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Experiences with the Use of the Aerological Method in Evaporation Studies in Northwestern Europe

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Two different approaches of the aerological method were used for estimating evaporation in northwestern Europe in the period 1969-1970.

Daily operational aerological observations (»the synoptic approach«) gave better results for homogeneous areas (e.g. the Baltic Sea) than for a nonhomogeneous surface. One drawback in this approach was the non-uniform station network due to a lack of observations and resulting in scattered values even for monthly means.

Based on annual mean moisture fluxes at the aerological stations (»the statistical approach«) the evaporation from the Bothnian Sea was estimated to be about 300 mm/year. The main convergence of the water vapor flux occurred below the 900 mb level and was largely due to the mean part of the flux. The results appeared to be quite dependent on the homogeneity of the data sample.

In both approaches the main source of error is the lack and low quality of data, because divergence calculations are sensitive to errors in wind data. The linearity approximation used may also fail in low levels. Careful data checking and the use of complete data samples are needed when the aerological method is applied.

Introduction

During the IHD period the water balance of the Baltic Sea has been the subject of many observational studies. Evaporation from the sea surface forms one of the most difficult and important terms in this balance. Methods to evaluate evaporation, *E,* or evaporation minus precipitation, *E-P,* can be roughly divided into semiempirical formulae such as

$$E = k(e_w - e_a)\,V \tag{1}$$

and the aerological method, which uses aerological (radio sounding) data from many pressure levels. An excellent review of the method is given by Palmén (1967).

The aerological method was used by Palmén and Söderman (1966) for evaporation studies of the Baltic Sea in 1961-1962. It yielded realistic results, the data being checked subjectively. These good results gave us reason to test the method using »operational« meteorological material. The results of two such efforts are reported here. The first (Alestalo) used annual mean values of some Swedish and Finnish aerological observations, the second (Savijärvi) daily aerological reports from northwestern Europe. On the basis of our experience, we recommend careful preselection and checking of aerological material, both of which are important in the planning of evaporation studies, e.g. for the IHP Methodological Pilot Year Study 1975-1976 (Dahlström 1976).

For comparison, the results of some previous evaporation studies for northwestern Europe are listed on page *55*

The Data and Method Used

General Outline of the Aerological Method

If the individual change in specific humidity per mass unit *dq*/*dt* is integrated over the mass of the atmosphere, the result is the difference between evaporation and precipitation at the surface unit area:

$$E - P = \int_0^\infty \frac{dq}{dt}\,\rho\,dz = \frac{1}{g}\int_0^{p_0} \frac{dq}{dt}\,dp =$$

$$= \frac{1}{g}\int_0^{p_0} \frac{\partial q}{\partial t}\,dp + \frac{1}{g}\int_0^{p_0} \nabla \cdot q\mathbf{v}\,dp + \frac{1}{g}\int_0^{p_0} \frac{\partial}{\partial p}\,q\omega\,dp \tag{2}$$

The last term in Eq. (2) vanishes as $\omega = 0$ at p_0 and $p = 0$. Taking the mean value over a suitable area *A*, and using Gauss' theorem the result is

$$\tilde{E} - \tilde{P} = \frac{1}{g}\int_0^{p_0} \frac{\partial \tilde{q}}{\partial t}\,dp + \frac{1}{qA}\int_0^{p_0} \oint_L q v_n\,dL\,dp \tag{3}$$

The quantity $q\mathrm{v}_n$ denotes the flux of the water vapor per unit mass normal to the boundary *L* (positive outwards), and the tilde represents areal mean value. The transports of water in liquid and solid form have been neglected. The closed area *A* is in practice selected to form a polygon with available aerological stations at the corners. The humidity and wind observations may thus be used to evaluate the water vapor flux through the polygon sides.

Method I, »Statistical Approach«

In Method I, the annual time mean values of the total water vapor flux $(\overline{qv})$ were first calculated at each station and then used in Eq. (3) (cf. Starr et al. 1965). The total flux may be divided into mean and transient parts according to the formula

$$\overline{qv} = \bar{q}\bar{v} + \overline{q'v'} \qquad (4)$$

The divergence of the water vapor flux was also calculated for these components of the total flux. The data used in Method I were from the two year period 1.11.1968 - 31.10.1970 and from the levels surface-95-90-85-80-70-60-50-40 cb.

The non-standard levels 95, 90, 80, and 60 cb were interpolated from significant observation points when the data were combined on magnetic tapes. The polygon for which the divergence computations are presented was formed by three aerological stations in Stockholm, Sundsvall, and Jokioinen (Fig. 1), covering most of the Bothnian Sea.

