MAHASAGAR
Vol.26, No.1 (June), 1993, pp. 1-7

EVAPORATION FROM THE MEDITERRANEAN SHELF WATERS OFF THE EGYPTIAN COAST

M.A. SAID
National Institute of Oceanography & Fisheries
Kayet Bay, Alexandria, Egypt

ABSTRACT

Evaporation from the Mediterranean shelf waters off the Egyptian coast was estimated during the period from August, 1983 to July, 1986, using different techniques. On the basis of the heat budget equations, evaporation was computed using *R'* and *R* respectively. Three different forms of the aerodynamic method were also used for computing the evaporation.

The agreement between the calculated values of evaporation by means of Sverdrup's formula and the estimated ones from observation was good, and considerably better than the results obtained by the other formulae. The total evaporation during the year was about 155.6 cm from the observations and 151.5 cm based on Sverdrup formula. These values were slightly more than 145 cm, the mean evaporation for the Mediterranean (Sverdrup, 1942; Daume, 1950; Wüst, 1959).

Key-words : Evaporation, Mediterranean shelf, Egypt coast.

INTRODUCTION

Evaporation is a physical process that takes place at the boundary surface between water and the air above it and depends on the conditions both in the water and in the air in the immediate vicinity of the surface (Defant, 1961).

Several attempts have been made to estimate evaporation from different zones of the Mediterranean Sea using different techniques. Nielsen (1912) reported evaporation as 175 cm/year. Schott (1915) computed evaporation by means of heat balance equations and found a total evaporation of 187 cm/year. Sverdrup (1942), Daume (1950) and Wüst (1959) calculated evaporation from the surface waters of the Mediterranean Sea as 145 cm/year. The annual evaporation value determined by Carter (1956) was 115 cm, with a minimum value (4 cm) in February and a maximum one (16 cm) in August. On the basis of observations over the sea during the period 1924 - 32, Tixeront (1970) found that the average evaporation from the Mediterranean Sea amounted to 120 cm/year. Ovchinnikov (1976), using long term climatic data, found the the evaporation reached its maximum values in September and December and a minimum in May.

The present communication gives an estimate of the evaporation from the Mediterranean shelf waters off the Egyptian coast using different techniques.

MATERIALS AND METHODS

During August 1983 to July 1986, eight cruises were carried out in the southeastern Mediterranean Sea between longitudes 29°45'E and 33°45'E using RV *Noor Ya Nabi*. During each cruise, surface meteorological and hydrographic data were collected at 24 stations located along eight sections extending perpendicular to the coast. Each section comprises three stations namely, coastal (2 m), middle (50 - 100 m) and offshore (200 m). Additional stations were sampled in the coastal area between Damietta and Port Said (Fig. 1).

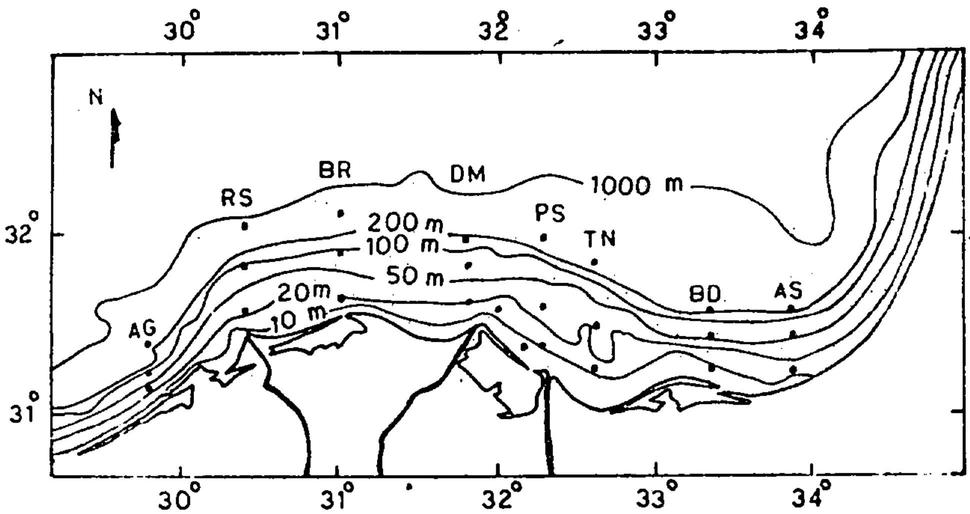

Fig. 1. Area of investigation, sections and stations sampled off the Egyptian Mediterranean coast. Sections : El-Agami (AG); Rosetta (RS); Burullus (BR); Damietta (DM); Port Said (PS); El-Tena (TN); Bardawil (BD) and El-Arish (AS).

