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A study on heat transfer in seasonal snow pack

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ABSTRACT. Two samples of stratigraphic observations of snow cover recorded at Kanzalwan (34 deg. 35′ N, 74 deg. 40′ E, 2410 m) during winters of 1977 to 1979 have been analysed with the aim to bring out (*i*) variations of snow surface temperatures and its correlation with the temperature of ambient air, (*ii*) march of temperature with time and depth of snow pack, (*iii*) the diurnal variations of snow temperatures in various layers of the snow cover, and (*iv*) the cold content of the seasonal snow cover and its temporal variations.

1. Introduction

Seasonal snow cover is formed when snow is sufficient to persist on the ground till the next spell of snowfall. The ablation of snow cover is a gradual process caused by evaporation, melting, wind drift and avalanches. In the regions of Western Himalayas seasonal snowcover forms by middle of December and lasts till July end. The average altitude of snow line is about 2500 m a.s.l. with a range from 1500 m in February/March to 4500 m in July. The depth of snow-pack increases till March and decreases rather rapidly thereafter. The average depth of standing snow in March over windward slopes of Greater Himalayas has been observed to be around 3 m. But more than 5 m of standing snow in the formation zones of avalanches are not uncommon.

The exchange of heat in a snow cover may be due to the following processes:

(*i*) The heat transfer from adjacent air due to molecular conduction.

(*ii*) The sensible heat transport by molecular mass flux through the pores of the snow-pack.

(*iii*) The heat exchange from the ground below.

Due to poor thermal conductivity of ice skeleton of snow crystals (10^{-4}cal cm^{-1} sec^{-1} deg^{-1}), the heat transfer from one part to the other by conduction is restricted only to a few centimetres. The bottom layer remains always near 0 deg. C owing to ground heat whereas the upper layers of the snowcover are influenced by temperature of ambient air and exhibit a diurnal variation (Upadhyay *et al.* 1977).

This paper is a preliminary study of the snowmelt model in which the parameters are:

(a) diurnal variation of temperature of snow layers,

(b) time-depth variations in the snow-pack,

(c) temperature of ambient air and

(d) temperature gradients.

2. Data

Two samples of observations consisting of snow cover stratigraphic data recorded at a station (Lat. 34 deg. 35′ N, 74 deg. 40′ E) in northwest Kashmir has been considered for this study. This station is situated at an altitude of 2410 m a.s.l. Each observation consists of snow temperatures of various layers at a depth interval of 10 cm. Observations were taken in snow and avalanches study establishment by digging a new pit in snowcover for each observation. The time of observation was 0800 and 1600 IST every day. The first sample covers 33-day observations from 17 December 1977 to 18 January 1978 and the second sample consists of 27 days observations recorded between the period 5 February and 20 March 1979.

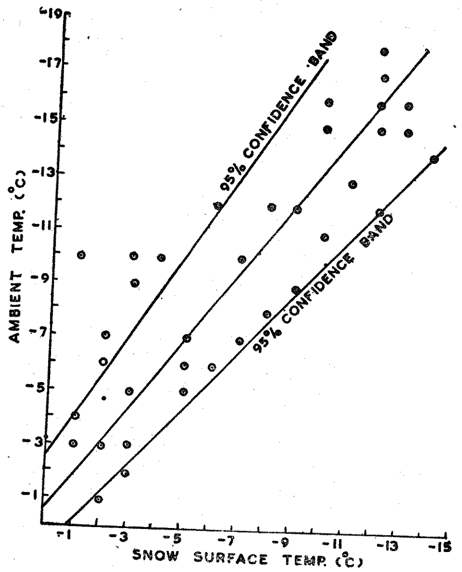

Fig. 1. Relationship of snow temperature with ambient air temperature (alongwith confidence interval)

3. Variations in snow surface temperature

Due to low thermal conductivity of air, only a few centimetres of the top layer of a snow cover is affected by the weather conditions of the adjacent air. During early morning hours when the screen temperature attains its minimum, the snow surface temperature also attains its minimum and the snow surface temperature is lowest. In the afternoon, the temperature of the snow surface rises considerably due to absorption of incoming solar radiation. The diurnal variation of snow surface temperature follows the same pattern as the air temperature above it. Thus the effect of cloudiness is reflected in snow surface temperature also causing lower temperatures on clear nights and lower day temperatures when the afternoons are overcast. Fig. 1 shows scatter diagram of snow temperature (S) and air temperature (T) for the sample of 47 observations (Some points are overlapping because of identical values). A linear relationship of

$$S=a+bT \tag{1}$$

is suggested. In this sample the value of the product moment correlation coefficient is equal to 0.91. Hence more than 80 per cent variability in 'S' may be explained by variations in 'T'.

