2)	4(2)	50(15)	104(17)	19(13)
1975	9(2)	13(2)	6(2)	34(18)	51(23)	11(10)
1976	10(5)	22(12)	7(4)	18(13)	23(13)	10(8)
1977	34(14)	59(31)	14(9)	29(18)	47(24)	19(14)
1978	7(1)	11(5)	5(1)	22(0)	26(0)	15(0)
1979	48(22)	86(24)	23(13)	0(0)	0(0)	0(0)
1980	12(1)	23(1)	11(1)	9(5)	9(5)	7(5)
1981	2(2)	3(3)	2(2)	1(0)	1(0)	1(0)
1982	27(12)	40(12)	15(11)	0 (0)	0(0)	4(1)
1983	0(0)	0(0)	0(0)	41(20)	46(20)	18(9)
1984	18(9)	24(9)	10(7)	27(9)	36(20)	15(8)
1985	5(0)	5(0)	5(0)	2(0)	2(0)	0(0)
1986	7(6)	11(10)	5(4)	1(0)	1(0)	1(0)
1987	2(0)	2(0)	2(0)	0(0)	0(0)	0(0)
1988	16(0)	24(0)	10(0)	0(0)	0(0)	0(0)
1989	23(6)	65(9)	10(6)	93(44)	223(73)	20(15)
1990	32(0)	56(0)	14(0)	56(2)	91(2)	20(5)
1991	76(11)	127(16)	17(7)	83(32)	120(46)	19(16)
1992	48(0)	66(0)	19(0)	116(0)	204(0)	27(0)
1993	104(13)	174(28)	23(8)	53(11)	69(11)	21(9)
1994	96(19)	172(27)	25(12)	26(2)	42(2)	21(2)
1995	103(62)	252(114)	28(24)	125(1)	185(1)	24(1)
1996	122(21)	227(27)	24(11)	61(4)	92(4)	20(11)
1997	25(5)	53(9)	11(4)	194(40)	3562(55)	24(13)
1998	183(70)	430(143)	29(26)	72(15)	149(22)	21(11)
1999	214(61)	512(90)	30(22)	74(6)	133(7)	19(1)
2000	69(9)	132(13)	21(5)	127(8)	242(13)	23(7)

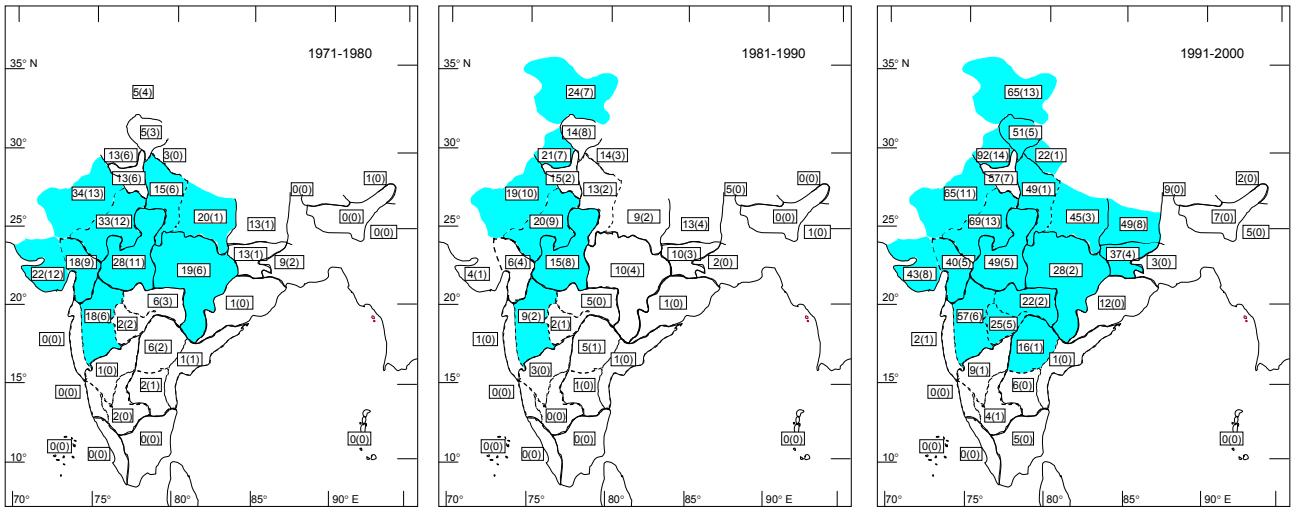

Fig. 4. Total number of CW (SCW) spells experienced by 35 meteorological sub-divisions of India during the Cold weather season (November - March) for the decades 1971-80, 1981-90 & 1991-2000. The sub-divisions that have experienced the number of CW spells of ≥ 15 are shown as shaded areas

