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INTRODUCTION

Saronikos Gulf, marine gateway to the metropolitan Athens area of Greece, invites the attention of marine scientists because euthrophication and other alterations are occurring in its naturally oligotrophic waters as a consequence of urban waste disposal. Recently, an international conference at Nafplion, Greece, 10—13 November 1972 studied systems approaches to eutrophication problems in the Eastern Mediterranean and specifically focused attention on Saronikos Gulf. Part II of the Conference Report. (Mactsaac, 1973) is a compilation of papers and abstracts representing the current state of knowledge concerning the Saronikos Gulf marine environment. It appears that the area offers a unique opportunity to follow the effects of pollution through a coordinated series of marine studies.

Partially as an outgrowth of the conference, the Saronikos Systems Project (SSP) was begun under the direction of Drs. T. S. Hopkins (IOKAE) and R. C. Dugdale (University of Washington). Six cruises have ben conducted to date, in December 1972 and in January, March, May, June and August 1973. These data constitute the only systematic oceanographic observations on water mass characteristics from the area, and this paper discusses those observed during the first two cruises.

The Saronikos Gulf is a northward extention of the Myrtoon Sea which in turn is the northwestern arm of the Cretan Sea. However, the source waters for Saronikos Gulf appear to come from the east as the southward flowing western boundary current of the North Aegean follows the continental shelf bathymetry around Evvia Island, through the Petalion Gulf, past the Attikis Peninsula, and into the Saronikos Gulf. This type of flow has been suggested by the Greek Hydrographic Office (unpublished), C. Yannopoulos and A. Yannopoulos (in press) and data collected and analyzed by Hopkins. At depths below 200 m, the Saronikos exhibits characteristics of Aegean Sea water, with salinities of about 38.9‰, temperatures between 14.5 and 15°C, and high O_2 values (5 ml/L). The station locations for the SSP cruises extended sufficiently south to sample water with these basic characteristics.

The Gulf is topographically divided into eastern and western sections by Aigina Island (Figure 1). The eastern part, at the head of which lies the Athens metropolitan complex, exhibits a relatively uniform bottom topography with depths shoaling from 200 m southeast of Aigina to 90 m between Aigina and Vouliagmeni. It is somewhat deeper (90 m) toward the Salamis shore and shallower (60 m) toward Aigina and Attikis. The main body of the eastern basin has depths between 70 to 90 m and shoals rapidly close to the shores.

The western part of Saronikos Gulf is deeper. From west of Salamis to the Korinthos-Loutraki land bridge, the basin is 130 m, and connects to the south with a deep (400 m) depression west of Aigina and the Methanon Penin-

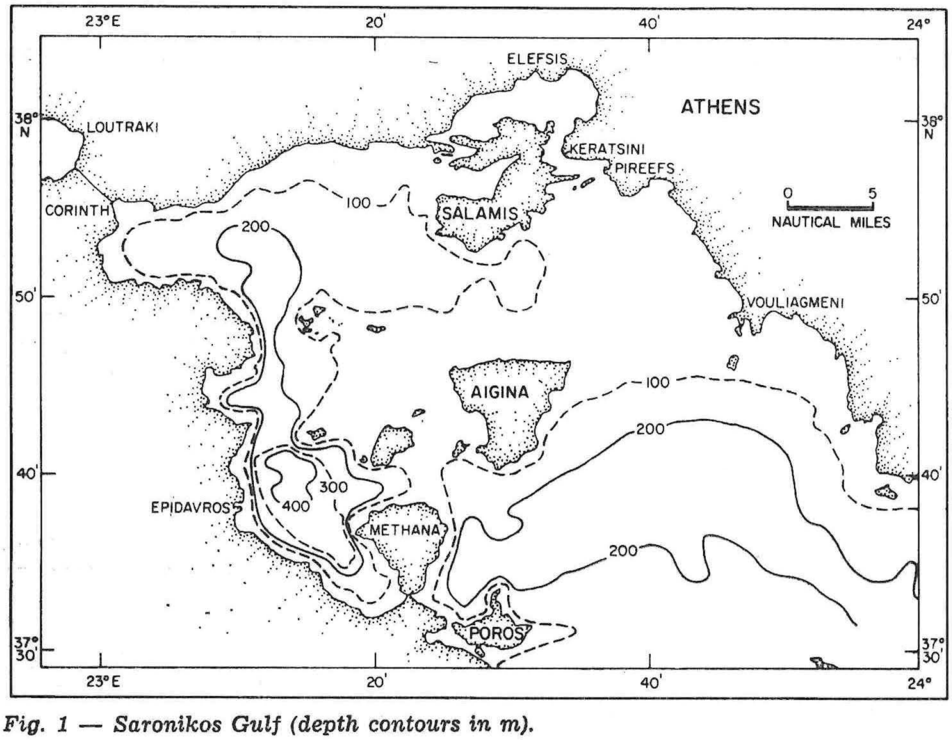

Fig. 1 — Saronikos Gulf (depth contours in m).

sula. The major connections between the basins are on the north between Salamis and Aigina with a sill depth slightly greater than 100 m, and to the south between Aigina and the Mehtanon Peninsula with a sill depth of about 80 m.

At the north end of the Gulf lies Elefsis Bay with depths of about 30 m. The Bay connects to the Gulf east and west of Salamis via narrow and shoal channels. The western connection has a maintained dredged ship channel of about 8 m. The eastern connection, with a wider dredged channel of about 11 m, connects with Keratsini Bay which is the main port of Athens. Depths in Keratsini are between 25 and 35 m deepening towards Saronikos Gulf. Psitalia Island in its mouth creates two channels between Keratsini and the Gulf, both with depths exceeding 35 m. The smaller ship harbor of Pireefs lies about one km outside the eastern channel.

Air temperatures range from around 0°C to 40°C over the year and thus the waters are subjected to strong cycles of summer heating and winter cooling. Rainfall is on the order of 40 cm/yr. It is variable and frequently severe, primarily occurring between late fall (November) and spring (May). The land conditions are such that the water of heavy rains largely runs directly and rapidly to the sea. River runoff is insignificant except during large precipitation. However, there is a continual source of freshwater into the eastern end of Keratsini Bay resulting from the sewage outfall of the metropolitan Athens area. The discharge is approximately 7 m^3/sec. At the northeast section of Keratsini there is a discharge of cooling water effluent from the Public Power Corporation generating plant at a rate of $\sim$ 19 m^3/sec at 10°C above ambient temperature.

Meteorological fronts pass eastwards fairly frequently during fall, winter and spring, with the greatest frequency between November and February. Severe winds associated with these storms can either advect warm moist air from the south, or cold dry continental air from the north. In summer (July--September) a strong (10 m/sec) wind from the north (Meltemi) is common, and when developed exhibits a diurnal character, blowing strongly during the day and lessening at night. When the Meltemi is not developed, smaller scale »sea breezes« of 5 to 10 m/sec generated by differential heating between land and sea develop almost every day and in Saronikos Gulf are often from the southwest and south.

METHODS AND MATERIALS

The station locations for the winter cruise SSP1 and SSP2 are shown in Figures 2 and 3, respectively.

Temperatures at individual depths were determined by reversing thermometers attached to Nansen bottles, and are considered accurate to $\pm$ 0.02°C. Water samples were drawn from the Nansen bottles into glass bottles for salinity analyses, made post-cruise on an inductively-coupled salinometer, standardized against Copenhagen water, and are estimated accurate to $\pm$ 0.01‰. Dissolved oxygen analysis was made aboard ship using the Winkler titration method. Further samples for nutrients were taken and frozen until later analysis with a Technicon autoanalyzer.

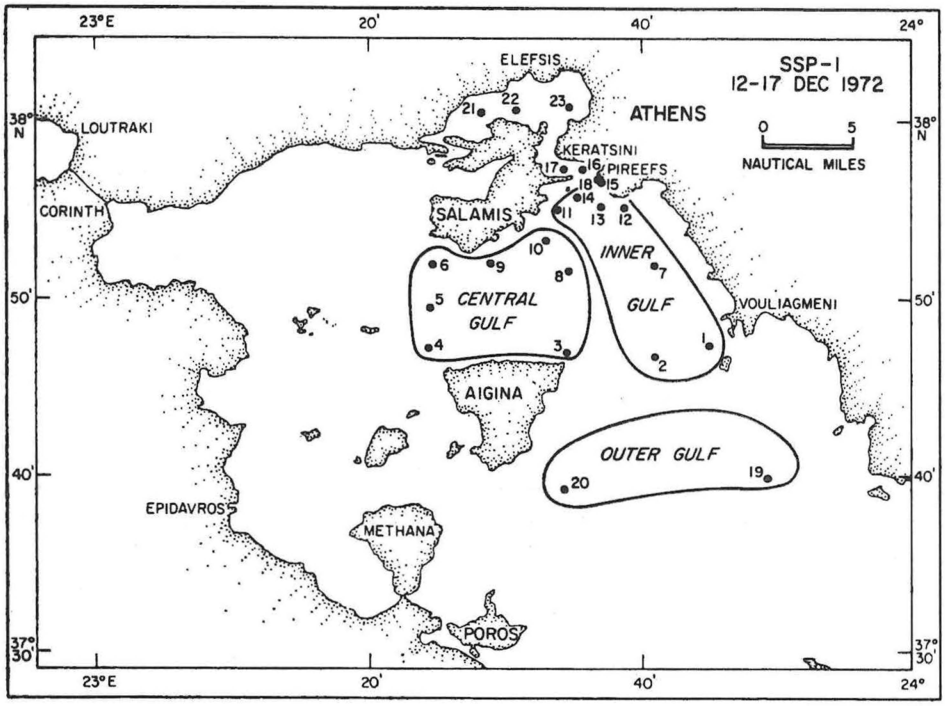

Fig. 2 — Location of stations of Cruise SSP1, 12—17 December 1972. Lines enclose water masses.

RESULTS AND DISCUSSION

Vertical distributions of temperature and salinity for selected stations are presented in Figures 4 and 5. The temperatures and salinities at 200 m in the outer Gulf (SSP1—19, SSP2—3) closely approach those of the Aegean Sea water with values of temperature 14.75°C and salinity 38.8‰.

An obvious characteristic of the water columns in the Gulf during winter was the vertical homogeneity. In the upper portions of the water columns in all cases temperatures varied by less than 0.2°C and salinities by less than 0.05‰. The depth of the homogeneous layer exceeded 30 m and in most instances extended to 50 m or to the bottom if shallower. The upper water columms were thus essentially isopycnal, indicating that vertical convection was actively in progress during both cruises. Surface water frequently exhibited slightly lower temperatures and/or slightly higher salinites than those deeper (of SSP1—14, SSP1—19, SSP2—11, SSP2—19) and hence these columns were actually slightly unstable.