The standard meteorological measurements (wind speed and direction, air pressure, cloud amount, dry bulb temperature, wet bulb temperature and sea surface temperature) were taken at 3 hours interval while the ship was stationary. These measurements were used to compute the surface heat budget components using Timofeev's equations (1970, 1983). For details, refer to Said (1987) and Said and Abdel-Moati (1992).

During the period of investigation, the recorded monthly evaporation data along the Egyptian Mediterranean coast were made available through the Egyptian Meteorological Authority, Cairo, Egypt.

The mean evaporation (E) of the sea surface could be calculated by the method, suggested by Schimdt (1915) using the heat budget components.

Denoting the mean annual energy gain of the sea surface due to sun and sky radiation by Qs, the energy loss due to outgoing radiation from the sea to the atmosphere Qb, the loss by evaporation with Qe, and the loss by convection (turbulent heat conduction) with Qh, then for a stationary state :

$$Qs = Qb + Qe + Qh \; . \tag{1}$$

Introducing $R=Qh/Qe$ and $E=Qe/L$, (where L is 585 cal/g the latent heat of evaporation of water), into the basic equation for the heat budget of the sea, then

$$E = \frac{(Qs - Qb)}{L\,(1 + R)} \tag{2}$$

Schmidt (1915) carried out his calculation using, $R'=Qe/(Qs - Qb)$ instead of R. Another possibility for determining the value of R was pointed out by Bowen (1926). For identical eddy coefficient for the diffusion of water vapour and turbulent conductivity of heat, the upward flux of the latent energy of water vapour and heat are given by

$$Qe = -L\,\frac{0.621}{P}\;A\;\frac{de}{dz} \;\text{ and }\; Qh = -Cp\;A\;\frac{d\theta}{dz}. \tag{3}$$

From these equations it follows that

$$R = \frac{Qh}{Qe} = \frac{Cp\,P}{0.621\,L}\;\frac{d\theta\,/\,dz}{de\,/\,dz}\,. \tag{4}$$

Putting L=585 and replacing the differentials by corresponding finite differences the Bowen ratio is obtained as

$$R \;=\; 0.66\;\frac{P}{1000}\;\;\frac{\theta s \;-\; \theta a}{e_s \;-\; e_a} \tag{5}$$

where θs and θa denote the temperature of water and air and e_s is the saturated vapour pressure of water at temperature θs and e_a is the actual vapour pressure in the air.

Aerodynamic evaporation was calculated from an aerodynamic relationship in the form

$$E = (e_s - e_a)\,(\,f\,(\,\bar{u})\,) \tag{6}$$

Aerodynamic relationships of this type have been discussed and developed by different authors. Among them are, Sverdrup (1937), Miller (1937), Norris (1948), Sutton (1949) and Penman (1956). Marciano and Herbeck (1954) and Meshal (1973) found that Sverdrup's (1937) and Sutton's (1949) formulae gave results in close agreement with the observations.

(i) Sverdrup's formula for determination of evaporation (E) as taken from Defant (1961) is in the form

$$E = \frac{\delta U_*}{\frac{k}{k_o} \ln \frac{z + z_o}{d + z_o} + U_* d} (e_s - e_a) \tag{7}$$

where U_* (the friction velocity) = $\frac{0.165}{\log[(z + z_o)/z_o]} Uz$ (8)

Uz is the wind velocity at height z and z_o is the roughness length=0.6 cm. δ is the diffusion coefficient of water vapour in the boundary layer with reference to vapour pressure, and is given by

$$\delta = k \frac{0.623}{P} \rho$$

P is the atmospheric pressure (mb) and ρ is the density of air=1.2×10^{-3} gm.cm^{-3}. e_s is the saturated vapour pressure corresponding to temperature and salinity of water, e_a is the vapour pressure in the air at height z, k_o is the dimensionless Von Karman's constant=0.4, k is the diffusion coefficient=0.235 cm^2/sec., d is the thickness of the diffusion layer (cm). It was adopted according to Von Karman (1934)

$$d = \frac{30 V}{U_*} \tag{9}$$

where V is the kinematic viscosity of the air=0.15 cm^2/sec.

Equation (9) was based on extensive measurements and gave satisfactory results (Marciano and Herbeck, 1954).

