551.524.36 (544.6)

LOW TEMPERATURES AND COLD SPELLS OVER RAJASTHAN DURING TWO DECADES

1. Certain optimum conditions of rainfall, temperature, sunshine etc. are required for healthy crop growth and good yield. Any deviation from the desired value need proper precautions to be taken to save the crop. The timely meteorological information's *viz*., occurrence of low temperatures, region of frost, state of sky etc. and their uses for effective agricultural planning operation is of considerable value. It helps to take protective measures from damage and thus increase quantity and quality of production leading to large economic gains. The low temperature and cold wave conditions in winter season over northern India including Rajasthan particularly during December to February is mainly caused due to the passage of western disturbances and induced cyclonic circulations over the region during the period. This results advection of dry cold northerly winds from higher latitudes over the area. For this purpose Low temperature is a stage when the temperature is less than or equal to 4° C causing a great hazard to crops at different stages and the crop cycle in the state.

Cold wave - When the normal minimum temperature is less than 10° C and the departure from the normal is –3 to –4° C, it is called cold wave conditions.

Severe cold wave - When the normal minimum temperature is less than 10° C and the departure from the normal is –5° C or less, it is termed as Severe Cold Wave. (Definition as per IMD, 1974 Heat and Cold Waves in India, Forecasting Manual IV P.6)

As per decision of AMR-2002, the revised criteria for declaring cold wave *w.e.f.* 1st March, 2002 being followed as :

(*i*) When normal minimum temperature is 10° C or more.

Cold wave	: Departure from normal is –5° C to –6° C.
Severe cold wave	: Departure from normal is –7° C or less.

(*ii*) When the normal minimum temperature is less than 10° C but above 0° C

Cold wave	Departure from normal is –4° C to –5° C.
Severe cold wave	Departure from normal is –6° or less

In most of occasions, the low temperatures, frost and cold wave conditions occur side by side. In every year during winter season over northern parts of the country, there occurs heavy losses to crops, toll of lives and uncomfortable situations due to low temperature and cold dry surface winds over the region.

Raghavan (1967) made a climatological study of severe cold waves in India using 51 years data from 1911 to 1961. Subbramayya and Suryanaryana Rao (1976) studies the occurrence of heat and cold waves that prevailed over Indian Sub-continent. Vashisth and Pareek (1991) made an attempt regarding forecasting aspects of minimum temperature at Jaipur and south Rajasthan.

2. *Data used* - Daily minimum temperature data for 6 selected stations of west Rajasthan *viz*., Ganganagar, Churu, Bikaner, Barmer, Jodhpur, Jaisalmer and 5 selected stations *viz*., Ajmer, Jaipur, Bharatpur, Kota, Dabok, A.P. (Udaipur) have been used as per classification given in climate of Rajasthan State, 1988 IMD. The temperature data from these stations were tabulated and compiled from monthly meteorological reports (MMRs) for the above stations of Rajasthan available at Meteorological Centre, Jaipur for the month of December, January and February for the years (1981-2001). In addition to this, low level wind data of few stations *viz*., Ganganagar, Churu, Dabok (A.P.) in the state have also been utilized. The extreme values of minimum temperature data available from climate of Rajasthan updated upto 1980 have also been utilized.

3. *Methodology* - The normal minimum temperature of some of the stations in Rajasthan in the month of January is of the order of 5° C. In order to satisfy the cold wave criteria, the minimum temperature should reach to a value of 1 to 2° C, whereas the low temperature warning is issued at the cut off temperature of 4° C for agricultural purposes.

Keeping this aspect in view, the present study of low temperatures of 11 selected stations in the state taking minimum temperatures 4° C or less for the period 1981-2001 have been carried out statistically. In order to study the trend of low temperature spells, data have been tabulated for the years 1981-91 and 1992-2001 separately.

4. *Analysis of data* - In order to analyse the low temperatures and cold spells over Rajasthan state, minimum temperature data for winter season from 1981 to 1991 and 1992 to 2001 have been utilized in three different temperatures ranges 4° to 2.1° C, 2 to 0.1° C and 0° to –2° C or below for the month of December, January and February for 11 selected stations of Rajasthan.