Horizontal variations in the Gulf were considerably greater. In December, temperatures of the upper mixed layer ranged between 15.5 and 17.5°C and salinities between 38 and 38.5‰ for the stations shown in Figures 4 and 5, with the exception of Elefsis where the temperature was much lower

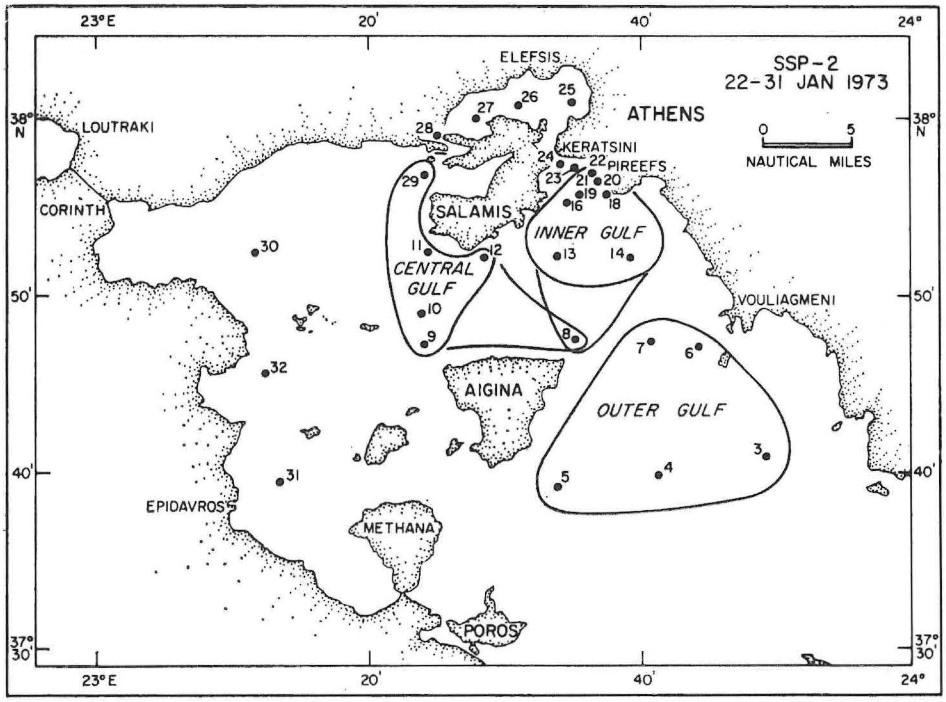

Fig. 3 — Location of stations of Cruise SSP2, 22—31 January 1973. Lines enclose water masses.

(~14.2°C). In January, the water columns had been cooled substantially (~2.5°C) and the horizontal range of temperatures over the Gulf reduced to less than 1°C (13.5 to 14.5°C), again with the exception of the Elefsis station which was more than 3°C colder than the others. The salinity values were similar in January to those in December except the range appeared to have narrowed (38.1 to 38.3‰).

The vertical distributions are representative of a system in which one of the major modifying processes is removal of heat thorugh the sea surface. With essentially neutral stability, any energy input (for example, from the wind) readily stirs the upper mixed layer and, therefore, heat can be lost fairly consistently throughout the entire layer to the colder atmosphere. In December, this mechanism was effective to about 50 m. Station SSP1—19 in the outer Gulf showed homogeneous conditions to 50 m, below which anomalously warm water was found in a halocline until the Aegean Sea water began at 200 m. At other stations, SSP1-2, the process was active to somewhere between 30 and 50 m, whereas other stations showed structure, primairly haline, right to the surface (SSP1—20).

The data from SSP2, obtained 40 days later, show the process of heat removal to have continued over the period. The water columns in the center of the Gulf, which in December showed slightly higher temperatures and

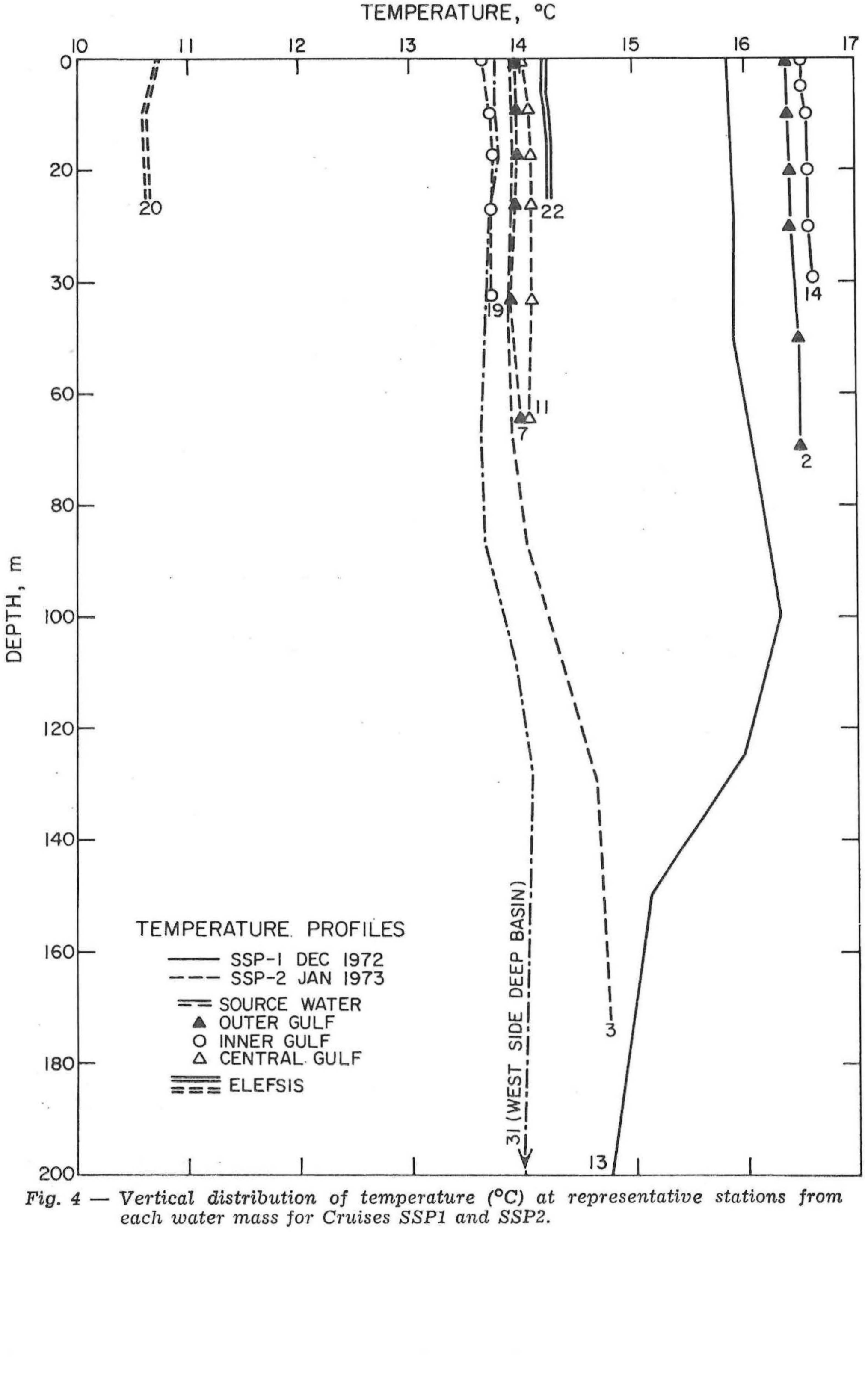

Fig. 4 — Vertical distribution of temperature (°C) at representative stations from each water mass for Cruises SSP1 and SSP2.

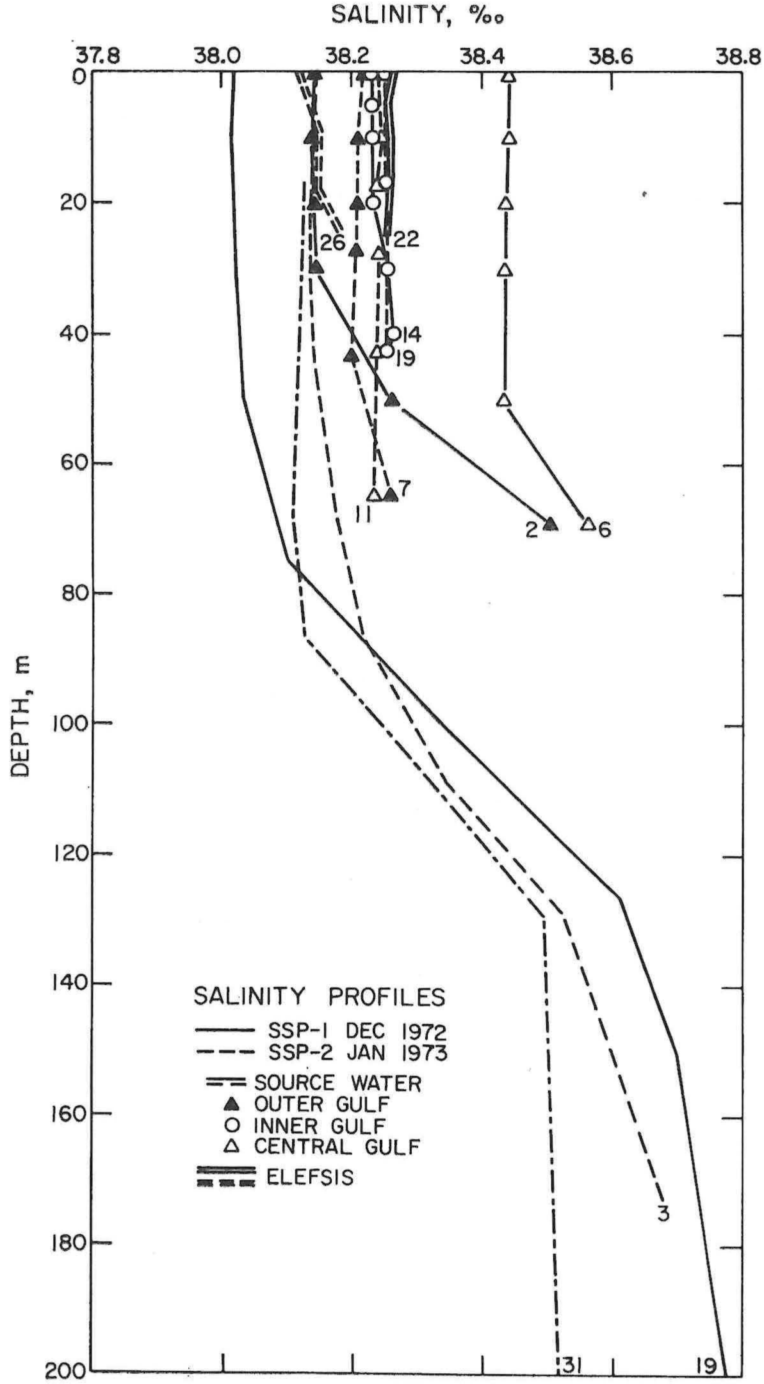

Fig. 5 — Vertical distribution of salinity (‰) at representative stations from each water mass for Cruises SSP1 and SSP2.

salinities (SSP1—2, SSP1—6) near the bottom, became homogeneuos throughout (SSP2—7, 11) indicating that the effective depth of vertical maxing had deepened. In the water columns towards the mouth of the Gulf, the reservoir of heat in the halocline was not present in late January (SSP2—3), and the temperatures increased smoothly from the bottom of the mixed layer to the values of the Aegean Sea source water. However, this water with the 100 m temperature maximum found at SSP1—19 must have been due to an advected intrusion (see below), so the mechanism of heat loss by vertical convection and escape to the atmosphere may not have been solely responsible for the observed cooling. The intrusive source may not have been present in January.

The changes in vertical profiles of salinity also reflected the deepening of the mixed layer over the period. However, unlike temperatures, they showed little net change in salt content had taken place; rather it appears more as if salt had been mixed upwards in the water columns (see Stations SSP1—19 with SSP2—3, SSP1—2 with SSP2—7 and SSP1—14 with SSP2—19).