The least square estimates of 'a' and 'b' are determined as $a=0.45$ and $b=0.78$. These results are obviously valid only for the months of January and February, when air is normally found to be colder than snow surface. During and after March when the day temperature of air becomes more than 0 deg. C, the melting of snow surface is also involved in determining its temperature.

It has been found that the regression coefficient is highly significant even at 99 per cent level. The results of the analysis are given in Table 1.

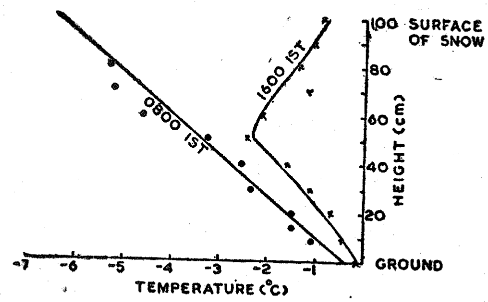

Fig. 2. Diurnal variation of temperature in a seasonal snow cover

TABLE 1

S. No.	Parameters for the snow layer at Kanzalwan	Value
1	Mean of air temp. (T)	—9.3 °C
2	S.D. of air temp.	4.6 °C
3	Coeff. of variation of air temp.	50 %
4	Mean of snow surface temp.	—6.8 °C
5	S.D. of S	4.1 °C
6	Coeff. of variation of S	61%
7	Corr. coeff. between T & S	0.91
8	Regression S on T	$S=.45+.78T$
9	Standard error of estimate	1.80
10	Standard error of a	0.650
11	Standard error of b	0.065

The confidence bands of the regression of S on T have been shown in Fig. 1. The equations of these lines have been worked out to be:

$$S=.85+.91\ T \tag{2}$$

and

$$S=1.75+.65\ T \tag{3}$$

The validity of Eqns. (2) and (3) are subject to the conditions $T<1$°C and $T<-3$°C respectively.

4. March of temperature in a seasonal snow cover

Fig. 3 shows a thermal structure of seasonal snow cover in Z-t plane, where 'Z' represents the depth of layer and t the days. The isotherm analysis at 0800 and 1600 IST samples clearly show, that the period of warm and cold regions in a snow cover alternate after a few days. However, no periodicity could be found from this sample. Owing to the transfer of ground heat, the temperatures of bottom layers remain practically zero degree centigrade and exhibits very little variability. As we go to the upper layers, the snow temperatures being influenced by current weather shows considerable diurnal fluctuations.

During morning hours the decrease in temperature follows a linear trend approximately up to the top layers with a lapse rate of nearly 0.6 deg. C per 10 cm. This temperature gradient is sufficient to cause significant moisture flow from warmer to colder regions of snow-pack through the pores. The periods of high and low

