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Equilibrium temperature as a parameter for estimating the net heat flux at the air-sea interface in the central Red Sea

Temperature
Heat flux
Air-sea interface
Red Sea

Température
Flux de chaleur
Interface air-mer
Mer Rouge

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ABSTRACT

The net rate of heat exchange at the water surface in the central Red Sea is calculated with reference to the equilibrium temperature and the thermal exchange coefficient, both of which depend on meteorological variables. The monthly means of this exchange agree well with the values computed on the basis of heat balance processes which include sensible, evaporative and radiative heat fluxes.

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RÉSUMÉ

Estimation du flux net de chaleur au centre de la Mer Rouge à l'aide de la température de l'interface air-mer

Le flux net de chaleur à la surface de l'eau au centre de la Mer Rouge est calculé à partir de la température d'équilibre et du coefficient d'échange thermique, paramètres qui dépendent des variables météorologiques. Les moyennes mensuelles obtenues sont en bon accord avec les valeurs calculées à partir des différents termes du bilan thermique : flux de chaleurs sensible, latente (évaporation) et radiative.

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INTRODUCTION

The processes of heat exchange between water and atmosphere take place at the air-sea interface. The methods of determining these processes, summarized by Kraus (1972) and Pond (1975), include the eddy correlation method, the dissipation method and the bulk aerodynamic method, all of which demand the recording of various types of independent environmental information, including routine hourly meteorological and oceanographic data. Among these methods the bulk aerodynamic method involves parametrization and is widely used for large-scale application. Encompassed within the bulk method are various transfer coefficient schemes which vary in complexity and sophistication. Partial summaries of many of these bulk coefficient schemes may be found in Friehe and Schmitt (1976), Kondo (1977), Garrat (1977) and Liu *et al.* (1979).

The monthly means of the surface heat fluxes for the central Red Sea, which include net long wave radiative flux, sensible and evaporative fluxes, have recently been calculated by Ahmad and Sultan (1987) using the well known equations given in Budyko (1974). Based on their computation of monthly averages for the above fluxes and the monthly means of the solar radiation recorded at inland stations around the central Red Sea (from Ahmad and Sultan,1989) the net surface heat flux Qt through the air-sea interface is calculated as,

$$Q_t = Q_s - Q_b - Q_e - Q_h$$

The terms Q_s Q_b, Q_e and Q_h denote the solar radiations, back radiations, evaporative and sensible heat fluxes respectively. Computed values for net surface heat flux Q_t are given in the last column of the Table and the plot is shown in Figure. In this paper, the concept of equilibrium

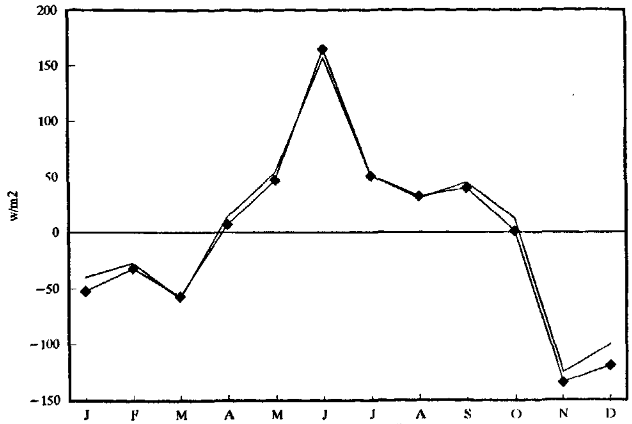

Figure 1 Net Heat Flux

—— On the basis of equilibrium temperature —◆— From Ahmad & Sultan (1987)

Figure

temperature T_e (Edinger *et al.*, 1968) is used to calculate the net heat exchange at the water surface. The equilibrium temperature, a hypothetical sea-surface temperature at which the net rate of surface heat exchange would be zero, depends on several heat exchange processes that operate at the air-sea interface. The thermal exchange coefficient K describes the rate at which water temperature responds to these heat exchange processes.

