Advances in Research
7(3): 1-12, 2016, Article no.AIR.26036
ISSN: 2348-0394, NLM ID: 101666096

SCIENCEDOMAIN *international*
www.sciencedomain.org

Estimation of Net Surface Heat Flux of Eastern Harbor, Alexandria Egypt using Different Techniques

Maged M. A. Hussein[1*] and Ebtisam E. E. Mohamed[2]

[1]Department of Physical Oceanography, National Institute of Oceanography and Fisheries, Egypt.
[2]Department of Shore Processing, National Institute of Oceanography and Fisheries, Egypt.

Authors' contributions

This work was carried out in collaboration between the both authors. Author MMAH designed the study, wrote the protocol and analyzed the data. Author EEEM conducted the study and managed the literature searches. Both authors generated and prepared the manuscript. Both authors read and approved the final manuscript.

Article Information

DOI: 10.9734/AIR/2016/26036
Editor(s):
(1) José Alberto Duarte Moller, Center for Advanced Materials Research, Complejo Industrial Chihuahua, Mexico.
Reviewers:
(1) Bharat Raj Singh, Dr. APJ Abdul Kalam Technical University, Lucknow, India.
(2) M. Jeevarani, Pondicherry University, Pondicherry, India.
Complete Peer review History: http://sciencedomain.org/review-history/14665

Original Research Article

Received 30th March 2016
Accepted 11th May 2016
Published 17th May 2016

ABSTRACT

In this study, two different techniques have been applied to estimate the net surface heat flux (NSHF) of the Eastern Harbor. The first one based on equilibrium temperature which is easy and direct way to calculate NSHF from the sea in comparison to the traditional method (Bulk aerodynamic formula). This technique is based on short wave radiation, net long wave radiation and latent and sensible heat flux. Daily variability of NSHF has been studied during winter, spring and summer 2009-2010 and winter and summer 2010-2011, the surface meteorological data were collected from Nozha Air Port and sea surface temperature using the immersed temperature sensor at NIOF site. The out put NSHF values of the two techniques have the same trend and there are high correlation between them reached to 94% in winter 2009, 87% spring 2009, 97% summer 2010, 96% winter 2010 and 98% summer 2011. This gives us a good reason to apply the first technique to get NSHF. There is more heat loss (negative NSHF) during many days of the winter season and more heat gain (positive NSHF) during spring and summer seasons. Thermal

---

**Corresponding author: E-mail: maged_hussain1@yahoo.com;*

exchange coefficient varies from 6.55 (W m^{-2} ℃$^{-1}$) to 22.4 (W m^{-2} ℃$^{-1}$) and it has a direct relationship with wind speed and inverse relationship with (NSHF) and equilibrium temperature.

Keywords: Alexandria Eastern Harbor; heat flux; equilibrium temperature; thermal transfer coefficient; enthalpy.

1. INTRODUCTION

Air-sea heat fluxes are crucial for understanding the role of the oceanic environment in the climatic processes as a main driver of the global atmospheric and oceanic circulations [1]. Air-sea heat fluxes are critical for the climate regulation and affect a number of significant processes for both ocean and atmosphere from the global to the local scale. They govern the oceanic and atmospheric circulation and they are important inputs in the numerical weather prediction models [2]. Energy arriving from the Sun is redistributed over the Earth mainly by the motions of the atmosphere and ocean. The interaction between air and sea, in terms of sea-surface heat flux and momentum flux, considered at various time scales, plays a fundamental role in determining the weather and climate during this redistribution process [3].

The heat balance is determined primarily by three radiative and two non radiative heat exchange processes. The absorption of direct and diffuse shortwave radiation from the sun and the atmosphere, respectively; the absorption of long wave radiation from the atmosphere; the emission of long wave radiation from the water surface; the exchange of latent heat between water surface and atmosphere due to evaporation and condensation; and the convective exchange of sensible heat between water surface and atmosphere [4-6].

The water surface temperature tends towards an equilibrium temperature, defined as the temperature at which the net heat flux would theoretically be zero [4]. The equilibrium temperature would be identical with the air temperature at the water surface if radiative heat exchange were negligible [7]. Sea surface temperature (SST) assists us in understanding the ocean dynamics and climate studies from which, the ocean heat flux, is derived and is defined as the exchange of energy between the ocean and the atmosphere [8].

It has been known that the estimated values of the heat flux are dependent on (1) the bulk aerodynamic formulas used to calculate the heat flux (2) the type of data acquisition (3) the spatial and temporal resolution of the data set [9].

The aims of this study are to (1) estimate net heat flux of Eastern harbor, Alexandria, Egypt using different techniques (2) evaluate the equilibrium technique and its suitability to estimate net heat flux in case of comparison with bulk aerodynamic formula technique.

1.1 Study Area

Alexandria Eastern Harbor is a shallow, protected, semi-enclosed circular basin. It covers an area of about 2.8 km^2 and occupies the central part of the coast of Alexandria. The southern part of the Harbor has been reinforced by concrete blocks. The Harbor is connected to the Mediterranean Sea through two openings: El-Boughaz (main central outlet) and El-Silsila (northeast opening). The seabed within the Harbour slopes gradually seawards, with an average depth of 5 m inside the Harbour and a maximum depth of 13 m at the eastern corner of El-Boughaz [10,11].