TABLE 1

No. of days when minimum temperature was less than 4° C

	December				January				February			
Station	4.0-2.1	2.0-0.1	0.0- –2.0	Total	4.0-2.1	2.0-0.1	0.0- –2.0	Total	4.0-2.1	2.0-0.1	0.0- –2.0	Total
For the year 1981-91												
Ganganagar	50	23	0	73	68	25	0	93	24	4	0	28
Churu	42	38	15	95	56	49	14	119	31	19	2	52
Bikaner	40	13	0	53	53	22	0	75	16	7	0	23
Barmer	2	0	0	2	2	0	0	2	2	0	0	2
Jodhpur	7	3	0	10	8	2	0	10	5	2	0	7
Jaisalmer	11	1	0	12	13	3	0	16	8	0	0	8
Ajmer	13	0	0	13	21	1	0	22	5	1	0	6
Jaipur	9	0	0	9	18	2	0	20	10	0	0	10
Bharatpur	13	0	0	13	34	1	0	35	5	0	0	5
Kota	2	0	0	2	1	0	0	1	3	0	0	3
Dabok - AP	49	10	1	60	51	14	5	70	17	4	1	22
For the year 1992-2001												
Ganganagar	57	23	3	83	74	48	2	124	26	2	0	28
Churu	77	48	17	142	72	59	18	149	22	7	4	33
Bikaner	23	2	0	25	30	5	0	35	2	1	0	3
Barmer	0	0	0	0	2	0	0	2	0	0	0	0
Jodhpur	1	0	0	1	2	0	0	2	3	0	0	3
Jaisalmer	4	0	0	4	5	0	0	5	0	0	0	0
Ajmer	0	0	0	0	0	0	0	0	0	0	0	0
Jaipur	3	0	0	3	19	0	0	19	1	0	0	1
Bharatpur	1	0	0	1	10	0	0	10	0	0	0	0
Kota	0	0	0	0	0	0	0	0	0	0	0	0
Dabok - AP	28	2	0	30	48	9	1	58	14	2	0	16

From Table 1, it is clear that the frequency of low temperature and cold spells are more in December, and January as compared to February. Further, in January the number of low temperature occurrences is more as compared to December which reduces considerably in February. Table 1 shows that Churu, Ganganagar, Dabok AP had 149, 124, 58 days respectively when minimum temperature was < 4° C in the month of January during 1992-2001 as compared to 119, 93, 70 days respectively during 1981-91. It is seen that the number of days of low temperature/cold spells occurrences are more in the northern parts than the southeastern parts of Rajasthan. Relatively less cold prone areas being the regions of Barmer, Jaisalmer and neighbourhood in the west Rajasthan and Kota, parts of Ajmer divisions in east Rajasthan.

Table 2 indicates the frequency of low temperature occurrences. On analysis of data, it is seen that large duration of low temperatures and cold spells are more in the month of January followed by December and February. During 1992-2001 at Churu, frequency is 15 days per year in January followed by 12 days in Ganganagar and 6 days in Udaipur (Dabok AP) respectively. In December month, it is 14 days in Churu, 8 days in Ganganagar and 3 days in Udaipur (Dabok AP), whereas in February, it reduces to 3 days in Churu, 3 days in Ganganagar and 0.2 days in Udaipur. During 1981-91, at Churu, frequency is 11 days per year followed by 8.5 days in Ganganagar and 6 days in Udaipur (Dabok AP) respectively in January. In December, it is 8.5 days in Churu, 6.5 days in Ganganagar and 0.2 days in Udaipur. The least/rare occurrences of low temperature/cold spells are the regions of Barmer, Jaisalmer and neighbourhood in west Rajasthan and Kota, adjoining parts of Ajmer division in east Rajasthan.

