STUDIES OF WINTER SINKING OF COLD WATER IN THE AEGEAN SEA

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Introduction.

The influence of winter conditions of cooling and surface mixing are strongest in the northeastern portions of the Mediterranean where continental seasons affect the water to a

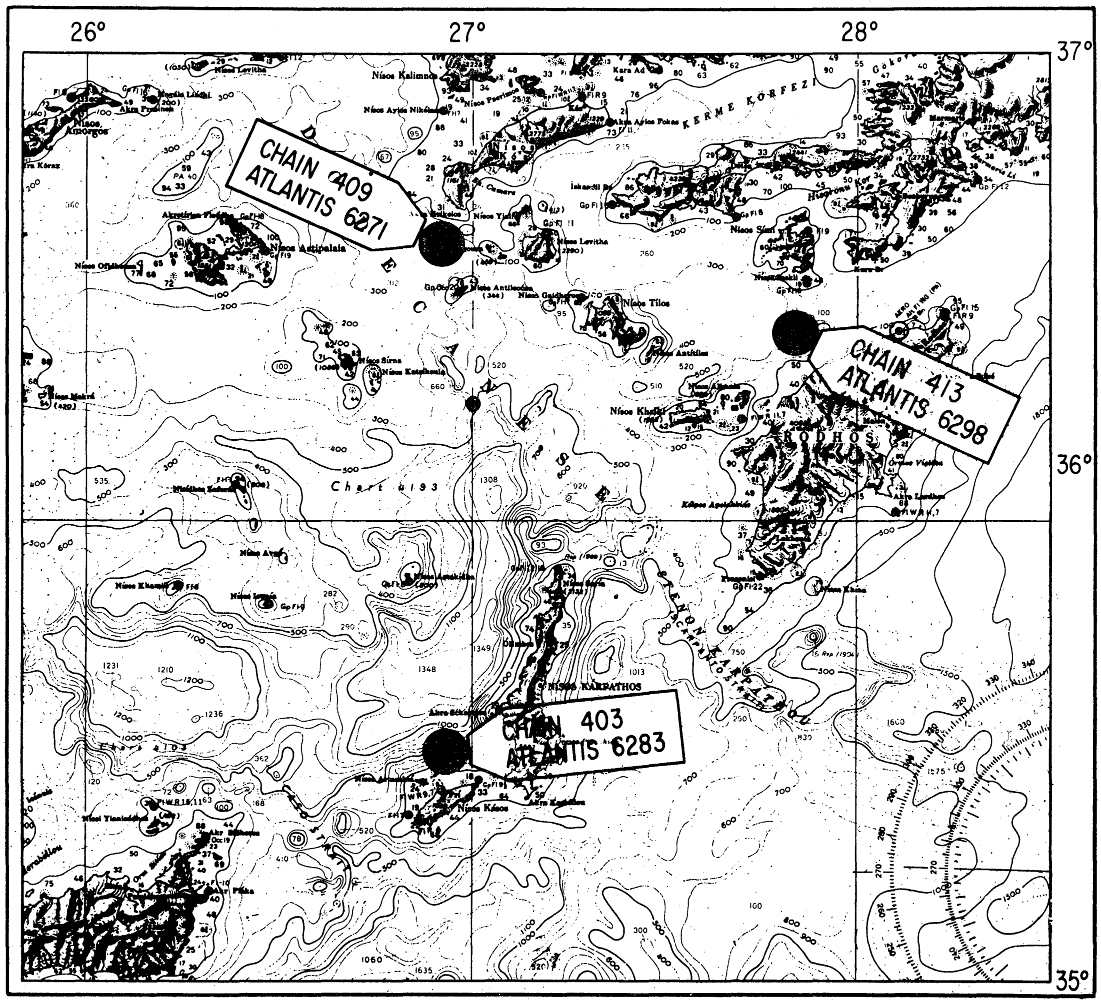

Fig. 1. — *Positions of hydrographic stations in fall by « Chain » (*403, 409 *and* 413*) and spring by « Atlantis » (*6271, 6283 *and* 6298*).*

greater extent than in the western Mediterranean. To study the effect of winter it becomes necessary to select a basin area which is both somewhat isolated from the rest of the Mediterranean and yet has maximum temperature changes from summer to winter. By being partially isolated, changes can occur more rapidly without damping by the remainder of the ocean. The resulting water exchange with the rest of the Mediterranean presumably can then be studied in the region of the straits connecting them.

