ON METEOROLOGICAL OBSERVATIONS AT LEH DURING WINTER (1960-61)

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Meteorological data recorded at Leh (3520 metres) during the winter (60-61) has been presented. January is the coldest month with lowest maximum and minimum air temperatures, the mean values being—2·4°C and —13·7°C respectively. The relative humidity is 48%. The hours of sunshine are also minimum, 16 hrs in four days. The solar radiation thermometer reads 20°C indicating a high solar energy flux on clear days. The sky remains mostly overcast from mid December to mid February. The average wind speed is quite low (range 0·43—5·12 km/hr) with occasional high velocity gusts for short duration. The readings of the solar radiation thermometer are always higher than the ground temperature. The globe thermometer also records a higher temperature except when higher wind speeds affect its readings. A steep temperature gradient is observed beneath the ground surface. Rains are scanty and rare. The data provides a basis for working out clothing requirements for comfort.

Leh situated at a height of 11,554 ft. (3520 metres) above sea level (Lat. 34° 09′ N, Long. 77° 34′ E) is the headquarters of Ladakh. In view of the strategic importance of Leh, it was considered necessary to collect the meteorological data, as a part of environmental studies, with a view to work out the requirements of clothing and equipment for comfort and operational efficiency of the personnel. This paper presents the meteorological and other data recorded during the winter 1960-61.

METHODS AND OBSERVATIONS

The following measurements were made between 1000 and 1600 hours I.S.T.:

1. Standard meteorological observations inside Stevenson Screen.
2. Hourly readings of dry and wet bulb air temperatures in shade with the Whirling Psychrometer, manually operated four feet above ground level.
3. Wind speed measurements with a rotating cupcounter anemometer, at five feet above ground level.
4. Duration of sunshine with Campbell stokes recorder placed on a platform 4 feet above ground level.
5. Hourly readings of solar radiation with vacuum black bulb solar radiation thermometer placed at a height of 2½ feet above ground level.
6. Hourly readings of black globe thermometer placed at a height of 2½ feet above ground level for assessment of solar heat load on man in relation to his clothing.
7. Hourly readings of ground temperatures recorded with a mercury-in-glass thermometer at the surface and below it.
8. General observations on state of the atmosphere, and cloud cover.

RESULTS

Meteorological Data

Maximum and minimum temperatures—The observations summarized in Table 1 show the monthly means and ranges of maximum and minimum air temperatures, relative

TABLE 1

MONTHLY MEANS AND RANGES OF MAXIMUM AND MINIMUM AIR TEMPRATURES, RELATIVE HUMIDITY AND AVERAGE WIND SPEED

Observations		October 1960	November 1960	December 1960	January 1961	February 1961	March 1961
Maximum temp °C	Mean	14·1	7·6	3·1	—2·4	—1·1	6·2
	Range	7·8 to 18·4	3·1 to 10·1	—3·1 to 7·1	—6·4 to 1·3	—5·0 to 6·3	3·4 to 10·5
Minimum temp °C	Mean	—1·2	—6·0	—10·4	—13·7	—12·5	—4·9
	Range	—4·8 to 3·0	—10·0 to 2·4	—14·4 to —4·4	—19·4 to —8·4	—18·4 to —8·1	—9·3 to 0·0
Dry Bulb temp °C	Mean	7·0	—0·4	—7·1	—11·6	—10·4	—1·9
	Range	1·4 to 12·2	—5·5 to 3·5	—10·9 to —2·7	—18·2 to —7·1	—15·3 to —5·9	—6·3 to 4·2
Wet Bulb temp °C	Mean	0·5	—5·1	—9·4	—13·3	—12·2	—3·6
	Range	—3·8 to 4·2	—9·7 to 2·1	—13·7 to —3·9	—20·0 to —9·0	—19·5 to —7·3	—8·7 to 0·9
Relative Humidity % at 0830 hrs. (I.S.T.)	Mean	29	33	41	48	51	65
	Range	20 to 41	16 to 56	21 to 62	16 to 89	30 to 84	44 to 87
Wind Speed* Km. hrs.	Mean	..	2·17	1·07	0·99	1·92	2·82
	Range	..	1·12 to 2·98	0·43 to 2·64	0·48 to 2·24	0·8 to 5·12	0·96 to 4·72
Hours of Sunshine		...	109	81	16	71	65
Barometric Pressure mbs.	Range	662 to 670	659 to 671	659 to 672	659 to 672	651 to 667	654 to 673

*Occasional high wind speeds have not been taken into account for calculating monthly mean values.

humidity and average wind speed. It will be noted that both maximum and minimum temperatures are lowest in the month of January, the mean values being—2·4°C and—13·7°C respectively. The daily variations in the maximum and minimum temperatures are shown in Figs 1 and 2. During the trial period it snowed frequently, from 15th December to 15th

