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ENERGY BALANCE CALCULATIONS FROM FIVE YEARS' METEOROLOGICAL RECORDS AT VERNAGTFERNER, OETZTAL ALPS

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With 7 figures

SUMMARY

During the months May to September, global radiation, longwave radiation, air temperature, relative humidity, precipitation, wind speed and direction are continuously recorded at the Pegelstation Vernagtbach (2640 m a. s. l.). Based on this material, monthly means of global radiation, air temperature and monthly sums of precipitation for the years 1978 to 1982 are discussed with respect to their influence on shortwave radiation balance and sensible heat flux of Vernagtferner. As the Albedo, which is derived from daily photographs of the glacier increases while global radiation decreases during summer, shortwave radiation balance usually rises from May to August; the lowest value was observed in June 1982 with 48 Wm^{-2}, the highest one in August 1980 with 96 W/m^2. The variation of sensible heat flux follows the change of air temperatures, as wind speed does not vary much during summer. Meltwater production as calculated from the energy balance, lies between 5 % and 30 % below the total measured runoff.

ENERGIEBILANZBERECHNUNGEN FÜR EINEN 5-JAHRES-ZEITRAUM AUF DER GRUNDLAGE METEOROLOGISCHER MESSUNGEN AM VERNAGTFERNER/ÖTZTALER ALPEN

ZUSAMMENFASSUNG

Während der Monate Mai bis September werden an der Pegelstation Vernagtbach (2640 m ü. NN) Globalstrahlung, Gegenstrahlung, Lufttemperatur und -feuchte, Niederschlag, Windrichtung und -geschwindigkeit kontinuierlich aufgezeichnet. Aus diesem Material werden die Monatsmittelwerte der Globalstrahlung und der Lufttemperatur und die Monatssummen des Niederschlags der Jahre 1978 bis 1982 vorgestellt und ihr Einfluß auf die kurzwellige Strahlungsbilanz und den Strom fühlbarer Wärme auf dem Vernagtferner diskutiert. Da die Albedoverteilung, die aus täglichen Photographien des Gletschers abgeleitet wird, der Abnahme der Globalstrahlung im Verlauf des Sommers entgegenläuft, steigt die kurzwellige Strahlungsbilanz durchschnittlich von Mai bis August; der absolut niedrigste Monatsmittelwert wurde im Juni 1982 mit 48 W/m^2, der höchste im August 1980 mit 96 W/m^2 bestimmt. Der fühlbare Wärmestrom verläuft im allgemeinen parallel zum Gang der Lufttemperatur, da die Windgeschwindigkeiten im Verlauf des Sommers sich nicht sehr stark ändern. Die Schmelzwasserproduktion, die aus allen Termen der Energiebilanzgleichung berechnet wird, liegt in den verschiedenen Jahren zwischen 5 % und 30 % unter dem gemessenen Gesamtabfluß.

1. INTRODUCTION

The interrelationship between climate and glaciers has been a matter of great interest throughout the centuries. Only in this century, however, has it become possible to obtain continuous, reliable records from more remote alpine, glacierized regions (Hoinkes 1964, 1968). The construction of the gauging station „Pegelstation Vernagtbach" (2640 m a. s. l.) in 1973 (Bergmann and Reinwarth 1976) provided a good opportunity to record important meteorological parameters, such as global radiation, atmospheric longwave radiation, air temperature, relative humidity, precipitation, wind speed and direction, at a site quite near Vernagtferner in the Oetztal Alps (46° 52′ N, 10° 49′ E, 9.5 km^2, 2740—3633 m). The albedo of Vernagtferner, probably the most significant of all the parameters affecting the energy balance of a glacier (Hoinkes 1968, Wagner 1979, 1980), is documented by daily pictures of the distribution of ice, firn or snow at the glacier surface, taken by two automatic cameras. By this means, we now have continuous meteorological data for five ablation periods — 1978 to 1982 — in the catchment of Vernagtferner.

2. TEMPORAL DISTRIBUTION OF GLOBAL RADIATION, AIR TEMPERATURE AND PRECIPITATION

Fig. 1 shows the monthly averages of global radiation in W/m^2 for May to September (June to September in 1979). The largest variance occurs in September, with the 1981 value less than half that of 1980. The highest value was recorded in June 1978, 300 W/m^2, whereas August 1982 displays the lowest of all five August values. Considering only global radiation, one would assume that 1978 was a year of high ablation, and 1982 of rather less melting on the glacier surface.

