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Solar radiation measurements on Gara glacier

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ABSTRACT. Solar radiation data collected during the 1970 interdisciplinary scientific expedition to Gara glacier are presented. The observations made include direct solar radiation, global solar radiation, reflected solar radiation from the underlying surface under different conditions and net radiation and extended over a period of 16 days at an altitude of 4700 m.

The low value of direct solar radiation, *viz.*, 1·5-1·57 cal/cm²/min suggests the atmosphere over the glacier is turbid mainly due to the relatively high water vapour content and particulate matter. The global solar radiation in September is of the order of 600 cal/cm². The mean daily albedo was 0·77 when the underlying surface was covered with snow. The maximum net radiation over the glacier on 12 September 1975, a clear day was 0·98 cal/cm²/min around noon. The results are compared with similar observations made at the high altitude stations.

1. Introduction

During 1974 and 1975, scientific expeditions to the Gara glacier (Himachal Pradesh) were organised jointly by the India Meteorological Department and Geological Survey of India. Radiation measurements in 1974 were made by the junior author while in the 1975 expedition both the authors as members of the India Meteorological Department team, made detailed radiation and surface meteorological measurements over the Gara glacier. The present paper discusses the results of radiation measurements made during the 1974 and 1975 expeditions.

2. Observational site

Gara glacier is in a high valley oriented in the NE-SW direction in the Sutlej catchment area in the Kinnaur district of Himachal Pradesh. The glacier camp in this valley (Fig. 1) was reached by a three-day trekking, from Morang village on the bank of the river *Sutlej*, which was accomplished in three stages.

The observatory site (Lat. 31°28′45″ N; Long. 78°26′30″E) was in this valley at an altitude of 4700 m (Fig. 2). The mountains on the east and the west rose to a maximum height of about 50 and 30 m respectively and caused obstruction to global radiation upto a maximum of 28 and 21 degrees respectively. The apparent sunrise in the valley was, therefore, around 0800 hr and sunset around 1545 hr.

3. Instruments and observations

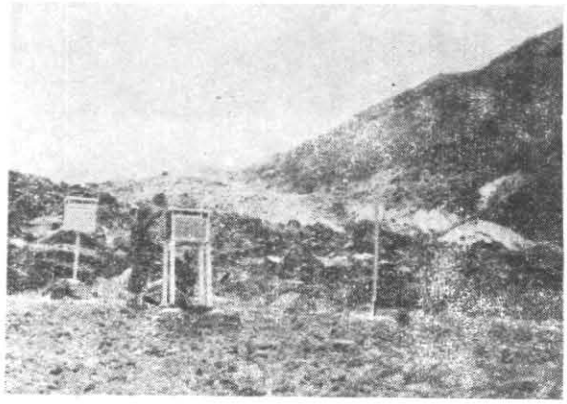
3.1. *Instruments*

The instruments used (Figs. 3 and 4) were (*a*) Moll thermopile pyrheliometer for the measurement of direct solar radiation; (*b*) I. M. D. and MG thermoelectric pyranometers for the measurement of global solar radiation from sun and sky at meteorological observatory site and on a moraine approximately 10 m higher than and to the south of the observatory site towards the glacier peak. The pyranometers were mounted on a horizontal bar 1·5 m long supported by stands and oriented in the N-S direction. The height of the sensor surfaces was about 1·3 m above the ground; (*c*) MG thermoelectric pyranometer for the measurement of reflected radiation also mounted on the same stand and (*d*) IMD net pyrradiometer for the measurement of the net radiation. The instrument was mounted on the stand with the sensor towards the south.

3.2. *Observations*

Observations during 1974 consisted only of direct solar radiation made with a Moll thermoele-

Fig. 1. Glacier camp, Gara glacier in the background



2. Observatory

Fig. 3. Radiation instruments near the observatory

Fig. 4. Global pyranometer on the moraine

ctric pyrheliometer for five days from 19 to 23 September.

The observing programme during 1975 covered a longer period of about 16 days from 31 August to 16 September.

