Spatio-Temporal Relations between Anomalies in Sea Surface Temperature Distribution and Chlorophyll Concentration in Hellenic Seas (SE Mediterranean)

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ABSTRACT

A time series of satellite imagery of AVHRR sea surface temperature (SST) and SeaWiFS chlorophyll concentration (CHL) for Hellenic waters are analyzed for the mapping of anomaly distribution in these environmental parameters. The spatial distributions of these anomalies are compared using a Geographic Information System (GIS) in order to identify and map areas of persistent environmental anomaly. These spatial distributions describe areas, which are characterized by highSST/lowCHL and lowSST/highCHL values. Generally, the first pair of anomalies implies the spatial extent of persistent cyclonic gyres while the second pair implies the extent of persistent anticyclonic gyres and upwelling. Such oceanographic features (gyres and upwelling) are processes, which along with eddies and fronts, consist the main factors of water mass mixing, particularly in the upper layer euphotic zone. A seasonal classification of these anomalies is developed because SST anomaly, in particular, is widely accepted as the proxy factor for a variety of oceanic and atmospheric-meteorological phenomena. In addition, lowSST/highCHL areas indicate offshore feeding grounds for many commercially important species, such as small pelagic fish (sardine and anchovy) and pelagic cephalopods (squids). A preliminary comparison of surveyed catch data to lowSST/highCHL areas shows a remarkable relation between species distributions and environmental anomalies. However, the main purpose of this work is the combined mapping and classification of SST/CHL anomalies in SE Mediterranean waters.

Keywords: Environmental Anomalies, Marine Geographic Information Systems, AVHRR, SeaWiFS, Oceanography, Fisheries

1. INTRODUCTION

A time series of monthly satellite images of sea surface temperature distribution (SST) and sea surface chlorophyll concentration (CHL) are processed under a Geographic Information System (GIS) in order to calculate, map and classify the spatial and temporal distribution of SST and CHL anomalies in SE Mediterranean Sea.

SST anomaly, in particular, is widely accepted as the proxy factor for a variety of oceanic and atmospheric-meteorological phenomena. Spatially large oceanic-atmospheric events, such as El Nino, La Nina and the North Atlantic Oscillation (NAO), which are basin-scale phenomena that are linked to global atmospheric circulation and associated weather anomalies, consist a normal part of the behavior of SST anomaly in the tropical Pacific and the North Atlantic, where the main variations occur through atmosphere-ocean interactions on interannual time scales[1]. Significant anomalies of the atmospheric circulation are related to previous SST anomalies in the North Atlantic. Specifically NAO-like signals in early winter are associated with SST anomalies observed in east of Newfoundland and in eastern subtropical North Atlantic during the preceding summer[2]. The role of SST anomaly in NAO reflects a tripole pattern with a cold anomaly in the subpolar region, a warm anomaly in the mid-latitudes centered off Cape Hatteras, and a cold subtropical anomaly between the equator and 30°N[3].

Patterns in wind force variation are commonly attributed to SST anomalies, particularly in coastal areas that are characterized by wind-induced persistent upwelling. The opposite effects of the synchronous changes of wind and SST anomalies on the turbulent heat flux minimizes the air-sea thermal coupling in the western tropical

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Indian Ocean on an interannual time scale, a variation that defines the main monsoon circulation[4]. Time series of satellite SST images and atmospheric and ocean models were used to simulate the effect of persistent SST anomalies (coastal upwelling) at Cabo Frio, Brazil on the sea-breeze circulation[5].

SST deviation from seasonal trends often impacts a variety of ecosystems and resources. A classification of the year-around ecological effects of NAO to marine and terrestrial ecosystems of Norway was conducted in 2001, based on the fact that whilst the connection between scalar wind and the NAO is only perceptible during the winter months, the link between the NAO and SST may carry over through to the summer as SST anomalies persist[6]. It was also demonstrated that very strong year-classes of Pacific herring of the Hokkaido-Sakhalin stock in Japanese waters have been produced during low to near-average SST periods whereas catches have been poor during high SST periods[7]. Strong spatial relation among cephalopod catches and SST anomalies are also observed in SE Mediterranean, where catches appear to take place along the boundaries of persistent SST anomalies that are an indication of SST fronts or upwelling[8].

Finally, there have been many efforts to understand the interaction and links between physical phenomena, biological production processes and fish stocks. As primer producers, diatoms (sensed by SeaWiFS) are considered to be the basic food source of the most commercially important fish stocks. Events in the water column that trigger diatom and therefore fish production, were first described in connection to spring bloom in temperate waters[9], in estuaries[10], coastal upwelling systems[11] and tidal fronts[12].