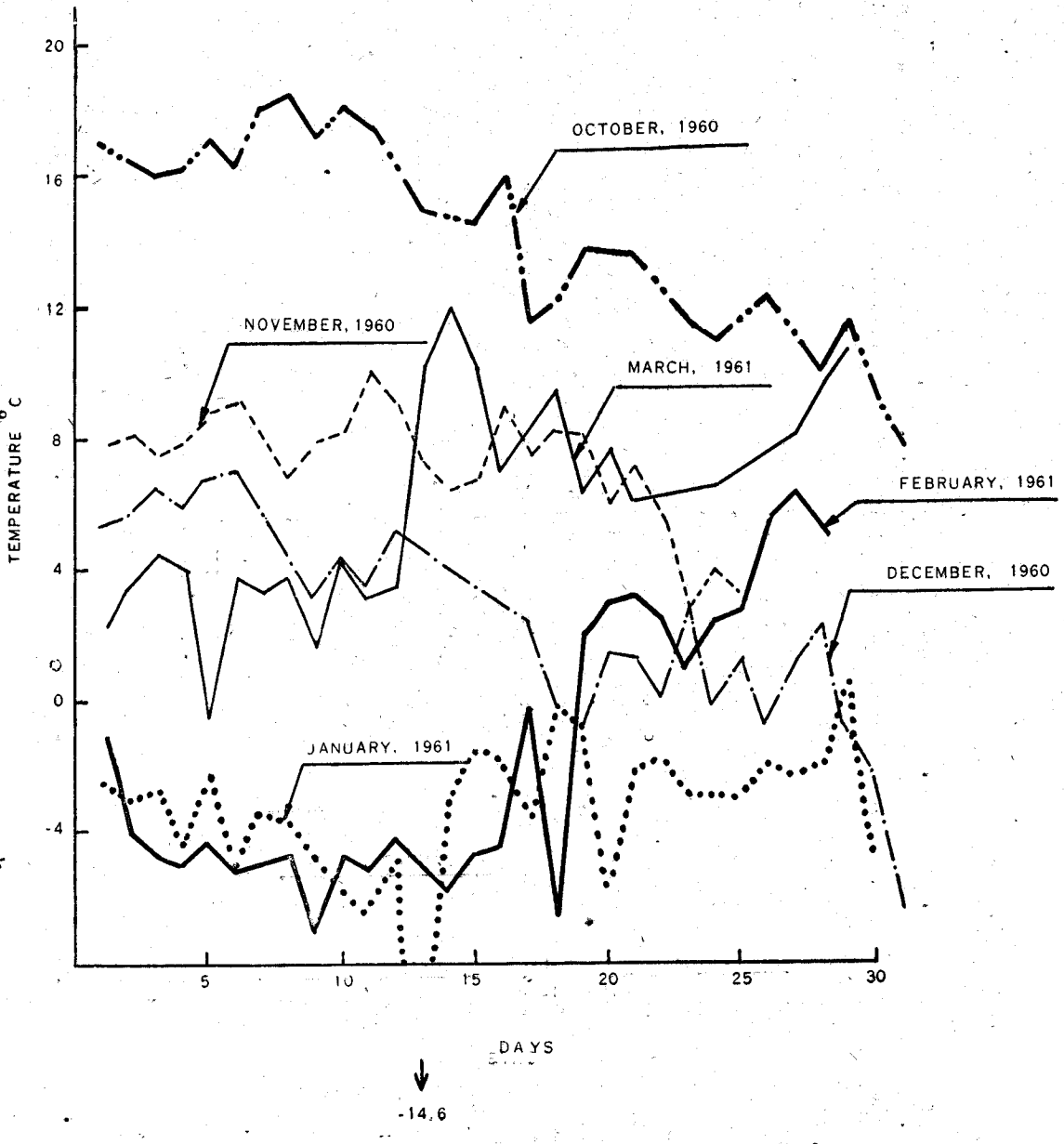

FIG. 1—Variation of maximum temperatures at 11554 ft.

February which resulted in a lowering of maximum and minimum temperatures. The lowest temperature of—19·4°C was recorded in mid January. For all these months the

maximum and minimum temperatures differed by 12·7°C on the average, the difference falling from 15·3°C in October to 11·1° C in March, being almost steady during January, February and March. This may be partly explained by the fact that the sky was mostly overcast during these months, while we had a very clear sky throughout October and mostly during November and December. Clouds absorb the sunlight and so the maximum temperature is reduced while in the night they act as a blanket to reduce cooling of the earth's