In order to examine the influence of the data sample on the results, three different samples were selected from the material in Method I. The first sample consisted of all

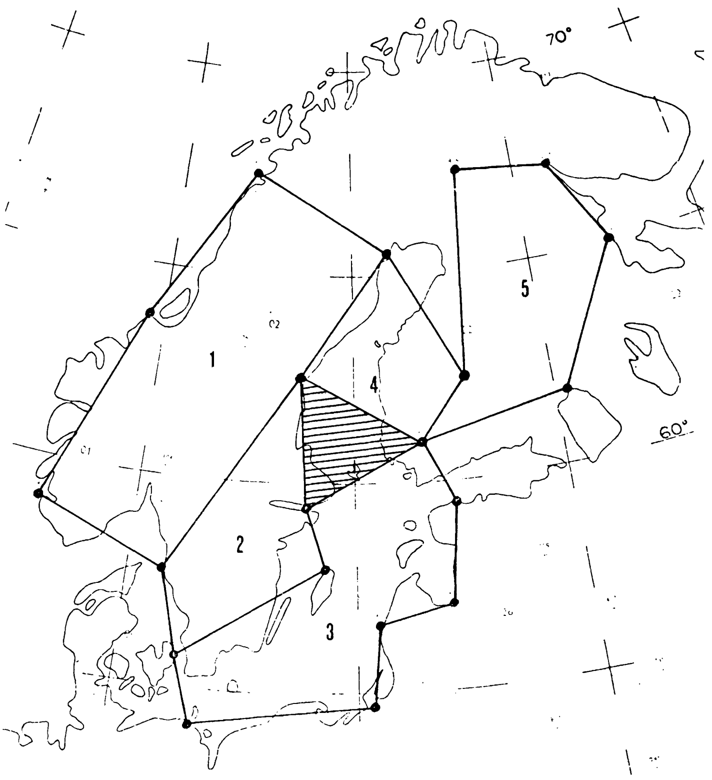

Fig. 1. The aerological network and areas used in the evaporation calculations. Method I: shaded area, Method II: areas 1-5.

available wind and humidity observations of the three stations under consideration. The number of observations is listed in Table 1a. This sample will be called Method Ia. In the second sample, Method Ib, at each level only cases were accepted in which there was a complete wind and humidity observation at each station. The number of observations in Method Ib is listed in Table 1b. The third sample, Method Ic, consisted of complete simultaneous radio soundings at each of the three stations between the surface and the 40 cb level, the number of observations being only 592 (40.5% of all possible cases (1460)). The lack of wind data at low levels in Sundsvall and partly in Stockholm was the most important factor in reducing the number of observations in Method Ib. At the 40 cb level, and thus in Method Ic, the lack of of humidity data was also important in forming the final data sample.

Table 1 - The number of all available observations for water vapor computations in Method Ia (a) and the number of observations accepted in Method Ib (b). XI. 1968 - X. 1970.

pressure		a		b
cb	Stockholm	Sundsvall	Jokioinen	
surface	1451	1442	1460	1433
95	1328	997	1453	907
90	1324	986	1450	889
85	1320	984	1453	885
80	1338	1118	1456	1024
70	1361	1234	1456	1152
60	1379	1253	1456	1183
50	1360	1245	1456	1162
40	1181	987	1454	850

Method II, »Synoptic Approach«

In the second attempt the data consisted of daily (00 and 12 GMT) aerological observations at 21 selected stations in northwestern Europe (Fig. 1). The period was 1.11.1969 - 31.10.1970 (equivalent to the second half of the Method I period). From these observations the areal mean value of E - P (Eq. (3)) was calculated daily at the five areas of Fig. 1 using both observed wind values and geostrophic approximation at the main pressure levels 100-85-70-50-40 cb. Significant observation points were not used as they were very often systematically lacking. The essential difference between Methods I and II thus lies in the order in which the time and areal averages are taken.

The calculation method in Method II was basically the same as that used by Palmén and Söderman (1966). The data contained errors and lacked observations, especially 100 cb observations in low pressure synoptic cases. An unavoidable drawback was that the polygons were sometimes smaller than those in Fig. 1 because of missing observations. This makes the results of Method II somewhat diffuse, and even the monthly mean values of $E - P$ were quite scattered.

Results

The Water Vapor Flux

The sensibility of the results on observation sampling can be seen in Fig. 2 where the components of the water vapor flux q v at Jokioinen (where the observation sample was nearly complete in Method Ia) are presented bases on the three samples described above 2.3. The differences in the mean vertical distributions are mainly due to differences in corresponding mean profiles of the wind components u and v. These differences are large at the level of maximum flux (95 - 90 cb). Differences in the transient flux were small between Methods Ia, Ib, and Ic.

