Journal of Glaciology, Vol. 13, No. 68, 1974

THE EFFECT OF SLOPE, EXPOSURE AND MOUNTAIN SCREENING ON THE SOLAR RADIATION OF McCALL GLACIER, ALASKA: A CONTRIBUTION TO THE INTERNATIONAL HYDROLOGICAL DECADE

By GERD WENDLER *and* NOBUYOSHI ISHIKAWA*

(Geophysical Institute, University of Alaska, Fairbanks, Alaska 99701, U.S.A.)

ABSTRACT. The McCall Glacier is located in the Brooks Range, north Alaska. Most of its slopes have a northerly exposure with an inclination between 5° and 15°. The reduction in direct solar radiation owing to this northerly exposure is small (1.7%) in summer (ablation period, solar declination 20°), as the reduction in radiation received on a north slope during the noon hours is mostly compensated by the increase of energy during the "night" hours, as the sun does not set at that latitude in summer. With the shortening of the solar path, the decrease in direct solar radiation as compared with a horizontal surface becomes more important. At the equinox the loss is 24.8%, and at a solar declination of −10° (20 October or 24 February) even higher with 32.6%.

A further reduction in solar radiation is caused by the steep mountains, which surround the McCall Glacier. The duration of sunshine is reduced during the ablation period by nearly 40%, which, however, represents an energy loss of only 13.4%, as the screening effect of the mountains is most important with low solar angles, i.e. at times when the total energy received at the surface is small. The screening effect of the mountains becomes more severe with lower sun angles and shorter paths of the sun. During the equinox a loss in duration of 67.6%, and in energy of 55.7% is observed. For a solar declination of −10°, there is hardly any direct sunshine on the glacier at all. There is then a loss in duration of 93.6%, resulting in a loss of energy of 87.8%.

Together, these two components reduce the direct solar radiation by about 15% in the ablation period, 67% at the equinox and more than 90% at a solar declination of −10°.

RÉSUMÉ. *Les effets de la pente, de l'exposition et de l'écran montagneux sur la radiation solaire sur le McCall Glacier dans l'Alaska: une contribution a la Décennie Hydrologique Internationale.* Le McCall Glacier est situé dans la chaîne de Brooks, au Nord de l'Alaska. La plupart de ses pentes ont une exposition Nord avec une pente de 5° à 15°. La réduction dans le rayonnement solaire direct dûe à son exposition Nord est faible (1,7%) en été (pendant la période d'ablation, la déclinaison du soleil est de 20°), car la réduction du rayonnement reçu sur une pente Nord pendant les heures de milieu de journées est en majeure partie compensée par l'accroissement de l'énergie reçue pendant les heures "nocturnes" puisque le soleil ne se couche pas à ces latitudes. Lorsque le chemin du soleil se raccourcit, le déficit en rayonnement solaire direct par rapport à une surface horizontale devient plus important. A l'équinoxe, la perte est de 24,8% et lorsque la déclinaison solaire est de −10° (20 octobre ou 24 février), elle est même plus forte avec 32,6%.

Une réduction supplémentaire du rayonnement solaire résulte du relief des montagnes entourant le McCall Glacier. La durée d'illumination est réduite, pendant la période d'ablation, de près de 40%, ce qui, cependant, ne représente une perte d'énergie que de 13,4%, car l'effet d'écran des montagnes est le plus important lorsque l'angle d'incidence du soleil est faible, c'est-à-dire au moment où l'énergie reçue en surface est faible. L'effet d'écran des montagnes devient plus sévère lorsque les angles d'incidence du soleil deviennent plus petits et plus court son trajet. A l'équinoxe, la perte en durée est de 67,6% et en énergie de 55,7%. Pour une déclinaison solaire de −10°, il y a rarement d'illumination directe du glacier. Il y a donc une perte en durée de 93,6% provoquant une perte en énergie de 87,8%.

Le réunion de ces deux effets réduit le rayonnement solaire direct d'environ 15% pendant la période d'ablation, de 67% à l'équinoxe et de plus de 90% pour une déclinaison solaire de −10°.

ZUSAMMENFASSUNG. *Der Einfluss von Exposition und Horizontabschirmung auf die Sonnenstrahlung des McCall Glacier, Alaska: ein Beitrag zur Internationalen Hydrologischen Dekade.* Der McCall Glacier liegt im nördlichen Alaska (Brooks Range). Die meisten Hänge haben nördliche Exposition mit Neigungen zwischen 5° und 15°. Der Verlust an Sonnenstrahlung, der von der nördlichen Exposition verursacht wird, ist im Sommer (Ablationsperiode, Sonnendeklination 20°) gering (1,7%), da der Strahlungsverlust der Nordhänge in den "Nachtstunden" kompensiert wird, da die Sonne in diesen Breiten im Sommer nicht untergeht. Mit kürzeren Sonnenbahnen wird der Strahlungsverlust bedeutender; für die Tag- und Nachtgleiche beträgt der Verlust im Vergleich mit der Horizontalen 24,8% und 32,6% für eine Sonnendeklination von −10° (20 Oktober bzw. 24 Februar).

Ein weiterer Strahlungverlust wird von den steilen Bergen verursacht, die den McCall Glacier umgeben. Die mögliche Sonnenscheindauer ist in der Ablationsperiode um fast 40% reduziert, was jedoch nur einem Energieverlust von 13,4% gleichkommt, da die Horizontabschirmung am Wirksamsten mit niedriger Sonnenhöhe ist, d.h. für Perioden, wenn die Energie, die am Boden ankommt, gering ist. Die Horizontabschirmung wird mit niedrigeren Sonnenhöhen und kürzeren Sonnenbahnen bedeutender; für die Tag- und

* On leave from the Institute of Low Temperature Science, University of Hokkaido, Sapporo, Japan.

