CHANGES OF THE TRIGLAV GLACIER IN THE 1955-94 PERIOD IN THE LIGHT OF CLIMATIC INDICATORS

SPREMEMBE NA TRIGLAVSKEM LEDENIKU 1955-1994 V LUČI KLIMATSKIH POKAZATELJEV

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The retreat of the Triglav glacier (the Julian Alps, Slovenia, between 2550 and 2400 m above sea level) in the past half century coincides, above all, with the decline of October precipitations, thus, with the quantity of snow in the accumulation season of the glacier. Among all climatic elements, summer temperatures and maximum daily temperatures in the months from May to September of the 1954-94 period are the ones that are statistically most closely correlated with the retreat of the glacier's lower end and the thickness of ice. This was established on the basis of annual records about changes in the glacier since 1946, and date of the Kredarica meteorologic station (2514 m) lying at 300 m distance from the glacier. Due to the extreme increase in summer temperatures in the last decade, particularly in the years 1993 and 1994, the glacier, which spread over 45 hectares in the eighties of the past century, has retreated to approx. 4 hectares and the structure of ice has changed.

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Spremembe na Triglavskem ledeniku 1955-1994 v luči klimatskih pokazateljev

Nazadovanje Triglavskega ledenika (Julijske Alpe, Slovenija, med 2550 in 2400 m n.v.) od sedemdesetih let preteklega stoletja dalje sovpada predvsem z zmanjšanjem oktobrskih padavin in s tem količine snega v redilni ledeniški dobi. Med vsemi klimatskimi prvinami dosežejo največjo statistično pomembnost z nihanjem ledeniškega konca poletne temperature in maksimalne dnevne tempereture mesecev od maja do septembra. To je bilo ugotovljeno na osnovi letnega merjenja konca ledenika po l. 1946 in podatkov vremenske postaje Kredarica (2514 m), ki leži 300 m stran od ledenika. Zaradi izjemnega porasta poletnih temperatur v tem desetletju, posebno pa v letih 1993 in 1994, se je ledenik, ki je v osemdesetih letih preteklega stoletja meril 45 ha, skrčil na okoli 4 ha in spremenil sestavo ledu.

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INTRODUCTION

On older lists of glaciers in the Alps, three small glaciers are registered at the southeast margin of the Eastern Alps. One of these is the glacier in the Kanin Mts, lying on the Italian

territory, very close to the border with the new state of Slovenia which runs along the 3 km long ridge Visoki Kanin (2587 m)-Prestreljenik (2499 m). In the eighties of the past century, when it was still one continuous glacier, its size was 133 hectares (Desio, 1927). Afterwards, already divided into several icefields on the shady side below the ridge, it disintegrated into smaller icefields in the upper part of the Kanin plateaux (Kaninski podi) by 1994.

The smallest is the glacier on the north-facing slope of the main ridge in the Kamnik and Savinja Alps (Kamniško-Savinjske Alpe). It lies below the peaks of Skuta (2532 m) and Kranjska Rinka (2453 m), caught between the steep slopes in the narrow cirque. Because of the shade, it has been preserved in the altitude between 2160 m and 2000 m. Like in some previous years, it also retreated in the dry 1993 and 1994 years even deeper into the upper cirque and disclosed the darker stratified ice (Archives of the GIAM ZRC SAZU).

A third one is the Triglav glacier which has a similar location as the Kanin glacier, i.e. on the north-facing slope of the 3/4 km long crest between Mt. Mali Triglav (2738 m) and Mt. Veliki Triglav (2864 m) on the upper edge of the Triglav plateaux (Triglavski podi) (see the survey map!). The Geographic Institute at the Center of Scientific Research of the Slovene Academy of Sciences and Arts (GI ZRC SAZU) in Ljubljana has each year since 1946 performed measurements of the changes in the glacier surface. In 1954, Kredarica, a meteorologic station of higher rank, began to operate at a distance of 300 m from the lateral end of the Triglav glacier. It is located at the altitude of 2514 m, which is at the upper half of the glacier, the upper end of which lies at 2550 m, and the lower end at 2400 m. The station by the glacier represents a challenge to the statistical calculations of changes of the glacier's size in the light of climatic fluctuations which is the subject of this paper.

In the nineties of this century this small glacier retreated to the critical size and disclosed the bedrock which had not been visible until then. If the present climatic conditions prove to be exceptional, and after some years the glacier resumes its "usual" size, it is necessary to register the current situation and analyse the bedrock which might be withdrawn for decades from geomorphological analyses by the freshly advancing glacier. If it completely retreats, i.e. disappears, this study retains its significance for the knowledge about geo-ecological conditions in shady, lee locations in high mountains.

THE REPRESENTATIVENESS OF CLIMATIC INDICATORS REGISTERED AT THE KREDARICA METEOROLOGIC STATION FOR THE GLACIER CONDITIONS

INSOLATION

Since the "elevated" (by mountains) horizon was taken into account at the Kredarica station which is, in the time of the low position of the sun, in the shadow behind the Triglav ridge (Klimatografija..., 1991, 3), more solar hours were ascribed to it than it had in fact. However, because the radiation energy is low then (see Table 3), this correction is irrelevant. Namely, winter insolation energy amounts but to 12% of the annual quantity, and its sum in the ablation season of the glacier (May-September) amounts to 82% (Hočevar et al., 1982).

It is surprising that, in the annual average, Kredarica has less solar hours (1787 hours) than the lower nearby mountains and even the valley station Rateče-Planica (1904 hours). In summer, the difference is above the average (Kredarica - 541 hours, Rateče - 684 hours) and in this season, even the Bohinj basin has more solar hours (Stara Fužina - 582 hours). This difference is mainly caused by mountainous clouds which are, when covering Kredarica, registered as fog, otherwise as cloudiness. The average summer cloudiness at Kredarica is just a little higher (6.4 tenths of the sky) than at Komna (5.8 tenths) or in Stara Fužina (6.3 tenths), but it occurs mostly at the time when the sun provides the greatest quantities of energy, i.e. at noon and in the early afternoon hours.

The duration of insolation is important for the glacier balance, above all in the melting season (May-September). Therefore, only this season is taken into account in the following table.

Table 1 - Hours of insolation and cloudiness from May to September at the Kredarica meteorologic station (1955-1994).

Tabela 1 - Ure sončnega sevanja in oblačnost od maja do septembra na postaji Kredarica (1955-1994).

	May	June	July	Aug.	Sep.	Total
Hours of insolation	158	178	208	196	153	903
Monthly cloudiness, 7 a.m.	6.3	6.2	4.9	5.0	5.2	5.5
" " 2 p.m.	7.9	7.9	7.5	7.3	6.5	7.4
" " 9 p.m.	6.8	6.7	6.2	5.3	4.9	6.0
Number of clear days	1.7	0.8	1.7	3.1	5.6	13
Number of cloudy days	11.7	8.9	8.4	8.6	8.5	46
Days with fog	21.3	19.5	18.5	18.0	16.7	94

Note: Clear day - when cloudiness is below 2/10 of the sky; cloudy day - above 8/10 of the sky are covered with clouds. Cloudiness is measured in tenths of the sky.

In all months, cloudiness is greater at 2 p.m. than at 7 a.m. or 9 p.m., which is, above all, due to the "cloud cap" above the Triglav ridge.

The glacier receives significantly less hours of insolation and less solar energy than the Kredarica station which is on the top of the ridge. The glacier is periodically shaded by the three nearby elevations. A first one is the Kredarica elevation with the northeast orientation. Its altitude increases in the same direction, i.e. from the contact with the Mali Triglav massif (peak - 2541 m), while the altitude of the glacier decreases in the opposite direction. Therefore, the shadow cast by the ridge is larger on the lower part of the glacier. This is not emphasized enough on the otherwise good sketch of the glacier's shadiness, made by a cartographer Vilko Finžgar (in: Meze, 1955, fig. 25). Between the spring and autumn equinoxes, when the sun rises north from the East, the upper part of the glacier receives rather considerable amount of insolation in the morning because the Triglav ridge runs, together with the north-facing slope, in the SSE-NNW direction (declination from the W-E direction is 20°C).

Major shadow is cast by the ridge running between Mali Triglav (1738 m) and Veliki Triglav (1864 m). At noon when in summer the sun reaches its highest position, no shadow falls on the glacier; however, it rapidly spreads in the afternoon hours over its entire upper half (see the above mentioned sketch). Since the glacier's surface is inclined northwards, mainly by 20 to 30°C, the angle of incidence of solar rays at noon in summer solstice amounts only to 37-47°, and in equinoxes, between 14 and 23°. Therefore, the insolation energy is reduced, particularly if albedo is taken into account, although the short-wave diffused radiation is relatively greater in the mountains in the slightly cloudy and foggy conditions. (See the discussion on the impact of climate on the glacier budget between dr. V. Manohin and I. Gams, 1959).

In the afternoon, when the sun is low, the shadow is cast on the glacier also by the ridge oriented from Veliki Triglav towards Kugy's shelf (Kugyjeva polica) on Triglav North Face (Severna Triglavska stena), with the altitude point of 2665 m on more detailed maps. Due to the NNW direction, the evening shadow in spring and autumn spreads over the northwest glacier. The rays of the summer evening sun have a relatively bigger angle of incidence here than on the eastern edge of the glacier (now a scree) which extends upwards to the foot of the Kredarica ridge.

In May, Kredarica receives 158 hours of insolation which is slightly more than in September, but the energy of radiation in May (see Table 3) is greater (138 kWh/m^2) than in summer months (Hočevar et al., 1982). Since all the snow fallen in May and some of the older snow, too, melts in May -- in the average of the 1954-94 period, the absolute depth of snow cover has already reduced -- it is ranked to the ablation season even though its average temperature is -0.2°C, and in 22 days the temparature drops below 0.0°C.

TEMPERATURE CONDITIONS

The averages measured in the 1961-1990 period at the Kredarica station are comprised in Table 2. (after: Klimatografija, 1988; Archives).

Table 2 - Averages of monthly mean temperatures in the melting season.
Tabela 2 - Povprečni mesečni povprečki v ablacijski dobi.

	May	June	July	Aug.	Sept.	V-IX	Annual
Monthly mean temperature	-0.2	3.3	5.8	5.8	3.8	3.7	-1.7
Daily mean minimum temp.	-2.5	1.0	3.3	3.4	1.4	1.3	-4.2
Daily mean maximum temp.	2.3	5.9	8.8	8.7	6.7	6.5	1.2
Absolute maximum temp.	14.0	16.3	21.3	18.1	18.4	21.3	21.6
Absolute minimum temp.	-9.6	-6.1	-6.0	-9.8	-15.6	-15.6	-28.3
No. of days below 0.0 deg C	22.7	11.6	5.8	5.0	10.0	55.1	249.2

Since the Kredarica station lies at the altitude of 2514 m, delay occurs and so, February is colder than January, August is as warm as July, and September by 4.0°C warmer than May.

Since this station is located on the top of a ridge, and therefore more windy, its temperatures are slightly lower than on the less windy, lee location. But in the time of calms -- the average number of days with registered calms is 19 per month, the greatest number (25.9 days) in August -- the near-to-surface layer of air on the glacier frequently drifts downwards because it is heavier and so cooler air drops on the glacier from the cooler surrounding slopes.

