A computation of the evaporation in Southern Sweden during 1957

By ALF NYBERG, *Swedish Meteorological and Hydrological Institute*

(Manuscript received February 27, 1965)

ABSTRACT

The monthly evaporation during 1957 from a region in Southern Sweden has been computed by means of studies of the precipitation and the net influx of water vapour into the area. Upper air charts have been used and from the geostrophic winds and humidity values the net flux has been computed twice a day. Various sources of error have been discussed, among them the effect of the ageostrophic component of the wind which for various reasons had to be neglected. No definite conclusion as to the importance of the ageostrophic component has been reached, but it seems likely that the errors caused are not very large in this area.

The method seems useful even over the rather small area studied, but an improved network with denser observations is desirable. The evaporation was largest during July and August and smallest during the winter months. The contribution to the run-off was largest during July–October. During April and May the evaporation was even larger than the precipitation.

The yearly value of evaporation agreed well with estimates from hydrologic studies.

Introduction

In many places various methods have been used to measure the evaporation. The first attempts were intended to allow for determining the evaporation from a single point with the aid of tanks or pans containing water or some wet material and the loss of weight or volume was observed. As regards the evaporation from very small areas up to some tens of square meters successful experiments have been made with lysimeters. The water lost by evaporation has been measured by different methods of weighing.

In later years it has been attempted to determine the evaporation on the basis of the variation with height of the humidity and the horizontal wind. This technic can compete with the lysimeter technic and can also be representative for somewhat larger areas. Such studies may be supplemented by direct observations of the vertical flux of water vapour during shorter periods (Priestley, 1959). Values of water vapour pressure and vertical winds in a fixed level are simultaneously recorded and the difference between the upward and downward fluxes is a direct measure of the evaporation (Högström, 1964).

The study of evaporation from larger areas involves several problems. One method that has been used frequently is the study of the water balance. In a certain area the precipitation is measured at several places as well as the surface run-off the ground water level and the soil moisture. If possible also subterranean water flows are estimated. If suitable time periods are chosen, i.e. if there is no change of the soil moisture and of the snow cover from the beginning to the end of the period the determination of evaporation can be made with comparatively great accuracy, but considerable problems exist in many cases and the measurements call for great experimental care if results are to be reliable.

Method used

Some years ago the problem of evaporation from large areas was attacked in a new way (Benton, 1950). The precipitation is computed in a normal way from measurements at existing stations. The amounts of moisture flowing into the area and out from it at various levels are computed with the aid of aerological observations. The changes of moisture in the same levels from the beginning to the end of the period are also computed. The evaporation is obtained from the following equation

