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Wind chill over India

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सार -- वायुमण्डल की ठण्डक शक्ति का माप पवन ठिठुरन है। इस अध्ययन में भारत के 15 चुने हुए मैदानी और पहाड़ी इलाकों के लिए सिपल और पेसल निदर्श से शीतकालीन महीनों, अर्थात दिसम्बर, जनवरी, फरवरी में पवन ठिठुरन का अभिकलन किया गया है। 5 से 10 वर्षों का दैनिक तापमान और पवन के आंकड़ों का उपयोग किया गया है। एक केन्द्र के लिए घंटेवार आंकड़ों का उपयोग कर पवन ठिठुरन पर विचार-विमर्श किया गया है। पवन ठिठुरन के सहचरता (कोवेरेंस) विश्लेषण से पवन ठिठुरन आंकड़े प्राप्त करने का प्रयास किया गया है। पवन और तापमान का ठंड में सापेक्ष योगदान को निर्धारित कर विचार-विमर्श किया गया है।

विश्लेषण से यह प्रकट होता है कि सामान्यत: ठिठुरन में प्रचंड तीव्रता होती है। अधिकतर ठिठुरन पवन की अपेक्षा तापमान के कारण होती है। यह भी देखा गया है कि भारतीय परिस्थितियों में मॉडल वास्तविक ठिठुरन को नहीं दर्शाता है।

ABSTRACT. Wind chill is a measure of cooling power of atmosphere. In this study, for 15 selected plain and hilly stations in India, wind chill has been computed from Siple and Passel's model for the winter month, *i.e.*, December, January and February. Daily temperature and wind data from 5 to 10 years have been used. Utilising hourly values, diurnal variation of wind chill has been discussed for one station. From the covariance analysis attempt has also been made to get true value of wind chill. Relative contribution of wind and temperature towards the chill has also been determined and discussed.

The analysis revealed that the chill is generally of severe intensity. Most of the chill is caused by the temperature rather than wind. It is also found that the model, in Indian conditions, does not truly reflect the chill.

1. Introduction

Chill is experienced by human body when the ambient air temperature is less than that of the human. However, temperature alone would not necessarily indicate how much cold one might feel, since many other environmental factors are also involved. The term "Wind chill", according to Schlatter (1981), refers to the common experience that at most temperatures it feels colder when the wind is blowing than when it is not. It was first introduced by Siple and Passel (1945) from experiments conducted in Antarctica. They gave the following equation for the wind chill :

$$H=(10\sqrt{V}+10.45-V)(33-t_a) \quad (1)$$

where, H is cooling power of the atmosphere (K cal m^{-2} hr^{-1}), V, the wind speed (m sec^{-1}), t_a, ambient air temperature (°C) and 33 is the bare skin temperature.

Other workers have obtained different equations to quantify the cooling power of the wind, mostly using Siple and Passel formula in some form or the other (Howe 1962 NOAA 1975, Lacy 1977, Smith 1979, Schlatter 1981 etc).

Steadman (1971) developed a chill formula based on thermal equilibrium of the body. His formula, though complicated, is more relevant to a person working outdoors than other formulae, as it considers all heat losses from clothed person and assumes wind speed at person's height (*i.e.*, 1.5 to 2 m) and not the anemometer height. He also allows for the possible gain in heat by insolation if a person is standing in full sunlight.

2. Wind chill equivalent temperature

A certain combination of wind speed and temperature is associated with certain rate of heat loss. The same heat loss may also be produced by combining a reference wind speed (*e.g.*, a person's walking speed) with a different temperature. This temperature is known as the equivalent temperature (T_e). The equivalent temperature represents the chilling effect of wind in terms of the lower temperature needed to produce the same sensation for a person walking in calm conditions. This is given by :

$$T_e=33-(33-T_a)(10.45+10\sqrt{V}-V)/20.69 \quad (2)$$

The measure of the wind chill is T_e-T_a. Normally wind speeds are reported in km hr^{-1} and, therefore, the wind chill in this unit becomes :

$$T_e-T_a=(33-T_a)(0.495-0.255\sqrt{V}+0.0134\,V) \quad (3)$$

The second bracket in the above equation assumed negative values when $4\cdot8<V\leqslant283$. Surface wind speed more than 283 km hr^{-1} are seldom observed in tropics