Nachtgleiche wird ein Verlust in Sonnenscheindauer von 67,6% bzw. in Energie von 55,7% beobachtet. Bei −10° Sonnendeklination erreicht fast gar keine direkte Sonnenstrahlung den Gletscher. Der Verlust in Sonnenscheindauer ist 93,6%, was einem Energieverlust von 87,8% gleichkommt.

Gemeinsam reduzieren Exposition und Horizontabschirmung die Energie der direkten Sonnenstrahlung um etwa 15% in der Ablationsperiode, 67% während der Tag- und Nachtgleiche und um mehr als 90% bei einer Sonnendeklination von −10°.

1. Introduction

The McCall Glacier is situated in the eastern and highest part of the Brooks Range, northern Alaska, in the Romanzof Mountains at lat. 69° 18′ N., long. 143° 48′ W. Investigations have been carried out on this glacier since 1969 (Wendler and others, 1972, in press; Wendler and Ishikawa, 1973[a], [b]; Trabant and others, in press), and it is the only Arctic glacier currently studied in the U.S.A. The program is part of the International Hydrological Decade (I.H.D.), and continues measurements made during the I.G.Y. by Keeler (1959), Orvig (1961) and Orvig and Mason (1963). The glacier owes its importance to the fact that it lies at the intersection of two glacier chains (the American and Arctic Circle chains), which were recommended for intensive study during the I.H.D.

The McCall Glacier has a size of 6.22 km², and is thus one of the larger ones in the Brooks Range. It stretches from the snout at about 1 350 m to the Mt Hubley (2 718 m), the third highest mountain of the Brooks Range.

In the present study calculations are made of the effects of slope inclination and direction and of the screening effect of the surrounding mountains on the incoming direct solar radiation. These data are required to calculate the heat balance of the McCall Glacier as a whole, and the results may help to explain why certain valleys are glacier covered, and why others, having similar altitudes, are bare.

2. Differences in exposure

The differences in the radiation owing to the influence of direction and angle of the slopes were calculated for the McCall Glacier. This work is based on Brandenberger's map (1960) which has a scale 1 : 10 000 with 5 m altitude lines. Four classes of inclination were separated. <5°, 5–15°, 15–25° and >25°. The areas with inclination <5° were considered as horizontal surfaces, independent of their slope direction. Slopes of 5–15° and 15–25° were considered as 10° and 20°, respectively. For slopes in excess of 25° the value of 30° was assumed, which seems to be justified, as areas in excess of 35° are limited to very small areas. Figure 1 shows the slope inclination. Areas in excess of 25° represent 13.3%, and are found mostly in the upper areas and at limited places at the steep side walls of the glacier. Areas between 15–25° are also not very frequent (13.2%) and again found mostly in the upper parts of the glacier. Most of the glacier has an inclination of 5–15° (64.4%), while relatively flat areas (<5°) are also infrequent (9.1%).

Eight directions of the slopes were distinguished; this means that a total of 25 slope characteristics were distinguished (eight directions with three inclination intervals, plus areas with a slope of less than 5°).

The map depicting slope directions of McCall Glacier (Fig. 2) shows that most of the glacier faces north. From Figure 3 and Table I, we can see that northerly exposures (N.E., N. and N.W.) are predominant (75.1%) and westerly exposure is found mostly in the upper firn basin (19.1%). S.W. (1.4%) and E. (4.4%) exposures are not frequent and there are no S. and S.E. exposures. There are several theoretical studies (Schubert, 1928; Kaempfert, 1942; Garner and Ohmura, 1968) which show the amount of direct solar radiation a slope of any direction and inclination receives for a particular geographic latitude, date and time of the day as compared with a horizontal surface. Tables from the literature were examined. Most of these calculations are done for lower latitudes, e.g. Sauberer and Dirmhirn (1958).

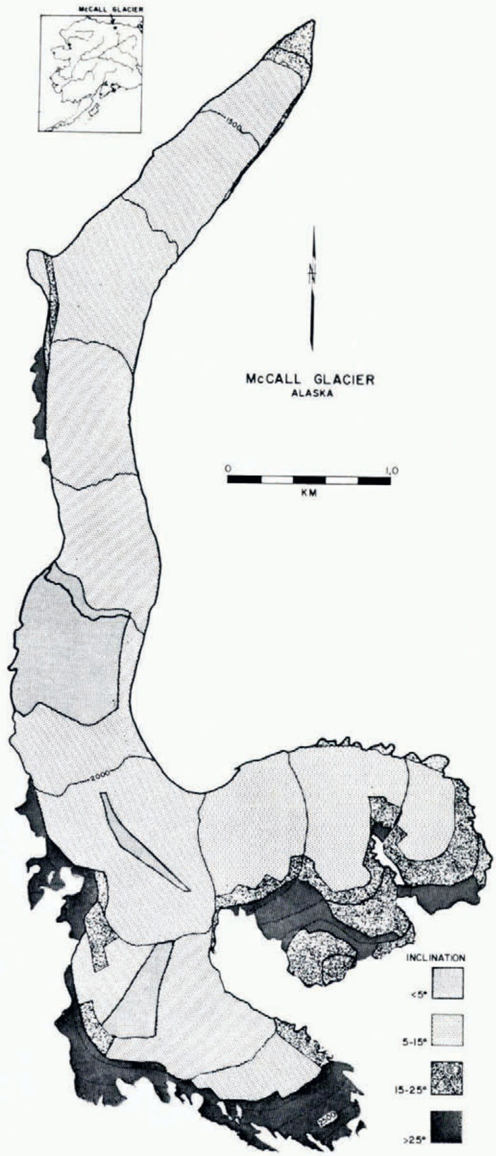

Fig. 1. Map of the inclination of the McCall Glacier, Brooks Range, Alaska.

