The Upper Layer Circulation of the Whole Mediterranean

by

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INTRODUCTION

Using climatological wind stress estimates, numerical simulations of the circulation of the eastern and western basins of the Mediterranean Sea have been performed. Because the two basins are effectively seperated at the Strait of Sicily models were run independently for each area.

FORCING FIELDS

Both models were primarily forced with climatological wind stresses obtained from twenty years of ship observations in the Mediterranean (May, 1982). Individual stress estimates were made using a quadratic aerodynamic drag law with a drag coefficient that depended on the wind speed and the stability. Monthly averages of the wind stresses were calculated by averaging the individual wind stress estimates from each month on a one degree latitude by one degree longitude grid. Spacial and temporal smoothing of the stress fields give a reasonable estimate of the annual stress cycle over the entire Mediterranean. Figure 1 shows the annually averaged wind stress field over the region.

WESTERN MEDITERRANEAN

The reduced gravity model of Hurlburt and Thompson (1980) has been adapted to the western Mediterranean basin. It may be viewed as a two-layer model with an infinitely deep lower layer which is at rest. The model retains non-linear advective terms, horizontal viscous terms, and a variable Coriolis parameter while ignoring bottom topography. For the western Mediterranean the model used an upper layer depth of 200 m with 21.4 km east-west and 18.6 km north-south grid spacing. A time step of 30 minutes and a spin-up period of 30 days were used with most simulations. The Strait of Gibraltar is modeled as a port where flow is specified as a boundary condition, while the Strait of Sicily is an open boundary where the flow is sufficient to conserve mass in the western basin. Three classes of experiments were carried out: (1) forcing by wind stresses only, (2) forcing by Strait of Gibraltar inflow only, and (3) combined wind stress and inflow forcing. Interface deviations (streamfunctions) for the three cases are shown in Figures 2-4 after model runs of approximately five years acheived nominal steady-state.

The results show that the combined forcing produces realistic flow patterns in the western Mediterranean Sea. Currents along the northern coast of the African continent, a large cyclonic gyre southwest of the Golfe du Lion, and a smaller cyclonic feature in the Tyrhennian Sea are features which appear in the model. Historical studies by Ovchinnikov (1966) show remarkably similar patterns in the surface circulation of the region.

EASTERN MEDITERRANEAN

Numerical simulations of the eastern Mediterranean were performed on the rectangular region shown in Figure 5. The two-layer rigid lid model of Holland and Lin (1975) was adapted to the actual topography for the region, and was run on a finite difference grid with 23 km by 18.5 km grid spacing. The model variables are the two layer thicknesses, h1(x,y,t) and h2(x,y,t) with h1 + h2 = H(x,y), the depth of the basin. Top layer transport is integrated forward in time from the Navier-Stokes equations on a beta-plane while bottom layer transport is obtained from a mass transport streamfunction relation. This formulation removes surface gravity waves whose presence would otherwise restrict the timestep to unreasonably small values. The mass transport streamfunction obeys a second order elliptic equation which is solved directly by the method of Madala (1978). Initial conditions for the time integrations are V1=V2=0 and h1=250m. Land areas are defined by setting V1=0 wherever H(x,y) is less than 300 m. The advantages of this heuristically motivated procedure is that it eliminates the need for extra storage for a capacitive matrix solution and the need to integrate separately the circulation around each island. The disadvantage is that it introduces an approximation of indeterminate accuracy in the results for V2 (Setting both V1 and V2 to zero on land areas results in accumulation of mass which violates the rigid lid condition). A no-normal-flow condition on the rectangular boundary results in enclosed circulation. The model was spun-up from rest by gradually imposing the wind stresses over a fourteen day period.

As the integration proceeds, two counter-rotating gyres become evident: an anticyclonic gyre in the Ionian Sea and a cyclonic gyre in the Levantine basin south of Crete. A smaller cyclonic circulation feature is encirles Cyprus. These features weaken by day 700 and then reform around day 950 (shown in Figures 6 and 7). By day 1500, the extent of the simulation, the circulation around Cyprus has intensified while the two gyres to the west have weakened and broken up.