According to Melik (1959, p. 157), in the fifties of this century the permanent snow line on Triglav was on 2550 m above sea level, which is 36 m above the meteorologic station. The average temperature of 3.7°C in months of ablation and the average temperature of 5.0°C in summer months would rank Kredarica among the warmest stations by the snow line. With the annual temperature of -1.7°C it would rank somewhere in the middle between the warmest and the coldest ones (see: Wilchelm, 1975, pp. 99-104, and Gams, 1959, p.137). But, besides temperature, total amount of snow precipitations and insolation are important. Although the glacier gets extra snow, the temperature of the warmest month (which is supposed to be equal on the climatic snow line from the North pole to 30°C of the North latitude, i.e. 4.5°C/Wilchelm, 1975/) at Kredarica seems to be too high, i.e. 5.8°C. In most of the post-war years, the snow line was supposed to be at about 2700 m (Gams, 1960).

PRECIPITATIONS

In contrast to temperatures, which are important for the survival of the glacier above all in the ablation season, the total amount and the form of precipitations are important all year round. Therefore the table below comprises data for all months (acc. to the source: Klimatografija, 1989; Archives; solar energy - acc.to Hočevar et al., 1982).

The smaller annual amount of precipitations at Kredarica than at the lower south margin of the Julian Alps is interpreted by certain authors: due to the wind, not all precipitations are caught in rain gauge. The proof that this circumstance does not essentially reduce the annual sum is offered by the annual amount of precipitations measured on the profile extending from the southern edge to the highest, i.e. central part of the Julian Alps. On the north-facing slope of the Bukovske gore (i.e. mountains south of Bohinj) totalizators collected over 3500 mm, 2393 mm at Komna (altitude - 1520 m, 1931-60 period), at the basin station of Stara Fužina 2332 mm (1961-90 period), at Mrzli studenec on Pokljuka 2122 mm (1931-60 period), and 1996 mm at Kredarica. Precipitations decrease northwards irrespective of the altitude of the station. The same can be seen in the valley of Trenta: Lepena - 3077 mm (altitude - 480 m, 1951-80 period), the source of the Soča - 2383 mm (880 m).

But it is questionable whether the same precipitation conditions as registered at the Kredarica station apply to the glacier. The majority of precipitations fall in cyclonic weather conditions with increased windyness. Due to the NNW-SSE direction of the Triglav crest the prevailing west winds change their direction. Southwest wind rounds Mali Triglav and

Table 3 - Precipitations, wind and insolation energy (1951-80).
Tabela 3 - Padavine, veter in energija sončnega obsevanja (1951-80).

	1	2	3	4	5	6	7	8	9	10	11	12	1-12
Total monthly precipitation in mm Vsota mesečnih padavin v mm	104	98	124	152	169	214	204	227	197	187	204	12	1955
No. of days with >0.1mm of precip. Št.dni s padavinami >0,1 mm	10	10	12	14	15	16	14	3	10	9	11	10	136
No. of days with >0.1mm of rain Št.dni z dežjem >0,1 mm	0	0	0	1	7	14	15	13	9	6	2	0	68
No. of days with snow cover at 7a.m. Št. dni s snežno odejo ob 7.uri	31	28	31	30	31	25	8	2	6	16	26	31	262
Maximum depth of snow cover in cm Maksimalna višina snežne odeje	434	521	588	690	630	422	438	30	95	198	254	310	690
Relative moisture in % Relativna vlaga v %	71	73	77	83	84	83	81	81	76	70	71	69	77
Calms, % Kalme, %	14	15	14	19	20	22	23	26	23	21	15	14	19
Days with wind of 8 Beaufort Dnevi z vetrom 8 in Beaufortov	11	7	8	5	4	3	3	2	3	5	9	11	73
SE wind frequency, % Pogostost JV vetra, %	19	22	18	24	26	22	21	24	22	27	24	20	22
NW wind frequency, % Pogostost SZ vetra, %	41	40	39	32	30	33	37	33	36	33	37	43	36
Insolation energy in kWh/m² Energija sončnega obsev.v kWh/m²	42	56	92	109	138	135	133	114	99	79	43	35	1074

Note: Since tenths have been omitted, the annual amount does not equal the sum of individual months.

Opomba: Ker so izpuščene desetinke, letna vsota ni enaka mesečnim seštevkom.

blows across Kredarica as SE wind; over one fifth of annual winds belong to this direction, with the maximum in October and November. The west wind rounds the crest on the north side and blows across Kredarica as NW wind; to the latter, over one third of all winds belong, 41% of them in winter. But the glacier's location is partly in the lee of these winds, particularly behind the crest of Veliki Triglav towards the Kugy shelf (Kugyjeva polica). But this location gets greater quantities of rain and particularly of snow. Due to its location, the meteorologic station registered very low frequency of south wind which supposedly prevails in baric depressions when cold fronts pass, since the Julian Alps receive the majority of precipitations on the southern margin which runs in the W-E direction. And as to these winds, the glacier is even more expressedly in the lee.

The maximum depth of snow cover at Kredarica increases, after the minimum in August, to 95 cm in September, and almost 2 m in October. Then follows a gradual increase until April (690 cm). In May, it already declines by 60 cm, but it declines most in August when it is by 408 cm thinner than in July. Thus, the majority of snow and ice melt in the month which is, as to the number of solar hours, already poorer than July. Yet, August surpasses July in the number of calms, since in August their number is the greatest in the whole year. It is the result of anticyclonic weather conditions which are most frequent in this month.

Out of 68 days with rain (0.1 mm or more), 42 (or 62%) belong to summer months. There are still more days with snow falls than rain in May, which is, again, the result of the dropping temperatures at cyclonic weather. Notwithstanding this, the increased radiation and longer insolation of the glacier reduce the maximum depth of snow cover. These are the averages. In 1956, the snow cover was deepest in June, but the next year, it was in January.

In the 1961-90 period, the snow cover, measured at 7 a.m. at the station, lasted all days in winter and spring months, and as follows: 25 days in June, 7 days in July, 1.6 days in August, 6 days in September, and 25 days in October. However, snow remains longer on the glacier.

In 136 precipitation days, the Kredarica station annually gets 1996 mm of precipitations, or 22 mm/day on the average. If the same is true of snow precipitations (131 days of snow falling), there would be 288 mm of water. Since average temperature in the accumulation season amounts to -5.5°C, dry snow prevails with the density of approx. 0.15. On this basis, the estimation is made of about 8.7 m high annual snow precipitations. Besides, the snow which slides from the surrounding slopes also accumulates on the glacier.

According to the above mentioned Finžgar's sketch of the glacier's shadiness (Meze, 1955, attachment 1), the north-facing slope of the Mali Triglav-Veliki Triglav ridge and the crest running towards the Kugy shelf comprises about 44% of the glacier (of the area from the end of the 1940's, i.e. 12 hectares). Due to the inclination of this slope, about 30°, which approaches the angle at which the uncompacted dry snow slides down, it is understandable that meteorologic surveyors from Kredarica, when making reports on the glacier, and other people, too, reported about the sliding of snow from the surrounding slopes, and avalanches sliding on the glacier (see Meze, 1955; Šifrer, 1963, 1976, 1986), even such ones that prolonged their way further on (Meze, 1955), but the latter are very rare. Only on a moderately inclined shelf below Veliki Triglav peak, more permanent snow can be retained all year round at this altitude of 2700 m. This is the so called Upper Snowfield which disappeared only once in the period surveyed.

Most probably, the amount of accumulated snow on the glacier is by one third greater on account of the sliding snow from the surrounding slopes. Therefore, the snow in the upper edge of the glacier in spring elevates in the form of snow fans in the furrows of the slopes where sliding snow is accumulated.

ANNUAL DATA ON OBSERVATIONS OF THE GLACIER USED FOR THE CALCULATION OF ITS SIZE

Investigators of the Geographical Institute at the Slovenian Academy of Sciences and Arts (now: GIAM ZRC SAZU) made marker signs at the edge of the glacier and began to measure distances of the glacier end in 1946. This was the basis for publishing a sketch of the glacier's size for each year from 1946 to 1952 (Meze, 1955, fig. 22). For the 1954-62 period, the glacier is marked on the photograph with lines for the years 1954, 1958, and 1962 (Šifrer, 1963, p. 190). For the 1963-1973 period, the glacier is also marked on the sketch for the year 1973 (Šifrer, 1976, p. 238), and for the 1974-85 period, also for the year 1983 (Šifrer, 1986, p. 129). Since the snow surface cannot be discerned from the ice surface on these photographs, the size of the glacier cannot be measured.

The size of the glacier for the missing years is not known. However, in the already quoted publications the following sizes of the glacier in hectares are stated:

1946: 12.66 ha	1952: 13.00 ha
1947: 13.90 ha	1954: 12.66 ha
1948: 16.00 ha	1956: 12.40 ha
1949: 13.97 ha	1958: 12.30 ha
1950: 13.29 ha	1962: 12.13 ha
1951: 17.78 ha	1973: 11.90 ha

In the quoted Institute publications, tables are published with the measurement data on the distance of the glacier's edge from marker signs. When the upper edge dropped so much in the fifties and the sixties, that the surveyors could not reach marker signs on the steep slope, tables stated less and less frequently the fluctuation of the upper edge which would be necessary for the calculation of the glacier's size.

First marker signs along the lower end of the glacier were made on the north part of the so called lower snowfield, located northeast and north of Glava elevation (on the names of the glacier's parts, see the next chapter!).

This snowfield filled in the depression which is called the depression of the lower snowfield on our schematic sketch. When this snowfield melted and roches moutonnées were disclosed, the distances of the new edge of the glacier became too big. Therefore, extra marker signs were made on the south-facing sides of the above mentioned roches moutonnées and a line or dot was added to each. In the years 1962-82, distances of the edge of snowfield were measured above all, without establishing whether there was ice under the snow or not. Towards the end of the eighties, the retreating lower end of the glacier broke into several ice belts in between the rocks of the so called central-glacier roches moutonnées and their altered distances from marker signs differed from point to point. The thinning of ice was ever more often registered with minium lines drawn on rock tops. For September 1993 and 1994 when the glacier broke into several icefields, there are no more data on measuring the distances from the too distant lower marker signs. At the eastern edge where the scree was progressing while the ice was thinning, the glacier often narrowed and rubble

Fig. 1 - In a century, the Triglav glacier has retreated, according to observations in the years 1993 and 1994, to approx. one tenth of its former size. It has retreated to the shady location under the Triglav crest only (the size of icefields is drawn according to coloured photographs). The autumn of 1994, when this picture was taken, was extremely unfavourable for the survival of snow and ice, which can be deduced from the fact that Mt. Škrlatica group in the background lacks its usual, permanent snowfields.

Sl. 1 - Po dobrih sto letih se je Triglavski ledenik v letih 1993 in 1994 skrčil na približno eno desetino površine in se umaknil v senčno lego pod greben Triglava (obseg ledišč je vrisan po barvnih fotografiji). Da je bilo jeseni 1994, ko je nastala ta slika, za ohranitev snega in ledu zelo neugodno, vidimo po tem, da je skupina Škrlatice v ozadju brez običajnih trajnih snežišč.

spread (see Šifrer, 1976, p. 238 - sketch of the glacier, and Šifrer, 1963, fig. 36) although the ice most probably remained beneath. On the top of the scree, rock debris often fall from the fissured limestone and roll down the depression below Mali Triglav peak. There runs a path to the mountain along it. On September 24, and 25, 1994, when the author of this paper, accompanied by a research assistant of the GIAM ZRC SAZU, Miha Pavšek, analysed the situation on the glacier, it was possible to discover pure (water) ice at several places by digging into the rubble. Besides, some recent collapses of rubble in the central part of rubble margin disclosed the ice base.

From the available, published materials and from the Archives of the GIAM ZRC SAZU which keeps all documentary materials from 1946 to 1994, it was not possible, due to the above stated reasons, to establish all annual sizes of the glacier, necessary to make comparison with the data from the meteorologic station.