TABLE 1

Details of the data used

Station	Location Lat. (°N)	Long. (°E)	Height above m.s.l. (m)	Period of data
Ambala	30°23′	76°46′	272	1971-1980
Amritsar	31°38′	74°52′	234	1971-1980
Bikaner	28°00′	73°18′	224	1971-1975, 1977-1979
Dehradun	30°19′	78°02′	682	1971-1974, 1976-1977
Dharamsala	32°16′	76°23′	1211	1971-1976
Ferozpur	30°55′	74°40′	200	1971-1980
Ganganagar	29°55′	73°53′	177	1971-1980
Hissar	29°10′	75°44′	221	1971-1980
Karnal	29°42′	77°02′	249	1972-1974, 1976-1980
Ludhiana	30°56′	75°52′	247	1971-1980
Mussoorie	30°27′	78°05′	2042	1971-1974, 1976-1977
Ootacamund	11°24′	76°44′	2249	1971-1980
Phalodi	27°08′	72°22′	234	1971-1980
Roorkee	29°51′	77°53′	274	1971-1977
Shillong	25°34′	91°53′	1500	1971-1975, 1977 and 1979

TABLE 2

Frequency distribution of chill
(% no. of days)

Range for wind chill	Dec		Jan		Feb	
	F	CF	F	CF	F	CF
(1)	(2)	(3)	(4)	(5)	(6)	(7)
(a) Amritsar						
0 to — 1.0	1.3	72.1	1.3	74.0	0.7	85.7
—1.1 to — 2.0	0.4	70.8	0.3	72.7	0.7	85.0
—2.1 to — 3.0	2.4	70.4	2.3	72.4	2.9	84.3
—3.1 to — 4.0	1.9	68.0	1.0	70.1	2.5	81.4
—4.1 to — 5.0	1.3	66.1	1.3	69.1	1.8	78.9
—5.1 to — 6.0	1.0	64.8	1.3	67.8	3.9	*77.1*
—6.1 to — 7.0	2.4	63.8	1.6	66.5	4.6	73.2
—7.1 to — 8.0	8.4	61.4	6.5	64.9	5.4	68.6
—8.1 to — 9.0	11.6	*53.0*	8.7	*58.4*	10.0	63.2

F—Frequency, CF—Cumulative frequency

TABLE 2 (*contd*)

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Amritsar (*contd*)						
—9.1 to —10.0	6.5	41.4	8.7	49.7	8.6	*53.2*
—10.1 to —11.0	4.9	34.9	4.5	41.0	3.9	44.6
—11.1 to —12.0	2.9	30.0	3.5	36.5	4.3	40.7
—12.1 to —13.0	4.5	27.1	3.2	33.0	9.6	36.4
—13.1 to —14.0	8.7	22.6	6.5	29.8	11.8	26.8
—14.1 or less	13.9	13.9	13.3	23.3	15.0	15.0
Man hourly chill	—1.5		—2.2		—2.6	
Standard deviation	0.6		0.6		0.4	
(b) Karnal						
0 to —1.0	0.0	83.8	0.0	65.9	0.0	81.5
—1.1 to —2.0	0.0	83.8	0.0	65.9	0.0	81.5
—2.1 to —3.0	0.8	83.8	0.5	65.9	1.0	81.5
—3.1 to —4.0	1.6	83.0	0.5	65.4	1.0	80.5
—4.1 to —5.0	1.6	81.4	0.5	64.9	1.0	79.5
—5.1 to —6.0	0.8	79.8	0.9	64.4	7.1	*78.5*
—6.1 to —7.0	5.5	*79.0*	1.4	63.5	4.6	71.4
—7.1 to —8.0	5.5	73.5	2.3	62.1	5.0	66.8
—8.1 to —9.0	12.9	68.0	4.5	59.8	6.8	61.8
—9.1 to —10.0	11.9	*55.1*	4.5	55.3	9.6	*55.0*
—10.1 to —11.0	9.7	43.2	8.7	*50.8*	16.8	45.4
—11.1 to —12.0	10.7	33.5	12.3	42.1	5.7	28.6
—12.1 to —13.0	11.3	22.8	11.0	29.8	12.9	22.9
—13.1 to —14.0	10.7	11.5	9.4	18.8	6.1	10.0
—14.1 or less	0.8	0.8	9.4	9.4	3.9	3.9
(c) Mussoorie						
0 to — 1.0	0.7	55.8	0.0	65.1	0.7	40.6
—1.1 to — 2.0	0.7	55.1	0.0	65.1	0.0	39.9
—2.1 to — 3.0	1.0	54.4	0.0	65.1	2.1	39.9
—3.1 to — 4.0	7.7	*53.4*	9.7	65.1	5.7	37.8
—4.1 to — 5.0	8.7	45.7	11.9	*55.4*	3.6	32.1
—5.1 to — 6.0	3.9	37.0	8.7	43.5	2.1	28.5
—6.1 to — 7.0	2.9	33.1	2.3	34.8	0.0	26.4
—7.1 to — 8.0	1.6	30.2	0.0	32.5	1.4	26.4
—8.1 to — 9.0	5.5	28.6	4.2	32.5	5.0	25.0
— 9.1 to —10.0	9.4	23.1	2.3	28.3	5.0	20.0
—10.1 to —11.0	4.9	13.7	10.7	26.0	8.6	15.0
—11.1 to —12.0	3.9	8.8	6.5	15.3	1.4	6.4
—12.1 to —13.0	3.2	4.9	2.3	8.8	2.9	5.0
—13.1 to —14.0	0.7	1.7	1.0	6.5	1.4	2.1
—14.1 or less	1.0	1.0	5.5	5.5	0.7	0.7