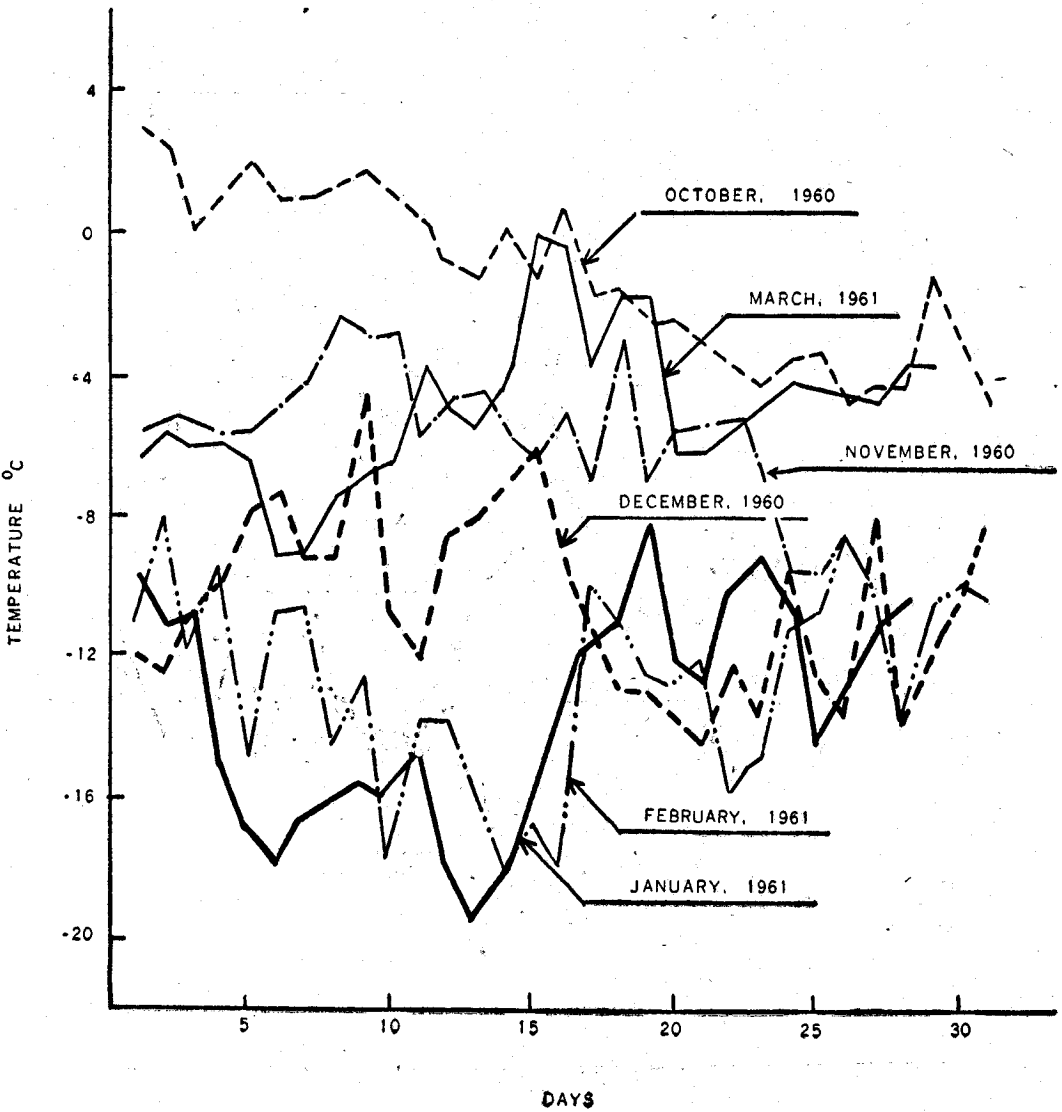

FIG. 2—Variation of minimum temperatures at 11554 ft.

surface. The results show greater drop in the maximum temperature while the minimum only slightly lowered.

Dry bulb air temperature—The daily dry bulb temperatures recorded at 0830 hrs I.S.T. for the trial period are given in Fig 3. The mean hourly variations of dry bulb temperatures

for the trial period are given in Tables 2 and 3. It may be seen that the highest temperatures occurred around 1500 hrs.

