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EVAPORATION-CONDENSATION AND SNOWMELT MEASUREMENTS IN FINLAND

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Measurements on evaporation and the melting of snow cover are presented, followed by an explanation of how the measured values depend on meteorological factors and the structure of the snow. The observations were made during the period 1968–1973 on an experimental field situated in southern Finland. The regression analysis of the evaporation gave no motive for the use of a non-linear wind function. A theoretical model based on the energy balance has been sought with the aim of explaining snowmelt. However, a simple model containing certain basic parameters gave better results.

Data

As the equipment and measurements have been described previously (Lemmelä 1972), only the main features of the measurements are presented here.

The experimental field is situated in southern Finland at 60° 23′ N latitude and 25° 01′ E longitude. The field lies on a glacifluvial delta formation and its mean height is 60 meters above mean sea level.

The snow depth was determined by reading 25 snow stakes on the experimental field. The stakes were 5 meters apart on a square measuring 20 by 20 meters. The density of the snow was determined with snow scales having a cylinder 100 cm² in cross section. In order to obtain the necessary precision, the number of density determinations complied as far as possible with the recommendations made by Hegedus & Szesztay (1967). The measurements showed that the dispersion of the water equivalent values remained rather constant, from 5 to 7 %, during the winter period. The dispersion started to increase noticeably as the snow melted, and increased to 30–40 % at the end of the snowmelt.

The snow pillow on the experimental field was used from 1st December, 1968. The pillow had a circular surface of 10.5 m^2 and the container was made of neoprene rubber reinforced with terylene fabric. The liquid was a 1:2 antifreeze mixture of water and ethanol. The agreement between the snow pillow values and the water equivalent determination to snow stakes and weighing was satisfactory. For instance, the correlation coefficient in 1969 was 0.999, and the standard deviation 4.1 mm. No interference caused by changes in air temperature could be observed.

For purposes of measurement, the amount of melt water released by the snow was collected in special containers called drip pans. Similar devices have been used, for example, by Forsman (1963), Kinosita et al. (1967) and Pysklywec et al. (1968). Two drip pans were set on the experimental field, each of which had a bottom surface of 1 m^2. The pans had rims 6 cm high and a bottom slope of 4 % towards the center. From the center, 20 mm plastic tubing sloping at 1:5 led the water to the observation well. The well contained a measuring tank and a limnigraph, which registered the amount of melt water. The amount of melt water could be measured to an accuracy of 0.2 mm.

Special evaporation pans were used to determine evaporation and condensation. The change in weight of these pans together with the measured precipitation provided the net daily evaporation. Different kinds of evaporation pans have been used, for example, by Kaitera (1939), Croft (1944) and Nyberg (1966). The pans used in this study had a free surface of 500 cm^2 and total heights of

Table 1.

The snow water equivalent Sn in millimeters at the beginning of snowmelt and the net evaporation E during the snowmelt period in millimeters and as a percentage.

Time		Sn (mm)	E	
			(mm)	(%)
1968	28.03 – 14.04	165	3.3	2.0
1969	03.04 – 12.04	152	3.9	2.6
1970	04.04 – 02.05	223	5.6	2.5
1971	31.03 – 10.04	119	3.7	3.1
1972	12.03 – 24.03	96	9.4	9.8
1973	23.03 – 27.03	71	– 0.2	– 0.3

10 and 20 cm. The pans were turned from white plastic on a lathe and consisted of double cylinders, so they could be adjusted according to variations in snow depth. The pans were generally weighed twice a day in the spring at 07.00 and 19.00 hours.

The measured net evaporation during different spring periods from the beginning of snowmelt to the disappearance of the snow is shown in Table 1.

Weather regime during the observation periods

Comparison with the long-term means shows that the weather during the observation periods from 1968 to 1973 did not deviate markedly from the normal. During these years temperatures from March to April were 1 to 2°C above the mean for the period 1931–1960. The thermal spring began about one week earlier than usual. The monthly mean of the relative humidity exceeded the long-term mean by 2 % for March and 4 % for April. The total radiation and the number of sunshine hours were rather close to the long-term mean; these variables did not change much from year to year.

The dominant winds were mainly from southeast to southwest. More than 80 % of the winds were less than 3.5 m/s. One wind meter was mounted at an elevation of 2 m; another, at 0.4 m, registered values almost as large as those of the former.

Precipitation and snow cover

February and March were close to normal with regard to precipitation during the observation periods from 1968 to 1973. The mean February precipitation was 32 mm and that of March 30 mm. Snow fell on 18 days in February and 13 days in March. The maximum intensity was 10 to 12 mm/day.