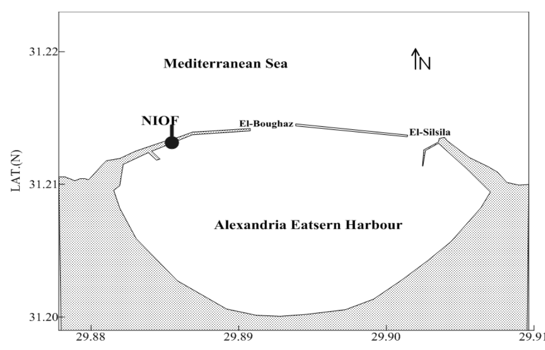

Fig. 1. Alexandria Eastern Harbour and the location of NIOF where the Radar tide gauge, holding with both pressure and sea surface temperature sensors, are installed since November 2009

Within the framework of collaboration between the Global Sea Level Observing System (GLOSS) and the Ocean Data Information Network of Africa (ODIN Africa), a tide gauge system has been installed on a sea wall at the

National Institute of Oceanography & Fisheries (NIOF) within Alexandria Eastern Harbour (AEH) Fig. 1. The system provides near real time data access using satellite communications with digital data recording capability and new radar/pressure water level sensors. In addition to the pressure sensor, a temperature sensor does also exist to record the sea surface temperature.

2. MATERIALS AND METHODS

The time series measurements (hourly) of sea surface temperature (SST) and surface meteorological parameters: air temperature (℃), dew point temperature (℃), relative humidity (%), wind speed (m/s) and atmospheric pressure (hpa) were used for various phases. SST and Meteorological data, collected from November 2009 to September 2011, have been used to compute the effective back radiation, latent heat and sensible heat fluxes, and wind stress. The data collected during phase I (5/11/2009-12/2/2010) (100 days), phase II (18/2/2010-17/4/2010) (59 days), phase III (6/6/2010-30/9/2010) (117 days), phase IV (1/11/2010-16/2/2011) (108 days), while phase V (1/7/2011-19/9/2011) (81 days). The SST was measured by immersed sensor (31.2128°N, 29.8854°E) at a depth 1.5 m. The heat budget components: Q_{Lh} (latent heat flux), Q_{Sh} (sensible heat flux), Q_{Lh} + Q_{Sh} (enthalpy), Q_{net} (net heat flux) are calculated from the observed data. Meteorological data has been measured by Alexandria Nozha Air Port meteorological station (about 5 km far away from AEH) and obtained through the following website:(http://www.wunderground.com/history/airport/HEAX/2009/11/5/DailyHistory.html).

2.1 Net Heat Flux Based on Equilibrium Temperature Method

The net heat flux (Q_{net}) (W/m^2) is expressed as a polynomial function of the model SST and can be linearized to first order [12-16] as the following:

$$Q_{net} = k \Delta T \qquad \Delta T = (Teq - SST) \tag{1}$$

Where, Teq is the apparent atmospheric equilibrium temperature (℃). The equilibrium temperature (Teq), a hypothetical SST at which the net rate of surface heat exchange would be zero, depends on several heat exchange process that operate at the air-sea interface [16,17].

The thermal exchange coefficient k (W/m2℃) is a key parameter and represents the sum of temperature-dependent heat exchange processes including sensible, evaporative and back radiative fluxes. Haney [12]; Ahmed and Sultan [17] and Abualnaja [16] have shown that a good approximation to Teq is:

$$Teq = T_{dew} + Q_s/k \tag{2}$$

Where Q_s is rate of incoming solar radiation per unit area (W/m^2. ℃) and T_{dew} is the dew point temperature (℃). According to Edinger et al. [18]; Ahmed and Sultan [17] and Abualnaja [16], the thermal exchange coefficient (k) could be calculated from the following formula:

$$k = 4.5 + 0.05*SST + (\beta + 0.47)\, f(W) \tag{3}$$

Where

$$\beta = 0.35 + 0.015*T_{avg} + 0.0012\,(T_{avg})^2 \tag{4}$$

$$T_{avg} = 0.5\,(SST + T_{dew}) \tag{5}$$

Several formula are summarized by Edinger et al. [18] for f (W), one of which is f (W) = 3.3 W when wind speed (W) is measured in m/s [16, 17]. The daily mean values of incoming short wave radiation Q_s are computed using the formula suggested by [16,19].

2.2 Net Heat Flux Based on Bulk Aerodynamic Formula Method

The classical bulk formulas [20,21] are used here to calculate the net heat flux. The net surface heat flux Q_{net} may be represented by:

$$Q_{net} = Q_s - Q_u \tag{6}$$

We use the formula which is derived by Reed [22]; Simpson and Paulson [23] to calculate Q_s and the net upward flux (Q_u) is:

$$Q_u = Q_{lw} + Q_{Sh} + L_v E_a \tag{7}$$

The vertical flux of sensible and latent heat in equation (7) [24,25] is parameterized by bulk turbulent transfer formulas Rosati and Miyakoda [20]:

$$Q_{Sh} = \rho\, C_p\, C_h\, (Ts - Ta)\, U_{10} \tag{8}$$

$$E_a = \rho\, C_e\, U_{10} \{e_{sat}(Ts) - R^* e_{sat}(Ta)\} (0.622/\rho) \tag{9}$$

Where L_v is the latent heat of vaporization ((2.5x10^6 J/kg/℃)), ρ is the density of air (kg/m^3), C_p is the specific heat of air at constant pressure

(1004 J/kg.K), U_{10} is the horizontal wind speed at the 10 m level (m/s), C_e and C_h equal to 1.1*10^{-3}, e_{sat} is the saturation vapor pressure. Wind stress is computed by the following equation Ramu et al. [19]:

$$\tau = \rho C_d U_{10}^2 \qquad (10)$$

Where, C_d is the drag coefficient.