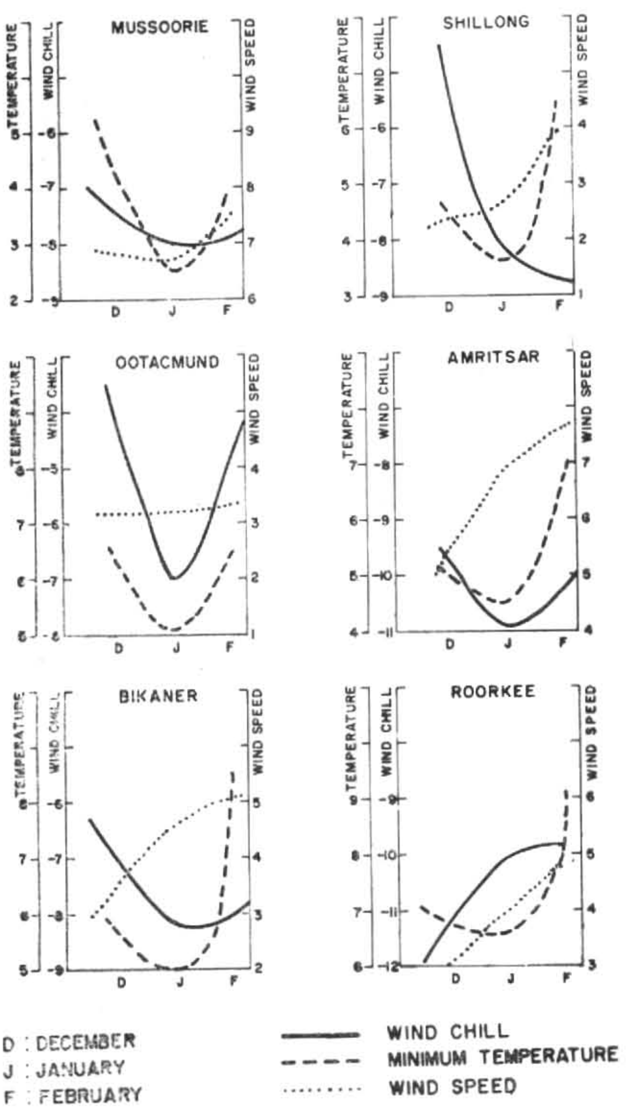

Fig. 1. Mean monthly wind chill (°C), wind speed (kmph) and minimum temperature (°C)

and, therefore, one may be quite justified in assuming that V exceeding 5 km hr^{-1} gives chill sensation in human's living in tropical areas, provided the air temperature is less than the skin temperature.

