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THE EVAPORATION FROM SNOW

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The observations referred to in the present article concerning the evaporation from snow were made in the spring of 1937 and 1938 in Helsinki at the Ilmala Observatory ($\varphi = 60^{\circ} 12' N$, $\lambda = 24^{\circ}55'$ E.Gr.). The meteorological observations carried out at the Observatory have been made use of in the investigation.

The observations were made by means of pans made of zinc sheets, 0.8 *mm* thick, painted white, the bottom of the pans being 500 cm^2 in area and their height about 8 *cm*.

The pan was filled with snow in such a manner that the evaporation surface formed an unbroken surface of snow. The pan, filled with snow, was weighed on ordinary shop scales. The exactitude of the scales was 1 *gr*, corresponding to 0.02 *mm* of evaporation. The pan was then placed at the observation point in a hole dug in the snow, so that the surface of the snow in the pan was as precisely as possible on a level with the surface of the snow surrounding the observation point (*fig.* 1-3). The observations were made between 7 and 9 *a. m.* On the following morning the pan, filled with snow, was weighed again after carefully removing the snow that had collected on the outside of the pan. If the snow had subsided within 24 hours owing to melting and had melted at the edges, so that it no longer filled the pan, fresh snow was placed in the pan in the manner already described.

A description of the observation points is given in Table I. The results of the observations and the observations concerning the temperature and moisture of the air and the wind conditions, made at the Ilmala Observatory, are given in Table II. The data were calculated from the difference between two successive weighing

Table I. — *Observation points for measuring the evaporation from snow.*

Observation point No.	Altitude above MSL = *m*.	Direction of steepest gradient.	Correspond slope *cm/m*.	Character of the observation point.	Immediat surroudings of the observation point to			
					N.	W.	S.	E.
1.	45	SSW	5	Shallow depression on exposed hill	Open space	Sparse leaf-trees, 10 *m* high, within 50 *m*	Conifers, 1-2 *m* high, within 10 *m*	Leaf-trees, 5 *m* high, within 40 *m*
2.	45	S	10	Open space on a hill	Open space, rise of ground ends within 5 *m*	Pine saplings, 1-2 *m* high, within 5 *m*	Open space	Sparse mixed trees, 5 *m* high, within 5 *m*
3.	46		0	Open space on a small knoll	Open space	Mixed trees, 6 *m* high, within 40 *m*	Open space	Sparse leaf-tree, saplings, 2-5 *m* high, within 20 *m*
4.	45	E	5	Open space	Mixed forest 6 *m* high, within 30 *m*	Open space	Open space	Sparse mixed trees, within 20 *m*
5.	45		0	Sparse birches, 10 *m* high, gaps 40 %	Forest ends within 20 *m*			
6.	35	SSW	30	Open slope of rock	Steep hill	Open space, prevailing wind WNW	Mixed trees, 8 *m* high, within 15 *m*	Open space, prevailing wind ESE
7.	30		0	Forest glade, 20 *m* diameter, NE edge	Mixed trees, 15 *m* high, within 2 *m*	Mixed trees, 15 *m* high, within 2 *m*	Mixed trees, 15 *m* high, within 20 *m*	Mixed trees, 15 *m* high, within 10 *m*
8.	30		0	Mixed forest, 15 *m* high, gaps 30 %	Mixed forest	Mixed forest	Mixed forest	Mixed forest
9.	40	NW	30	Open slope	Open space, within 30 *m* the tops of trees just above measuring point	Open N slope, along which the winds can blow	Steep hill	Open N slope, along which the winds can blow
10.	40	N	30	Open slope of rock	〃	〃	〃	Conifers within 40 *m*
11.	46	N	10	Open space on edge of N slope	Open space	Open space	Open space, land surface 0.5 *m* higher, within 5 *m*	Open space
12.	40	N	30	Open slope	Open space	Sparse trees, within 30 *m*	Steep hill	Sparses trees, within 20 *m*

results, allowing too for the observed rainfall during the time concerned. If the rainfall between two weighings exceeded 1.0 *mm*, the corres-

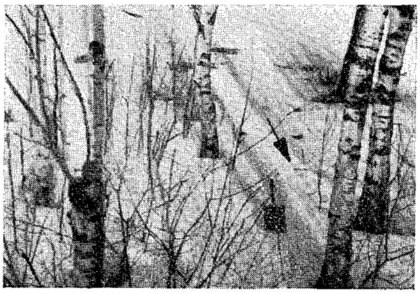

Fig. 1. — The observation point 5.