Fig. 2 shows the distribution of air temperature during the same period. Averaged over the five months and the five years, air temperature amounts to 4.1° C. Precipitation (fig. 3) displays great variability, which is again highest in September.

The interaction of air temperature and precipitation can be critical to albedo values. Low air temperature and moderately high precipitation in August 1978, for example, led to several spells of snowfall on the glacier, resulting in quite high albedo. In August 1981, higher air temperature meant that a comparable amount of precipitation fell as rain, and the average albedo of the glacier remainded low, a situation that was well documented for Hintereisferner, in 1971 (Wagner 1979, 1980).

3. SNOW-ICE DISTRIBUTION ON VERNAGTFERNER

The date when the first free ice is visible on the glacier surface (table 1) varies from the beginning of June to nearly the end of July. This difference of about 8 weeks is caused not only by winter accumulation but also by the type of precipitation during May and June. The large difference in the extension of ice at the end of the ablation period between 1978 and 1982 (with nearly half the glacier area free of snow) is quite remarkable. Nevertheless, the effect of this large figure on albedo should not be overestimated, since it is only the final value of the ablation season. The temporal development of energy budget components is discussed in the following section.

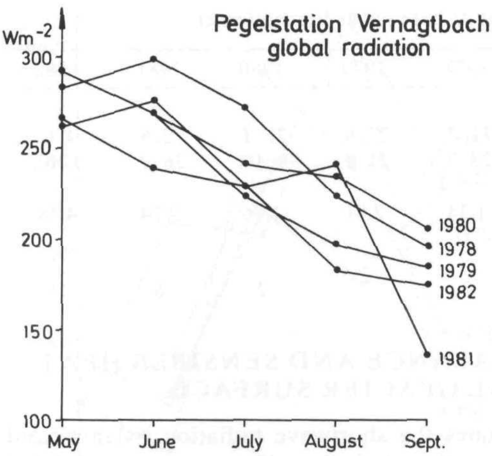

Fig. 1: Monthly means of global radiation for 5 ablation periods 1978—82, measured at the Pegelstation Vernagtbach

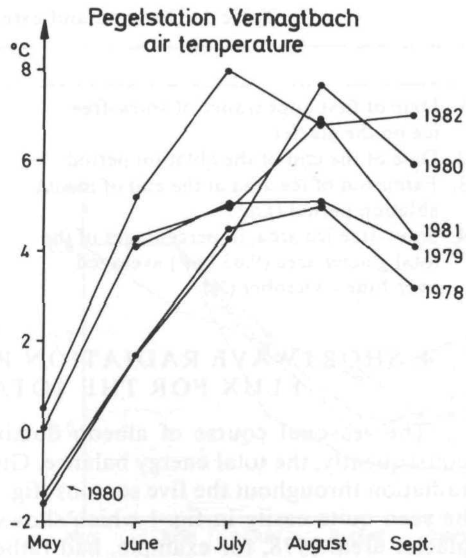

Fig. 2: Monthly means of air temperature for 5 ablation periods 1978—82, measured at the Pegelstation Vernagtbach

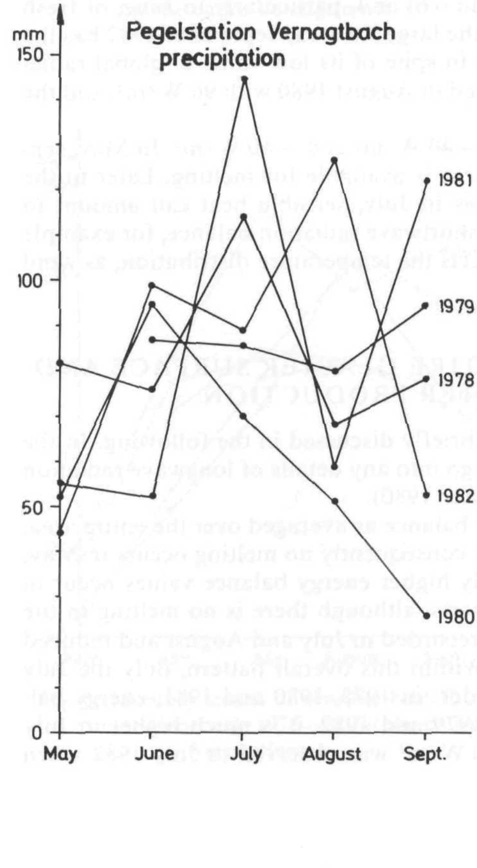

Fig. 3: Monthly sums of precipitation height for 5 ablation periods 1978—82, measured at the Pegelstation Vernagtbach

