REVIEW ARTICLE

GLACIAL-METEOROLOGICAL INVESTIGATIONS IN SWEDISH LAPPLAND

GLACIAL-METEOROLOGICAL INVESTIGATIONS ON THE KARSA GLACIER IN SWEDISH LAPPLAND 1942-1948. *By* CARL CHRISTIAN WALLÉN. *Stockholm: Geografiska Annaler, Vol. 30, Pts. 3 and 4 (1948) pp. 451-672; maps, diagrams, tables, bibliography.*

THE SHRINKAGE OF THE KARSA GLACIER AND ITS PROBABLE METEOROLOGICAL CAUSES. *By* CARL CHRISTIAN WALLÉN. *Stockholm: Geografiska Annaler, Vol. 31, Pts. 1 to 4 (1949) pp. 275-291; tables.*

Some scientific papers merit immediate acclaim because they fulfill an obvious need. Such a work is Carl Christian Wallén's glacial-meteorological study of Karsa Glacier.[1] This competent and thorough analysis of factors affecting nourishment, wastage, and the heat economy of a glacier is a major contribution to glaciology.

Karsa Glacier is a relatively small body of ice on the eastern slope of the northern Swedish mountains, a few kilometres east of the Norwegian border in the Torneträsk region (approximately 68°N., 18°E.). The glacier descends to 820 metres above sea level, but its largest area lies between 1000 and 1200 metres, and the surrounding peaks attain 1400-1600 metres. This ice stream extends eastward 3 km., is up to 1 km. wide, and covers 1.95 square km. The area-distribution curve shows it to be transitional between a cirque and a valley glacier.

This glacier was chosen because of accessibility, a lengthy record of marginal fluctuations, and proximity to meteorological stations at Riksgränsen and Abisko. Field studies were made during ten separate periods totalling 164 days and extending from late April 1942 to early September 1948.

This study is an attempt to carry to a higher degree of development and refinement the pioneering works of Angström, Sverdrup, Eriksson and others on meteorological factors affecting nourishment and wastage of glaciers. The first step in this endeavour is an analysis of meteorological conditions prevailing during the years investigated. Records of accumulation and ablation for the same period are then summarized and followed by a theoretical treatment of heat balance at the glacier surface. Calculations thus derived are compared with the observational records, and the influence of various meteorological factors on ablation is evaluated. Finally, the shrinkage of Karsa Glacier is discussed and the probable meteorological causes are considered. The introductory chapter also gives a good historical review of glacial-meteorological studies, and the text is supplemented by an extensive bibliography containing many references new to most North American readers.

The analysis of meteorological records is commendable for its separate and special treatment of conditions attained during the ablation and accumulation seasons. Generalizations based on observations in other areas do not necessarily apply here, and the meteorological factors affecting Karsa Glacier are shown to be delicately interdependent. For example, in comparing the effects of winds from different directions, it is essential that the nature of the air mass, its humidity and temperature, be considered in relation to the local morphological conditions.

Radiation income on this glacier reaches a maximum in spring at about 800 cals./cm.^{2}/day and then decreases progressively during summer to a mean of 215 cals./cm.^{2}/day in September. The decrease of incoming radiation with increasing cloud cover follows a parabolic curve, with greater proportionate decreases under cloud covers greater than 5 tenths. Wallén follows Angström in arguing that the relatively high I_{10}/I_0 ratio (radiation income with 10 tenths cloud cover to income with clear sky) in far northern areas is more largely the product of multiple reflections between the clouds and snow-covered or ice-covered ground than of thinness in the cloud cover as maintained by others. He is impelled to this by the fact that the ratio between incoming radiation received at glacier

[1]In this review place names are spelled as in Dr. Wallén's papers. *Ed.*

and at ground stations in the Karsa area increases rapidly and progressively with increasing cloud cover.

Local measurements of the albedo[2] and analysis of determinations from other areas yield the following generalized values: the albedo on old frozen snow surfaces is 70-75 per cent, on wet, melting snow surfaces it is 60 per cent, and on glacier ice 40 per cent seems best. The author points out that 40 per cent is enough below the 50 per cent value used in most earlier calculations to be significant.

Micrometeorological observations of temperature, humidity, and wind were made at a camp on Karsa Glacier at 1025 metres altitude. Initially, temperature and humidity were recorded at ½- to 2-hourly intervals at 4, 170, and 600 cm. above the ice. Subsequent observations were limited to heights of 10, 100, and 170 cm. because a local glacier breeze complicates calculation of heat balance in a thicker layer. These observations show that micrometeorological conditions are strongly influenced by local factors, and that the Karsa area is different from other parts of the North Atlantic region in which micrometeorological studies have been made. Wind direction and the type of air mass involved are found to be of prime importance in ablation. It is also demonstrated that temperature records at Riksgränsen meteorological station, about 10 km. away, can be used to calculate temperatures on Karsa Glacier with reasonable reliability.

