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On the Evaporation from the Northern Baltic

By

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At the study of evaporation from the sea, attention must, according to SVERDRUP (3), be paid to the following aspects: 1) above the sea-surface lies a thin laminar layer in which the transport of water vapour takes place by molecular diffusion. 2) Above this layer the transport of water vapour takes place by eddy conductivity. 3) At eddy conductivity the roughness of the surface, resulting from the variations of wind velocity, must be considered. With these aspects as his starting-point and basing himself on the principles of the turbulence theory, SVERDRUP (4) finds the following formula for the evaporation from the sea:

$$E = \frac{\frac{\chi \, 0.623}{p} \varrho \, (e_w - e_z) W}{\frac{\chi}{k_0} \ln \frac{z + z_0}{d + z_0} + dW} \tag{1}$$

where

$$W = \sqrt{\frac{\tau}{\varrho}} = \frac{k_0}{\ln \frac{z + z_0}{z_0}} W_z. \tag{2}$$

In the formulas χ denotes the diffusion coefficient $= 0.235$ cm²/sec., k_0 the universal turbulence constant $= 0.4$ (KA'RMA'N), z the height of observation in cms., z_0 the roughness parameter $= 0.6$ (ROSSBY), $d = 4.12/W$ the thickness of the laminar layer, and τ the tangential stress of wind. p is the pressure in mbs., ϱ the density g/cm³, e_w and e_z the vapour pressure at sea surface and in air in mbs., and w_z the wind velocity cm/sec.

For practical computations, Formula 1 can be reduced to

$$E = k\,(e_w - e_z)\,W_z, \tag{3}$$

where k is an approximate constant. If the values of the above-mentioned parameters are substituted in the Formulas 1 and 2, and p is set $= 1000$, $\varrho = 1.2 \times 10^{-3}$, $z = 600$, and $d = 0.14$, which corresponds to the value of the wind velocity $W_z = 500$, the evaporation during 24 hours can, according to JACOBS (1), be written with the formula

$$E_1 = 0.108\,(e_w - e_6)\,W_6, \tag{4}$$

where E_1 denotes the evaporation in mm., e_w the vapour pressure at sea surface, e_6 vapour pressure in the height of 6 m, in mbs., and W_6 the wind velocity in the height of 6 m., in m/sec.

As an application of Formula 4, the evaporation from the Northern Baltic in the region of Bogskär lighthouse can be computed ($\varphi = 59°\ 31'$; $\lambda = 20°31'$), basis being taken on the meteorological and talassological observations made at Bogskär in 1901—13. On computating $e_w =$ the influence of salinity can be excluded, this due to the fact that, according to the formula $e_w = e_d\ (1 - 0.0053\ S)$, where e_d is the vapour pressure at the surface of distilled water and s the salinity in parts per thousand, the decreasing influence of salinity on vapour pressure is $< 5 \times 10^{-5}$ mb. The vapour pressure and the wind velocity recorded at Bogskär lighthouse, 24 m. above the sea surface, have been reduced to the height of 6 m. In the reduction of the wind, HELLMAN's formula $V : v = \sqrt[5]{H} : \sqrt[5]{h}$ has been used.

Some average monthly values of the temperature of the air and the surface water, of the differences of vapour pressures, of the wind velocity, and of the evaporation computed from these, are given in Table 1. It is assumed that the sea remains free from ice all through the winter. The table shows that in autumn when the cold air comes into contact with the comparatively warm water the evaporation is at its highest, and in early summer when, conversely, the water is relatively cold in comparison with the air, the evaporation is at its lowest. The maximum value of E_1, 77 mm, is reached in November at which time the wind velocity also is at its highest. The secondary minimum occurs in September which results from the small difference between the temperatures of the air and water. At our earlier studies of the course of the heat current between the air and the

Table 1. The average temperature of the surface water (t_w) and of the air (t_a), the difference of the vapour pressure ($e_w—e_a$), the wind velocity (W_6), and the evaporation (E_1) at Bogskär (1901—13).

	J	F	M	A	M	J	J	A	S	O	N	D	Year
t_w °C	2.3	1.1	0.6	1.3	3.6	8.5	13.9	15.4	12.6	9.9	6.8	4.4	6.7
t_a °C	—0.4	—1.4	—0.2	2.0	5.9	10.9	14.6	14.9	11.7	7.9	3.4	0.8	5.8
$e_w—e_a$ mb ..	1.9	1.9	1.5	0.8	0.3	0.3	1.4	3.4	2.5	2.4	2.9	2.8	1.8
W_6 m/sec ..	8.2	8.0	7.2	6.1	5.1	5.3	5.2	5.9	6.1	7.3	8.3	8.1	6.7
E_1 mm	52	46	35	16	6	6	24	67	50	58	77	75	512

water at Bogskär (2) we found that the flow of heat from the water in September was lower than, through interpolation, one might expect. On the average, namely, the flow of heat from the water at Bogskär is 800 in August, 700 in September, and 3,000 cal/cm² in October. Thus the amount of average annual evaporation is 512 mm.

We have tried to determine the constant k in Formula 3 basing ourselves on the evaporation records (6) taken in the region of the sea near the coast at Jungfruskär ($\varphi = 60°8'$; $\lambda = 21°4'$). At our disposal we have some measurements of evaporation taken with six different types of gauges on the shore of Jungfruskär, 23—30 July 1922. According to these records and the meteorological observations made on the spot, three different gauges give the result: $k = 0.24$; 0.25; 0.26. If, according to Wüst (7), we assume that, in order to determine the evaporation from the sea, this result given by the evaporation gauge is to be multiplied with the number 0.48, the product is: $k = 0.12$ which value, however, is too great.

We will still compute the evaporation on the basis of heatb alance. If Q denotes total solar energy, rQ_t solar heat reflected from sea surface, Q_b total back radiation, Q_e heat of evaporation, Q_c heat exchanged between sea and atmosphere through convection, and Q_v amount of heat added to or removed from the water mass through advective processes, we find that

$$(5) \qquad Q_t - rQ_t - Q_b - Q_e - Q_c - Q_v = O.$$

Not considering Q_v and substituting $R = Q_c/Q_e$, the amount of evaporation will be

$$(6) \qquad E_2 = \frac{Q_t - rQ_t - Q_b}{(1 + R)\, L_t},$$

where L is latent heat of vaporization of water. »Bowe's ratio» R is computed from the formula

$$R = 0.66 \frac{p}{1000} \left(\frac{t_w - t_a}{e_w - e_a}\right) \tag{7}$$

According to our calculations of the heat balance of the sea (2) at Bogskär $Q_t = 850 \times 10^2$, $rQ_t = 67 \times 10^2$, and $Q_b = 412 \times 10^2$ cal/cm². From Formula 7 we derive $R = 0.2$. Substituting these values to Formula 6, we see that $E_2 = 52.2$ g/cm² which corresponds to the amount of evaporation 522 mm. This value is 10 mm greater than the values of E_1 computed above.

According to JACOBS (1), Formula 4 generally gives too small values, wherefore k is set $= 0.108\ E_2/E_1$. Using the corresponding method we get $k = 0.110$ which value thus will be applicable to use in the Baltic.

WITTING has resulted in 566 mm as being the amount of average annual evaporation (5). Our calculations make this value seem too great and it is more likely that, in the Northern Baltic at least, the annual evaporation is about 52 cm.

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