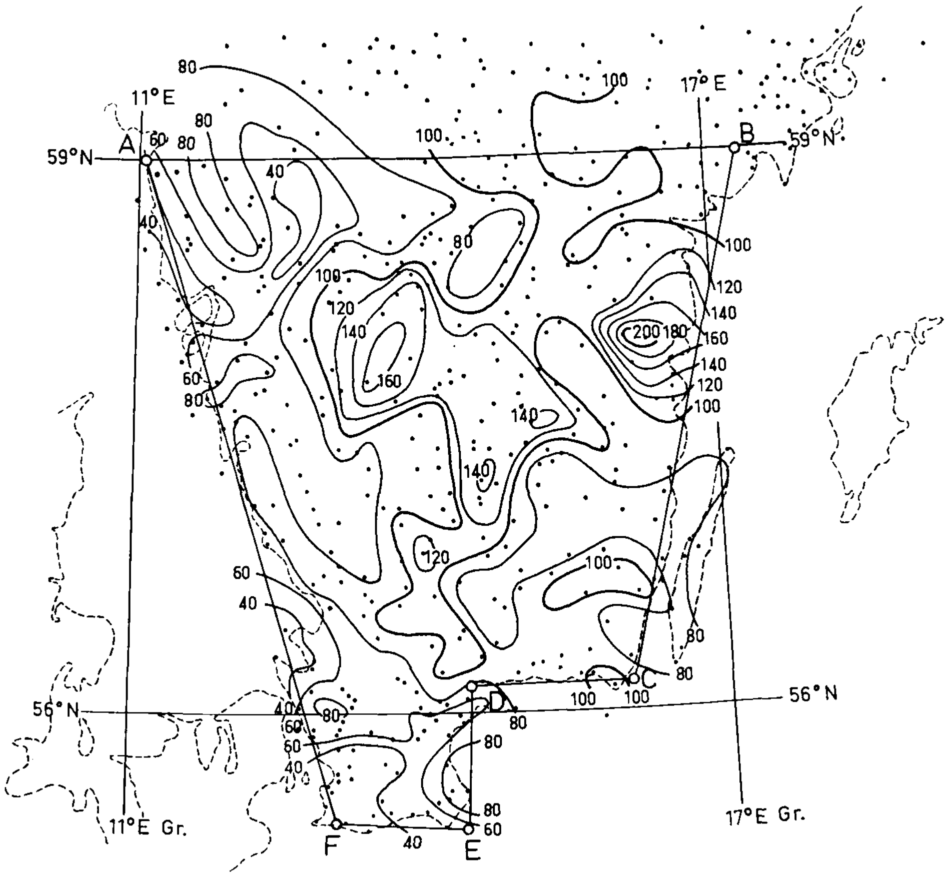

FIG. 1. Observing stations and measured precipitation during the month of July in the region *ABC DEFA* (Southern Sweden).

$$E = P - A + K, \qquad (1)$$

where E is the evaporation, P the precipitation, A the convergence of absolute humidity in the area and K the difference between the water vapour content at the beginning and at the end of the period. Such studies have been carried out for the North American continent with great success, e.g. by BENTON (1950). When using the same technic for smaller areas certain difficulties arise. However, an attempt to compute the evaporation over Finland using this technic (NYBERG, 1958) gave results indicating that the method yielded results of some value even in areas of the size of Finland.

At first some details about the methods used. The area studied, *ABCDEFA*, is to be found in Fig. 1. On the basis of more than 400 observing stations precipitation charts have been drawn for each month during 1957 and the total amount of precipitation has been computed. A discussion of the accuracy of the results is given below.

In the studied area and in surrounding areas radiosondes were launched twice a day at the stations marked on Fig. 2. Observations were made from 1 January to 31 March at 03 GMT and 15 GMT and thereafter at 00 GMT and 12 GMT. On the basis of these observations charts were analyzed showing the height fields of the pressure surfaces and the moisture (mixing ratio given in g/kg) at 1000 mb, 850 mb, 700 mb and 500 mb.

The area which roughly includes the land

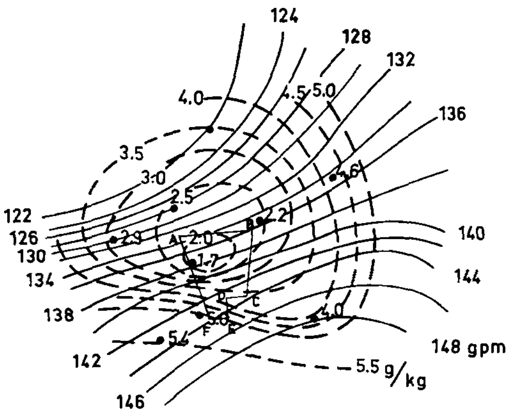

FIG. 2*a*. Values of geopotential, in geopotential decameters and mixing ratio in g/kg within and near the region *A B C D E F A* on the 850 mb level at 15 GMT 5 February 1957.

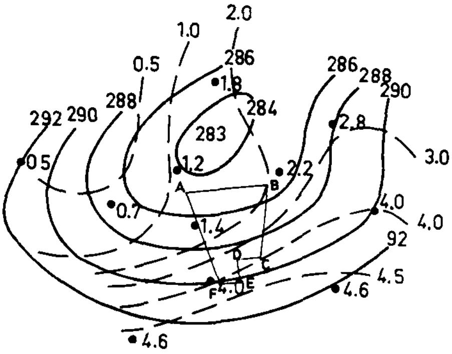

FIG. 2*b*. Values of geopotential, in geopotential decameters and mixing ratio in g/kg within and near the region *A B C D E F A* on the 700 mb level at 12 GMT 23 September 1957.

area of Southern Sweden has the form of a polygon *A B C D E F A*. The difference of geopotential $\Delta\phi_1$ between *A* and *B* for each day and each synoptic hour was multiplied by the mean value at the same time of the mixing ratio along the line *A B*, x_1, and to this product was added the corresponding products obtained for the other parts of the polygon as shown in Table 1.

The following equations show the computational procedure which was followed.

The net flux per second into a volume of area *A B C D E F A* and height Δz at the level *p* mb is

TABLE 1. *Values of geopotential in geopotential meters, φ_i and humidity x_i (mixing ratio).*

The values $x_i\Delta\varphi_i$ are proportional to the humidity flux. The value $\sum_{AB}^{FA} x_i\Delta\varphi_i$ is taken around the polygon *A B C D E F A*.