3. RESULTS AND DISCUSSION

The output net heat flux results obtained from the two mentioned techniques used in this study will be represented in detail, and then the comparison between these tow methods carried out.

3.1 Net Heat Flux Based on Equilibrium Temperature Method

The average values of sea surface temperature (SST), Dew point (T_{dew}), wind speed (W), exchange coefficient (k) and equilibrium temperature (Teq) are shown in Table 1.

The short wave radiation value at the maximum SST reached to 178.1 W/m^2, 290.48 W/m^2, 358.37 W/m^2, 166.19 W/m^2, and 353.46 W/m^2 during the all phases respectively. The correlation between the thermal exchange coefficient (k) and the wind speed (W) is high value during the all phases (0.96, 0.97, 0.96, 0.97 and 0.99) respectively. Also, the correlation between the net heat flux (Q_{net}) and the difference between equilibrium temperature and SST is high during phases I to IV (0.95, 0.83, 0.96 and 0.92) respectively, while it is moderate high during phase V (0.67). There is an inverse relationship between thermal exchange coefficient (k) and net heat flux (Q_{net}) and equilibrium temperature (Teq) during all phases under investigation. The minimum value of (k) is always occurred at the minimum value of wind speed. While the maximum value of (k) is occurred at the second maximum value of the wind speed during (phase-I, II and V), during phase-III it is occurred at the third maximum value of wind speed, and during (phase-IV) it is occurred at the maximum value of the wind speed.

The relationship between thermal exchange coefficient (k) with equilibrium temperature (Teq), wind speed and net heat flux (Q_{net}) and also the relationship between net heat flux with (Teq – SST) during the first and third phases are represented in Figs. (2 & 3) (the selection of these two phases just for an example).

3.2 Net Heat Flux Based on Bulk Aerodynamic Formula Method

The daily variability of net long wave radiation (Q_{lW}), net heat flux, enthalpy (Q_{LH}+Q_{SH}) and wind stress have been presented in the Figs. (4 and 5).

3.2.1 During phase I

The value of short wave radiation during the maximum SST reached to 178.25 W/m^2, the average value of net long wave radiation is 79.75 W/m^2 and varied between 58.62 W/m^2 and 107.92 W/m^2. The average value of net heat flux is 18.02 W/m^2 and varied between -118.91 W/m^2 and 115.3 W/m^2. There is a good correlation between enthalpy and wind stress as reflected in their graphical presentation Fig. 4. The linear correlation factor between these two parameters is 0.81. However, the maximum enthalpy coincides with the second maximum wind stress. While the former is 148.40 W/m^2 which may be due to moderate wind speed (5.7 m/s) prevailing at that time, the later is 0.11 N/m^2 associated with the maximum recorded wind speed (8.29 m/s).

Table 1. Average parameters of SST, dew point temperature, wind speed, thermal exchange coefficient and equilibrium temperature for all available data

Parameter/Phase	I	II	III	IV	V
SST (℃)	18.22	18.27	28.03	19.10	28.65
(T_{dew}) (℃)	10.47	10.84	20.98	11.45	21.60
Wind speed m/s	03.64	04.22	04.27	02.98	03.80
Exchange coefficient (W/m^2)	11.45	12.48	16.60	10.56	15.59
Equilibrium temp (Teq)	23.89	30.96	43.09	26.49	45.58

