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The study of heat budget and heat fluxes in northeast Oman sea (Chabahar Bay)

H. Mehrfar[1] and Z. Mohamadi Pasand[2]

[1]Physical Department, Ayatollah Alozma Boroujerdi University, Boroujerd, Iran
[2]School of Engineering, Boroujerd Branch, Islamic Azad University, Boroujerd, Iran

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ABSTRACT

Heat budget is one of the most important factors in physical study of seas and oceans. Due to its effect on environmental factors and leveling marine structures as well as sea water level, study of this subject has a great importance. Conducting research on various analogs including the sunshine angle, cloudiness of the sky, albedo of water surface, special humidity, atmosphere structure, short-wave sunshine, net sunshine with long-wave, sensible heat transfer, evaporation heat transfer, heat transfer by oceanic streams and raining, wind speed, and local dimensionless (sensible and latent heat flux coefficient),calculated heat budget flux in the Bay the basis of data Iranian meteorological organization and the most recent formulation . The results show that in the year of 2005 in Chabahar Bay, the short-wave radiation flux has been (+227.56 w/m^2), net long-wave flux (-59.91 w/m^2), insensible evaporation heat flux (-112.16 w/m^2) and sensible heat flux (-8.00 w/m^2). Considering the above mentioned parameters, heat budget flux in this Bay is equals to (+47.49 w/m^2) . In order to achieve heat balance it is required that such heat flux exit from the Bay by water exchange between Oman Sea and Chabahar Bay and raining.

Key words: Heat budget, Chabahar Bay, Heat fluxes

INTRODUCTION

The heat changes stored in the upper layers of the ocean are the result of the imbalance between the incoming and outgoing heat through the sea surface. This surface heat transition is called heat flux. Heat budget involves the total heat fluxes coming into or going out of a water volume. Today a large number of research on heat budget have been undertaken and they have been computed for the various seas and oceans in the world. Among the new relevant initiatives are as follow: Kara (1999) obtained the latent heat flux coefficients and the sensible ones and also the drag coefficient on the basis of wind speed and the difference between the sea and air temperature which are of a significant precision and can be applied to different areas. Also, He compared the calculation of heat fluxes and wind stress (in Arabian Sea) by using mathematical relations and ocean-atmosphere models together with the satellites, indicating that how precise the formulas for calculating the heat budget are [1] In Bergen university of Norway, Simonsen and Hugan (1996) Studied the heat budget of the North Mediterranean Sea and the surface heat flux of Nordic Sea, and they presented their paper in which they could achieve the changes occurred in each of heat hudget sentences compared to the different months during the year through making use of frequency data collected from different centers.[2] Naoki et al (1996) determined the heat budget for Japan Sea using the existing relations.[3] Fan and Brown (2003) of Massachusetts university made efforts to study the heat budget for the Mt. Hope bay (between 71° 06′ and 71° 18′. West Longitude and 41° 36′ and 41° 48′ North Latitude) in which case the impact of rivers has been included, too [4] and soon. In Iran, Mehrfar et al (2007), also, used the heat budget relations related to Gorgan Bay with respect to the features of the Bay. after doing the computations required for the individual parameters, He obtained each associated sentence percentage, and eventually compared the resulting values to the global average quantities and also found out how the alteration made and the factors impacting on the heat budget sentences.[5] In relation to Persian Gulf heat budget, some studies were undertaken by Jariani of Kish University. In addition, Partovi of Azad University North Tehran branch (2006) studied the heat budget equation for Oroumieh Lake and calculated each of the sentences. Since the climatic changes of any particular area are studied based on its heat budget, it becomes necessary to calculate the heat budget in a certain area including Chabahar Bay which enjoys a special strategic situation. Among the natural sight of the Bay are the rare marine and coastal beauties and the vision at the time of sunrise or sunset over the sea in addition to its spectacular situation. The position of the bay in Oman Sea which is between East Longitude ($60^\circ 25'$ & $60^\circ 37'$) and North Latitude ($25^\circ 17'$ & $25^\circ 26'$) in south east Iran. The entrance of the bay is 13.5 km wide and the water in this part is 14.5 m deep, but it lessens while approaching the extremes as the depth is equal to 5.5 m when we are 13.5 km away from the north and west extremes. From the north to the south, it is 17 km long while from the east to the west, at the widest point, it is 20 km wide. No significant river flows into the bay. Using the data required to determine the heat fluxes which have been obtained and collected from different sources like the meteorology Organization, the National Center for ocean studies and many others, and based on the state-of-the art formulas, we deal with determining the heat flux for the individual heat budget sentences of the Bay during the year 2005 month by month.