	Date: 5 Feb. 1957 15 GMT Level: 850 mb			
Point	φ_i	$\Delta\varphi_i$	x_i	$x_i\Delta\varphi_i$
A	1330	−21	2.0	− 42
B	1351	−87	2.5	−218
C	1438	10	3.5	35
D	1428	−17	4.0	− 68
E	1445	08	5.0	40
F	1437	107	2.9	310
A	1330	$\Sigma x_i\Delta\varphi_i$		+ 57

$$F = F_g + F_{ag} = \sum_{AB}^{FA} L_i u_i \varrho_i x_i \Delta z =$$

$$\sum_{AB}^{FA} L_i (u_{gi} + u_{agi}) \varrho_i x_i \Delta z, \qquad (2)$$

where u_{gi} is the horizontal geostrophic and u_{agi} the horizontal ageostrophic wind components normal to the boundary, ϱ_i the density of the air, x_i the mixing ratio and L_i the length of *AB*, *BC* and so on.

(2a) The geostrophic flux F_g into a volume of the hight Δp may also be written

$$F_g = -\sum_{AB}^{FA} \frac{1}{fg} x_i \Delta\phi_i \Delta p,$$

where *f* is the Coriolis parameter, *g* the acceleration of gravity, $\Delta\phi_i$ the geopotential difference between *A* and *B*, *B* and *C* and so on.

The total vertically integrated net geostrophic influx during 30 days, from the surface pressure p_0 to 400 mb, is

$$\mathbf{F}_g = -\int_{p_0}^{400} \left[\sum_{1}^{30} \sum_{AB}^{FA} \frac{t}{fg} x_i \Delta\phi_i\right] dp. \qquad (3)$$

Here *t* is the time of 24 hours in seconds.

The corresponding ageostrophic flux $\mathbf{F}_{ag}$ is

$$\mathbf{F}_{ag} = -\int_{p_0}^{400} \frac{t}{g} \sum_{1}^{30} \sum_{AB}^{FA} L_i u_{agi} x_i \, dp. \qquad (4)$$

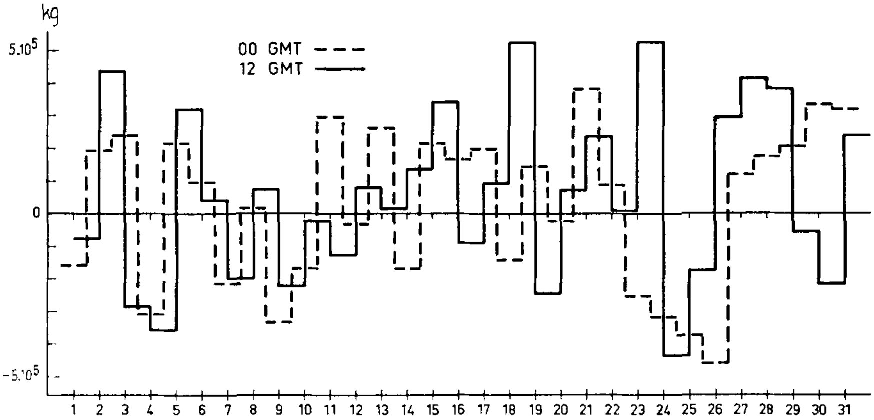

FIG. 3. The variation of the net flux of water vapour in g/sec into a unit mb deep layer during October 1957 at the 850 mb level for 00 GMT dotted line and for 12 GMT whole line.

The vertically integrated mean value of u_{ag} taken along the boundary of the area and over a long period is close to zero. However, if there is a correlation between u_{ag} and x, there may be a net ageostrophic influx of humidity. In this study the value $\mathbf{F}_{ag}$ was neglected and only the geostrophic flux $\mathbf{F}_g$ was computed.

For the computation of the flux through AB the line is divided into parts as necessary and the flux is computed for each separate part. Each day and each level thus gives a net flux value which may be positive, as in Fig. 2*a*, or negative, as in Fig. 2*b*. Fig. 3 shows the daily values of

$$\frac{1}{fg}\sum_{AB}^{FA}(x_i\,\Delta\phi_i)$$

for a layer, the thickness of which is 1 mb, at the 850 mb level during the month of October both at 00 GMT and 12 GMT. The monthly sum of the flux, at 00 GMT and 12 GMT separately, was computed for each level. These monthly sums were inserted in a flux–pressure diagram, Fig. 4, and the total flux value for the month, and respective synoptic hour, was computed by integration from the surface to 400 mb, the level at which the flux was assumed to be equal to zero.

