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ESTIMATES OF THE HEAT BALANCE TERMS AT THE AIR-SEA INTERFACE OFF THE COAST OF KARACHI

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The exchange of heat across the air-sea interface is a dominant factor that governs the temperature of water body. The rate of heat exchange at the water surface is the sum of the rates at which heat is transferred by incoming solar radiation, conduction, evaporation and back radiation. Heat balance terms for waters near Karachi show that the mean annual heat input at the water surface is 15.8×10^4 cal/cm^2 an the loss due to conduction, evaporation and back radiation is approximately 0.8×10^4, 9.1×10^4 and 5.0×10^4 cal/cm^2 respectively throughout a year. The dominant component of heat loss from the sea is evaporation and is almost twice as large as that of back raidation. The conduction is even less than 10 per cent of the evaporation.

INTRODUCTION

A body of water exchanges heat with its surrounding by short and long wave radiation, conduction and evaporation. These processes of heat exchange between water and atmosphere are fairly well known. Almost every study related to thermal changes in a body of water begins with a mention of them. The processes take place mainly at the air-water interface and a summation of these heat exchange processes gives the net rate of heat exchange per unit area of the air-water interface H_n as:

$H_n = (H_s - H_r) \pm H_c - H_e - H_b$ where

H_s = Incoming solar radiation.
H_r = Reflected component of the incoming solar radiation from the water surface.
H_c = Heat loss or gain due to conduction.
H_e = Heat loss due to evaporation.
H_b = Net long wave radiation from the water surface.

The first two terms on the right hand side of the above equation is named the absorbed radiation H_{ab} defined as $H_{ab} = H_s - H_r$. The absorbed radiation is independent of the water surface temperature.

Incoming Solar Radiation H_s: The short wave solar radiation is the radiant energy which passes directly from the sun to the earth. Almost 99 per cent of the short wave Solar Radiation is contained in a wavelength range between 0.14 and 4.0 µm with the maximum intensity at about 0.5µm. The amount of short wave solar radiation reaching the surface of the earth is depleted by reflection, absorption, scattering by Ozone, suspended particulate matter, water vapours and cloud cover.

The total amount of Solar Radiation (direct and diffused) is more easily measured by solar meters than computed. The mean monthly values of these radiations in cal/cm^2 recorded at Karachi (Lat.24° 54′N Long 67° 08′E) based on data from 1970 to 1979 are given in Table 1.

Reflected Radiation H_r. The fractions of the Solar and atmospheric radiant energy that are reflected from a water surface are calculated using reflectivity coefficient. The Solar reflectivity is more variable than the atmospheric reflectivity. The former is a function of the sun's altitude and type and amount of Cloud cover while latter is relatively constant. The total reflectance depends on the angle of incidence and increases from, equator to poles and its value is taken as 6 per cent[1] for the whole day. If H_s is the recorded radiation then the absorbed radiation at the sea surface, H_{ab} is $H_{ab} = H_s\ (1-r)$. The computed mean monthly values of absorbed radiation H_{ab} at the sea surface are given in Table 2.

Conduction. The temperature of the water body usually is not equal to that of the layers of air lying above it. As a consequence there appears a vertical flux of heat between the underlying surface and the atmosphere, conditioned by the eddy or turbulent heat conductivity of the atmosphere. The rate of heat conduction is an order of magnitude less than other terms in the heat balance at the air-water interface. The rate at which heat is conducted between the two media is proportional to the temperature difference

Table 1. Monthly totals of solar radiation cal/cm², sea surface temperature °C, air temperature °C vapor pressure mb, wind speed m/sec. and cloudiness fractions of unity.

Month	Monthly totals of solar radiation in cal/cm² 1970-79	Sea surface temperature t_o in °C	Air temperature t_a in °C 1930-1960	Vapor pressure in mb 1930 to 1960	Wind speed in m/sec 1930-1960	Cloudiness in fraction of unity 1971-1975
January	11782	23.0	16.2	9.8	2.4	0.21
February	12040	24.0	18.6	12.2	2.6	0.21
March	15480	25.0	23.0	17.0	3.3	0.20
April	15652	27.0	26.5	22.2	4.1	0.23
May	16856	28.5	29.0	28.6	5.4	0.38
June	16254	30.0	30.2	32.5	6.1	0.56
July	14620	29.5	29.2	31.8	6.2	0.69
August	13674	29.0	27.9	30.0	6.0	0.69
September	14620	28.0	27.4	28.5	4.9	0.45
October	14534	28.0	25.8	21.2	2.8	0.13
November	11868	27.0	21.8	14.0	2.1	0.04
December	10922	25.0	17.7	11.5	2.0	0.18

Table 2. Computed values of absorbed solar radiation H_{ab} conduction H_c evaporation H_e and back radiation H_b and net heat exchange H_n in cal/cm² -month.

Month	H_{ab}	H_c	H_e	H_b	H_n
January	11094	1634	6622	6192	–3354
February	11352	1290	6278	5246	–1462
March	14534	688	7482	5160	1204
April	14706	172	8084	4128	2322
May	15824	–258	8600	3354	4128
June	15308	–86	8944	2236	4214
July	13760	172	8944	2322	2322
August	12814	688	8288	2322	516
September	13760	258	6794	2924	3784
October	13674	602	7138	4558	1376
November	11180	1032	6622	5590	–2064
December	10234	1548	6192	6106	–3612

between the two media i.e.

$H_c = f(w) (t_o - t_a)$ were

t_o is the sea surface temperature
t_a is the air temperature and
w is wind speed.

An expression given by Kraus[2] is

$H_c = \rho_a C\ddagger C_{10} (t_o - t_a) w$ where

ρ_a = Density of air.
C_p = Specific heat of air at constant pressure.
C_{10} = Drag coefficient for wind measured at 10 m height 1.3×10^{-3}

ρ_a & C_p depend on temperature but are taken constant for the whole year.