EQUILIBRIUM TEMPERATURE MODEL

If the sea surface temperature is T_s, the rate of heat exchange per unit area across the water surface $K(T_e - T_s)$ equals the time change of heat storage per unit area

$\rho C_p H\, dT_s/dt$ within the water column. Thus

$$\rho C_p H\, dT_s/dt = K(T_e - T_s) \quad (1)$$

where C_p is the specific heat of water and ρ its density. H is the depth.

The temperature T_s increases or decreases with time, according to whether the sum of its heat inputs and outputs Qt is positive or negative *i.e.* :

$$dT_s/dt = Q_t/\rho C_p H \quad (2)$$

From equation (1) and (2)

$$Q_t = K(T_e - T_s)$$

The thermal exchange coefficient K is a key parameter and represents the sum of temperature-dependent heat exchange processes including sensible, evaporative and back radiative fluxes. Brady et al. (1969) have shown that a good approximation to T_e is :

$$T_e = T_d + Q_s/K$$

where Q_s is the rate of incoming absorbed solar radiation per unit area and T_d is the dew point temperature. On an annual basis, both T_d and Q_s are generally much greater during summer than in winter and the dominant contribution to the seasonal fluctuations of T_e is the dew point temperature.

Edinger *et al.* (1974) give :

$$K = 4.5 + 0.05\, T_s + (\beta + 0.47)\, f(W)$$

where

$$\beta = 0.35 + 0.015\, T_m + 0.0012\, T_m^2$$

$$T_m = 0.5\,(T_s + T_d)$$

Several formulas are summarized by Edinger *et al.* (1974) for f (w), one of which is f (W) = 3.3 W when wind speed W is measured in m/s. The thermal exchange coefficient K enters at two points: directly as, the proportionality coefficient for converting the temperature difference ($T_e - T_s$) into an equivalent rate of heat exchange, and indirectly,

Table

Montly means of absorbed solar radiations Q_s; wind speed w; sea surface temperature T_s dew point temperature T_d; Equilibrium temperature T_e; thermal exchange coefficient K; net surface heat flux at the air sea interface Q_t and Q_t.*
(Q_t is computed on the basis of equilibrium temperature and Q_t is from sensible; evaporation and radiation heat fluxes).*

Month	Q_s W/m²	W m/s	T_s C	T_d C	T_e C	K W/m².C	Q_t W/m²	Q_t* W/m²
1	154	4.8	24.8	19.0	23,6	33,4	-40	-52
2	188	5,8	24,5	19,0	23,8	38,9	-27	-37
3	214	8,1	25,2	20,1	24,1	53,7	-59	-57
4	243	6,3	26,5	21,4	26,8	45,0	14	7
5	245	5,4	28,0	23,5	29,3	41,9	54	47
6	260	3,8	28,8	25,7	33,6	32,8	157	165
7	249	4,2	30,5	25,0	31,9	36,3	51	51
8	238	5,2	30,8	26,2	31,5	44,6	31	33
9	226	5,6	29,5	25,5	30,5	45,1	45	40
10	215	5,1	28,5	23,5	28,8	40,3	12	1
11	181	6,2	27,5	20,7	24,7	44,8	-125	-134
12	161	5,0	26,5	19,2	23,7	35,6	-100	-119

* After Ahmad and Sultant (1987)

as the divider of the solar radiation component in the approximation for T_e, showing the versatility of this parameter in representing the combined rate of evaporation, conduction and back radiation in the equilibrium temperature concept.