When integrating it was assumed that there was a linear variation of the values from one level to the next one. This is, however, particularly uncertain when going from the 1000 mb level to the 850 mb level, where the mixing ratio may change rapidly with height. The computed geostrophic winds are also in a shallow layer considerably stronger than the actual winds. Similar difficulties of interpolation would be encountered if actual winds at 1000 mb and 850 mb had been used. In Fig. 4 is indicated by dotted lines one extreme of many possible interpolation curves which, if accepted, would have given a smaller influx value and a higher evaporation value.

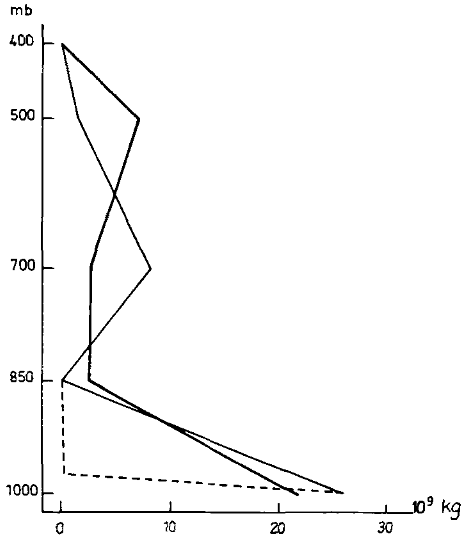

FIG. 4. The mean variation with height of the humidity flux in a layer of unit mb thickness December 1957 00 GMT, whole thin line, and 12 GMT, whole thick line. Dotted line shown as one extreme possibility of non-linear variation of the humidity flux between the 1000 mb and the 850 mb levels.

Similarly the change in water vapor content over the area was integrated and the evaporation could be obtained from equation 1.

Discussion

When computing the evaporation during January based on observations of the flux at 00 GMT we have 31 observations from 1 January to 31 January. Each of these cases gives the instantaneous flux at the time 00 GMT. However, we let each such value represent the mean value of the flux during 24 hours and the first value is valid for the period 12 GMT 31 December 1956 to 12 GMT 1 January 1957 and the total period for the month of January includes the time from 12 GMT 31 December 1956 to 12 GMT 31 January 1957. Correspondingly we have for the computation of the flux at 12 GMT that the total flux value during January includes the period from 00 GMT 1 January 1957 to 00 GMT 1 February 1957. These two computations for 00 GMT and 12 GMT have been carried out quite independently.

The precipitation is observed at all stations at 06 GMT and only at some stations also at 18 GMT. The precipitation for January represents the time period from 06 GMT 1 January to 06 GMT 1 February.

The precipitation relating to the flux at 00 GMT should be computed as from 12 GMT 31 December to 12 GMT 31 January. A correction has been made in such a way that the precipitation during the period 18 GMT 31 December to 06 GMT 1 January has been added and the precipitation during the period 18 GMT 31 January to 06 GMT 1 February has been deducted. The precipitation during the period 12 GMT to 18 GMT 31 December had to be neglected and instead the precipitation during the period 12 GMT to 18 GMT 31 January has been included. In a similar way another period has been neglected and another one added when computing the precipitation relating to the flux at 12 hrs. The errors caused by this procedure are small and often negligible. The error for the year is equally small and less than 2 mm.

When computing the value of K, the change in moisture content, the values at 12 GMT 31 December and 12 hrs at 31 January are used in case A (flux at 00 hrs) and in the case B the moisture content at 00 hrs 1 January and 00 hrs at 1 February.

The Fig. 3 shows that there is from day to day and even during the day a very rapid variation of the flux values which often occurs in connection with moving depressions. It is not feasible to give any exact value of these truncation errors which arise from the assumption that an instantaneous flux value is representative for 24 hrs, whereas the real flux varies in a complicated way during these 24 hrs. The resulting standard truncation error is however estimated to be at a size of the order of 5 mm/24 hrs. Naturally these errors decrease when the number of observations increases. 30 observations a month may give a standard error of the monthly mean of about 30 mm and the mean of the two series then has a standard error of about 20 mm. A certain measure of the standard error is also the difference of the values obtained from the series A and B, see Fig. 5.