The obtained values of E (eq. 7) were multiplied by N, the number of seconds in the given month to get the monthly mean values of evaporation.

(ii) Particular formulation for E, adopted by Penman, 1956 is

$$E = 0.165(e_s - e_a)(0.8 + U_2/100) \tag{10}$$

where E is in mm/day, e_s and e_a respectively the saturated and actual vapour pressure at screen level in mb and U_2 is the wind speed at a height of 2 m in km/day. The obtained values of E were converted to cm/month.

(iii) A simple bulk aerodynamic method have been used to compute E for the sake of comparison is

$$E = \rho\, CE\, (e_s - e_a)\, U/L \tag{11}$$

where L is the latent heat of evaporation of water (585 cal/g). CE is the bulk transfer coefficient for latent heat flux.

RESULTS AND DISCUSSION

The net surface heat budget with all its components was calculated for all eight cruises by Said and Abdel-Moati (1992), using Timofeev's equation (1970, 1983). The results obtained by them in Wm^{-2} are averaged over eight transects and presented in Table I. The total solar radiation Qs varies through the period of investigation from 169.2 to 337.9 Wm^{-2}. Higher values are observed in summer, while the lower values are observed in winter. The amount of heat loss from the sea surface due to the effective back radiation Qb varies between - 70.6 and - 83.1 Wm^{-2}, and the loss due to latent heat flux Qe fluctuates between - 97.5 Wm^{-2} in winter and -159.5 Wm^{-2} in summer. These seasonal variations of latent heat flux is mainly due to the variation in wind speed and in the vapour pressure gradient. The sensible heat flux Qh ranges between - 36.0 and 14.4 Wm^{-2}.

Table I – Seasonal variation of the heat budget components (Wm^{-2}) of the Mediterranean shelf waters off the Egyptian coast.

Year	1983		1984		1985		1986	
	Aug	Feb	July	Oct	Apr	July	Feb	July
Components								
Qs	321.0	169.2	337.9	201.4	293.0	337.9	169.2	337.9
Qb	-71.9	-81.8	-75.9	-79.5	-83.1	-70.6	-80.1	-74.5
Qe	-140.1	-97.5	-142.6	-118.4	-131.9	-159.5	-106.2	-147.6
Qh	-0.7	-22.9	14.4	3.9	-1.5	-7.7	-36.0	8.7

The calculated components of the heat budget at each station were used for the computation of evaporation from the Mediterranean shelf waters off the Egyptian coast using eq. 2 with R and R' given below :

(i) $R' = \dfrac{Qe}{Qs - Qb}$ (Schmidt, 1915)

(ii) $R = 0.66 \dfrac{P}{1000} \dfrac{\theta s - \theta a}{e_s - e_a}$ (Bowen, 1926)

The computed values of evaporation are averaged over eight transects and listed in Table II. The monthly evaporation is generally greatest in summer and least in winter. The maximum values (18.6 and 32.1 cm/month) are found in July 1984, while the minimum ones (4.0 and 6.6 cm/month) are observed in February 1986, when using R and R' respectively. The evaporation values are higher than the measured values during summer and lower in the other seasons.

Table II presents a comparison between the calculated and observed E values. The agreement between the observed and the calculated values by Sverdrup's formula is good, and considerably better than the cases treated by Schimdt (1915),

Table II – Seasonal and annual values of evaporation (cm) from the Egyptian Mediterranean shelf waters using different techniques.

Year / Method	1983 Aug	1983 Feb	1984 July	1984 Oct	1985 Apr	1985 July	1986 Feb	1986 July	Annual Evaporation
1. Observations	14.3	11.9	14.3	13.8	13.0	15.6	8.7	14.8	155.6
2. Heat budget equation using									
a - R′ (Schmidt)	16.6	4.2	18.6	6.8	14.0	18.4	4.0	18.5	128.7
b - R (Bowen)	26.2	7.3	32.1	13.9	22.0	27.9	6.6	30.8	216.2
3. Aerodynamic method using									
a - Sverdrup's formula	14.6	9.4	14.8	12.3	13.4	16.6	9.7	15.3	151.5
b - Penman's formula	20.4	12.8	20.2	17.4	18.0	22.6	13.5	20.8	208.4
c - Simple formula	18.3	12.7	18.6	15.5	17.5	20.8	14.0	19.3	196.8

Bowen (1926) and Penman (1954). The evaporation formula shows that the dependence of evaporation on the meteorological conditions in the atmosphere is more complicated than was assumed by previous relationships. Moreover, a deeper insight into these phenomena can only be obtained by a geophysical analysis of the evaporation process (Defant, 1961).