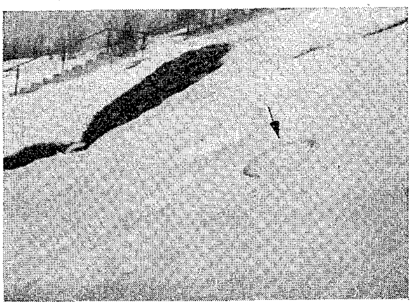

Fig. 2. — The observation point 6.

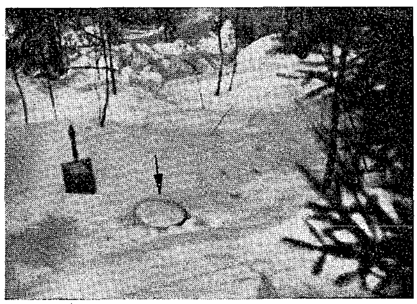

Fig. 3. — The Observation point 7.

ponding differences in Table II have not been taken into account in the calculations.

Besides evaporation (*E*) there can also be a condensation (*K*).

TABLE II. — *Precipitation* (P), *temperature* (t), *relative humidity* (r), *dew-point* (τ), *and effective evaporation* ($E — K$) *on the different*

Day.	P. (*mm.*)	t. Min.	t. Max.	t. *M.*	r. Max.	r. Min.	τ. 7h.	τ. 13h.	τ. 21h.	d. (*mm.*)	$\bar{v}$ (*m./s.*). 7h.	$\bar{v}$ (*m./s.*). 15h.	$\bar{v}$ (*m./s.*). 21h.	*M.*
1937														
Mar. 24	–	– 1.2	1.5	0.1	95	69	– 2.2	– 3.3	– 2.9	0.7	3.4 SW	4.0 W	3.0 WSW	3.9
25	–	– 6.2	1.8	– 2.4	94	57	– 7.1	– 4.8	– 5.3	0.6	0.6 N	2.0 E	3.8 NE	2.5
26	2.0*	– 1.6	0.7	– 0.7	97	65	– 5.7	– 5.3	– 1.8	0.8	7.5 N	6.7 N	2.4 NW	5.7
27	0.5*	– 2.7	1.0	– 1.0	96	77	– 2.5	– 2.2	– 2.5	0.4	0.8 WNW	2.2 E	3.6 E	2.5
29	0.2*	– 3.1	2.9	0.2	97	63	– 0.8	– 1.2	– 5.3	0.6	3.4 NNW	4.6 SW	3.7 WSW	3.7
30	–	– 4.9	2.2	– 1.9	92	34	– 6.2	– 9.7	–10.9	0.9	4.0 WNW	6.2 WNW	4.7 WNW	5.0
31	–	– 7.7	6.3	– 0.5	88	35	– 8.6	– 7.1	– 5.3	1.0	4.8 WNW	7.4 WNW	5.0 WNW	5.2
Apr. 1	–	– 3.5	6.7	0.5	91	45	– 5.3	– 4.8	– 3.6	1.0	4.9 WSW	5.5 WSW	4.2 WSW	4.8
2	–	– 5.3	4.6	0.3	95	49	– 5.7	– 5.3	– 6.2	1.0	2.2 NW	3.1 SSW	3.3 SE	2.8
3	–	– 4.1	5.0	0.3	94	62	– 4.0	– 1.8	– 2.9	0.8	5.5 E	4.3 ESE	3.8 E	4.2
4	–	– 2.0	4.9	1.6	84	59	– 3.6	– 1.8	– 4.0	1.1	5.4 E	4.7 ESE	5.0 E	5.3
5	–	– 1.5	7.6	2.6	78	45	– 4.8	– 2.5	– 4.4	1.2	3.6 NE	2.4 ESE	2.0 SE	3.0
6	–	– 3.2	7.7	2.3	81	46	– 6.2	– 4.4	– 4.4	1.3	4.4 E	2.4 ESE	2.8 SE	2.9