experienced highest number of SHW spells (6 &10 respectively). Konkan & Goa, coastal Karnataka and Kerala along the west Coast, north interior Karnataka and Karnataka and Kerala along the west coast, north interior Karnataka and both the island sub-divisions (Lakshadweep and Andaman & Nicobar) did not experience any HW/SHW spells.

Except for Rajasthan state and East Madhya Pradesh & Chattisgarh, all other sub-divisions had experienced relatively less number of HW/SHW spells during 1981-90, in comparison to that during 1971-80. West Rajasthan (16) and East Rajasthan (15) experienced ≥15 HW spells. The highest number of SHW spells was experienced by West Rajasthan and East Madhya Pradesh and Chattisgarh (4 each). On the other hand, island sub-divisions, all sub-divisions from northeast India and some sub-divisions from west coast of Peninsular India & adjacent interior areas did not experience any HW/SHW spells.

During 1991-2000, the number of HW/SHW spells experienced by almost all the sub-divisions showed sharp increase. 25 sub-divisions experienced ≥15 HW spells. Highest number of HW (SHW) spells were experienced by West Rajasthan [80 (32)] followed by East Rajasthan [74 (26)]. However, Arunachal Pradesh, Kerala and two islands sub-divisions did not experience any HW/SHW spells. In fact, the latter three sub-divisions did not experience any HW/SHW spells during the entire data period (1971-2000).

Month wise distribution of HW/SHW spells indicated that the HW/SHW activity during July was nearly absent during all the years except 1982. During July 1982, 13 met subdivisions were affected by HW. However, the HW/SHW activity during March in most of the sub-divisions for the period 1981-90 was less in comparison to that of other two decadal periods.

Table 2 gives the sub-division numbers of the sub-divisions, which have experienced the highest number of HW and SHW spells or events during each year for the period 1971-2000. The interannual variation of the total number of HW (SHW) spells experienced by all the affected sub-divisions is shown in the first column of the Table 3.

3.1.2. *HW / SHW days*

Fig. 3 shows the sub-division wise distribution of the total number of HW and SHW days during the hot weather season (March to July) for the decades 1971-80, 1981-90 and 1991-2000. In all the three maps (Fig. 3), the sub-divisions that had experienced ≥25 HW days are shown as shaded areas. It is seen that just as in the case of number of HW/SHW spells, the number of HW/SHW days experienced by most of the sub-divisions also shows sharp increase during the decade (1991-2000). During 1981-90, except for Rajasthan, Madhya Pradesh, Chattisgarh, Punjab, Haryana, Chandigarh & Delhi, all other sub-divisions (particularly sub-divisions from East coast) experienced relatively less number of HW/SHW days compared to that during 1971-80.

In 1971-80, the highest number of HW (SHW) days were experienced by coastal Andhra Pradesh [50 (27)] followed by East Madhya Pradesh and Chattisgarh [38 (14)]. In 1981-90, sub-divisions that had experienced highest number of HW (SHW) days are West Rajasthan [32 (6)] and East Madhya Pradesh and Chattisgarh [26 (6)]. In 1991-2000, West Rajasthan [204 (62)] and East Rajasthan [195 (52)] experienced the highest number of HW (SHW) days.

The last two columns of Table 2 give the sub-division numbers of the sub-divisions, which had experienced the highest number of HW and SHW days each year during the period 1971-2000. The interannual variation of the total number of HW (SHW) days experienced by all the affected subdivisions is shown in the second column of the Table 3.

3.1.3. *Persistency*

When HW/SHW conditions start appearing over a sub-division, it is interesting to know as to how many days these conditions are likely to persist or prevail. On examining this aspect it is found that during all the decadal periods and for most of the sub-divisions 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 longer periods (about 10 days/5 days) over some of the sub-divisions.