Determining short-wave radiation flux (Qsw) in Chabahar Bay:
In the heat budget flux equation, the first part is the extent of the radiant flux, and the water is uptaken in the desired place. To calculate the flux, the following formula is used [6].

$$Q_{sw} = (1-\alpha) Q_C \left(1 - 0.62C + 0.0019\theta_N\right) \qquad (1)$$

Where α is the albedo of water surface which ranges 3-40 percent based on the radiant angle to the water surface. θ_N is noon solar elevation to the surface in terms of degrees, and it is obtained by the equation $\theta_N = 90 - (\varphi - \delta)$ where δ is the sun zenith angle calculated in degrees, and φ is the latitude in degrees which is $25^\circ 17'$ or approximately 25.28 degrees in Cha-bahar Bay; C is fractional cloud cover which has been obtained from the data in the Meteorology Organization Calender book during 2005 month by month, and is included in Table.1 .

Q_C is the incoming solar radiation flux in Wm^{-2} which reaches the water surface when the sky is clear; its Value can be achieved by the equation $Q_C = 0.7 Q_I \sin\theta_N$ and depends on the radiant angle, atmosphere conductivity coefficient in a clear sky (equal to 0.7), and the extent of the incoming radiation to atmosphere. In the above equation, Q_I is the incoming radiant flux to the atmosphere in the related latitude, and its Values during 2005 month by month in Cha-bahar Zone have been presented in Table.1 [11].

Table 1. The quantities required to determine short wave radiation flux in Chabahar Bay (2005)

Month parameter	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
δ (degree)	**-21**	**-13**	**-2**	**10**	**19**	**23.5**	**21**	**14.5**	**3.5**	**-8**	**-18**	-23
θ_N (degree)	**43.7**	**51.7**	**62.7**	**74.7**	**83.7**	**88.2**	**85.2**	**79.2**	**68.2**	**56.7**	**46.7**	41.7
α (%)	**11.4**	**10.0**	**9.5**	**5.8**	**5.4**	**4.7**	**4.8**	**5.5**	**5.9**	**8.5**	**10.5**	10.8
C	**0.25**	**0.0**	**0.0**	**0.12**	**0.12**	**0.25**	**0.25**	**0.37**	**0.25**	**0.0**	**0.0**	0.25
Q_I (w/m^2)	**280**	**330**	**338**	**435**	**461**	**468**	**442**	**430**	**402**	**347**	**292**	264
Q_{SW} (w/m^2)	111.7	179	245	295	321	316	309.7	263.3	239.8	203.1	145	101.5

Calculating net long-wave radiation flux (Q_{LW}) in Cha-bahar Bay:
According to the radiation Law (Stephan-Boltsman), any object whose temperature is above the absolute zero will radiate. Therefore, the sea surface, due to its temperature, sends out the radiant energy in the form of electromagnetic waves with long wave length, for the atmosphere, also, sends long-wave radiation, part of which called returning radiation reaches the ocean surface. Consequently, another important factor in heat budget is the

difference between the long-wave radiation of sea water and the atmospheric returning radiation, which is known as net long-wave radiation. To calculate the net long-wave radiant flux for Cha-bahar Bay, the following formula is used: [6]

$$Q_{LW} = \varepsilon\sigma_{SB}T_s^4\left(0.39-0.05e^{1/2}\right)\left(1-KC^2\right)+4\varepsilon\sigma_{SB}T_s^3\left(T_s-T_a\right) \qquad (2)$$

Where ε is the transmittancy of sea surface which equals approximately to 0.98; σ_{SB} is the constant (Stephan-Boltsman) which equals to $5.67\times10^{-8}\,\mathrm{wm^{-2}k^{-4}}$; e is vapor pressure in milibars which has been calculated for each month during 2005 in Cha-bahar Bay (Table.2) based on the data in the Meteorology organizations calendar book (2005). K is the cloud cover coefficient which is equal to approximately 0.64 for the area based on Cha-bahar Latitude.