There are also errors caused by deficiencies in the radiosondes used. The humidity values

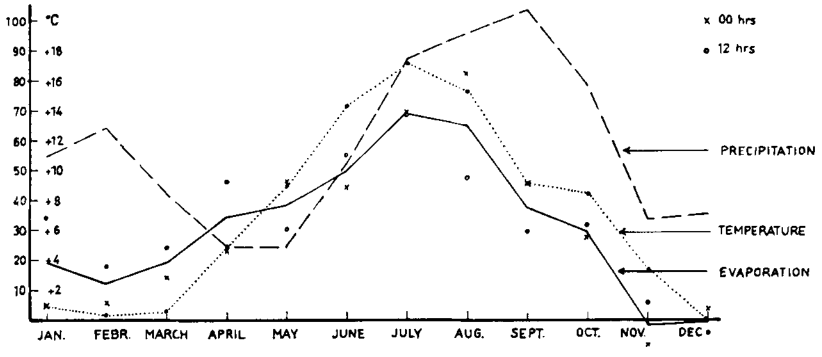

FIG. 5. The monthly mean values of evaporation in Southern Sweden 1957, computed on the basis of the humidity flux at 00 GMT and 12 GMT, the precipitation and the mean temperature in the region.

TABLE 2

The net geostrophic influx per second in a layer with unit pressure thickness (mb) is

$$F_g = -\frac{1}{fg}\sum^{FA}(x_i\,\Delta\phi_i) \quad \text{[se eq. (2)].}$$

The sum of such influx values for the month, i.e.

$$\frac{1}{fg}\sum_{1}^{30}\sum_{AB}^{FA}(x_i\,\Delta\phi_i),$$

is shown in columns *a*. The moisture content in the same layer, i.e. $(S/g)\,(\bar{x}_i/1000)$, where $\bar{x}_i$ is the mean of x_i taken over the area S of the polygon, is given in columns *b*. The vertically integrated monthly net geostrophic influx from the surface (pressure p_0) to the 400 mb level is given in equation (4).

$$-\int_{p_0}^{400}\frac{t}{fg}\left[\sum_{1}^{30}\sum_{AB}^{FA}(x_i\,\Delta\phi_i)\right]dp.$$

This value divided by the area of the region is given in column 9 as the total net influx.

		Monthly net influx and moisture content over the area in a layer of 1 mb thickness. The units are in columns *a* 10^9 kg/month and in columns *b* 10^9 kg								Total net influx from 1000 mb to 400 mb in kg/m²	*K* the correction in kg/m² for the change of moisture content	Precipitation values in mm as computed from precipitation charts	Correction of precipitation values due to time difference between precipitation and flux charts	Evaporation in mm	Mean avaporation in mm
		1000 mb		850 mb		700 mb		500 mb							
		a	*b*	*a*	*b*	*a*	*b*	*a*	*b*						
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
1956 31.XII	12		2.6		2.4		0.9		0.2						
1957 1.I	00		2.8		2.0		1.0		0.4						
January	00	23.0		10.3		9.2		1.0		50.2	0	55	0	5	
January	12	16.8		4.8		7.6		−2.9		28.7	8	55	0	34	20
31.I	12		3.3		2.4		0.9		0.1						
1.II	00		4.0		3.7		2.9		1.0						
February	00	27.4		23.0		−4.6		5.0		54.6	−2	64	1	6	
February	12	18.8		16.3		−2.2		0.2		35.1	−11	64	0	18	12
28.II	12		3.5		1.3		0.4		0.4						
1.III	00		2.0		0.8		0.6		0.5						
March	00	39.3		6.7		−3.6		−0.8		32.1	3	43	0	14	
March	12	10.3		11.4		1.3		−3.1		22.5	4	43	0	24	19
31.III	12		5.2		1.8		1.0		0.3						
1.IV	00		3.7		2.5		1.0		0.4						
April	00	4.5		0.9		4.3		2.5		4.0	2	25	0	23	
April	12	−5.4		−2.2		−5.2		−2.6		−20.2	−1	25	0	46	34
30.IV	12		4.0		2.7		1.5		0.4						
1.V	00		3.5		2.2		0.9		0.4						
May	00	−3.2		−2.9		−6.5		−0.2		−18.4	3	25	0	46	
May	12	13.0		−0.1		−7.6		0.1		−3.4	8	25	0	30	38
31.V	12		5.9		4.0		0.8		0.8						
1.VI	00		6.7		4.2		2.3		0.8						
June	00	−21.4		2.5		13.2		4.1		17.0	9	53	0	44	
June	12	−30.2		2.3		0.7		7.5		3.2	5	53	0	55	49

Table 2 (*continued*)