The observations consisted of the following :

(*a*) Direct solar radiation on 2 days when the solar disc was free from clouds ;

(*b*) Global solar radiation at the glacier observatory site for 17 days and simultaneously on the moraine for 4 days ;

(*c*) Reflected radiation on a horizontal surface for 13 days ;

(*d*) Net radiation for about 7 days.

4. Weather conditions on the glacier

During the period of observations the weather was cloudy to overcast with precipitation towards afternoon except for one day on 12 September which happened to be a sunny day. Occurrence of fog during night and in the early hours of the morning was a regular feature. From 6 to 10 September the sky was overcast and there was continuous rain followed by snowfall from 8 September. It was understood that the precipitation was above normal for the period and rain at the glacier height was also an uncommon feature. Winds were generally calm in the morning till about 0830-0900 hr. Thereafter, the surface wind was from a northwest direction in the morning and changed over to one from a southwest direction towards the afternoon on most of the days with speed rarely exceeding 8 kt. During the period of snowfall it was calm. Maximum temperatures ranged between 1·8° C and 11·4° C and the minimum between —1·2° C and 3·1°C.

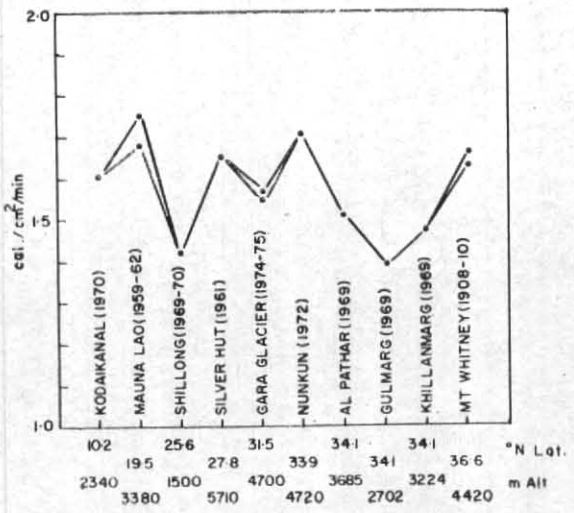


Fig. 5. Values of direct solar radiation

5. Discussion

5.1. *Direct solar radiation*

There were two occasions on 12 and 18 September in between the spells of rain and snow when the sun's disc was free from clouds for the measurement of direct solar radiation.

The highest values obtained were 1·53 cal/cm²/min at 1154 hr on 12th and 1·55 cal/cm²/min at 1305 hr on 18th while the junior author obtained a value of 1·57 cal/cm²/min during 1974. The slight difference in these values may be due to the relative water vapour content in the atmosphere on account of the prevalent weather conditions during the two periods. Then considering the altitude (4700 m) and comparing with the maximum values observed at other high altitude stations (Fig. 5, Mani *et al.* 1973, 1975) it may perhaps be concluded that the value is rather low for the altitude and is due to (*i*) the comparatively high atmospheric turbidity and consequent extinction of direct solar radiation by aerosols and (*ii*) the high water vapour content due to precipitation on the preceding days. Even the normal seasonal value of the average water vapour content over this region is of the order of 4 dgm/cm² in July and 1·5 dgm /cm² in October (Bannon and Steel 1960).

5.2. *Global solar radiation*

Table 1 gives the hourly and daily values of global solar radiation from 31 August to 16 September. The values varied between 221 cal/cm² and 608 cal/cm². This variation and the relatively low values may be attributed to the prevailing weather conditions. With the site being located in a valley, it would be too much to expect a clear day. Clouding during the afternoons was the most common feature. Nevertheless, the day on 12th could be considered a clear day — cloud amount being 1 octa — and hence the global radiation of 608 cal/cm² as reasonably the order of the maximum value of global radiation received in the valley during the period under consideration. The lowest value of 221 cal/cm² recorded was on 6th with overcast sky and light continuous rain. These extreme values cannot be considered to be representative of the altitude as the values are vitiated by the horizon obstructions of the site.