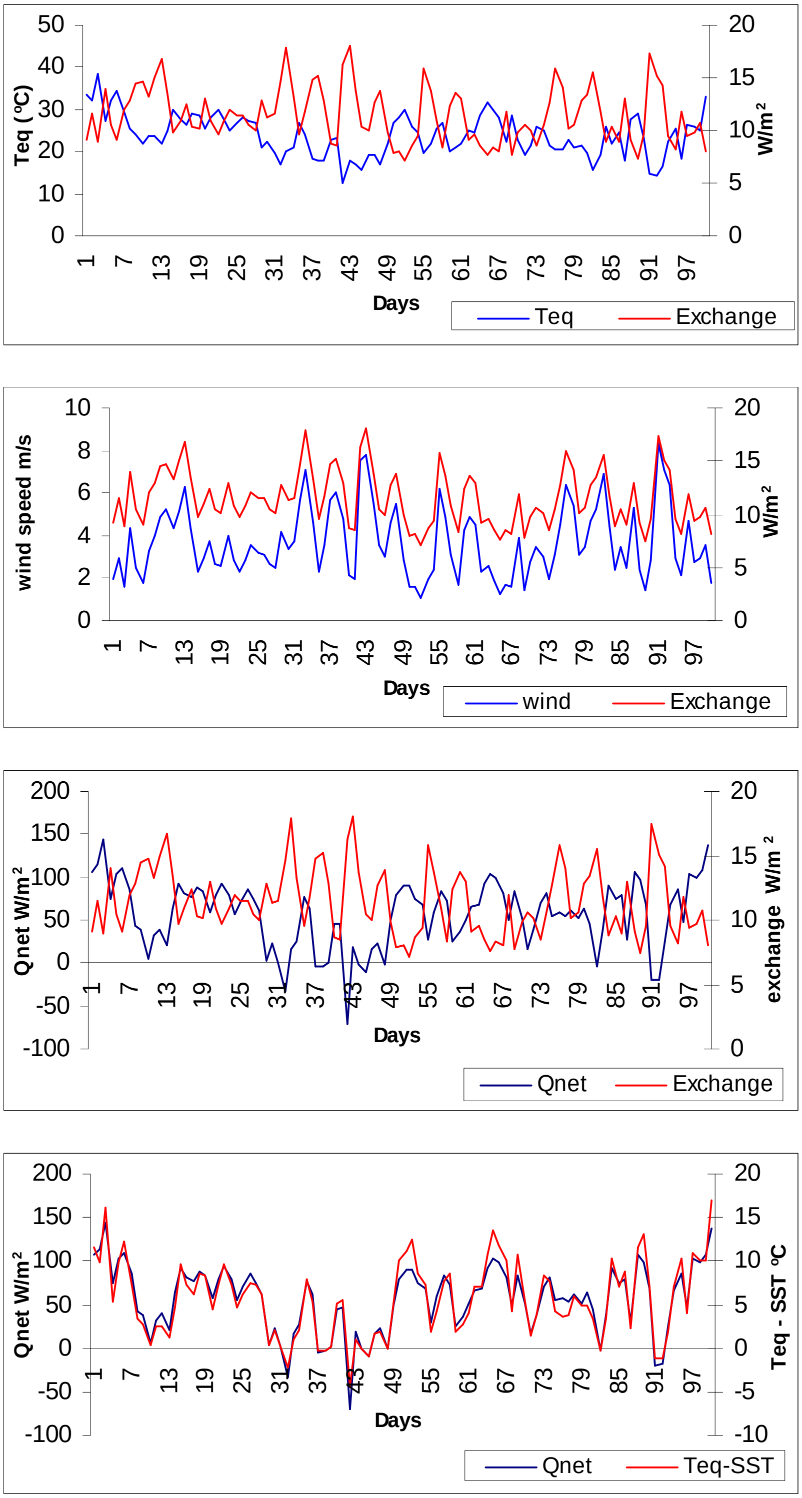

Fig. 2. Relationship between thermal exchange coefficient (k) with equilibrium temperature (Teq), wind speed and net heat flux (Q_{net}) and relationship between net heat flux with (Teq – SST) during phase-I