7	–	– 2.5	8.6	2.9	83	45	– 4.4	– 2.9	– 1.8	1.3	3.2 E	3.2 SSW	5.0 SSW	2.7
8	–	– 0.7	7.6	2.8	87	63	– 2.5	+ 0.1	– 0.8	1.1	2.6 SE	2.2 SE	3.0 SE	[illegible]
9	–	0.4	9.3	4.5	88	54	– 1.2	+ 1.0	– 1.2	1.3	2.6 ESE	2.0 SE	4.0 SE	2.8
10	–	1.6	10.4	5.0	81	49	– 0.8	+ 0.1	– 2.2	1.5	3.6 SE	4.5 SE	4.5 E	4.0
11	–	1.0	9.3	4.2	90	54	– 1.2	+ 0.7	– 1.5	1.3	4.5 E	4.3 ESE	4.5 ESE	4.1
12	–	– 0.7	10.5	4.4	89	44	– 1.2	– 1.5	– 2.2	1.3	4.0 E	2.4 ESE	3.0 ESE	2.8
13	–	0.6	9.5	4.5	86	53	– 1.5	+ 0.4	– 2.2	1.3	3.2 E	4.7 E	5.3 E	4.5
14	–	0.6	9.1	5.2	94	57	– 0.5	+ 1.5	– 0.2	1.4	5.3 E	4.5 ESE	6.0 E	4.9
1938														
Mar. 8	–	– 4.8	1.4	– 1.7	92	51	– 9.2	– 8.1	– 8.1	1.0	8.1 NW	9.1 WNW	4.1 WNW	7.2
9	2.5*	– 7.1	0.2	– 3.2	99	76	– 7.6	– 3.6	– 2.9	0.4	4.1 NNE	4.2 E	3.7 E	3.5
10	–	– 5.8	0.4	– 2.2	98	60	– 3.6	– 5.7	– 6.2	0.5	2.7 E	4.6 E	2.1 E	3.2
11	–	–10.2	0.1	– 5.2	91	56	–11.6	– 7.6	– 9.7	0.6	4.0 NNE	6.9 N	6.9 N	5.3
12	–	– 7.7	– 1.1	– 5.4	98	63	– 9.2	– 7.6	– 8.6	0.5	3.4 N	4.3 N	3.4 NNW	4.0
13	0.6*	– 8.1	6.4	0.2	97	72	– 4.0	+ 1.8	+ 1.3	0.5	7.6 WSW	5.7 WNW	5.8 WNW	6.0
14	–	1.1	9.3	4.9	95	60	+ 0.4	+ 1.5	+ 1.0	1.2	5.6 WNW	5.4 WNW	4.9 W	5.2
15	0.0	1.5	7.9	3.6	99	65	+ 0.4	+ 1.5	– 0.2	0.9	4.7 W	6.7 SSW	7.2 WSW	5.8
16	–	0.5	7.5	3.3	99	68	+ 0.1	+ 1.3	+ 1.5	0.7	4.9 WSW	5.7 WSW	4.3 WSW	4.6
17	0.3*	– 5.4	1.5	– 0.8	98	54	– 0.8	– 5.3	– 8.6	0.8	7.6 ENE	6.4 NE	4.3 NE	5.2
19	0.2	1.7	7.5	3.8	98	55	+ 0.4	– 0.8	+ 2.6	0.8	6.6 W	4.7 SW	5.0 SW	5.2

* Snow.

saturation deficit (d), velocity and direction of wind ($\bar{v}$), number of hours with sunshine (z), observation points at Ilmala in 1937 and 1938.