However, Kondratyev (1969) gives tables for lat. 70° N. and eight directions and different slope angles, from which values relevant for the McCall Glacier were interpolated for four solar declinations: midsummer (+23.5°), a typical value for the ablation season (20° at 21 May or 24 July), equinox (21 March or 23 September) and an early winter value (−10° at 20 October or 24 February). These data are given in Table II. It is not possible, of course, to calculate a midwinter value, as the sun does not rise above the horizon. From the table, one can see that in midsummer (24 h with sun above the horizon) all slopes receive very similar amounts of energy to that falling on a horizontal surface. The lower the solar height

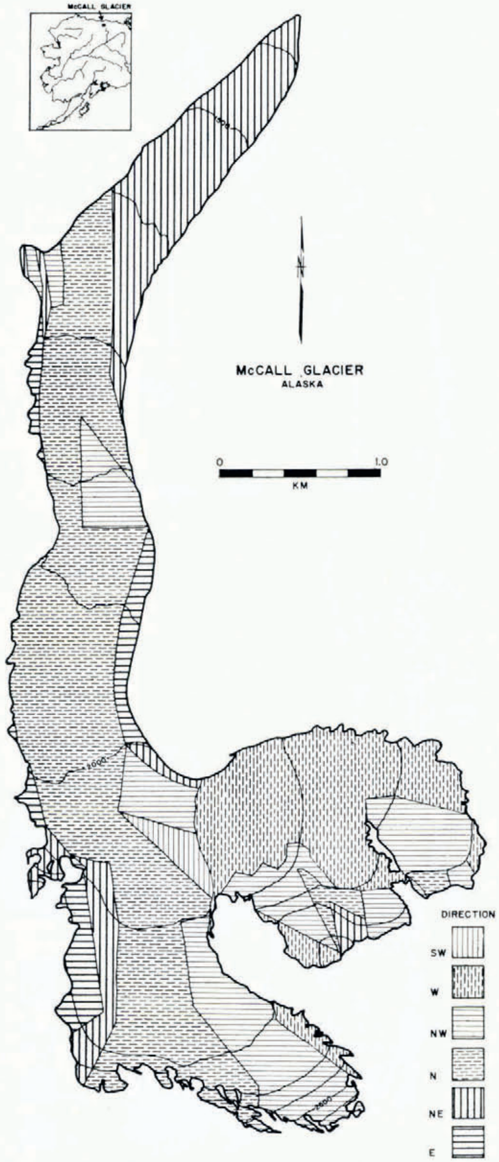

Fig. 2. Map of the slope direction of the McCall Glacier, Brooks Range, Alaska.

and the shorter the daily path of the sun, the greater the differences become, e.g. for a solar declination of $-10°$, a $30°$ inclined south slope receives 3.7 times as much energy as a horizontal surface, while a $30°$ inclined north slope does not receive any energy at all.

By knowing the different directions and inclinations of the McCall Glacier (Table I), and the radiation these surfaces receive as compared with the horizontal (Table II), the effect of the exposure for the glacier as a whole could be calculated (Table III). It may be seen from this table that, resulting from the long path of the sun, the total incident energy that could be received by the glacier as a whole varies only little during the summer. For example,

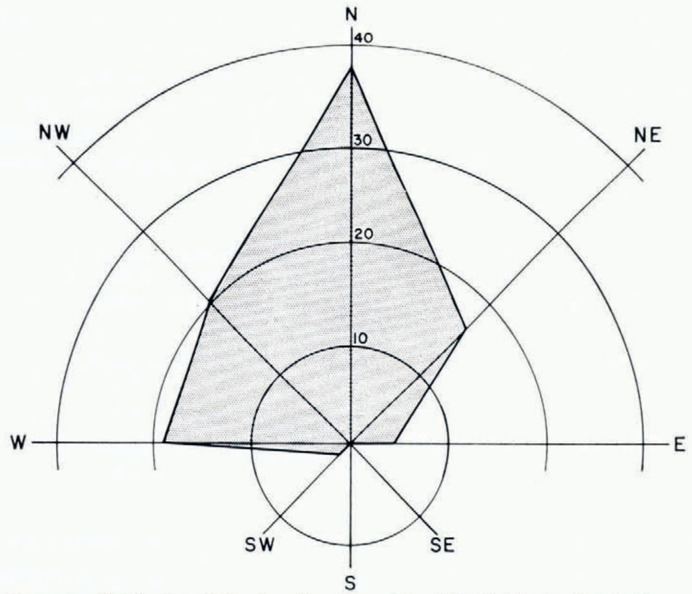

Fig. 3. Frequency distribution of the slope directions of the McCall Glacier, Brooks Range, Alaska.

TABLE I. AREA (PER CENT) OF THE McCALL GLACIER HAVING SPECIFIED SLOPE EXPOSURES AND INCLINATIONS

Direction	*Angle* 10°	20°	30°	Σ
N.	25.4	0.5	3.0	37.9
N.E.	11.9	2.5	2.2	16.7
E.	2.6	0.4	1.4	4.4
S.E.	—	—	—	—
S.	—	—	—	—
S.W.	1.4	—	—	1.4
W.	12.6	5.6	0.9	19.1
N.W.	10.5	4.2	5.8	20.5
Σ	64.4	13.2	13.3	90.9

9.1% flat areas.