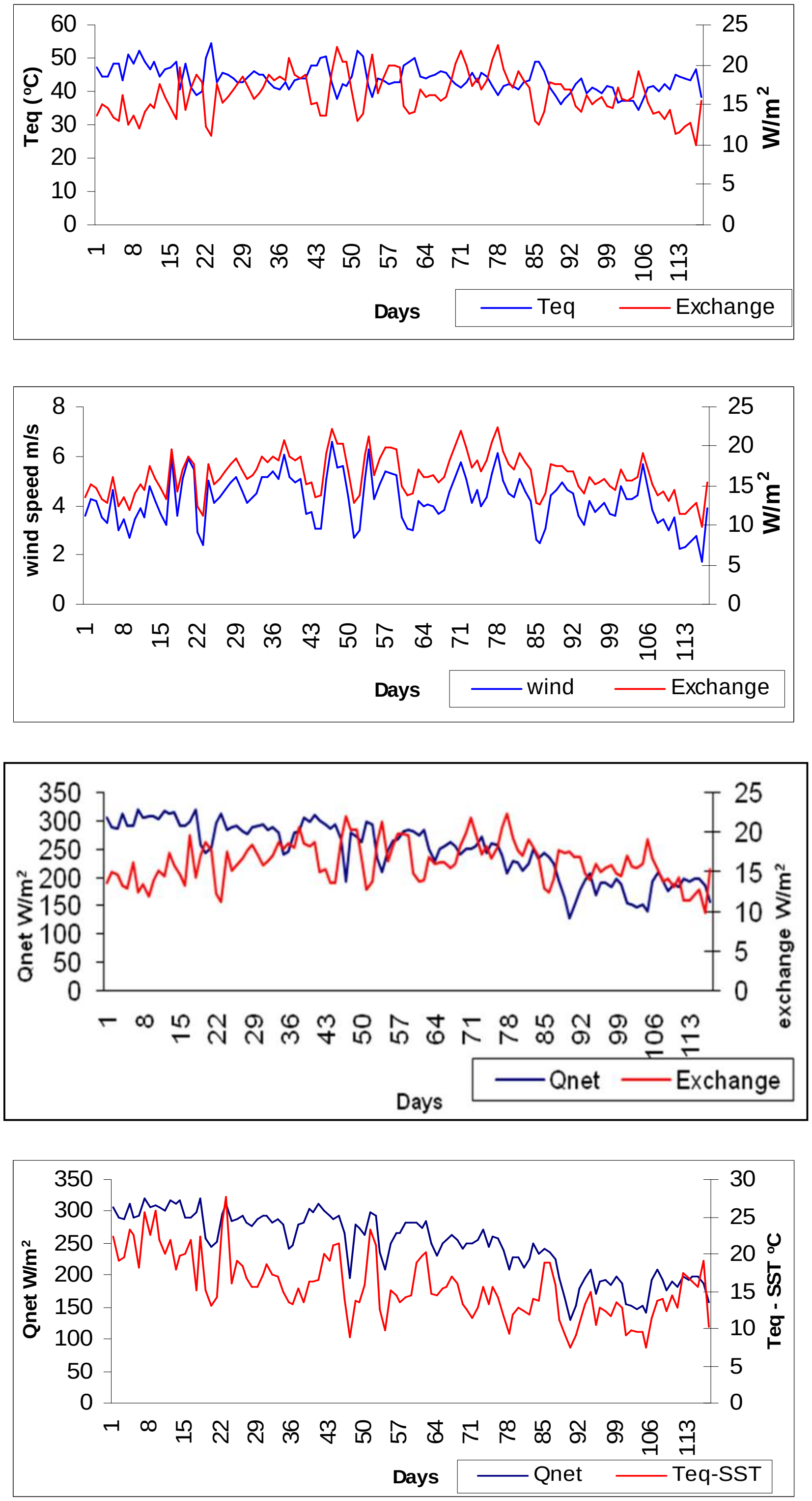

Fig. 3. Relationship between thermal exchange coefficient (k) with equilibrium temperature (Teq), wind speed and net heat flux (Q_{net}) and relationship between net heat flux with (Teq – SST) during phase-III

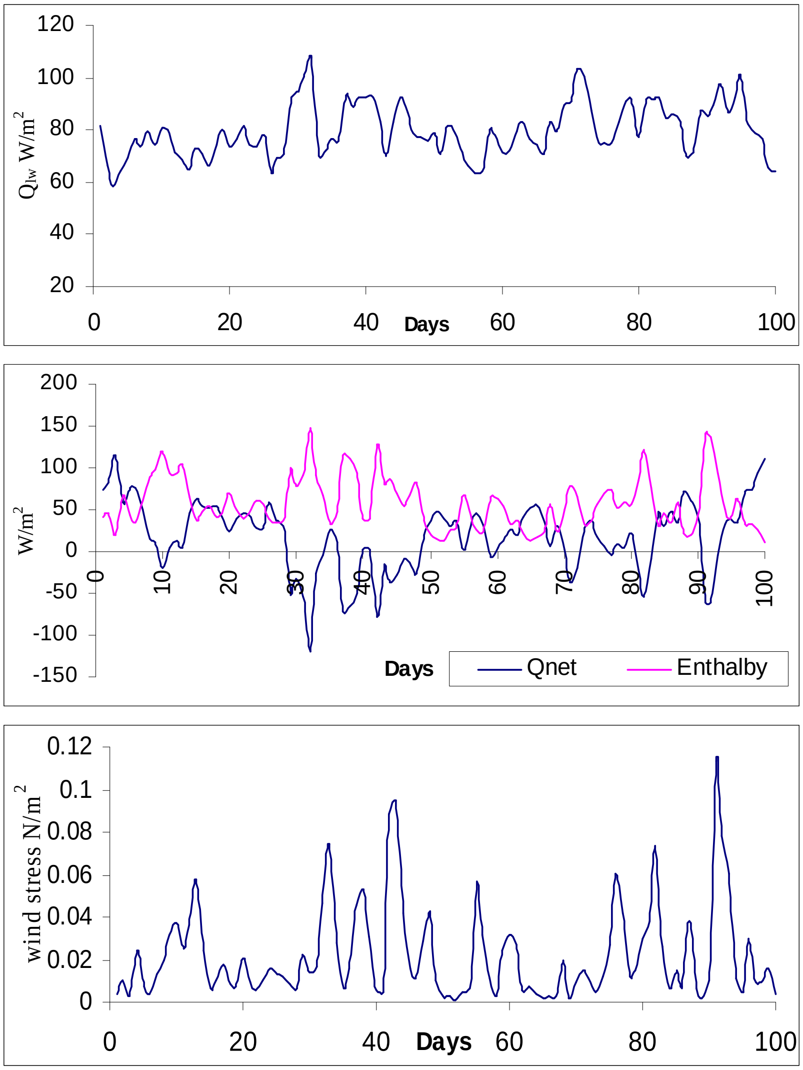

Fig. 4. net long wave radiation Q_{LW} (W/m^2), relationship between enthalpy (Q_{SW}+Q_{LW}) ((W/m^2) and net heat flux and wind stress (N/m^2) during phase-I (5/11/2009 – 12/2/2010)

3.2.2 During phase II

The value of short wave radiation during the maximum SST reached to 335.90 W/m^2, the average value of net long wave radiation is 72.75 W/m^2 and varied between 43.52 W/m^2 and 95.34 W/m^2. The average value of net heat flux is 142.83 W/m^2 and varied between 18.02 W/m^2 and 249.52 W/m^2. There is a good correlation between enthalpy and wind stress. The linear correlation factor between these two parameters is 0.78. While the minima of the two parameters do not coincide with each other, the maximum enthalpy coincides with the maximum wind stress. While the former is 163.13 W/m^2 which may be due to high wind speed (7.82 m/s) prevailing at that time, the later is 0.098 N/m^2 associated with the maximum recorded wind speed (7.82 m/s).

3.2.3 During phase III

The value of short wave radiation during the maximum SST reached to 361.95 W/m^2. The mean values of net long wave radiation, net heat flux, enthalpy and wind stress were 52.56 W/m^2, 238.74 W/m^2, 101.01 W/m^2 and 0.023 N/m^2 respectively Fig. 5.

The net long wave radiation, during this phase, varied between 20.35 W/m^2 and 71.22 W/m^2. The net heat flux varied between 101.29 W/m^2

and 365.04 W/m^2. While the enthalpy varied between 45.19 W/m^2 and 183.10 W/m^2 due to moderate wind speed (4.96 m/s) prevailing at that time, the wind stress varied between 0.003 N/m^2 and 0.06 N/m^2. The linear correlation factor between the enthalpy and wind stress is 0.70, which reflects good relationship between them. The two maxima do not coincide with each other.