The sum of hours of snowfall in February averaged 24 hours and in March 31 hours. This sum corresponds to increasing loads on the snow pillow as registered. It eliminates snowing at very low intensity. Precipitation in April did exceed the normal value, as the mean for the observation period rose to 51 mm. The intensity was also above normal, e.g., during these five years a maximum of 13 mm in one day was observed.

The mean maximum water equivalent of the snow cover during the years of observation was 138 mm, which is somewhat above the long-term mean. On an average the maximum value occurred ten days later than usual.

Snowmelt and factors influencing it

The length of the snowmelt period varied greatly from year to year. The longest one was 28 days and the shortest 5 days. Table 2 presents the maximum melting during one, five and ten day periods for the different years as well as the dates of these periods.

Melting has been measured with drip pans in addition to the snow pillow. The drip pans generally yield daily values about 10 % greater than the snow pillow and the snow disappears more quickly from the pans than from the pillow. It is possible that the drip pans trap enough solar radiation to cause this difference. However, the explanation also can be found in the fact that the drip pans are smaller than the snow pillow and slope toward the center, making the melt water run down into the measuring tank without much delay. The snow pillow is more than ten times larger and the water can run off only along the rim; some of the melt water has to traverse a long horizontal distance before it is unloaded from the snow pillow. In Fig. 1 the hourly melting, obtained by comparing the recorded values for 24 days without precipitation and with intensive melting, appears. Both methods give a maximum between 13.00 and 14.00 hours. Nyberg & Hårsmar (1971) have found that the maximum occurs at around 13.00 hours. Forsman (1963) found two maxima of melt connected with the culmination of the sun and the thermal maximum.

However, the values found with the snow pillow are noticeably lower, particularly at the maxima. The delay in the snow pillow is also seen in the falling part of the curve, which renders values greater than those from the drip pans between 17.00 and 21.00 hours. The snow pillow registrations will be used below for computing melting values. Since the basic period is 12 or 24 hours, the delay in registration for the snow pillow does not affect the results.

Table 2.
Maximum melting as registered with the snow pillow during one, five and ten day periods in late winter from 1968 to 1973.

	Maximum melting with duration in days					
Year	1 day		5 days		10 days	
	(mm)	(date)	(mm)	(date)	(mm)	(date)
1968	27	29.3	102	25–29.3	122	24.3– 3.4
1969	27	12.4	109	8–12.4	151	3–12.4
1970	24	27.4	84	25–29.4	130	20–29.4
1971	28	8.4	74	5– 9.4	105	31.3– 9.4
1972	12	22.3	37	19–23.3	50	15–24.3
1973	24	27.3	70	23–27.3	70	18–27.3

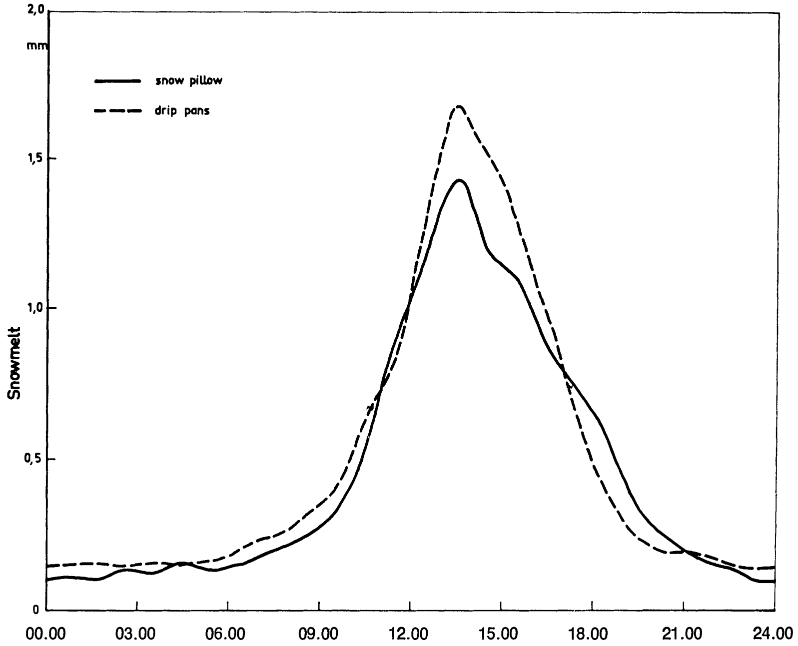

Fig. 1.