3. Data

Unlike studies on wind chill in the western hemisphere, not much work has been done on this subject in India. In the first such work, Mukherjee and Raman Rao (1982) examined wind chill for Leh located in the Himalayan mountain range. In the present work wind chill has been studied for a few selected stations in India which are generally subjected to severe cold in winter and for which more than 5 years data were available.

Station which had daily mean minimum temperature of $\leqslant 7.5$ °C in January were identified. 15 such stations including one from Peninsular India, satisfying this criterion were selected. Particulars of these stations are given in Table 1. The illustrations are, however, confined to a few selected stations only due to lack of space. Daily temperature and wind data were collected from records of India Met. Dep. The temperature (T_a) corresponds to the minimum temperature and was assumed to represent mean chill for the night.

Among the 15 stations selected hourly data of wind and temperature were available for only one station, *i.e.*, Amritsar. Diurnal variation in wind chill temperature was, therefore, examined for this station. T_a in this case represents dry bulb temperature at different hours.

4. Discussion

The coldest month in India are December, January and February. The discussion in the following paragraphs is, as such, restricted to these months.

4.1 *Mean wind chill temperature*

While appreciating the relationship between different factors in the wind chill problem, it may be remembered that human react to the instantaneous weather and not to the climatic averages. Yet the normal or averages gives him some idea so that a man adjusts himself accordingly.

Mean values of wind chill for January, February and December for some of the stations is shown in Fig. 1. For the sake of comparison, mean minimum temperatures and mean wind speed are also given in the figure.

The wind chill is found, in general, to follow the minimum temperature pattern. This would suggest that effect of wind speed does not largely modify the pattern of wind chill temperature and, perhaps, wind chill is controlled generally by temperature (cf. Mukherjee and Raman Rao 1982). Wind chill at most of the stations was found to increase from December to January. In February the chill temperature, though smaller than that in January, was nevertheless comparable to that in December. In the hilly regions of western Uttar Pradesh, however, the winter appears severest during December. February month also appears chillier compared to January. In the hilly regions of northeast India, largest wind chill temperatures (negatively) are felt in February. In southern India, at the Conoor-Palni hills, Ootacamund reflects chilly conditions for the winter season. The chill values at this station are found to be slightly more than that in the northern parts of the country.

4.2. *Wind chill distribution*

The distribution of wind chill days is shown in Table 2. Percentage number of days when chill in different ranges are experienced, is also shown in Table 2 alongwith their cumulative totals. For the sake of convenience, the wind chill values have been classified in intervals of 1°C. Over areas in north India, nearly 50% or more of the days in winter experience chill of various degrees. By and large, the maximum number of days are during February followed by January and December. Over hilly areas of northeast India the chilly days never exceed 50% in a month. The trend observed over northwest India, however, persists in the northeast too with the lowest number of chilly days confined to December. In the south Indian hills the number of chilly days never exceed 25% in a month; the largest number occurring in December.

Values of the wind chill when they exceed second and third quartiles days are italics in the table. Though the third quartile values are seldom observed in nearly half of the days the wind chill during minimum temperature epoch is −8°C or more in some of the stations in northwest India. This suggests that in nearly 50% of the days the cold sensation is felt severely. In the remaining stations, the median values are either not observed, or wherever they are observed the chill is not severe. The third quartile values of the chill are observed in February at Ambala, Amritsar, Dehradun, Hissar and Karnal when chill temperature of $-2°, -5°, -3°, -2°, -6°C$ or more respectively are seen. On 75% or more days in December at Karnal and January in Ambala, wind chill could be as low as $-7°$ and $-3°C$ respectively. These stations, thus, can be deemed to experience, colder conditions, on 75% or more days in winter particularly in February. A remarkable observation that emerges from the table is that in north India, not all days give chilly sensation. This is due to the basic definition of chill, *i.e.*, the temperature should be less than the skin temperature of 33° C and simultaneously the surface wind speed should exceed 5 km hr^{-1}. No wonder, under these stringent conditions, very few days or rather nights qualify to be termed as "chilly".