Table 2. Root mean square error (RMSE), correlation, mean and standard deviation of the two NSHF methods

	RMSE	Correlation	Q_{net}1	Q_{net}2	SD-1	SD-2
Phase-I	40.39	0.94	56.09	18.02	38.47	42.08
Phase-II	28.47	0.87	149.69	129.25	36.71	41.02
Phase-III	16.07	0.97	248.3	238.74	49.23	56.2
Phase-IV	43.36	0.96	67.01	27.03	49.23	56.2
Phase-V	13.41	0.98	257.08	246.81	36.58	42.62

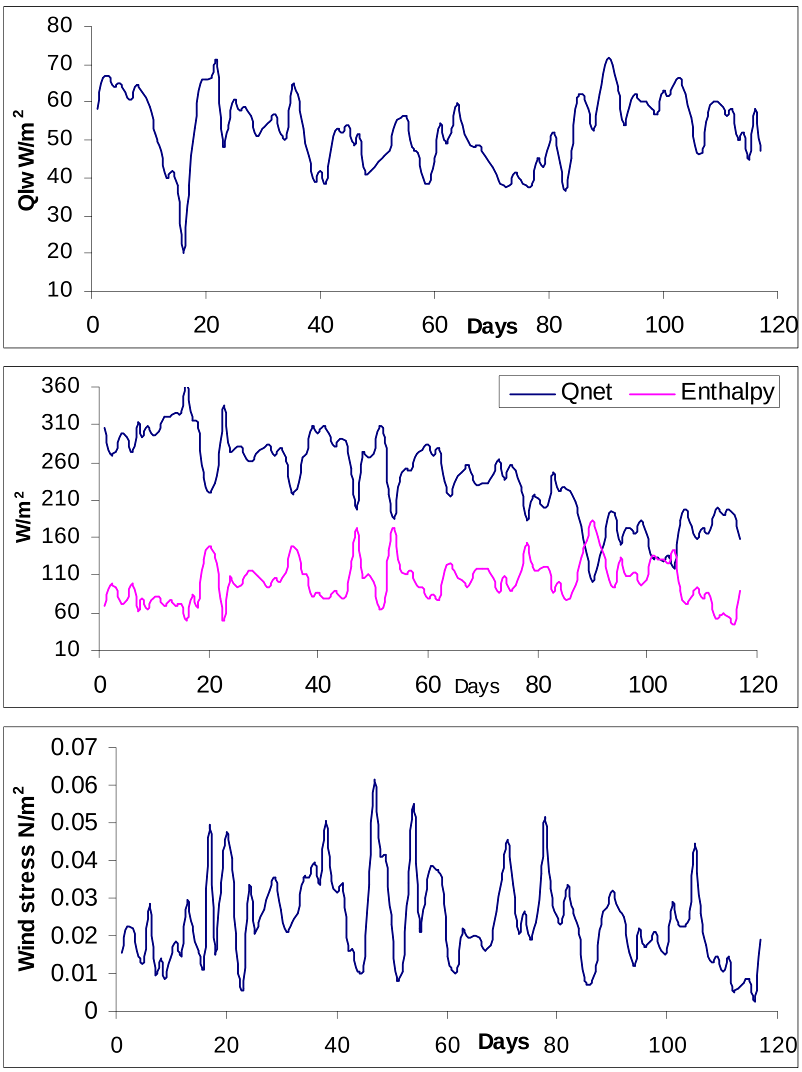

Fig. 5. Net long wave radiation Q_{LW} (W/m^2), relationship between enthalpy (Q_{SW}+Q_{LW}) ((W/m^2) and net heat flux and wind stress (N/m^2) during phase-III (06/06/2010 – 30/09/2010)