The Aegean and the Adriatic Seas fulfill these requirements reasonably well with the former being more statisfactory as it connects with the Mediterranean through straits which are small relative to the area of the Aegean basin itself. Current measurements made of the inflow or outflow through the straits are somewhat simplified because of the smaller area. The Aegean basin is very roughly 2×10^5 km^2 which is about one tenth the area of the Mediterranean. There are three major straits connecting it : Andikithira Channel in the southwestern boundary of the Aegan having a sill over 700 m deep about 2 miles wide and a portion of the channel which is 550 m deep about 6 miles wide; Caso strait, with a sill over 350 m about 12 miles wide in the southern boundary; and Scarpanto Strait having a sill over 550 m deep about 5 miles wide in the southeastern boundary. Since Scarpanto Strait was the furtherest east and might be most influenced by the continental effect, the work discussed here was done in this area.

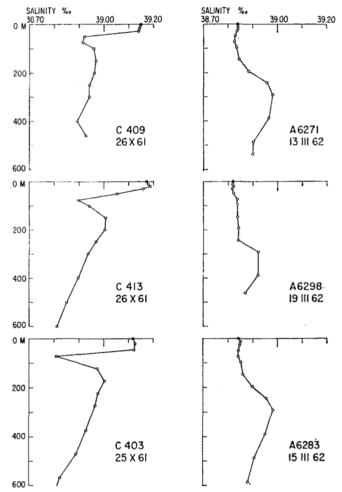

FIGURE 3. Salinity curves for fall 1961 (left column) and spring 1962 (right column)

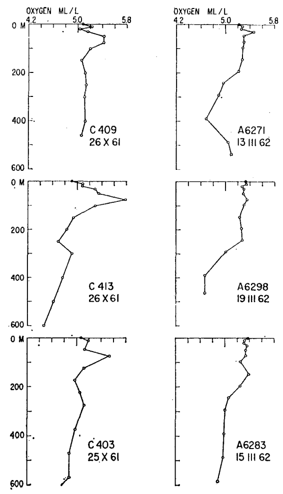

FIGURE 4. Oxygen curves for fall 1961 (left column) and spring 1962 (right column)

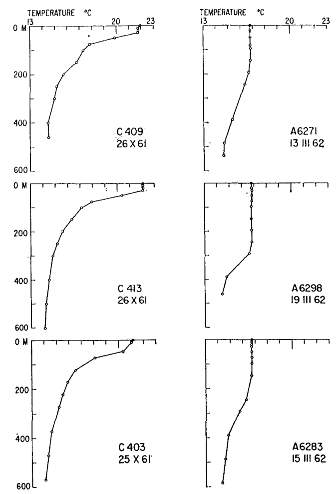

FIGURE 2. Temperature curves for fall 1961 (left column) and spring 1962 (right column)

FIGURES 2, 3, 4.

Hydrographic stations.

Hydrographic stations were made in the fall of 1961 by « Chain » in the southern Aegean and again in the spring of 1962 by « Atlantis ». The changes brought about by winter in the upper portion of the water layer may be seen in contrasting the stations. Figure 1 shows three areas picked to represent the southern Aegean where hydrographic stations were made. The temperature, salinity, and oxygen curves of these stations are typical of most of the « Atlantis » and « Chain » stations.

Figure 2 shows temperature curves for the three areas both in fall and spring. During the fall (october 1961) the strong thermal gradient produced by summer heating exists between 30 m - 100 m. Above 30 m the wind mixed layer is nearly isothermal. Apparently the summer period is only long enough to produce a layer approximately 30 m deep. After October the layer would generally lose heat and the gradient would relax through the winter to the condition seen in the spring (March 1962) temperature curves. Here the gradient has completely disappeared, and a mixed layer extends down to 200 m or more, being nearly isothermal. Below the mixed layer a weak gradient exists to about 400 m The water in the layer between 200 m to 400 m is warmer in spring than in the fall because of strong mixing down to 400 m by winter winds.