The waters of the west portion of Saronikos Gulf were not sampled during December. In January (represented in Figures 4 and 5 by SSP2—31), the water properties shallower than about 80 m were basically the same as elsewhere in the Gulf, while the temperature and salinity characteristics of the deeper layers were colder by 1°C and less saline by ~ 0.2‰ and thus diverged from those of the deep water east of Aigina. The deep basin of the west side is apparently effectively isolated below sill depth, which between Aigina and Methanon is about 80 m, from the Aegean Sea source water at 200 m depth in the eastern part of the Gulf, and can, therefore, develop separate deep-water characteristics.

The Water Masses

On the T-S plane, the various waters of Saronikos Gulf in winter separate into five distinct water masses. Figures 6 and 7 present the data from both cruises. The stations from Keratsini and the western portion of the Gulf are not included in these figures, but are discussed later. In the T-S diagrams, the deepest observation is denoted by the station number, and the lines defining each water mass curve connect the observations sequentially upward. At certain stations the 50 m observation is denoted by an arrow, and lines of equal σ_t are shown.

The water masses based on the December data (Figure 6) are given below. The spatial relationships of the water masses are shown in Figure 2.

Outer Gulf Water. — The Outer Gulf or source water is described by the curves for stations SSP1—19 and SSP1—20. They exhibit an inverted U-shape, characteristic of a water column which initially was fresh and warm at the surface grading to cooler and more saline at depth but from which heat has been subsequently lost from the upper layer. In December 1972, the upper layer had a salinity of 38.1‰ and a temperature between 15.5 and 16°C, the halocline region with salinities from 38.3 to 38.4‰ had a temperature ~ 16.3°C, and the deepest observations approached those of the values for Aegean Sea water (temperature 15.75°C, salinity 38.75‰). It is to be noted that in the lower part of the halocline region, from the intermediate temper-

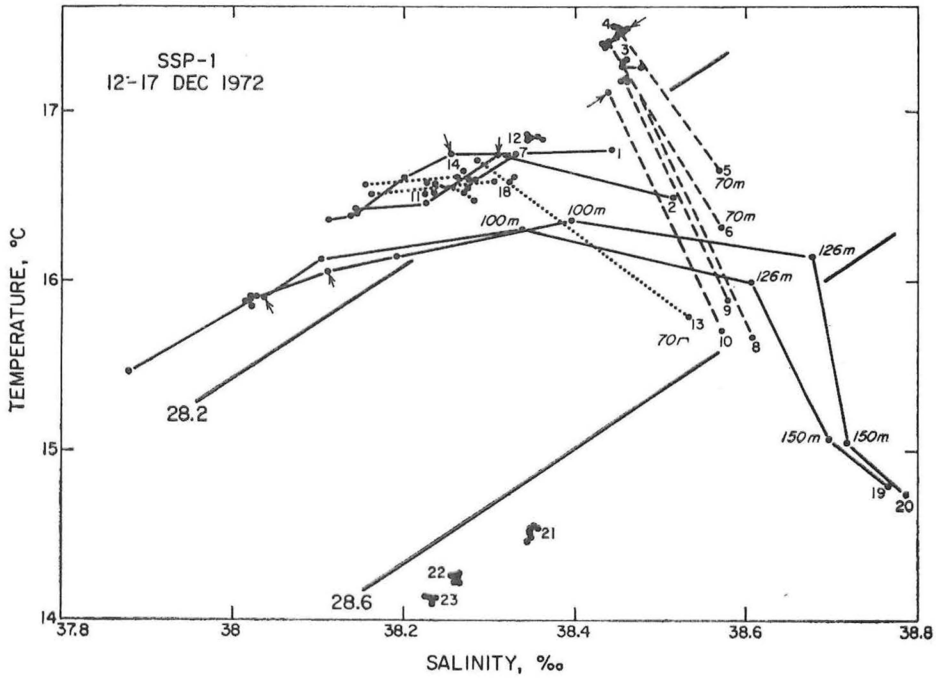

Fig. 6 — T-S diagram for Cruise SSP1 with stations arranged by deepest observation and lines connecting observations sequentially upward. Arrow denotes 50 m observation.

ature maximum down to Aegean Sea water, the water was not a simple mixture of one layer with the other, i. e., the observations from 125 to 150 m depth and with 38.6 < S < 38.7‰ had too high temperatures (> 16°C). This must have been due to an intrusion of intermediate density water which occurred outside Saronikos Gulf and which was being advected with the source water.

Central Water. — The water observed between Salamis and Aigina (SSP1—3 to 6, 8 to 10) forms a distinct water mass. Its values at 50 m showed narrow ranges of temperature (17 to 17.5°C) and of salinity (38.42 to 38.48‰). Though no observations were made west of Salamis in December, it is believed that water with these characteristics probably filled the whole region and, we shall term it Central water.

The Central water was the warmest water in Saronikos Gulf in December and since strong cooling was taking place, must have been residual from the previous summer. The Central water over the same depth range (0 to 50 m) had the same density (28.1 < σ_t < 28.2) as that of the source water mass.

Stations SSP1—4, 5 and 6, the westernmost stations, were actually slightly less dense than the others, and hence this was the lightest water in the Gulf.

The deep (70 m) observations from the Central water mass showed a layer of slightly higher salinity (0.1‰) and 1 to 1.5°C colder. There was no

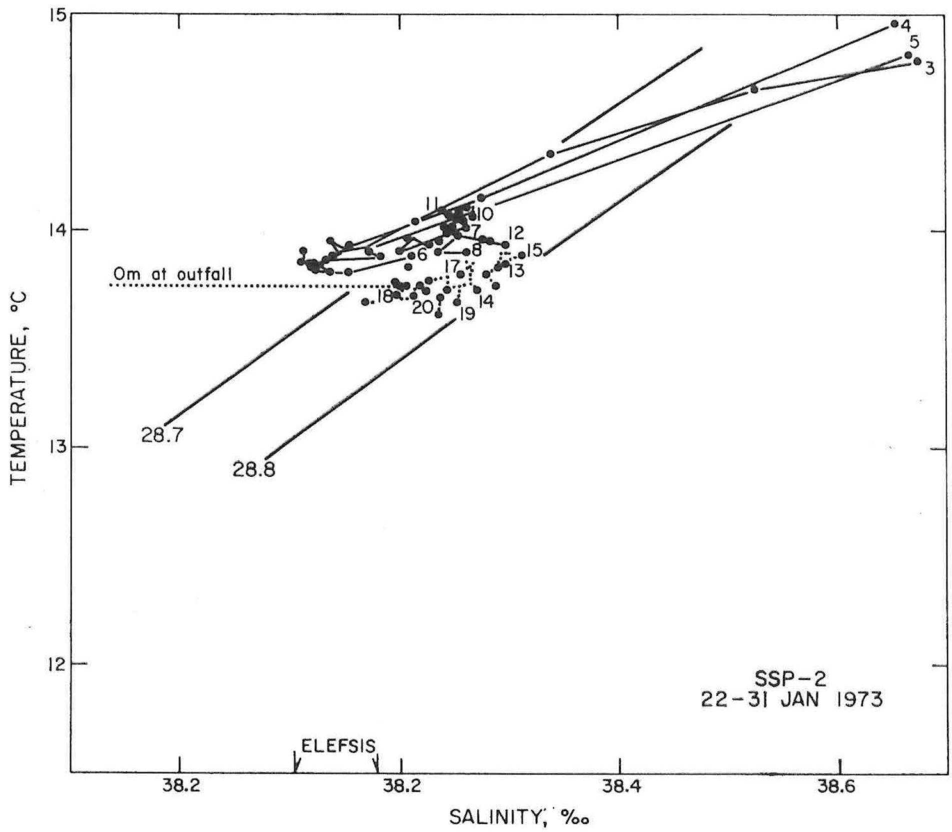

Fig. 7 — T-S diagram for Cruise SSP2 with stations arranged by deepest observation and lines connecting observations sequentially upward.

continuity between the deep Central water and Outer Gulf water, as the Outer Gulf water to deeper than 100 m was definitely less saline. It thus appears that the deeper Central water was also relict from the previous summer, with the remnants of a thermocline (and hence pycnocline of about 0.4 σ_t units) present > 50 m in December. There was apparently a continuity of the deeper Central water with the deeper water of the water mass adjacent to the east, represented by stations SSP1—1, 2 and 13.

Inner Gulf Water. — This water mass occupied the northeastern portion of the Gulf (Stations SSP1—1, 2, 7, 11—15 and 18). It had the same density ($28.1 < \sigma_t < 28.2$) as the Central water and the upper layer of Outer Gulf water, with the exception of the three observations from 70 m at stations SSP1—1, 2 and 13. The temperature and salinity characteristics of this water mass showed the properties of a mixture of upper layer Outer Gulf water and Central water, and, for the water mass as a whole, the quantitative relation was about 50 percent from each source.

The observations deeper than 50 m in this water mass showed, as previously remarked, a definite T-S correlation with the deeper observations from the Central water. For example, the deepest observation at station SSP1—13 closely approached those at stations SSP1—8, 9 and 10, adjacent to the southwest (Figure 2), while those at SSP1—1 and 2 though warmer approached the higher values of the deep Central water.

Elefsis Bay Water. — In Elefsis Bay the water properties were relatively homogeneous (temperature 14.1 to 14.6°C, salinity 38.2 to 38.4‰). The temperatures, however, were 2°C colder than those of the Inner-Gulf water to which Elefsis Bay connects via Keratsini, and the Elefsis water was 0.5 σt units denser than the upper layer water of the Gulf.

Figure 7 presents the T-S correlation for SSP2 during January 22—31, 1973. Stations SSP2—23 and 24 in Keratsini, SSP2—29 off the west channel from Elefsis, and SSP2—30, 31 and 32 from the western basin are omitted from the figure. The Elefsis stations (SSP2—25, 26 and 27) are too cold to show in this correlation but the range of salinity is indicated by arrows on the abscissa. The deepest values at the outermost stations (SSP2—3, 4 and 5) showed the characteristics of Aegean Sea water in temperature ($\sim$ 14.7°C) but were less saline ($<$ 38.7‰), probably because the observations only extended to 172 m depth.

The range of temperature and salinity for all observations in the upper 100 m are so small that meaningful correlations are difficult to discern. However, close examination shows that all stations from the Inner Gulf (SSP2—13 to 21) as a group are about 0.2°C colder than stations from the Outer Gulf (SSP2—3 to 7), while the latter appear to be as a group about 0.1‰ less saline. Stations SSP2—9, 10 and 11 from between Salamis and Aigina showed about the same salinity as the Inner Gulf stations, but were 0.2 to 0.3°C warmer. These relationships can be more readily seen in Figure 8 which plots these stations on an expanded scale. The arrows indicate observations at 50 m depth.

The water masses present in January, essentially the same as in December, are given below. Figure 3 shows the spatial relationship between the January water masses.

Outer Gulf Water. — The Outer Gulf water is represented at stations SSP2—3 to 7, and its properties in the upper 50 m fall within the ranges 13.7 to 14.0°C and 38.10 to 38.23‰. This water mass in January extended farther into the Gulf along the eastern side than in December (Figure 3).