However, the record of 12th was extrapolated taking into consideration the timings of sunrise and sunset in order to allow for the obstructions cutting off the global radiation in the morning and evening. On extrapolation, the value of global radiation obtained was 682 cal/cm², which is higher than the original measured value by about 12 per cent. This value, *viz.*, 682 cal/cm² could be taken as a fair estimate of the global radiation re presentative of the altitude.

Global solar radiation record for 8th was vitiated due to snow cover on the pyranometer glass dome.

5.3. *Reflected solar radiation*

The daily values of reflected solar radiation are presented in Table 2. The values ranged between 47 and 209 cal/cm². The values on 12 September was 173 cal/cm² as compared to the highest value of 209 cal/cm² on 31 August, a day with a relatively more clouding till evening. 9 September represents an interesting case. On that day the reflected radiation from the surface

TABLE 1

Values of global solar radiation over Gara glacier

Date (1975)	Hourly (in L.A.T.) global radiation (cal/cm²)													Sum of hourly values
	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19	
31 Aug	7·3	20·5	58·4	73·7	99·7	77·2	83·1	59·0	29·5	32·4	8·5	3·1	0·2	553
1 Sep	—	—	—	69·8	87·1	73·0	66·7	75·9	37·8	13·3	13·1	11·9	4·1	(453)
2 Sep	4·3	8·1	12·7	19·7	25·1	30·1	42·1	27·2	40·7	21·5	14·0	9·9	3·4	259
3 Sep	5·4	17·9	16·1	33·5	53·1	95·8	92·7	61·5	70·3	52·3	14·1	3·4	0·5	517
4 Sep	3·1	8·1	12·7	54·5	79·0	38·2	33·6	42·5	26·3	29·4	18·5	7·8	0·1	354
5 Sep	3·1	16·2	49·7	48·7	66·0	87·1	64·7	47·9	52·0	49·9	6·6	3·2	0·1	495
6 Sep	2·5	6·7	14·1	22·2	22·2	16·7	22·6	38·5	33·6	22·3	14·3	5·3	0·0	221
7 Sep	2·9	11·7	20·2	33·5	44·2	80·7	42·5	33·1	25·1	13·3	10·3	1·3	0·0	319
9 Sep	0·0	0.9	9·7	22·7	36·8	27·2	65·1	38·2	21·9	19·8	19·5	7·1	2·9	272
10 Sep	5·5	14·1	18·3	33·9	41·9	52·9	36·1	67·3	59·1	31·0	10·9	2·9	0·1	374
11 Sep	3·5	20·4	21·6	25·7	46·8	90·1	97·9	46·7	49·7	15·0	9·8	8·6	2·5	438
12 Sep	1·2	7·3	48·7	66·7	73·7	88·7	96·4	60·9	78·9	63·1	17·5	3·9	1·2	608
13 Sep	3·8	5·5	52·2	55·5	59·3	48·3	67·3	75·3	13·9	48·6	4·2	5·0	1·7	441
14 Sep	5·2	15·5	27·6	36·7	37·7	43·9	37·9	41·5	31·0	19·7	16·3	4·9	1·2	319
15 Sep	—	—	56·1	53·1	63·7	66·5	49·6	23·0	33·7	24·5	11·3	4·1	0·1	(386)
16 Sep	2·0	9·2	22·7	33·9	47·7	59·8	24·7	74·7	30·3	13·2	9·1	3·5	0·4	331
On the moraine														
13 Sep	3·1	5·3	41·3	56·9	46·2	43·0	44·9	45·7	13·1	56·3	21·4	5·1	0·9	383
14 Sep	5·5	17·1	32·4	40·5	39·1	46·5	38·9	36·4	40·1	20·8	15·7	4·6	0·7	338
15 Sep	—	—	59·0	74·2	51·3	67·8	53·5	25·6	34·2	28·5	11·8	3·8	0·0	(410)
16 Sep	2·2	9·5	24·6	37·1	45·9	51·3	25·2	70·5	35·5	16·4	9·0	3·0	0·2	330

covered with fresh snow was 209 cal/cm² whereas the global radiation was hardly 272 cal /cm². The effect of fresh snow is very revealing.