Figure 3 shows salinity for the same areas as figure 2. The highly saline water produced by evaporation during the summer in the mixed layer is very evident. Below is a strong halocline then a salinity minimum of nearly 0.3 ‰ less than the mixed layer. Below the minimum a smaller submaximum occurs at about 175 m. The March curves show that during the winter the upper isohaline layer has disappeared as well as the submaximum at 150 m. An approximately isohaline layer of 38.84 ‰ extends down to nearly 200 m. Below this layer a maximum

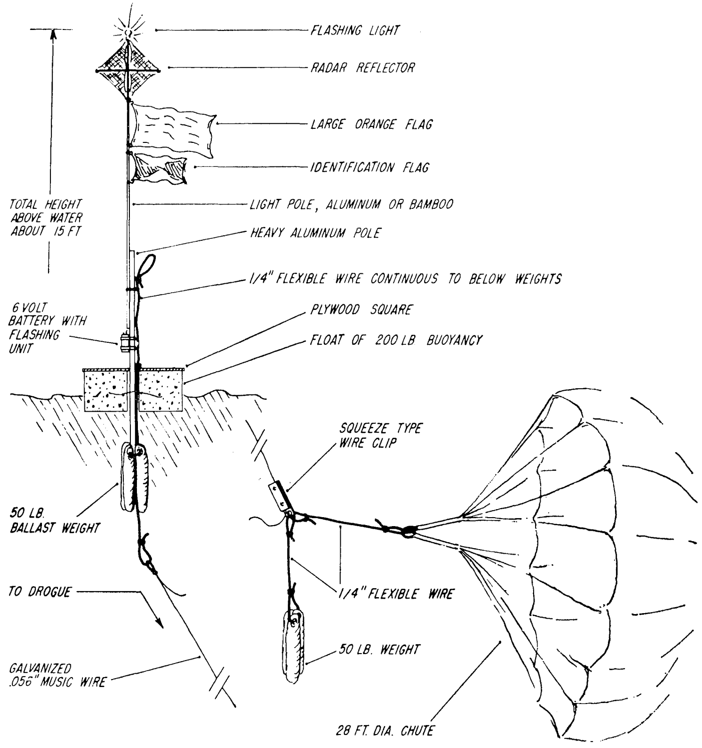

FIG. 5. — *Construction of drogue.*

occurs between 160 m and 350 m. Winter cooling, having relaxed the strong thermocline shown in figure 2, allows the high salinity layer produced during the summer to sink. In a similar manner the summer salinity submaximum also must sink slightly. Thus a source of cold, high salinity water exists during the winter which seems to sink to the depth of the spring maximum between 160 m - 350 m. This depth may be partially a function of the sill depth of the strait which would allow outflow of this water into the rest of the Mediterranean.

Figure 4 gives the dissolved oxygen curves indicating an oxygen maximum just below the mixed layer in the fall. The high salinity of the mixed layer may lower the oxygen saturation value in the mixed layer enough to create this condition. Below the oxygen maximum the concentration drops slightly to 600 m. In spring a well mixed layer of 5.30 ml/l water extends down to 200 m - 300 m.

The temperature, salinity, and oxygen curves all seem to indicate the sinking of cold surface water to depths of 200 m - 300 m during winter months. It was felt that exchange through the straits could be measurable at these depths by making direct current measurements.

Current measurements.

During March 11 to 18 several parachute drogues were released, the first group being set about 30 miles northwest of Scarpanto Strait and then a second group in the strait itself. The drogues were set first at depths of 200 m, then at depths down to 600 m. When using drogues the principale is to set in the water an open ballasted parachute at some desired depth which is controlled by the amount of wire upon which it is suspended. It is supported by a small surface float upon which are mounted marker flags, radar reflector, and light. A diagram is shown in figure 5. Because of the constant strain and chafing the drogue is best supported completely by flexible steel wire, and from the diagram it may be seen that all ballast weights, parachute, and connecting lines are wire. The chances of losing the parachute from the system