In this work, the spatial relations of SST and CHL anomalies are mapped and classified into two main classes: Areas that are characterized by a) highSST/lowCHL patterns and b) lowSST/highCHL patterns. We produce images of the seasonal distribution of the second pair of patterns, which indicate marine species feeding grounds and we compare these patterns with sampled catch data for small pelagic fish (anchovy and sardine) and cephalopods (long-finned and short-finned squids).

2. DATA AND METHODS

A time series of monthly satellite images of SST distribution derived from the Advanced Very High Resolution Radiometer (AVHRR) was downloaded from the German Aerospace Agency (DLR) for the period March 1993 to December 2001 (1.6 km resolution). In addition, a time series of monthly satellite images of CHL concentration derived from the Sea-viewing Wide Field of view Sensor (SeaWiFS) was download from the National Aeronautics and Space Administration (NASA) for the period October 1997 to December 2001 (4 km resolution).

Both time series of images cover the SE Mediterranean Sea (Fig. 1) and were processed under Environmental Systems Research Institute's (ESRI) ARC/INFO GIS[13]. Monthly climatology for SST and CHL were calculated from the time series. Then, subtraction of the actual monthly data from the corresponding climatological data derived SST and CHL anomalies. Finally, both SST and CHL anomalies were intersected in GIS for the development of highSST/lowCHL and lowSST/highCHL patterns. Intersecting anomaly data for the four seasons of each of the year 1998-2001 (e.g. dec97/jan98/feb98 for winter98) developed the seasonal classification of these pairs of parameters.

Fisheries catch data for anchovy, sardine and pelagic squids were obtained through the Management System of Hellenic Fisheries Resources, which is a network of 25 official sampling stations scattered all over Greece gathering and storing monthly catch data in a central database maintained at the Institute of Marine Biology of Crete, Greece.

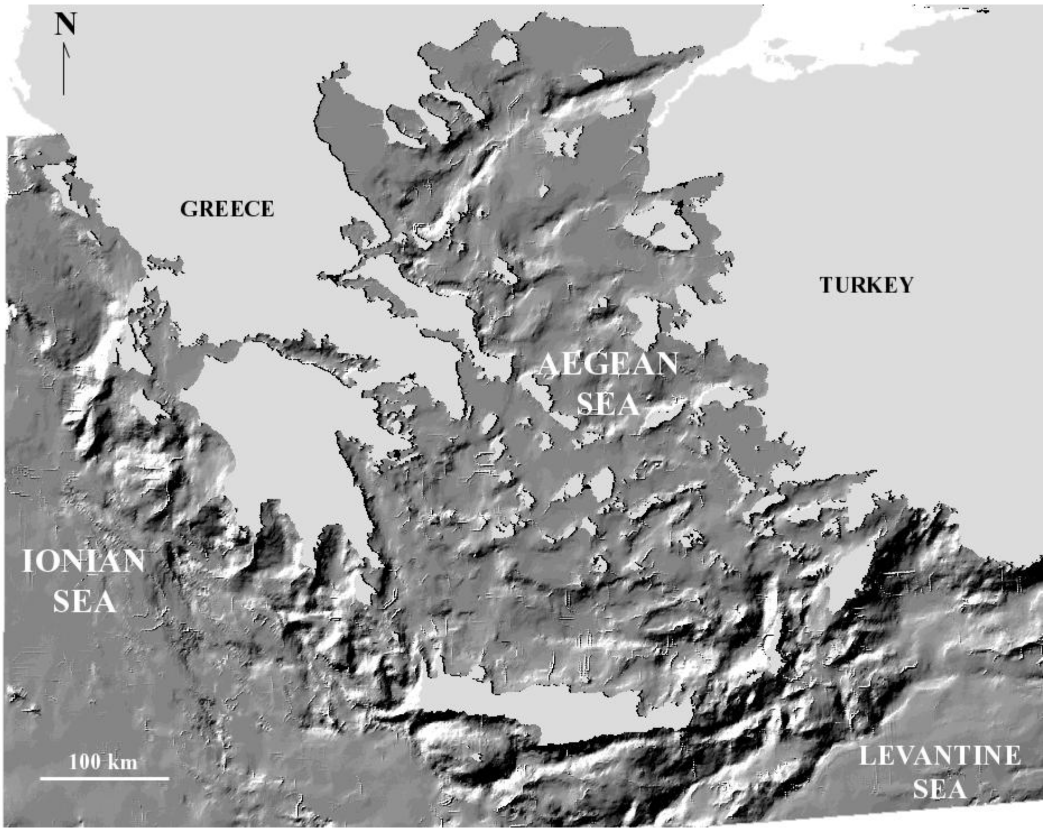

Fig. 1: The study area is located in Eastern Mediterranean Sea. This bathymetry image shows the Aegean, Ionian and Levantine seas.