T_s is the water surface temperature in Kelvin for Cha-bahar Bay which has made use of the data from the National Center for ocean studies and the Meteorology Organization for each month during 2005. T_a is the air temperature at 10-meter reference level which is calculated in Kelvin and the data from the Meteorology Organization's calendar book (2005) for each month in 2005 have ben used.

Table 2. The quantities required to calculate the net long wave radiation flux in Chabahar Bay (2005)

Month parameter	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
T_a (K)	**293.5**	**294.1**	**297.1**	**299.8**	**302.2**	**304.0**	**302.3**	**301.8**	**301.8**	**300.7**	**298.0**	295.5
T_s (K)	**294.4**	**295.2**	**298.5**	**299.2**	**303.4**	**303.2**	**301.2**	**302.0**	**302.7**	**301.2**	**298.8**	296.5
e (mb)	**14.2**	**19.6**	**25.5**	**27.2**	**33.1**	**37.8**	**33.5**	**32.5**	**32.3**	**28.6**	**21.1**	17.3
C	**0.25**	**0.0**	**0.0**	**0.12**	**0.12**	**0.25**	**0.25**	**0.37**	**0.25**	**0.0**	**0.0**	0.25
Q_{LW} $\left(w/m^2\right)$	-85.7	-77.8	-68.0	-53.2	-55.6	-33.3	-38.8	-37.5	-53.1	-59.1	-75.7	-80.6

Calculation of sensible heat flux (Q_S) in Cha-bahar Bay:
One of the other important sentences in heat budget flux is called sensible heat flux which is exchanged through the molecular conduction between the sea and the atmosphere. Because sea surface temperature is generally higher than that of the environment, the sensible heat usually flows from the sea to the air. As a result, the sentence is usually minus but when the air temperature is higher than the surface one, heat flows from the atmosphere to the sea. Therefore, under these conditions, the sensible heat flux sentence will become positive. To compute the sensible heat flux for each month in 2005 in Cha-bahar Bay, the following formula is used [1, 2, 3, 5, 6, 7]:

$$Q_S = \rho_a C_s C_p U_{10}\left(T_a - T_s\right) \qquad (3)$$

Where ρ_a is the density of the air surrounding the sea surface ($\mathrm{kg/m^3}$) which has been measured from the equation (4) with regard to the pressure and the temperature in each month, and the result was presented in Table.3 ; C_p is the specific air heat with a constant pressure equal to 1012 J kg^{-1} K^{-1} ; C_s is sensible heat flux coefficient which has been measured in terms of the temperature difference (sea-air) and the wind speed in a ten-meter altitude for all the year months. [1]
U_{10} is the wind blowing speed in m/s at 10-meter level that has been reckoned on the basis of the data from the Meteorology Organization's Calendar book (2005) for the different months in 2005, and the values are given in Table.3 .

T_a is the air temperature at 10-meter reference level in Kelvin or Celcius.

T_s is the water surface temperature in Cha-bahar Bay calculated in Celcius or Kelvin.

$$\rho_a = \frac{100p_a}{\left[R_{gas}\left(T_a + 273.16\right)\right]} \qquad (4)$$

P_a : Atmospheric pressure at sea surface (mb) , R_{gas} : Gas constant (287.1 J kg^{-1} K^{-1})

Table 3. The quantities required to calculate sensible heat flux in Chabahar Bay (2005)

Month parameter	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
T_a (K)	**293.5**	**294.1**	**297.1**	**299.8**	**302.2**	**304.0**	**302.3**	**301.8**	**301.8**	**300.7**	**298.0**	295.5
T_s (K)	**294.4**	**295.2**	**298.5**	**299.2**	**303.4**	**303.2**	**301.2**	**302.0**	**302.7**	**301.2**	**298.8**	296.5
p_a (mb)	**1017.0**	**1015.0**	**1012.4**	**1010.3**	**1006.0**	**999.1**	**999.1**	**1008.2**	**1000.6**	**1004.8**	**1014.9**	1016.7
ρ_a (kg/m^3)	**1.21**	**1.20**	**1.19**	**1.17**	**1.16**	**1.14**	**1.15**	**1.15**	**1.16**	**1.17**	**1.19**	1.20
U_{10} (m/s)	**8.2**	**11.8**	**9.7**	**8.2**	**8.2**	**8.2**	**8.2**	**8.7**	**6.2**	**6.2**	**8.2**	8.2
$C_S \times 10^3$	**1.40**	**1.58**	**1.58**	**1.30**	**1.51**	**1.30**	**1.12**	**1.38**	**1.40**	**1.40**	**1.40**	1.40
Q_S (w/m^2)	-12.6	-27.1	-25.8	7.5	-17.4	9.8	11.76	-2.79	-9.1	-5.1	-11.1	-13.9