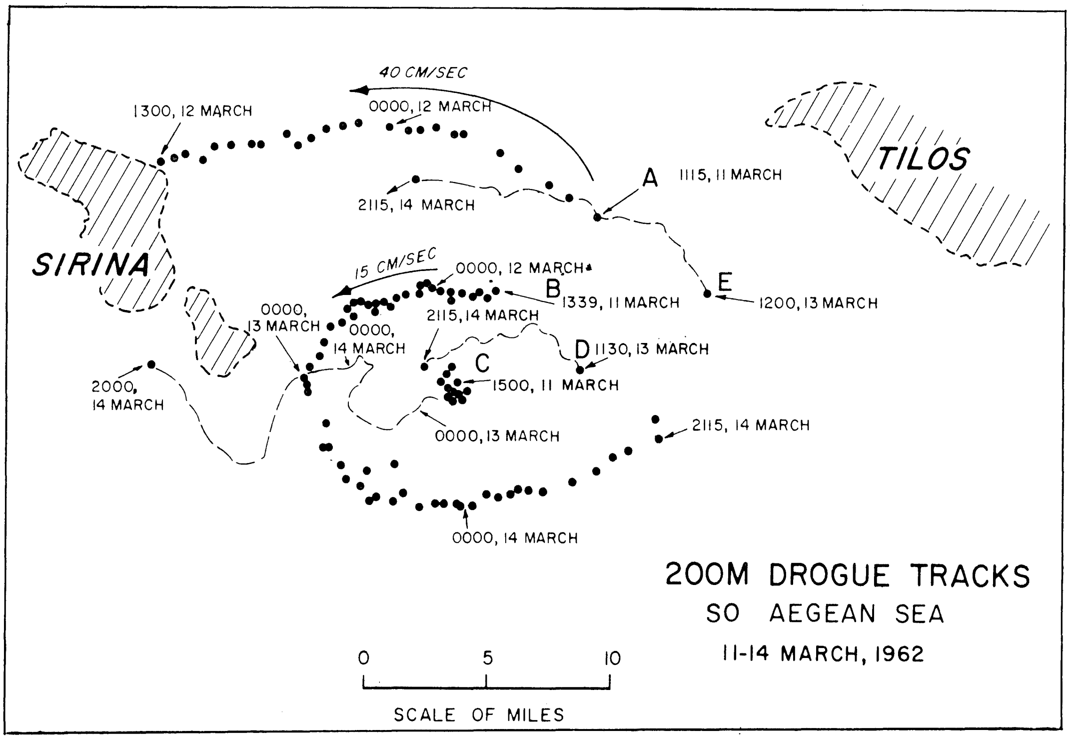

FIG. 5. — *Drogue tracks between Sirina and Tilos.*

must be a minimum, and it is sometimes difficult to tell from the float movements whether it is still attached. After a tracking period of several days the float should always be retrieved to determine by the strain on the wire if the parachute is still attached and filled. It is important that the area of the drogue be large relative to that of the surface float (about 100 : 1) to present the drag of surface wind or current from giving a bias to the track. In making measurements of this type in regions where turbulent flow might exist and small changes in the direction of the track are important, it is necessary first, to have extremely accurate navigation such as Decca, Loran C, or radar if a large fixed target for a point of reference is available. The islands in the Aegean Sea make especially suitable radar targets because of their height and sheer walls and were picked up by radar up to 80 miles away during this work.

Secondly, a drogue should be monitored for a reasonable length of time (2 - 3 days or more) to allow it to describe a flow with some detail. Cnecks of position have to be made about once an hour. Thirdly, some idea of the movement of the surface water and wind should be known to determine its effect on the surface float. It is, of course, preferable to have a steady flow at the surface as shear between the float and drogue are necessary to keep the parachute filled.

