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Sensible and Latent Heat Fluxes in Coastal Waters of Dhahran, Arabian Gulf

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ABSTRACT. Based on 30 years of meteorological data (1961-1990) at Dhahran and the sea surface temperature, the monthly means of sensible and latent heat fluxes in coastal waters of the Arabian Gulf are estimated using the bulk formulas. The stability of the atmospheric boundary layer; the thermal differences between sea-air and the corresponding wind speed at 10m are considered when choosing the heat transfer coefficients. The calculated mean annual sensible and evaporative fluxes are + 0.1 and – 133 w/ m^2, respectively. The small annual mean of sensible heat flux indicates a near balance condition between summer and winter seasons. Maximum evaporation rate occurs in September while minimum rate in May. The latent heat flux compares favourably with the Pan measurements at the same location. It is concluded that the use of a constant transfer coefficient in earlier studies seems to overestimate the evaporative heat flux.

Introduction

The Arabian Gulf is characterized by a negative water budget since evaporation greatly exceeds precipitation and runoff. Being in an arid area in addition to its shallowness, the Arabian Gulf water is subjected to higher evaporation rate than any zonal water body. Evaporation from semi-enclosed seas has been the subject of considerable studies in the recent years because of its significance in determining the salt, heat and water budgets.

Due to high evaporation in the Gulf, a horizontal pressure gradient is developed and a less dense surface water flows from Gulf of Oman into the Arabian Gulf through Strait of Hormuz (Abdelrahman and Ahmad, 1993). Evaporation is one of the major causes for density variation along the Arabian Gulf and in turn for the density driven circulation.

Emery (1956) gave the following dimensions for the Gulf: area 239 × 10^3 km^2 and volume 8.63 × 10^3 km^3 which corresponds to an average depth of about 36 m. Hartmann *et al.* (1971) estimated an annual water budget in the Gulf as follows: inflow 3365 km^3, outflow 3110 km^3, evaporation 326 km^3, precipitation 34 km^3 and river inflow 37 km^3.

The heat budget of the Gulf has been charted by Hastenrath and Lamb (1979) on the basis of observations from 1911 to 1970. Annual mean evaporation flux was estimated as 110 w/m^2 with a small net annual sensible heat flux. Maximum evaporation occurs during winter (from November to April) and minimum during summer (from May to October).

Privett (1959) estimated evaporation from the open waters of the Gulf as 144 cm/year. Highest evaporation was in December while lowest in May. Meshal and Hassan (1986) calculated the monthly mean evaporation during 1981-1982 at two coastal stations; Doha (Qatar) and Manama (Bahrain). The annual mean evaporation was estimated as 202 cm with a maximum in June and a minimum during January/February. They showed that evaporation from the open water constitutes about 70% of their coastal estimates and referred it to the higher temperature and the dry continental winds over the coastal waters of the Gulf. In their annual mean surface heat fluxes in the Arabian Gulf, Ahmad and Sultan (1991) estimated the latent and sensible heat fluxes; – 168 and 1 w/m^2, respectively based on coastal data at Dhahran from 1970 to 1984.

The above studies are mainly based on a constant exchange coefficient for sensible and evaporative flux calculations. The present work is undertaken with a view to estimate these values, with exchange coefficients that depend on the stability of the atmosphere boundary layer; sea-air temperature difference and the wind speed at 10 m. A long term meteorological data set at Dhahran (Fig. 1) that extends over a period of 30 years (1961-1990) is considered.

Data Analysis and Methodology

Climatological normals (30 years; 1961-1990) collected at Dhahran (Lat. 26°15′34″N, Long. 50°09′39″, Z = 16.77 m) are used to calculate the sensible and latent heat fluxes in the Arabian Gulf. These data include air temperature, relative humidity, wind speed and air pressure. Sea surface temperatures measured at two nearby stations (reported in Ahmad and Sultan, 1991) are considered in the computations.