Table 3 shows the number of low temperature spells (temperature 4° C or less). Again, it is found that the regions of Churu and Ganganagar in north Rajasthan have

TABLE 2

Frequency of low temperature (No. of days/year)

Station	December		January		February	
	1981-91	1992-2001	1981-91	1992-2001	1981-91	1992-2001
Ganganagar	6.5	8.0	8.5	12.0	2.5	3.0
Churu	8.5	14.0	11.0	16.0	5.0	3.0
Bikaner	5.0	2.5	7.0	3.5	2.0	0.3
Barmer	0.2	-	0.2	0.2	0.2	-
Jodhpur	1.0	0.1	1.0	0.2	0.7	0.3
Jaisalmer	1.0	0.4	1.0	0.5	0.7	-
Ajmer	1.0	-	2.0	-	0.5	-
Jaipur	1.0	0.3	2.0	2.0	1.0	0.1
Bharatpur	1.0	0.1	3.0	1.0	0.5	-
Kota	0.2	-	0.1	-	0.3	-
Dabok - AP	5.5	3.0	6.0	6.0	2.0	0.2

TABLE 3

Frequency of low temperature spells (Minimum temperature 4° C)

Station	December		January		February	
	1981-91	1992-2001	1981-91	1992-2001	1981-91	1992-2001
Ganganagar	21(15)	23(13)	22(18)	40(27)	13(08)	14(06)
Churu	24(22)	34(26)	26(24)	33(27)	18(14)	14(08)
Bikaner	16(10)	12(05)	23(17)	17(10)	10(06)	02(01)
Barmer	02(-)	-	02(00)	02(00)	00(01)	-
Jodhpur	04(03)	01(00)	06(03)	02(00)	02(01)	02(00)
Jaisalmer	06(04)	02(01)	16(11)	04(01)	04(03)	-
Ajmer	06(03)	-	11(06)	-	03(01)	-
Jaipur	03(02)	03(00)	12(06)	12(04)	04(02)	01(00)
Bharatpur	06(04)	01(00)	15(09)	16(03)	04(01)	-
Kota	02(00)	-	01(00)	-	02(01)	-
Dabok - AP	14(12)	16(12)	16(12)	27(14)	00(05)	12(03)

The figures in bracket indicates the spell of low temperature of 2 days or more whereas the first figure denotes the spells including 1 day

larger number of cold spells in the month of January and December, whereas it reduces slightly in the month of February. The other regions of more number of low temperature spells are over Udaipur division in the month of January and December which reduces considerably in the month of February. It may be added that the northern parts of Rajasthan experiences more number of low temperature spells during December to February as compared to south Rajasthan. Similarly less number of occasions of low temperature spells are the regions of

TABLE 4(a)

Lowest minimum temperature °C records (1981-2001)

Station		December		January		February
Ganganagar	-0.5	09/10 Dec 1996	0.2	10 Jan 2001	1.0	17 Feb 1991
Churu	-2.0	09 Dec 1996	-2.0	1 Jan 1991	-1.0	10 Feb 1991
Bikaner	-0.8	15 Dec 1986	0.5	5 Jan 1986	1.8	18 Dec 1991
Barmer	2.5	30 Dec 1990	3.0	6 Jan 1985	4.0	21 Feb 1984
Jodhpur	2.0	25/27 Dec 1984	2.0	3 Jan 1986	1.0	21 Feb 1984
				11 Jan 1989		
Jaisalmer	1.5	31 Dec 1990	1.6	4 Jan 1986	2.1	22 Feb 1984
Ajmer	2.3	20 Dec 1986	1.6	14 Jan 1983	2.0	5 Feb 1983
Bharatpur	2.8	16 Dec 1986	1.0	01 Jan 1990	3.0	6 Feb 1984
		28 Dec 1989				
Jaipur	2.4	20 Dec 1985	1.0	1 Jan 1991	3.0	21 Feb 1984
Kota	4.0	31 Dec 1990	4.0	31 Jan 1984	4.0	21 Feb 1984
Udaipur (Dabok – A.P.)*	-0.8	15 Dec 1986	-1.2	1 Jan 1992	-1.0	22 Feb 1984

TABLE 4(b)

Minimum temperature °C records (Climate data upto 1980)