In such situation, notwithstanding the existing photographs of which many show just the size of the snowfield, we had to, while establishing the glacier's fluctuations, rely on data about distances of the lower glacier's end from a certain point where measurement data are best coordinated with the rest of them, and are the most numerous. This is marker sign number 11. Since there is a knickpoint above it in the steep slope of the rocky bedrock, the snow fluctuated but a little in the 1964-71 and 1972-82 periods. Therefore, measurement data for these periods were taken from among the more flexible data of marker 12. Deviations at both marker points were unified to 100%. Some numbers from the published tables for the years 1963-73 (Šifrer, 1963) were rectified with the data from the text. For the rare missing measurements at these marker points interpolations were made on the basis of other data or photographs.

Thus, complete data for 38 years were established, but the distance of more than a hundred meters of the lower edge in 1993 and 1994 was not added, not to over-reduce the previous variations.

THE RESULTS OF STATISTICAL CORRELATION BETWEEN CLIMATE AND SIZE OF THE GLACIER

For the above mentioned climatic averages of the Kredarica station and the annual retreat of the lower end of the glacier, calculations of correlations were made by D. Perko, Ph. D., for which I would like to thank him. He calculated correlations for the changes in distance of the glacier's end from year to year, and afterwards, for the deviation of the glacier's end as to the 1955-92 period's average.

Correlation coefficients of changes at the lower end of the glacier (markers 11 and 12).

	Changes from year to year	Deviation - 38-year average
October-May precipitations	0.1269	0.1846
June-August precipitations	-0.0361	-0.1689
Maximum depth of snow cover	0.0935	-0.1575
Average June-August temperature	-0.4362	-0.5296
Average maximum May-September temperature	-0.3178	-0.2942
Insolation hours	-0.2465	-0.2138

With the 99% confidence level, the correlation between the average summer air temperature and the annual advance or retreat of the glacier's end (-0.4362) is statistically significant. The correlation factor between the summer temperature and the deviation of the glacier's end as to the average over many years amounts to 0.5296. But with 95% confidence level, also the correlation between annual fluctuation of the glacier's end and the average maximum temperature of the May-September season becomes statistically significant. All other correlations are statistically insignificant. Irrelevance of total amount of precipitations in the October-May season can be explained by the fact that we are taking into account the lower end, while quantities of snow precipitations form snow/ice reserves on the upper edge of the glacier. That the summer temperatures are the principal factor of the glacier's fluctuation can be explained by the supposedly 200 m higher snow line in the past decades than the altitude of the Kredarica station is.

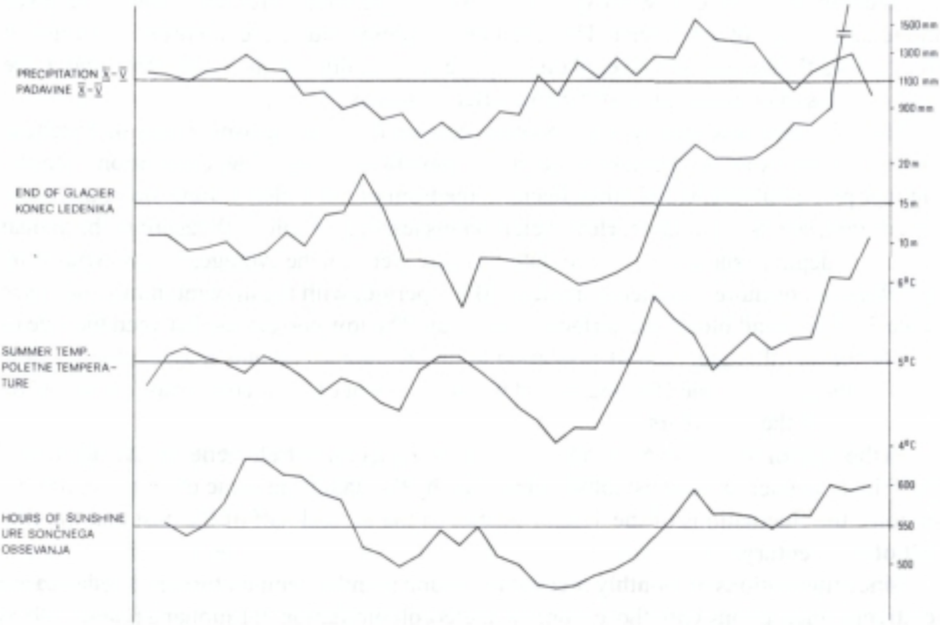
The relatively low statistical correlation derives from the measurements of distances from the markers to the glacier's edge or the snowfield's edge. Low correlation with the summer precipitations, which often occur in the form of snow also in June, but most of the time as rain, seems reasonable. However, it seems less reasonable with regard to the annual maximum depth of snow cover at the station. There were, on the average, 73 days with wind of 8 Beaufort or more, registered in the 1961-90 period, with the maximum in winter (see Table 3). This wind blows the surface snow away. The low correlation between the size of the glacier and the total sum of insolation hours in summer months may be due to snow cover of the glacier in the 1964-82 period when the extent of snow cover was influenced by the surplus of the past years.

In the light of the above mentioned most significant climatic elements for the balance of the Triglav glacier, we can establish, supported by the data from some older meteorologic stations, the fluctuations of the Triglav glacier in the second half of the past and the first half of this century.

Since fluctuations of monthly precipitations and monthly temperatures at Kredarica are relatively sinchronous with those from the meteorologic station in Ljubljana (Gams, 1988) we can come to conclusions about the glacier on the basis of older data from this station; however, considering temperature fluctuations, conclusions can even better be made on the basis of the data from the meteorologic station of Trieste where the growth of the town has lesser impact on the rising of temperatures (Gams-Krevs, 1990; Ogrin, 1994). Regular observations in both stations began in the middle of the past century.

As to precipitations, until the beginning of the 1940's, their October amount, and subsequently also their annual amount, was larger than later. In the 1920's when the glacier was bigger again, October precipitations and annual precipitations were above the average, and concurrently a series of colder summers (Trieste) began, which lasted until the middle of the century. The decline in October precipitations, which at Kredarica mostly appear as snow, can be considered as an important cause of the post-war retreat of the glacier. Another cause was the drop in summer temperatures (particularly in Trieste) below the 150-year average, which lasted until the end of the 1980's.

Several photographs of the Triglav glacier from the inter-war period were published in Kugy's book (1938). Unfortunately, the dates when the photographs had been taken were not stated. The photographs between the pages 1/2, 136/137, 344/345 show a size such as often occurred after World War II, while on the photographs between the pages 48/49, 104/105, the glacier is larger. On the first photograph, the inclination of the surface at the tran-



The lines proceeding from top downwards denote the three-year moving averages for:
Od vrha navzdol si sledijo črte, ki pomenijo triletne drseče sredine za :

- *the amount of precipitations from the previous autumn to the end of spring in the current year, including May and October, on the Kredarica station;*
  - *vsota padavin od prejšnje jeseni do konca spomladi tekočega leta, vključno maj in oktober, na postaji Kredarica,*
- *annual distance of the lower edge of the glacier from marker sign 11. In the years 1962-1982 the distances from marker sign 12 were taken into account, only that deviations from the average were dimensioned upon the deviations from marker sign 11;*
  - *letna oddaljenost spodnjega roba ledenika od markacije št 11. V letih 1962-1982 so upoštevane razdalje od markacije št. 12. s tem, da so bili odkloni od povprečka dimenzionirani po odklonih pri točki 11;*
- *average temperatures of summer months in degrees C (the Kredarica station);*
  - *povprečne temperature poletnih mesecev v stop.C (postaja Kredarica);*
- *the sum of insolation hours in summer months at the Kredarica station;*
  - *vsota ur s sončnim obsevanjem v poletnih mesecih na postaji Kredarica.*

sition of the central glacier's roche moutonnée is essentially steeper than the lower part of the glacier where a gentle step occurs. Better than on the photograph reproduction of a Pernhart painting in Meze's article (1955), the steep lower end of the glacier near the peak of the Triglav slope is seen on Kugy's reproduction of another oil painting by the same painter (p.112/113).

To calculate the averages of the 1931-60 series, there were but a few years with surveying data available for Kredarica. As to the interpolations then made for similar stations, it is worth comparing, regardless the small number of years, the averages (Pučnik, 1980; Furlan, 1965) with the 1961-90 series (Archives). This comparison reveals that in the first series the average of precipitations (2149 mm) at Kredarica was by 153 mm higher. During this time, precipitations were lesser mostly in the following months: July-September, November-December, and March-April, and they were more plentiful in the rest of the months. In the accumulation season, 1238 mm fell from October to May in the first series, and only 1157 mm in the second. The average annual temperature was equal in both series, i.e. -1.7°C, but in the 1961-90 period the months from October to February were warmer, and the rest of the months were colder. These precipitation and temperature differences do not testify to worse conditions for the glacier in the recent series, if we disregard the reduced October and May precipitations.

A stronger correlation than the one mentioned above, calculated from the fluctuations of climatic elements and the changes of the lower end of the glacier, is presented on the diagrams of the three-year moving averages (the sketch) of the 1955-94 series. Parallels can be observed between the fluctuations of the distance of the lower end of the glacier from the marker sign 11 (in the 1964-82 years, marker 12) and the fluctuations of summer temperatures and insolation hours. Until the beginning of the eighties, summer temperatures were below the average, except for the average temperatures in the years towards the end of the fifties and at the beginning of the sixties. Similar is the trend of insolation hours. The congruence of summer temperatures and insolation hours is particularly increased by the frequency of summer anticyclonic weather when the air is dry and the temperature at the altitude of Kredarica (2500 m) is above the average (Gams, 1988). Between 1962 and the end of the seventies summer temperatures were below the average. The size of the glacier follows this with delay. It was at its lowest at the end of the seventies when also the quantity of precipitations and the number of insolation hours were below the average. These are the years when the glacier was, except for two years, covered with snow until autumn. In such conditions the ice thickens under the snow which melts in summer. Therefore we can establish that with the average summer temperature below 4.2°C and the average precipitations in the accumulation season, the glacier is stationary or it even gets thicker. This is not to be necessarily understood that with this, the snow line drops to the middle of the glacier (about 2450 m), for the glacier receives extra snow due to its lee location and snow sliding from the surrounding slopes; besides, it lies in the shadow of the neighbouring elevations, while the snow line is defined on a level, unshaded surface.

In the seventies and at the beginning of the eighties (Šifrer, 1989) it happened several times that the snow cover on the glacier thickened, while in the second half of the eighties the ice in the base thinned. This was the result of the increased summer temperatures. The average summer temperature at Kredarica in the 1961-90 series was 5.0°C, and in the 1981-90 series, it was 5.4°C.

In the nineties, the size of the Triglav glacier has come to its lowest in the past century and a half. Climatic averages for the 1992-94 and 1961-90 years are as follows:

	1961-90	1992-94	1992-94/ 1961-90
Precipitations October-May	1156 mm	1167 mm	101
Precipitations June-August	642 mm	645 mm	100
Maximum depth of snow I-XII	690 cm	318 cm	42
Insolation hours VI-VIII	177	197	111
Temperatures VI-VIII, °C	5.0	6.6	132
Temperatures in May, °C	-0.2	+1.6	
Daily maximum temperatures, V-IX (°C)	7.3	7.5	103

The years 1992-94 are characteristic, if compared with the 1961-90 series, for warmer and sunnier summers and considerably warmer May and low annual maximum of snow depth. The combination of much warmer months from May to August and average precipitations in the accumulation season occured for the first time in the 1992-94 period in three consecutive years, since before this, warmer summers had usually coincided with greater quantity of precipitations in the accumulation season. The average temperature in May 1991, when the glacier thickened, was -3.7°C, and in the following years, between 0.9 and 1.8°C. Thus the season of intense ice melting began a whole month earlier. The average daily maximum temperature in May was 2.3°C in the 1961-90 period, and 3.5°C in the years 1992-94. Hence, the extremely low maximum annual depth of snow (205 cm) in 1993.