ρ_a = 1.2×10^{-3} gm/cm^3 at 25°C
C_p = 0.239 cal/gm at 25°C and normal atmospheric pressure.

Putting the numerical values

$$H_c = 3.24\,(t_o - t_a)\,w \text{ cal/cm}^2\text{/day}$$

where w is measured in m/sec.

Mean monthly values of the sea surface temperature are taken from oceanographic Atlas of the Indian Ocean[3] supplemented by available data near the coast of Karachi. The mean monthly values of wind speed in m/sec based on data from 1931 to 1960 and the corresponding air temperature recorded at Karachi shown in Table1. The computed values of heat loss by conduction integrated over a month are given in Table 2.

Evaporation. The conversion of energy in evaporation (latent heat flux) is equal to the product of latent heat of evaporation by the amount of evaporation. The latent heat of evaporation under natural conditions varies slightly in accordance with the change in temperature of the evaporating surface. The task of determining evaporation from the surface of the water bodies is simplified in comparison with land because the humidity at the level of the water surface is equal to the saturation humdity at the temperature of the water surface and over more or less large bodies of water the vertical gradients of temperature in the lowest layer of the air are, as a rule appreciably smaller than the corresponding gradients on land. The rate of evaporation depends on the difference in vapour pressure at sea level and at height h, and the wind speed at that height:

A general expression has the form:

$$H_e = f(w)\,(e_s - e_a)$$

where w is wind speed.

e_a is the air vapour pressure and e_s is the saturation vapour pressure of air adjacent to the water surface. An expression favoured by Budyko[4] is $E = \rho_a\, C_{10}\, (q_o - q_a)\, W$

q_o = saturation specific humidity at sea surface temperature t_o.
q_a = specific humidity in the air at temperature t_a.

Putting the numerical values the equation becomes:

$H_e = 5.0\,(e_s - e_a)\,w$ cal/cm^2/day, w is measured in m/sec.
e_s = saturation vapor pressure at t_o.
e_a = vapor pressure in the air at t_a.

The values of e_s were noted from the tables for the saturation vapor pressure over water and the vapor pressure at the air temperature t_a was calculated on the basis of dry and wet bulb temperature.

The computed values of evaporation integrated over a month are given in Table 2.

Net Back Radiation H_b. The sea surface radiates energy back to the atmosphere in the form of long wave radiation in the wavelength range from 4 to 120 μm. This back radiation accounts for a substantial portion of the heat loss from a body of water. The value of the net long wave radiation depends on air temperature, humidity, cloudiness and the vertical gradient of temperature and moisture in the atmosphere[5].

M. E. Berliand[6] established a theoretical dependence of the net long wave radiation under cloudless skies. The dependence found by Berliand can be expressed as:

$H_b = \epsilon\, \sigma\, T_o^4\ (0.39\text{-}0.0504\sqrt{e_a}$ where e_a in mb
ϵ = is the coefficient of emissivity with an average value of 0.985 given by Kraus[2].
σ = is Stephan-Boltzman constant 82×10^{-12}cal/ min/cm^2]deg^4
T_o = is the absolute sea surface temperature.

For checking the available formulae Efimova[7] processed a great many observational data of net long wave radiation obtained during the period of international Geophysical year. It was established in his work that Berliand formulae is applicable at average and high humidities. As the humidity in the area is comparatively high, the above formulae was applied for computation of back radiation. Besides the temperature and humidity net long wave raidation is influenced by cloudiness and also depends on latitude. In some investigations there are indications that observational data show that the decrease of net long wave radiation with the increase of cloudiness is not linear but is more rapid. The effect of cloudiness and latitude can be expressed as:

$$H_b = H_b'(1 - cn^2)$$

where n is cloudiness in fraction of unity
c is a factor which depends on latitudes given by Budyko[4].
$H_b'$is long wave radiation under cloudless sky.

Taking all factors into account the expression becomes:

$$H_b = 0.985\, \sigma\, T_o^4\, (0.39\text{-}0504\sqrt{e_a}\ \ (1\text{-}0.61\, n^2)\text{cal/cm}^2\text{/min}$$

The values of cloudiness in fraction of unity based on data from 1971 to 1975 are given in Table 1 and the computed values of H_b summed over a month are shown in Table 2.

Net Heat Exchange H_n. The net rate of heat exchange H_n at the air water interface is obtained from

$$H_n = H_{ab} \pm H_c - H_c - H_b$$

The values of this terms from January to December are given in Table 2. The calculations show that there is a net gain of heat from March to October and net loss from November to Febraury.

RESULTS AND DISCUSSION

The heat input at the water surface is higher during the summer months as expected and is maximum in May-June. It is comparatively less during the July-September because of the higher amount of cloud cover.

The mean annual heat input at the water suface is 15.8 x 10^4 cal/cm^2 and the approximate values of heat released from the water surface due to conduction, evaporation and back radiation are 0.8 x 10^4, 9.1 x 10^4 and 5.0 x 10^4 cal/cm^2 respectively throughout a year. The loss of heat due to evaporative process in the summer months is comparatively higher because of the higher wind speed and is maximum in August but the difference is by no means significant as the absolute humidity in the winter months is less, a favourable condition for evaporation. The contribution of baek radiation during the summer months is less because of higher humidity and the amount of cloud cover. The contribution of conduction is significantly less. It is positive throughout the year except for May and June. The figure suggest that the dominant contribution to heat loss from the sea surface is due to evaporation which is almost twice as higher as that of back radiation. The contribution of conduction is even less that 10 per cent of the evaporation.

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