WATER MASS SPREADING PATTERNS AND LARGE-SCALE CIRCULATION OF THE EASTERN MEDITERRANEAN SEA INFERRED FROM NEUTRAL SURFACE ANALYSIS

Athanasios J. THEODOROU

Department of Agriculture, Crop and Animal Production, University of Thessaly
Pedion Areos, Volos, 383 34, Greece

The general features of the water masses and their circulation patterns in the Eastern Mediterranean have been known for some time - see, *inter alia*, EL-GINDY and EL-DIN (1986), MALANOTTE-RIZZOLLI and HECHT (1988), OZSOY, HECHT and UNLUATA (1989). The aim of the present study is to infer the quantitative circulation patterns of the Levantine Intermediate Water (LIW) and of the Deep Water (DW) within the Eastern Mediterranean Sea via neutral surface analysis based techniques.

To this end, first the idea of a "perfect" neutral surface is re-explored and some possibilities for approximating the latter are comparatively examined, leading to the introduction of a new modified version of the "central-reference-pressure" (THEODOROU, 1991) approach; the latter in conjunction with CTD data collected within the framework of POEM experiments supported with historical hydrographic data is used to obtain a number of neutral surfaces on which the spreading of LIW and DW will be examined.

Neutral Surface Analysis. The salinity distribution on those neutral surfaces was qualitatively examined and detailed patterns of the spreading of LIW and of the DW within the eastern Mediterranean were inferred. The topographies of the neutral surfaces were found to follow closely the configuration of the bottom bathymetry. The isohalines on all neutral surfaces were approximately parallel to the depth contours of the respective topographies, and the salinity maxima persisted for hundred of km without being eroded. Vertical mixing was important in the source regions of the two main water masses, whilst all features of the three dimensional salinity distribution could be accounted for in terms of lateral mixing and flow.

Water Mass Analysis. Plots of oxygen versus salinity on the neutral surfaces enabled the identification of the characteristics of the source waters and also of the number of water types involved in the mixing. Within this framework a variant of the technique of "mixing triangles" was employed and quantitative spreading patterns of the unmodified LIW on a number of neutral surfaces were obtained; these results were coherent with the inferences from the analysis of the salinity distribution on the same neutral surfaces

Dynamic Inferences. Using "composite sectional diagrams" dynamic inferences were made; these inferences in conjunction with the associated thermohaline alternations provided a description of the modification patterns of the LIW and of DW along their respective courses. In the same context, occurrence and development of mesoscale "disturbances" and loci of possible cross-isopycnal mixing were identified.

Geostrophic Fluxes. The qualitative picture of the flow field, obtained from the configuration of the neutral surfaces, under the assumption of geostrophy, was quantitatively examined by the computation of geostrophic currents and transports. The latter were further analysed, in conjunction with the mixing triangles defined within the study area, and numerical estimates of the relative proportion of the main water masses were obtained.

Circulation Patterns. The results were combined within the constraint of mass balance and in conjunction with the spreading patterns deduced, produced detailed quantitative patterns of the large-scale time mean flow of the intermediate and deep waters of the Eastern Mediterranean.

REFERENCES

EL-GINDY A. A. H and EL-DIN S. H., 1986. Water masses and circulation patterns in the deep layer of the Eastern Mediterranean. *Oceanologica Acta*, 9, (3) : 239-248.

MALANOTTE-RIZZOLI P. and HECHT A., 1988. Large-scale properties of the Easterb Mediterranean : a review. *Oceanologica Acta*, 11, (4) : 323-336.

OZSOY E., HECHT A. and UNLUATA U., 1989. Circulation and Hydrography of the Levantine Basin. Results of POEM coordinated experiments 1985-1986. *Prog. Oceanog.* 22 : 125-170.

THEODOUROU A. J., 1991. Some considerations on neutral surface analysis. *Ocean. Acta*, 14(3) : 205-222.

ONE YEAR OF HYDROBIOCHEMICAL OBSERVATION IN A TRANSECT IN FRONT OF SENIGALLIA (NORTH ADRIATIC SEA)

TOTTI C., ARTEGIANI A., DELLA SALA K., PASCHINI E. and A. RUSSO

Istituto Ricerche sulla Pesca Marittima (IRPEM), CNR, Ancona, Italia

In the framework of ELNA project (Eutrophic limits of the Northern Adriatic Sea), a monthly cruise is conducted from February 1993 in a transect in front of Senigallia, in order to monitoring the outflow of the North Adriatic. Stations sampled during each cruise (st. 0, st. 1, st. 2, st. 3, st. 4, st. 5) are located at 0.5, 1.2, 3, 6, 10, 15 NM from the coast. At each station sampling is done with CTD profiler, coupled with a Rosette multisampler, for the measure of temperature, conductivity, dissolved oxygen and fluorescence. Samples for nutrient salts, chlorophylls and phytoplankton determination are taken at significant depths checked on the basis of the CTD profile.