Daily snowmelt intensity measured with snow pillow (solid line) and drip pans (broken line) on intensive melting days from 1968 to 1973.

The dependence of the rate of melting on the mean temperature of the day and especially on the mean temperature of that part of the day when the temperature is above freezing (the degree-day-factor) is obvious. In Fig. 2 the sum of the melting appears as a function of the sum of the degree-day-factor for the separate years. The differences between the years tend to form at the beginning of the melting period; later the curves are more or less parallel.

The mean melting per degree centigrade is 4.47 mm, which is rather close to the value of 4.94 mm/°C found by Kaitera (1939).

Regression analysis was used in determining how the rate of melting depends on meteorological factors and on the properties of the snow. This was done in two ways. On the one hand, theoretical models based primarily on the energy balance equation were used. On the other hand, combinations of variables chosen according to intuitive experience were tried.

The use of the models based on the energy balance equation is somewhat restricted because of the length of the basic period of 12 to 24 hours. The functions applied to the momentary values of the variables should not be applied to their mean values. Therefore the regression models based on the energy balance did not provide satisfactory results. The use of hourly values might bring about an improvement. This may also be seen in Fig. 3, where the phases of melting for one period of melt are shown according to Johnson & Archer (1972). The deviations during phases 1 and 3 from the line determined by phase 2 are not always the same, which leads to an error when using mean values.

The following pertains to the day period from 07.00 to 19.00 hours. In the combination of variables made up by personal choice, attention has been paid primarily to temperature, net radiation and to a factor describing the properties

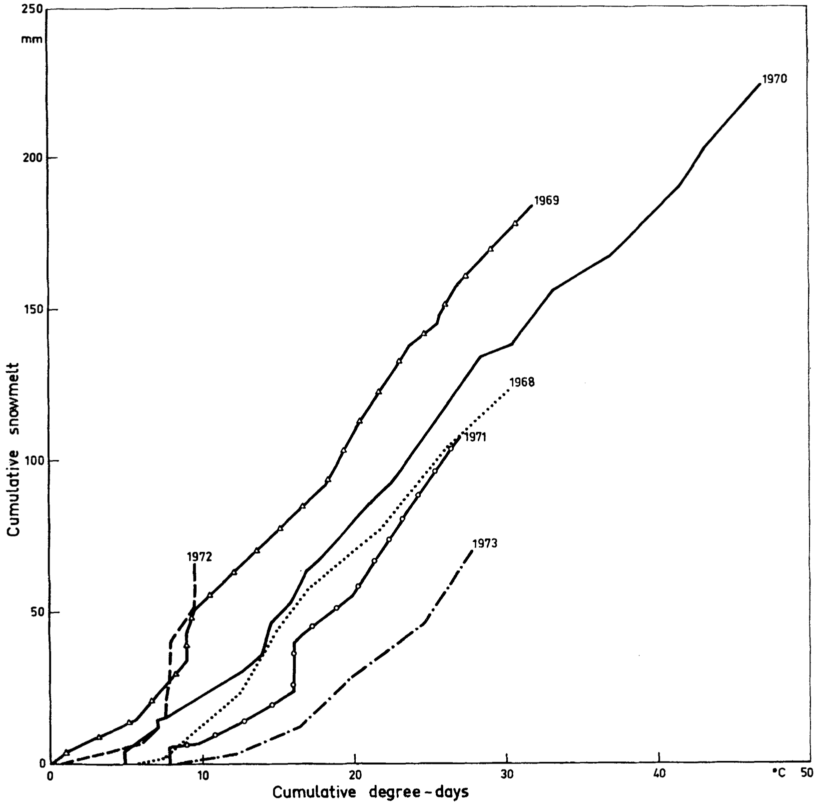

Fig. 2.

Cumulative snowmelt against cumulative degree-days for the years 1968–1973.

