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Heat transfer by sea water to air and environment's impacts

Dimitrios Dellaportas[1] and Anna Alexandratou[2]

[1]Mechanical Engineering, Ms of Physics, Pedagogics, Principal of 1st Vocational of Piraeus Greece
[2]Mathematician- Ms of Mathematics, Ph.D of Mathematics-Pedagogics, Director of 15th Primary School of Piraeus

Abstract

In the aquatic environment, thermal transfer is understood as a result of any process that changes ambient water temperature. In oceans, such change in water temperature that goes beyond the natural range of temperature variation may be caused by discharged heated water coming from different areas of Globe (Sea Gulf Streams, sea districts around Equator, or districts near Arctic and Antarctic create waves of heat emission that is depended on solar radiation and climatic conditions in any sea area.

Main Theme

The Earth's surface is approximately covered by seventy percent of water. Sea water makes up 97.4% of the total water available. The global-ocean can be classified as a continuous body of water that separates into several major oceans and seas. The major ocean divisions, according to their size, are the Pacific Ocean, Atlantic Ocean, Indian Ocean, Southern Ocean, and the Arctic Ocean. The average temperatures of the ocean waters hardly exceed 30ºC or reduce below -2ºC. It is the water in the oceans that prevents wide variations of temperature on the Earth's surface globally. Moreover, the Earth is the only planet in the solar system with oceans. The processes that control the atmosphere are closely related to the sea water processes. Changes in weather and climate are a result of the interaction between the Sun, the atmosphere, and the water on the Earth's surface . The major source of thermal energy entering the ocean is from the Sun. The ocean plays an important role in maintaining the global energy balance of the Earth's atmosphere.

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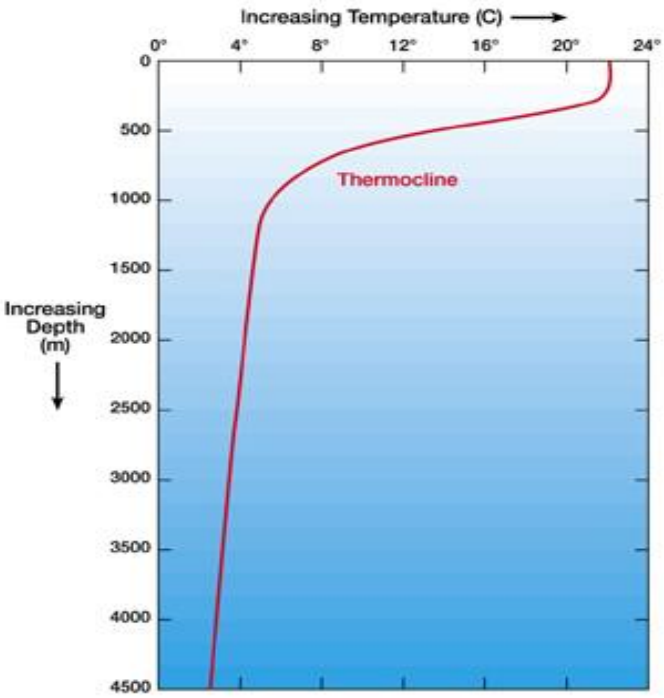
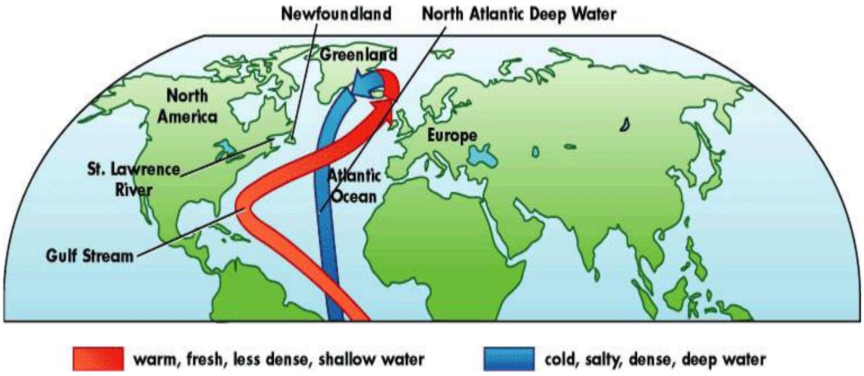
So, we can consider the sea as a vast thermal tank. The thermal energy in the oceans is distributed around the globe by moving sea Currents. The waters of the ocean are continuously moving. Whereas winds are described in terms of where they are blowing from, ocean currents are described in terms of where they are blowing towards. The circulation of waters in the oceans helps to distribute the thermal energy in the lower latitudes to certain areas in higher latitudes, (Northern territories of the Earth) thus modifying climate conditions. (Ocean current of Kuro Siwo, Gulfstream of Mexico, etc.) Sunlight provides a lot of heat to the uppermost layers of the ocean in areas outside the polar regions. The warming sunlight only penetrates to depths of a few tens of meters. Sea surface temperatures range from slightly below freezing near the poles to an annual average near 30° C in the tropics. Wind-driven surface waves and the tides stir the surface layer so the heat is distributed throughout the top few hundred meters of ocean water. Since the surface layer is exposed to the atmosphere, a warming atmosphere can transfer heat to the upper layers of the ocean.