Calculating vaporization latent heat flux (Q_L) in Cha-bahar Bay:

Ocean and seas are frequently vaporized. This vaporization which results from the molecules going out of the free water surface is called surface vaporization. Due to the surface vaporization, the liquid loses its latent Vaporization heat so that the temperature decreases. Thus, the decrease in sea water temperature is because of the surface vaporization. Therefore, the transmition tone of vaporization latent heat takes place generally from the sea to the atmosphere. To calculate the vaporization latent heat flux in Cha-bahar Bay, the following formula is used: [1,3,5,6 and 7]

$$Q_L = \rho_a C_L L_E U_{10} \left(q_a - q_s\right) \qquad (5)$$

Where C_L is the Vaporization latent heat flux coefficient which has been measured with regard to wind speed and temperature difference (sea-air) in all the year months.[1]; L_E is vaporization-specific latent heat with a constant pressure equal to $\left(2.5\times10^6 \, \mathrm{Jkg}^{-1}\right)$ q_a is the specific humidity at 10-meter reference level in terms of kg/kg which has been measured using the formulas (6), (8) & (9) for the different months during 2005 in Cha-bahar Bay and has been included in Table-4. [1]

q_s is the specific humidity at the sea level in terms of kg/kg which has been measured based on the equations (7), (8) & (9) for the different months in 2005, and has been included in Table-4. [1]

$$q_a = RH q_{sat}\left(T_a\right) \qquad (6)$$

$$q_s = 0.98 q_{sat}\left(T_s\right) \qquad (7)$$

$$q_{sat}\left(T\right) = \frac{0.622 e_s\left(T\right)}{p_a - 0.378 e_s\left(T\right)} \qquad (8)$$

$$e_s\left(T\right) = 6.1112\left(1 + 3.46\times10^{-6} p_a\right)\exp\left[17.50/\left(240.97+T\right)\right] \qquad (9)$$

RH : Relative humidity (%) , The factor of 98% for saturation humidity over sea water compensates for the salinity. e_s : saturated water vapor pressure (mb)

Table 4. The quantities required to calculate vaporization latent heat flux in Chabahar Bay (2005)

Month parameter	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
T_a $(^\circ C)$	20.5	21.1	24.1	26.8	29.2	31.0	29.3	28.8	28.8	27.7	25.0	22.5
T_s $(^\circ C)$	21.4	22.2	25.5	26.2	30.4	30.2	28.2	29.0	29.7	28.2	25.8	23.5
p_a (mb)	1017.0	1015.0	1012.4	1010.3	1006.0	999.1	999.1	1008.2	1000.6	1004.8	1014.9	1016.7
ρ_a (kg/m^3)	1.21	1.20	1.19	1.17	1.16	1.14	1.15	1.15	1.16	1.17	1.19	1.20
U_{10} (m/s)	8.2	11.8	9.7	8.2	8.2	8.2	8.2	8.7	6.2	6.2	8.2	8.2
RH (%)	58	77	84	77	81	84	82	82	82	77	67	64
$e_s(T_a)$ (mb)	24.19	25.10	30.11	35.35	40.66	45.08	40.75	39.73	39.73	37.26	31.78	27.34
$e_s(T_s)$ (mb)	25.56	26.84	32.73	34.12	43.56	43.06	38.36	40.19	41.85	38.37	33.32	29.04
q_a (g/kg)	8.87	12.32	16.09	17.30	21.19	24.52	21.60	20.96	20.68	18.13	13.24	10.84
q_s (g/kg)	15.41	16.28	19.95	20.85	26.83	27.25	23.75	24.86	25.79	23.45	20.26	17.60
$C_L \times 10^3$	0.46	1.65	1.65	1.36	1.58	1.36	1.17	1.44	0.46	0.46	0.46	0.46
Q_L (w/m^2)	-74.6	-231.3	-183.8	-115.8	-211.9	-86.7	-59.3	-140.4	-42.2	-44.4	-78.7	-76.5