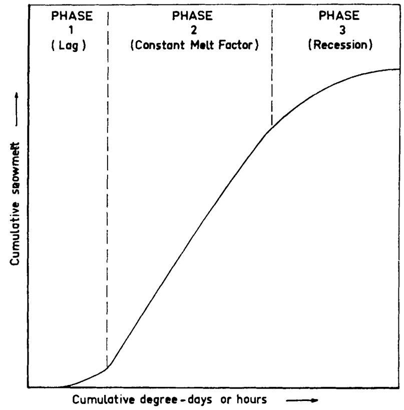

Fig. 3.
Conceptual phases of a snowmelt event.

of the snow. The expression for the temperature giving the best correlation (R = 0.70) is as follows:

$$T \equiv \begin{cases} T_{max} + T_{min}, \text{ when } T_{min} > 0°C \\ T_{max}\ , \text{ when } T_{min} \leqq 0 \end{cases}$$

T_{max} = maximum temperature for the period concerned, °C
T_{min} = minimum temperature for the period concerned, °C

Almost as good a correlation as the above variable is given by the degree-day-factors $D_{(0)}$ and $D_{(1)}$, defined as follows:

$$D_{(x)} \equiv \begin{cases} \overline{T}\ , \text{ when } \overline{T} - x > 0 \\ 0, \text{ when } \overline{T} - x \leqq 0 \end{cases}$$

$\overline{T}$ = mean temperature for the period concerned, °C

The correlation of the net radiation R_n with the rate of melting was 0.53 in the present material. The total radiation correlation was less than expected.

The properties of the snow may be depicted by its density ϱ, which gave the best correlation with the rate of melting (R = 0.43). The amount of liquid water present in the snow also gave a good correlation.

The equation best representing the rate of melting as measured in this investigation contained the variables $D_{(0)}$ (°C), R_n (cal cm^{-2}) and ϱ (g cm^{-3}):

$$M \text{ (mm/12 h)} = 1.8\ D_{(0)} + 63\ \varrho + 0.028\ R_n - 23.3$$

The total correlation coefficient is 0.83 and the residual variance 3.7 mm.

The material covers 84 days and the mean melting was 8.0 mm/12 h. The mean temperature of the days concerned was 2.9°C and the mean net radiation 95 cal cm^{-2}.

The same model was applied only to those days which were free of precipitation and showed a melt exceeding 5 mm. This led to the equation

$$M = 1.7\ D_{(0)} + 52\ \varrho + 0.030\ Rn - 19.6;\ R = 0.81$$

The net radiation was more important in the latter equation.

These results for the rate of melting are preliminary. An analysis with a basic time unit of one hour will be tried together with the theoretical models.

Evaporation from the snow cover

This study is based on the material relating to 94 periods of 12 hours between 07.00 and 19.00 hours. The mean values of the most important variables and their range appear in Table 3.

The temperature, the relative humidity and the wind velocity were measured at an elevation of 2 m.

The distribution of the evaporation in different size classes may be seen in Fig. 4, where daytime and nighttime evaporation are shown separately.

The mean daytime evaporation was 0.25 mm and the nighttime 0.03 mm. Condensation dominated almost every night but was present in only 21 % of the daytime observation periods.

Table 3.

Maximum, minimum and mean values of the principal variables used in the daytime evaporation study

Variable	Symbol	Mean	Range
Evaporation (mm)	E	0.25	-0.74 - 1.85
Snowmelt (mm)	M	4.4	0.0 - 26.6
Mean temperature (°C)	$\overline{T}$	1.0	-13.8 - 7.4
Maximum temperature (°C)	T_{max}	3.4	-9.8 - 12.4
Minimum temperature (°C)	T_{min}	-2.7	-20.2 - 3.7
Total radiation (cal cm^{-2})	R_t	240	26 - 464
Relative humidity (%)	r	72	40 - 99
Wind velocity (m s^{-1})	v	2.2	0.6 - 5.2
Difference in vapor pressure between snow surface and air (mmHg)	$e_s - e_a$	0.63	-1.97 - 3.27