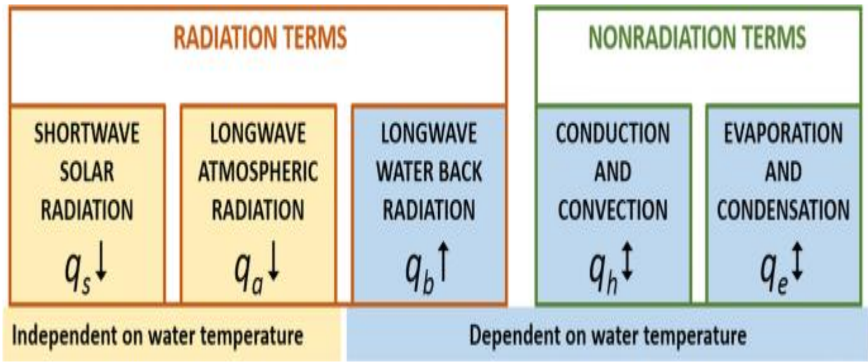


Sunlight provides a lot of heat to the uppermost layers of the ocean in areas outside the polar regions. The warming sunlight only penetrates to depths of a few tens of meters. Sea surface temperatures range from slightly below freezing near the poles to an annual average near 30° C in the tropics. Wind-driven surface waves and the tides stir the surface layer so the heat is distributed throughout the top few hundred meters of ocean water. Since the surface layer is exposed to the atmosphere, a warming atmosphere can transfer heat to the upper layers of the ocean. We are aware that relatively small changes in natural ambient temperature might create substantial environmental problems; for instance, they may influence the dissolved oxygen concentration (Rajwa-Kuligiewicz et al. 2015), population of fish and other aquatic organisms and plants (Brett 1956; Coutant 1999; Currie et al. 1998; Murray 2002). The list of potential environmental impacts of thermal transfer to air is very long and widely discussed in the literature Therefore, the prediction of possible water temperature increase and assessment of its environmental impact, for example, before constructing human facilities become mandatory. The list of potential environmental impacts of thermal transfer to air is very long and widely discussed in the literature. Therefore, the prediction of possible water temperature increase and assessment of its environmental impact, for example, before constructing human facilities become mandatory. While trying to predict the potential increase of natural water temperature below the heated water discharge, one might have problems with making assumptions and relevant simplifications to obtain a desirable solution. Heat transport models generally consist of nonlinear differential equations with no analytical solutions under real conditions, and therefore, they must be solved numerically. Choosing a proper solution to a problem is a challenge. It requires not only a compromise between the computation time and cost needed to obtain the results and the desired accuracy of the solution but also depends on the availability of input data and their accuracy.