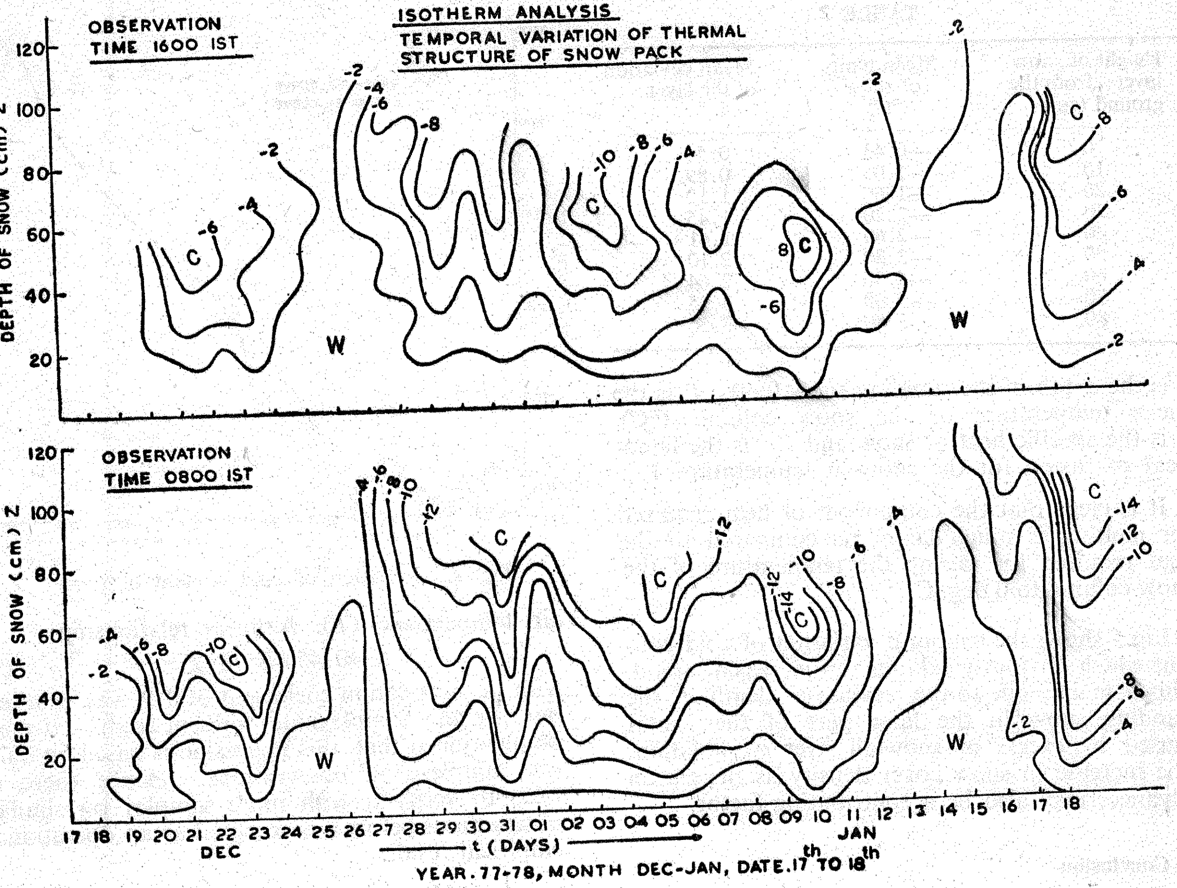

Fig. 3. Thermal structure of seasonal snowcover (Kanzalwan, 2410 m)

temperature gradient also alternate after a few days when a western disturbance approaches the station, sudden increase in cloudiness and advection of warm air causes marked rise in the temperature of snow surface and reduces temperature gradient appreciably. Similarly with the sudden clearing of sky, fall in snow surface temperature and formation of surface hoar are noticed. Thus the temperature gradient of snow cover and hence the various metamorphic processes are the functions of current weather conditions of ambient air.

As shown in Fig. 2 at 1600 IST the vertical temperature profile of snow cover shows a different pattern. The main aspects of difference are:

(1) Almost each layer becomes slightly warmer.

(2) The rate of rise of temperature increases as we go to the upper layer, in the evening.

(3) From the middle of the snow cover, approximately the temperature starts rising up to the top forming an inversion layer, which is in contrast with the pattern of morning observation.

(4) The lapse rate of the lower half is estimated approximately at 0.45 deg. C per 10 cm and that in the upper half about 0.2 deg. C per 10 cm. Thus the average temperature gradient of snow cover in the afternoon almost vanishes.

(5) A linear relationship between snow temperature and depth may be suggestive from morning temperature profile whereas at 1600 IST, the pattern appears to follow a parabolic trend.

(6) Mean deviation of snow temperatures is lowest for the ground layer and increases continuously till the top of the cover. The values computed for the present sample have been given in Table 2.