TABLE II. MEAN DAILY DIRECT SOLAR RADIATION ENERGY (EXPRESSED AS A PERCENTAGE OF THAT ON A HORIZONTAL SURFACE) FOR UNSCREENED SURFACES WITH SPECIFIED EXPOSURES, INCLINATIONS, AND SOLAR DECLINATIONS

Direction	*Slope angle*	*Solar declination* −10°	0°	20°	23.5°
N.	10	43.0	50.6	99.7	100.7
	20	9.7	17.2	96.7	99.0
	30	0.0	0.0	91.7	95.1
N.E. or N.W.	10	59.0	74.5	99.0	99.8
	20	33.4	58.0	96.2	97.4
	30	23.3	50.5	91.6	92.6
E.	10	111.1	108.2	98.9	98.3
	20	125.4	118.8	99.0	96.8
	30	143.0	131.7	100.4	95.5
S.E. or S.W.	10	169.2	136.2	100.4	97.6
	20	234.3	169.8	102.1	96.6
	30	295.4	200.8	105.0	97.0
S.	10	197.3	146.9	101.1	97.7
	20	289.1	189.5	102.9	96.6
	30	375.4	227.6	105.5	96.8

a north slope, which one would expect to receive less energy, receives less during the "day" hours, but more during the "night" hours when the sun is in the north. Hence, the "day-time" loss is mostly compensated by the "night-time" gains, and the total amount is similar to the amount received on a horizontal surface. During the equinox, however, the influence of the northerly exposure of McCall Glacier becomes more important, as it then receives only three quarters the energy incident on a flat surface. With low sun angles and shorter solar paths these differences become even more pronounced.

Table III. Direct solar radiation energy deficit received on the whole McCall Glacier as compared with the horizontal unscreened surface for given solar declinations

Solar declination deg	*Date*	*Radiation loss* %
23.5	21 June	1.3
20	21 May or 24 July	1.7
0	21 March or 23 September	24.8
−10	20 October or 24 February	32.6

3. The screening effect of the surrounding mountains on the radiation

As the area is very mountainous, the maximum possible duration of sunshine shows great differences for various parts of the glacier (Fig. 4). It is natural that the shadowing effect of the surrounding steep valley walls and mountains is important, especially as there is more than 1 300 m altitude differences between the snout of the glacier and Mt Hubley in a distance of not more than 7 km. A theodolite (Wild T2) was used to survey the horizon at 52 points (see Fig. 6) on the glacier during the summers of 1970 and 1971. By plotting the horizon for each point of measurement and superimposing the paths of the sun at different times of the

Fig. 4. View of McCall Glacier looking towards the south-west. Note that the western parts of the glacier tongue are in shadow. (Photograph by Dr K. O. L. F. Jayaweera.)

https://doi.org/10.3189/S0022143000023030 Published online by Cambridge University Press

year, the sunrise and sunset could be determined. An example is shown in Figure 5. Another instrument, which could have been used, and makes the evaluation less time-consuming is a "Tagbogenmesser" (Schmidt, 1933), which is a modified theodolite. When adjusting to any given solar declination, the sunrise and sunset can be read directly. However, such an instrument was not available. More recently Williams and others (1971) produced a map by computer showing calculated length of bright sunshine for grid points covering a whole area.

For each of the 52 points the loss in possible sunshine duration in the morning and evening was calculated for four solar declinations—midsummer (23.5°), equinox (0°), late autumn (−10°) and the ablation period (20°). Similar studies have been carried out previously by Thams (1955), Baumgartner (1960) and Hoinkes and Wendler (1968).

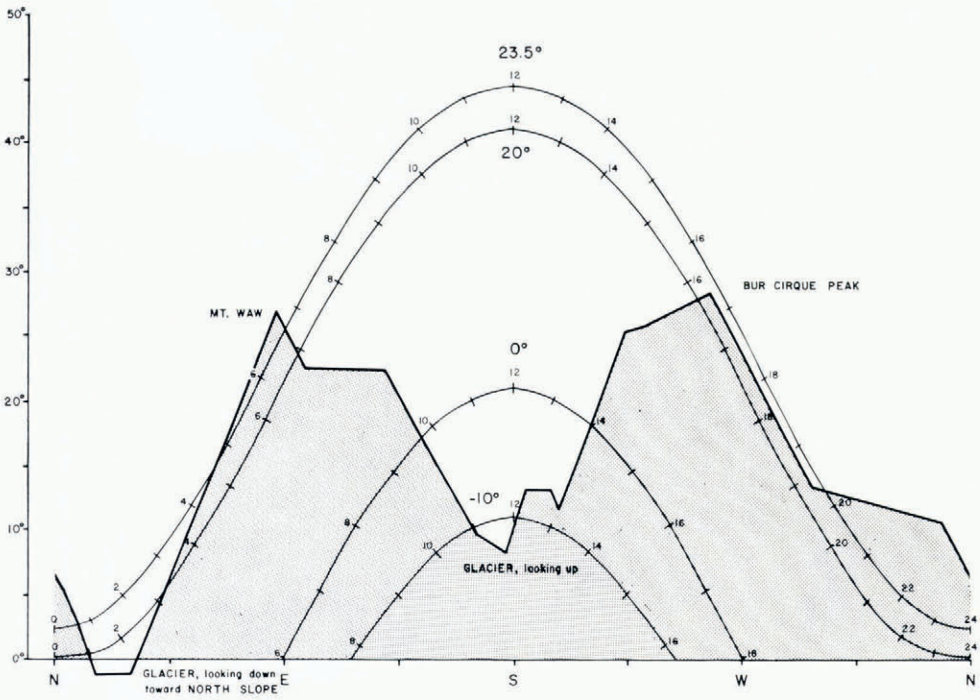

Fig. 5. The screening of the mountains for the micrometeorological site, and four sun paths for the solar declinations of 23.5°, 20°, 0° and −10°.

For midsummer (Fig. 6a), most of the glacier surface has a loss of 20–40% in the duration of sunshine, which means that most areas are in shadow for 5–10 h on a clear day. There is only one area with a loss of less than 20%, which is situated at the confluence of the three firn basins. Areas with a loss of more than 40% are limited to the edges of the glacier at higher altitudes. By planimetering the map a mean value of 32.6% was found.