Central Water. — The Central water was represented at stations SSP2—9 to 12 and occupied the salinity band 38.23 to 38.30‰. This water mass still showed the warmest upper layer (0 to 50 m) temperatures of any water in the Gulf (13.9 to 14.1°C). The densities of the Central water were the same as the upper water of the Outer Gulf water mass ($\sigma_t \sim 28.7$).

Inner Gulf Water. — This water mass was both colder (13.6 to 13.9°C) and more saline (38.23 to 38.31‰). The highest salinities were observed in the western stations (SSP2—13, 14 and 15). Station SSP2—12 showed transitional character with the deepest observations closely related to stations SSP2—13 and 15 while the shallow observations were correlated with the Central water. Likewise station SSP2—8, off the northeast tip of Aigina, show-

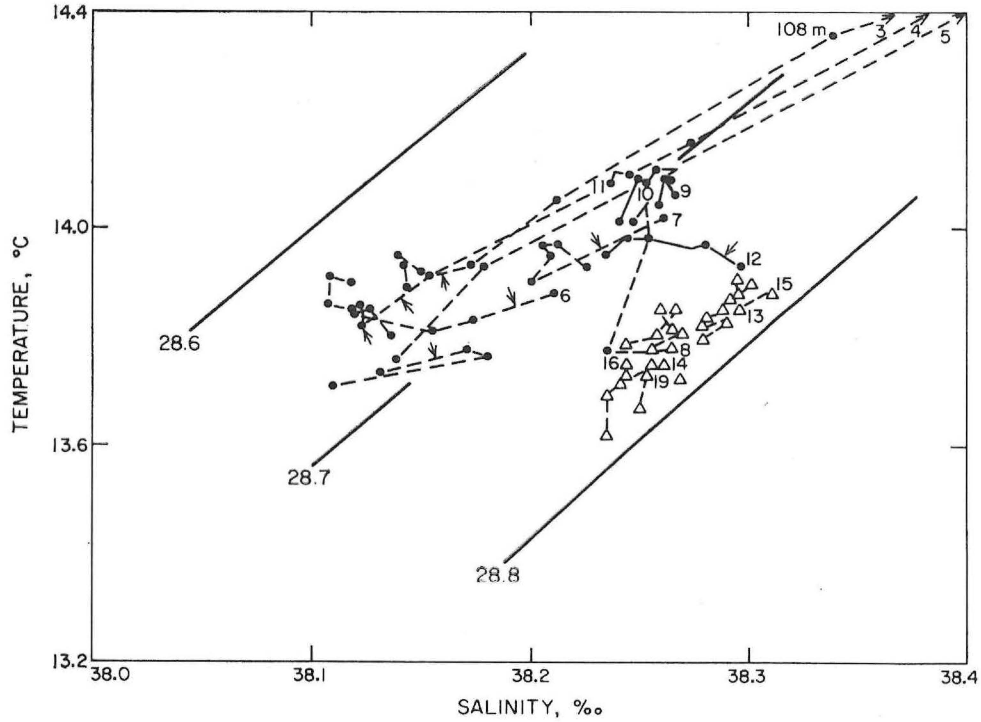

Fig. 8 — Expanded scale of T-S diagram of selected stations from Cruise SSP2

ed a similar transitional character though the deep salinities were not quite. so high.

In January, the relationship among these water masses was quite different than in December, i. e., Inner Gulf water was definitely not a a product of mixing Central and Outer Gulf waters as suggested during December. Rather, it exhibited the highest salinities of the upper layer waters and a definitely higher density. This point is reconciled below.

Elefsis Bay Water. — The Elefsis Bay water was again unique, relatively homogeneous in temperature (10.6 to 11.0°C) and in salinity (38.10 to 38.18‰) and much denser ($\sigma_t \sim$ 29.2 to 29.3). Thus this water was in the same salinity band as Outer Gulf water and, therefore, less saline than the Inner Gulf water with which it can communicate. The temperature contrast with Inner Gulf water was $\sim$ 3°C.

Western Basin Water. — Observations were made during SSP2 in the western deep basin. The stations (SSP2—30, 31 and 32) and their relationship with the other water masses is shown in Figure 9. The arrows indicate observations from 86 m depth.

Deeper than 86 m, the Western Basin water was clearly different than other waters in the Gulf, with temperature 0.3°C colder for equal values of salinity in the eastern basin, and the bottom water (SSP2—31, 344 m) was

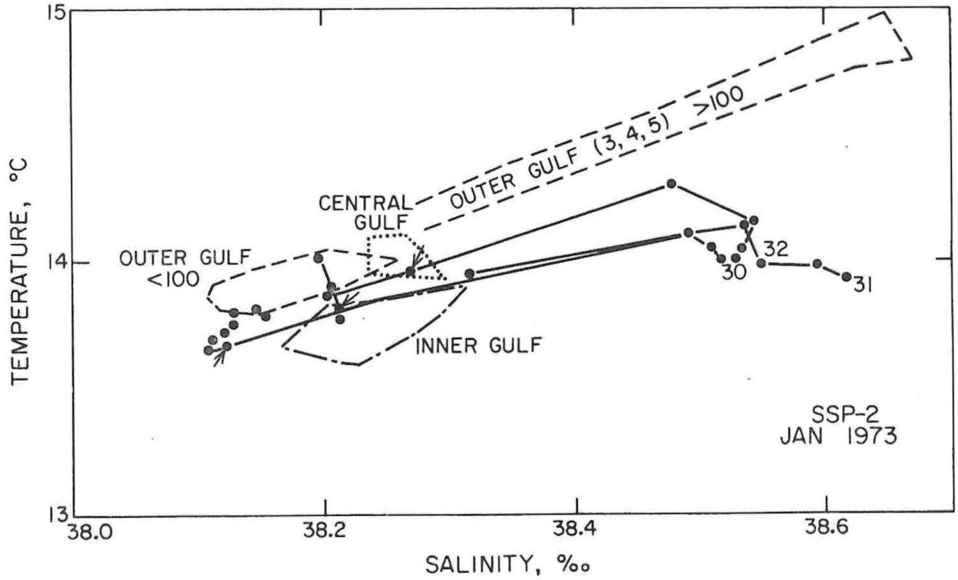

Fig. 9 — T-S diagram of stations from the western basin (Cruise SSP2) showing the relationship to other water masses.

almost 1°C colder than Aegean Sea source water. Thus, Western Basin water exhibited the characteristics of the Outer Gulf water mass in salinity but perhaps a trifle (0.1 to 0.2°C) colder, on the average. The Western Basin water definitely does not appear to be either Central or Inner Gulf water.

Circulation

For initial interpretation of the circulation patterns obtained during December (SSP1) and January (SSP2), the distributions of phosphate and ammonia in the upper mixed layer are presented in Figures 10 through 13. Phosphate concentrations in the source waters to Saronikos Gulf are low ($<$ 0.08 μg at/L), and ammonia does not persist for any appreciable time because it is converted to nitrate. The source of these nutrients in Saronikos Gulf is almost solely from the Keratsini sewage outfall. Unknown amounts of nutrients are also introduced directly into Elefsis and along the shoreline to the southeast from Piraeus, but as the population densities in these areas are not great in comparison with that of metropolitan Athens, they are assumed insignificant compared to the Keratsini outfall.

As the upper layer was actively convecting during both cruises, the total μg-at of the elements under a one cm^2 of sea surface over the depth of the mixed layer at each station was calculated. In most instances this depth was 50 m, but was taken to be shallower if the water depth at the stations was less than 50 m or the hydrographic data showed evidence that mixing did not extend to 50 m.

The December distribution of both PO_4 (Figure 10) and NH_4 (Figure 11) were similar. Large quantities were observed adjacent to the outfall, and part way along Salamis to the southwest. Farther seaward, the highest values were observed to the southeast along Attiki. Low values were observed in the region of the Central water between Salamis and Aigina. Very high values, particularly of NH_4, were observed in Elefsis, the circulation of which is discussed in a later section.

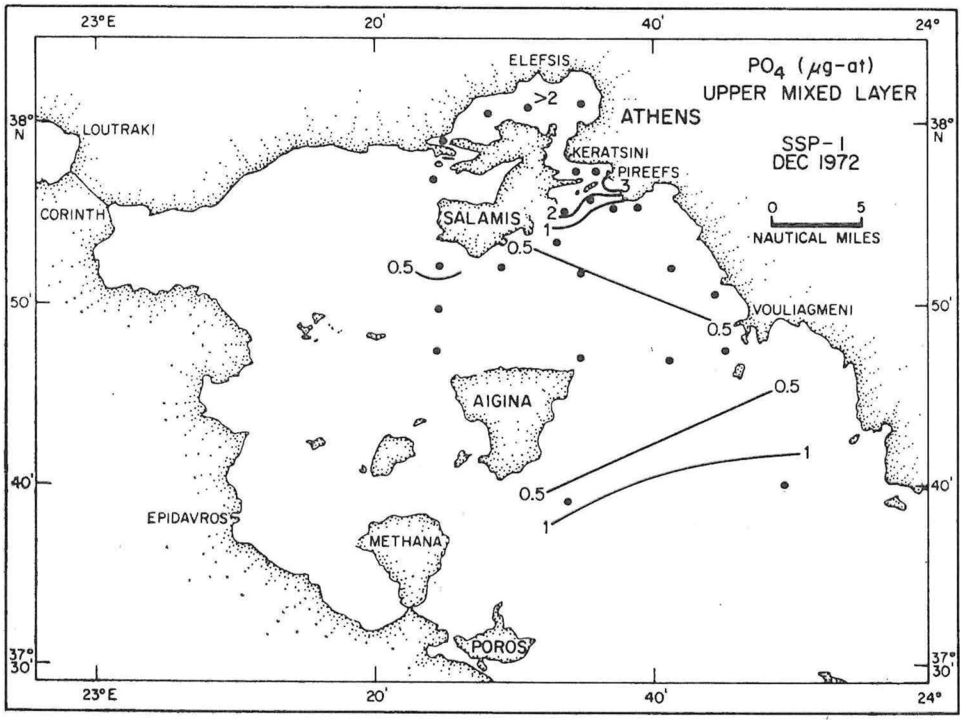

Fig. 10 — Distribution of PO_4 (μg at/L) in the upper mixed layer during Cruise SSP2 (late January 1973).

In January (Figures 12 and 13), the distribution of nutrients was different than in December. High values were present near the Keratsini outfall and a tongue-like distribution extended southwest along Salamis. These high values persisted into the region north of Aigina whereas low quantities occurred along the Attikis Shore. Again PO_4 and NH_4 values were very high in Elefsis.

The circulation in the upper layer through which the nutrients were distributed is interpreted to have been basically different between mid-December and late January. In December, it appears that the circulation was clockwise, with upper layer water from the Outer Gulf entering the west side of the eastern part, towards the Aigina shore. This water was mixing with the large body of Central water occupying the region between Aigina and Salamis, and which had the same density, creating the Inner Gulf water. The T-S relationships of Figure 6 indicate that the Inner Gulf water was an approximately 50 to 50 mixture of Outer Oulf and Central water. The Inner Gulf water was then moving out of the Gulf along Attikis. Stations SSP1—1 and 2, off Vouliagmeni, exhibited the characteristics of Inner Gulf water and the very high NH_4 contents (Figure 11) suggest this water was downstream from the ammonia source of the Keratsini outfall.