For most of the stations, the chill is less than $-8°C$ for more than half of the occasions. This is nearly true for all the three months considered in the analysis at all the stations. A steady increase in the number of chilly days till $-10°$ C during January and February is seen. However, frequency of wind chill when less than $-10°$ C is found far more prominent than those with lower chill values. This means that whenever wind chill is experienced, it is, on large number of occasions, of severe nature.

4.3. *Wind and minimum temperature*

Assessment of their relative contribution to chillness — It is clear from Eqn. (3) above that both wind and temperature contribute towards the wind chill. Which of these two factors contribute more towards the chill is a complex problem not easily identifiable. However, it is possible to find out the relative contribution of wind and temperature to the cold. With this aim in view, mean monthly minimum temperature and wind speed have been plotted for each month along with the mean chill values and shown in Fig. 1. It is evident from the figure that low values (negative) of chill are associated with lower values of minimum temperature and higher values of wind speed.

This apparently simple relationship is not always satisfied. For instance, in February at most of the locations in northwest India, a rise in wind speed is unable to off-set the effect of rise in temperature, with the result, the chill temperature registers a rise. At some of the stations (Bikaner, Dehradun, Roorkee etc), this rise is, however, not found very large, although wind speed revealed a prominent increase. However, at Phalodi and Shillong a rise both in wind speed and temperature in February lowers the chill temperature. Perhaps at these places, the effect of wind predominates over that of temperature.

In December, as it well known there is overall fall in minimum temperature in association with low solar altitude. The wind speed, however, is indifferent at most of the stations and as such low chill values observed in this month can be singularly attributed to the fall in minimum temperature.

During January the downward trend in minimum temperature continues and the wind speed also registers, in most of the cases, a rise. But though, in general, this give rise to increase in chillness at Roorkee, Ferozepur and Darjeeling, a slight rise in chill temperature is observed.

TABLE 3

Classification of chill (days %) of various categories

Category	Dec	Jan	Feb	Dec	Jan	Feb
		Amritsar			**Dehradun**	
Moderate	7.3	6.2	8.6	1.7	3.9	6.5
Very cold	29.9	26.8	32.5	26.1	36.3	37.8
Extremely cold	34.9	41.0	44.6	21.1	33.6	31.2
		Karnal			**Bikaner**	
Moderate	4.0	1.5	3.0	10.6	4.7	14.5
Very cold	36.6	13.6	33.1	17.2	13.4	23.3
Extremely cold	43.2	50.8	45.4	7.5	8.2	12.9

TABLE 4

Mean wind chill and covariance

	Mean chill (°C)	Covariance	True chill values
		Ootacamund	
Dec	—4.2	+0.57	—4.8
Jan	—7.0	—3.14	—3.9
Feb	—5.0	—.06	—4.9
		Ganganagar	
Dec	—6.4	—0.41	—6.8
Jan	—7.9	+3.86	—11.8
Feb	—7.2	+5.82	—13.0
		Hissar	
Dec	—9.6	+11.15	—20.7
Jan	—10.4	+2.56	—13.0
Feb	—9.4	+0.97	—10.2
		Amritsar	
Dec	—9.8	—6.3	—3.5
Jan	—10.9	—9.18	—1.7
Feb	—10.3	—3.28	—7.0
		Phalodi	
Dec	—8.5	+7.7	—16.2
Jan	—8.9	+9.8	—18.7
Feb	—7.3	+3.7	—11.0

The index used in the present study is based on wind and temperature. Temperature and wind at a place are mostly correlated. Average values of the wind chill gives a very general picture to the public. If V is the instantaneous wind speed and T the temperature, (′) denotes departure from the mean, then :

$$\overline{VT} = \overline{(\overline{V} + V')\ (\overline{T} + T')}$$
$$= \overline{V}\,\overline{T} + \overline{V'T'}$$

To get the true wind chill, elements of covariance should be removed from the origional value. It may, however, be mentioned that the relationship is not always in the same direction. Whereas in Amritsar, wind and temperature appear to nullify each other's effect, at the remaining stations temperature and wind act in the same direction and thus, contribute jointly to the increased chill.

Covariance for some selected stations is shown in Table 4 alongwith mean value and the true chill values.