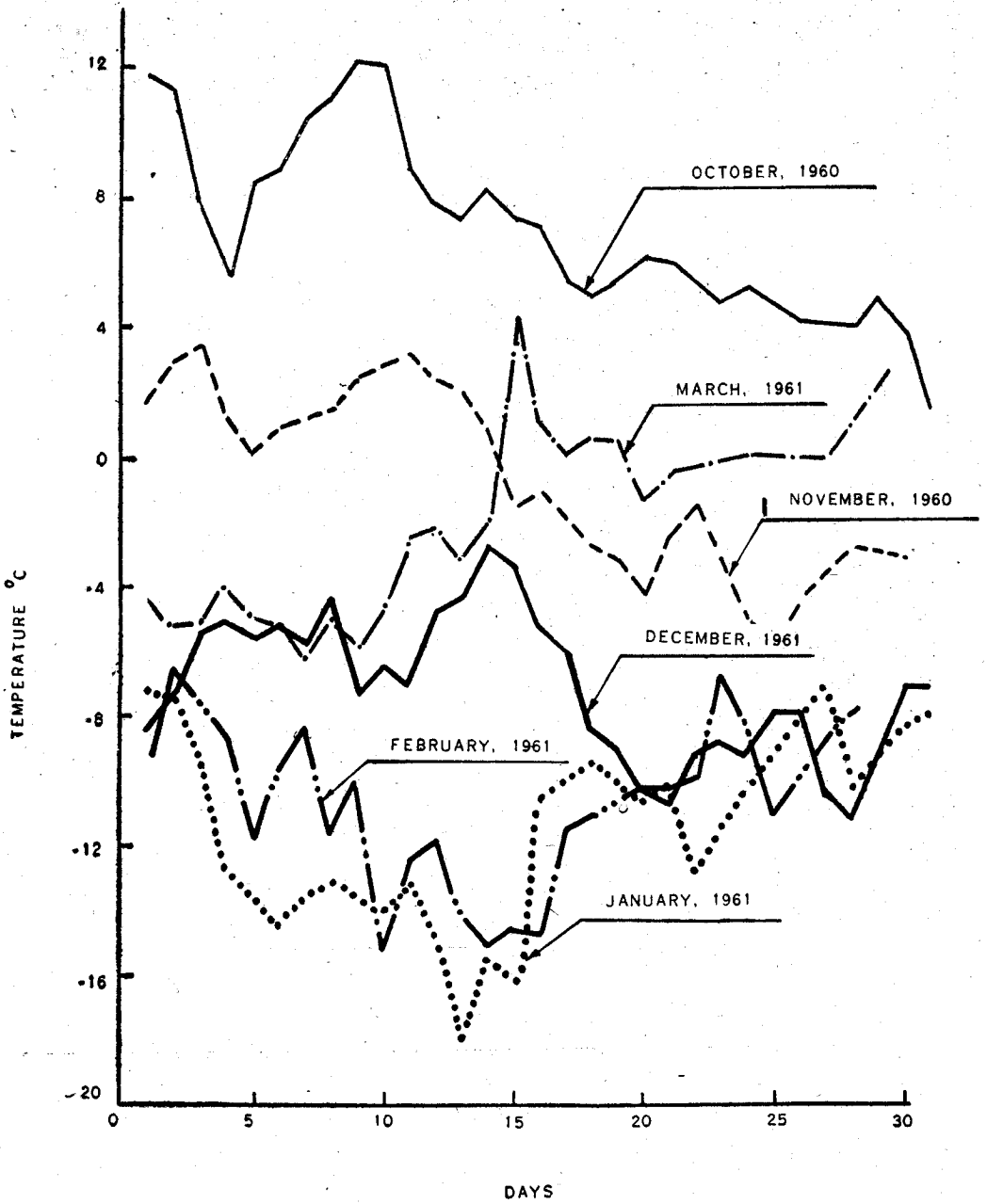

FIG. 3—Variation of dry bulb temperatures at 11554 ft.

Wet bulb air temperature—The monthly means and ranges of dry and wet bulb temperatures recorded at 0830 hrs I.S.T. for the trial period are given in Table 1. There is little for comment here except to note a fall in the difference of dry and wet bulb temperatures

TABLE 2

MEAN HOURLY VARIATION OF GROUND TEMPERATURE, AIR TEMPERATURE, SOLAR RADIATION THERMOMETER, BLACK GLOBE THERMOMETER AND WIND SPEED AT LEH

Month		Times of observations Hours— (I.S.T.) 1000	1100	1200	1300	1400	1500	1600
		°C	°C	°C	°C	°C	°C	°C
November 1960	Ground Temperature	13·1	19·0	21·7	21·6	21·7	21·1	13·1
	Ta, Air Temperature	1·2	2·5	3·8	5·4	5·2	5·7	6·2
	Sol. Rad. Thermo.	25·0	29·0	30·0	31·0	30·6	29·1	27·3
	Black Globe Thermo.	23·3	24·5	26·6	27·7	24·4	28·7	20·6
	Wind Speed km/hr	2·1	3·3	3·6	3·7	4·0	4·7	5·6
December 1960	Ground Temperature	8·9	13·9	17·0	18·0	17·0	13·0	10·4
	Ta, Air Temp.	— 3·3	—0·7	—0·6	0·6	2·0	2·5	2·0
	Sol. Rad. Therm.	21.3	23.6	24.0	25.8	26.0	24.5	22.1
	Black Globe Thermo.	20·2	21·1	22·8	23·6	24·9	22·5	19·4
	Wind Speed km/hr	1·6	2·4	3·1	3·2	3·0	3·1	2·3
January 1961	Ground Temperature	..	..	..	..	..	..	..
	Ta, Air Temperature	—10·0	—9·7	—8·7	—8·4	—6·7	—6·2	—3·3
	Sol. Rad. Thermo	14·5	16 4	19·0	20·0	20·0	18·3	..
	Black Globe Thermo	9·6	12·2	16·1	15·2	17·2	14·3	10·0
	Wind Speed km/hr	0·6	1·9	2·4	2·7	2·4	1·3	3·8
February 1961	Ground Temperature	15·2	18·3	23·7	23·7	25·6	23·9	17·9
	Ta, Air Temperature	—5·0	—4·8	—3·8	—2·8	—1·7	—0·9	—0·9
	Sol. Rad. Thermo	23·6	24·2	25·5	26·7	26·6	28·6	25·4
	Black Globe Thermo	16·4	16·8	19·3	19·4	20·3	20·0	17·8
	Wind Speed km/hr	4·4	4·2	4·6	8·6	7·5	4·3	4·5
March 1961	Ground Temperature	21·0	27·8	31·2	31·8	24·7	23·3	22·4
	Ta, Air Temperature	1·7	3·6	5·9	6·1	6·4	6.4	6·2
	Sol. Rad. Thermo	26·2	26·3	32·5	35·9	32·6	34·7	29·7
	Black Globe Thermo	26·1	27·8	28·3	30·0	31·2	29·6	26·2
	Wind Speed km/hr	3·9	4·5	7·0	6·4	5·9	5·8	5·8

TABLE 3

READINGS OF AIR TEMPERATURE AT LEH

Month		Time of observation Hours 1000	1100	1200	1300	1400	1500	1600
		°C	°C	°C	°C	°C	°C	°C
November 1960	Mean	1·2	2·5	3·8	5·4	5·2	5·7	6·2
	Range	—3·9 to 5·0	—3·3 to 6·1	—0·6 to 7·8	0·6 to 10·0	0·6 to 8·9	—0·6 to 8·9	2·2 to 8·3
December 1960	Mean	—3·3	—0·7	—0·6	0·6	2·0	2·5	2·0
	Range	—6·1 to 1·1	—5·0 to 1·7	—4·4 to 3·3	—2·8 to 3·3	—2·8 to 5·6	—1·7 to 6·1	—0·6 to 6·1
January 1961	Mean	—10·0	—9·7	—8·7	—8·4	—6·7	—6·2	—3·3
	Range	—12·8 to —7·2	—12·8 to —6·7	—12·8 to —4·4	—11·1 to —3·9	—8·1 to —3·9	—6·9 to —4·4	—3·3
February 1961	Mean	—5·0	—4·8	—3·8	—2·8	—1·7	—0·9	—0·9
	Range	—11·1 to 2·0	—10·0 to 2·2	—9·4 to 3·0	—8·9 to 4·2	—7·8 to 4·2	—6·1 to 5·3	—5·6 to 2·8
March 1961	Mean	1·7	3·6	5·9	6·1	6·4	6·4	6·2
	Range	—4·4 to 7·8	—1·1 to 7·8	0·6 to 12·8	2·2 to 11·7	2·0 to 11·1	3·0 to 11·1	2·8 to 11·1

from 6·5°C (October) to 1·7°C (December—March). This indicates an increased humidity in the respective months due to cloudy weather.