3. RESULTS AND DISCUSSION

Results include 96 images of monthly SST and CHL anomalies, 96 images of highSST/lowCHL and lowSST/highCHL patterns, and 32 images of seasonal anomalies for the period 1998-2001. Here, we present a selected set of results, which show the general picture of the spatial distribution of these monthly and seasonal anomalies and their relation to fisheries catch data (complete set of results may be accessed at http://arch.imbc.gr).

Seasonal distribution of areas of lowSST/highCHL pattern are generally scattered all over the study area in smaller (<35 km²) and larger (>35 km²) patches (spatial extents of minimum area of 0.5 km² and maximum area of 730 km² were observed). During fall 2000, larger patches (Fig. 2) dominate the north part of the study area (North Aegean Sea), which is highly influenced by river plume and inflow of Black Sea water[14] as well as coastal upwelling[15]. During winter, these patches 'migrate' in central-eastern Aegean Sea while in spring and summer months, they are scattered all over the study area. On a monthly basis, areas of highSST/lowCHL patterns with a peak of lowSST/highCHL pattern in late winter-early spring characterize year 2001 (Fig. 3).

Generally, these SST/CHL anomaly patterns follow the annual cycle of mixing and stratification of surface waters in the Aegean Sea triggered primarily by the Etesians (summer northerly dry winds), which cause upwelling along the east coast of the Aegean Sea and along central Aegean (Cyclades Plateau) establishing an east-to-west temperature gradient in the central Aegean Sea[16]. During winter (no Etesians), when an overall cyclonic surface circulation is established, SST/CHL anomaly patterns are more evident along the northerly current of the Asia Minor coast and less evident along the relatively weaker southerly current of the Greek coast.

Relations among lowSST/highCHL areas and sampled fisheries catch data for four pelagic commercially important species are shown in Fig. 4. Areas characterized by the lowSST-highCHL anomaly pattern reveal known fishing grounds as well as indicate species' major feeding grounds, which may be used as alternative fishing activity areas. The spatial distribution of seasonal catch on sardine (*Sardina pilchardus*), anchovy (*Engraulis encrasicolus*) and pelagic long-finned and short-finned squids (*Illex coindetti* and *Loligo vulgaris*) shows a remarkable relation to the distribution of lowSST/highCHL anomalies, especially in North Aegean Sea where the majority of fishing activity takes place.