Table 1: Duration and extent of bare ice at Vernagtferner

	1978	1979	1980	1981	1982
1. Date of first appearance of snow-free ice on the glacier	22. 7.	27. 6.	22. 7.	2. 6.	4. 6.
2. Date of the end of the ablation period	28. 9.	21. 9.	9. 10.	26. 9.	1. 10.
3. Extension of ice area at the end of the ablation period (km^2)	1.34	2.81	1.76	2.74	4.38
4. Snow-free ice area, in percentages of the total glacier area (9.65 km^2) averaged over June—October (%)	2	7	2	6	15

4. SHORTWAVE RADIATION BALANCE AND SENSIBLE HEAT FLUX FOR THE TOTAL GLACIER SURFACE

The seasonal course of albedo dominates the shortwave radiation balance, and consequently, the total energy balance. Given the relatively uniform structure of global radiation throughout the five seasons (fig. 1), the large effect of albedo distribution can be seen quite easily in fig. 4 which shows absorbed shortwave radiation for the total glacier area. 1978, for example, had rather high global radiation values especially in June and July. Nevertheless, due to the particular albedo values (fig. 5), shortwave radiation balance is quite small in these months, as the glacier surface did not consist of ice (with an albedo of 0.4), but firn (albedo 0.6) and, particularly in June, of fresh snow (albedo 0.8). On the other hand, due to the large ice area, September 1982 has the highest value of shortwave radiation balance in spite of its low value of global radiation. The highest shortwave radiation is reached in August 1980 with 96 W/m^2, and the lowest in June 1982 with 48 W/m^2.

Sensible heat flux (fig. 6) ranges between -40 W/m^2 and $+60$ W/m^2. In May, sensible heat flux is negative, i. e. no sensible heat is available for melting. Later in the year, particularly in June, but also sometimes in July, sensible heat can amount to monthly mean values half as high as those of shortwave radiation balance, for example in 1982. Generally, the sensible heat flux reflects the temperature distribution, as wind speeds do not vary greatly during summer.

5. ENERGY BALANCE OF THE ENTIRE GLACIER SURFACE AND RESULTING MELTWATER PRODUCTION

The energy balance of the total glacier is briefly discussed in the following. In the restricted space available, it is not possible to go into any details of longwave radiation balance or of latent heat flux (see Escher-Vetter 1980).

Fig. 7 shows the monthly means of energy balance as averaged over the entire area. Typically , the energy balance is negative and consequently no melting occurs in May, even in the lowest part of the glacier. Slightly higher energy balance values occur in June, leading to some melting in the lower parts, although there is no melting in the upper reaches of the glacier. High values are recorded in July and August and reduced energy balance values again in September. Within this overall pattern, only the July and August values can sometimes change order: in 1978, 1980 and 1981, energy balance rises from July to August, whereas in 1979 and 1982, it is much higher in July than in August. The maximum of nearly 100 W/m^2 was observed in July 1982 when

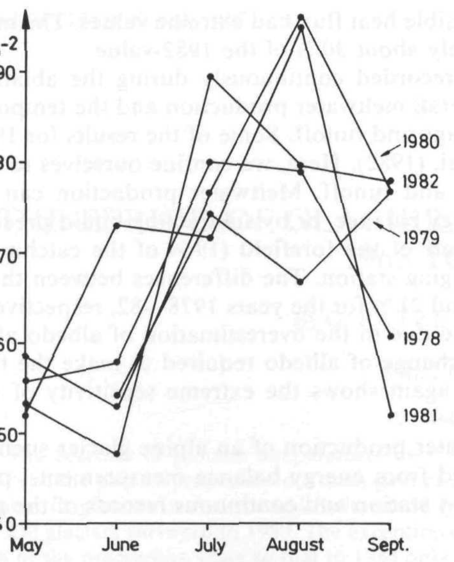

Fig. 4: Monthly means of shortwave radiation balance for 5 ablations periods 1978—82 for the entire Vernagtferner