For the equinox (Fig. 7) the losses in sunshine are much bigger owing to the lower path of the sun. Most of the glacier and especially the lower part had a loss of 60–80%. The upper firn basin was the sunnier, while in part of the lower one no direct solar radiation was then received at all. By integrating the whole map, a mean loss in the duration in sunshine of 67.6% was found.

https://doi.org/10.3189/S0022143000023030 Published online by Cambridge University Press

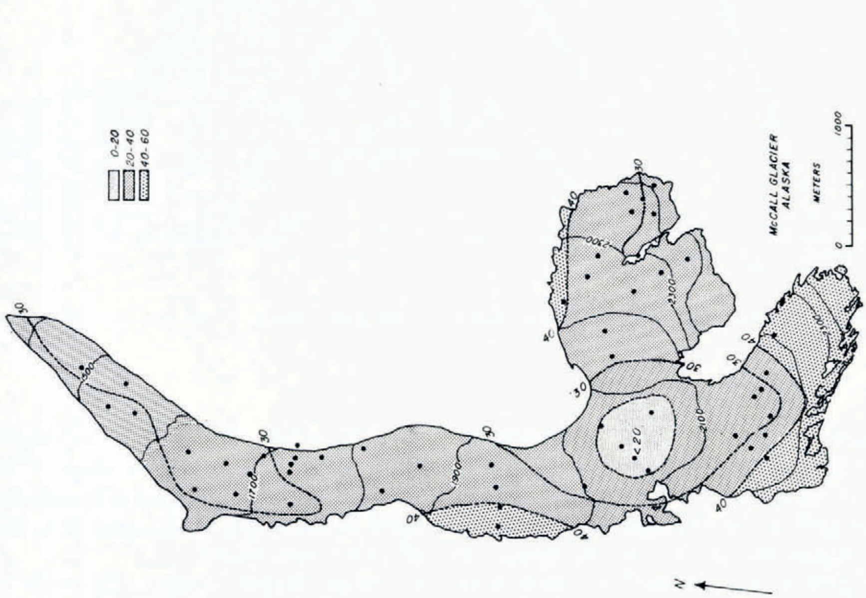

Fig. 6. The loss in duration of sunshine of McCall Glacier in midsummer, solar declination 23·5°.

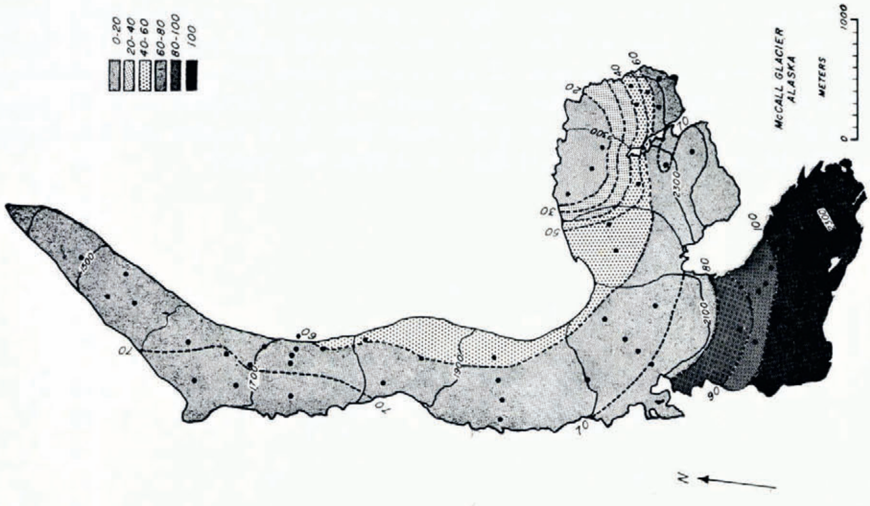

Fig. 7. The loss in duration of sunshine of McCall Glacier at the equinox, solar declination 0°.

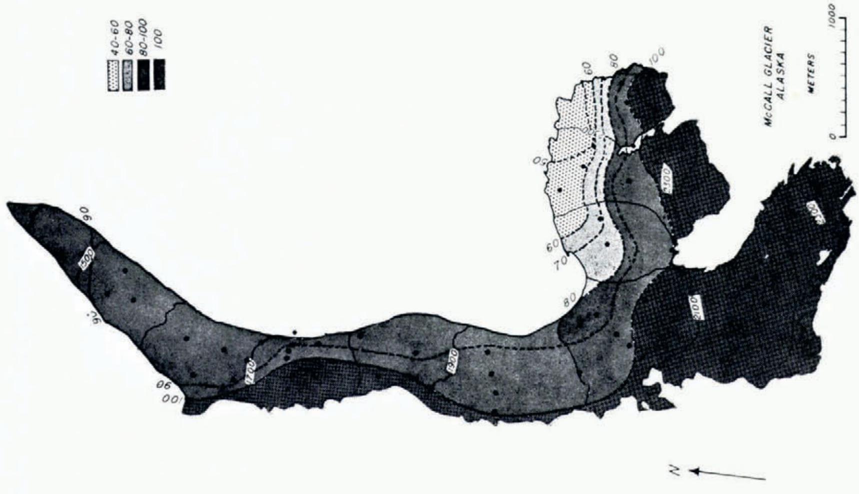

Fig. 8. The loss in duration of sunshine of McCall Glacier in the autumn, solar declination −10°.