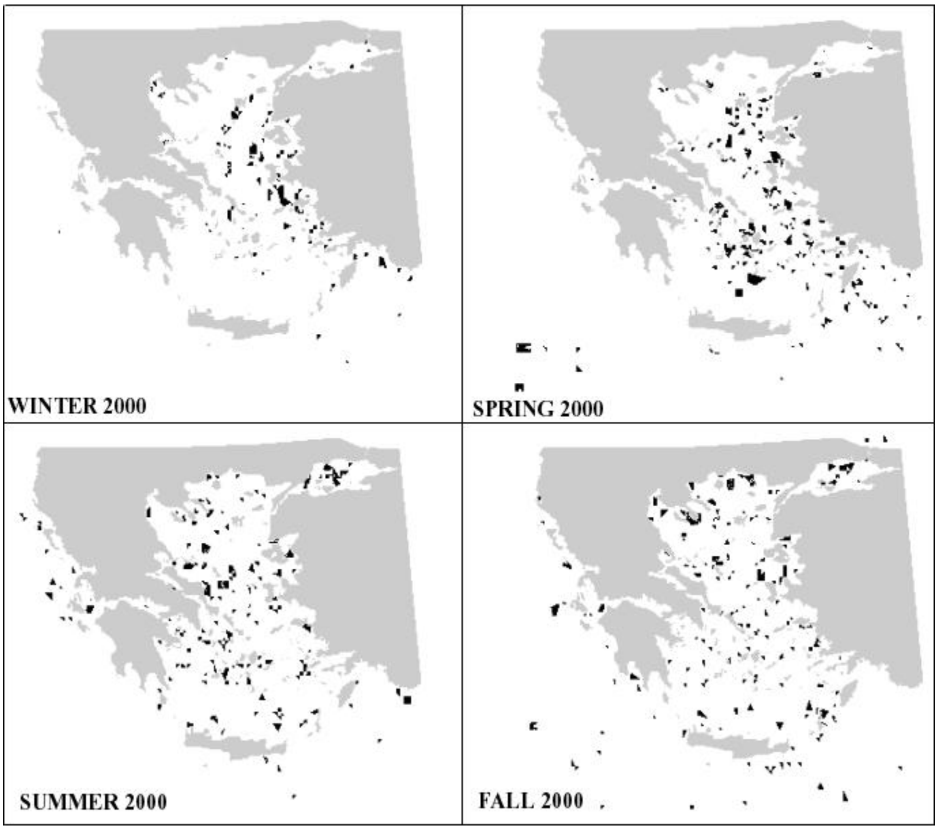

Fig. 2. Seasonal large (>35 km²) lowSST/highCHL anomaly patterns in Hellenic waters. Such relations of SST and CHL anomalies describe high productivity centers and may be considered as major feeding grounds for coastal and pelagic fish.

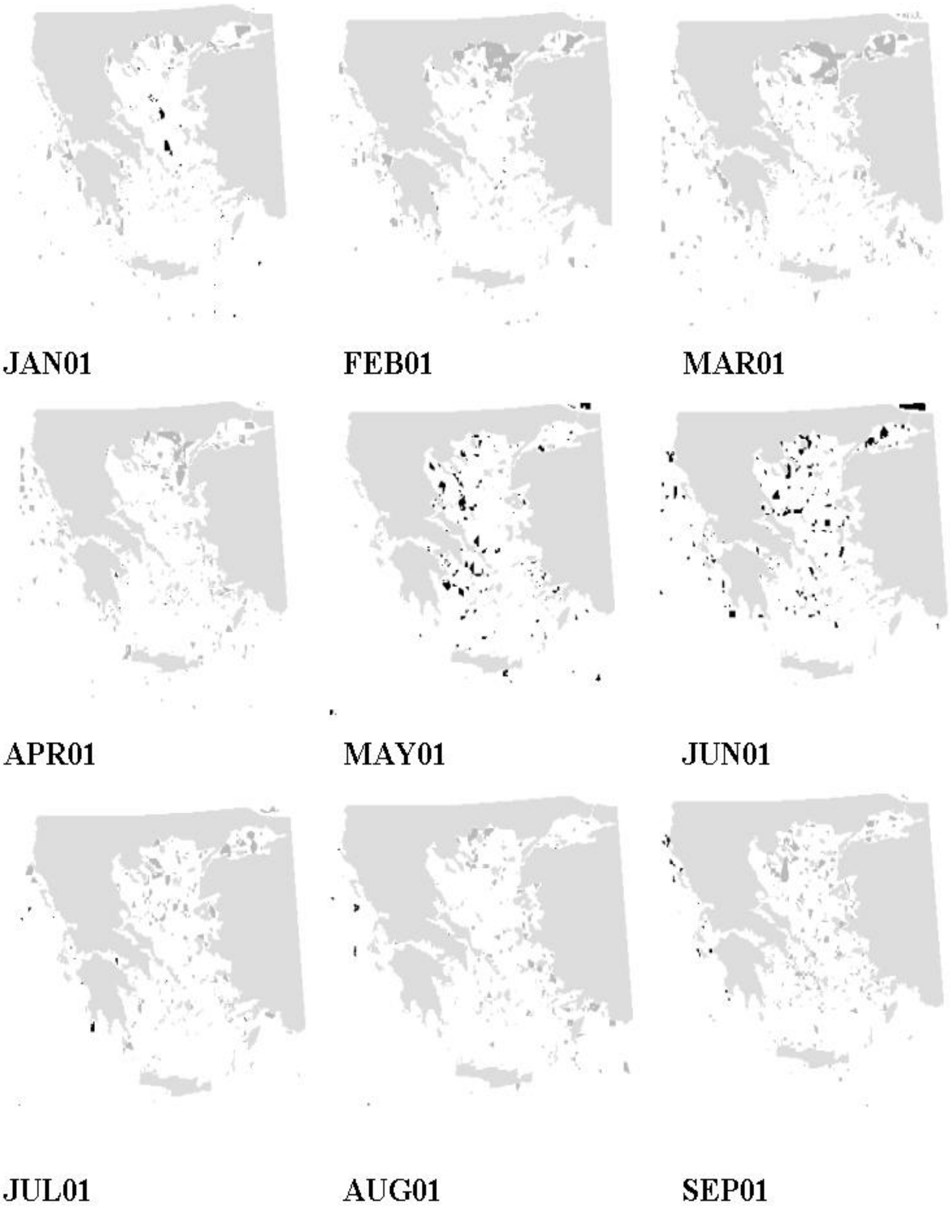

Fig. 3. Monthly relations of SST and CHL anomalies for 2001. LowSST/highCHL (in black) and highSST/lowCHL (in light gray) anomaly patterns are shown.