The bulk formulas for estimating the vertical heat fluxes are given as (Gill, 1982);

$$Q_e = -\rho_a \cdot L \cdot C_e (q_s - q_a)\ W, \quad (1)$$

$$Q_h = -\rho_a \cdot C_p \cdot C_h (T_s - T_a)\ W; \quad (2)$$

where ρ_a is the density of air, L is the latent heat for evaporation corrected to sea surface temperature L = (2500.8 – 2.3 T_s) KJ/Kg, T_s and T_a are sea surface and temper-

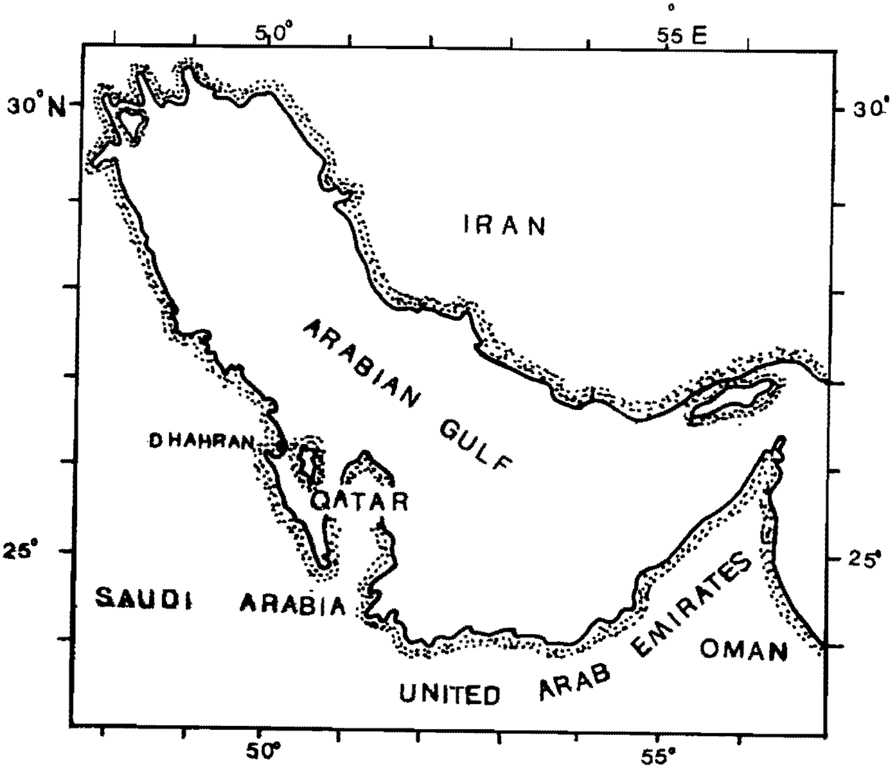

FIG. 1. Map of the Arabian Gulf showing the location of the coastal meteorological station (•) at Dhahran.

atures in degrees, q_s and q_a are the saturated specific humidity at sea surface temperature corrected for salinity and specific humidity in the air respectively, W is the wind speed corrected to the standard elevation at Z = 10 m, C_p is the specific heat of air at constant pressure, C_e and C_h are the heat exchange coefficients for evaporation and sensible heat respectively.

In terms of vapour pressures, equation (1) can be written and simplified as

$$Q_e = - \rho_a \cdot C_e \cdot L \{ 0.622 (e_s - e_a) W \} \quad (3)$$

where e_s is the saturated vapour pressure at sea surface temperature corrected for salinity and e_a is the vapour pressure at air temperature.

The values of latent and sensible heat fluxes depend much on the choice of heat exchange coefficients C_e and C_h . Smith (1980) suggested that the sensible heat coefficient C_h varies according to the stability of the atmospheric boundary layer. For unstable conditions, the sensible exchange coefficient is given 1.1×10^{-3} while for the stable condition is 0.83×10^{-3}, thus C_h does not increase with the increase in wind speed. Masagutov (1981) used a variety of eddy correlation measurements and proposed exchange coefficient for sensible and latent heat as a function of sea-air virtual potential temperatures difference and the wind speed at 10 m. The two nomograms given by Masagutov (1981) were converted to tabular forms by Blanc (1985). A coefficient of 1.3×10^{-3} for both sensible and latent heat calculations at Dhahran was suggested by Ahmad and Sultan (1991).

Results and Discussion

Based on the climatological normals of 30 years (1961-1990) at Dhahran, the latent and sensible heat fluxes are calculated. The monthly variations of the mean atmospheric and oceanographic parameters, air temperature, relative humidity in addition to sea surface temperature are shown in Fig. 2. The lowest temperatures for both air and sea surface occur during winter in January and February while highest temperatures occur during summer in July and August. There is a lag of one month between the annual extreme temperatures of air and water which is referred to the difference in heat capacity between the two fluids. The monthly mean wind speed at 10 m height varies from a minimum of 3.34 to a maximum of 5.73 m/sec throughout the year and becomes strongest during June. The monthly mean wind speed shows a weak seasonality at Dhahran. The prevailing wind direction at Dhahran is from north through all months except in January, November and December where the wind becomes northwesterly. A comparison between the monthly means of 15-years (1970-1984) of meteorological data in Ahmad and Sultan (1991) with the monthly means of 30 years data (1961-1990) at Dhahran show an increase in air temperature of 0.3°C associated with a decrease in relative humidity of 0.75% and wind speed of 0.03 m/sec.