Advective heat flux (Q_V) in Cha-bahar Bay:

The heat going into or out of a marine basin or a certain area in the sea through ocean currents or precipitation (rainfall) is called advective heat. In order to calculate its flux, no exact operating formula was found. Therefore, it was impossible to measure its value in Cha-bahar Bay; but, from the studies and measurements done in the project, it was found that the sign of the flux in the Bay is minus, meaning that it has to exit the Bay. Since the impact of the extent of flux in the world wide on the heat budget flux is slight, it has been ignored but such an impact cannot be neglected in a limited area. If the heat balance in Cha-bahar Bay is to be realized, the advective heat flux should be equal to (-47.49) W/m^2 in the Bay in 2005.

Calculating heat budget flux (Q_T) in Cha-bahar Bay:

This flux is the arithmetic sum of short-wave radiant flux, net long-wave radiant flux, sensible heat flux, vaporization latent heat flux, and advective heat flux [5, 6, 7].

$$Q_T = Q_{SW} + Q_{LW} + Q_S + Q_L + Q_V \tag{10}$$

Since there is no exact operational equation to compute advective heat flux (Q_V), it is for now impossible to calculate precisely the heat budget flux in a specific marine area. However, the advective heat flux has been disregarded in almost all the calculations on a world scale, and the sum of four resulting quantities was considered as heat budget flux. In this study, the sign of (Q_V) related to Cha-bahar Bay was found negative. Thus, ocean currents and precipitation should bring water body with a temperature lower than the Bay water into the area so that the heat can be taken out of the Bay. Regardless of advective heat flux, heat budget flux resulting from the other four sentences in the above formula related to Cha-bahar Bay has been specified in 2005 as equal to (+47.49) w/m^2. This very quantity of heat as advective heat flux should leave the Bay if a heat balance is to be kept in the area. Other wise, it can be claimed that the value for (Q_T - Q_V) in the Bay in 2005 is (+47.49) w/m^2.