z. (hrs.)	E — K (mm.) at different points of measurement. 1	2	3	4	5	6	7	8	9	10	11	12	Day.
													1937
	0.0 b					0.2 b	0.0 a			0.1 b			Mar. 24
3.9	0.8 b					0.3 b	0.5 a			0.5 b			25
–	0.1					0.2	0.0			0.1			26
–	0.0 b					0.5 b	0.1 a			0.5 b			27
2.5	0.3 b					0.5 b	0.0 a			0.2 b			29
8.7	−0.2 c		0.9 c			0.8 c	0.3 a			1.1 c			30
11.4	1.3 c		1.5 c		1.0 b	2.5 c	0.1 a			0.7 c			31
8.9	0.0 b				0.8 b	0.6 b	0.1 a	0.2 a	0.5 b				Apr. 1
10.9	0.6 b		0.7 b		0.1 b		0.3 a	0.3 a	0.0 b				2
9.1	0.3 b		0.0 b		0.4 b		−0.1 a	0.0 a	−0.2 b				3
9.4			0.2 c		0.5 b		0.3 a	0.3 a	0.1 b				4
10.3	0.5 b		0.4 b		0.4 b	0.2 b	0.0 a	0.1 a	0.0 b				5
11.7	0.6 b		0.5 b		0.4 b	0.3 b	0.2 a	0.2 a	0.4 b				6
11.8	0.3 b				0.6 b	2.4 b	0.1 a	0.0 a	0.3 b				7
.8	0.3 b	0.7 b	0.1 b		0.3 b	0.3 a	0.0 a	0.1 a	0.1 b				8
.2		0.0 b	0.0 b		0.1 b	0.1 b	0.0 a	−0.1 a	0.6 b				9
6.6	0.8 b	0.4 b	0.4 b	0.5 b	0.2 b	0.3 b	−0.1 a						10
8.6	0.4 b	0.2 b			0.3 b		0.2 a	0.1 a	0.3 b				11
9.5				0.4 b			0.2 a	0.1 a	0.1 b				12
5.5				0.3 b			0.2 a	0.2 a					13
10.9				0.2 b			0.1 a	0.0 a	0.1 b				14
													1938
9.7			1.1 c		0.9 c	1.4 c					0.7 c		Mar. 8
3.8 } 5.4 }		0.1	0.1		0.9	0.2	1.9				0.6		{ 9 { 10
9.8		0.3 c	1.0 c		0.2 b	0.2 b	0.0 a				1.6 c	0.3 c	11
5.1		0.5 b	0.9 b		0.6 b	0.3 a	0.6 a				−0.1 b	0.1 b	12
0.7					0.0 b	−0.4 c	0.4 a				−0.2 c	−0.3 c	13
7.0					−0.2 b	−0.1 c	0.0 a				0.0 c	0.0 c	14
6.4			−0.4 c		−0.1 b	0.4 c	0.0 a				−0.3 b	−0.2 b	15
5.1			−0.3 b		−0.4 b	−0.7 b	−0.1 a				−0.4 b	−0.3 b	16
0.4			0.3 c		1.0 b	0.1 b	0.6 a				1.3 c	0.6 b	17
5.0			−0.3 c		−0.4 b	0.1 b	0.0 a					−0.2 b	19

The figures in Table II represent the difference between these two terms ($E - K$) and this difference is called effective evaporation. Considerable divergences in effective evaporation are noticeable at different points of observation and at different times. Negative figures also occur.

If group averages are calculated by including those observations, in which the mean temperature during 24 hours was below 0° C, in the first group; those, in which the temperature was between 0.1 and 30° C, in the second; and those, in which the temperature was above 3° C, in the third, we obtain the figures given in Table 3. The table also includes the group averages of the saturation deficit and the mean error of the average effective evaporation (m).

TABLE III.

Group averages of the mean temperature during 24 hours (t), the saturation deficit (d) and the effective evaporation of the surface of the snow ($E - K$), classified according to rising t-values.

Group No.	n.	t (C°).	d (mm).	$(E - K) \pm m$ (mm per 24 hrs).
1	43	—2.6	0.7	0.64 ± 0.08
2	64	1.4	1.0	0.26 ± 0.05
3	53	4.3	1.2	0.05 ± 0.04

According to the Table the effective evaporation decreases with increasing temperature of air and saturation deficit. This is contrary to the rule, thus our results apparently depend on special circumstances.

Let us next examine, whether the wind conditions effect the results. For this purpose the results of observations given in Table II are classified according to the influence of the wind in three groups (a, b, and c), such observations being referred to group a, in which the influence of the wind may be considered insignificant; such observations to group b, in which the influence of the wind is restricted by the obstacles described above or in which the strentgh of the wind (the average for 24 hours) is below 5 m/s; and such observations to group c, in which the point of observation is exposed freely to a wind of 5 m/s or more. The classification is also shown in Table II.

If the group averages of the temperature of the air and of the evaporation are determined in groups a, b, and c, the results given in Table IV are obtained.

TABLE IV.

Group averages of the temperature of the air (t) and of the effective evaporation ($E - K$) according to the influence of the wind.