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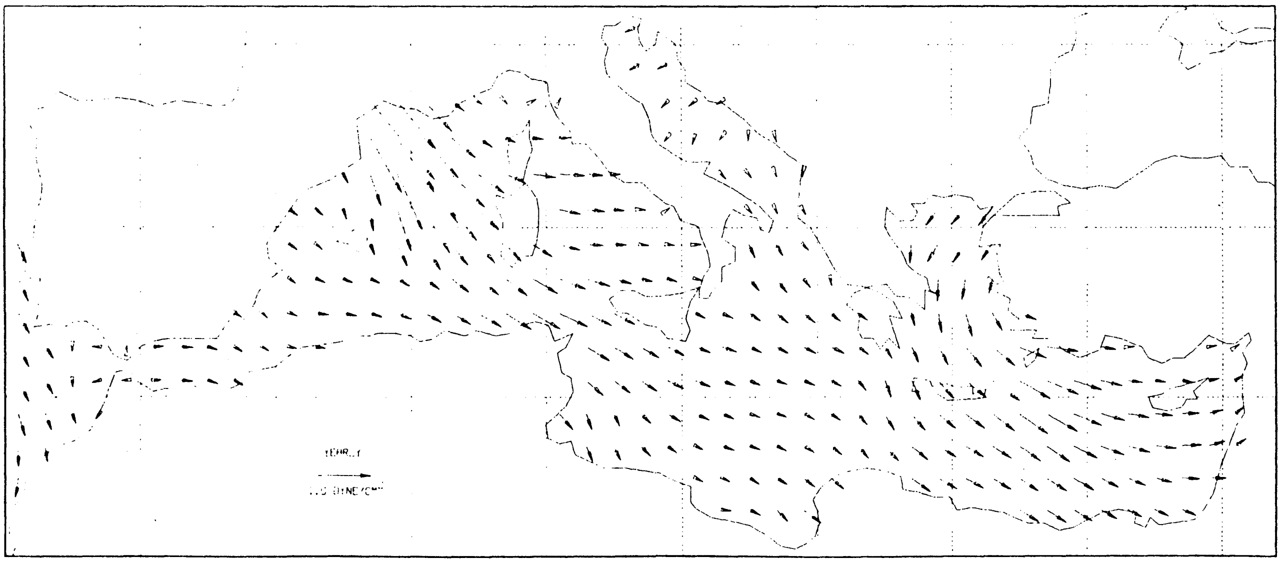

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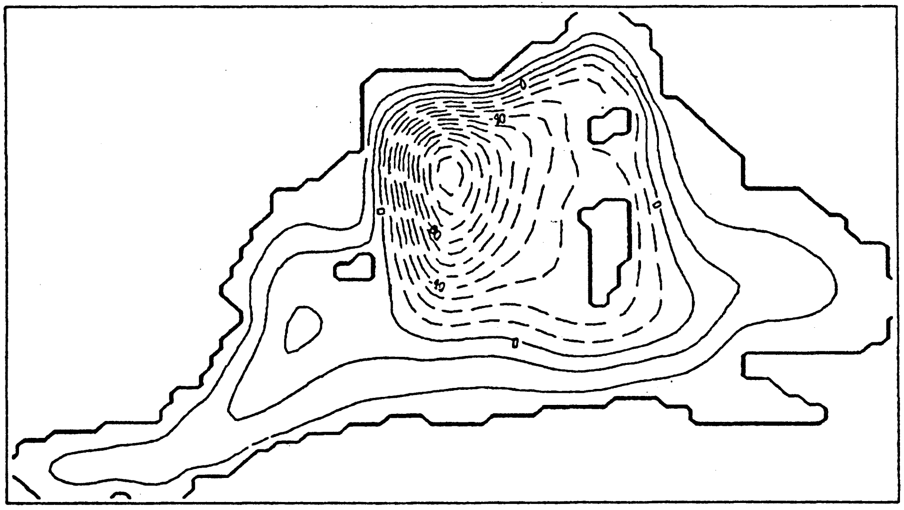