Relative humidity—Relative humidity data calculated from 700 mb Tables[1] indicate a substantially dry climate during the months of trial, the monthly mean progressively rising from 29 per cent in October to 65 per cent in March. At higher altitudes where the barometric pressure is much lower than that at sea level, water vapour required to saturate dry air (1 lb) is increased and hence ordinary tables do not supply the correct data. On the other hand, lower temperatures decrease the amount of water vapour to saturate the requisite amount of dry air[2]. In general, the lower the temperature falls the more the vapour concentration approaches saturation, although the amount declines in absolute terms. It may, however, be pointed out that accurate estimation of the wet bulb temperature below ice point presents an anomaly. Repeated observations with whirling psychrometer in shade rarely yielded a steady value. On several occasions the wet bulb thermometer registered a negative depression of the wet bulb[3, 4]. These instances of the negative wet bulb depression indicate supersaturation of the atmosphere. It may be possible to eliminate this anomaly by using alcohol—water mixture or saline [5] to depress the freezing point of the wetting agent.

Wind velocity—Observations on wind speed were recorded at 5 feet above ground level. It may be considered to be the optimum height from the operational stand-point particularly in relation to the actual working conditions of the service personnel. These data should be distinguished from those recorded at meteorological observatory at a height of twenty feet above ground. It will be seen from Table 1 that the average wind speed is quite low, being in the range of 0·43 to 5·12 km/hr. On very rare occasions high wind speeds ranging from 16—32 km/hr have also been recorded in February and March for short durations.

Hours of sunshine—Hours of sunshine were recorded during working hours from November to March. The maximum of 109 hours in 22 days was recorded in November and the minimum of 16 hours in four days in January, the sky being mostly overcast during this month. The sunshine hours being 71 for 12 days in February and 65 hours for 15 days in March.

Solar radiation—The radiation components of the thermal radiation balance at the ground are the direct solar radiation, the diffused sky radiation, the reflected solar radiation and the long-wavelength temperature radiation, which is exchanged within the terrestrial system. As in the case of short wave components three categories of long wave radiation transfer are involved; viz. outgoing infra red radiation from the earth and its atmosphere, incoming infra red radiation resulting from downward emission by the atmospheric constituents and reflected infra red radiations at various natural surfaces. The energy spectrum of each of the components has well known limits, although its maximum may vary with elevation above sea level, atmospheric transparency or turbidity, the nature and size of particles responsible for such turbidity, the local character of terrain etc. Changes in the conditions of atmospheric absorption and reflection determine the diurnal, monthly and seasonal variations in the energy fluxes at the ground surface. The depletion of the strength of the solar rays results chiefly from selective absorption from atmospheric gases and water vapour, from backward scattering by molecules and solid and liquid particulate matter and from reflection outwards to space by larger particles and cloud surface. Dust absorbs as well as scatters solar radiation.

An estimated of the solar radiation was made from the readings of the vacuum black bulb solar raiation thermometer. The monthly mean and ranges of hourly readings from

TABLE 4

WIND SPEED IN KILOMETERS PER HOUR AT LEH

Months		Time of observation Hours 1000	1100	1200	1300	1400	1500	1600	Average wind speed (24 hours)
November 1960	Mean	2·1	3·3	3·6	3·7	4·0	4·7	5·6	2·2
	Range	0·3—4·6	1·6—6·4	1·3—6·4	1·0—5·8	1·3—5·4	2·2—7·4	2·2—12·8	1·1—3·0
December 1960	Mean	1·6	2·4	3·1	3·2	3·0	3·1	2·3	1·0
	Range	0·3—3·8	0·3—4·5	0·6—6·4	0·3—5·1	1·9—5·1	1·6—4·8	1·0—3·8	0·4—2·6
January 1961	Mean	0·6	1·9	2·4	2·7	2·4	1·3	3·8	1·0
	Range	0·3—1·9	1·6—2·2	1·3—3·2	1·6—3·2	1·3—3·2	0·6—2·1	..	0·5—2·2
February 1961	Mean	4·4	4·2	4·6	8·6	7·5	4·3	4·5	1·9
	Range	1·6—19·2	1·3—12·8	1·9—16·0	2·9—32·0	—3·2—32·0	2·9—6·4	2·4—6·4	0·8—5·1
March 1961	Mean	3·9	4·5	7·0	6·4	5·9	5·8	5·8	2·8
	Range	1·6—6·4	1·0—11·2	1·6—14·4	1·6—11·2	1·6—19·2	3·2—11·2	3·2—16·0	1·0—4·7

1000 to 1600 hrs, during November to March are given in Table 5, which includes only the observations taken under clear sky. The maximum value is reached between 1300 and 1400 hrs. The mean maximum values obtained in the months November to March are 31·0, 26·0, 20·0, 28·6 and 35·9°C respectively. The highest reading of 42·2°C was recorded on 14th March 1961.