Group.	n.	t (C°).	$(E-K) \pm m$ (mm/24 hrs).	δ (mm).
a..........	42	1.7	0.14 ± 0.03	0.18
b..........	90	1.6	0.28 ± 0.04	0.40
c...........	28	—0.4	0.59 ± 0.14	0.73

It is evident from these figures that the wind exercises an influence that increases the effective evaporation. The mean errors of the individual observations (δ) are also shown in the table. The error increases appreciably as the strength of the wind increases. Thus the effective evaporation varies greatly in places exposed to wind and when there is a strong wind, which may be explained by the wind being able to increase evaporation in some conditions and condensation of vapour on the surface of the snow in others. The latter influence is especially noticeable in North Finland, in localities exposed to the wind, where a thick layer of anow, called « tykky », collects round the trees (1).

Table IV also shows that the temperature of the air was low in windy weather on the days of observation, which may partly account for the high (*E-K*) figures of group 1 (Table III). In order to eliminate any possible error caused by this, the group averages of the temperature of the air and of the effective evaporation in the group in Table III were also calculated, omitting the figures belonging to group *c*. The results are shown in Table V. This table also indicates the share of *a*-figures in each group. As this share is the same in an the groups 1-3, the influence of the wind on the group averages may be considered to be small.

TABLE V.

Group averages of the average temperature during 24 hours (t), maximum (r_{max}) and minimum (r_{min}) of relative humidity during 24 hours, hours of sunshine (z) and effective evaporation ($E - K$).

Group No.	n.	*a*-Figures in % of the group figures.	t (C°).	r_{max} (%).	r_{min} (%).	z (hrs).	$(E-K) \pm m$ (mm/24 hrs).
1.......	25	32	—2.9	95	59	4.6	0.41 ± 0.06
2.......	60	32	1.5	88	54	7.7	0.29 ± 0.05
3.......	47	32	4.3	91	56	7.0	0.07 ± 0.04

(1) TYKKY, a crust of ice formed by the snow on trunks and branches of trees in a S or *w* wind.

According to the table the (*E*-*K*) figures of group 1 have decreased in comparison with the figures in Table III, but there is still the tendency of the (*E*—*K*) figures to decrease as the *t*-figures increase. The group averages indicating the daily maximum and minimum relative humidity do not give any indications, by means of which this tendency can be explained. Nor does the number of hours of sunshine seem to be the cause of the tendency referred to.

Let us further examine, whether the point of observation possibly exerts an influence on the evaporation. This is done by determining the average daily evaporation in all the observations at each point of observation. These averages are compared with the averages for the corresponding observation days at the point 7. The point of comparison is a forest glade entirely protected from the wind [1]. The results of the comparison are given in Table 6.

TABLE VI.

Group averages (E — K) of the effective evaporation at different points of observation, averages $(E — K)_7$ of the corresponding observation days at observation point 7 and the differences between (E — K) and $(E — K)_7$.

Observation point.	1937				1938			
	n.	$(E-K) \pm m$ (*mm*).	$(E-K)_7 \pm m$ (*mm*).	$(E-K) - (E-K)_7$ (*mm*).	*n.*	$(E-K) \pm m$ (*mm*).	$(E-K)_7 \pm m$ (*mm*).	$(E-K) - (E-K)_7$ (*mm*).
1.	15	0.40 ± 0.10	0.11 ± 0.04	0.29				
2.	4	0.33 ± 0.15	0.03 ± 0.06	0.30				
3.	10	0.47 ± 0.15	0.10 ± 0.05	0.37	6	0.20 ± 0.26	0.18 ± 0.18	0.02
4.	4	0.35 ± 0.06	0.10 ± 0.07	0.25				
5.	12	0.43 ± 0.08	0.09 ± 0.04	0.34	8	0.09 ± 0.17	0.19 ± 0.10	—0.10
6.	13	0.69 ± 0.22	0.10 ± 0.04	0.59	8	—0.01 ± 0.13	0.19 ± 0.10	—0.20
7.								
8.	13	0.12 ± 0.03	0.12 ± 0.03	0.00				
9.	12	0.19 ± 0.07	0.12 ± 0.01	0.07				
10.	6	0 52 ± 0.47	0.17 ± 0.08	0.35				
11.					7	0.27 ± 0.31	0.21 ± 0.12	0.06
12.					8	0.00 ± 0.11	0.19 ± 0.10	—0.19