The annual variation of evaporation can be examined from Table II. The results show that the evaporation is maximum in summer and minimum in winter which is in agreement with the early reports. The total evaporation during the year is about 155.6 cm from the observations and that estimated from Sverdrup's formula is 151.5 cm which is in good agreement. These values are slightly more than 145 cm, the mean evaporation for the Mediterranean (Sverdrup, 1942; Daume, 1950; Wüst, 1959).

REFERENCES

Bowen, I.S., 1926.The ratio of heat losses by conduction and by evaporation from any water surface. *Physical Review*, **27**: 779-787.

Carter, D.B., 1956. The water balance of the Mediterranean and Black Seas. (Drexel Institute of Technology, Laboratory of Climate). *Climatology*, Centerton, New Jersy, **11**: 123-174.

Defant, A., 1961. *Physical Oceanography*. Pergamon Press, Oxford, London, New York, Paris, Vol. 1, 729 pp.

Daume, W., 1950. Der Wasseraushalt des Mittelmeers, Erdkunde, Bonn.

Marciano, J.J. and G.E. Harbeck, 1954. *Mass transfer studies*. Prof. Paper No. 269, Washington, US Geological Survey, 46-70.

Meshal, A.H., 1973. *Water and salt budgets of Lake Qarun, Faiyum, Egypt*. Ph.D. Thesis, Alexandria University, 278 pp.

Millar, F.G., 1937. Evaporation from free water surface. Department of Transport, Division of Meteorological Services, Canada, *Canadian Meteorological Memoirs,* **1**: 39-45.

Nielsen, I.N., 1912. Hydrography of the Mediterranean and adjacent waters. *Report of Danish Oceanographic Expedition in the Mediterannean,* 1908-1910, **1**: 77-191.

Norris, R., 1948. Evaporation from extensive surface of water roughened by waves. *Quarterly Journal of Royal Meteorological Society,* **74**: 1-12.

Ovchinnikov, I.M., 1976. *Water Balance of the Mediterranean Sea,* edited by Borkov, Leningrad, 60-89 (Russian).

Penman, H.L., 1956. Evaporation. An introductory survey. *Netherlands Journal of Agricultural Science,* **4**: 9-29.

Said, M.A., 1987. Heat exchange processes between the Eastern Mediterannean and the atmosphere. *Journal Acta Adriatica,* **28**: 33- 43.

Said, M.A. and A.R. Abdel-Moati, 1992. Seasonal heat budget of the south-eastern Mediterannean waters off the Egyptian coast during 1983-1986. *Journal Acta Adriatica* (in Press).

Schott, G., 1915. Die Gewasser des Mittelmeeres. *Annual Journal of Hydrography and Marine Meteorology,* **43**: 1-18, 49-79.

Schmidt, W., 1915. Strahlung und Verdunstung an freien Wasserflachen; ein Beitrag zum Warmehaushalt des Weltmeers und zum Wasserhaushalt der Erde. *Annual Journal of Hydrography and Marine Meteorology,* Bd., **43**: 111-124.

Sutton, O.G., 1949. The application to micrometeorology of the theory of turbulent flow over rough surface. *Quarterly Journal of Royal Meteorological Society,* **75**: 335-350.

Sverdrup, H.U., 1937. On the evaporation from the oceans. *Journal of Marine Research,* **1**: 3-14.

Sverdrup, H.U., 1942. *The Oceans.* Prentice-Hall, No. 4, 1087 pp.

Timofeev, N.A., 1970. On the external components of the heat balance in the oceans. In: *The Marine Hydrographical Investigation,* Morsky Gidrofizical Institute : Sevastopol, **1**: 148-165 (Russian).

Timofeev, N.A., 1983. *Radiation Regime of Oceans.* Kiev, 24 pp (Russian).

Tixeront, I., 1970. Le billan hydrologique de la Mer Noire et de la Mer Mediterranee. Cah. *Oceanography,* **22**: 227-237.

Von Karman, Th., 1934. Turbulence and skin friction. *Journal of Aeronautical Society,* **1**: 1-20.

Wüst, G., 1959. Sulle componenti del bilancio idrico fra atmosfera oceans e Mediterraneo. Ann. Institute, University of Navale, Napoli, **28**: 371-386.