The reflected radiation on 12th when extrapolated was 197 cal/cm² resulting in the same order of increase as global radiation when allowed for the obstructions.

5.4. *Albedo*

Table 2 gives the hourly and mean daily values of albedo computed from the continuous records of gobal and reflected solar radiation obtained over Gara glacier. The hourly variation of albedo of the underlying surface did not always follow the usual pattern with higher values at lower solar altitudes because of frequent changes in the nature of the underlying surface and due to rain and snow as well as due to the obstruction of the horizon. The mean daily value was of the order of 0·35 for a dry ground surface. For the wet surface, the albedo was 0·21 on the average.

There was snowfall on 8th, 9th and 10th morning. The pronounced influence of snow on the albedo is clearly seen. When the snow was fresh the albedo reached a value as high as 0·84. There was a steep fall in the value of albedo after the snowfall had ceased at 1200 hr and the snow became less fresh as seen from the hourly values of

TABLE 2

Hourly and mean daily values of albedo and daily reflected radiation over Gara glacier

Date (1975)	Hourly values of albedo (Hours in L.A.T.)													Mean daily albedo	Daily values of reflected radiation
	6-7	7-8	8-9	9-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19		
31 Aug	·28	·32	·38	·36	·38	·39	·38	·41	·35	·38	·37	·50	·50	·38	209
1 Sep	—	—	—	·41	·38	·38	·38	·38	·43	·33	·32	·30	·35	·38	(173)
2 Sep	·34	·26	·19	·24	·24	·23	·24	·22	·31	·27	·25	·15	·34	·25	65
3 Sep	·26	·21	·27	·27	·32	·36	·39	·34	·40	·42	·32	·38	·67	·35	183
4 Sep	·39	·25	·26	·41	·40	·38	·26	·26	·29	·29	·32	·33	·47	·34	120
5 Sep	·31	·29	·34	·34	·41	·38	·41	·43	·45	·43	·36	·36	·47	·39	194
6 Sep	·34	·26	·24	·23	·24	·22	·22	·22	·13	·22	·22	·23	—	·21	47
7 Sep	·26	·23	·28	·29	·28	·27	·26	·24	·29	·25	·22	·38	—	·27	85
9 Sep	—	·65	—	·94	·84	·78	·72	·63	·68	·63	·59	·51	·50	·77	209
10 Sep	·50	·49	·49	·45	·41	·30	·24	·26	·25	·28	·29	·35	·47	·32	121
11 Sep	·24	·23	·22	·24	·28	·27	·27	·25	·24	·27	·27	·27	·37	·26	114
12 Sep	·49	·33	·24	·23	·26	·27	·29	·33	·32	·33	·32	·26	·37	·28	173

9th. There was, however, a sudden increase in the values due to another spell of snowfall at 1330 hr. On the 10th the decrease in the albedo value was due to the melting of snow and the increase in the evening was due to lower solar elevations. On 12th, a relatively clear day (1/8 *Sc*) the hourly values of albedo followed the usual trend with higher values at lower solar altitudes. A comparison of the hour to hour as well as the mean daily albedo values of 12th with those of 11th — a cloudy day (3-4/8 *Sc, Cu* till about 1730 hr)—brings out clearly that clouding also contributes for further increase in the albedo values at low solar elevations, while at higher elevations the effect is not very significant.