The influence of the point of observation is evident. In 1937 the effective evaporation at points 1-5, situated on a hill and exposed to wind, was on an average 0.25-0.37 *mm* greater than at point 7. At point 6 the difference is 0.59 *mm* and greater than at the other

[1] The rainfall observations of the Ilmala Observatory are made in the same forest glade in which the point of comparison is situated.

points. This may be due to the sunshine. At point 8 on the NW slope, where there is only a little direct sunshine in the spring, the difference is only 0.07 *mm*, but at point 9, where the conditions are approximately the same as at the previous point, the difference is 0.35 *mm*. In 1938, when, judging by the effective evaporation, the conditions display a divergence from the conditions in 1937, the figure for point 6 on the SW slope is 0.20 *mm* and the figure for point 12 on the N slope is 0.19 *mm* less than that of the point of comparison. There is thus some irregularity in the results. This may be due, among other things, to changes in the wind conditions. The Ilmala hill and the neighbouring woods may cause air currents, so that the direction and strength of the wind differ considerably from the results of the observations given in Table II.

Possibly the difference in the effective evaporation at different points of observation may influence the tendency of the (*E-K*) figures in Tables III and V. There is reason to assume, however, that there are other factors that are responsible for it.

Vapour can be condensed more plentifully on the surface of the snow in warm weather than in cold. Besides, the structure of the snow at the and of spring is different from its structure in warm weather in the early spring.

Woeikof (1890, p. 38) points out that, when the temperature of the air is below 0° C, the temperature of the surface of the snow is mostly higher than the dew-point of the upper air. In such conditions no condensation fo vapour occurs on the snow. On the other hand, when the temperature of the air is above 0° C, there will be a condensation of vapour on the surface of the snow. Brückner (1890, p. 150) finds that the observations of the temperature of the surface of the snow at Sagastyr in the winters 1882-1883 and 1883-1884 lead to means which are lower than the corresponding dew-points and that thus a snow-cover will in general cause a condensation of vapour on ist surface.

Keränen (1920, p. 188) expresses the opinion that, when the temperature of the air in spring rises during the day above 0° C, the temperature of the snow is often ± 0° C. Table 2 gives the dew-point of the air at 7, 13 and 21 o'clock according to the humidity measurements carried out at Ilmala. It will be noted that the dew-point rises above 0° C on some days. At any rate on those days, on which the average daily temperature was generally higher than + 3° C, the dew-point was higher than the temperature of the surface of the snow and the conditions were consequently favourable for the condensation of vapour on the snow. In examining the (*E-K*)-figures for these days, we see that in general they are very low. Most of the *minus*-figures also occur in these days. As the temperature of the snow was not measured, it cannot be checked in regard to all the observations, when condensation on the surface of the snow could have occurred. The principal cause, however, of the (E-K)-figures decreasing in general, when the temperature of the air rises, seems to be that in warm weather the dew-point was above the temperature of the snow, when the condensation of vapour occurred on the surface of the snow and the evaporation was slight or did not occur at all.

On the basis of the above the following conclusions can be drawn :

1. The wind conditions exert an influence on evaporation, which generally increases, when the influence of the wind increases. In open spaces the evaporation is in general greater than in places protected from the wind, but wind can also promote the condensation of vapour on the surface of snow.

2. When the temperature of the air rises the evaporation seems to decrease according to the observations made at Ilmala in the spring of 1937 and 1938. The cause of this has not been explained with certainty owing to the incompleteness of the material of observation, but it is probable that in warm weather there is a greater number of instances for the dewpoint of the air being higher than the temperature of the surface of the snow, *i.e.*, for the vapour being condensed on the surface of the snow, than in cold weather. The observations indicate, that, when the ground is covered by snow, the evaporation cannot be determined by such methods, in which the evaporation is presumed to be chiefly dependent on the temperature of the air and to increase as the temperature of the air rises.

LITERATURE.

Ed. BRÜCKNER, Verdunstung einer Schneedecke, *Meteorologische Zeitschrift*, Wien, 1890.

J. KERÄNEN, *Über die Temperatur des Bodens und der Schneedecke in Sodankylä*, Helsinki, 1920.

A. WOEIKOF, Verdunstung einer Schneelage, *Meteorologische Zeitschrift*, Wien, 1890.