Accumulation on Karsa Glacier is remarkably consistent in amount and distribution from year to year. Only in years with winds predominantly from abnormal directions is the amount and distribution of snow notably different. In such instances, the local morphology has a strong effect because of its influence on snow drifting.

The specific gravity of Karsa firn increased from 0.50 to 0.55 between May 28 and 11 June 1946. This is attributed to "settling of the snow and the depositing of melt water", but it is not clear what is meant by "depositing". Normally, "refreezing" would be inferred, but "depositing" is said to continue after the firn is at 0°C. Lack of further analysis of possible causes for this density increase is disappointing. Following Schytt, Wallén shows that net ablation can be calculated from gross ablation with reasonable accuracy by using a firn density somewhat below the average. On Karsa Glacier a density of 0.50 gives good results.

Wallén's studies and analyses bear out Ahlmann's earlier generalizations on the decrease of ablation with increasing altitude and on the greater magnitude of the decrease on ice as compared with snow. A few observations of accumulation and ablation at each altitude interval on Karsa Glacier are shown to be sufficient for calculation of the total glacier regime.

Detailed measurements with a Devik ablatograph, corrected in a way not wholly comprehensible to those who have not used this instrument, reveal some interesting relations. The mean daily ablation for spring was 1.7 cm. of water, for summer 3.0 cm., and for fall 2.9 cm. The maximum daily record was 5.7 cm. of water, on 29 July 1946, and the maximum 2-hourly record was 1.4 cm. of water, on 8 June 1943. A more normal 2-hourly record is 0.9 cm., and the abnormal value of June 8 is attributed to the strong winds and high temperatures prevailing during the observation.

From curves showing daily ablation during different seasons it appears that the ratio of day-time ablation to night-time ablation decreases from 5.5 in spring to 1.6 in late summer. This is attributed to the decreasing influence of insolation as the season advances. The peak of the daily ablation curve also shifts from about noon in spring to mid-afternoon in late summer owing to the increasing influence of temperature and convectional heating.

Table 32, page 556, will be of particular interest to glaciologists for it shows, among other things, what percentage of the glacier's surface was occupied by

[2]Ratio between radiation energy reflected by the surface and the total incoming radiation falling on the surface.

the accumulation and ablation areas each year. The variations are amazingly large, the accumulation area, for example, ranging from 9.2 per cent in 1941-42 to 75.0 per cent in 1947-48. Admittedly 1941-42 was abnormal, owing to easterly winds during winter, but the accumulation area for 1945-46, a more normal year, covered only 27.7 per cent of the glacier's surface.

During this study only the year 1947-48 had an excess of accumulation over ablation. Total accumulation for 1947-48 was about normal, but ablation was definitely subnormal. Leaving out abnormal 1941-42, the loss of material averages 0.2 million cubic metres of water per year. This appears to be less than the loss prevailing during the 1920's and '30's.

The sum of ablation and accumulation at the firn limit on Karsa Glacier deviates only 4 per cent from the average regime of the entire glacier. This bears out Ahlmann's thesis that measurement of total accumulation or ablation at the firn limit permits reasonably accurate calculation of glacier regime. The firn limit on Karsa Glacier is now considerably higher than it was 20 years ago, even though average temperatures during the ablation season are about the same. This is ascribed to an accelerated retreat of the glacier as its area diminishes.

The treatment of heat balance at the glacier surface is designed for experts in this field. Of principal interest to glaciologists will be the conclusion that formulas and constants governing exchange of momentum and heat must be established for each glacier by local studies. For example, relations discovered by Sverdrup on Isachsen's Plateau in Spitsbergen do not hold here because a local glacier breeze produces a decrease rather than an increase in wind velocity above the surface.

Table 42, on pages 602-3, offers the most complete analysis of relations between ablation and meteorological factors yet published, and Table XII, pages 662-3, showing the amount of ablation caused by different meteorological factors and the percentage influence of these factors in total ablation under different weather conditions, is a masterpiece. The influence of insolation on ablation decreases progressively throughout the ablation period. In spring, radiation causes 60-70 per cent of the ablation on snow, but this decreases to 37 per cent by late summer. Concurrently, the effect of conduction increases from 25 per cent to 45 per cent, and ablation by condensation rises from 4 per cent to 15 or 20 per cent in mid-summer, followed by some decrease towards fall. Evaporation is relatively unimportant throughout the ablation season and has appreciable effect only in spring and late summer when it causes not more than 1.8 per cent of the total wastage. The insignificance of evaporation is attributed to maritimity of climate and comparatively high humidities. The above relations were established by studies at the camp on Karsa Glacier at 1025 metres altitude.