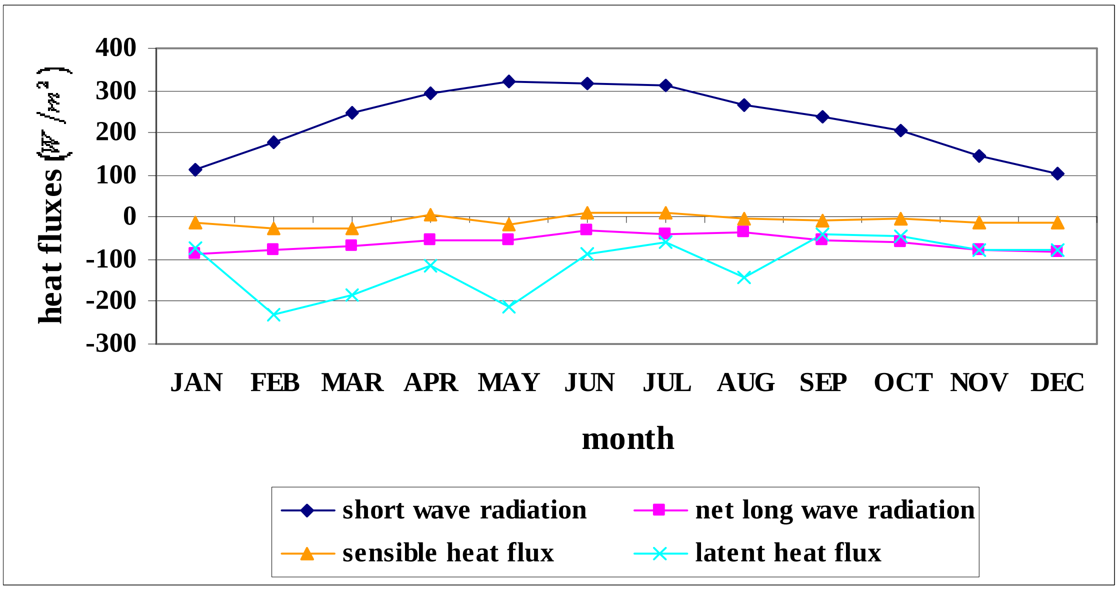

Figure 1. Comparison of heat fluxes based on the months in 2005 in Chabahar Bay

Figure-1 is obtained by drawing the diagram for fluxes (short-wave radiation, long-wave radiation, sensible heat and vaporization latent heat) based on the months in 2005. It shows that the average short-wave radiant flux is higher than the other three fluxes and the average sensible heat flux is lower than the average for each of the other three fluxes in Cha-bahar Bay. From Figure-1 the conclusion can be made that the short-wave radiant flux uptaken by the Bay water on May 2005 was the highest and on December was the lowest. The average of this quantity in this year was +227.57 w/m^2. It is noteworthy that the world average of this quantity in an area with the same latitude as the Bay was measured as approximately equal to +200 w/m^2. The difference between two measurements could be due to an error in the computation (albedo , fractional cloud cover, sun zenith angle, sun radiant angle and sun incoming radiation). The maximum net long-wave radiation flux on January and its minimum quantity on June in 2005 in the Bay transmitted from the sea to the atmosphere. The annual average of the quantity in the same year in this Bay was equal to -59.91 w/m^2. comparing this value with the world average in an area with the same latitude as the Bay, which is approximately -50 w/m^2, indicates a difference equal to 2.91 w/m^2.

The difference can be the result of any error in measuring such influential parameters on the flux as water surface temperature, air temperature, vapor pressure, fractional cloud cover and cloud cover coefficient. Also, in 2005, the maximum sensible heat flux on February and its minimum value on August transmitted from the sea to the atmosphere, and the highest sensible heat flux on July was from the atmosphere to the sea in Cha-bahar Bay. Except for July, April and June during which the transmission was from the atmosphere to the sea, in the other months of the same year the sensible heat was transmitted from the sea to the atmosphere.

With regard to the calculations, the annual average sensible heat flux was -8 w/m^2 Cha-bahar Bay in 2005. It is noteworthily that the world average of the quantity in an area with the same latitude as the Bay was measured at nearly -10w/m^2. Therefore, the difference between two calculations is equal to 2 w/m^2, and it is indicative of a very slight difference between the results obtained, which could result from the error in measuring such influential quantities on the flux as the water surface temperature, air temperature, wind speed, air density and the air-specific heat. Vaporization latent heat transmitted from the sea to the atmosphere during all the months in 2005, in which case the maximum transmission on February and its minimum on September were taken place. According to the calculations, the annual average vaporization latent heat flux for the Bay in this year was equal to -112.16 w/m^2. It is necessary to add that the world average value for this quantity in an area with the same latitude as the Bay was calculated at about -110 w/m^2. Comparing two measurements results in a difference equal to 2-16 (w/m^2). Consequently, the results coming out of the measurements are too close, and the resulting difference is probably produced by an error in determining the quantities haring influence on the flux Value.

CONCLUSION

In this study, the following were obtained:

1. In Cha-bahar, Sun radiation angle, one of the effective important factors in heat budget, is high, and it is even close to 90 degrees in some months. In this case, the annual average radiation angle in this area is 65.22 degrees.

2. Both latent and sensible heat flux coefficients are dimension-free small numbers depending on wind speed and temperature difference (sea-air), and it is necessary to use them in determining heat budget. In this study, the annual average coefficients in the Bay were: $C_S = 1.40\times10^{-3}$ & $C_L = 1.04\times10^{-3}$

3. To calculate the heat budget flux in any area an the basis of the theories presented to date, we need five elements or quantities including short-wave radiant flux, net long-wave radiant flux, sensible heat flux, vaporization latent heat flux and advective heat flux, in which various Closely-related formulas have been prepared, arranged and presented for the first four, and the latest have been employed in the study even through no precise formula was available for advective heat flux. It is hoped that the scientists can diligently calculate the quantity in the coming future.

4. According to the measurements in the present study, the average short-wave radiation flux was computed at +226.56 w/m^2, the average net long-wave radiant flux -59.91 w/m^2, vaporization latent-heat flux -112.16 w/m^2, and sensible heat flux -8 w/m^2 in Cha-bahar Bay for the year 2005. Regarding these four parameters, the heat budget flux in the Bay will be +47.49 w/m^2. To ensure the heat balance, this very value of the quantity has to exit the Bay through water exchange between the Bay and Oman Sea, and through precipitation. In this case, advective heat flux in the Bay keeps the heat balance. It is noteworthy that the resulted quantities of the fluxes are within the world limits determined for the oceans.

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