Table 4 gives the details of HW spells of duration ≥10 days and SHW spells of duration ≥ 5 days experienced by various sub-divisions during the period 1971-2000. As seen in this table, most of these events occurred during the year 1972 and during the period since 1990.

During 1991-2000, the HW spell of highest duration (16 days) was experienced by West Rajasthan, which is also the longest HW spell during the entire data period. During 1971-80, East Madhya Pradesh and Chattisgarh is the only sub-division, which have experienced a HW spell of longer than, 10 days *i.e.* 11 days. During 1981-90, none of the sub-divisions experienced HW spell of ≥10 days. The longest HW spell (9 days) during this period was experienced by West Rajasthan.

During the entire period under study (1971-2000), the SHW spell of highest duration (9 days) was experienced by three sub-divisions, *viz.* East Uttar Pradesh, East Madhya Pradesh & Chattisgarh and West Rajasthan.

3.1.4. *Spatial coverage*

The spatial coverage of a HW/SHW varies from wave to wave and from a small part of a sub-division to a 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 number of sub-divisions affected by HW/SHW also varies.

The interannual variation of the number of sub-divisions affected by HW (SHW) during the hot weather season (March-July) for the period 1971-2000 is presented in the third column of Table 3. During the decade 1971-80, the year with highest (lowest) number of sub-divisions affected by HW was 1979 (1971). In 1979, 23 sub-divisions were affected by HW. Of these, 13 sub-divisions were affected by SHW. In 1971, one sub-division was affected by HW and none were affected by SHW. During the same decade, the year with the highest number of sub-divisions (14) affected by SHW was 1972. During the decade 1981-90, the year with highest (lowest) number of sub-divisions affected by HW/SHW was 1982 (1983). In 1983, none of the sub-divisions was affected by HW/SHW. In 1982, 15 sub-divisions were affected by HW and 11 of these sub-divisions were affected by SHW.

During the first half of the decade (1991-2000), the number of sub-divisions affected by HW showed a increase. After 1997, the year during which the number of sub-divisions affected by the HW was lowest, a sharp increase was observed in the number of sub-divisions affected by HW. During 1998 & 1999, 29 & 30 sub-divisions (26 & 22 sub-divisions) respectively were affected by HW (SHW). During the decades 1971-80, 1981-90 & 1991-2000, the average number of sub-divisions affected by HW (SHW) per year were 9.9 (4.6), 7.3(3.0) & 22.7 (11.9) respectively. This indicates significant increase in the average spatial coverage of HW (SHW) during the decade1991-2000 in comparison to the two previous decades.

3.2. *Cold Wave (CW)/Severe Cold Wave (SCW)*

3.2.1. *Frequency of CW/SCW Spells*

A CW/SCW spell is the duration during which CW/SCW conditions are continuously experienced by a sub-division. The duration of the spell may vary from one day to several days. Fig. 4 depicts the sub-division wise distribution of the total number of all such CW/SCW spells or events that had occurred during the cold weather season (November to March) in the decades 1971-80, 1981-90 and 1991-2000. In all the three maps, sub-

TABLE 4

Heat wave spells of duration ≥ 10 days & severe heat wave spells of duration ≥ 5 days that were experienced by various sub-divisions of India during the period 1971-2000