Total ablation of the entire glacier during the decade 1930-39 is calculated to be 59 per cent by radiation, 30 per cent by heating from the air, and 11 per cent by condensation. The predominating influence of radiation is the result of high altitude and the type of air masses invading the area. Wastage by heat from the air is secondary because winds are weak during periods of high temperature.

These general conclusions are supplemented by more detailed considerations of factors affecting ablation at different seasons, under different weather conditions, and in relation to one another. Only a few highlights from these details can be reported. Since the variation in intensity of radiation is greater than the variation in heating from the air, maximum absolute ablation occurs in late spring or early summer when radiation is greatest. Absolute ablation of ice and, to a less degree, of snow, decreases with increasing cloudiness during all seasons. In this area wind velocity has more influence than cloudiness upon the relative importance of different meteorological factors causing ablation. Wind velocity is also more effective than temperature for increasing ablation by heat supply from the air. Furthermore, any variable, such as cloudiness, does not have a constant and consistent effect on an ablation factor, such as radiation, throughout the ablation season. Radiation achieves its greatest relative importance in spring with almost clear skies, but in summer a half-covered sky is more favourable.

In the 1949 volume of the *Geografiska Annaler* dedicated to H. W. Ahlmann, Wallén describes the probable meteorological causes for recession of Karsa Glacier. Early observations were limited to recording the terminal recession. For this glacier, marginal recession is fortunately a reasonably reliable index of total shrinkage. From 1884 to 1917 no great recession of the glacier margin occurred. Between 1917 and the late 1930's it receded and at an accelerating rate, but in the '40's recession became slower. Total marginal recession since 1917 is about 200 metres.

Accumulation on Karsa Glacier is remarkably constant, so the principal cause of shrinkage and retreat must lie in climatic changes affecting ablation. The increased ablation is largely a result of an increase in heat supplied from the air rather than a change in radiation. Heat from the air has increased its total share in ablation by approximately 37 per cent since the beginning of the century. This has been caused by: increased summer temperature; increased summer humidity; a prolonged ablation season; and possibly increased wind velocity. Of these changes, prolongation of ablation season and rise of mid-summer temperature are considered the most important. Mean temperature of the ablation season increased about 1.4°C between the decade 1906-15 and the decade 1930-39. Winter temperatures at Riksgränsen also increased during this interval but dropped somewhat in the 1940's, and both summer and winter temperatures show more variability and wider fluctuation than formerly. In spite of the increase in winter temperature, no decrease in solid precipitation is apparent.

These changes are the result of accentuated maritimity during winter and an increase in southerly winds during summer. However, both summer and winter show more frequent fluctuations between maritime and continental climatic characteristics and, during some periods of summer, strong continental conditions prevail bringing abnormally warm and fair weather.

This pattern is not wholly consistent with changes throughout Scandinavia and the North Atlantic region where a general increase in winter but not in summer temperatures has occurred during the last decades. Winter precipitation has also increased, and summer temperatures may have risen since 1940. The reader should mark well Dr. Wallén's insistence that the results reported here apply to Karsa Glacier only and possibly also to the Swedish Mountains.

These papers are not for the casual reader. Unfortunately, the format does not make for quick reading or scanning and better grouping of related materials would have been helpful. In spite of the fact that significant statements are italicised, these statements cannot be properly understood when lifted bodily from their context. In many instances they may seem contradictory or repetitious without the understanding provided by careful reading of the accompanying text. The numerous diagrams and figures are an asset, but occasionally more explanation is desirable. The labelling of some features on the map, Fig. 4, p. 461, would help, and in Fig. 49, p. 604, no explanation is given for the two types of lines used on the graph. Nor is any explanation offered as to why the decade 1930-39 is selected for calculation of ablation relations rather than the decade 1939-48 which would include the period of actual study. One of the unfortunate by-products of glacial-meteorology may be the tendency to substitute calculations from data at nearby meteorological stations for actual observations on the glacier.

These are relatively minor points. This is a thorough and competent scientific work. It carries the study of glacial-meteorology to a higher degree of development and perfection by building firmly upon earlier pioneering efforts. Certain concepts of ablation held heretofore are confirmed and strengthened, others are refined or altered, and some are demonstrated to be fallacious. Glaciologists in English-speaking countries will deeply appreciate Dr. Wallén's presenting his work in such excellent English.

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