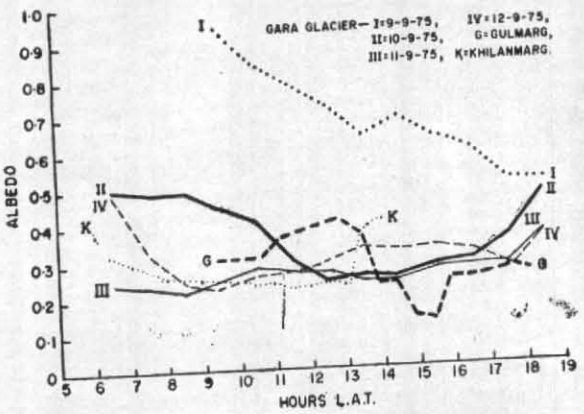


Fig. 6. Hourly values of albedo

The albedo values obtained over Gara glacier on 9th, 10th, 11th presented in Fig. 6 along with those obtained at Gulmarg on 12 June 1969 and Khilanmarg on 14 June 1969 (Mani *et al.* 1975). The values of albedo obtained over Gara glacier were generally of the same order as those at Gulmarg and Khilanmarg. The difference in the values is attributable to the nature of the surfaces. At Gulmarg where the underlying surface consisted of grass, the albedo varied between 0·25 and 0·38 when the grass was wet and 0·22 and 0·25 when dry. The values obtained at Gara glacier and Gulmarg clearly bring out the effect of wetness on the respective underlying surfaces. The ice at Khilanmarg was old and dirty and its albedo varied between 0·3 and 0·4. These values are of the same order as those over Gara glacier recorded on 10th forenoon.

5.5. *Net radiation*

The spot readings of net radiation made on 9th,

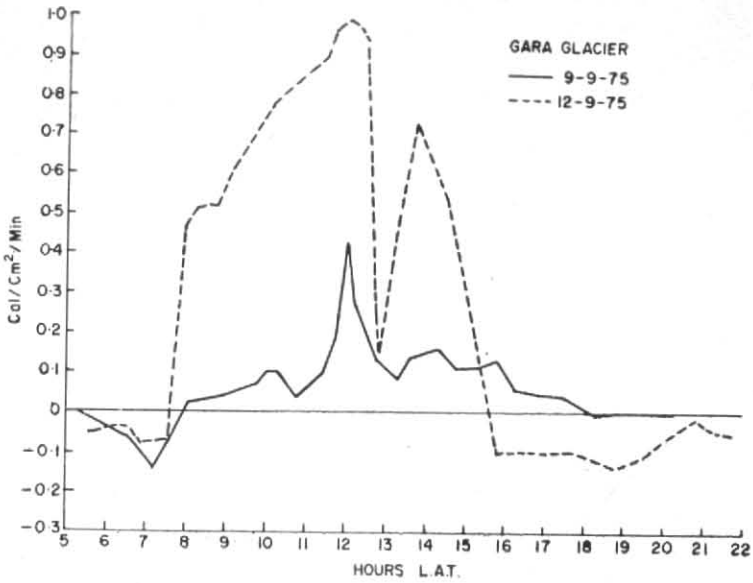


Fig. 7. Net radiation

an overcast day and 12th a clear day (1 octa) are represented in Fig. 7.

The underlying surface at Gara glacier on 9th was covered with snow while on 12th the surface was natural and dry. Snow has high emissivity in the atmosphere transparency window 8-12μm which explains for the effect of the snow cover, *viz.*, the considerable decrease in the net radiation during the day, considering the reduction due to snowfall also.

The maximum (spot reading) values of the net radiation was observed around noon on both the days. The value on 12th was 0·98 cal/cm^2/min while on 9th around the same time, the value was 0·43 cal/cm^2/min.

There was a sudden decrease of net radiation around 1245 hr on 12th (Fig. 7). This was due to the sun being obscured by a cloud patch at that time.

The zero points on both the days did not obviously coincide with the moments of sunrise and sunset. However, it is clearly brought out from the figure that the transition time of net radiation from negative to positive value in the morning as well as in the evening on 9th outrun those on 12th. This is, understandably, due to the dual effect of the snow cover on the underlying surface and the overcast sky.

The steep rise of the value in the morning and the fall in the evening are due to the obstruction by the hills to the east and west.