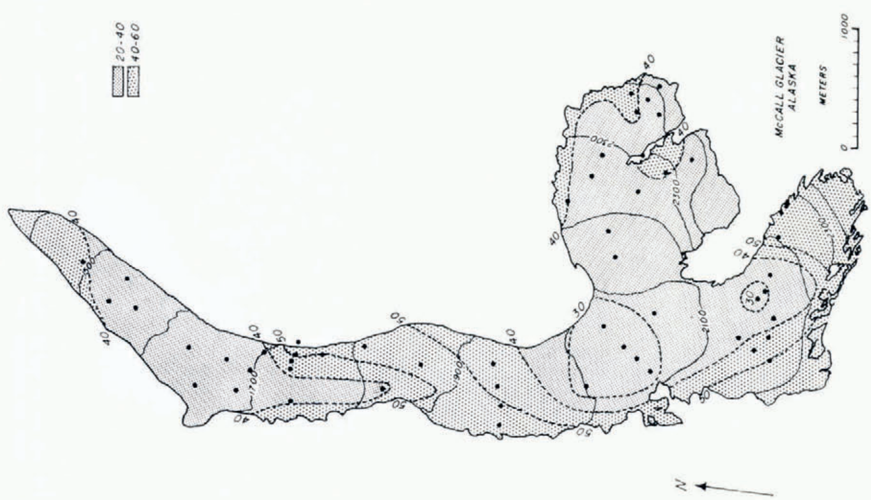

Fig. 9. The loss in duration of sunshine of McCall Glacier in the ablation period, solar declination 20°.

https://doi.org/10.3189/S0022143000023030 Published online by Cambridge University Press

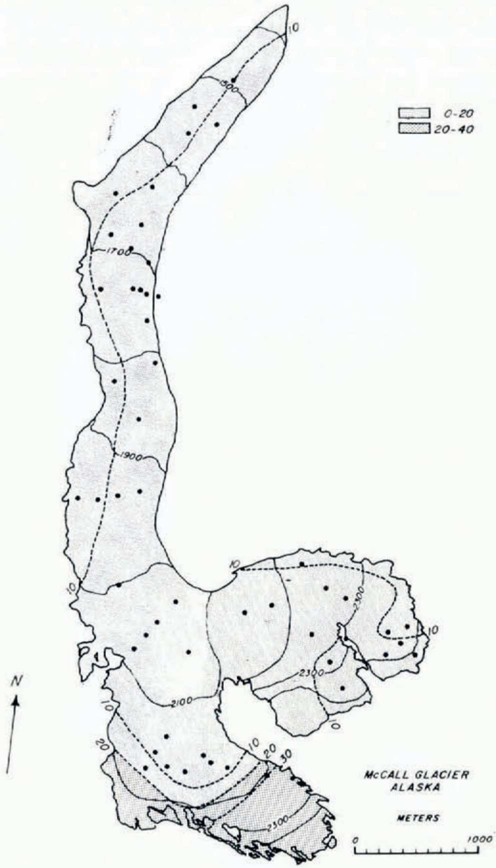

Fig. 10. The loss in energy of direct solar radiation of McCall Glacier in midsummer, solar declination 23.5°.

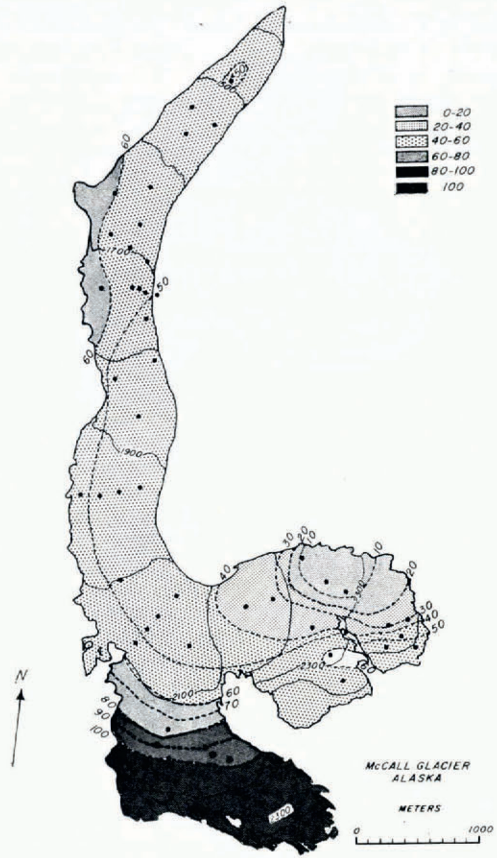

Fig. 11. The loss in energy of direct solar radiation of McCall Glacier at the equinox, solar declination 0°.

https://doi.org/10.3189/S0022143000023030 Published online by Cambridge University Press

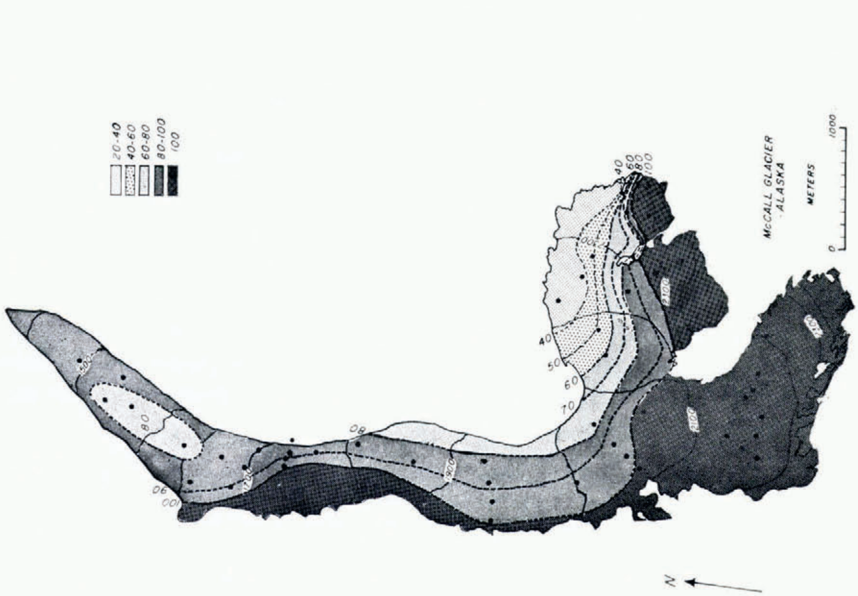

Fig. 12. The loss in energy of direct solar radiation of McCall Glacier in the autumn, solar declination $-10°$.