S. No.	Sub-division (No.) that experienced the entire spell	Period	Duration of spell in days	Total number of affected sub-divisions
		Heat wave spells of duration ≥ 10 days		
1	20	11 Jun to 21 Jun 1972	11	14
2	19	15 May to 24 May 1989	10	10
3	19	29 May to 7 Jun 1991	10	11
4	14	28 Apr to 8 May 1993	11	19
5	18	19 May to 31 May 1994	13	19
6	17	7 May to 16 May 1995	10	6
7	13	31 May to 9 Jun 1995	10	24
8	18	30 May to 9 Jun 1995	11	24
9	26	30 May to 10 Jun 1995	12	24
10	27	28 May to 6 Jun 1997	10	8
11	13	22 May to 3 Jun 1998	13	28
12	14	23 May to 1 Jun 1998	10	28
13	17	14 May to 23 May 1998	10	17
14	18	25 May to 3 Jun 1998	10	28
15	19	21 May to 3 Jun 1998	14	28
16	28	24 May to 3 Jun 1998	11	28
17	10	25 Apr to 4 May 1999	10	23
18	20	7 Apr to 16 Apr 1999	10	22
19	13	25 Apr to 8 May 1999	14	23
20	17	25 Apr to 10 May 1999	16	24
21	18	25 Apr to 7 May 1999	13	24
22	19	25 Apr to 6 May 1999	12	24
23	20	25 Apr to 5 May 1999	11	24
24	26	25 Apr to 6 May 1999	12	24
25	17	25 Apr to 6 May 2000	12	21
		Severe heat wave spells of duration ≥ 5 days		
1	8	16 Jun to 21 Jun 1972	6	12
2	10	14 Jun to 22 Jun 1972	9	12
3	20	13 Jun to 21 Jun 1972	9	12
4	27	6 Jun to 13 Jun 1972	8	9
5	27	18 May to 22 May 1978	5	1
6	13	9 Jun to 13 Jun 1993	5	8
7	18	5 Jun to 9 Jun 1995	5	19
8	20	2 Jun to 8 Jun 1995	7	19
9	17	15 May to 23 May 1998	9	6
10	18	18 May to 23 May 1998	6	6
11	18	25 May to 1 Jun 1998	8	20
12	27	27 May to 2 Jun 1998	7	21

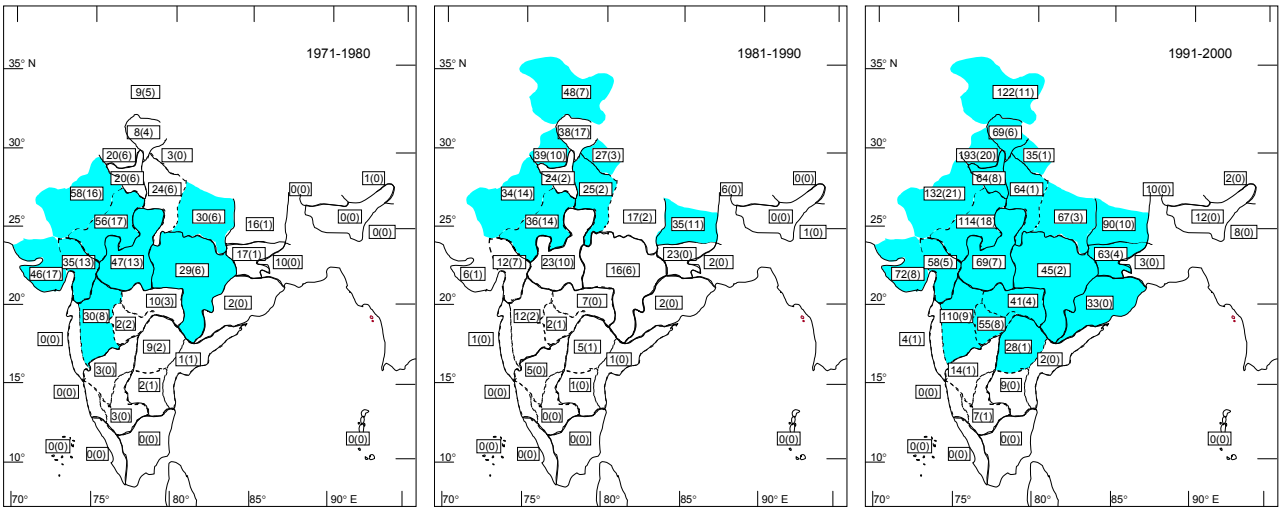

Fig. 5. Total number of CW (SCW) days experienced by 35 meteorological sub-divisions of India during the Cold weather season (November - March) for the decades 1971-80, 1981-90 and 1991-2000. The sub-divisions that have experienced the number of CW days of ≥ 25 are shown as shaded areas

divisions that had experienced number of CW spells ≥15 are shown as shaded area. In 1971-80, these sub-divisions were West and East Rajasthan, Gujarat region, Kutch & Saurashtra, West Madhya Pradesh, East Madhya Pradesh & Chattisgarh, Madhya Maharashtra and plains of East and West Uttar Pradesh. The highest number of CW & SCW spells (34 & 13) was experienced by West Rajasthan. During 1981-90, Rajasthan state, West Madhya Pradesh, Punjab, Jammu & Kashmir and Haryana, Chandigarh & Delhi had experienced total number of CW spells ≥15. The highest number of CW spells was experienced by Jammu & Kashmir (24) and highest number of SCW spells was experienced by West Rajasthan (10). It is thus seen that the region of highest frequency of CW/SCW spells during 1981-90 was relatively north of that during 1971-80.