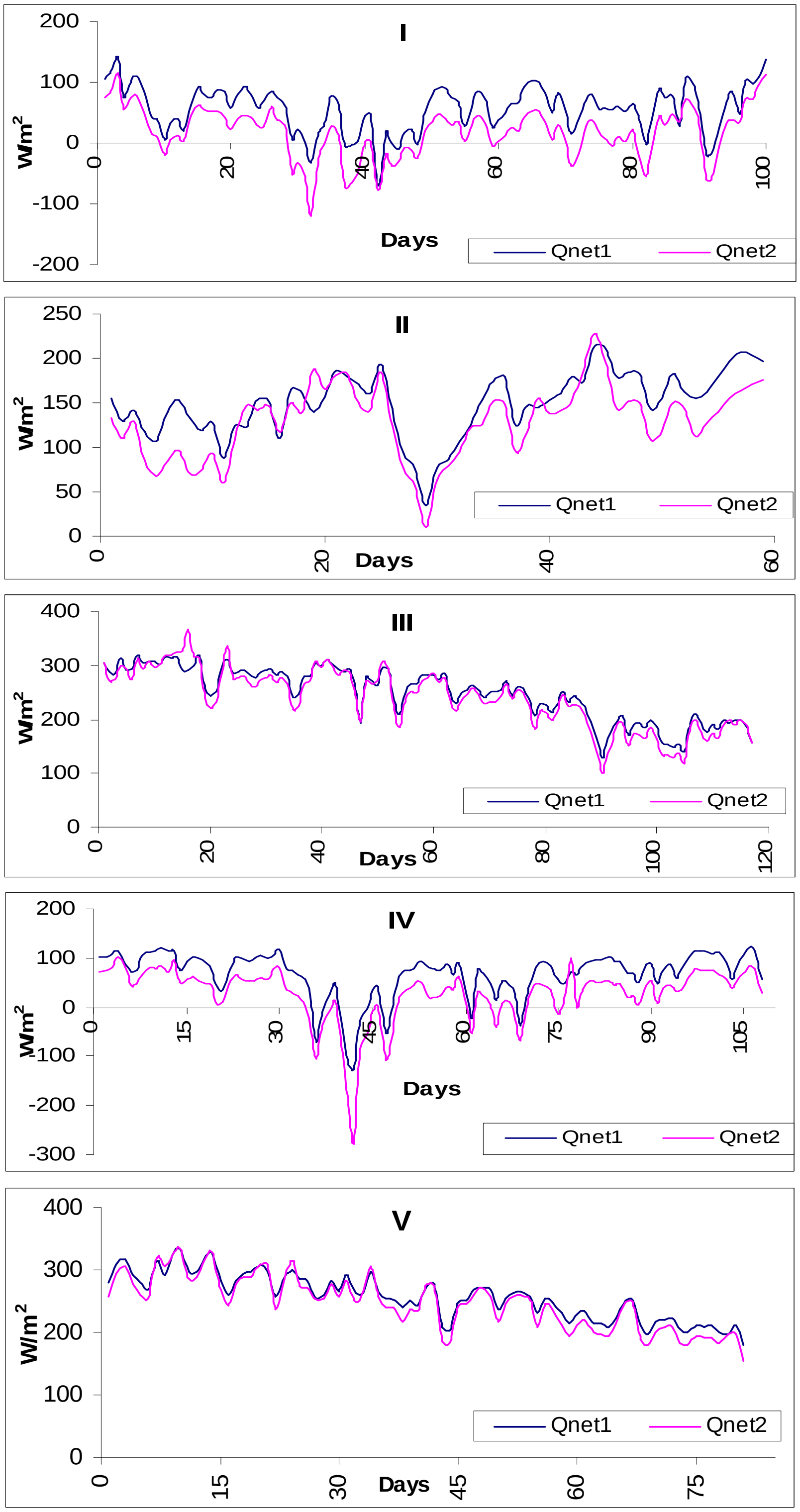

Fig. 6. Net heat flux estimated based on equilibrium temperature (Qnet1) and bulk aerodynamic formula (Qnet2) during the five phases

3.2.4 During phase IV

The value of short wave radiation during the maximum SST reached to 175.01 W/m^2. The mean values of the calculated parameters were 81.01 W/m^2, 27.03 W/m^2, 50.34 W/m^2 and 0.017 N/m^2 for the net long wave radiation; net heat flux, enthalpy and wind stress respectively.

The net long wave radiation varied between 46.80 W/m^2 and 118.37 W/m^2 and net heat flux fluctuated between -275.53 W/m^2 and 103.13 W/m^2. There is a very good correlation of 0.88 between enthalpy and wind stress. The maximum enthalpy coincides with the maximum wind stress. While the former is 291.92 W/m^2 with maximum wind speed (10.82 m/s), the later is 0.21 N/m^2 with also maximum wind speed (10.82 m/s).

3.2.5 During phase V

The value of short wave radiation during the maximum SST reached to 377.48 W/m^2. The mean net long wave radiation was 51.95 W/m^2, net heat flux was 246.81 W/m^2 and the means of the enthalpy and wind stress were 92.31 W/m^2 and 0.019 N/m^2 respectively. The net long wave radiation varied between 37.28 W/m^2 and 69.11 W/m^2 and the net heat flux changed between 154.76 W/m^2 and 333.12 W/m^2. The correlation between the enthalpy and the wind stress during phase V is high; 0.85. While the minima of the two parameters do not coincide with each other, the maxima coincide with each other. This is the same trend between the two parameters as in phase II. The minimum enthalpy was 51.86 W/m^2 and that of wind stress was 0.006 N/m^2. Both maxima occurred with 158.36 W/m^2 for the enthalpy and 0.059 N/m^2 for the wind stress due to maximum wind speed (6.24 m/s) prevailing at that time.

4. COMPARISON BETWEEN NET HEAT FLUX RESULTS

The daily values of estimated net heat flux during the five phases has been obtained from two different methods (equilibrium temperature and bulk aerodynamic formula) are represented in Fig. 6 with almost identical trend. The correlations between the two methods are high as shown in Table 2. The RMS in summer and spring are smaller than in winter Table 2. The standard deviation (SD) of the two methods for each phase is closed to each other. The mean value of the two methods are closed during phase III and V (summer), while the difference of the mean value during phase II (spring) is slightly increased, finally, during phase I and IV (winter) the differences in the mean values are more increased Table 2.

5. CONCLUSION

This manuscript here is one of series of research articles will apply on Eastern Harbor for studying this harbor in deep and in different aspects. The magnitude of the short wave radiation is high during summer and low during winter (i.e. seasonally dependent), so air temperature; sea surface temperature (SST) and equilibrium temperature (Teq) are increases or decreases according to the season (i.e. seasonally dependent). Thermal exchange coefficient (k) value which is depends on SSt, Teq and wind speed values are also seasonally dependent, it is means that, k has high value during summer and low value during winter. The inverse relationship between net heat flux and thermal exchange coefficient clearly appear in summer and winter seasons, which means that when (k) in high value the Q_{net} in low value, this also agrees with seasonally dependent approach. Finally we can conclude that, the changes of all I/O parameters values in different phases (seasons) are seasonally dependent.