The unfavourable beginning of the nineties was interrupted by precipitations in the accumulation season between October 1990 and May 1991 (1705 mm), when the ice at the lower end of the upper icefield thickened by 1.7 m if compared with the previous year.

On the almost vertical 3.4 m high slope of the roche moutonée in the middle of the lower edge of the upper icefield, ice levels were marked in the 1987-94 period, which show the following changes in the thickness of ice from year to year:

1988-1989: decline by 40 cm
1989-1990: decline by 26 cm
1990-1991: increase by 172 cm
1991-1992: decline by 143 cm
1992-1993: decline by 163 cm
1993-1994: decline by 10 cm

The greatest disintegration of the glacier took place in the 1987/88, 1991/92, and 1992/93 glacier years, and this situation did not improve in the next two years. Upon the estimated size of about 4 hectares, the Triglav glacier together with its eastern scree, hardly deserves to be called a glacier. Since the ice retreated from the plateaux, the glacier has had an explicit piedmont location in the shelter of the Triglav slopes. Together with this, the significance of avalanches for the glacier budget has increased and the glacier is acquiring ever more explicitly the features of an avalanche-type glacier (in the sense of Wilchelm, 1975, p.135).

Fig. 2 - On the rock in the background, the lines and year numbers show the thinning of ice at the contact of the upper icefield and central-glacier roches moutonées: gradual decline between 1987 and 1990 (this number is more to the right), then increase until 1991, and decline again until 1993 (marker sign in the middle of the picture is on the lower roche moutonée by the ice which is in the lower half of the picture dissected with water grooves and tossed with rubble). The roches moutonées are evidently well polished.

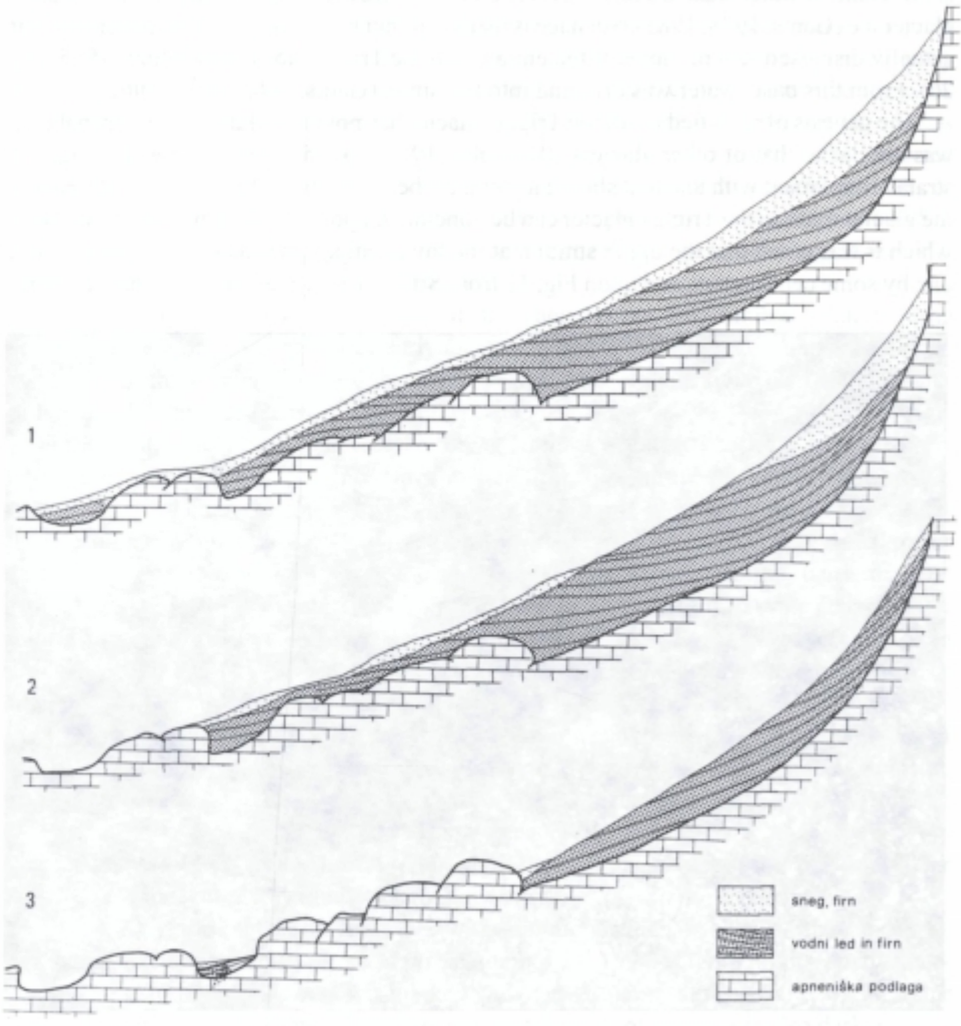
Sl. 2 - Na skali v ozadju je po črtah in letnicah vidno tanjšanje ledu na stiku zgornjega ledišča in srednjeledeniških grbin: postopen upad med leti 1987 in 1990 (ta letnica je nekoliko bolj desno), nato narast do l.1991, nakar sledi upad do l.1993 (markacija sredi slike na nižji grbini ob ledu, ki je v spodnji polovici slike razbrazdan z vodnimi žlebi in posejan z gruščem). Opazna je izglajenost skalnih grbin.

We do not know whether the worst combination of low precipitations in the accumulation season and high temperatures with high number of insolation hours in the melting season is going to continue. As the size of the glacier after the accumulation season of 1993-94 with above average precipitations (1336 mm) is but little changed from the previous year, it seems that with such precipitations and so extremely high summer temperatures as 7.9°C, the upper icefield is almost stationary. An equally warm summer with only average precipitations would make the matter even worse. As the ice thickness in the upper icefield probably does not exceed 10 m, it would retreat further. With the possible "improvement" of the climate, it would take many years to cover central-glacier roches moutonées with the impermeable ice base formed from the melted snow cover each year. This would consequently accelerate the thickening of ice and thus the advance of the glacier to its former size.

CHANGES IN THE STRUCTURE OF THE GLACIER'S MASS

North of the glacier, there are two concaves at the edge of the Triglavski podi (the Triglav plateaux). In the first one, which is closer to the glacier, snowfield still occurred periodically even after World War II, and along its sides, surveyors made first marker signs. Over this depression the ice was still flowing in the second half of the past century towards the Triglav face, above which moraines are preserved north of Glava hill. Close to the then totalizator, rubble of the lateral moraine collapsed in 1962 into a 7 m deep abyss (Gams, 1957). Up to this point, most probably the glacier advanced in 1876; calculating from a map, Richter (1888) assigned it the size of 45.9 hectares. To check this number, we have drawn on a topographic map of 1:10,000 a glacier which also covers the rock shelves under Veliki Triglav -- i.e. the bright rocky surfaces under the Triglav crest and the ridge of Kredarica which were already defined by Šifrer (1963) as the highest level of the glacier in the mid-past-century -- and also the two above mentioned concaves on the border plateau. The size of the glacier we have got thus was 35.6 hectares (see also the situation map!). It might well be the size from the middle of the past century when also the Carinthian glaciers were large in size (Lang-Lieb, 1993).

No data on structure of the ice in the past century are known, nor can we make any conclusions from the oldest oil painting by Pernhart, possibly made around 1860 (see Meze, 1955, fig. 14a), as to where we could place the ice of the glacier in the course of diagenesis of snow crystals and further on in the diagenesis of firn - glacier ice, or, snow - water ice. From the photograph by Pavel Kunaver taken in 1924 (see Meze, 1955, fig.11) no stratified structure of the glacier, characteristic of recent times, can be seen along its longitudinal crevasses. This structure with the typical stripes on the glacier running west-east is visible already in 1947 (see Meze, 1955, fig.18), and also later on whenever the ice was disclosed from the snow cover. Such stratified ice is of darker, greenish-bluish colour. This colour was probably the origin of the popular name given to the glacier - the Green Snow. This darker ice is denser than the old firn or névé. Measurements of density in 1994 were performed by means of a bowl of water into which a lump of ice was dipped, and its volume



was measured on the basis of the risen level of water and after it, the same lump of ice was weighed. In summer 1981 the densities of two samples were 0.9 and 0.97. The compacted old snow on the glacier had the density of 0.83 and 0.88 at the end of August 1982 (Gams, 1982, 1983, p. 248; Šifrer, 1986, p. 120). On September 24 and 25, 1994, densities of 0.95 and 0.93 were measured at the lower edge of the upper icefield, west of the 2247 m point, and 0.86 under the rubble in the collapse under the water pump beneath Kredarica. The former two densities surpass the characteristic density of firn (which is 0.8-0.85) and the density, characteristic of glacier ice (i.e. 0.91 - Wilchelm, 1975, p.135). They are closer to the density of water ice. The genesis of such mass is supposed to be a result of the melting of surface snow, water penetration to the impermeable basis, the flow over it and periodical freezing of water soaked snow mass. Therefore, there are fewer air bubbles in it than in glacier ice (Gams, 1978, 1983). Such ice is usually found in the base of snow cover and was actually disclosed several times at the entrance to the Triglav abyss (see Meze, 1955, fig. 20). From this base, water was dripping into the abyss (Gams, 1963, 1957, 1962).

The genesis of stratified ice of the Triglav glacier has not been clarified yet. Probably, it was similar to that of other glaciers (Wilchelm, 1972, pp. 159-160), where the origin of strata is explained with unequal sliding at contacts between strata. Such sliding of strata of the glacier mass in the Triglav glacier can be concluded upon rare personal observations in which it was noted that the upper stratum at the lower edge was projecting over the lower one by some centimeters, and upon Fig. 11 from Šifrer (1976, p. 225), where darker bands

Fig. 3 - On the part of the lower icefield (the picture of which was taken on September 24, 1994), there is ice (seen in the middle of the upper third of the photograph), tossed with and partly covered with rubble. Since glacier water deposits humus particles on the soaked snow, the ice is separated from the snow with a dark band. When it freezes at night, it gradually changes into more or less dense water-ice.

Sl. 3 - Na upodobljenem delu spodnjega ledišča (24. sept. 1994) je sredi zgornje tretjine fotografije led, posejan in delno prekrit z gruščem. Ker na premočen sneg ledeniška voda odlaga humusne delce, loči led in sneg temna lisa. Kadar ponoči zmrzne, se spremeni v bolj ali manj gost vodni led.

which mark the ends of individual strata slightly undulate above the obstacle - an isolated roche moutonée. The bands normally run in the west-east direction, and they usually curve most strongly downwards in the western part of the glacier where the upper icefield depression is the widest. The unequal sliding of the upper ice strata has also been demonstrated by the recent, mostly unsuccessful experiments with the iron marker poles hammered into the ice, which were ejected next summer (Meze, 1955, 29/30). The movement of the ice has also been confirmed by the coloured stones which were, wrapped in the PVC foil, inserted on the glacier's surface in two profiles in the west-east direction. Between the summers of 1981 and 1982, the stones moved downward in the lower profile of the glacier, from 0.45 to 2.85 m (by 1.6 m on average). In the upper profile the result was void since stones slid unequally over the steeper surface (Gams, 1983).

The melting of snow on the surface of the glacier is not only limited to the melting season. In clear, late September or early October days with warm noons and cold nights, surveyors of the glacier observed that water murmur under the snow cover of the glacier only ceased to be heard late in the evening.