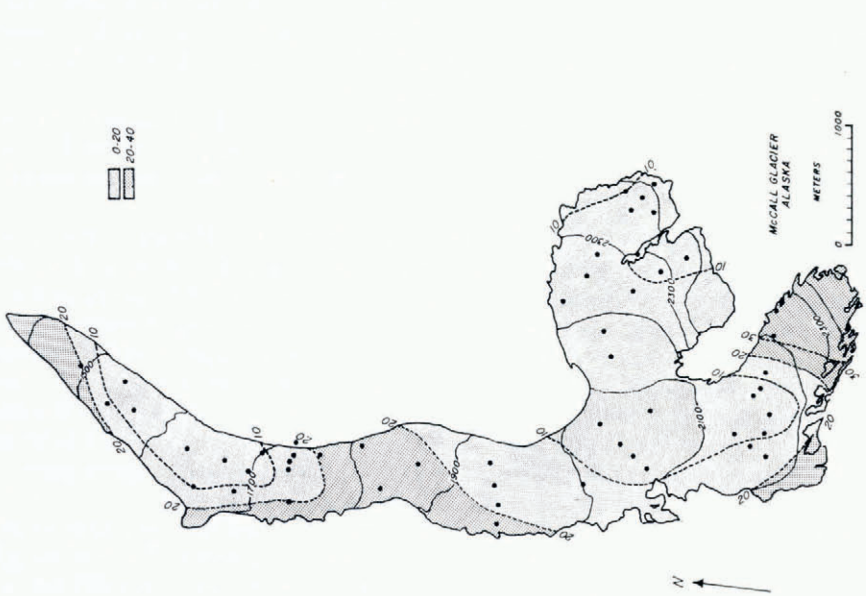

Fig. 13. The loss in energy of direct solar radiation of McCall Glacier in the ablation period, solar declination $20°$.

https://doi.org/10.3189/S0022143000023030 Published online by Cambridge University Press

For a solar declination of −10° (20 October or 24 February) the losses in sunshine duration become even more pronounced. About half of the glacier does not receive any direct sunshine at all (Fig. 8). Only the northern part of the upper firn basin receives sunshine of any length. By integrating the whole map, a loss of 93.6% was found.

The loss in duration of sunshine was also calculated for a solar declination of 20°, which represents the mean of the ablation period (Fig. 9). The map is fairly similar to the map for midsummer (Fig. 6); however, the losses are somewhat larger. A mean loss in duration of 39.9% was calculated.

A certain loss in duration of sunshine does not normally result in the same loss of energy, as the energy received is a function of the solar height. Normally, the losses in duration are higher than those of energy, as the screening effect of mountains is more frequent at low solar angles, at times when the energy received at the surface is relatively low (Kondratyev, 1969; Geiger, 1965). Hence, for each point, the losses in duration were changed into losses of energy, and new maps were constructed (Figs. 10–13). Generally, one can see that the losses in energy are somewhat smaller, with the exception that a loss of 100% in duration is naturally equal to the same loss in energy. For a solar declination of 23.5° (Fig. 10), the loss in energy over the whole glacier surface is less than 20% with the exception of the upper parts of the lower firn basin. The mean value of the deficit for the glacier was 10.1%.

For the equinox the losses are substantially higher (Fig. 11), and the only area which was not affected very seriously was the northern part of the upper firn basin. Most of the glacier received about half of the energy, but the upper area of the lower firn basin did not receive any sunshine at all. A mean value for the whole glacier indicates a loss in energy of 55.7%.

For the solar declination of −10° (Fig. 12), the south and east part of the glacier does not receive any energy at all; the only area where any amount of energy is received is the northern part of the upper firn basin. A mean loss in energy of 87.7% occurs for the glacier.

For the ablation season (Fig. 13) the map is somewhat similar to the map of midsummer, but the losses are higher. A mean value for the glacier of 13.4% was calculated. The losses in duration and energy are summarized in Table IV.

Table IV. Loss in duration and energy for the whole McCall Glacier owing to the screening effect of the surrounding mountains for different solar declinations

Solar declination deg	*Loss in duration* %	*Loss in energy* %
23.5	32.6	10.1
20	39.9	13.4
0	67.6	55.7
−10	93.6	87.8

4. The combined effect of exposure and screening of the mountains

In the previous two paragraphs, the effects of the exposure of the glacier and the screening effect of the mountains has been described separately. However, these two effects are both present and the energy lost can be seen from Table V.

Table V. Energy received on the McCall Glacier for different solar declinations

A horizontal surface without any screening of the sun is considered to receive 100% energy

Solar declination deg	*Exposure* %	*Screening* %	*Total* %
23.5	98.7	89.9	88.8
20	98.3	86.6	85.1
0	75.2	44.3	33.3
−10	67.4	12.2	8.2

https://doi.org/10.3189/S0022143000023030 Published online by Cambridge University Press

Summarizing, it can be stated that the screening effect of the mountains is much more important than the northerly exposure in reducing the energy received on the glacier.

For the ablation period (solar declination 20°), which is the most important time for the "health" of the glacier, the combined effects results in a reduction of 15% in the energy of the direct solar radiation. With lower sun passes, the direct solar radiation which is received on the glacier drops drastically. For the equinox it is only one third and for a solar declination of −10°, less than 10% of that falling on a horizontal surface.