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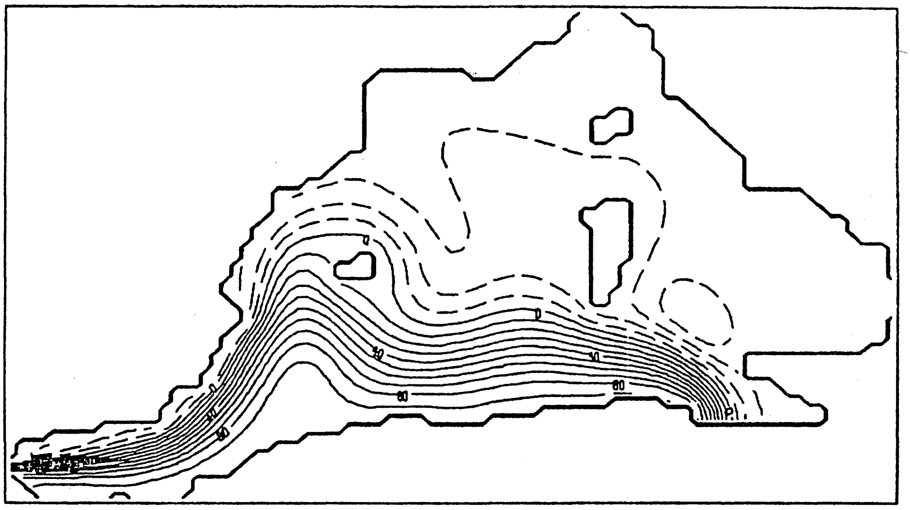

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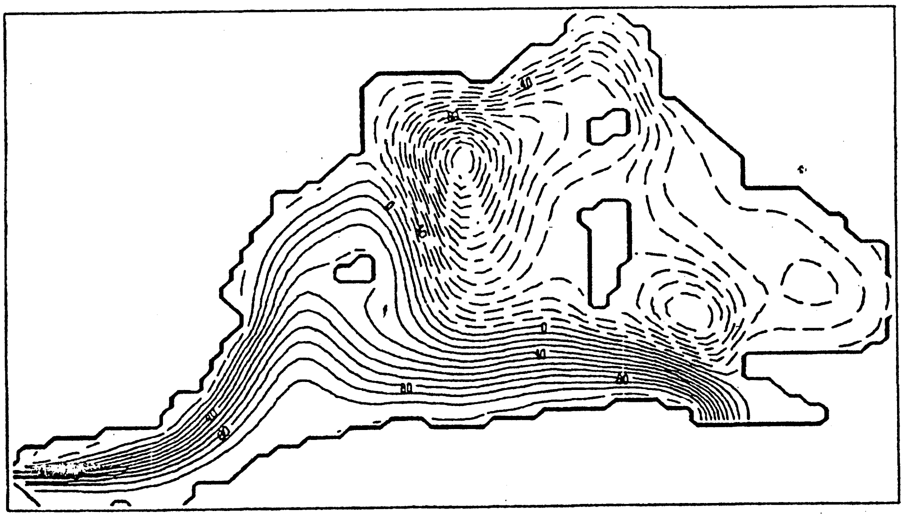