The thermohaline water structure exhibits a well defined seasonal evolution (fig.1). A coastal front present in the winter period confines along the coast the run-off of the northern Adriatic and local rivers, with very low value of salinity and high concentration of total inorganic nitrogen (st. 0, 1 and 2). In the deeper layer of the offshore part of the section it is possible to see the influence of the North Adriatic bottom water.

The spring period is characterised by a surface (0-10 mt.) thermohaline vertical gradient present over all the section. Two principal factors determine this configuration : the air-sea heat exchange begins to be positive for the sea and the river run-off has his maximum in spring.

In summer a two layers system dominates the section : a surface well mixed layer (15 mt. depth) with T> 23°C and S>38 PSU, and a deep layer, from 30 m to the bottom with T<14°C and S>38.0 PSU. Between the two layers a sharp thermocline is developed.

In fall it was registered a situation similar to spring: a thermohaline vertical gradient is present in the first 10 mt., but with a reversal thermal gradient, that is cold water at the surface, and warm water at the deeper layers. The stability conditions are preserved by the low values of salinity.

In general the nutrients are distributed with a negative gradient from coast to offshore. The nitrate fraction dominates the total nitrogen. A maximum in nitrogen concentration is detected in spring due to increasing runoff. A second strong peak was detected in December, during a period of low phytoplankton density. Good correspondence is found between nitrate trend and phytoplankton density trend, with a typical phase-difference between the two time series. Phosphorus, as orthophosphate, is present in very low concentration, often under the detection limit of analytical method. Phosphorous source for phytoplanktonic metabolism must necessarily be supported by the more consistent organic fraction.

Phytoplankton annual cycle is showed in fig.2. Quantitative data for phytoplankton cell density are expressed as cells/ml; no biomass measurements by now are done. Average values are integrated on water column. Abundance trend shows a maximum value in 2 stations onshore (over 9000 cells/ml) in correspondence of winter-spring diatom bloom, due to *Skeletonema costatum*, a typical winter blooming species in the Adriatic sea. Bloom started in February, extended from st.0 to st. 2 and touches maximum values in March. Next peak in phytoplankton trend was registered during May, and corresponds to an increase of phytoflagellate component that represented over 80% of total abundance. Then another peak appears in correspondence of autumnal season, and was again due to diatoms (*Chaetoceros radians* with an high diatom species diversity). Annual cycle ends in January again with a maximum; phytocenosis was now dominated by phytoflagellate component but also diatoms were well represented with *Asterionella glacialis* and *Skeletonema costatum* association.

For total values and for all the groups except Coccolithophorids, decreasing gradient from coast to offshore was regularly found. Stations from 6 nM offshore always seem to be scarcely productive, in terms of phytoplanktonic activity, and are considered representative of an olygotrophic system. Good correspondence was found between chlorophyll data and phytoplankton abundance, for chlorophyll a as well as chlorophyll c.

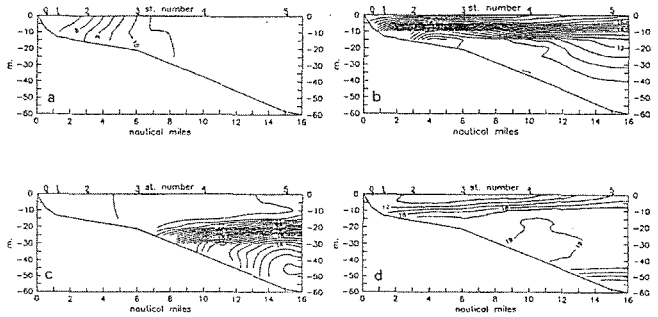

Fig.1. Temperature distribution on the section during winter (a), spring (b), summer (c) and fall (d)

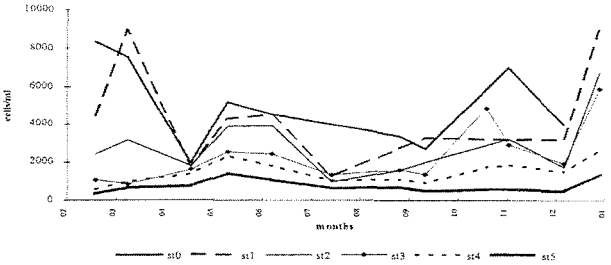

Fig.2. Phytoplankton abundances in cells/ml - Average integrated on water column