5. Conclusion

In this paper, the effect of the topography on the solar radiation has been discussed for an Arctic glacier in North America. The type of calculation presented here may point to a better understanding of why glaciers are maintained in particular valleys while in others, with similar altitudes, no glacier is present.

The results found here will be applied for a specific albation period (summer 1971), when the combined heat, ice, and water balance will be estimated for McCall Glacier.

Acknowledgements

The research was supported by the Atmospheric Sciences Section, National Science Foundation, under Grants GA-28278x and GA-37306; logistic support was given by the Air National Guard. The authors thank Mr S. Corbin, Dr K. O. L. F. Jayaweera and Mr J. Slivkoff, who helped in carrying out the field measurements. Mrs T. McClung and Mrs J. Leap reduced the data, and Professor N. Streten's valuable comments on the manuscript improved this paper.

MS. received 11 September 1973

REFERENCES

Baumgartner, A. 1960. Gelände und Sonnenstrahlung als Standortfaktor am Grossen Falkenstein (Bayerischer Wald). *Forstwissenschaftliches Centralblatt*, Bd. 79, Ht. 9–10, p. 286–97.

Brandenberger, A. J. 1960. McCall Glacier. (*In* Nine glacier maps: northwestern North America. *American Geographical Society. Special Publication* No. 34, Sheet 9.)

Garner, B. J., *and* Ohmura, A. 1968. A method of calculating the direct shortwave radiation income of slopes. *Journal of Applied Meteorology*, Vol. 7, No. 5, p. 796–800.

Geiger, R. 1965. *The climate near the ground.* Cambridge, Mass., Harvard University Press.

Hoinkes, H. C., *and* Wendler, G. 1968. Der Anteil der Strahlung an der Ablation von Hintereis- und Kesselwandferner (Ötztaler Alpen, Tirol) im Sommer 1958. *Archiv für Meteorologie, Geophysik und Bioklimatologie*, Ser. B, Bd. 16, Ht. 2–3, p. 195–236.

Kaempfert, W. 1942. Sonnenstrahlung auf Ebene, Wand und Hang. *Wissenschaftliche Abhandlungen des Reichsamtes für Wetterdienst*, Bd. 9, No. 3.

Keeler, C. M. 1959. Notes on the geology of the McCall Valley area. *Arctic*, Vol. 12, No. 2, p. 87–97.

Kondratyev, K. Y. 1969. *Radiation in the atmosphere.* New York and London, Academic Press. (International Geophysics Series, Vol. 12.)

Orvig, S., *ed.* 1961. McCall Glacier, Alaska: meteorological observations, 1957–1958. *Arctic Institute of North America. Research Paper* No. 8.

Orvig, S., *and* Mason, R. W. 1963. Ice temperatures and heat flux, McCall Glacier, Alaska. *Union Géodésique et Géophysique Internationale. Association Internationale d'Hydrologie Scientifique. Assemblée générale de Berkeley, 19–8—31–8 1963. Commission des Neiges et des Glaces*, p. 181–88.

Sauberer, F., *and* Dirmhirn, I. 1958. Das Strahlungsklima. (*In* Steinhauser, F., *and others, ed.* Klimatographie von Österreich. Mit Beiträgen mehrerer Mitarbeiter hrsg. und bearbeitet von F. Steinhauser, O. Eckel, F. Lauscher. 1. Lief. *Österreichische Akademie der Wissenschaften. Denkschriften der Gesamtakademie*, Bd. 3, 1. Lief., p. 12–102.)

Schmidt, W. 1933. Der Tagbogenmesser, ein Gerät zum Verfolgen der Bahn der Sonne am Himmel. *Meteorologische Zeitschrift*, Bd. 50, Ht. 9, p. 328–31.

Schubert, J. 1928. Die Sonnenstrahlung im mittleren Norddeutschland nach Messungen in Potsdam. *Meteorologische Zeitschrift*, Bd. 45, Ht. 1, p. 1–16.

Thams, J. C. 1955. Zur Bestimmung der Sonnenscheindauer in einem stark kupierten Gelände. *Archiv für Meteorologie, Geophysik und Bioklimatologie*, Ser. B, Bd. 6, Ht. 4, p. 417–30.

Trabant, D., *and others*. In press. Mass-balance and superimposed ice formation on McCall Glacier, Brooks Range, Alaska, 1971 and 1972 hydrologic years, by D. Trabant, C. Fahl and C. S. Benson. *Journal of Glaciology*.

Wendler, G., *and* Ishikawa, N. 1973[a]. Experimental study of the amount of ice melt using three different methods: a contribution to the International Hydrological Decade. *Journal of Glaciology*, Vol. 12, No. 66, p. 399–410.

Wendler, G., *and* Ishikawa, N. 1973[b]. Heat balance investigation in an Arctic mountainous area in northern Alaska. *Journal of Applied Meteorology*, Vol. 12, No. 6, p. 955–62.

Wendler G., *and others*. 1972. Mass balance studies on McCall Glacier, Brooks Range, Alaska, [by] G. Wendler, C. Fahl and S. Corbin. *Arctic and Alpine Research*, Vol. 4, No. 3, p. 211–22.

Wendler, G., *and others*. In press. On the hydrology of a partly glacier-covered Arctic watershed, by G. Wendler, D. Trabant, and C. [S.] Benson. [Paper presented at International Symposia on the Role of Snow and Ice in Hydrology, Banff, Canada, UNESCO Session 4, 8 September 1972.]

Williams, L. D., *and others*. 1971. Application of computed global radiation for areas of high relief, by L. D. Williams, R. G. Barry and J. T. Andrews. *Journal of Applied Meteorology*, Vol. 11, No. 3, p. 526–33.