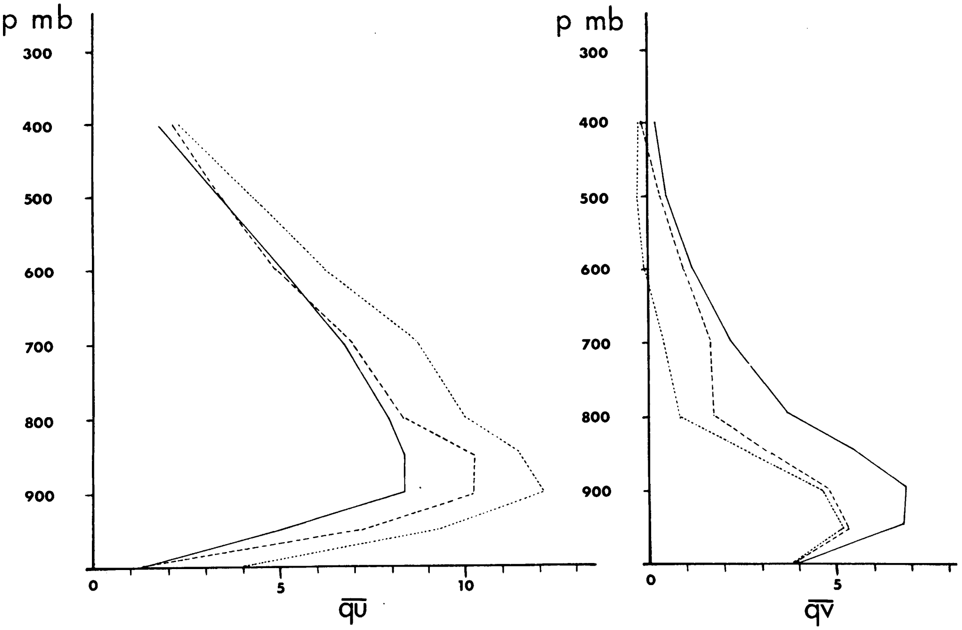

Fig. 2. The vertical distribution of zonal and meridional components of the total water vapor flux at Jokioinen based on three different data samples (see text). XI.1968-X.1970. Method Ia —, Method Ib ---, and Method Ic .... Unit 10^{-1} ms^{-1}.

Vertically integrated values of the mean total and transient water vapor flux vectors are presented in Fig. 3. The total water vapor flux is strongly influenced by the mean westerly circulation at the latitudes of the stations under consideration. The effect of the Gulf of Bothnia can be seen at Sundsvall where the flux veers to the south from the general direction of other vectors because of southward meridional water vapor flux at Sundsvall. The transient flux is much smaller in magnitude than the total flux (15 - 25% of the total) and is generally directed to the north.