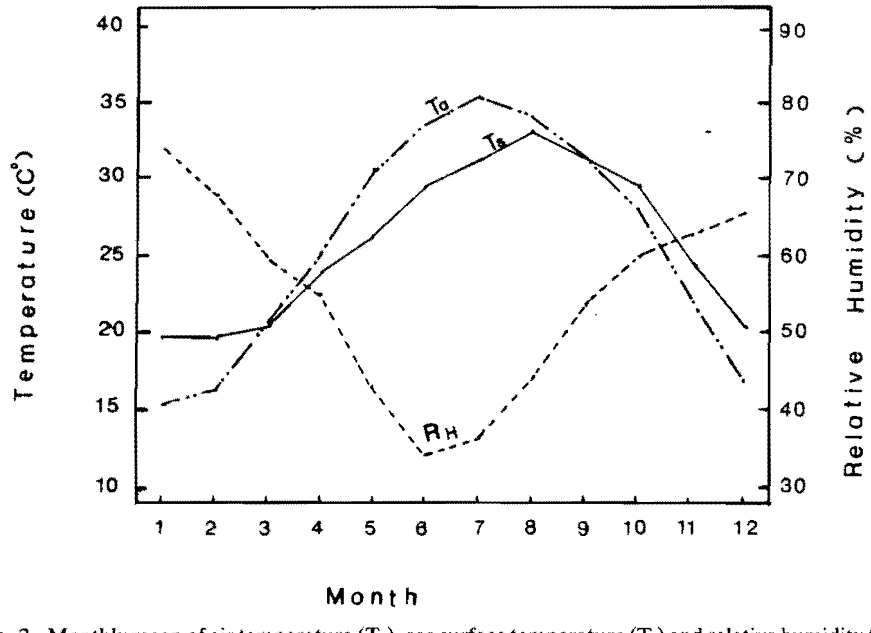

FIG. 2. Monthly mean of air temperature (T_a), sea surface temperature (T_s) and relative humidity (R_H) at Dhahran.

Using the bulk formula and considering the stability conditions, the sensible heat flux is calculated and shown in Fig. 3. The monthly mean sensible heat flux shows a seasonal pattern; a negative flux (loss from sea surface) during winter while water gains heat by conduction during summer. However, the net annual heat transfer between air-sea by conduction shows a small gain (0.1 w/m^2). A small value of the net sensible heat (1 w/m^2) was also obtained by Ahmad and Sultan (1991) in the same region but based on a common exchange coefficient for both latent and sensible fluxes. Considering a constant coefficient of $C_h = 1.3 \times 10^{-3}$, neglecting the stability of the atmospheric boundary layer, the sensible heat gain will increase to 2.6 w/m^2 which still comparable with earlier studies.