The water below that of the upper layer (50 m to the bottom) was probably circulating in a similar manner in the absence of any significant baroclinicity. The deepest observations of the Central water (Stations SSP1—5, 6, 8—10 and 13) show a trend towards the colder and slightly more saline character of the deeper Outer Gulf water which suggests that Outer Gulf water was the source for this water at some previous time. Again it appears that stations SSP1—1 and 2 were downstream as the deepest observations suggest the consequence of a vertical mixing between the deeper Central water and the upper layer water of Central and Inner Gulf characteristics and/or a horizontal mixing of deep Central water (SSP1—5 and 6) with Outer Gulf water from between 50 and 100 m depths. The deeper waters in the Outer Gulf do not appear to have been materially affected at the time of the cruise

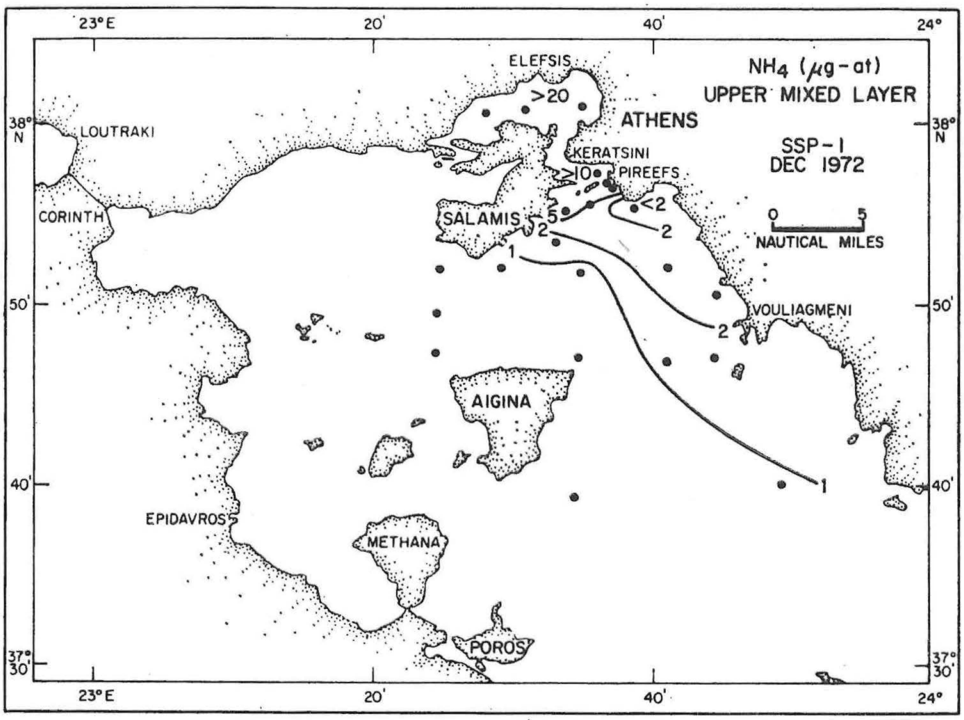

Fig. 11 — Distribution of NH_4 (µg at/L) in the upper mixed layer during Cruise SSP—1 (mid-December 1972).

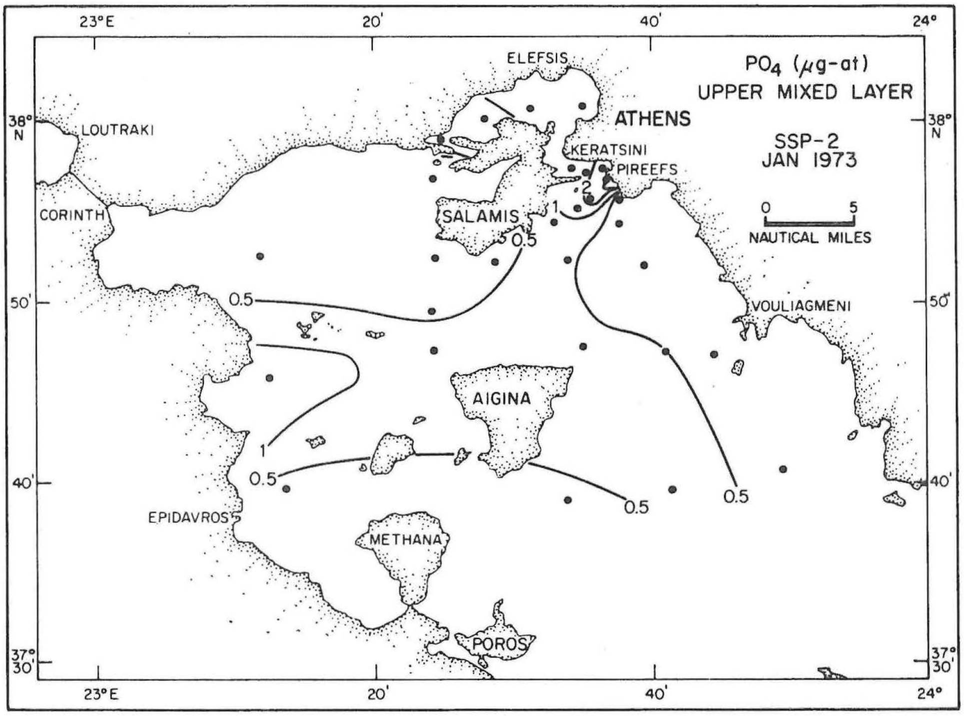

Fig. 12 — Distribution of PO_4 (μg at/L) in the upper mixed layer during Cruise SSP—2 (late January 1973).

by the intrusive layer, marked by the higher salinities at 126 m depth, found in the Outer Gulf water (SSP1—19 and 20).

In late January, the circulation appears to have been basically counterclockwise as demonstrated by the continuity of high nutrient values from Keratsini south into the Central water region north of Aigina. Upper layer water of the Outer Gulf was flowing in along the Attikis shore, as shown by the T-S characteristics of station SSP2 (Figure 8). However, in the Inner Gulf region the T-S characteristics indicate an upwelling was in progress, which was providing salt to the upper layers to raise the salinities of the Inner Gulf waters slightly above those of the other upper waters of the system. The continuity of the deeper waters in Figure 8 cannot be traced because the observations at stations SSP2-6 and 7 did not reach bottom but only to 65 m depth. However, the only possible source for the slightly higher salinities and hence densities on Inner Gulf water was the deeper (>50 m) more saline Outer Gulf water. Station SSP2-3 had a salinity of 38.34‰ at 108 m depth.

The upwelling appeared to be most influential in affecting the water properties in the middle Inner Gulf and toward the Salamis shore. Stations SSP2-13 and 15 and the deeper observations at SSP2-12, showed the most marked influence. The Central water in January occupied a smaller region than in December, as Inner Gulf water had moved in north of Aigina, and

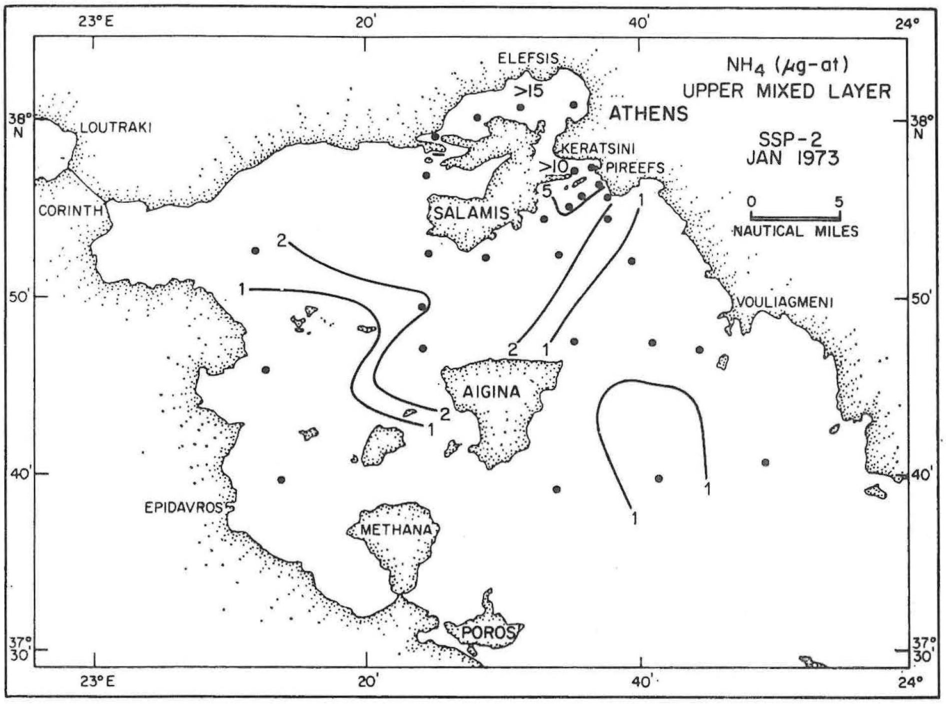

Fig. 13 — Distribution of NH_4 (µg at/L) in the upper mixed layer during Cruise SSP—2 (late January 1973).

both waters were moving out of the Gulf around Aigina. There was relatively little mixing occurring between them, rather, the denser Inner Gulf water was layered beneath the Central water. Station SSP2-8 showed Central water above 20 m depth and Inner Gulf water below (Figure 8). This feature, found at both SSP2-8 and 13 but more so in SSP2-8, provides good evidence of a circulation flowing south from Salamis and to the Outer Gulf via the eastern shore of Aigina.

The water properties of the western Gulf maintained an identity separate from those of the east, and hence the Western water appears to be somewhat isolated from the circulation in the eastern basin which might flush it with Aegean source water.

Tides are insignificant in Saronikos Gulf so that tidal mixing can be ignored. The only significant energy sources are the wind and the buoyancy flux which due to winter cooling and evaporation adds potential energy to the water columns. It is anticipated that the wind provides the major driving force for the circulation. An indication of the winds during SSP1 and SSP2 is given in Figure 14 from values taken from a meteorological station on the Piraeus Harbor jetty. Observations were recorded at 0800, 1400, and 2000 hours in Beaufort scale and to the nearest 22.5° in direction. They agree reasonably with those taken from shipboard during the stations occupations, which are also shown in Figure 14.