In 1991-2000, the frequency of SW/SCW spells increased over most of the sub-divisions. The highest number of CW & SCW spells was experienced by Punjab (94 & 14). Except for some southern sub-divisions of Peninsular India and some sub-divisions in east India, most of the other sub-divisions had experienced CW spells ≥15. The sub-divisions, which did not experience any CW/SCW activity during all the three decadal periods, are Kerala, coastal Karnataka, Lakshadweep and Andaman & Nicobar Islands.

Table 5 gives the sub-division numbers of the sub-divisions, which had experienced the highest number of CW and SCW spells or events during each year for the entire period 1971-2000. The interannual variation of the total number of CW (SCW) spells experienced by all the affected sub-divisions is shown in the fourth column of the Table 3.

3.2.2. *CW/SCW days*

Fig. 5 shows the sub-division wise distribution of the total number of CW/SCW days during cold weather season for the three decadal periods 1971-80, 1981-90 & 1991-2000. In all the three maps, the sub-divisions that had experienced ≥ 25 CW days are shown as shaded areas. It is seen that for each of the three periods the shaded sub-divisions in both the Figs. 4 & 5 nearly coincide. In 1971-80, highest number of CW days was experienced by West Rajasthan (58) and highest number of SCW days was experienced by East Rajasthan and Saurashtra & Kutch (17 days each). During 1981-90 and 1991-2000, the highest number of CW days was experienced by Jammu & Kashmir (48 days) and Punjab (193 days) respectively. During the same periods, the highest number of SCW days were experienced by Rajasthan state (14 days) and West Rajasthan (21 days). It is seen that in the last decade, the CW/SCW activity over many sub-divisions has increased significantly. Over northern most six sub-divisions (Jammu & Kashmir, Punjab, Himachal Pradesh, Uttaranchal, Haryana, Chandigarh & Delhi and plains of West Uttar Pradesh), the increase was upside from one decade to the next. But in sub-divisions of Northwest India and Central India, the number of CW days decreased during the period 1981-90 and then increased again during the decade (1991-2000).

The last two columns of Table 5 give the sub-division numbers of the subdivisions that have

TABLE 5

Highest number of CW/SCW spells and days experienced by any sub-division each year and the corresponding sub-divisions during the period 1971-2000

Year	Highest number of			
	CW spells [sub-division number (s)]	SCW spells [sub-division number (s)]	CW days [sub-division number (s)]	SCW days [sub-division number (s)]
1971	3 (19)	-	4 (19 & 22)	-
1972	9 (19)	3 (17, 18 & 22)	19 (9)	4 (17 & 18)
1973	6 (18)	3 (19)	10 (18)	3 (19, 21, 22 & 24)
1974	6 (18 & 24)	2 (18, 20 & 21)	11 (18)	3 (18)
1975	5 (17 & 18)	4 (17)	10 (17)	5 (17 & 18)
1976	2 (28)	1 (10, 13, 16, 17, 18, 20, 26 & 28)	4 (28)	1 (10, 13, 16, 17, 18, 20, 26 & 28)
1977	5 (10)	2 (10,15, 17 & 22)	8 (10)	5 (22)
1978	5 (17)	-	9 (17)	-
1979	-	-	-	-
1980	2 (17 & 18)	1 (17, 18, 19, 20 & 22)	2 (17 & 18)	1 (17, 18, 19, 20 & 22)
1981	1 (22)	-	1 (22)	-
1982	1 (15, 24, 25 & 26)	1 (15)	1 (15, 24, 25 & 26)	1 (15)
1983	6 (17 & 18)	4 (17 & 18)	7 (17, 18 & 24)	4 (17 & 18)
1984	3 (17 & 18)	2 (14)	6 (17 & 18)	4 (17, 18 & 21)
1985	-	-	-	-
1986	1 (16)	-	1 (16)	-
1987	-	-	-	-
1988	-	-	-	-
1989	13 (16)	7 (16)	33 (16)	14 (15)
1990	8 (14 & 16)	1 (18)	12 (9 & 16)	2 (17 & 18)
1991	10 (16)	5 (16)	14 (16)	8 (16)
1992	9 (8 & 24)	-	20 (9)	-
1993	8 (14)	2 (18 & 25)	16 (14)	2 (18 & 25)
1994	4 (14 & 17)	1 (24 & 25)	9 (22)	1 (24 & 25)
1995	11 (14)	1 (16)	19 (16)	1 (16)
1996	16 (14)	5 (18)	37 (14)	9 (14 & 17)
1997	15 (14)	2 (8, 9 & 14)	31 (14)	3 (14)
1998	10 (14)	2 (9, 10, 13, 16, 17, 18, 19, 22 & 24)	26 (16)	6 (17)
1999	9 (24)	1 (16)	15 (24)	1 (16)
2000	14 (14)	3 (14)	33 (14)	4 (14)