North Atlantic Ocean Circulation System



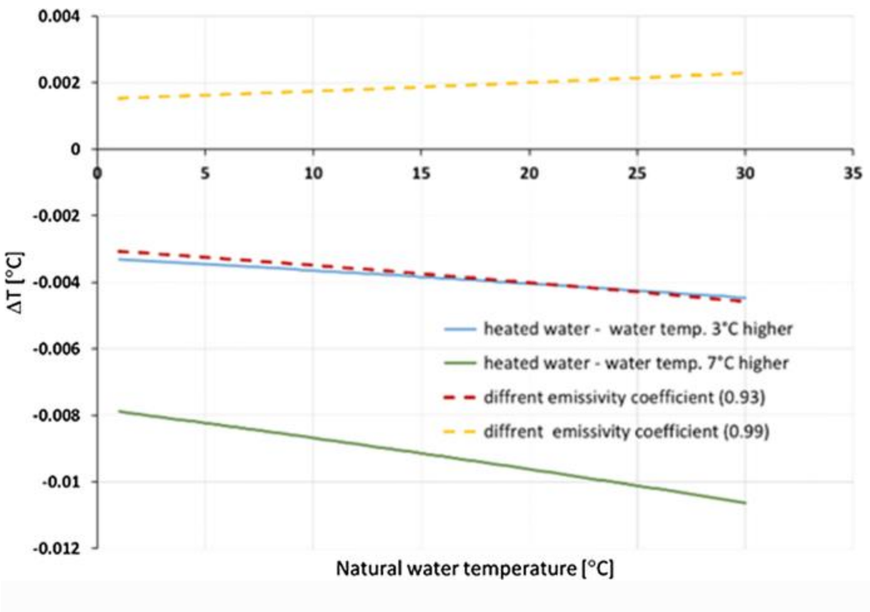
An estimate of the net heat flux at the water–air interface turns out to be a challenge, especially when it has to be based on historical data. The first problem is related to obtaining of necessary input data for the analysed site. Intuitively, the best source in case of meteorological data is the nearest meteorological station. Unfortunately, in many cases, the nearest station does not provide all the necessary data or is still too far from the considered river reach. Another problem is associated with the differences in data obtained from the neighbouring stations. Even in conducive situations when the necessary meteorological data are available in the vicinity of the river reach, we still may receive uncertain results related to the location of the station, for which conditions such as shading or wind speed are often considerably different from those at the river channel.



Natural water temperature and thermal emission

Finally, the net heat flux **QA [W m−2]** that results from the energy balance at the water-air interface is defined as follows:

QA=qs+qa−qb±qe±qh,



Conduction and convection

Conduction is the process of heat exchange between bodies of different temperatures, which are in direct contact. It consists in transmitting the kinetic energy of the chaotic movement of particles as a result of their collisions.

The process leads to the equalisation of temperature between the bodies. Convection is a process of heat transfer associated with the macroscopic movement of matter. Both processes take place at the border of water and air and can be described using the equation resulting from the Bowen ratio (Bowen 1926; Ji 2008):