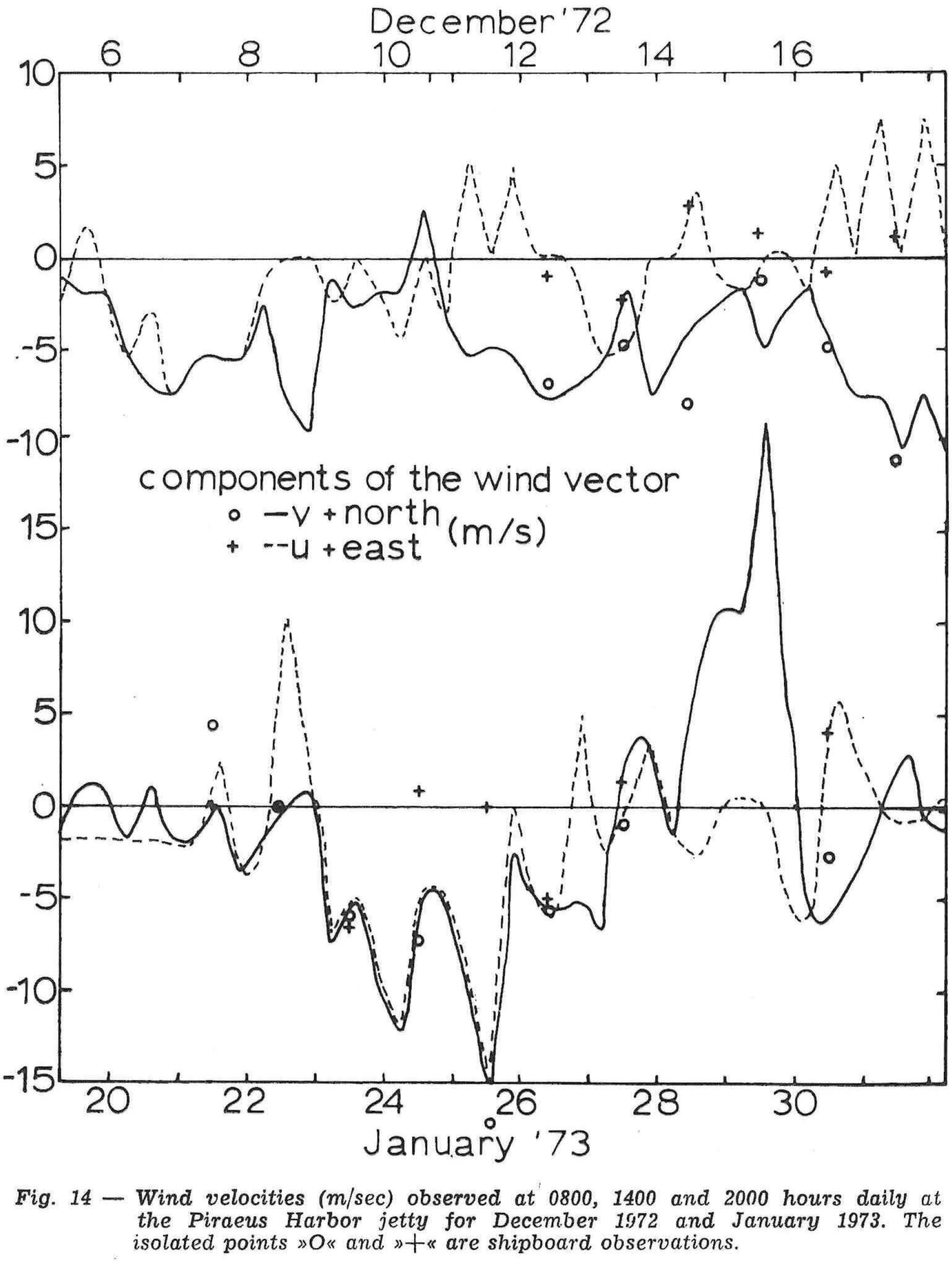

Fig. 14 — Wind velocities (m/sec) observed at 0800, 1400 and 2000 hours daily at the Piraeus Harbor jetty for December 1972 and January 1973. The isolated points »O« and »+« are shipboard observations.

The evidence thus far has shown that the circulation pattern during SSP2 had reversed from that during SSP1, and that horizontal circulation must be wind generated. Neither the wind record from the Piraeus Harbor nor from the station data show any marked difference in the wind regimes between the two cruises. The shipboard data indicate that during SSP-1 to 20 the average direction was from slightly west of north (350°) at an average speed of 5.1 m/sec; while during SSP2—3 to 24 the wind was definitely from east of north (40°) and stronger with an average speed of 8.7 m/sec. It is much clearer that the strong north easterlies could drive the counterclockwise circulation of January, than could the light north-westerlies drive the clockwise circulation of December. The Ekman transport under northeasterlies would cause a set-up along Salamis island and thereby drive a barotropic current south or southwest along Salamis. The possibility of upwelling along the Attikis coast exists with strong offshore winds; higher salinity (Outer Gulf) water was observed in the Inner Gulf during January. Further speculation about the relation between wind and circulation is not merited without more reliable data. It is clear, however, that the system could change modes fairly rapidly. For example, winds of 17 m/sec would drive approximately 40 cm/sec currents within 3 hours running downwind to 45° to the right of the wind, so that within 10 hours the surface water would have moved 10 km or half the length of the upper Saronikos. It is expected that winds blowing hard for more than a day would establish a characteristic circulation dependent on their strength and direction.

Elefsis and Keratsini

The water properties in Elefsis in both December and January reflected the effective isolation of the Bay from the upper Saronikos Gulf. For example, the water temperatures were 2°C colder than Inner Gulf water during SSP1 and 3°C colder during SSP2. Figure 15 shows the T-S characteristics of the Elefsis water during both cruises and its relationship with the adjacent waters.

The water columns in winter were nearly homogeneous, implying that vertical convection was actively in progress. Oxygen values in December ranged between 4.4 and 5.3 ml/L while in January oxygen values were 6.0 to 6.4 ml/L, suggesting more complete convection during January. The small variations were between stations and not vertically in the water column.

Examination of the T-S characteristics (Figure 15) shows vertical homogeniety and subtle horizontal gradients. The water columns in the west end of the bay were warmer (SSP1—21, SSP2—27) than those of the eastern end (SSP1—23, SSP2—25), and in December (SSP1) they were also slightly more saline.

The T-S characteristics of the stations in Keratsini, which connects the eastern end of Elefsis with the Inner Gulf, show a marked cooling and on the T-S plane demonstrate what must be an intimate connection between the warmer Inner Gulf water and the much colder Elefsis water. Further, during both cruises the water columns in Keratsini were also relatively well-mixed in the vertical but showed a horizontal gradient along the bay from colder in the west (near Elefsis) to warmer in the east (near the Inner Gulf). At SSP1—16, towards the east end, the surface water is characteristic of the

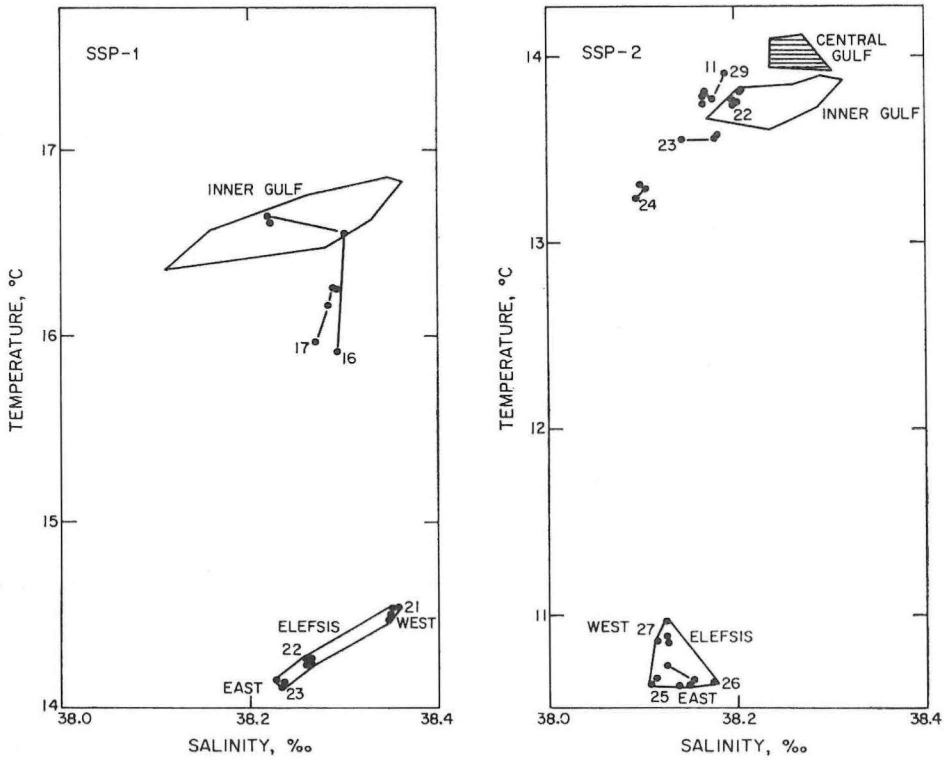

Fig. 15 — T-S diagram for Elefsis Bay and Inner Gulf water and stations from Keratsini and off the western Elefsis channel.

Inner Gulf, while the water below 20 m is cooler and exhibits the same properties as the entire column of SSP1—17 at the west end. The implication is that of cold water flowing from west to east in Keratsini and thus also in Elefsis. No stations were occupied off the western entrance to Elefsis during December but in January, station SSP2—29 showed no sign of cold water present; rather, the bottom (43 m) temperature was 13.9°C and, therefore, warmer than any water of the Inner Gulf and more like Central water.

Thus the evidence indicates a net circulation through Elefsis from west to east. Water entering through the west channel is warm Central water, which probably fills the area west of Salamis. Within Elefsis the water columns are progressively cooled as they move eastward. On entering Keratsini, the water mixes with resident Inner Gulf water as it moves through Keratsini and finally flows out the channels around Psitalia Island. However, the amounts of water circulating were sufficiently small and/or the mixing in Keratsini was sufficiently vigorous such that no traces of Elefsis water reached the station outside Keratsini.

An approximation of the eastward transport through Elefsis and Keratsini can be made from the temperature budget calculations in the two Bays during the December and January cruises. In this case the temperature can hardly be considered in steady state nor can it be treated as a conservative property. Further discussion regarding the latter is included below.

Since the only significant gradients lie along the axis of the Bays, the conservation of temperature can be approximated by

$$\frac{\delta\Theta}{\delta t} = -u\frac{\delta\Theta}{\delta x} + K_x\frac{\delta^2\Theta}{\delta x^2} + S \qquad (1)$$

where u is the vertically averaged velocity along the axis, Θ is the temperature, K_x the horizontal diffusion coefficient, and S the atmospheric source/sink term. Under the assumption that S, K_x and the volume transport are the same in both Bays, and using the observed temperature gradients (Table 1), the flow through the system can be estimated. That is, equation 1 becomes for Keratsini

$$-7.80 \times 10^{-7} = -1.42 \times 10^{-6}u_K + 2.10 \times 10^{-12}K_x + S \qquad (2)^*$$

and for Elefsis

$$-1.02 \times 10^{-6} = 5.79 \times 10^{-7}u_E - 9.24 \times 10^{-13}K_x + S \qquad (3)^*$$

Observing the ratios of the cross sectional areas (just east of the middle stations), we find that,

$$u_K = 4.5\ u_E \qquad (4)$$

Combining equations (2) and (3) and using (4), we obtain,

$$u_E = -0.4 + 4.3 \times 10^{-7}K_x$$

Table 1. Temperature gradients at Keratsini and in Elefsis Bay.

Keratsini		*Cruise SSP1* Sta.	Temp. (°C)	ΔX km	*Cruise SSP2* Sta.	Temp. (°C)	ΔX km
West end		17	16.12		24	13.28	
				1.9			2.0
Middle		16	16.37		23	13.56	
East end		18	16.59		21	13.74	
				2.1			1.7
$\frac{\Delta\Theta}{\Delta X}$	°C/cm		1.19×10^{-6}			1.65×10^{-6}	
$\frac{\Delta^2\Theta}{\Delta X^2}$	°C/cm		1.63×10^{-13}			4.04×10^{-12}	
$\frac{\Delta T}{\Delta t}$	°C/cm		-7.84×10^{-7}	(17,24)		-7.76×10^{-7}	(16,23)

* In (2) and (3), the heat diffusion term is taken to oppose the advective heat term.