Station		December		January		February
Ganganagar	-1.7	28 Dec 1950	-2.2	12 Jan 1945	-2.8	11 Feb 1950
Churu	-4.6	28 Dec 1973	-4.6	16 Jan 1974	-4.6	7 Feb 1974
Bikaner	-2.8	04 Dec 1950	-4.0	26 Jan 1964	-2.5	7 Dec 1974
Barmer	2.3	17 Dec 1959	-1.7	15 Jan 1935	4.0	11 Feb 1957
Jaisalmer	-0.6	27 Dec 1950	-5.9	12 Jan 1967	-4.4	8 Feb 1972
Ajmer	-0.6	24 Dec 1945	-2.8	16 Jan 1935	-1.1	1 Feb 1905
Bharatpur *Dholpur	0.4	20 Dec 1976	-1.2	11/12 Jan 1967	0.2	8 Feb 1974
Jaipur	0.0	13 Dec 1964	-2.2	31 Jan 1905	-2.2	1 Feb 1905
Kota	2.6	27 Dec 19961	1.7	31 Mar 1929	2.2	1 Feb 1928
Udaipur (Dabok – A.P.)	0.6	29 Dec 1950	0.9	22 Jan 1962	1.0	9 Feb 1961

*Climate data for Bharatpur not available. In view Dholpur climate data taken as representative

Barmer, Jaisalmer and neighbourhood in west Rajasthan and Kota and adjoining parts of Ajmer division in east Rajasthan. The number of cold spells in Jaisalmer and Bharatpur in the month of January is relatively more as compared to the neighbouring region.

Table 4(a) gives the record of lowest minimum temperature in this data set. It is seen that the years 1984, 1986, 1991, 1996, 2001 are the years in which the significantly low temperatures were recorded in the state. The lowest minimum temperature of –2° C was recorded in the state on 1 January 91 at Churu. However, the lowest ever recorded minimum temperature at Churu being –4.6° C on 26 December, 1973, 16th January, 1974 and 7 February, 1974. The study and analysis of minimum temperature data reveal that all time established lowest record at Dabok AP in the month of December being –0.8° C on 15 December 1986, -1.2° C on 1 January 1992 and –1.0° C on 22 February 1984. In the data set for the period 1981-91, there has been cases of low temperature records below 4° C at Kota whereas there has been no such case in the data set 1991-2001. This may be due to growth of Industrialisation at Kota during this decade as compared to other regions of state. It is also observed that February 1984 has been most significant in respect of severity of cold spells/low temperature records

TABLE 5

Longest duration low temperature spell (No. of days/year)

	December		January		February	
Station	1981-1991	1992-2001	1981-91	1992-2001	1981-1991	1992-2001
Ganganagar	19 15 Dec 1986 – 02 Jan 1987	19 06 Dec 1996 – 24 Dec 1996	20 14 Jan 1986 – 2 Feb 1986	15 06 Jan 2001 – 20 Jan 2001	4 21 Feb 1986 – 24 Feb 1986	6 10 Feb 2001 – 06 Feb 2001
Churu	20 14 Dec 1986 – 02 Jan 1987	18 07 Dec 1996 – 24 Dec 1996	17 14 Jan 1984 – 30 Jan 1984	17 01 Jan 2000 – 17 Jan 2000	7 04 Feb 1984 – 10 Feb 1984	7 1 Feb 2001 – 07 Feb 2001
Bikaner	18 14 Dec 1986 – 31 Dec 1986	9 08 Dec 1996 – 16 Dec 1996	12 20 Jan 1984 – 31 Jan 1984	4 10 Jan 1997 – 13 Jan 1997	6 1 Feb 1983 – 06 Feb 1983	-
Barmer	-	1 12 Dec 1994	-	1 18 Jan 1996	2 21 Feb 1984 – 22 Feb 1984	1 14 Feb 2000
Jodhpur	6 22 Dec 1984 – 27 Jan 1984	1 12 Dec 1994	4 08 Jan 1989 – 11 Jan 1989	1 18 Jan 1996	5 20 Feb 1984 – 24 Feb 1984	1 14 Feb 2000
Jaisalmer	7 29 Dec 1990 – 04 Jan 1991	3 10 Dec 1994 – 12 Dec 1994	5 10 Jan 1983 – 14 Jan 1983	-	3 21 Feb 1984 – 23 Feb 1984	-
Ajmer	3 14 Dec 1986 – 16 Dec 1986	-	4 11 Jan 1983 – 14 Jan 1983	-	3 03 Feb 1983 – 05 Feb 1983	-
Jaipur	6 20 Dec 1986 – 25 Dec 1986	1 31 Dec 1997	6 30 Dec 1990 – 04 Jan 1991	4 16 Jan 1998 – 19 Jan 1998	6 21 Feb 1984 – 26 Feb 1984	1 03 Feb 2001
Bharatpur	4 20 Dec 1986 – 23 Dec 1986	1 11 Dec 1996	5 11 Jan 1989 – 15 Jan 1989	3 18 Jan 1993 – 20 Jan 1993	3 04 Feb 1983 – 07 Feb 1983	-
Kota	1	-	1	-	2	-
Dabok - AP	9 14 Dec 1986 – 22 Dec 1986	9 12 Dec 1994 – 20 Dec 1994	7 8 Jan 1989 – 14 Jan 1989	7 1 Jan 1992 – 07 Jan 1992	6 01 Feb 1983 – 06 Feb 1983	3 20 Feb 1993 – 22 Feb 1993