The average daily minimum temperature at Kredarica amounts to 1.4°C in September, and the maximum 6.7°C. The most favourable climatic conditions necessary to form ice occur in May when the average daily minimum temperature is -2.5°C, and the maximum is 2.3°C, and at that time, the sun is already strong (see tables 1,2,3). A considerable number of days with positive maximums occur, besides in October and in spring, particularly in April, when the mean daily maximum temperature amounts to 1.8°C. At the peak of daily temperature and insolation the surface snow intensely melts, and during the night or in colder weather this water freezes on the cooler basis. In late summer, when the weather is anticyclonic, less water freezes because most of it is drained into the rocky base.

On larger glaciers snow water percolates deep into snow, forming water envelopes of snow, firn, and ice grains, and accelerates the formation of firn and glacier ice (Paterson, 1969). Such transformation of snow into glacier ice, under the greater pressure of the upper masses, takes several decades or hundreds of years (Wilchelm, 1975, p. 137). The Triglav glacier is thin, therefore there are no required pressures of the upper masses and the glacier mass regenerates relatively rapidly by melting snow.

Fig. 3 shows the contact of ice surface with snowfield which is soaked with water flowing over the ice of the lower icefield on September 24, 1994. In cold nights, such water-soaked snow freezes. The contact is marked with darker humus dust particles which water keeps depositing on the snow. Therefore, the stratified ice of the base is also darker.

On the uncovered darker ice whose albedo intensely lags behind the albedo of fresh, white snow, ablation absolutely prevails in summer. Water accumulated to form streams cuts deep gullies (half a meter or even more) into the ice, exceptionally also holes, the latter most probably in the crack where it reaches the rocky base.

The experiences gained by surveying the glacier in melting season when flowing water was gurgling under the rubble cover, have been supported by collapses as they were seen in September 1994. When the roche moutonée with the 2472 m point poked up through the ice, a more permanent stream began to flow onto it from the ice under the rubble, which was used as water supply to the neighbouring mountain hut for several years. The collapse which occurred lower down on the scree and closer to the slope of Kredarica allowed the access to the rock over which the water was flowing with an estimated discharge of 0.1 l/sec. It undoubtedly originated from the ice under the rubble in higher locations. Namely, the rubble on the surface receives more solar energy because it is of darker colour than the snow. Cool spells in May and June, partly also later, intensely cooled this rubble well under 0°C. When later on rainwater percolates through it, it freezes. Therefore, the ice under screes is not necessarily the fossil glacier ice.

As to the changes of the glacier mass under Triglav three periods can be discerned. In the second half of the past century the glacier most probably consisted of firn or glacier ice, but there are no data on the existence of darker ice. In the post-war period 1946-88, it consisted above all of darker ice in the base covered with snow; in accordance with the climate, the former occured as an island in this snowfield, or, in "drier" years, it was sometimes completely disclosed on the entire surface. In the nineties, also this ice base of the glacier disintegrated.

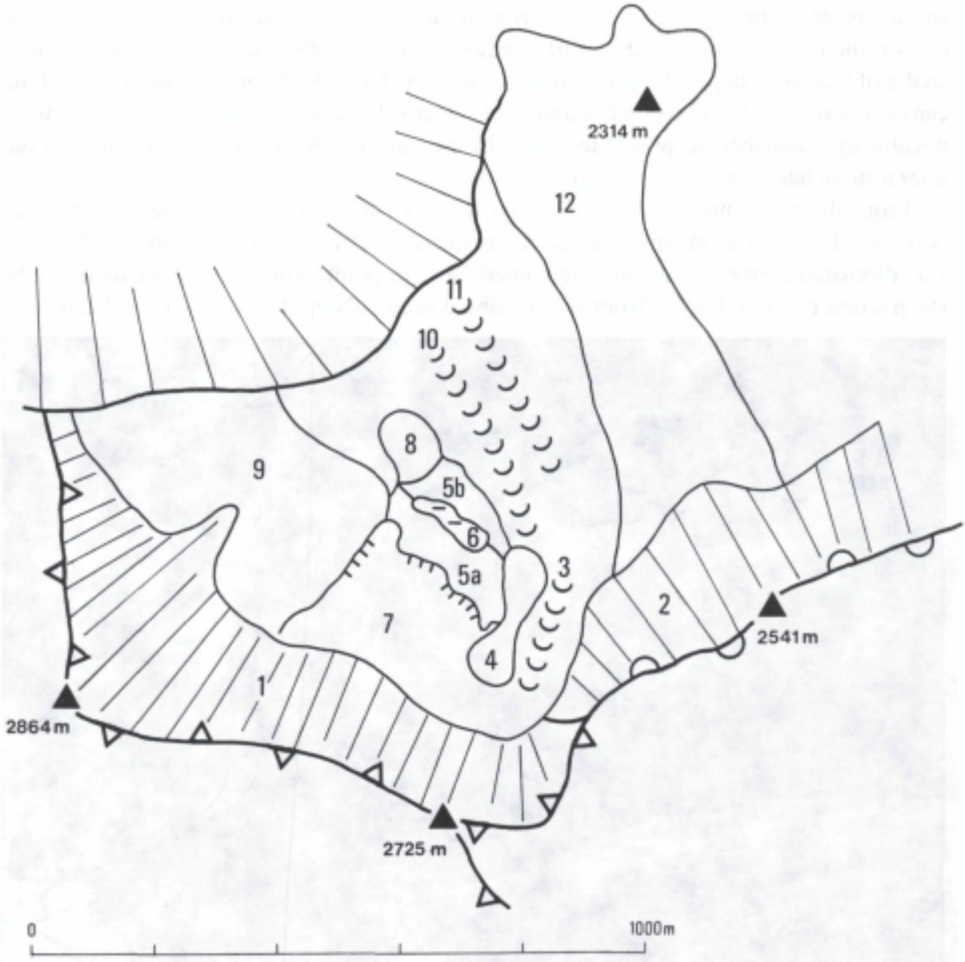
BEDROCK RELIEF UNDER THE GLACIER

It entirely consists of lower Triassic rock, the so called Triglav unstratified limestone. The numbered geomorphologic units on a special sketch have the characteristics as follows.

In the summers of 1993 and 1994 (the photographs no. 4 and 5 were taken in 1994) it was for the first time after the beginning of annual surveyance (in 1946) that the contours were laid bare of the lower end of the so called upper glacier depression (7). The greater distance between the lower edge and the Triglav slopes is in the western part. In the central part it is at a distance of 137 m from marker point 14. The bottom is unknown since it was covered with ice even in September 1994. It can be concluded from the conditions on the glacier that the ice gets thinner in the direction towards the slopes of Triglav. In September 1994, the glacier's surface was not curved upwards, as had been the case in previous years. Judging from this, the bedrock has lesser inclination in the central part and at the lower end than the average of the entire icefield (29 °s) is. On September 24, 1994, all the water from the glacier sank at the lower end. The water which comes running down the rocky slopes in rainy weather, flows over the rock under the glacier, too, all to the first fissure or abyss. At the lower end of the icefield, 1 to 3.5 m higher rock surface rises, which starts a series of unequally high roches moutonees (5a).

The bedrock is also unknown of the eastern under-glacier depression (number 3 on the sketch), which lies at the foot of Kredarica.

The rest of under-glacier bedrock primarily consists of chaotic clusters of roches moutonées. Abraded tops of higher rocks are the common characteristic where on polished surfaces shallow scratches (striations) occur in the direction of ice movement, i.e. in the direction of the greatest inclination (N). The rock is more polished and scratched in the western part than in the eastern part. We did not see scratched rubble, since it is undersized. In between higher roches moutonées there are lower depressions oriented downwards; the



Geomorphologic units of the under-glacier bedrock relief.
Geomorfološke enote podledeniškega skalnega reliefa.

1-2 - the slope of rock elevations shading the glacier
- pobočje skalnih vzpetin, ki senčijo ledenik

3 - the eastern, now the scree depression
- vzhodna, zdaj meliščna ulegnina

4 - the eastern roches moutonées
- vzhodne grbine

5a - the central glacier roches moutonées
- srednjeledeniške grbine

5b - the lower-glacier roches moutonées
- spodnjeledeniške grbine

6 - the lower icefield basin
- kotanja spodnjega ledišča

7 - the upper icefield depression
- ulegnina zgornjega ledišča

8 - Glava hill
- grič Glava

9 - the western rock shelves
- zahodne skalne police

10 - the lower snowfield depression
- ulegnina spodnjega snežišča

11 - the outer snowfield depression
- ulegnina vnanjega snežišča

12 - the ridge of Velike Glave
- hrbet Velikih glav

surface is less abraded here. In the transversal direction, i.e. in the W-E direction of rock cracks, there are narrower grooves of unequal width, with rubble at the bottom. Several shafts of unknown depths lie open on their bottoms. They slant northwards so that rubble can accumulate on their less inclined southern slopes. Because of their inclination we were not able to establish the depths of the shafts by measuring the echoing time from the bottom after a stone had been thrown down.

From all roches moutonées, the first one to appear from under the glacier was the rock with the 2472 m point on top of east glacier roches moutonées (4). In 1993 and 1994, a rock was disclosed above the already mentioned 2472 m point, which continues towards the steep slope of Mali Triglav from which rubble accumulates. In the downward direction

Fig. 4 - Rock shelves beneath Veliki Triglav, uncovered more than ever before in the post-war era (upper right-hand corner), and roches moutonées which separate the upper icefield (in the middle) and the lower icefield (lower right-hand corner; only the marginal snow with its white colour is noticeable). The photograph was taken from the position at the edge of Kredarica the slope of which is seen in the lower left-hand corner. The edge line makes the size of the icefield more distinct.

Sl. 4 - Bolj kot v povojni dobi kadarkoli prej razkrite skalne police pod Velikim Triglavom (desni zgornji kot) in skalne grbine, ki ločijo zgornje (sredi) in spodnje ledišče (na njem izstopa z belo barvo le robni sneg v spodnjem desnem oglu). Fotografirano z roba Kredarice, katere pobočje je vidno v spodnjem levem kotu. Robna črta napravlja obseg ledišča vidnejši.

from that point a belt of roches moutonees, covered with scree, gets wider and is, in general, the highest of the entire under-glacier relief. From it, the biggest cluster of underglacier roches moutonées extends westwards, called central glacier roches moutonées (7). Their inclination towards the north is 31°C. This is more than the surface inclination of the upper icefield was at that time (29°C). Whenever the glacier retreated and was smaller in size in past decades, bulging was seen in this place in the longitudinal profile of the entire glacier. It was especially distinct in 1978 (Šifrer, 1986, p.112, al.11). From among the tops of the central glacier roches moutonées the first ones to be uncovered from under the ice were those at the lower end, i.e. at the knickpoint towards the basin of the lower icefield.