		Monthly net influx and moisture content over the area in a layer of 1 mb thickness. The units are in columns *a* 10^9 kg/month and in columns *b* 10^9 kg								Total net influx from 1000 mb to 400 mb in kg/m^2	*K* the correction in kg/m^2 for the change of moisture content	Precipitation values in mm as computed from precipitation charts	Correction of precipitation values due to time difference between precipitation and flux charts	Evaporation in mm	Mean evaporation in mm
		1000 mb		850 mb		700 mb		500 mb							
		a	*b*	*a*	*b*	*a*	*b*	*a*	*b*						
		(1)	(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)	(10)	(11)	(12)	(13)	(14)
30.VI	12		9.4		6.5		2.4		1.0						
1.VII	00		8.6		4.1		3.6		1.5						
July	00	3.9		−1.9		−1.7		17.3		22.8	4	88	0	69	
July	12	−3.3		−0.4		1.7		19.0		28.7	9	88	0	68	69
31.VII	12		10.6		6.8		4.0		1.2						
1.VIII	00		9.5		7.5		5.3		1.7						
August	00	6.7		−1.5		6.6		−2.5		10.6	−1	96	−2	82	
August	12	2.0		6.8		10.4		4.5		36.6	−12	96	0	47	64
31.VIII	12		8.7		5.8		4.4		1.8						
1.IX	00		7.0		5.0		2.5		0.7						
September	00	32.6		4.4		2.9		7.1		46.8	−12	104	1	45	
September	12	11.6		18.6		17.6		7.0		68.4	−7	104	−3	29	36
30.IX	12		4.4		2.8		2.4		1.4						
1.X	00		4.2		2.7		1.7		0.5						
October	00	28.3		20.0		16.5		8.1		54.7	3	79	−3	27	
October	12	19.3		16.6		11.6		−6.4		59.1	11	79	0	31	28
31.X	12		6.5		3.5		2.8		0.9						
1.XI	00		7.5		6.3		3.0		1.0						
November	00	22.8		0.3		2.0		8.9		36.7	−9	34	3	−9	
November	12	20.9		3.9		2.7		−4.8		19.1	−10	34	0	5	−2
30.XI	12		2.5		1.7		1.0		1.1						
1.XII	00		3.8		3.1		1.8		0.5						
December	00	26.3		0.1		8.3		1.5		36.4	4	36	−1	+3	
December	12	22.0		2.5		3.0		6.9		35.6	−5	36	0	−5	−1
31.XII	12		3.6		2.5		2.0		1.4						
1958 1.I	00		2.5		1.7		0.9		0.2						
1957	00													354	
1957	12													382	
1957 mean value															368

in the levels above 500 mb are so unreliable that they have not been used at all and the assumption was made that the flux value at 400 mb was zero. Errors in the monthly values due to this assumption are considered small during the winter but they may amount to 5 mm or even more in July. Cf. the great monthly flux values during July, Table 2, Col. 7. Also at lower levels errors in the humidity values occur and in single cases they may cause errors in the evaporation figures amounting to as much as 10 mm in extreme cases. However, the standard error due to errors in humidity observations is of course much smaller. The flux errors caused by temperature errors are considered still smaller and the total standard error in the obtained daily evaporation as caused by all factors discussed above is considered to be only slightly above 5 mm in 24 hrs.

In a study of the evaporation over the Baltic Palmén (1963) found that the use of geostrophic winds yielded too high evaporation values and that measured winds gave much better results, i.e. the ageostrophic flux as given in equation (4) had a considerable value.

It is clear that the geostrophic winds obtained from the analysed upper air charts represent a mean value over a certain time and a certain distance whereas momentary winds measured at a point with the aid of balloons show large random deviations from the mean value. There are, as is well known, during many weather situations large and rapid local fluctuations as regards both direction and velocity. Random errors in the flux values as computed on the basis of 3 wind observations in Stockholm, Copenhagen and Gardermoen (north of Oslo) must be considerably larger than the random errors obtained when geostrophic winds are taken from the charts. Wind observations at Stockholm-Bromma show that with the instrument used at Bromma in 1957 (radiodirection finder SCR 658) a vector error in an individual determination easily amounted to several meters per second. We assume that wind observations at the other stations had similar random errors.

Computations of the mass divergence up to 200 mb could only be made for a small percentage of the days during the year. Some of these show that the divergence was positive up to and including 200 mb. This divergence would have caused a pressure fall of 30 mb in 3 hrs and only part of it could have been compensated for by convergence above 200 mb. One single value of the mass convergence up to 100 mb gave a pressure rise of 50 mb in 3 hrs. This indicates the magnitude of the random errors in the wind observations in agreement with the experience from Bromma. The random errors when using only measured winds, if available at all, should thus have become much greater than those obtained when using geostrophic winds.

Actual observations up to 500 mb simultaneously at the 3 stations were not regularly available, e.g. during October only 9 days so that for the computation of the flux for the whole month no other winds than the geostrophic winds could be used.