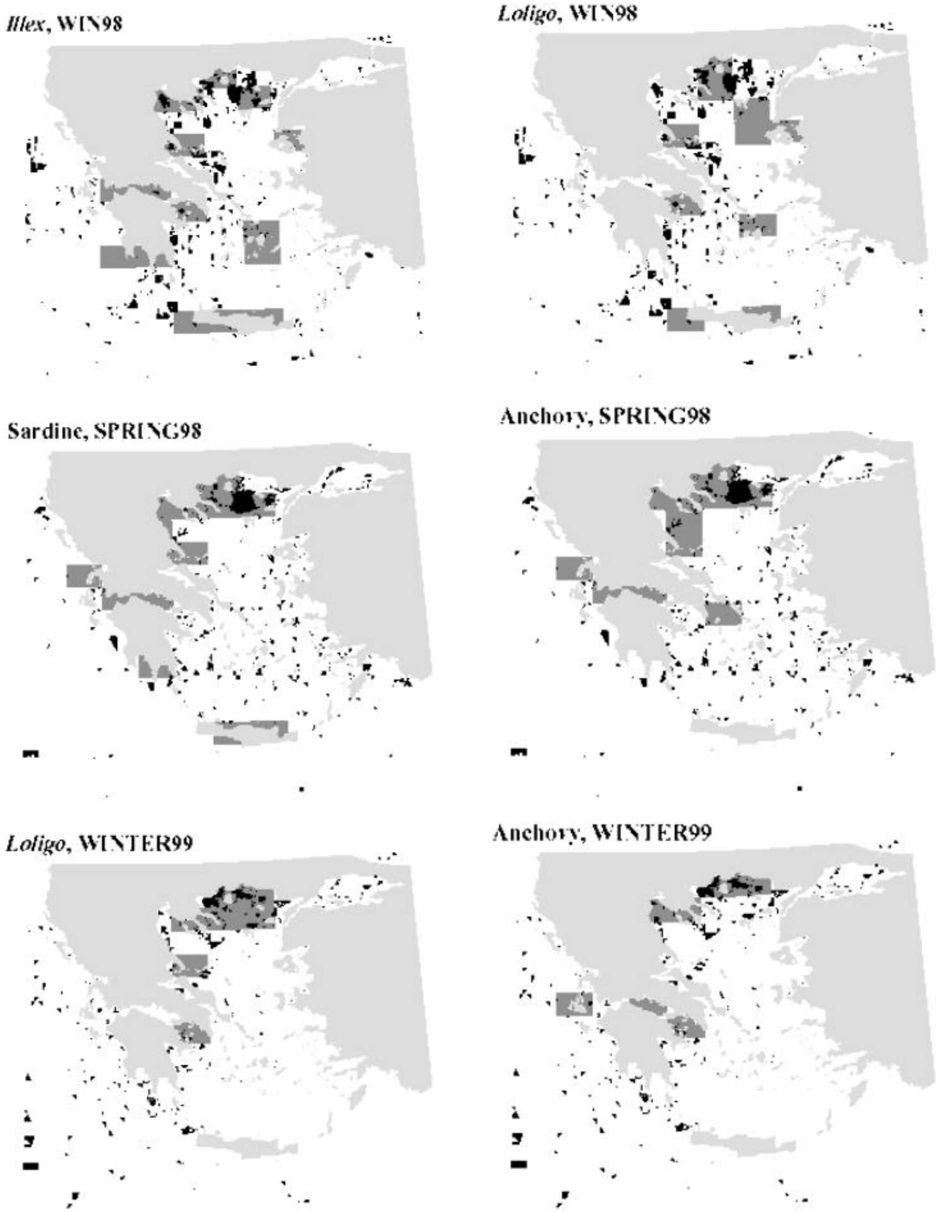

Fig. 4: Seasonal spatial relations among catch data (dark gray) and lowSST/highCHL anomalies (black) in SE Mediterranean.