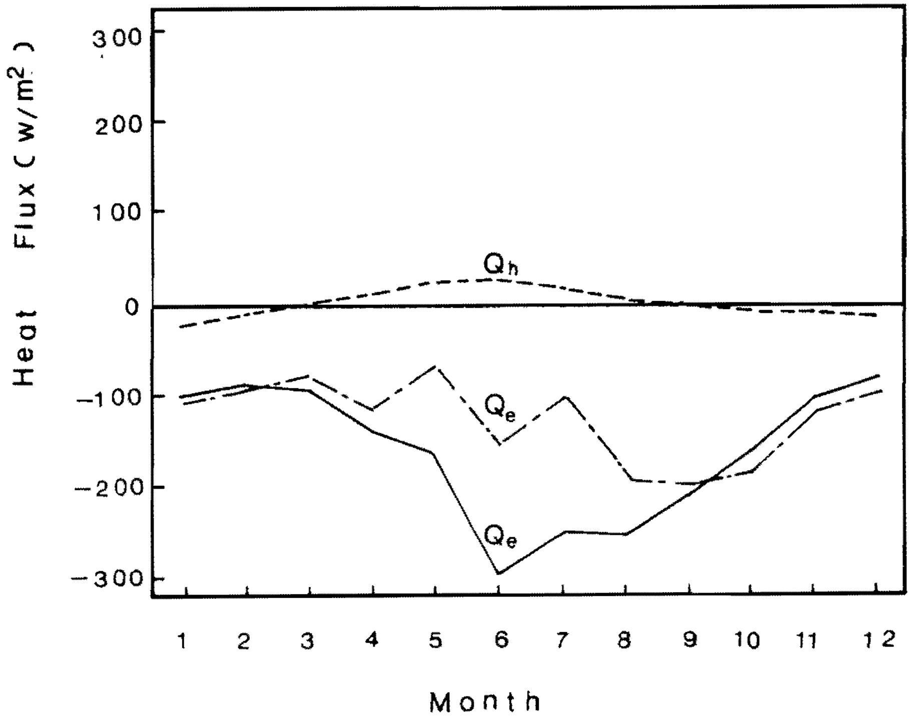

FIG. 3. Temporal variations of the calculated sensible (Q_h) and latent (Q_e) heat fluxes: —— - —— —— C_e depends on the stability of the atmospheric boundary layer, and ———— $C_e = 1.3 \times 10^{-3}$.

The evaporative heat fluxes are calculated first by considering the stability of the atmospheric boundary layer and then by neglecting it. Following Masagutov (1981), a monthly coefficient is extracted based on the sea-air virtual potential temperature differences and the wind speed at 10 m. The resulting annual mean evaporative flux is – 133 w/m^2 (169 cm/year) with maximum in September and minimum in May as shown in Fig. 3. The flux increases to – 146 w/m^2 (185 cm/year) when an annual average of C_e (1.15×10^{-3}) is applied (about 10% higher). An annual mean flux of – 165 w/m^2 (209 cm/year) results when C_e is considered constant 1.3×10^{-3} as suggested by Ahmad and Sultan (1991) at Dhahran.

It is worth mentioning that evaporation rates at three coastal stations on the Saudi coast of the Arabian Gulf; (Safaniya, Ras Tanura and Dhahran) were measured. based on pan measurements by ARAMCO Engineering (1977). The resulting evaporation rates were presented in a graphic form with an annual rate of 238 cm at Dhahran. It is well established that evaporation from pan measurements is higher than from a natural water body and an empirical reduction factor may be recommended. An average factor of 0.7 was suggested by Houghton (1985) to reduce the annual A-pan measurements. The observed rate then reduced to 167 cm/year. This result is in good agreement with our estimate that considers the stability conditions.

Our conclusions suggest that the choice of the heat transfer coefficients that depend on the stability of the atmospheric boundary layer, sea-air temperature differences and corresponding wind speeds, increases the reliability of recent flux estimates in the Arabian Gulf. Furthermore, the attempt to neglect the stability conditions seems to overestimate the evaporation heat flux and smoothes out the monthly variation. Offshore weather data from the open waters of the Arabian Gulf are highly recommended to improve the estimates of evaporation for this marginal sea.

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دفــق الحرارة المحسوسة بالتوصيــل والكامنــة للبخر من الميــاه الساحليــة للظهران بالخــليج العربي

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المستخلص . قدرت المتوسطات الشهرية لدفق الحرارة المحسوسة بالتوصيل والكامنة للبخر من المياه الساحلية للخليج العربي (الظهران) باستخدام بيانات مناخية لمدة ثلاثين عامًا من سنة ١٩٦١م إلى سنة ١٩٩٠م . وقد أخذ في الاعتبار استقرارية الطبقة الحدية الجوية حيث أخذت الفروقات بين درجتي حرارة الهواء والماء وكذلك سرعة الرياح المقاسة عند ١٠ أمتار وذلك عند اختبار معامل الحرارة للبخر والتوصيل .

وقدرت القيم السنوية المتوسطة لدفق الحرارة المحسوسة بالتوصيل والحرارة الكامنة للبخر : (+ ٠,١ و -١٣٣ وات/م^{٢}) على الترتيب . وتدل القيمة الصغيرة للحرارة المحسوسة على وجود حالة قريبة من الاتزان بين التغيرات الفصلية في الشتاء والصيف . وقد وجد أن أعلى معدل للبخر يحدث في شهر سبتمبر وأقل معدل في شهر مايو . واتفقت التقديرات المحسوبة لمعدلات البخر مع القيم المقاسة بطريقة الأواني عند نفس المنطقة . واتضح أن إهمال الأخذ بحالة استقرارية الطبقة الحدية للجو يؤدي إلى زيادة في المعدلات السنوية المحسوبة للبخر والحرارة المحسوسة بالتوصيل .