which is due to the influence of active western disturbances. In the data set (1981-91), the minimum temperature of February, 1984 for most of stations *viz*., Churu, Barmer, Jodhpur, Jaisalmer, Bharatpur, Jaipur, Kota and Udaipur have been recorded lowest minimum temperature for the month.

In the data set (1992-2001), the years 1992, 1994, 1996, 2000 and 2001 were significant with regard to low temperature records. The lowest minimum temperature of –0.5° C was recorded on 9 & 10 December, 1996 at Ganganagar. At Churu, it was –2.0° C on 9 December, 1996, -1.8° C on 15 January, 2000 and 0° C on 2 February, 2001.

Table 4(b) indicated lowest minimum temperature record from climate data upto 1980. The analysis of Tables 4(a&b) reveals that Udaipur being only station which established all time minimum record in the decade 1981-2001 whereas in the case of other stations, there has been no occasion when the minimum temperature touched the past climate record.

5. *Impact of low temperature on agriculture* - With the passage of active western disturbances over northern India, there is change in wind flow pattern from westerly/southwesterly to northerly/northwesterly in the lower and middle troposphere resulting flow of dry and cold air mass from higher latitude to over northwest India

TABLE 6

Low level wind pattern (0000 UTC) 1981-2001

S. No.	Spell of low temperature	Date	Ganganagar			Churu			Dabok		
			0.9 km	1.5 km	2.1 km	0.9 km	1.5 km	2.1 km	0.9 km	1.5 km	2.1 km
1	10 – 15 Feb 1985	11	34010	35010	34015	35010	34010	34015	02010	36010	36005
		12	34010	34015	34015	34010	34020	34015	04010	03015	02005
		13	30005	30005	32010	34005	30010	36010	07010	03005	03005
2	02 – 11 Jan 1986	4	34015	34015	34010	35010	34010	29015	04003	02005	29005
		5	34015	32015	32005	34015	34020	32010	03010	03010	31010
		6	32005	29010	26005	32005	29005	25005	02005	26005	25010
3	24 – 31 Dec 1983	26	34005	32015	02010	36005	32010	32010	03015	03015	04015
		27	34010	32015	34015	34010	32010	34015	03410	02005	02010
		28	34010	36015	35015	36010	36015	36015	04010	03010	02005
4	30 Dec 1991 – 04 Jan 1992	2	34010	32012	31015	34015	32015	32025	06005	29005	29010
		3	34020	36010	30015	34010	35010	03010	05010	35010	34020
5	08 – 16 Jan 1992	12	Fog			01020	34015	31020	05015	05005	34010
		13	02010	36010	30005	36010	36005	29005	07005	25010	26011
6	20 – 22 Feb 1993	20	28515	28512	28010	33015	35012	35019			
		21	29505	29006	31005	01007	31017	29022			
		22	10006	24507	Nil	01504	30014	30522			
7	12 – 20 Dec 1991	15	32010	32513	32518	34513	01513	35017			
		16	30508	32513	32012	33008	33017	33517			
		17	02505	05507	02501	06508	00507	34010			
8	07 – 24 Dec 1996	9	33509	35011	30013	34013	35019	33018			
		10	30509	31510	29014	36015	32015	29510			
		11	35503	32006	30010	32506	29009	31013			
9	06 – 18 Jan 1997	12	34502	28505	31006	01505	31507	31010			
		13	33006	28009	27008	01507	29506	32006			
		14	02008	32010	30005	33006	27505	33005			
10	08 – 20 Jan 2001	9	36009	00511	35506	Fog			01510	34005	31505
		10	29505	33503	27505	35006	02010	09008	04505	21005	27005
		11	26007	24011	24507	35003	31006	28509	13505	23005	23005
11	01 – 07 Feb 2001	1	31509	28516	28017	35514	34516	33011			
		2	31009	33514	32511	34015	32018	33017			
		3	29003	28506	26510	33512	30513	28014			