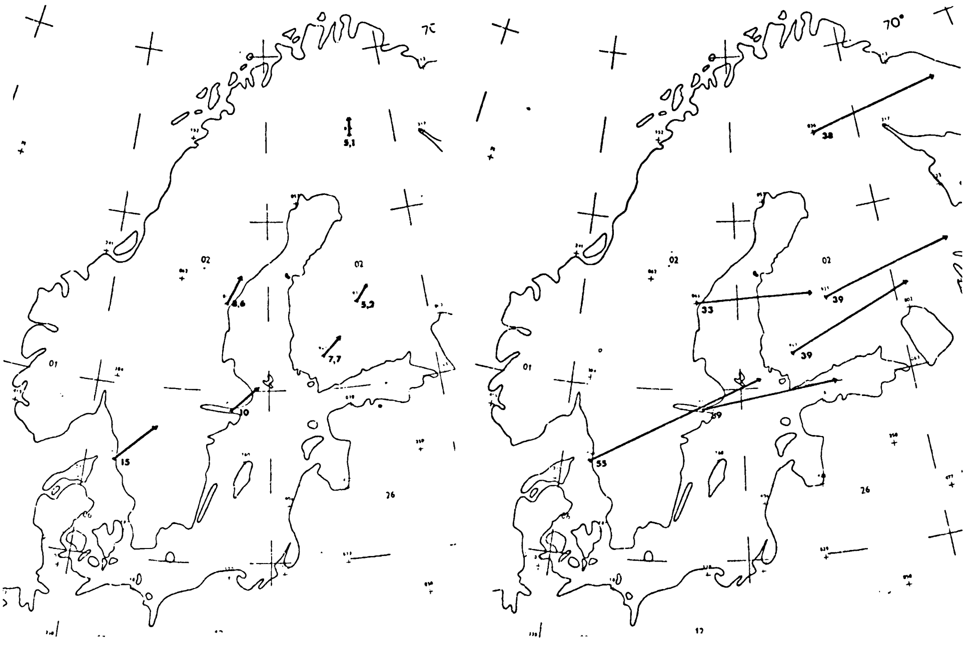

Fig. 3. Vertically integrated vectors of the total (right) and transient (left) water vapor flux. XI.1968-X.1970. Unit kg m^{-1} s^{-1}.

Evaporation

The vertical distribution of the divergence of the total and transient water vapor flux for the polygon formed by Stockholm, Sundsvall, and Jokioinen is illustrated in Fig. 4 (Method Ia). The general distribution is qualitatively typical at the latitudes of strong cyclone activity; divergence in the middle troposphere and convergence in the lower troposphere (cf. Hutchings, 1957). Quantitatively the distribution is not, however, realistic, as it gives an estimate of - 570 mm/year for the time an areal mean of $E - P$ when integrated vertically. According to this result there could have been no evaporation from the area under consideration. If the divergence is considered realistic in the middle troposphere, the main source of error is connected with factors leading to great negative values of divergence especially at the 95 cb level. Closer examination showed that this convergence was largely due to the convergence of the wind field. It is obvious that the lack of data in the lower troposphere has led to an unrealistic wind distribution and that local effects (Gulf of Bothnia) produce inhomogeneities in the wind field which the method used (Eq. (3)) fails to take into consideration (e.g. linear interpolation between stations). The two other samples gave qualitatively similar results, but the numerical values or $E - P$ estimates differed considerably (Table 2). The vertical integrals of the mean and transient parts of the total flux are also included in Table 2.

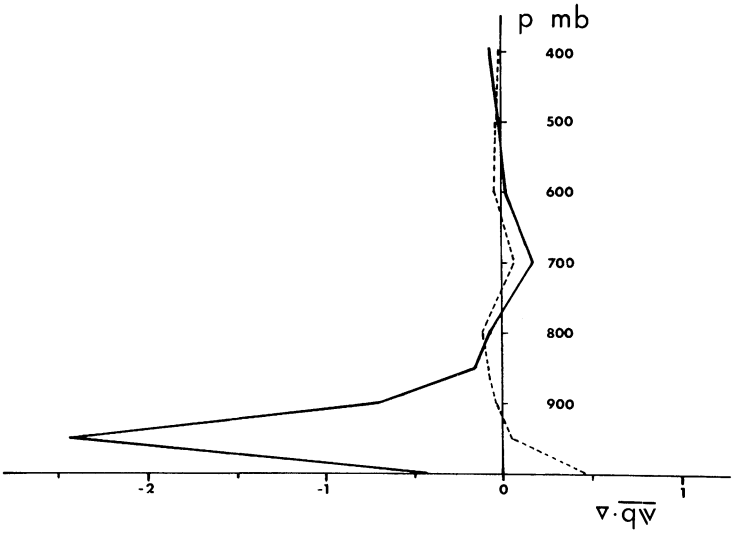

Fig. 4. The vertical distribution of the divergence of the total (—) and transient (---) water vapor flux of the polygon formed by Stockholm, Sundsvall, and Jokioinen (Fig. 1) in Method Ia. XI.1968-X.1970. Unit 10^{-8} s^{-1}.

According to Table 2, Method Ib yields the most realistic results, giving an estimate of about 300 mm/year for evaporation in the two year period XI. 1968 - X. 1970 for the shaded area of Fig. 1. Precipitation (about 550 mm/year) has been estimated with the aid of isohyetal charts and precipitation reports from climate stations. Thus a homogeneous data sample (Method Ib) seems to give better results than a data sample where no concern has been given to the inconsistency of the data (Method Ia). Method Ic obviously fails because of the very small number of accepted observations although the data sample is even more homogeneous than in Method Ib. The contribution of the divergence of the transient flux to the E - P estimates seems to be small but its annual variation is relatively large.