experienced the highest number of CW and SCW days during each year for the period 1971-2000. The interannual variation of the total number of CW (SCW) days experienced by all the affected sub-divisions is shown in the fifth column of the Table 3.

3.2.3. *Persistency*

As in the case HW/SHW, it is found that the duration of most frequent CW/SCW spells in most of the sub-divisions is about 1-2 days. However, the duration of the longest CW/SCW spell showed some difference from one sub-division to another. Table 6 shows the CW spells that persisted for ≥ 7 days and SCW spells that persisted for ≥ 5 days over various sub-divisions. There were only a few occasions when a CW spell over a subdivision lasted for more than 10 days and there were only two occasions when a SCW spell persisted for ≥ 5 days. Table 6 also indicates that most of the longest CW/SCW spells were experienced only from 1989 onwards.

During 1971-80, the longest CW spell of 7 days was experienced by Gujarat Region and the longest SCW spell (3 days) was experienced by Saurashtra & Kutch and East Rajasthan (not given in the Table 6). During 1981-90, the CW spell of longest duration (10 days) was experienced by Bihar plains and longest SCW spell (7 days) was experienced by Jharkhand. In 1991-2000, the longest CW spell of 11 days was experienced by Jammu & Kashmir and the longest SCW spell of 4 days was experienced by West Rajasthan, Madhya Maharashtra and Marathwada.

TABLE 6

Cold wave spells of duration ≥7 days & severe cold wave spells of duration ≥ 5 days that were experienced by various sub-divisions of India during the period 1971-2000

S. No.	Sub-division (No.) that experienced the entire spell	Period	Duration of spell in days	Total number of affected sub-divisions
		Cold wave spells of duration ≥ 7 days		
1	17	24 Feb to 1 Mar 1972	7	11
2	18	24 Feb to 1 Mar 1972	7	11
3	21	6 Feb to 12 Feb 1974	7	15
4	8	21 Jan to 28 Jan 1989	8	13
5	9	18 Jan to 27 Jan 1989	10	13
6	14	17 Feb to 23 Feb 1989	7	8
7	15	15 Feb to 23 Feb 1989	9	8
8	25	1 Jan to 10 Jan 1992	10	21
9	26	1 Jan to 9 Jan 1992	9	21
10	18	7 Dec to 16 Dec 1996	10	20
11	14	9 Jan to 16 Jan 1997	8	11
12	13	20 Jan to 26 Jan 1998	7	15
13	14	20 Jan to 27 Jan 1998	8	15
14	17	16 Jan to 23 Jan 1998	8	15
15	16	23 Dec 1998 to 2 Jan 1999	11	15
16	14	21 Dec to 28 Dec1999	8	5
17	8	2 Jan to 8 Jan 2000	7	13
18	9	4 Jan to 10 Jan 2000	7	19
19	14	18 Feb to 27 Feb 2000	10	13
		Severe cold wave spells of duration ≥ 5 days		
1	8	22 Jan to 28 Jan 1989	7	7
2	9	22.Jan to 27 Jan 1989	6	7

3.2.4. *Spatial coverage*

In general, as the cold season advances, the CW/SCW starts affecting more and more sub-divisions. The spatial coverage becomes highest during January & February and reduces abruptly in March. The last column of Table 3 shows the interannual variation in the number of sub-divisions affected by CW (SCW) during the cold season (November-March) for the entire period 1971-2000. It is seen that during the years 1979, 1985, 1987 & 1988, none of the sub-divisions were affected by CW/SCW and in 1981 and 1986 only one sub-division each was affected by CW. Five of these six years during which the CW/SCW activity was absent or minimum pertains to the decade 1981-90.