However, the question which systematic errors arise from the use of geostrophic winds is of considerable interest. It is obvious that over any area deviations from the geostrophic winds occur so that there is sometimes a convergence and at other times a divergence. This divergence and convergence may in individual cases be rather large but the mean effect cannot immediately be found. However, it is clear that further studies of this problem are required.

If convergence appears at relatively high humidity and divergence at lower humidity a systematic underrating of the net influx will be made when geostrophic winds are used (see equ. 4). This would mean that the evaporation computed on the basis of geostrophic winds would be larger than the real evaporation. An attempt was made to compute the correlation between convergence and humidity in the lower layers (up to 700 mb). In the upper layers where a compensating divergence is supposed to take place the humidity is so low, due to the low temperature, that the influence of the divergence on the humidity flux can be neglected. The computation did not show any such correlation. As a matter of fact a slight net outflow was found as a result of convergence–divergence. However, the material was not large enough to give reliable results. Perhaps it is still justified to draw the conclusion that the mean effect of the ageostrophic component is not very large in this area.

As mentioned above Palmén when computing the evaporation from an area over the Baltic arrived at the conclusion that values derived from the geostrophic winds were systematically much too high. Using the measured winds he got a yearly value of the evaporation amounting to 510 mm whereas using geostrophic winds he got 712 mm. Estimates made in other studies quoted by him, the accuracy of which is however unknown, had given 514 mm. One should remember that over land areas the precipitation can hardly be determined with greater accuracy than 5 to 10% (see below page 481) and over the sea it is most likely more difficult to make an estimate of the accuracy. In addition we have the random errors which are large especially when measured winds are used, as shown above. Palmén has used 6 stations instead of 3 but still the standard error for the yearly evaporation must be of the order of magnitude of 100 mm. His study can therefore hardly give any definite answer to the problem of the importance of the ageostrophic component in the determination of evaporation by means of studies of the humidity flux.

It is of course possible that a mean circulation exists over the Baltic, especially during the autumn when the sea is warmer than the surrounding land areas and the warm air above the sea therefore has a tendency to rise. This would then mean that there is a net influx (by means of an ageostrophic component of the wind) in the lower humid layers and a compensating divergence in upper layers where the absolute humidity is lower. It is not very likely that a similar net circulation would be established over land areas.

One source of error in this study is the neglect of the water content in liquid form in clouds. It is likely that this amount of water is positively correlated with large values of the mixing ratio, so that the computed net influx of humidity is underestimated and the computed evaporation is overestimated. It is, however, considered that the effect is not very large. Clouds do not exist all the time and only in some levels and the content of liquid water is generally much less than the content of vapour.

Certain errors which may be systematic arise because there may be a large change in the flux from the surface to the 850 mb level. At the vertical integration of the flux this change has been considered linear, but there are reasons to believe that there is a very rapid decrease with height in the lowest layers and then a slower decrease (see Fig. 4). This would mean that the obtained values of evaporation were too low during the winter months, when the surrounding seas are rather warm and there are inversions over land so that the influx is high and outflux low in the surface layer. Correspondingly summer values of evaporation may be too high. Computations including one of the levels 950 or 900 mb would give more reliable values.

The mean value of the precipitation as computed from the precipitation charts does not seem to cause large errors. The representativeness of stations in Southern Sweden is comparatively good as regards site and exposure. More serious is the problem of the reliability of the precipitation gauges. An investigation by ANDERSSON (1964) shows that the values are systematically too small by about 7% and another investigation carried out at the Valdai hydrometeorological station in the U.S.S.R., which the author visited in September 1964, indicates that precipitation gauges at a normal height of 2 m give an undervalue of 10%.

Results

In Table 2 are shown the results of the computations for each month of 1957. In the first line is given the computations for 00 hrs and in the second for 12 hrs. The flux values are given for the 4 levels. Then follows the integrated value given in mm precipitation. Further is given the correction for the change during the month of the water vapour content, the precipitation computed from the chart and the corrections due to the difference of the periods of the precipitation charts and the flux. In the following column is given the computed evaporation and the mean monthly evaporation. These values are given for the individual months and the yearly mean is given for the two sets of monthly values and also the yearly mean including all monthly values.

There are considerable differences in the evaporation values obtained based on the flux values at 00 hrs and 12 hrs. The difference has been explained as resulting from the deficiencies in the observational data and especially from the fact that a mean value of the flux computed from 30 isolated moments cannot give the exact mean flow for the month.

The observations at 00 hrs in February indicate that there is no evaporation at all and the observations at 00 hrs in November and December give a condensation instead of an evaporation. These condensation values are so large that also the total mean values, including the values from 12 hrs, indicate condensation. The relative humidity is high and fog or frost may deposit on obstacles and snow without being caught by the precipitation gauges. The inaccuracy of the method must, however, be kept in mind. Probably a certain but small evaporation is occurring even during these months.