DATA ANALYSIS

The present study is undertaken to demonstrate the capability of equilibrium temperature and the thermal exchange coefficient to furnish estimates of the net heat flux at the air-sea interface in the central Red Sea. The knowledge of Q_s, W, T_d, T_s is sufficient to determine K and T_e. The data collected by the Saudi-Sudanese Commission for the exploitation of the Red Sea resources during the «Environmental Survey Programme», 1977-1978, Atlantis II Deep Project, are used in the present study. Surface heat fluxes for the central Red Sea have already been calculated, on the basis of equations given in Budyko (1974), by using these data (Ahmad and Sultan, 1987). Monthly means of sea surface temperature, wind-speed data and the dew-point temperature computed from air temperature and the relative humidity are given in the Table. Solar radiation measurements are obtained from land-based stations Taif and Biljurshi near the eastern coast of the central Red Sea. An allowance for average reflection of 6 % at the sea surface (Ahmad, 1982) is made and the values are given in the Table. The computed values of thermal exchange coefficient, equilibrium temperature and the computed net surface heat flux at the air-sea interface are also given in the Table and the plot of the latter is shown in Figure. The equilibrium temperature is lower than the sea-surface temperature by an average of about 1.7° C from November to March and is highe by 1.4° C from April to October. The value of K varies from a low of 32.8 in June to a high of 53.7 in March.

RESULTS AND DISCUSSION

The exchange of heat across the air-sea interface is the most important factor governing the temperature of a water body. The net rate can be evaluated in terms of a thermal exchange coefficient and equilibrium temperature, both of which depend on observable meteorological variables. The values of the net heat exchange at the air-water interface in the central Red Sea show a net gain of heat from April to October and a net loss from November to March. The plot of the net heat flux at the air-water interface computed on the basis of equilibrium temperature and that obtained from sensible, evaporative and radiative heat fluxes follow the same trend. Therefore equilibrium temperature and the thermal exchange coefficient can safely be used for computing the net rate of heat exchange at the water surface in the central Red Sea.

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REFERENCES

Ahmad F. (1982). Heat exchange processes at the water surface in the eastern Irish Sea. *Pakistan J. scient. ind. Res.*, **25**, 192-197.

Ahmad F. and S.A.R. Sultan (1987). A note on the heat balance in the central region of the Red Sea. *Deep-Sea Res.* 34, **10**, 1757-1760.

Ahmad F. and S.A.R. Sultan (1989). Surface heat fluxes and their comparison with the Oceanic heat flow in the Red Sea. *Oceanologica Acta*, 12, **1**, 33-36.

Brady D.K., W.L. Graves and J.C. Geyer (1969). Surface heat exchange at power plant cooling lakes. Cooling water discharge. Project report No. 5. Electrical Institute publication No 69-901, New York, USA.

Budyko M.I. (1974). Climate and Life. International Geophysical Series 18. English Edition edited by David H. Miller, Academic Press, 508 p.

Edinger J.E., D.W. Duttweller and J.C. Geyer (1968). The response of water temperature to meteorological conditions. *Wat. Resour. Res.*, **4**, 1137-1145.

Edinger J.E., D.K. Brady and J.C. Geyer (1974). Heat exchange and transport in the environment. Cooling Water discharge project report No 14. Electrical Power Research. Institution Publication No 74. - 049-00-3; Palo Alto.

Friehe C.A. and K.F. Schmitt (1976). Parametrization of air-sea interface fluxes of sensible heat and moisture by the bulk aerodynamic formulas. *J. phys. Oceanogr.*, **6**, 801-809.

Garrat J.R. (1977). Review of drag coefficient over oceans and continents. *Mon. weath. Rev.*, **105**, 915-929.

Kondo J. (1977). Comparasion of the Kondo's bulk transfer coefficients with the recently made direct observations of fluxes on the sea surface. *J. met. Soc. Japan.*, **55**, 51-77.

Krauss E.B. (1972). *Atmosphere-Ocean interaction.* Claredon Press. Oxford, UK, 275 pp.

Liu W.T., K.B. Katsataros and J.A. Businger (1979). Bulk parametrization of air-sea exchanges of heat and water vapours including the molecular constraints at the interface. *J. atmos. Sci.*, **36**, 1722-1735.

Pond S. (1975). The exchange of momentum, heat and moisture at the ocean-atmosphere interface in Numerical models of ocean circulation. *Proceedings of the symposium. National Academy of Sciences, Washington D.C., USA*, 26-28.