Elefsis		Sta.	*Cruise SSP1* Temp. (°C)	ΔX km	Sta.	*Cruise SSP2* Temp. (°C)	ΔX km
West end		**21**	**14.50**		**27**	10.90	
				3.9			4.6
Middle		**22**	**14.25**		26	10.65	
				5.7			5.5
East end		**23**	**14.14**		25	10.63	
$\frac{\Delta\Theta}{\Delta X}$	°C/cm		**—6.15 x 10^7**			—5.43 x 10^7	
$\frac{\Delta^2\Theta}{\Delta X^2}$	°C/cm²		**8.43 x 10^{13}**			**1.0 x 10^{12}**	
$\frac{\Delta T}{\Delta t}$	°C/sec		—1.01 x 10^6	(21,27)		—1.02 x 10^6	(22,26)

It is assumed that the eddy diffusion coefficient varies with the horizontal size of the system, that is varyng from 10^5 cm²/sec for small (order, 1 km) systems to more than 10^8 cm²/sec for oceanic basin scales (Okubo and Ozmidov, 1970). Keratsini and Elefsis are small, having length and width dimensions of 5 by 1.5 and 16 by 4.5 km respectively. The curvature term is made less reliable by the eastern stations in both cases. In Elefsis the eastern station was perhaps off the axis of the flow, and in Keratsini the eastern station was the outfall stations. Using $K_x = 5 \cdot 10^5$ cm²/sec gives $u_E = 0.2$ cm/sec, $u_K = 0.8$ cm/sec and a volume transport of 240 m³/sec.

With this transport, Elefsis, with a volume of $13.5 \cdot 10^8$ m³, has a replacement time of approximately two months. The production of heavy water during winter and its passage through the deeper and wider eastern channel probably causes this flow. The winter flushing is fortunate in terms of evacuating the accumulation of nutrients built up previously. The mean NH_4 concentration was reduced from 11.6 to 7.5 μg at/L between mid-December and late January, likewise PO_4 was reduced from 0.88 to 0.38 μg at/L. During the same period, the oxygen concentration rose from 88 to 100 percent of saturation in December to 101 to 112 percent of saturation in January.

As for Keratsini, such a transport existing from Elefsis dwarfs by an order of magnitude the influxes of freshwater and heat due to the sewage outfall and the power plant discharges into Keratsini. Even so, Elefsis water as such was not observed outside Keratsini. However, the additions of contaminants associated with this water might be quite apparent as they occur naturally in much smaller concentrations in the outside waters.

Time Change and Budgets

The water masses of Saronikos Gulf changed temperature and salinity characteristics between mid-December and late January consistent with the meteorological conditions occurring during winter. Figure 16 shows the changes on the T-S planes and Table 2 summarizes the results.

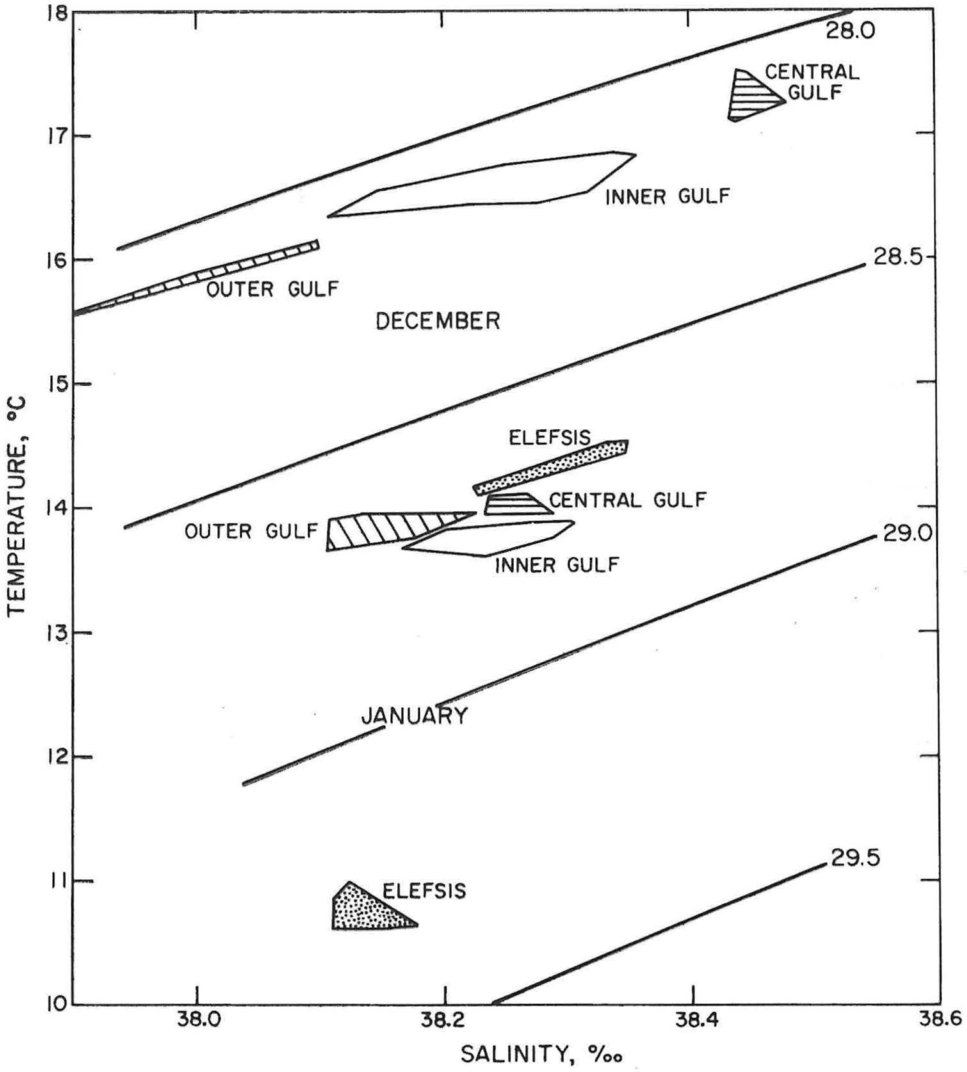

Fig. 16 — Summary T-S diagram of the upper 50 m water masses for December 1972 and January 1973.

The major change was loss of heat by all water masses. The source water (Outer Gulf) temperature change was the least (2°C), the greatest loss was observed in Elefsis (3.5°C), while the others showed intermediate values of change. This appears to be consistent with the volumes of water from which the heat was lost to the colder atmosphere. The source water is more or less continuously supplied from the Aegean Sea while Elefsis holds a small volume and has a restricted exchange with the outside. The correlation with depth is also obvious, as the surface water in deep stations will systematically approach the bottom water temperature as winter convection proceeds, while the water in shallow stations is not similarly restricted.

Table 2. Water mass characteristics (mean values for upper 50 m) of the Saronikos Gulf.

Water Mass	Cruise SSP1			Cruise SSP2			Change	
	Sta.	Temp. (°C)	Sal. (‰)	Sta.	Temp. (°C)	Sal. (‰)	△T	△S
Outer Gulf	19, 20	15.83	38.00	3, 7	13.87	38.16	—1.96	+0.16
Inner Gulf	1, 2, 7, 11—15, 18, 3— 6	16.60	38.25	13—21	13.78	38.25	—2.82	0
Central	8—10	17.30	38.45	9—12	14.06	38.26	—3.24	—0.19
Elefsis	21—23	14.28	38.28	25—27	10.71	38.14	—3.57	—0.14

The Elefsis and Central water masses both showed reductions in salinity (0.1 to 0.2‰) over the period, due to winter rainfall and proximity of these water masses to runoff from the surrounding land. The Inner Gulf water, even though also close to land, showed no salinity change. This could be because the source (Outer Gulf) water actually increased salinity (0.1 to 0.2‰), which through mixing, offset the dilution effect of the winter runoff.

In terms of heat, during the approximately 40-day interval between the two cruises, every regime lost heat to the atmosphere. The data are insufficient to resolve between the various losses, but some discussion on the net loss is possible. Since insignificant atmospheric temperature deviations over the area can be expected, the areas of warmer surface temperatures would suffer the greatest heat losses. This is particularly true for the sensible heat exchange as it is proportional to the sea surface temperature gradient. Elefsis Bay, being fairly shallow, is probably responsive enough to approach the mean atmospheric temperature, which was 9.12°C for the mid-December to end of January period. However, the deeper stations have another constraint. Their surface temperatures approach the deep water temperature, after which surface heat losses are manifested by a deepening of the convective layer.

To estimate the atmospheric heat loss Q_A in Elefsis, it can be considered to be the difference between the total heat loss (Q) and the advective heat gain (Q_{in}—Q_{out}).

$$Q_A = Q - (Q_{in} - Q_{out})$$

The Q was determined by taking the difference between the total calories in the Bay between the two cruises, or

$$Q = 0.955 \cdot \frac{\text{cal}}{{}^\circ\text{C cm}^3} \cdot \frac{(10.70 - 14.25)^\circ\text{C} \cdot 13.5 \cdot 10^{14}\ \text{cm}^3}{74.2 \cdot 10^{10}\ \text{cm}^2 \cdot 41\ \text{days}} = \frac{-150\ \text{cal}}{\text{cm}^2\ \text{day}}$$

The advective heat flux is given by,

$$Q_{adv} = \varrho CpV\Theta$$

where V = transport, cm^3/sec, and Θ the mean temperature over the period. V was taken as 240 m^3/sec. The temperature for Q_{out} was taken as the mean (12.5°C) of the mid-December (14.25°C) and late January (10.65°C) Elefsis temperatures, at the eastern station.

An estimate of the mean temperature of the inflow could not be obtained as simply as no stations were taken in the west channel during December. In January the mean temperature in the west channel (SSP2—28) was 11.3°C while outside the channel (SSP2—29) it was 13.8°C and at SSP2—27 in the Bay 10.9°C. It appears that the Central water outside feeding Elefsis had already lost about three-fourths of the temperature difference between outside and inside while transitting the tortuous, shallow west channel. That is, in January the temperature measured in the western channel was only 0.5°C warmer than Elefsis water whereas the temperature contrast between inside and outside was 3°C. It is estimated that the mean temperature of the inflow would have averaged between 0.5 and 1°C warmer than the mean temperature of Elefsis water for the period (12.5°C), and would have been in the range 13 to 13.5°C. Using a 1°C difference the calculation reveals that,

$$Q_{in} - Q_{out} = 0.955 \cdot \frac{\text{cal}}{\text{cm}^3\ {}^\circ\text{C}} \cdot \frac{(13.5 - 12.5)^\circ\text{C} \cdot 2.07 \cdot 10^{13}\ \text{cm}^3/\text{day}}{74.2 \cdot 10^{10}\ \text{cm}^2} = \frac{27\ \text{cal}}{\text{cm}^2/\text{day}};$$

thus giving an atmospheric loss for Elefsis of $\frac{-177\ \text{cal}}{\text{cm}^2/\text{day}}$

The average rate of heat loss from the other water masses over the period can be estimated from their respective temperature changes. The heat from the upper 50 m of Outer Gulf water was,

$$\frac{(15.83^\circ - 13.87^\circ) \cdot oCp \cdot 50\ \text{m})}{37\ \text{days}} = 253\ \text{cal/cm}^2/\text{day}$$

This figure is used as representative of the atmospheric heat loss in the comparisons with the Inner Gulf and Central water masses given below. Actually the Elefsis value of 177 may be more precise because of its topographic isolation from other water masses. Further studies will clarify this point.