5. Cold content of seasonal snowcover

The cold content of a snowcover is defined as the quantity of heat required to melt the snow column standing on a unit area (Badar *et al.* 1954). The snowcover resting on the slopes of the station between 5 February and 20 March has been examined to study the variation of its cold content. It can be expressed as :

$$C=\overline{\rho}h(\overline{T}q+L_f) \qquad (4)$$

where C is the cold content (calories), $\overline{\rho}$ is the average density (gm cm^{-3}) of a snow column,

TABLE 2

Height of snow layers from the ground (cm)	Mean temp. of snow (°C)	Mean deviation of the layer
0	—0.43	0.54
10	—1.05	0.89
20	—1.60	1.12
30	—2.20	1.45
40	—2.60	1.61
50	—3.20	2.10
60	—4.30	2.64
70	—5.00	3.25
80	—3.80	3.50

h is the depth of the standing snow (cm), $\bar{T}$ is the mean temperature of the snow column (°C), q is the specific heat of snow and L_f is the latent heat of fusion for the snow at temperature T.

It is clear that the component of heat required for melting is much larger as compared to the heat required for raising the temperature of the snow column to 0 deg. C.

Fig.4 shows the temporal variation of cold content which obviously exhibits an increasing trend. This is mainly due to the increase in depth of the standing snow in the later part of the winter caused by excess of snowfall over its ablation. The increase in snow cover density as the season advances may also be a contributing factor.

6. Conclusion

In this sample study temperature and density observations recorded at an interval of 10 cm depth in snowpack have been analysed and the following inferences in respect of (*i*) surface temperature variabilities, (*ii*) two dimensional (*Z-t* plane) thermal structure of snowcover and (*iii*) cold content of the pack have been drawn :

(*i*) Bottom layers of snowpack remains almost isothermal near 0 deg. C owing to heat transfer from the ground underneath.

(*ii*) Snow temperature decreases linearly upward up to the top surface during night and morning. But a parabolic trend

$$S=a+bZ+cZ^2 \quad (5)$$

may be suggested for the snow temperature (S) at depth (Z) of the pack during day time. The inversion layer in the upper parts of the pack may be attributed to the penetration of the solar radiation. In this range the penetration of radiation may follow the well known exponental law (Quervain 1972) given by :

$$I_z=I_0+e^{-\epsilon z} \quad (6)$$

where ϵ is the extinction coefficient and $I_0 = R(1—a)$, R=Incident solar radiation at the snow surface and a=albedo of snow.

(*iii*) Temperature of snow surface (S) exhibits similar diurnal variation to that the ambient

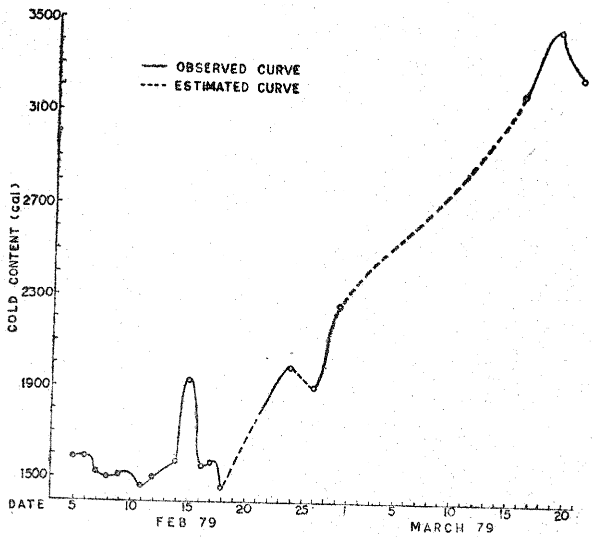

Fig. 4. Variation of cold content of snow

air temperature (T). A linear relationship:

$$S=0.45+0.78\ T \quad (7)$$

with a correlation coefficient of 0.9 was worked out for the sample under present study. It may be mentioned that this regression is based on only one sample of 47 observations. Hence there is need to verify it with more samples on similar observations before it is accepted as an operational empirical result.

(*iv*) 'Mean deviation' of snow temperature is lowest at the ground level and increases continuously upward up to the surface.

(*v*) Cold content of the snow pack increases as the winter advances till March. It varies directly as the depth of standing snow.

(*vi*) The aim of this analysis is to determine suitable parameters to be used in the development forecasting models for snow melt runoff relationship.

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