Black globe Thermometer—The monthly mean and ranges of black globe thermometer readings for the trial period are given in Table 6. It may be observed that the maximum readings are obtained around 1400 hrs and are 28·7, 24·9, 17·2, 20·3 and 31·2°C from November to March respectively.

Majumdar and Sharma [6, 7, 8] derived an expression for the effective increment in the dry bulb temperature due to solar heat load so that the given outdoor environment with air temperature T_a' is reduced to a thermally equivalent indoor environment with air and surrounding surfaces at the uniform temperature T_a'

Thus

$$\left(T_a' - T_a\right) = \frac{1 - F}{0{\cdot}95}\left(T_g - T_a\right)$$

Where $T_a' - T_a$ represents an increment in the dry bulb

$1 - F$ the absorbing power expressed as a function of the clothing or skin for total solar radiation

0·95 the absorbing power of the black globe.

Now to integrate solar heat load with other environmental factors, T_w, the wet bulb temperature is also corrected for solar radiation. The corrected values of T_a and T_w are then used in place of the dry bulb and wet bulb readings together with the prevailing wind speed in the effective temperature chart on the normal scale for clothed subject. The effective temperature thus combines air temperature, humidity, air velocity and solar heat load into one composite index of total environmental warmth which the authors have named as Modified Effective Temperature (M.E.T.[6, 7])

A comparative study of the heat load indices has been made utilizing the data in this paper.

Further, Billingham and Kerslake[9] have used H, I_c, I_a and T_g to calculate the conditions required for thermal comfort by the equation

$$T_s = T_g + KI_a\left[T_g{}^4 - (T_s - I_c\ H)^4\right] + H(I_c + I_a)$$

where T_s is mean skin temperature of man, taken as 33°C

T_g is the globe thermometer temperature

K is effective radiation heat transfer coefficient for man

I_a Air insulation for man

I_c Clothing insulation

H Total heat exchange at T_s

This equation has been utilised to work out the clothing requirements and will be published elsewhere.

TABLE 5

READING OF SOLAR RADIATION THERMOMETER AT LEH

Time of observation Hours

Month		1000 C°	1100 °°	1200 C°	1300 C°	1400 °C	1500 CC	1600 C
November 1960	Mean	25·0	29·0	30·0	31·0	30·6	29·1	27·3
	Range	18·3—29·4	21·1—34·5	23·9—35·0	26·7—38·6	29·4—37·0	23·9—30·2	21·1—28·6
December 1960	Mean	21·3	23·6	24·0	25·8	26·0	24·5	22·1
	Range	18·3—23·9	21·1—27·8	21·1—28·3	21·1—28·3	22·8—28·3	21·1—27·8	18·9—25·5
January 1961	Mean	14·5	16·4	19·0	20·0	20·0	18·3	..
	Range	13·9—14·7	16·1—16·7	17·8—19·5	19·5—20·5	19·5—20·5	18·0—18·6	..
February 1961	Mean	23·6	24·2	25·5	26·7	26·6	28·6	25·4
	Range	23·3—27·3	20·0—28·3	19·5—31·1	22·2—32·2	21·1—30·6	25·0—31·0	22·8—27·8
March 1961	Mean	26·2	26·3	32·5	35·9	32·6	37·7	29·7
	Range	20·5—30·6	22·8—33·3	19·4—36·1	15·0—40·0	18·3—39·5	29·4—42·2	21·8—33·3

TABLE 6

READING OF BLACK GLOBE THERMOMETER AT LEH

Month		1000 °C	1100 °C	1200 °C	1300 °C	1400 °C	1500 °C	1600 °C
November 1960	Mean	23·3	24·5	26·0	27·7	24·4	28·7	20·6
	Range	19·2—27·0	19·4—31·1	21·5—30·8	22·5—35·5	21·0—30·8	3·20·8 —30·3	16·8—23·1
December 1960	Mean	20·2	21·1	22·8	23·6	24·9		19·4
	Range	17·2—22·7	18·3—23·0	20·4—26·7	17·8—25·9	21·1—29·3	22·5 18·1—26·1	17·2—21·4
January 1961	Mean	9·6	12 ·2	16·1	15·2	17·2	14·3	10·0
	Range	8·3—11·1	10·6—15·0	14·4—17·8	15·0—18·3	15·0—20·0	11·1—18·9	10·0
February 1961	Mean	16·4	16·8	19·3	19·4	20·3	20·0	17·8
	Range	12·2—16·7	13·3—23·1	17·0—22·8	15·6—25·6	17·5—25·3	16·1—25·6	17·2—18·3
March 1961	Mean	26·1	27·8	28·3	30·0	31·2	29·6	26·2
	Range	20·0—35·0	23·9—32·2	22·0—33·9	15·6—25·6	17·5—32·2	24·2—33·3	21·1—34·4

Ground Temperature—The ground's surface temperature is of interest when considering the heat insulation necessary for the protection of feet against frost bite. With this end in view it was thought desirable to note the surface temperature with mercury in glass thermometer, duly shielded from direct sun-light.