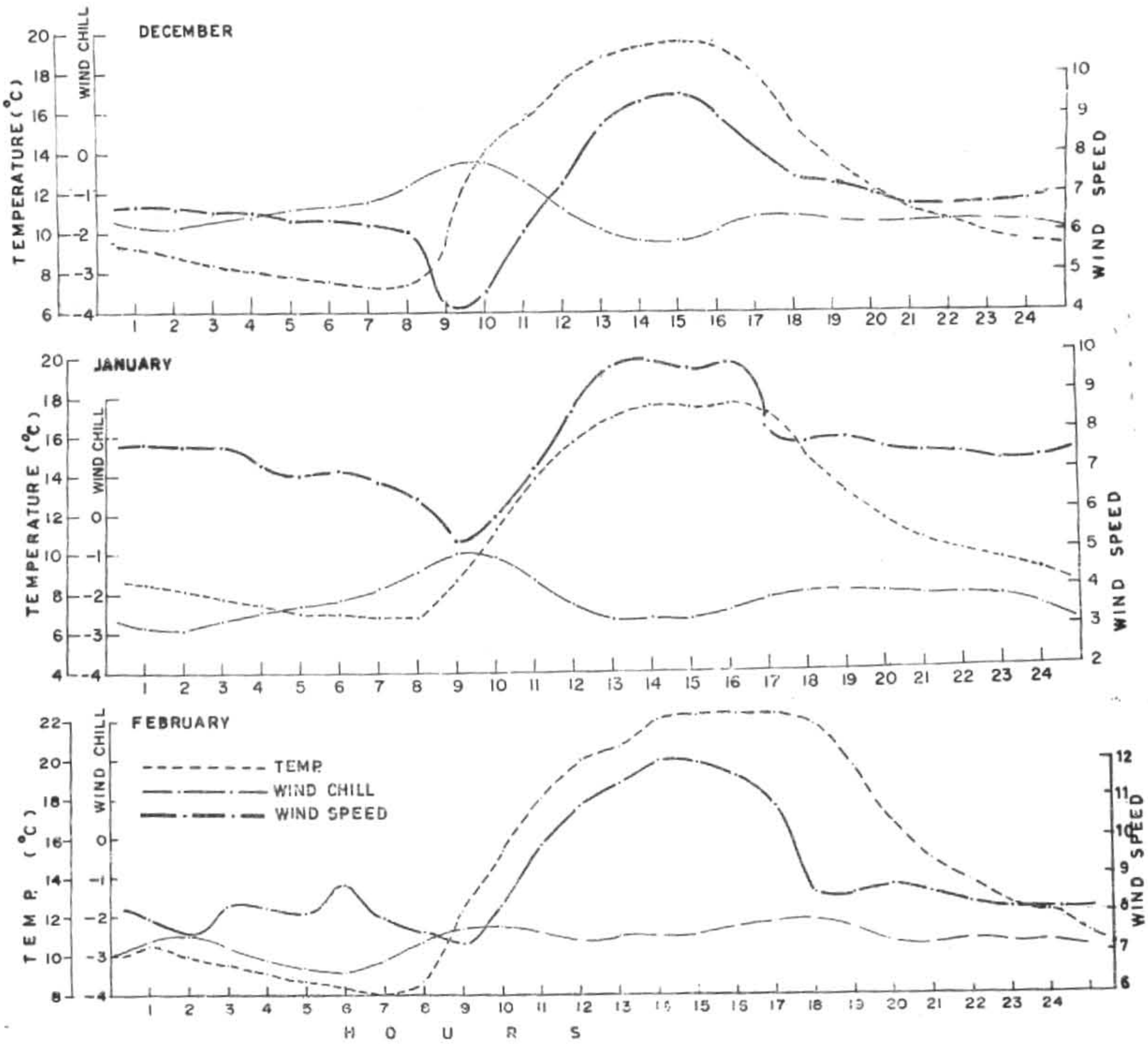

Fig. 2. Diurnal variation of wind chill (°C), wind speed (km/hr)and dry bulb temperature (°C) at Amritsar

Covariance at some of the north Indian stations, during December and January was found large comparable to the wind chill values in absolute terms, supporting the view that wind and temperature variations are often correlated. The higher values of chill, observed earlier are, perhaps, the consequence of the mean values, masking the true covariance:

4.4. *Classification of wind chill*

Utilising the frequency distribution of wind chill values the following classification has been proposed in this study. It may be mentioned that the ranges chosen are purely arbitrary :

Wind chill (°C)	*Sensation*
0 to —5.0	Moderate cold
—5.1 to —10	Very cold
less than —10	Extremely cold

Frequency distribution of the number of days, for some selected stations, is shown in Table 3.