The net heat flux values of the two techniques applied here (equilibrium temperature and bulk aerodynamic formula) have almost identical trend and the correlations between them are high. The present study is undertaken to demonstrate the capability of equilibrium temperature and thermal exchange coefficient to furnish estimates of the net heat flux at the air-sea interface in the Eastern Harbor, Alexandria. The values of short wave radiation (Q_s), wind speed (W), dew point ($T_{dew)}$ and sea surface temperature (SST) is sufficient to determine thermal exchange coefficient (K) and equilibrium temperature (Teq) and then to calculate net heat flux.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Papadopoulos VP, Chronis TG, Ruiz S, Tragou E, Josey S, Feredinos G. Air-sea heat fluxes estimation in the Aegean Sea

(Eastern Mediterranean Sea). Rapp. Comm. int. Mer Médit. 2010;39.

2. Papadopoulos VP, Bartzokas A, Chronis T, Ruiz S, Zarokanellos N, Ferentinos G. Correlation between air-sea heat fluxes over the Aegean Sea and the total perceptible water over Europe and North Africa. Advances in Science and Research. 2011;6:63-67.
3. Murkami H, Kawamura H. Relations between sea surface temperature and air-sea heat flux at periods from 1 day to 1 year observed at ocean buoy stations around Japan. Journal of Oceanography. 2011;57:565-580.
4. Edinger JE, Duttweller DW, Geyer JC. The response of water temperature to meteorological conditions. Water Resource Research. 1968;4:1137-1145.
5. Sweers HE. A nomogram to estimate the heat exchange coefficient at the air water interface as a function of wind speed and temperature; a critical survey of some literature. Journal of Hydrology. 1976;30: 375-401.
6. Livingstone DM, Imboden DM. Annual heat balance and equilibrium temperature of Lake Aegeri, Switzerland. Aquat. Sci. 1989;51:351-369.
7. Dingman SL. Equilibrium temperatures of water surfaces as related to air temperature and solar radiation. Water Resource Research. 1972;8:42-49.
8. Mishara PA, Rai S, Peandey AC. An estimation of heat flux and its variability in the Southern Indian Ocean (SIO) using ocean general circulation model. Journal of Indian Geophysics Union. 2007;11(4): 217-228.
9. Hsiung J. Mean surface energy fluxes over the global ocean. Journal of Geophysical Research. 1986;91:10585-10606.
10. El Geziry TM, Abd Ellah RG, Maiyza IA. Bathymetric chart of Alexandria Eastern Harbor. Egyptian Journal of Aquatic Research. 2007;33(1):15-21.
11. Hussein MMA, El Geziry TM. Diurnal variability of heat fluxes and bowen ratio over Alexandria Eastern Harbor. Journal of King Abdul-aziz University: Marine Science. 2014;25(2):57-85.
12. Haney RL. Surface thermal boundary condition for ocean circulation models. Journal of Physical Oceanography. 1971; 1:241-248.
13. CHU PC, Chen Y, Lu S. On Haney-type surface thermal boundary conditions for Ocean Circulation Models. Journal of Physical Oceanography. 1998;28:890-901.
14. Paiva AM, Chassignet EP. The Impact of surface flux parameterizations on the modeling of the North Atlantic Ocean. Journal of Physical Oceanography. 2001; 31:1860-1879.
15. Wallcraft AJ, Kara AB, Hurlburt HE, Chassignet EP, Helliwell GH. Value of bulk heat flux parameterization for ocean SST prediction. Journal of Marine Systems. 2008;74:241-258.
16. Abualnaja YO. Estimation of the net surface heat flux in the Arabic Gulf based on the equilibrium temperature. Journal of King Abdul-aziz University: Marine Science. 2009;20:21-29.
17. Ahmed F, Sultan SAR. Equilibrium temperature as a parameter for estimating the net heat flux at the air-sea interface in the central red sea. Journal of Oceanologica Acta. 1994;19:341-343.
18. Edinger JE, Brady DK, Geyer JC. 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; 1974.
19. Ramu Ch V, Bharathi G, Sadhuram Y, Prasad KVSR. Diurnal variation of the heat fluxes over the coastal waters off Visakhapatnam during post-monsoon and winter seasons. Indian Journal of Marine Sciences. 2010;39(1):128-135.
20. Rosati A, Miyakoda A. A general circulation model for upper ocean simulation. Journal of Physical Oceanography. 1988;18:1601-1926.
21. Staneva JV, Stanev EV, Rechev NH. Heat balance estimates using atmospheric analysis data: A case study for the Black Sea. Journal of Geophysical Research. 1995;100:581-596.
22. Reed RK. On estimating insolation over the ocean. Journal of Physical Oceanography. 1977;7:482-485.
23. Simpson JJ, Paulson CA. Mid-ocean observations of atmosphere radiation. Quaternary Journal of Royal Meteorological Society. 1979;100:487-502.

24. Hsu SA. A relationship between the Bowen ratio and sea-air temperature difference under unstable conditions at sea. Journal of physical oceanography. 1998;28:222-2226.

25. Rohlei RV, Hsu SA, Lofgren BM, Binkley MR. Bowen ratio over Lake Erie. Journal of Great Lakes Research. 2004;30(2):241-251.

Peer-review history:
The peer review history for this paper can be accessed here:
http://sciencedomain.org/review-history/14665