Mean hourly ground temperatures for the trial period are shown in figure 4. The ground temperature remains higher than the temperature of air at $4\frac{1}{2}'$ level. The difference between the two ranges from—10·8°C to —0·3°C in November and December and —1·7°C to 10·3°C in February and March. This difference may partly

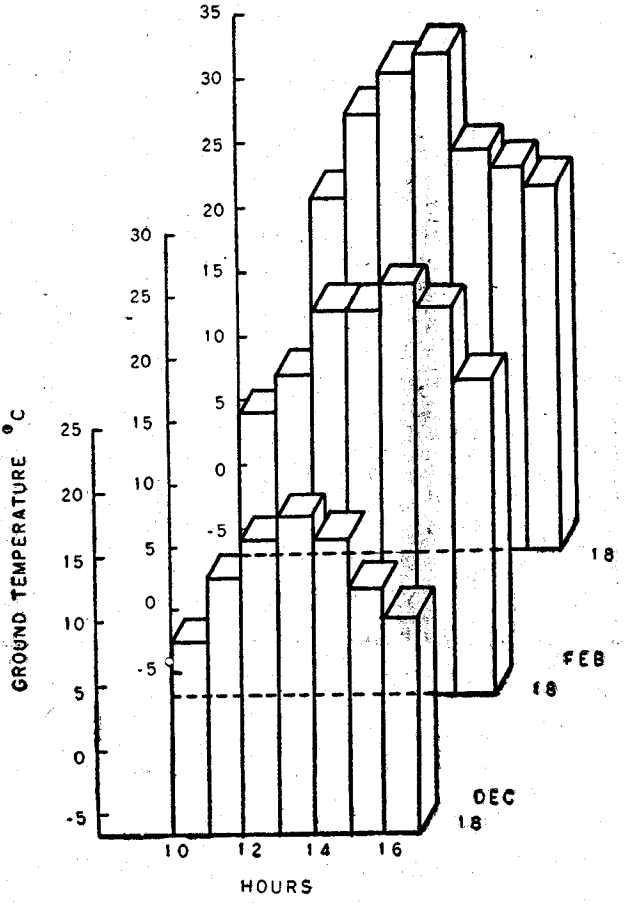

FIG. 4—Mean hourly ground temperatures at 11554 ft., for the month of December, February and March.

be explained due to the higher wind speed in the months of February and March (Table 2). It appears that the air temperature has been affected more than the ground temperature at the site of the observation. The solar radiation thermometer always records a higher temperature than the ground temperature in all the months. The globe thermometer also recorded a higher temperature than that of the ground temperature except in February when a higher wind speed affected the readings of the globe thermometer and a negative difference was observed *i.e.*, the reading of the ground temperature was more than that of the globe thermometer (Table 2).

Hourly ground temperature variation on some typical days are shown in figure 5. At the time of snowing a minimum ground temperature of 3·3°C was observed. When the sky was overcast or cloudy the temperature ranged from 4·4°C to 15·6°C. On clear sky days a maximum temperature of 42·8°C was observed on 13th March 1961. A steep temperature gradient was observed beneath the ground surface (Table 7, Fig. 6).