5.6. *Comparison with Gulmarg values*

The global, reflected and net radiation values at Gara glacier on 12 September 1975 together with those recorded at Gulmarg on 12 June 1969 are presented in Fig. 8.

In general, the radiation at Gara glacier is less than that at Gulmarg. There is, in addition, a reduction in radiation due to the obstructions to the east and the west. Apart from the fact that their locations, altitude and the solar elevations are different, the hour to hour values of global solar radiation suggest that the atmosphere over Gara glacier, is more moist and turbid than over Gulmarg due to the relatively high water vapour content and the dust particles. This is also brought out from the discussions on the measurements of direct solar radiation *vide* para 5.1.

The underlying surface at Gara glacier was of sand and rocks while at Gulmarg it was covered with grass. The difference in the nature was also brought out by the order of the values recorded at the two places and shown in the figure.

The net radiation, being a function of the incoming solar radiation during the day and the characteristics of the underlying surface, was less over the Gara glacier than at Gulmarg.

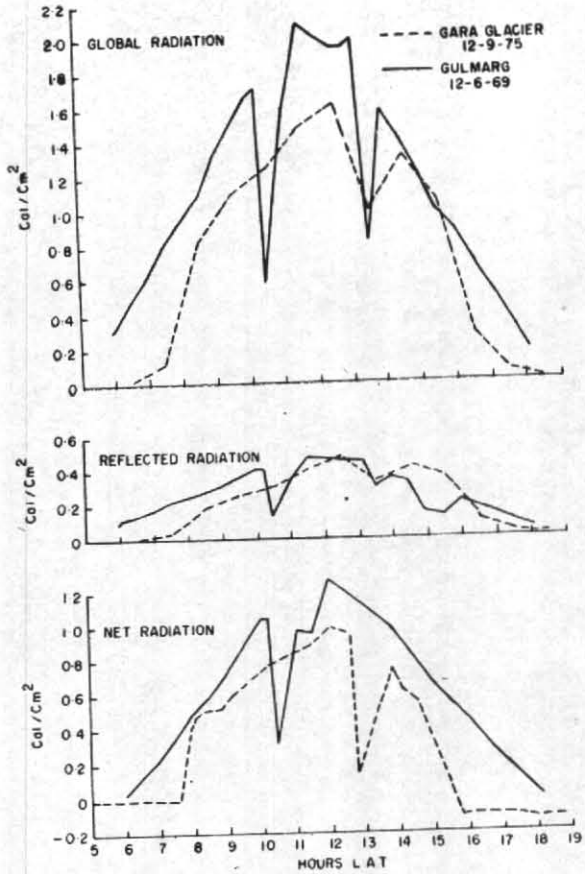


Fig. 8

6. Conclusion

The values of direct solar radiation, *viz.*, 1·55-1·57 cal/cm²/min recorded over the Gara glacier is relatively lower than that recorded at similar high altitude stations. These low values may be mainly due to the increased water vapour content in the atmosphere due to the precipitation that had occurred on the preceding days and the atmospheric aerosols.

The value of global solar radiation on a clear day in September is of the order of 600 cal/cm². The value representative of the altitudes of 4700 m is estimated to be of the order of 680 cal/cm² on extrapolation of the record to allow for the obstructions cutting off the radiation in the morning and evening. Thus there is a reduction of nearly 12 per cent of the daily global radiation due to the obstructions. Corresponding reduction in the reflected radiation is also found to be of the same order.

The albedo of fresh snow recorded on 9th was as high as 0·94 for high angles of incidence. The mean daily albedo of the day also was 0·77 due to the snow on the underlying surface. The albedo values obtained otherwise are in keeping with the values characteristic of the underlying surface.

Net radiation over the glacier on the clear day (12th) was maximum around noon and was of the order of 0·98 cal/cm²/min. The effects due to the snow cover on the underlying surface and the overcast sky, *viz.*, the lower net radiation value and the later transition of the net radiation through the zero point, were well brought out from the observations of 9th.

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