During 1971-80 & 1991-2000, the spatial coverage of CW/SCW during each year was significantly more. Particularly, in the decade 1991-2000, the number of sub-divisions affected by CW has increased and is 19 or more during every year. During this decade, the average number of sub-divisions affected by CW (SCW) was 21.9 (7.1) per year. During the decades 1971-80 & 1981-90, the same were 12.8 (7.6) & 7.9 (3.8) respectively. This indicates a significant increase in the spatial coverage of CW during the recent decade in comparison to the two previous decades. However, average spatial coverage of SCW during 1991-2000 was less than that during 1971-80, but significantly more than that during 1981-90.

The years with the highest number of sub-divisions affected by CW for each of the three decades were 1972 (21 sub-divisions), 1989 (20 sub-divisions) and 1992 (27 sub-divisions) respectively. The corresponding years in respect of SCW were 1972 & 1979 (14 sub-divisions each), 1989 (15 sub-divisions) and 1991 (16 sub-divisions) respectively.

4. Conclusions

On examining the various features of heat and cold waves over India for the three decades of 1971-80, 1981-90 and 1991-2000, the following conclusions can be drawn.

(*i*) Significant increase in the frequency, persistency and spatial coverage of HW/SHW and CW/SCW has been observed during the recent decade (1991-2000) in

comparison to that during the earlier two decades. These changes might be the regional impact of the observed general increase in the global warming during the recent decade (1991-2000), which is the warmest decade during the past 140 years (WMO 2001). Other possible reasons behind these changes are local factors such as deforestation, urbanization etc. However, the magnitudes of the changes in the characteristics of the cold waves were relatively less than that of heat waves.

(*ii*) During the decade 1971-80, the frequency of HW/SHW spells was highest in coastal Andhra Pradesh, Orissa and East Madhya Pradesh & Chattisgarh. During the next two decades, the maximum HW/SHW zone moved over to Northwest India (west and east Rajasthan). The changes in the number of HW/SHW days also showed nearly similar changes. During the entire data period, the longest HW spell of duration (16 days) was experienced by West Rajasthan. The longest SHW spell of duration (9 days) was experienced by East Uttar Pradesh, East Madhya Pradesh & Chattisgarh and West Rajasthan. Also, most of the longest HW/SHW spells were experienced in 1972 and during the period since 1990. According to the latest WMO statement on the status of the Global Climate (WMO 2001), the first seven among the warmest years of past 140 years are from the recent decade (1998, 1997, 1995, 1990, 1999 and 1991). The observed increase in the frequency of HW/SHW activity and their persistency during recent decade, therefore, might have resulted from the increase in the decadal scale Global Warming. In most of the sub-divisions, the HW/SHW activity was relatively less during the intermediate decade (1981-90) as compared to that during the other two decades. It is observed that three sub-divisions, namely Kerala, Lakshadweep and Andaman Nicobar did not experience any HW/SHW activity at all during the entire data period.

(*iii*) During the decade 1971-80, the most frequent CW/SCW spells and highest number of CW/SCW days were experienced by West Madhya Pradesh. In the decades 1981-90 & 1991-2000, the maximum CW activity was noticed over Jammu & Kashmir and Punjab respectively and maximum SCW activity was experienced by Rajasthan and Punjab. The CW/SCW activity over northern India showed increase from one decade to the next. Over most of the other areas, the CW/SCW activity was relatively less during the intermediate decade (1981-90) in comparison to the other two decades. Two coastal sub-divisions; Kerala and coastal Karnataka and two island sub-divisions; Lakshadweep and Andaman & Nicobar did not experience any CW/SCW conditions during the entire data period. The longest CW spell (10 days) was experienced by Jammu & Kashmir and longest SCW spell (7 days) was experienced by Jharkhand.

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