The results for evaporation calculations of Method II are collected in Table 3. Precipitation data of 5 - 8 climate stations at each area for the one year period is included in the table. For the total area formed by polygons 1 - 5 the evaporation (based on E - P values of Method II and precipitation data given) is 250 mm/year, which is quite realistic. However, when geostrophic winds are used the result is slightly too large; 415 mm/year. In individual areas the results are more variable and geostrophic values differ greatly from those given by observed winds. The tendency for small E - P values above sea areas is clear. When the annual means of q and v of Method II data were used in Eq. (3), the result for Area 4 was E - P = - 600 mm/year. For the same one year period but a smaller area (shaded in Fig. 1) and slightly better data material of Method Ia the corresponding value was - 670 mm/year (Table 2), showing good agreement.

Table 2 - *E* - *P* results of Method I for the one year periods XI. 1968 - X. 1969 (above) and XI. 1969 - X. 1970 (middle) and for the two year period XI. 1968 - X. 1970. Unit mm/year.

		Method		
		Ia	Ib	Ic
XI. 1968 - X. 1969	$\int_0^{p_0} \nabla \overline{q\mathrm{v}} \frac{dp}{g}$	-600	-260	-380
	$\int_0^{p_0} \nabla \bar{q}\bar{\mathrm{v}} \frac{dp}{g}$	-420	-230	-350
	$\int_0^{p_0} \nabla \overline{q'\mathrm{v}'} \frac{dp}{g}$	-180	- 30	- 30
XI. 1969 - X. 1970	$\int_0^{p_0} \nabla \overline{q\mathrm{v}} \frac{dp}{g}$	-570	-240	-280
	$\int_0^{p_0} \nabla \bar{q}\bar{\mathrm{v}} \frac{dp}{g}$	-670	-380	-540
	$\int_0^{p_0} \nabla \overline{q'\mathrm{v}'} \frac{dp}{g}$	100	140	260
XI. 1968 - X. 1970	$\int_0^{p_0} \nabla \overline{q\mathrm{v}} \frac{dp}{g}$	-570	-250	-360
	$\int_0^{p_0} \nabla \bar{q}\bar{\mathrm{v}} \frac{dp}{g}$	-570	-300	-440
	$\int_0^{p_0} \nabla \overline{q'\mathrm{v}'} \frac{dp}{g}$	0	50	80

Table 3 - *E* - *P* results of Method II for the one year period XI. 1969 - X. 1970. Unit mm/year.

	AREAS				
	1	2	3	4	5
$\int_0^{p_0} \nabla \overline{q\mathrm{v}} \frac{dp}{g}$	-780	-740	- 22	- 26	-440
$\int_0^{p_0} \nabla \overline{q\mathrm{v}}_g \frac{dp}{g}$	-700	-230	49	-360	125
E_{obs}	60	-140	630	520	180
amount of rain	850	600	650	550	625
number of cases (max = 730)	501	520	547	460	535

For comparison we list the following earlier results:

Palmén and Söderman 1966, Baltic Sea X. 1961 - IX. 1962, aerological method:
$E - P = -41$ mm/year (observed winds), $E = 528$ mm/year
$E - P = 244$ mm/year (geostrophic winds), $E = 813$ mm/year
Hankimo 1964, Baltic Sea XII. 1961 - V. 1962, Eq. (1):
$E = 276$ mm/6 months
Simojoki, 1948 and 1949, Baltic Sea, Eq. (1):
$E - P = -42$ mm/year, E = 512 mm/year
Simojoki 1949, Bothnian Sea, Eq. (1):
$E - P = -48$ mm/year, E = 425 mm/year
Nyberg 1965, Southern Sweden 1957, aerological method, geostrophic winds:
$E - P = -330$ mm/year

The large scatter in our $E - P$ results seems unnatural as both the amount of rain and ice cover in winter were nearly or slightly above normal during the periods. Because the scatter is somewhat similar in the two trials and Method II yielded fully consistent results when the Palmén and Söderman 1966 data were used, we point out that this scatter lies in the deficiences in the data material, or more accurately in the sensitivity of the divergence calculations to the (wind) data, especially at low levels. A careful check of daily observations thus seems to be important in order to obtain reliable results.

Conclusions

Even if the scatter in our results is large, we venture to draw the following conclusions:

- the transient water vapor flux seems to be generally small, although the divergence of the transient flux may be comparable to the divergence of the total flux
- because most of the water vapor flux occurs near the surface, a standard pressure level between the 100 and 85 cb levels would be very desirable
- in a homogeneous and flat area (Baltic Sea) the results seem to be much better than in a nonhomogeneous surface, in which case Eq. (3) easily fails because of linearity approximation along the sides of area used
- geostrophic approximation should be used only when wind data are sparse or erroneous, e.g. when topography around the station may cause systematic errors in low level winds
- results based on incomplete data may be very misleading indeed, depending on how systematically lacking observations are associated with certain wind or humidity conditions

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