During the winter the evaporation values for 12 hrs are larger than the values for 00 hrs and during the summer the opposite occurs. This may be caused partly by the procedure of linear interpolation of the flux values between 1000 mb and 850 mb which may have different effects during winter and summer, but the main cause is most likely the random errors which we have discussed.

Studying the standard deviation of each individual monthly mean value from the mean of the values obtained at 00 hrs and 12 hrs we get the value of only 9 mm. However, even the mean values of the two series have a deviation from the true mean value and we have above given the standard deviation of the monthly values as about 20 mm. This will give a standard deviation for the yearly mean of one series as about 70 mm and for two series as about 50 mm. The yearly value as computed from the 00 hrs series is 354 mm and as computed from the 00 hrs series 382 mm. The mean yearly value is 368 mm. The true evaporation value may be given as $E = 368 + p \pm 50$ where p is the systematic error caused by errors in the precipitation observations. p is positive and here probably not larger than 50 mm.

The evaporation varies very much during the year. There is a high correlation with the monthly mean temperature as computed from the monthly mean temperature of 10 stations in different parts of the region. During most months the precipitation is much larger than evaporation and a larger or smaller contribution to the run-off is obtained. This contribution is especially large during July–September. Part of the contribution is during the winter stored as snow until the snow-melt in the spring. During April and May the evaporation is larger than the precipitation and water must then be taken from melting snow, from the soil moisture and to some extent from the lakes and rivers which, however, at this time are fairly cold.

The evaporation figures obtained may be compared to the values obtained from the observed run-off values. The yearly values above agree well with values computed from run-off values during normal years. No complete computation of the evaporation based on the hydrological method is available but from selected parts of the whole area A. Forsman has computed a mean value of 360 mm. This result which is almost exactly the same as that of the present study 368 mm was found quite independently. The precipitation values used in both methods were the same, but the agreement is still incidental as both methods have an estimated standard error of about 50 mm.

Conclusion

The air humidity flux method is useful also for studies of the evaporation from an area of such a size as Southern Sweden, but it is necessary to use rather long periods to reduce random errors. The obtained yearly evaporation agrees well with results given by the hydrological method. The yearly variation, with surplus of evaporation in the spring and very large contributions to the run-off during the autumn, is probably rather correct although in this case other methods for direct comparison are lacking.

The flux method can be improved by more accurate observations. The introduction of radarwind measurements in Stockholm and Copenhagen which already have taken place are important. An aerological station on Gotland has recently been established and will contribute effectively to an improved analysis. An increase of the number of aerological observations to 3 or 4 a day would also reduce the random errors. The problem of the accuracy of precipitation measurements needs further study.

The question of the role of the ageostrophic component has been discussed. It is considered that the geostrophic assumption gives acceptable results over Southern Sweden but also that further studies are desirable.

Computations of this kind are well suited for treatment with electronic computers and such studies are planned.

Acknowledgement

This study has been made possible by the assistance of the staff at the aerological stations in Östersund and Göteborg, who computed the humidity flux values. Mrs. Lory Håland, Oslo, former meteorologist at the Swedish Meteorological and Hydrological Institute, took a very active part as supervisor of the work during long periods and also contributed to many of the further computations.

REFERENCES

ANDERSSON, T., 1964, Further studies on the accuracy of rain measurements. *Arkiv för Geofysik*, vol. 4, no. 16. Kungl. Vetenskapsakademien, Stockholm.

BENTON, G., BLACKBURN, R., and SNEAD, V., 1950, The rôle of the atmosphere in the hydrologic cycle. *Trans. Am. Geoph. Un.* **31**, pp. 61–73.

HÖGSTRÖM, U., 1964, Preliminär rapport över avdunstningsmätningarna i Ugerup. Sveriges meteorologiska och hydrologiska institut, klimatbyrån, Stockholm.

NYBERG, A., 1958, A determination of some monthly values of evapotranspiration in Finland and in a region in the north-eastern Atlantic. *Geophysica* **6**, 3–4. Helsinki.

PRIESTLY, C. H. B., 1959, *Turbulent Transfer in the Lower Atmospheric.* Chicago.

PALMÉN, E., 1963, *Computation of the evaporation over the Baltic Sea from the Flux of Water Vapour in the Atmosphere.* General Assembly of Berkeley. Committee for Evaporation. *Publ.* No. **62** de l'Association Int. d'Hydrologie Scientifique. Gent and Brugge, pp. 244–252.