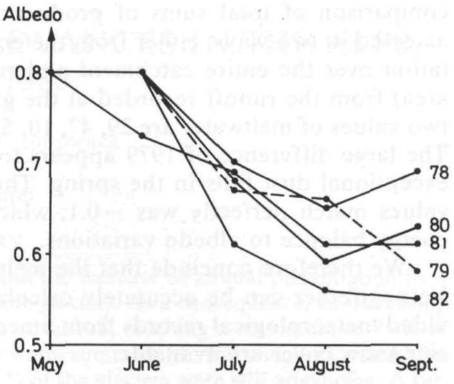

Fig. 5: Monthly means of albedo for 5 ablation periods 1978—82 for the entire Vernagtferner

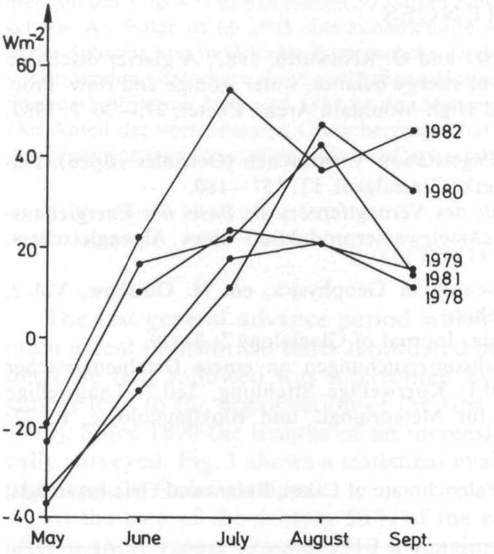

Fig. 6: Monthly means of sensible heat flux for 5 ablation periods 1978—82 for the entire Vernagtferner

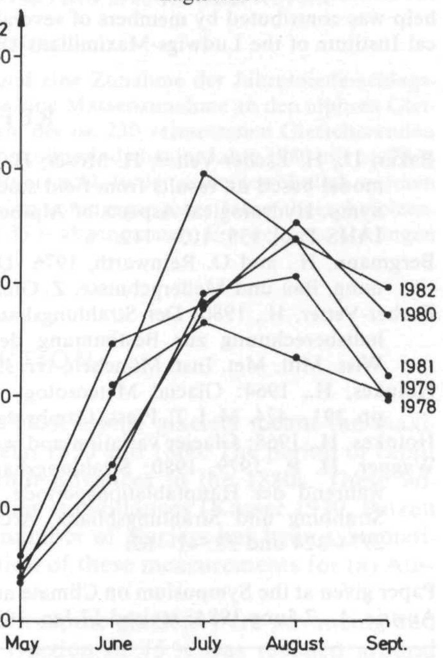

Fig. 7: Monthly means of energy balance for 5 ablation periods 1978—82 for the entire Vernagtferner

shortwave radiation balance as well as sensible heat flux had extreme values. The minimum July value occurred in 1979 with only about 30 % of the 1982-value.

As the runoff from Vernagtferner is recorded continuously during the ablation period, it is possible to check both the overall meltwater production and the temporal distribution of meltwater production, storage and runoff. Some of the results for 1979 have already been discussed by Baker et al. (1982). Here, we confine ourselves to the comparison of total sums of production and runoff. Meltwater production can be assessed in two ways, either from the energy balance, or by subtracting liquid precipitation over the entire catchment and runoff of the forefield (19 % of the catchment area) from the runoff recorded at the gauging station. The differences between these two values of meltwater are 29, 47, 10, 5 and 21 % for the years 1978—82, respectively. The large difference of 1979 appears to be due to the overestimation of albedo after exceptional dust falls in the spring. The change of albedo required to make the two values match perfectly was −0.1, which again shows the extreme sensitivity of the energy balance to albedo variations.

We therefore conclude that the meltwater production of an alpine glacier such as Vernagtferner can be accurately calculated from energy balance measurements, provided meteorological records from a nearby station and continuous records of the glacier snow cover are available.

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