The Inner Gulf and Central water showed even greater rates of heat loss. Using the temperature changes given in Table 2, Central water lost heat from the upper 50 m at a rate of 377 cal/cm²/day while the Inner Gulf heat loss rate was 328 cal/cm²/day.

As the Outer Gulf water comes from the Aegean and is in large supply, the heat loss amount would be less effected by advective loss from other parts of the Gulf. The heat loss values are sensitive to the choice of depth for the convective layer; 50 m was used based on the vertical structure of temperature and salinity (see Figures 4 and 5).

The losses for the Central and Inner Gulf waters were higher, implying an additional advective loss to the Outer Gulf water. Two corrections to the Inner Gulf value from the Elefsis Bay outflow and the cooling water discharge from the Public Power Plant in Keratsini are imposed. Using an outflow volume from Elefsis of 250 m^3/sec, a mean temperature difference of 2.65°C, and an Inner Gulf area of $1.5 \cdot 10^{12}\ cm^2$ gives an advective cooling of $\frac{36\ \text{cal}}{\text{cm}^2\ \text{day}}$; and using a thermal effluent volume of $19 \cdot 10^6 \cdot \frac{\text{cm}^3}{\text{sec}}$ at 10°C above ambient, and the same area gives an advective warming of $\frac{10\ \text{cal}}{\text{cm}^2\ \text{day}}$. Hence the net loss rate of Inner Gulf water is estimated at 302 $cal/cm^2/day$.

The average heat loss rates for both Inner Gulf and Central waters were significantly greater than can be accounted for by exchange to the atmosphere and the difference must have been removed by advection. The Outer Gulf water, which over the period averged a lower temperature (14.85°C) than Inner Gulf (15.2°C) and Central (15.7°) waters, must have acted as a heat sink and through mixing and recirculation advected heat out of the interior of the Gulf.

With the assumption that the advective heat losses of the Inner Gulf, and Central water masses came only from exchange with the Outer Gulf water, the volume exchanges necessary to generate the corresponding heat losses can be calculated. To use again the expression:

$$Q_{adv} = [\varrho CpV\Theta_{in} - \varrho pCpV\Theta_{out}] \cdot \text{area}$$

where V is the exchange volume per the 41 day interval. Table 3 gives the results, showing that the Inner Gulf water had more exchange with the Outer Gulf water than did the Central water. The choice of areas is critical; a result is shown in parenthesis for a Central water area equal to Inner Gulf area. It is important to point out that the areal extent of the Inner Gulf water increased and that of the Central water decreased during the period. Also, the exchange between these two waters will tend to increase the value for the amount of outer Gulf water exchange with the Inner Gulf water and decrease it for the Central water, because the Central water can lose heat from both Inner Gulf and Outer Gulf waters, whereas the Inner Gulf water can lose heat only to the Outer Gulf and gains heat from the Central water. A transport of 2500 m^3/sec entering half the cross-section between Aigina and Attikis would give a mean speed of 1.5 cm/sec.

Table 3. Advected heat loss for December 1972 and January 1973 in the Saronikos Gulf.

Water Mass	Temp. (°C)	Heat Loss ($cal/cm^2/day$)			Area ($X\ 10^{12}\ cm^2$)	Trans. (m^3/sec)
Outer Gulf	14.85	250	250			
Inner Gulf	15.2	300	250	50	1.5	2597
Central	15.7	380	250	130	0.8	1480
					(1.5)	(2780)

In terms of salt, the mean salinity of Elefsis was reduced over the period from 38.28‰ to 38.14‰, which must have been due to the excess of rainfall and runoff over evaporation. The mass of freshwater addition was calculated as:

$$FW\,(g) = [\varrho_2 \cdot (1 - 10^3\,S_2) - \varrho_1 \cdot (1 - 10^3\,S_1)] \cdot \text{volume}$$

where ϱ and S are mean values of density and salinity, respectively, at the times of SSP1 and SSP2. The calculation gave $FW = 1.2 \cdot 10^{12}$ g which is equivalent to a net direct rainfall to the Bay (area of $7.4 \cdot 10^{11}\,cm^2$) over the period of 1.6 cm. This value is well below actual rainfall for the period (about 6 cm for Elefsis), and does not include any additions due to runoff from the drainage basin. This strongly suggests evaporation as an important process in the air-sea exchange. If this is true, then a good portion of the atmospheric heat loss must come from evaporation. For example, the evaporation of 5 cm of water would provide for 25 percent of the Elefsis Bay heat loss. Elefsis Bay presents an excellent opportunity for determining both mass and heat budgets precisely on the accumulation of more environmental data.

SUMMARY AND CONCLUSIONS

Source water to Saronikos Gulf is provided from the Aegean Sea, and water of appropriate characteristics (temperature 14.75°C, salinity 38.8‰) was always found at 200 m depth in the Outer Gulf. In December, above the Aegean water, an intrusive layer with a small temperature maximum (> 16°C at 100 m) was observed but was not present in January when the upper layer water (~ 80 m) graded regularly into Aegean water. Waters inside the Gulf were not directly affected by water below approximately 100 m depth from outside.

During winter at least, the upper 50 m of the water column is essentially isothermal and isohaline. Under such homogeneous conditions, energy inputs primarily from the wind readily excite vertical convection, as evidenced by the frequent neutral or unstable surface density gradients. The depth of the convective layer had deepened by January, as the deeper (70 to 90 m) water columns of the Gulf which were stratified below 50 m in the December were mixed to the bottom.

In December, horizontal ranges were 15.5 to 17.5°C and 38.0 to 38.5‰, with the exception of the relatively isolated Elefsis Bay which was always colder by 3°C and denser by $0.5\sigma_t$ units. In January the horizontal salinity range had narrowed to between 38.1 and 38.3‰, no net change in salt content had occurred, and the temperature range had narrowed to between 13.6 and 14.2°C, a cooling of 2.5°C.

Five water masses in the upper layer based on subtle but distinct differences in T-S characteristics were distinguished:

Outer Gulf water provides the source water to the upper layer and was the least saline in both December and January. In December it was also the coolest (with the exception of Elefsis water) but in January Inner Gulf water was slightly cooler.

Inner Gulf water occupied the head of Saronikos Gulf, and was, therefore, both connected with Elefsis Bay via Keratsini Bay, the major port of Athens, and was the recipient of pollutants from the sewage and power plant cooling water outfalls. In December, Inner Gulf water was an approximately 50 to 50 mixture of Outer Gulf and Central waters. In January, upwelling in the area made Inner Gulf water slightly more saline and slightly (0.1 σ_t unit) denser.

Central water, the warmest water in Saronikos Gulf, occupied the area between Salamis and Aigina. These islands affect separation of the Gulf into an eastern and western portion and Central water probably extended throughout the western portion to the west of Salamis though no observations were made there. This water is residual from the previous summer. It was the most saline in December, but Inner Gulf water was slightly more saline in January.

Elefsis Bay water was much colder than the other water masses, being 14.3°C in December and 10.7°C in January, while the salinity was reduced from 38.28‰ to 38.14‰.

Western basin water, above the 80 m sill depth between Aigina and the Methanon Peninsula, was essentially the same as Outer Gulf water. Deeper than 80 m temperature and salinities approach unique values of 14°C and 38.6‰, demonstrating the isolation of this deep basin.

Circulation in the Saronikos Gulf was interpreted from distribution of PO_4 and NH_4, both added at point sources in Keratsini, and the T-S characteristics. The western portion of the Gulf appeared to be less active than the eastern portion. In December circulation in the eastern portion was clockwise, with Outer Gulf water entering toward the western (Aigina) side, mixing with Central water to form the water of the Inner Gulf, and outflow was along the Attikis Peninsula. In January, circulation was counterclockwise with Outer Gulf water entering along Attikis. There was evidence for some upwelling in the northern part of Saronikos proper and towards Salamis. The Inner Gulf water was exciting around the east side of Aigina together with but underneath Central water. The winds observed during both cruises were northerly with only small differences in average directions and speeds, and the cause for the basically different circulation modes awaits further research.

Elefsis Bay contained enormously high concentrations of PO_4 and NH_4, and was slightly undersaturated in O_2 (90 to 100 percent) in December and slightly supersaturated (100 to 110 percent) in January. There was a net circulation from west to east judging from a mean transport of 240 m^3/sec estimated from the longitudinal gradients and curvatures of temperatures in Keratsini and Elefsis. The transport would provide an approximate renewal time for Elefsis of two months, and was sufficient to reduce the nutrient concentrations by one-half over the 41 day period between cruises.

A heat budget calculation for Elefsis gave a mean atmospheric heat loss over the 41 days of about 180 cal/cm^2/day. The atmospheric heat loss of Outer Gulf water was about 250 cal/cm^2/day, but that from Inner Gulf and Central waters was significantly greater. The difference was removed from the Gulf by advection, with Outer Gulf water serving as a heat sink. Calculations suggested the advected heat loss could have been accomplished by an exchange transport of 2500 m^3/sec between the Outer Gulf water and either the Central or Inner Gulf water.

The observed salinity reduction in Elefsis showed an admixture of freshwater equivalent to 2 cm of direct rainfall. The discrepancy between this and the actual rainfall of 6 cm suggests the importance of evaporation.

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VODENE MASE ZALJEVA SARONIKOS U ZIMSKOM RAZDOBLJU

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KRATAK SADRŽAJ

Analiziran je materijal prikupljan na dva zimska krstarenja. U zaljevu se do dubine od najmanje 50 m pojavljuje u osnovi izotermni i izohalini sloj. Vjetar uslovljuje vertikalnu konvekciju, a dubina konvektivnog sloja se je u siječnju spustila u odnosu na prosinac. U prosincu su se temperature kretale od 15.5 do 17.5°C, a salinitet od 38.0 do 38.5, uz iznimku zaljeva Elefsis, koji je bio hladniji. U siječnju se je salinitet malo promijenio, a temperature su se kretale od 13.6 do 14.2°C.

Na osnovu T-S karakteristika određeno je 5 tipova vode u gornjem sloju: vanjska zaljevska voda, unutarnja zaljevska voda, središnja voda, voda zaljeva Elefsis i voda zapadnog bazena.

Cirkulacija je određena na osnovu raspodjele PO_4 i NH_4, te T-S karakteristika. Čini se, da je u zapadnom dijelu zaljeva strujanje slabije nego u istočnom. U prosincu je u istočnom dijelu zaljeva cirkulacija bila anticiklonalna uz prodor vanjsko zaljevske vode prema zapadnoj strani uz miješanje sa središnjom vodom i formiranjem unutarnjo zaljevske vode. Izlazna struja teče uzduž poluotoka Attikis. Uočeno je uzdizanje vode (upwelling) u sjevernom dijelu zaljeva i prema Salamisu (Salamini).

Longitudinalni gradijenti temperature su poslužili za određivanje srednjeg neto transporta, pa je preliminarno izračunata i brzina izmjene vode u zaljevu Elefsis. Izmjena se izvrši u dva mjeseca, što je dovoljno da smanji koncentraciju hranjivih soli na polovinu u 41 danu između dva krstarenja.

Izračunat je toplinski budžet za zaljev Elefsis. Proračun pokazuje da je gubitak topline advekcijom tolik, da se između vanjskog i unutarnjeg dijela zaljeva može pretpostaviti transport vode od 2500 m^3/sek. Odnos između promjena saliniteta i količine kiše pokazuje da je evaporacija značajna.