Between the points 16 and 12A the wide basin (6) of the lower icefield sinks from 10 to 20 m into the complex of roches moutonées. In September 1994 it was filled with water ice, the inclination of which on the rubble cover was only a few degrees. Above the lower end

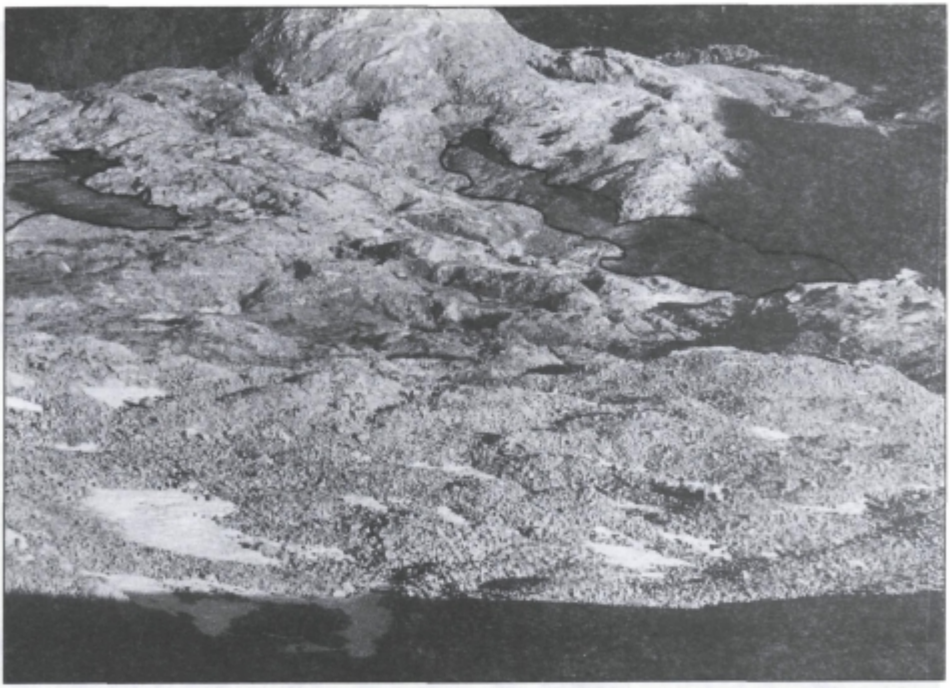


Fig. 5 - The lower third of the picture is occupied with the scree under Mali Triglav. The melting of ice in the rubble basis produces hummocky surface. Behind the scree, there are central under-glacier roches moutonées which first appeared completely from under the ice in autumn 1993 and 1994 (the photograph was taken on September 24, 1994). At the upper edge is Glava hill. The edge of the glacier is highlighted with a line.

Sl. 5 - Spodnjo tretjino zavzema melišče izpod Malega Triglava. Taljenje ledu v podlagi grušča ustvarja kupčasto površje. Za meliščem srednje podledeniške grbine, ki so se jeseni 1993 in 1994 (fotografija iz 24. sept. 1994) prvič v celoti pokazale izpod ledu. Ob gornjem robu grič Glava. Rob ledišča poudarjen s črto.

rises 2-3 m higher lower-glacier cluster of roches moutonées (5b) extending towards Glava hill and northwards. North of point 5A, on the first flat plateaux, there are two valley-like depressions which end near Triglav North Face. They are separated by the less continuous series of roches moutonées. The more to the north, the higher they elevate and end near the Prag knick with point 2314 m of Vzhodne glave. In the south they begin on the slope of Kredarica and are called the ridge of Great Roches Moutonées. The relief there is glaciokarstic; however, the glacial traces are less recent than in both the above mentioned depressions by which there are accumulations of morainic rubble on the rocky slope.

In September 1994, the western rock shelves (9) between the steep slopes of Veliki Triglav and Triglav North Face were completely uncovered from beneath the usual snow (9). The inclination of the surface here is greater than in the rest of the under-glacier relief. Therefore, no darker ice has been uncovered from beneath the snow cover after World War

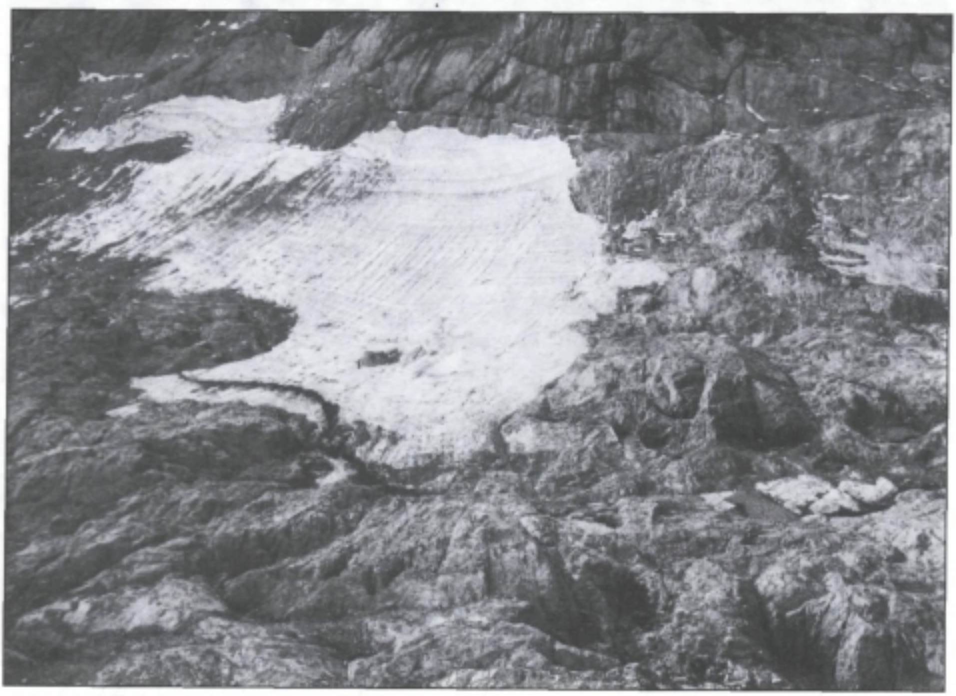


Fig. 6 - The view from Glava hill towards the South where the western part of the glacier is longest. On the rock elevation towards the center of the photograph, there are marker signs denoting the decline of the upper icefield, presented on Fig. 2. The ice on the western edge retreated by 20-30 m from the marker signs made on higher roches moutonées.

Sl. 6 - Slika z Glave proti jugu, kjer je zahodni del ledenika najdaljši. Na skalni izboklini v smeri srede fotografije so markacije o upadu zgornjega ledišča na sl. št.2. Na zahodnem robu se je led odmaknil za 20-30 m od markacij na višjih grbinah.

II here, and this snowfield was not counted as part of the glacier, also because a few rock tops on which marker signs 9 to 5 had been made, poked up from the snow at the eastern edge of smoother rock shelves. They can not yet be seen on the photographs taken in the previous century (see Meze, 1955). In autumn 1994, two snowfields were disclosed below the steep slope, containing a patch of darker water-ice each, similar to the glacier.

Corrosion capacity of the water flowing from the glacier, was established through measuring water streams at the top of Triglav abyss. In 1962 this water had 38 mg of carbonate and calcium hardness and 41 mg $CaCO_3$/l of total hardness which is usual of the surface waters running on barren high mountainous area of the Julian Alps (Gams, 1966). The water ran into the abyss across the rock or from the ice base under the snow at the entrance to it. Because the abyss is under the snow cover in winter, and the warmer air inside it ascends, the summer air temperatures amount to about 0.2 - 0.8°C (Gams, 1962, 1961,

Fig. 7 - From under the glacier above the vertical mouth of the Triglav abyss (lower right-hand corner), several openings to caves of unknown depths occurred among roches moutonees. At the mouth, they mostly slant northwards. They testify to local, accelerated marginal corrosion by the glacier water. 1 (All photographs were taken by I. Gams.)
Sl. 7 - Nad navpičnim ustjem Triglavskega brezna (spodnji desni kot) se je izpod ledenika pojavilo med grbinami še več odprtin v votline neznane globine. Na ustju visijo večidel proti severu. So dokaz lokalno pospešene robne korozije ledeniške vode.1 (Vse fotografije I.Gams).

1963). Such air temperatures can also be expected in the abysses under the glacier into which snow water percolating through the cracks in the ice is drained. If such water flows over the rubble base which is exposed to moist for a longer time, it is substantially harder. The sample of water coming from the ice-and-rubble mass in the central part of the east-glacier depression, taken in the collapse on September 24, 1994, had 81 mg of carbonate and calcium hardness, and 84 mg $CaCO_3$/l of total hardness. The first time that waters from the glacier get into contact with carbonates is under the glacier or at its end. From the area of over 40 hectares such aggressive water drains into rock abysses; on the contact with the ice it moistens rubble and rock, thus corroding them with accelerated speed (Gams, 1962, 1963, 1966). In 1993 and 1994, the abundant water stream from the upper icefield caused the concentration of such local, accelerated corrosion on the lower edge of the upper glacier depression which is deepened there by several meters. Judging from this, we can make a conclusion that the glacier had similar size as it had had in the past centuries. This could have been in the warmer Boreal period in the Holocene epoch, or possibly in the Middle Ages when glaciers had been smaller.

Most of the post-war years, the water from the glacier drained into the bedrock at the lower edge of the lower icefield where an explicit basin is situated in west-east direction, that is to say at the lower end of the glacier. Also here, we can presuppose the existence of a similarly long-lasting glacier in the past, of the size of 12-14 ha as had prevailed in the post-war period.

Translated by Branka Klemenc

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SPREMEMBE NA TRIGLAVSKEM LEDENIKU 1955-1994 V LUČI KLIMATSKIH POKAZATELJEV

Povzetek

UVOD

Geografski inštitut Antona Melika ZRC SAZU od l. 1946 dalje domala vsako leto registrira spremembe na Triglavskem ledeniku, ki je poleg Skutinega ledenika edini na Slovenskem. 300 m vstran od njega deluje v n.v. 2514 m vremenska postaja višjega reda. To nudi v svetu redko priložnost primerjave sprememb klimatskih prvin z letnim spreminjanjem na ledeniku, katerega zgornji rob (v n. v. okoli 2550 m) je malo više in spodnji rob (ok. 2400 m) malo niže od vremenske postaje Kredarica.

Po nekaj neugodnih letih je l. 1993 in 1994 ledenik razpadel na dve ledišči. Če bo v naslednjih letih izginil, je potrebno njegovo dosedanje krčenje osvetliti s klimatskimi spremembami in s tem prispevati k poznavanju ekoloških pogojev visokogorskih osojnih leg vobče. Če bo spet zavzel običajni obseg, ne bo mogoče analizirati zdaj izpod ledu razkritega reliefa, kar je tudi naloga te študije.

Zahvaljujem se sodelavcem GIAM ZRC SAZU: M. Pavšku za pomoč pri delu na ledeniku 24. in 25. septembra 1994, dr. D. Perku za izračun korelacijskih koeficientov, mag. M. Gabrovcu in dr. D. Mezetu za pregled teksta.

V tem slovenskem povzetku je izpuščena podrobnejša dokumentacija, ki je objavljena v angleškem tekstu.

METEOROLOŠKI PODATKI POSTAJE KREDARICA

Povzeti so v glavnem po Arhivu HMZS in zvezkih 1, 2 in 3 Klimatografije Slovenije v izdaji HMZS.

Sončno obsevanje

Tab. 1: Ure sončnega obsevanja in oblačnost v mesecih maj-september 1955-1994.

	Maj	Junij	Julij	Avgust	September	Skupno
Ur sončnega obsevanja	158	179	208	196	153	903
Mesečna oblačnost, 7 h	6,3	6,2	4,9	5,0	5,2	5,5
" " 14 h	7,9	7,9	7,5	7,3	6,5	7,4
" " 21 h	6,8	6,7	6,2	5,3	4,9	6,0
Štev.jasnih dni*	1,7	0,8	1,7	3,1	5,6	13
Štev. oblačnih dni	11,7	8,9	8,4	8,6	8,5	46
Dnevi z meglo	21,3	19,5	18,5	18,0	16,7	94

*Op.: Jasen dan je, ko je oblačnost pod 2/10 neba, oblačen, ko je pokritost neba 8/10 ali več, oboje v desetinkah.