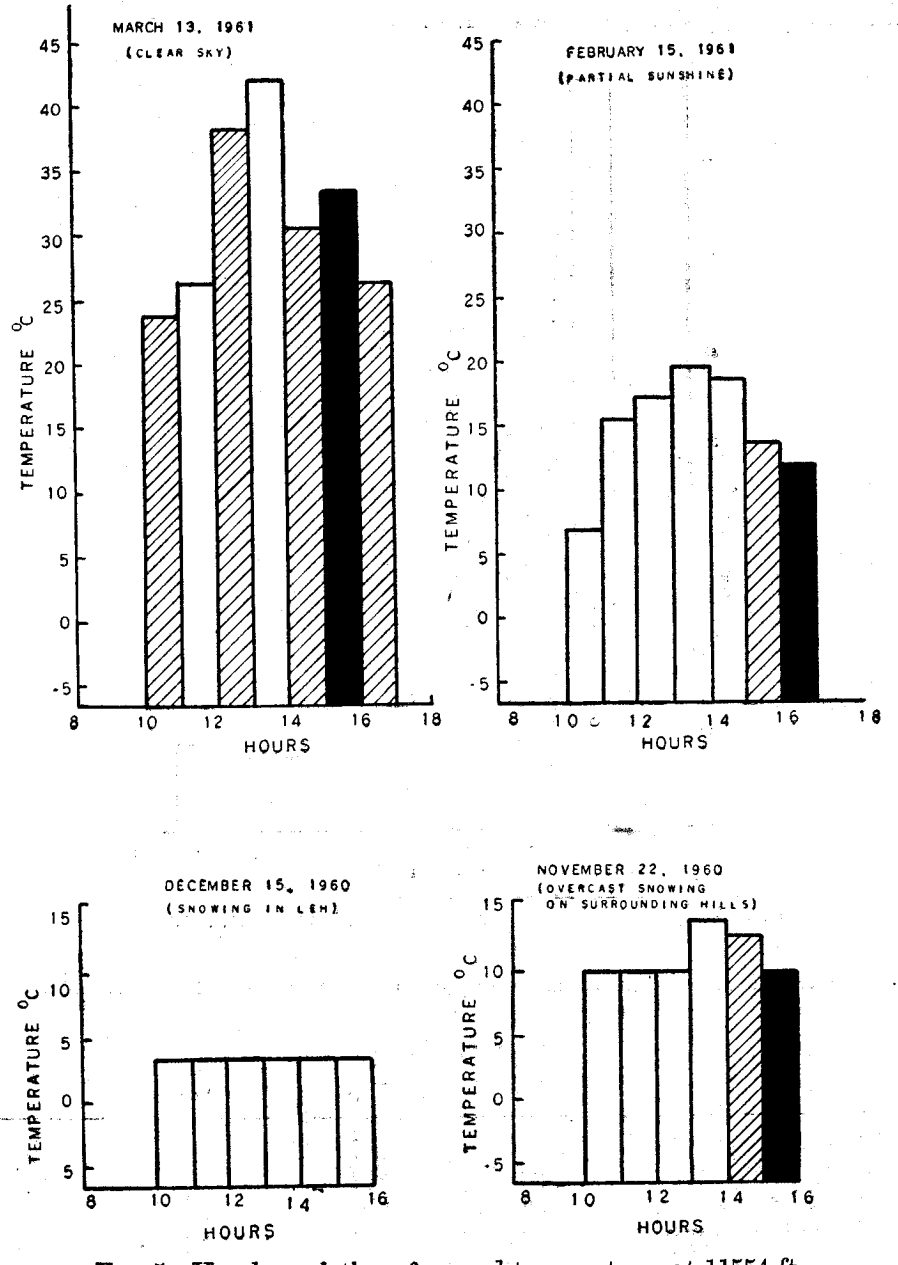

FIG. 5—Hourly variation of ground temperatures at 11554 ft.

Barometric pressure—During the entire period of trial the atmospheric pressure at station level varied from 651 to 673 mb. From the table of Pugh[10] the barometric pressure is 667 mb for an altitude of 11,800 ft, which was observed at Namche. This, on extrapolation, gives a barometric pressure of 658 mb[11], a figure comparable to the mean barometric pressure observed at Leh. The range of variations was minimum in October, being 8 mb and progressively increased to the maximum value of 19 mb in March. There seems to be a significant correlation between the monthly range of variation of atmospheric pressure and the corresponding average sky conditions.

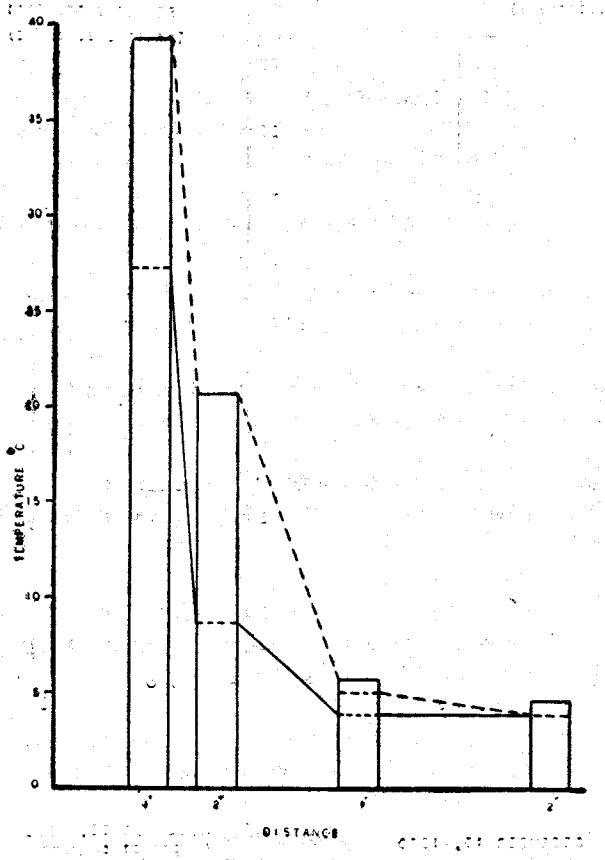

FIG. 6—Temperature gradient beneath the ground surface.

TABLE—7

TEMPERATURE GRADIENT BENEATH THE GROUND SURFACE AT LEH (14TH MARCH 1961)

	Time of observation Hours			
	1000 °C	1200 °C	1400 °C	1600 °C
Air Temperature	5·6	7·2	11·7	11·1
Solar Radiation Thermometer	30·6	24·4	42·2	21·7
Black Globe Thermometer	25·6	22·0	36·1	21·7
Ground Temperature	27·2	26·7	39·4	30·0
Ground Temperature 2" below surface	8·9	15·0	20·6	20·6
Ground Temperature 1 below surface	3·9	3·9	5·0	5·6
Ground Temperature 2 below surface	3·9	3·9	3·9	4·4

CONCLUSIONS

1. The month of January is the coldest and has the lowest maximum, minimum air temperatures, wind speed and hours of clear sun shine.

2. Lowest temperature in January was—19·4°C.

3. The difference between the mean values of maximum and minimum air temperature fell from 15·3°C in October to 11·1°C in March, being almost steady during January, February and March.

4. The relative humidity progressively rose from 29 per cent to 65 per cent from October to March respectively and the same trend was observed in the range of variation in atmospheric pressure.

5. The months of January, February and March were mostly overcast.

6. The average wind speed varied from 0·43 to 5·12 km/hr but on a few occasions it rose upto 16 to 32 km/hr for short durations.

7. The highest individual reading of 42·2°C of the Solar radiation thermometer was recorded on 14th March 1961.

8. The monthly mean of the daily maximum readings of the Solar radiation thermometer is lowest in January and highest in March being 20·0°C and 35·9°C respectively.

9. The monthly mean of the daily maximum readings of the Black globe thermometer is also lowest in January and highest in March being 17·2°C and 31·2°C respectively.

10. The maximum value of the Solar radiation thermometer as well as that of Black globe thermometer is reached between 1300 and 1400 hrs.

11. The ground temperature during the day remains higher than the temperature of the air. The Solar radiation thermometer and Black globe thermometer record a higher temperature than that of ground surface. There is a steep temperature gradient beneath the ground surface.

12. The data presented in this report may be utilised for assessment of indices of comfort and clothing requirements.

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