including Rajasthan. Advection of cold dry air causes abrupt fall in temperature leading to cold wave and low temperature conditions. The advance knowledge about the occurrences of low temperatures and areas of frost to be affected is an important aid to the agriculturist for planning operation and protective measures to be taken to save from damages. This also helps to take precautionary measures to guard against destructive pests and deceases which can be avoided.

5.1. *Frosts* - It is a phenomena in which moist air in the atmosphere in the regions of crops is condensed in the form of waterdroplets/ice particles and get deposited on the plants near the ground where temperature reaches near 0^{o} C. Damage due to frost is on account of destruction of protoplasm and break in moisture supply through the roots. The destruction of protoplasm is due to variations in density of water at 4^{o} C and formation of ice. The effect of frost and subsequent damage also take place to new growing buds, flowering and budding stages of plants. The damage varies with the different species of the crops. The tender species are found to suffer most on account of it.

In the open area where there is no blanket of vegetation, the cold wind influences area much more and temperature fall to a lower value, whereas in the forest areas, its influence is moderate and there is less chance of frost occurrences in these places. The development of frost in open areas is of severe intensity as compared to the forested regions.

TABLE 7

Time lag between cold prone zones 1981-2001

S. No.	Spell of low temperature	Date	Ganganagar	Churu	Dabok A.P.
1	10 – 15 Feb 1985	11	-	1.0	-
		12	-	-	-
		13	-	-	2.0
2	02 – 11 Jan 1986	4	0.7	-0.6	-
		5	-	-	-
		6	-	-	0.4
3	22 – 29 Dec 1987	23	2.8	3.8	-
		27	-	-	-
		28	-	2.4	3.7
4	24 – 31 Dec 1988	26	3.4		-
		27	-	-	-
		28	-	-	2.4
5	24 – 27 Jan 1988	26	2.2	-	-
		26	-	2.0	4.0
6	09 – 15 Jan 1989	12	1.2	0.0	-1.1
7	30 Dec 1991 – 04 Jan 1992	2	-	-1.0	-
		3	-	-	1.0
8	08 – 16 Jan 1992	12	2.0	0.0	-1.0
9	20 – 22 Feb 1993	20	4.8	3.6	1.0
		21	1.8	0.4	1.4
		22	3.9	0.2	3.8
10	12 – 20 Dec 1994	15	1.8	0.2	4.0
		16	2.4	2.8	3.8
		17	1.7	0.4	3.0
11	07 – 24 Dec 1996	9	-0.5	-2.0	3.5
		10	-0.5	-1.5	2.6
		11	0.2	-1.0	2.0
12	06 – 18 Jan 1997	12	1.6	0.4	8.6
		13	1.5	0.4	7.3
		14	1.5	1.2	9.4
13	08 – 20 Jan 2001	9	1.8	2.4	5.4
		10	0.2	1.4	4.2
		11	1.5	2.0	5.0
14	01 – 07 Feb 2001	1	2.5	0.9	13.6
		2	3.5	0.0	10.6
		3	2.4	0.2	3.4

The favourable conditions required for occurrence of frost are (*i*) mainly clear sky (*ii*) calm or very light wind (*iii*) low level inversion (*iv*) nocturnal cooling. The calm or very light wind allow very little remixing of air in the vicinity of vegetation resulting maximum loss of long wave radiation during night and thereby enhanced the cooling of the ground.

5.2. *Crop protection* - The protection of crops/plants from frost is an important aspect, particularly to farmers/agriculturist, forest management in the frost prone areas. The various method employed to protect and avoid frost damages and also to minimize losses are :

(*i*) Irrigation and supply of sufficient quantity of water to the crops/plants through tubewells canals etc. Fountain irrigation is more effective in such situations.