Na Kredarici odpade na mesece maj-september 50 % letnega števila ur s soncem (1787 ur). Toda kalorična vrednost tedanjega sončnega sevanja je po Hočevarju et al., (1982, gl. tab. 3) 82 % letno sprejete sončne energije.

Ure in kalorična vrednost sončnega sevanja so na ledeniku bistveno manjše zaradi zasenčenosti po treh vzpetinah na obrobju. To so greben Veliki (2864 m) - Mali (2738 m) Triglav, njegov stranski greben (ronek) v SSZ smeri proti Kugyjevi polici s koto 2665 m, in zložnejši plečati hrbet Kredarice, ki se dviguje od izpod Malega Triglava proti SV do vrha 2541 m. Obseg sence teh vzpetin je prikazan na skici V. Finžgarja (Meze, 1955, pril. 1). Do opoldne ob najvišjem poletnem soncu triglavski greben domala ne meče sence na ledenik. Hitro se povečuje z oddaljevanjem od junijskega solsticija. Senca ronka Triglava pada le na severozahodni rob ledenika. Na omenjeni skici je prikazana, glede na terenska opažanja, premajhna senca hrbta Kredarice na spodnji del ledenika v jutranjih urah.

Bolj kot zasenčenost je pomemben naklon ledeniškega površja proti S za ok. 20-35°. Ob poletnem solsticiju znaša opoldne zato vpadni kot sončnih žarkov 47-37° in ob ekvinokciju 23-14°. Zato je albedo na snegu velik, večji kot pri temnejšem starem poletnem snegu ali na "zelenem ledu".

Vse mesece je oblačnost ob 14. uri večja kot zjutraj ali zvečer. To je v veliki meri posledica pogoste opoldanske in zgodnjepopoldanske "gorske oblačnosti" oz. "gorske kape". Če s spodnjo bazo zajame še Kredarico, jo opazovalci beležijo kot meglo. Ker je ta oblačnost poleti najpogostejša, ima postaja tedaj manj ur s sončnim sevanjem (541 ur) kot dolinska postaja Rateče - Planica (648) in kotlinska postaja Stara Fužina (582).

Temperature

Tab. 2: Povprečne temperature v ablacijski dobi 1961-90.

	Maj	Junij	Julij	Avgust	Sept.	Skupno	Letno
Povpr.mesečna temp.	-0,2	2,3	5,8	5,8	3,8	3,7	-1,7
Pov. dnevne min.t.	-2,5	1,0	3,3	3,4	1,4	1,3	-4,2
Pov.dnevne maks. t.	2,3	5,9	8,8	8,7	6,7	6,4	1,2
Absolutne maks. t.	14,0	16,3	21,3	18,1	18,4	17,6	21,6
Absol.minimalne t.	-9,6	-6,1	-6,0	-9,8	-15,6	-9,4	-28,3
Št. dni s t. pod 0,0	22,7	11,6	5,8	5,0	10,0	55,1	249,2

Ker je kredariška postaja vrhslemenska in je bolj vetrovna, je domnevno rahlo hladnejša, kot bi bila na ravnini. Na ledeniški površini moramo računati še z nižjimi povprečki zaradi padajočega hladnega zraka, ki ob brezvetrju piha z hladnejšega ostenja Triglava ali (in) navzdol po ledeniku.

Zaradi višinske klime ima Kredarica pri nas največje zamike v temperaturnem poteku za gibanjem sonca: avgust je enako topel kot julij, september je za 4,0°C toplejši od maja in februar je hladnejši od januarja. Na ledenikih med severnim polom in 30°C s. g. š. znaša na snežni meji temperatura najtoplejšega meseca ok. 4,5°C (B. Messerli, po Wilchelm 1975, s.

98). Glede na to se zdi julijska temperatura Kredarice 5,8°C previsoka za klimatsko snežno mejo. Slednja je bila mnoga povojna leta domnevno na 2700 m (Gams, 1960). Na to kaže tudi julijski temperaturni gradient, izračunan po postajah Komna in Kredarica (0,68°C/ 100 m).

Postaja je v nizu 1961-1990 maja namerila negativno mesečno temperaturo (-0,2°C). Če dodamo začetna štiri devetdeseta leta, je temperatura ok. 0,0°C. Ker pa odpade na ta mesec največja energija sončnega obsevanja (Hočevar et al., 1982) in ker se tedaj stopi ves v tem mesecu zapadli sneg, pa še nekaj starejšega, je ta mesec tu vštet v ablacijsko dobo.

Padavine 1961-90

Glej tabelo št. 3

Vprašanje, ali postaja na Kredarici kot tudi vse druge visokogorske postaje beležijo premalo letnih padavin, do neke mere osvetljuje primerjava z okoliškimi postajami: severno pobočje Bohinjskih (Bukovskih) gora ok. 3500 mm, Komna, 1520 m, 1931-60, 2393 mm, kotlinska postaja Stara Fužina, 1961-90, 2332 mm, Mrzli studenec na Pokljuki, 1931-61, 2332 mm, Kredarica, 2514 m, 1961-90, 1996 mm. Od pasu največjih padavin vzdolž južnega goratega oboda Julijskih Alp se proti notranjosti oz. Triglavu letne vsote padavin znižujejo ne glede na nadmorsko višino tudi vzdolž Trente: Lepena, 480 m, 3077 mm, izvir Soče, 880 m, 2383 mm.

Na Kredarici ima maj več dnevov s sneženjem kot dnevov z dežjem, ker sneži večidel ob depresijskem vremenu, ko je v višinah nižja temperatura. 62 % vseh dnevov z dežjem v letu odpade na poletne mesece.

V 136 padavinskih dnevih pade 1996 mm padavin, kar je povprečno 22 ml na dan. Ob taki gostoti padavin med sneženjem bi to dalo 288 mm vode. Ker je povprečna temperatura redilne dobe -5,5°C, lahko računamo z gostoto snega okoli 0,15. Po tej oceni letno pade okoli 8,7 m snega.

Maksimalna višina snežne odeje pri postaji Kredarica nastopa včasih globobo v zimi. Dommevni vzrok je odpihavanje vrhnje snežne odeje ob močnih vetrovih. Za to govori tudi naslednji izračun. Če narast največje višine snežne odeje v mesecu (v cm) delimo z vsoto mesečnih padavin (v mm), vidimo, da imajo količniki od novembra do marca nepričakovane nizke vrednosti (z izjemo januarja). Ti količniki znašajo za oktober 0,55, november 0,28, december 0,46, januar 1,19, februar 0,89, marec 0,54 in maj 0,67. Od novembra do marca pa je na Kredarici največ dnevov z registriranim vetrom nad 8 Beauforta (gl. tab. 3!). Močan jugovzhodnik del odpihanega snega z grebena Kredarice odloži na ledeniku.

Greben Mali - Veliki Triglav je odklonjen za 20° od smeri Z-V, in sicer v smer JJV-SSZ. Zato prevladujoči jugozahodni in južni deženosni in snegonosni vetrovi dosežejo postajo kot jugovzhodnik, na katerega odpade 22 % vseh letnih registracij vetrov. Zahodnik greben odklanja v severozahodnik, na katerega na postaji odpade 36 %. Na preostale vetrovne smeri odpade majhen delež in 19 % registracij predstavlja brezvetrje. Zaradi omenjene lege grebena in smeri prevladujočih vetrov je zlasti ob sneženju ledenik v izrazitem zavetrju. Zato pade nanj nadpovprečno snega, ki obleži na ledeniku ali na njegovem robu mnoga leta do druge zime, čeprav traja na vrhu Kredarice snežna odeja na leto v povprečju le 262 dni. Snežna odeja na ledeniku se podaljša za okoli dva meseca ali več.

Maksimalna snežna odeja na Kredarici se v povprečju postopno debeli od najnižjega stanja avgusta, ko je ob prevladi dolgotrajnega anticiklonalnega vremena največ jasnih dni, do viška v aprilu. Odeja se od meseca do meseca zdebeli za 100 cm in več le med septembrom in oktobrom, med decembrom in januarjem in med marcem in aprilom (največ padavin je v redilni dobi oktobra, novembra in aprila. V nasprotju z nizom 1931-60 je bil v letih 1961-90 mesečni višek avgusta). Največji upad maksimalne snežne odeje je med majem in junijem in zlasti med julijem in avgustom.

Na pobočja okoliških vzpetin odpade okoli 44 % površine, ki jo je imel ledenik v povprečju v povojnih letih (12 ha). Ker je strmina triglavskega grebena blizu posipnega kota za sveži suhi sneg, se na ledenik sneg obletava že med sneženjem ali kasneje v obliki plazičev. Le redki se podaljšajo preko ledenika in preko polic do vrha Triglavske stene, kamor zdrvijo. Ocenjeni dodatek snega na ledenik s tega vira je okoli ene tretjine.

PODATKI O SPREMEMBAH V OBSEGU LEDENIKA

Zanje so tu izrabljena objavljena poročila o dosedanjem opazovanju ledenika po l. 1946 (Meze, 1955; Šifrer, 1963, 1976, 1987) in deloma Arhiv GIAM ZRC SAZU. Inštitutski sodelavci so l. 1946 na severnem robu tedaj večjega ledenika zarisali oštevilčene markacije za vsakoletno merjenje oddaljenosti ledeniškega konca, prav tako pa ob zgornjem in nekatere tudi na zahodnem robu. Ko se je ledenik kasneje odmaknil, so bliže izdelali pomožne markacije. Najprej so postale nedosegljive te na skali nad zgornjim robom. V poznih osemdesetih letih se je spodnji ledeniški rob razkrojil v jezike med ulegninami srednjeledeniških grbin (gl. imena na reliefni skici!), do katerih niso bile enake razdalje v raznih smereh. Zlasti v letih 1964-1982 je ves ledenik ali njegove robove prekrival sneg in opazovalci so se morali zadovoljiti z oddaljenostjo do snežišča, ne da bi preverjali, ali ni pod njimi še led. Tega niso ugotavljali tudi pod novejšim meliščem na vzhodnem ledeniškem robu. Vse to je vedno bolj oteževalo izračunavanje ledeniškega obsega, ki je neugotovljiv tudi s fotografij, ako rob zakriva sneg. V poročilu za leta 1946 - 1952 (Meze, 1955) so navedeni obsegi za vsa leta. V kasnejših poročilih je teh podatkov vedno manj.

Tabelarni pregled objavljenih letnih obsegov je tak-le:

1946:14,73 ha	1952:13 ha
1947:13,96 ha	1954:12,66 ha
1948:16 ha	1956:12,4 ha
1949:13,97 ha	1958:12,3 ha
1950:13,29 ha	1962:12,13 ha
1951:17,78 ha	1973: 11,9 ha

Ob takem stanju smo se pri izračunavanju korelacije med klimatskimi prvinami s postaje Kredarica in ledenikom morali zadovoljiti z meritvami dveh najpogosteje merjenih oddaljenosti spodnjega roba ledenika, in sicer pri točki 11 in 12. Ker je nad tč. 11 izrazit pregib v strmini, je bila v letih snežne pokritosti roba ledenika (1964-1982) oddaljenost premalo diferencirana. Zato so takratne spremembe povzete po točki 12, ob potrebnem dimenzioniranju odstopanja od povprečne vrednosti glede na točko 11.

STATISTIČNA KORELACIJA MED SPREMEMBAMI V KLIMI IN NA LEDENIKU

Potem, ko je bilo mogoče v nekaj letih manjkajoče opazovanje interpolirati po fotografijah, smo dobili 38 neprekinjenih let. Leti 1993 in 1994 nismo upoštevali, da ne bi preveč zmanjšale obsega starejših nihanj.