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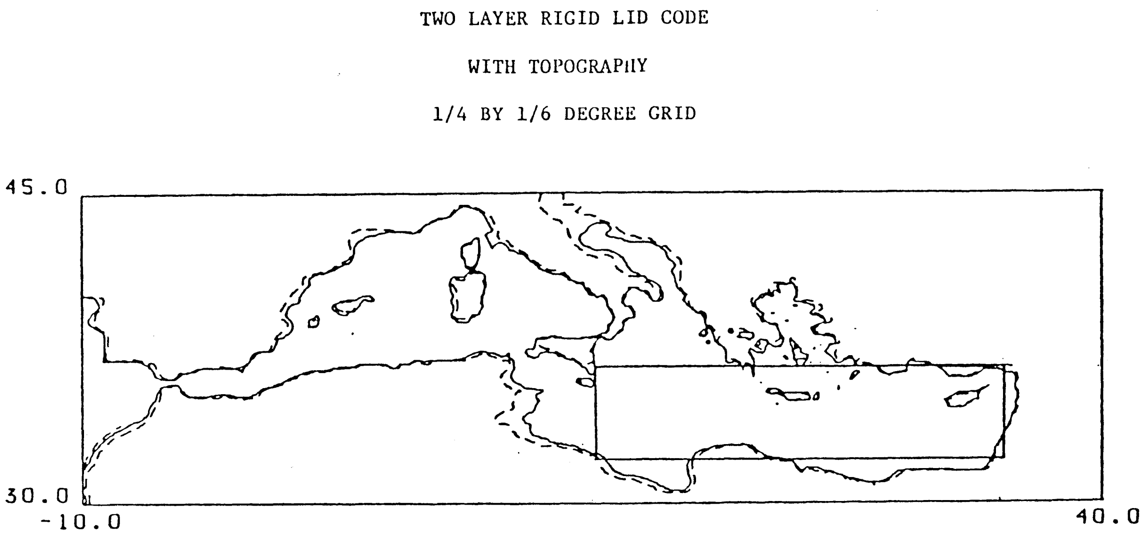

Boundaries used to simulate eastern Mediterranean circulation.

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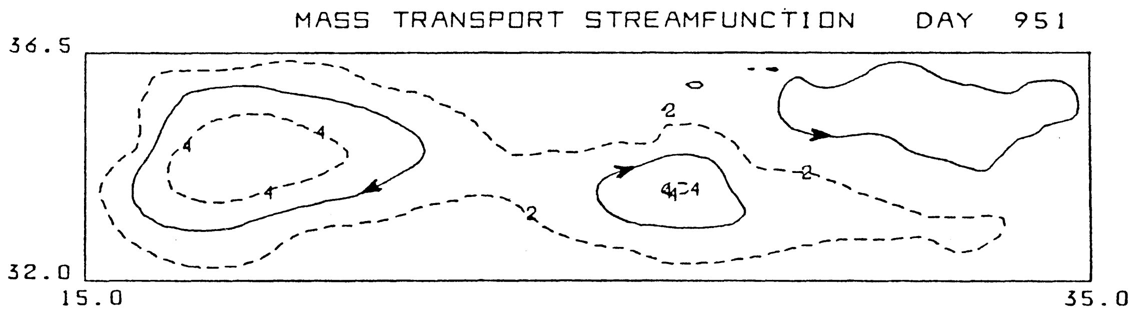

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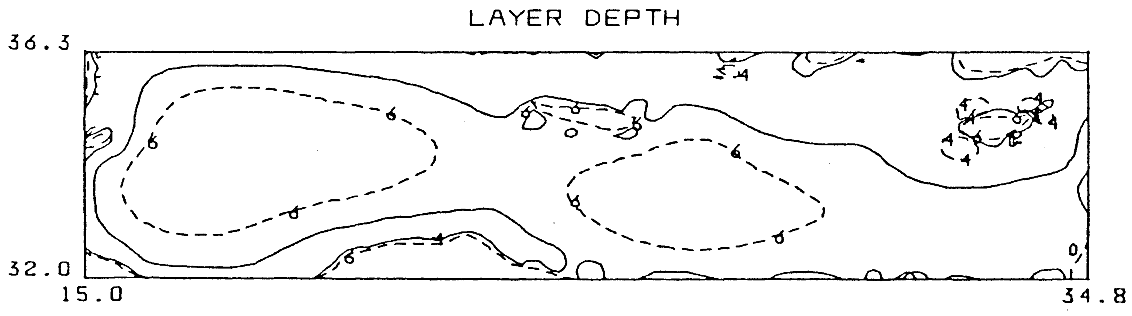

Streamfunction and layer depth h_1 at day 951. Depth contours are 4 = 190 m, 5 = 230 m, 6 = 270 m.