4. CONCLUSIONS

1. The mapping of seasonal relations between anomalies in SST and CHL provides important information on surface water processes, which are the main factor for water mixing in the euphotic zone.

2. Such spatial relations in SE Mediterranean Sea follow the general pattern of summer surface temperature stratification (especially in Aegean Sea) versus the relative uniformity of surface waters during winter.

3. LowSST/highCHL patterns provide important information on coastal and pelagic feeding grounds for a variety of commercially important marine species.

4. There is a remarkable relation between catch data for small pelagic fish and cephalopods and lowSST/highCHL patterns (especially in North Aegean Sea).

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REFERENCES

1. S.G. Philander, *El Nino, La Nina, and the Southern Oscillation*, p. 293, Academic Press, 1990.

2. A. Czaja and C. Frankignoul, "Influence of the North Atlantic SST on the atmospheric circulation," *Geoph. Res. Let.* **26(19)**, pp. 2969-2972, 1999.

3. M.H. Visbeck, J.W. Hurrell, L. Polvani, and H.M. Cullen, "The North Atlantic Oscillation: Past, present, and future," *12th Annual Symposium on Frontiers of Science*, November 2-4, Irvine, CA. National Academies of Science and Engineering, 2000.

4. M. Konda, N. Imasato, and A. Shibata, "Interannual variability of the sea-surface temperature in the Indian Ocean in response to the air-sea turbulent heat exchange," *Deep-Sea Res. II* **49**, pp. 1527-1548, 2002.

5. S.H. Franchito, V.B. Rao, J.L. Stech, and J.A. Lorenzzetti, "The effect of coastal upwelling on the sea-breeze circulation at Cabo Frio, Brazil: a numerical experiment," *Annal. Geophys.* **16**, pp. 866-881, 1998.

6. G. Ottersen, B. Planque, A. Belgrano, E. Post, P.C. Reid, N.C. Stenseth, "Ecological effects of the North Atlantic Oscillation," *Oecolog.* **128**, pp. 1-14, 2001.

7. K. Nagasawa, "Long-term variations in abundance of Pacific herring (*Clupea pallasi*) in Hokkaido and Sakhalin related to changes in environmental conditions," *Progr. Ocean.* **49**, pp. 551-564, 2001.

8. V.D. Valavanis, S. Georgakarakos, D. Koutsoubas, C. Arvanitidis, and J. Haralabus, "Development of a Marine Information System for Cephalopod Fisheries in the Greek Seas (Eastern Mediterranean)," *Bull. Mar. Sci.* in press, 2002.

9. H.U. Sverdrup, "On conditions for the vernal blooming of phytoplankton," *Journal du Conseil Permanent International pour l' Exploration de la Mer* **18**, pp. 287-295, 1953.

10. P. Cury and C. Roy, "Optimal environmental window and pelagic fish recruitment success in upwelling areas," *Can. J. Fish. Aquat. Sci.* **46**, pp. 670-680, 1989.

11. D.H. Cushing, "A difference in structure between ecosystems in strongly stratified waters and in those that are only weakly stratified," *J. Plankton Res.* **11**, pp. 1-13, 1989.

12. D.M. Ware and R.E. Thomson, "Link between long-term variability in upwelling and fish production in the Northeast Pacific Ocean," *Can. J. Fish. Aquat. Sci.* **48**, pp. 2296-2306, 1991.

13. V.D. Valavanis, S. Georgakarakos, and J. Haralabus, “A Methodology for GIS Interfacing of Marine Data,” *Proceedings of GIS PLANET 98: International Conference and Exhibition on Geographic Information*, Lisbon, Portugal, September 7-11, IMERSIVA CD-ROM, 1998.

14. A. Theocharis and D. Georgopoulos, “Dense water formation over the Samothraki and Limnos Plateaux in the north Aegean Sea (Eastern Meditteranean Sea),” *Continent. Shelf Res.* **13**, pp. 919-939, 1993.

15. V.D. Valavanis, P. Drakopoulos, and S. Georgakarakos, “A Study of Upwellings Using GIS,” *Proceedings of CoastGIS99 International Conference GIS and New Advances in Integrated Coastal Zone Management*, September 9-11, Brest, France, IFREMER, 1999.

16. D.A. Metaxas, “Air-sea interaction in the Greek Seas and resulted Etesian Characteristics,” University of Ioannina, Techn. Report No. 5, pp. 1-23, 1973.