Izračunani korelacijski koeficienti med letnim gibanjem spodnjega roba ledenika (tč. 11 in 12) po vsakoletnih spremembah (prva kolona) in po oddaljenosti od dolgoletnega povprečka (druga kolona) ter izbranimi klimatskimi spremenljivkami s postaje Kredarica za leta 1954-1990, so naslednji.

	Spodnji rob ledenika	
	razlika od leta do leta	letni odklon od dolgoletnega povprečka
Padavine oktober - maj	0,1269	0,1846
Padavine junij - avgust	-0,0361	-0,1689
Maksimalna višina snežne odeje	0,0935	-0,1575
Povprečna temp. junij-avgust	-0,4362	-0,5296
Povp.maksimalna temp. maj-sept.	-0,3178	-0,2942
Ure sončnega obsevanja	-0,2465	-0,2138

Pri 99 % zaupanju je statistično pomembna povezanost letne oddaljenosti ledeniškega konca in letnega odklona ledeniškega konca od povprečka 1954-1990 s poletno temperaturo zraka (-0,4362 oz. -5,296).

Pri 95 % zaupanju pa je statistično pomembna tudi povezanost med vsakoletnim spreminjanjem ledeniškega konca s povprečno maksimalno temperaturo zraka maj-september.

Vpliv ostalih klimatskih prvin je manj pomemben. Nepričakovan je zlasti slabši vpliv letnih padavin na ledeniško stanje. To je mogoče razložiti s tem, da je pri izračunu upoštevan le spodnji ledeniški rob, sneg, zapadel v redilni dobi (pri padavinah so upoštevani zadnji trije meseci preteklega in pet mesecev tekočega koledarskega leta), pa se nabere predvsem na vrhnjem robu in vpliva na nižji ledenik preko pretakanja ledeniške vode in plazov šele v naslednjih letih. Preseneča tudi slaba korelacija med poletnim številom ur sončnega obsevanja in spremembami v obsegu ledenika, saj ga povečuje isti vzrok kot poletne temperature - anticiklonalno jasno vreme (Gams, 1985). Toda na diagramu (glej skico na str.

94) črte triletnih drsečih povprečkov dokaj vzporedno potekajo ne le s poletnimi temperaturami, ampak tudi z urami sončnega obsevanja. Obe ti dve klimatski prvini dosegata konec osemdesetih in v začetku devetdesetih let visoke vrednosti. V opazovani dobi so doslej visoke temperature spremljale navadno tudi nadpovprečne padavine oktober - maj. V zadnjih letih pa ostajajo slednje povprečne. Skupni učinek je upad ledu in razpad ledenika v letu 1993 in 1994.

Iz spoznanja, da vplivajo poletne temperature, v manjši meri povezane s padavinami v redilni dobi, najbolj na ledeniško bilanco, lahko presojamo starejši obseg ledenika po starejših klimatskih postajah v okolici. K temu nas opravičuje ugotovitev, da potekajo temperaturna in padavinska nihanja na Kredarici in v Ljubljani dokaj sinhrono (Gams, 1985). Letne padavine ljubljanske postaje, ki deluje od l.1851, so po višku v dvajsetih letih t. st. upadle in to predvsem zaradi zmanjšanja oktobrskih padavin. Te so pričele upadati že v začetku t. st., izraziteje pa konec štiridesetih let. Izpad oktobrskih padavin ni v celoti nadomestil rahli porast poletnih padavin od začetnih šestdesetih let dalje (Gams-Krevs, 1990). Porast oktobrskih padavin pomeni na Kredarici več snega v redilni dobi, porast poletnih padavin pa manj ledu.

Ker na temperature Ljubljane bolj vpliva širjenje mestnega naselja kot na postajo v Trstu, kaže po slednji iskati temperaturne spremembe. Na obeh postajah so namreč podobni trendi (Gams-Krevs, 1990). Poletne temperature so bile razmeroma visoke v tretji četrtini preteklega stoletja, konec tridesetih in v štiridesetih letih t. st. (Ogrin, 1994). Na Kredarici so bile nizke v drugi polovici šestdesetih in v sedemdesetih letih t. st., ko je ledenik tudi poleti pokrival sneg ob sočasnih povprečnih padavinah redilne dobe (gl. diagram na str. 94).

V okviru nakazanih klimatskih sprememb so tudi razlike med nizoma 1931-60 in 1960-90, ugotovljene po višinskih postajah okoli Kredarice. Letne temperature 1961-90 na postaji Komna, 1520 m (Pučnik, 1980) so bile nižje za 0,4°C od niza 1961-90 (Arhiv HMZS). V slednjem je oktober toplejši za 0,4°C istočasno pa je dobil za 35 mm manj padavin kot prej. Poleg njega beleži upad tudi januar, za 29 mm.

Dvig poletnih temperatur se je začel že v osemdesetih letih t. st. Na Komni so porasle v tem desetletju s 4,97°C, kot znašajo v celem nizu 1961-90, na 5,4°C.

Še večji je poletni temperaturni dvig v letih 1992-1994, kot govori spodnja preglednica za postajo Kredarica.

	1961-1990	1992 - 1994	1992-1994 1961-1990
Padavine oktober - maj	1156 mm	1167	101
Padavine junij - avgust	641 mm	645	100
Maksimalna višina snega	690 cm	318 cm	42
Ur sončnega obsevanja VI-VIII	177	197	111
Poletne temperature (VI-VIII)	5,0	6,4	128
Temperatura maja	-0,2	+1,6	
Dnevne maksimalna temp. V-IX	7,3	7,5	

V letu 1991 so bile nadpovprečno visoke poletne temperature in ure sončnega obsevanja. Ker pa je bilo v redilni dobi 1990/91 izjemno veliko padavin (1705 mm), se je led sredi ledenika zdebelil za 172 cm. To potrjuje pomembnost padavin za stanje na zgornji polovici ledenika. Ob povprečnih padavinah v redilni dobi in toplemu poletju pa je sledilo kasneje ponovno stanjšanje ledu. O tem pričajo v poletjih 1987 - 1994 na robu ledu (snega) vrisane črte na strmem pobočju skale ob zgornjem robu srednjih ledeniških skalnih grbin, in to ob jesenskem opazovanju. Od teh markacij izmerjeno nihanje ledu (gl. sl. 2) je naslednje:

1988/89 : upad za 40 cm
1989/90 : " " 26 cm
1990/91 : zdebelitev za 172 cm
1991/92 : upad za 143 cm
1992/93 : " za 163
1993/94 ; upad za 10 cm
Močno je led upadel jeseni 1987, 1991 in 1993.

Septembra je zgornje in spodnje ledišče, skupno z delom gruščnatega vzhodnega roba, obsegalo dobre 4 ha. To je le še ena desetina ledenika pred dobrim stoletjem, kot ga je določil Richter (1888).

SPREMEMBE V SESTAVI LEDENIŠKEGA LEDU

Po svetli barvi in po prečnih ledeniških razpokah je po najstarejših slikah in fotografijah, tudi še iz časa visokega ledostaja v začetnih dvajsetih letih, mogoče sklepati na pravi ledeniški led ali firn. Kadar se je kasneje poleti izpod snega razkril led v otokih ali po celem ledeniškem površju, je bil temnejše barve (gl. fotografije v omenjenih inštitutskih objavah v Geografskem zborniku !). Gre za modrikasto-zelenkasti led, ki ima po dosedanjih nesistematičnih meritvah gostoto 0,9 do 0,95. S to gostoto je med običajnim ledeniškim ledom (z gostoto ok. 0,80 do 0,85) in vodnim ledom, ki se obdobno pojavlja na večjih snežiščih v osojni legi (Gams, 1978, 1983, 1988). Verjetno je po takem ledu nastalo ljudsko ime Zeleni sneg.

Zaradi nizke lege ledenika oz. za ledenike visoke temperature prihaja do občasnega taljenja vrhnjega snega že spomladi in še jeseni. Povprečna dnevna maksimalna temperatura v maju je 2,3, junija 5,9, julija 8,8, avgusta 8,7 in septembra 6,7°C. Absolutni ekstremi mesečne temperature pa so maja l4,0, v naslednjih mesecih pa 16,3, 21,3, 18,3 in 18,4°C (vse v razdobju 1961-90, Arhiv HMZ). Od septembra naprej te temperature upadajo do januarja (7,6°C) in že aprila se dvignejo na 7,9°C. Ko snežnica z ledeniške površine ponikne v sveži sneg, ponoči ali ob ohladitvi zmrzne in tako prihaja brez dolgotrajne obtežitve debelih vrhnjih ledenih gmot do hitrejše tvorbe gostega ledu z relativno malo zračnih mehurčkov.

Tudi ta temnejši led na Triglavskem ledeniku polzi v plasteh, ki izdanjajo na ledeniškem površju in ustvarjajo videz luskaste sestave. V led zabite železne palice je to drsenje izvrglo. Na ledenik l. 1981 položeni obarvani kamni so do prihodnjega septembra na spodnj polovici ledenika zdrseli povprečno za 1,16 m (razpon med 0,45 in 2,85 m, Gams, 1983; Šifrer, 1987). Tudi del vode, ki teče po ledeniški osnovi proti spodnjemu kraju, prispeva k prepojitvi snega in nastajanju ledu (gl. fotografijo št. 3).

PODLEDENIŠKI SKALNI RELIEF

Po letu 1946 je bila jeseni 1993 prvič razkrita večina podledeniškega reliefa. Gradi ga čisti spodnjetriadni neskladoviti razpokani apnenec, ki prepušča vodo skozi razpoke in votline, od katerih je bilo doslej najbolj znano Triglavsko brezno (Gams, 1957, 1962, 1963). Zaradi možnosti, da bo v bodoče spet zakrit za dalj časa, je tu objavljenih nekaj fotografij iz 24. in 25. septembra 1994.

Skalne grbine podledeniškega reliefa so drobno razene in ledeniško zglajene (torej glaciokraško oblikovane), vmesne depresije pa bolj korozijsko razžrte.

Neznano površje ostaja na dnu vrhnje depresije, ki je med ostenjem Triglava in srednjeledeniškimi skalnimi grbinami (gl. geomorfološko skico!), ter v spodnjeledeniški kotanji, kajti obe je tudi jeseni 1994 zapolnjeval temnejši led.

Trdota ledeniške vode ja bila doslej ugotovljena le vrh Triglavskega brezna in je znašala med 3 in 14 mg $CaCO_2$/l (Gams, 1962, 1963). 24. sept. 1994 vrh svežega ugreza zajet vodni curek iz grušča pa je vseboval 84 mg $CaCO_3$/l, kar dokazuje precejšnjo korozijsko sposobnost vode na dalj časa ovlaženem grušču ali skali. Učinek agresivne snežniške in ledeniške vode na kraško razčlenjevanje je predvsem v skoncentriranem pritoku na apnenec.

Ker največ ledeniške vode prenika na spodnjem kraju ledenika, avtor predvideva nastanek obeh površinskih depresij (zgornje ulegnine in spodnjeledeniške kotanje) ob večstoletnem ohranjanju podobnega obsega. Spodnja kotanja je v tej luči učinek večstoletnega ledeniškega obsega, kot je bil v desetletjih po zadnji vojni (12-14 ha), zgornja ulegnina z obsegom v letih 1993 in 1994 (4 ha) pa večstoletnega obsega v toplejši klimi od sedanje, verjetno iz borealne zgodnjeholocenske dobe in iz toplejšega srednjega veka.

Ker je od oktobra 1993 do septembra 1994 upadla le snežna odeja in to za okoli 10 cm, lahko smatramo tedanji obseg zgornjega ledišča (okoli 4 ha) kot plod ledeniškega leta s 1336 mm padavinami v mesecih X - V in s poletno temperaturo okoli 7,1°C (temperatura maja okoli 0,9°C).