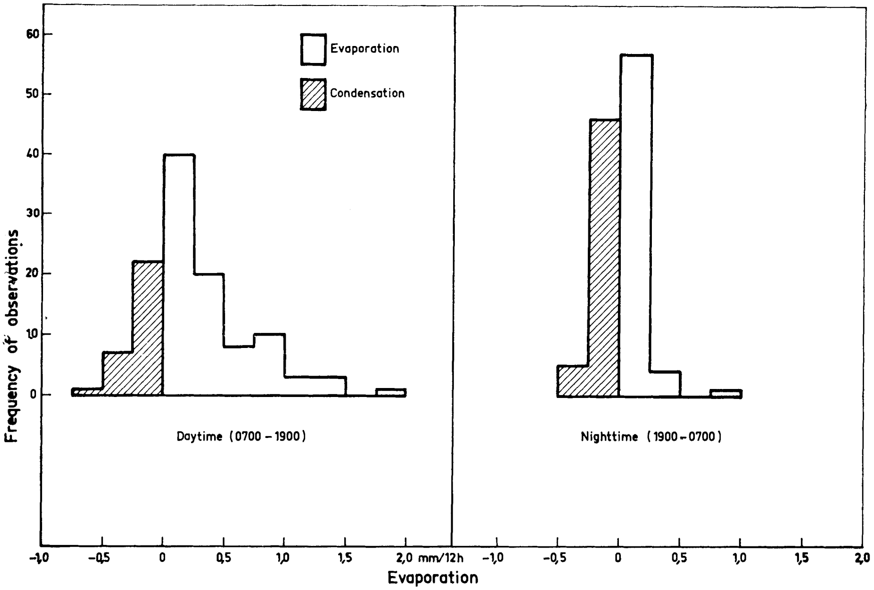

Fig. 4.
The distribution of the evaporation in the different size classes during the observation period.

In analyzing the evaporation data different mathematical expressions were studied. All had the form

$$E = [a + b\ f\ (v)]\ (e_s - e_a),$$

where a and b are empirical constants, f (v), a function of the wind speed and $e_s - e_a$ the difference in vapor pressure between the snow surface and the air. As wind speed functions, f (v), the functions v, v^2, $\sqrt{v}$ and log v were tried. With units of E = mm/12 h, v = m/s, $e_s - e_a$ = mmHg, the following equations were obtained:

$$E = (0.087 + 0.097\ v)\ (e_s - e_a) + 0.04 \qquad R = 0.80$$
$$E = (0.32 - 0.00024\ v^2)\ (e_s - e_a) + 0.05 \qquad R = 0.75$$
$$E = (0.19 + 0.33\ \sqrt{v})\ (e_s - e_a) + 0.04 \qquad R = 0.80$$
$$E = (0.11 + 0.27\ \log v)\ (e_s - e_a) + 0.04 \qquad R = 0.81$$

As the total correlation coefficient varies only a little when the wind function is changed, the wind function cannot be very important in the equation. The humidity difference alone provides a correlation of 0.75, the term f(v) $(e_s - e_a)$

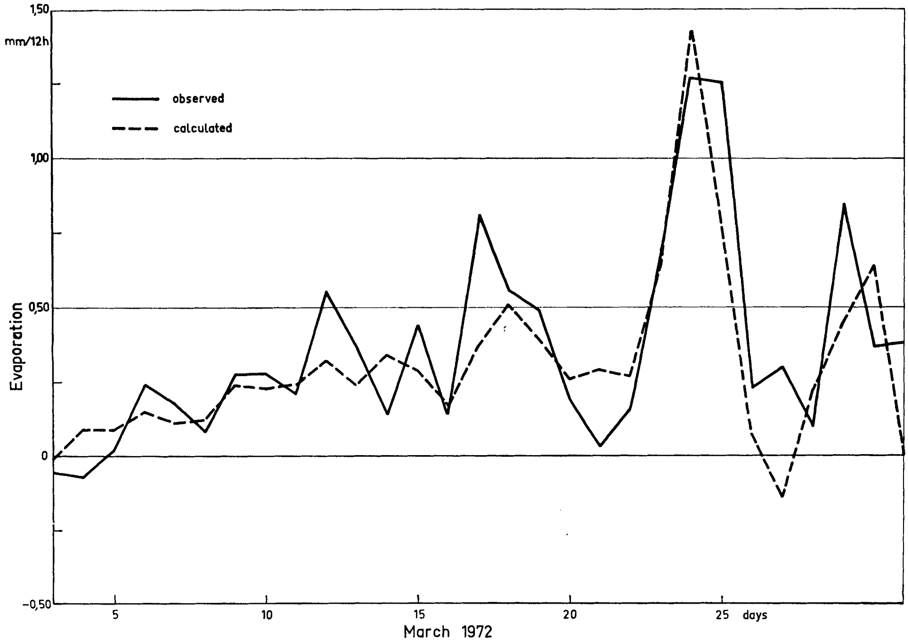

Fig. 5.
Observed (solid line) and calculated (broken line) evaporation in 1972.

supplying only 0.00 to 0.06 units. In the equation with $f(v) = v^2$, the negative sign of this term is physically unrealizable, as it requires the evaporation to decrease as the wind speed increases. When the total radiation is entered as a variable, one obtains

$$E = (0.0027 + 0.10\,v)\,(e_s - e_a) + 0.0016\,R_t - 0.31 \qquad R = 0.88$$

This model is also significant at the 0.1 % level. The value of the F-test is 103. The residual variance is 0.19 mm.

An example of the evaporation observed and calculated daily in accordance with the last equation is presented in Fig. 5.

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