(*ii*) By generating smoke around the field by burning waste materials particularly in opposite direction of wind flow, so that a thin film of smoke is found over a region of crops which act as a shield and thereby protecting further radiative cooling of the ground during night.

(*iii*) Sprinkling of 0.1% (1 litre of H_2S0_4 per 1000 litre water) sulphuric acid also helps in protection from longer low temperature spell.

(*iv*) Putting cover of straw material over small and fruity trees to save the plants/trees from frost.

5.3. *Forecasting aspects* - The analysis of minimum temperature data reveal that there exist two cold prone pockets in the state one comprising the regions of Churu, Ganganagar and adjoining areas in north Rajasthan and the other/near Udaipur and neighbourhood in southeast Rajasthan. Table 5 indicates the persistency of low temperature spell. On examination, it is found that longer duration of low temperature spells of the order of 20 days are only in the month of December and January in the

northern parts of state with its centre near Churu whereas in the southeastern parts at Dabok (A.P.), Udaipur and neighbourhood, the duration of spell being 7 to 9 days. Barmer in west Rajasthan and Kota in east Rajasthan experiences cold spell of one day only in December and January.

The wind field over the state reveals that in the northwest Rajasthan, the low level wind pattern during low temperature spell is from northnorthwesterly (NNW) and it changes to northnortheasterly (NNE) while reaching the southeastern parts of state (Udaipur division). This is due to the presence of seasonal anti-cyclone over the area. Table 6 shows that during the cold spell, there is backing of wind observed with height in both the cold pockets which indicates cold air advection over the region.

It has been observed that the fall of minimum temperature in the northwest Rajasthan (Churu, Ganganagar and neighbourhood) begins first and thereafter it extends to the southeastern parts (Udaipur division). There is observed, a time lag of 12 to 24 hours exists in the advection of cold wave from the northwest boundary to southeast boundary of the state. However, the time lag variation between two cold pockets depends on the strength of low level wind field and its extension to higher altitude. Table 7 gives the idea of time lag in different low temperature spells. The aspect of time lag in development of cold spell in the northern and southern parts of state is also highlighted in the analysis of minimum temperature departure from normals and 24 hours minimum temperature change during various spells as it is clear from Tables 1&7. This indicates that the severity of cold spell is attained in the southern part of the state in the next date.

6. The following conclusions are drawn from the present study :

(*i*) There develops two cold prone pockets in Rajasthan during the period from December to February, one near Churu and neighbourhood in northern parts and other near Udaipur division in southeastern parts of state.

(*ii*) The frequency, persistency, severity of low temperatures/cold spells are more in December and January as compared to February months.

(*iii*) The frequency, persistency, severity are more in these two cold prone pockets as compared to the other parts of the Rajasthan state.

(*iv*) Kota and neighbourhood in east Rajasthan, Barmer and adjoining areas in west Rajasthan are relatively warmer where the frequency of low temperature occurences is found to be rare (1 day in 5 years).

(*v*) The frost occurrences during low temperature spells are found to be relatively more in these two cold prone zones. The commencement of frost takes place initially in the northern parts comprising of Churu and neighbourhood and later extends, in general by next day, in the Udaipur division.

(*vi*) The comparative analysis of lowest minimum temperature during this decade with past climate records shows less severity in cold temperatures during winters which may be due to population growth, industrialization and increased human activities etc.

(*vii*) The severity in low temperature in north Rajasthan (Churu and neighbourhood) is due to loose soil characteristics, less vegetation, low humidity and high albedo where as in southeast Rajasthan (Udaipur division) is due to stagnation of northnortheasterly winds for longer duration and gelophysical features.

7. The authors are very much thankful to Dr. S. K. Srivastav, Director General of Meteorology, New Delhi for providing necessary facilities and constant encouragement during the course of present study. Thanks are also due to Smt. L. L. Iyer, Smt. Jalaja R. Nair, S/Shri N. L. Sharma, Joginder Singh for typing and allied work.

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(*23 April 2004, Modified 26 July 2004*)