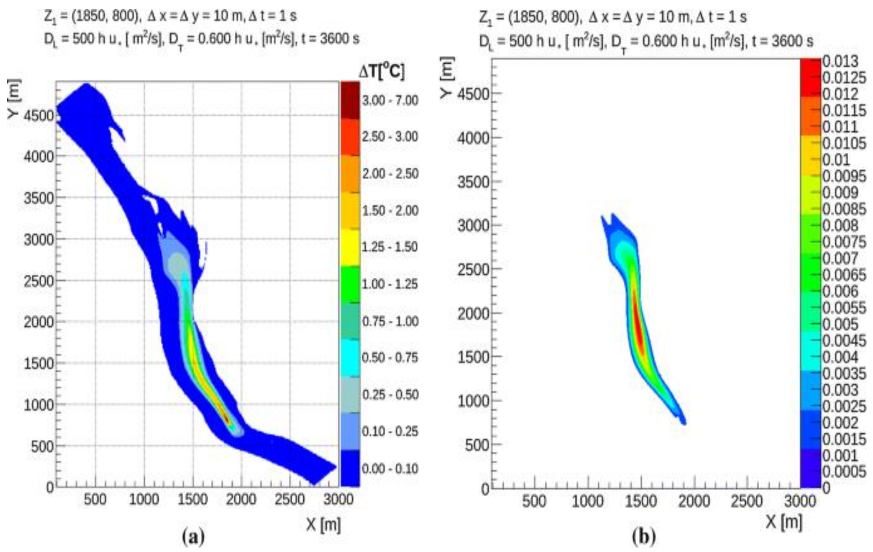
B=qhqe=CBpap0Tw−Taes−ea,B=qhqe=CBpap0Tw−Taes−ea,

where *B*—Bowen ratio [−], C_b—Bowen coefficient (approximately $C_b = 0.62$ mb°C^{-1}), p_0—reference air pressure (= 1013 mb).

qh=Cbpap0f(u)(Tw−Ta),qh=Cbpap0f(u)(Tw−Ta),

(20)

Usually, the same wind speed function as for evaporation and condensation heat flux term is used, and the same problems and similar large uncertainty connected with the empirical coefficients and wind speed velocity values apply here. However, the value of the conduction and convection heat flux is usually small compared to the values of other heat fluxes, and its impact on the final results is smaller.



To illustrate the influence of the inclusion of the heat exchange term on the results of thermal pollution modelling in the mid-field zone, the real case study exemplary results have been analysed. The detailed description of the case study may be found in Kalinowska et al. (2012). The River Mixing Model (RivMix), developed by Author, computing the temperature change, has been used (Kalinowska and Rowiński 2008) to predict the water temperature increase caused by heated water discharged from a designed power plant. Two variants of computation have been performed for the examples of chosen (least favoured) conditions. The first variant has been treated with the heat flux caused by water–air heat exchanges included in the calculations (see Fig. 13a), the second one without the heat flux inclusion. After 1 h, the observed difference between the two variants is of the order of 10−2 (see Fig. 13b). Such a difference is relatively small compared to the other sources of errors performed while solving the 2D heat transport equation numerically. For instance, the huge source of uncertainty is the dispersion coefficients estimation. Those coefficients are very difficult to estimate, and therefore, usually different scenarios with various possible values of coefficients are analysed. However, the difference between such scenarios results may be much higher, up to 1 °C (see Kalinowska and Rowinski 2012), compared to the

difference obtained with and without the included heat exchange with the atmosphere. Other sources of uncertainty have been analysed in (Kalinowska and Rowin).
Similarly to all terrestrial objects, water also emits longwave radiation, which can provide a significant contribution to heat loss from the water surface. The value of outgoing water longwave radiation heat flux usually varies from 300 to 500 W m−2 (Deas and Lowney 2000), and assuming that water temperature is known, it is relatively easy to estimate. Similarly to longwave atmospheric radiation, it may also be computed using the Stefan Boltzmann law:

$$q_b = \varepsilon_w \sigma (T_w + 273.15)^4$$

In the paper, for thermal pollution modelling applications, it is recommended to use models that compute the temperature change instead of the actual river temperature whenever it is possible. Such approach reduces the amount of necessary input data and finally the computation error. In most cases in the mid-field zone, omission of all terms related to heat exchange with the environment including the heat exchange with the atmosphere is recommended. Not perfect input data may in some cases introduce much larger error to the final results than just simple omission of the heat fluxes terms. The problem is especially important in practical cases when we deal with limited and not ideal data. We of course fully realize that in some applications it is necessary to include the heat exchange with the atmosphere and/or other heat fluxes.

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