BUOYANCY FLUXES IN THE AEGEAN SEA

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Abstract

Recent observations have shown that outflowing Aegean waters have replaced about 20% of the deep and bottom waters of the eastern Mediterranean basin. This indicates changes in the hydrology of water masses in the Aegean Sea and the corresponding thermohaline circulation. In this work we estimate the driving mechanism of the thermohaline circulation, the buoyancy fluxes using 45 years of COADS data. The long term buoyancy loss is estimated to be about $5x10^{-6}$ kg m^{-1} s^{-3}. However for certain periods lasting a few years the flux reverses sign and there is buoyancy gain . The reversal of sign is expected to lead in changes of the thermohaline circulation in the basin.

Key-words: air-sea interactions, river input, hydrology, Aegean Sea

Introduction

The Aegean Sea constitutes the northeasterly part of the eastern Mediterranean Sea located northward to the island of Crete . It covers an area of approximately $1.8x10^{11}$ m^2 containing a water volume of some $7.4x10^{13}$ m^3 [1]. The basin has a complex topographical structure with irregular bathymetry (water depths >2,000 m). At its northeastern end, the Aegean Sea exchanges flows with the Black Sea through the Sea of Marmara and the Dardanelles. To the south, the Aegean Sea communicates with the open (eastern) Mediterranean Sea through the Cretan Straits.

Recent developments in the understanding of deep water formation in the eastern Mediterranean Sea have shown that a water mass (Cretan Deep Water (CDW)), originating in the southern Aegean Sea, exits through the Cretan Straits; it sinks there in the deep layers of the adjacent SE Ionian and NW Levantine Seas [2]. Furthermore, Aegean Sea water has replaced about 20% of the deep and bottom waters of the eastern Mediterranean basin [3]; it was believed previously that the only source of such waters was the Adriatic Sea. This influx has induced changes in the overall characteristics and upward displacement of older waters of the Eastern Mediterranean and is caused by an increasing salinity and thermohaline circulation pattern changes in the Aegean Sea waters.

The present investigation examines, against this background, the water budget, the freshwater balance and the buoyancy fluxes in the Aegean Sea, as this is implied by heat budget calculations, freshwater inputs, and horizontal advection of sea water masses (*i.e.* Dardanelles Strait exchanges).

Water Budget

The water balance (W) of the Aegean Sea is descibed by the relationship:

$$W = P+R+E+B\pm C$$

where, P is the amount of precipitation, R is the river runoff, E the evaporation, B is the inflow from the Black Sea and C is the exchange of fluxes between the Aegean and the open (eastern) Mediterranean Sea.

Precipitation

Annual precipitation over the Aegean Sea varies generally between 400 and 700 mm per annum [4], with a mean annual relative humidity of between 65% and 75%. Observed levels of precipitation, representing mean monthly precipitation levels based upon daily average measurements from 10 coastal meteorological stations over a 16 year period (1975-1990), were between 372 mm (Athens) and 672 mm (Rhodes), with an overall mean value of some 495 mm yr^{-1}

River inputs

The Aegean Sea receives the freshwater outflows from various Greek and Turkish rivers discharging along its coastline. The main Greek rivers (Axios, Aliakmon, Gallikos, Pinios, Sperchios, Evros, Strimon and Nestos) provide some $19x10^9$ m^3 of freshwater whilst the smaller Turkish rivers (K. Menderes, Bakir, Gediz, Kuguk Menderes, and Bujuk Menderes) discharge some $5.1x10^9$ m^3 [5]. The previous referred discharge levels represent only part of the river catchment area (60-90%) as the location of the gauge stations do not coincide with the river mouths. In addition to the riverine supply, a substantial water inflow is attrributed to the sewage outfall of the numerous cities located adjacent to the coastlines; for example, Athens discharges some $0.22x10^9$ m^3 yr^{-1} of waste [6]. Hence, the total amount of freshwater water inputs (R) to the Aegean Sea is expected to reach as much as $25x10^9$ m^3 yr^{-1}, when the inputs of the numerous small ephemeral rivers and torrents are incorporated into the total water discharge of the main river systems.

Evaporation

The evaporation rate is derived by evaluating empirical bulk formulae. Here we adopt the estimation of Poulos *et al.* [5] which is based upon the calculation of the overall heat budget of the Mediterranean Sea, on the basis of monthly observations averaged for a long period (1945-1990); the source of data was the COADS (Comprehensive Ocean Atmospheric Data Set [7]). The estimated value is -104 Wm^{-2} which corresponds to an evaporation rate of 1.3 myr^{-1} .

Black Sea Waters.

The Aegean Sea receives the colder and less saline Black Sea Water (B) though the Dardanelles Strait, where a two-layer stratification and opposing flow circulation has been established, on the basis of density differences between the Aegean and Black Sea waters [8]. Furthermore, the two different water masses are separated by a pycnocline, at an average depth of 25 m. The upper layer is occupied by the less saline (S=29.6 psu) Black Sea Waters (B) and the lower layer by the more saline (S=38.9 psu) Aegean Sea Waters [9]. The surface layer in the Dardanelles flows towards the Aegean Sea, at velocities ranging between 50 and 200 cm s^{-1} wlile the bottom layer moves in the opposite direction, towards the Sea of Marmara, with velocities ranging from 20 to 40 cm s^{-1} [10]. Thus, Umluata [9] have calculated that some 1257 km^3 of colder and fresher water outflows annually into the Aegean Sea whilst, at the same time, 957 km^3 of the more saline Aegean Sea Water enters the Sea of Marmara through the Dardanelles Strait. The former implies a net annual water inflow to the Aegean Sea equal with 300 km^3.

The annual mean components comprising the water balance of the Aegean Sea are presented on Table 1.

Table 1 : The main components of the annual water balance of the Aegean Sea.

	($m\ yr^{-1}$)
Precipitation (P)	+0.5
Evaporation (E)	-1.3
River Runoff (R)	+0.1
Black Sea Water (B)	+1.7
Water balance (W):	+1.0

The annual amount of evaporation (E) over the region exceeds the sum of precipitation (P) and river runoff (R). However, if the net Black Sea Water inflow (B) is considered, then the water balance of the Aegean Sea is positive (*i.e.* P+R+B-E>0) indicating net outflow through the Cretan Straits.

Estimation of Fresh Water Balance

The amount of equivalent fresh water input from the Black Sea V_f is given by:

$$V_f = \left[V_b \; \frac{V_a + V_b}{V_a + V_b} - 1 \right]$$

where V_b is the outflow from the Black Sea with salinity S_b and V_a is the volume of the Aegean with mean salinity S_a. The salinity of the Black Sea outflow is ~29.6 psu and the mean salinity of the Aegean ~38.9 psu. Assuming the net volume transport through the Dardanelles