The tracks of the first group of drogues all set at a depth of 200 m is shown in figure 6. Drogues A, B, and C were set on 11 March between Sirina and Tilos, tne shoal areas of which are enclosed by a dashed line. Drogue A moved first northwestward and then westward with an average speed of approximately 40 cm/s finally grounding on Sirina at 1300 12 March. During this period B moved westward at approximately 15 cm/s then turned south during 13 March and east during 14 March, thus nearly completing a loop. C remained approximately motionless until 13 March then moved generally westward. The three drogues described what suggests a large gyre rotating counterclockwise with a nearly motionless center and a rapidly moving outer edge. Drogue D and E were placed in tne same area on 13 March, D moving

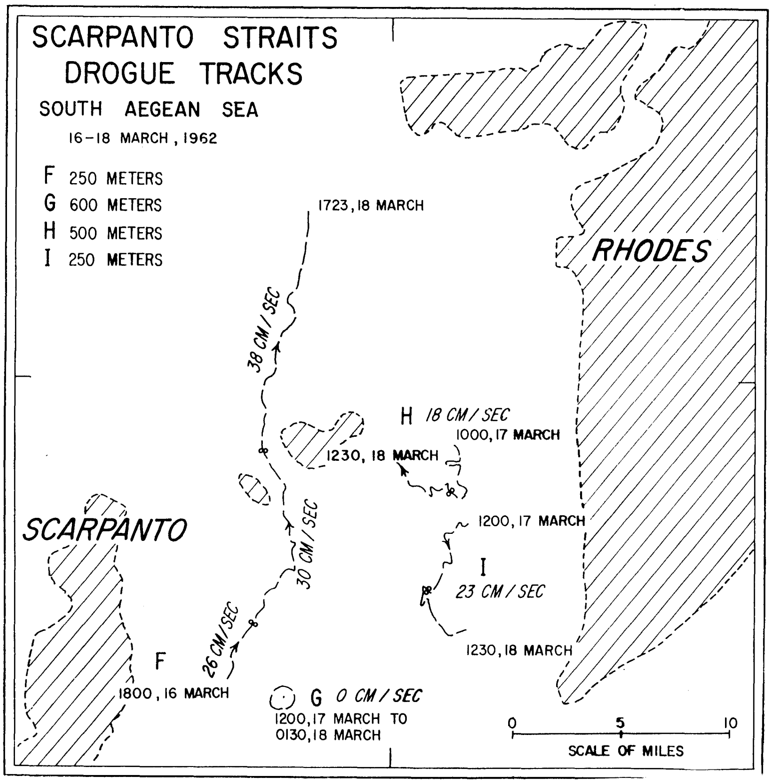

FIG. 7. — *Drogue tracks in Scarpanto strait.*

generally westward at 12 cm/s and E northwestward and then westward at 22 cm/s. The latter two drogues also lend to the picture of a gyre. At the rate of movement of B the gyre would complete a revolution in about 5 days. The wind was light on 11 Marcn and then from the southeast from force 3 - 5 through 14 March.

From 16 — 18 March four drogues were placed in Scarpanto Strait as shown in figure 7. Drogue F, 250 m, placed on 16 March moved north northeastward then more northly on 18 March, first averaging about 30 cm/s then 38 cm/s. Drogue G. 600 m, set on 17 March showed almost no movement through 0130 18 March. H, 500 m, set on 17 March averaged 18 cm/s in a small clockwise gyre about two miles in diameter. I, 250 m, placed on 17 March moved about 23 cm/s generally toward the south until 18 March.

Conclusion.

The drogues placed between Tilos and Sirina being at 200 m were approximately at the base of the mixed layer and could have been influenced by surface currents produced by the wind. Because of their relatively high velocities (up to 40 cm/s) it seems possible that horizontal mixing of sinking cold water could occur in a time scale of two or three days for the area bounded by Rhodes, Tilos, and Sirina. It is also possible that strong horizontal density gradients would be produced by the sinking and thus account for the high velocities of currents. Local sinking might have produced the large eddy between Tilos and Sirina described here. None of the 200 m drogues showed a tendency to flow out of either Scarpanto or Caso Strait. Drogue F at 250 m in Scarpanto Strait indicated a flow into Aegean basin through the strait. Only drogue I indicated an outflow. It is felt that mixing by means of horizontal eddies of sizes from 2 — 3 miles across to 12 — 15 miles across is an order of magnitude higher in velocity than any mean translation out of the Aegean basins of the cold water formed in the winter. A tracking period of 4 to 5 weeks might be necessary to observe such a translation. The use of drogues for such a study could be combined with north-south hydrographic sections although some caution would be required in interpreting the hydrographic sections since the horizontal velocities of the mixed layer are high.

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