It may be seen from the table that, in general, the largest number of chilly days belong to the very cold category. However, at Amritsar, Dehradun and Karnal, there are more number of days with extreme cold than those in other categories. It is, thus, clear that in most parts of north India, strong wind and low temperature combine together, give rise to extremely cold sensations during winter.

4.5. *Diurnal variation of the wind chill*

Diurnal variation of the wind chill is a field which has largely not been studied, perhaps due to lack of data. Mean wind chill values described above are based on minimum temperature. The minimum temperature epoch, as is well known, occurs just before sunrise and the chill values computed from that temperature cannot be considered as truly representative of a full day. At different hours of the day a person may experience different chill sensation because of variations both in temperature and wind. Among the stations chosen in the study, only for one station, *viz.*, Amritsar hourly tabulations of both temperature and wind were available. These have been computed for each of the winter months from Eqn. (3) above, and discussed below.

The hourly plot of the wind chill for the each month is shown in Fig. 2. For comparison sake, in each of the figures, wind and dry bulb temperature have also been

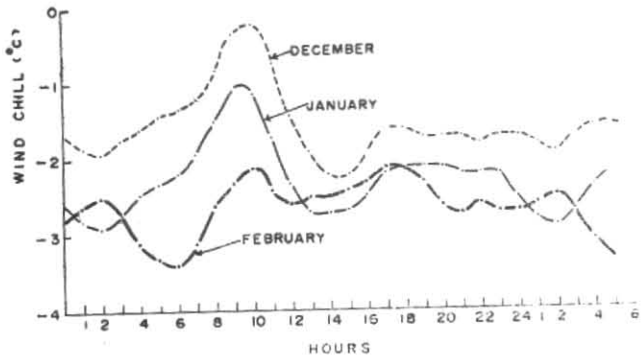

Fig. 3. Diurnal variation of smoothened chill (°C) at Amritsar

given. The chill values were smoothened by using the weights 1, 2 and 1 to three consecutive chill values, a, b, c and the smoothened value b', corresponding to actual value b is given by :

$$b' = \frac{a + 2b + c}{4}$$

The resulting curves are shown in Fig. 3. Contrary to the general presumption chill values appear quite low (negatively) during the morning hours between 0800 and 1000 hr. The chill values go on increasing (negatively) after attaining the peak.

The lowest negative values of chill temperature are surprisingly observed during 1400 to 1500 hr, *i.e.*, about the time of maximum temperature epoch and not during the minimum temperature epoch. This is a general trend observed for December and January months. During February the lowest negative chill temperature corresponds to the minimum temperature epoch in the afternoon hours, and that too, these are comparable to those in early morning hours. In February the peak is also not as conspicuous as in other two months.

From analysis of hourly data it appears that temperature does not alone contribute to the wind chill, but perhaps at most of the hours, significant influence is exerted by the wind factor.

The mean hourly values of the wind chill is shown in Table 2(a) for each month along with the standard deviation. A comparison of the mean hourly wind chill values with the daily values given in Table 4 reveal that the former is much greater than the latter. This is because the hourly values are based on the temperatures for all the 24-hr whereas the daily values utilises a single value attained during the minimum temperature epoch.

5. Conclusions

In this study wind chill index has been calculated from the wind and minimum temperature for a few selected stations in India. The lower chill values are associated with lower temperature. Rise in surface wind force contributes, to some extent, to the chill and at some of the locations studied, the wind effect predominates over the effect due to fall in minimum temperature to produce severe chilly sensation.

Analysis of covariance revealed that the much larger than mean values computed from Siple and Passel's model do not truely reflect the state of affairs. In order to obtain objective values, the elements of covariance of temperature and wind must be removed from the mean values.

From the examination of diurnal pattern it is inferred that the largest (negative values) of chill are often realised at the time of maximum temperature epoch and not during the minimum temperature epoch.

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