Figure 1. Top: Topography of Euro-Asian continent. The Caspian Sea, currently $\sim 28m$ below sea level, shown in blue, bottom: CZCS average pigment concentration (mg/m^3) in the eastern Mediterranean, Black Sea and Caspian Sea regions. Data after NASA/GSFC

being among the most troubled waters of the world ocean (IOC, 1993). Land use / cover and subsequent hydrological changes in the adjacent lands lead to desertification and scarcity of water (Moreno and Oechel, 1995; Jeftic, 1992, 1996; Glanz and Zonn, 1997), amplified by cultural and socio-economic contrasts in the region.

At present the causal relationships explaining the evolution of the ocean-atmosphere system projected onto the region are not well established. Often the changes are mediated through sub-basin and meso-scale processes, and are therefore difficult to be identified.

2. Large-Scale Controls

The region is one of the foremost areas of the world where interannual and long term climatic variability is predominant. In the Mediterranean region such variability is well known (*e.g.* Garrett *et al.*, 1992; Robinson *et al.*, 1993; Malanotte-Rizzoli and Robinson 1994; Jeftic et al., 1992, 1996). The Mediterranean variability appears correlated with global teleconnection patterns, and coupled with the Indian Monsoon system and El Nino / Southern Oscillation (ENSO) (Ward, 1996). For example, good correlation has been found between heavy rain and snow in Israel during the last 100 years and ENSO (Alpert and Reisin, 1986). Similarly, global versus regional climate interaction has been emphasized in the case of the Caspian Sea (Rodionov, 1994) as well as in the Black Sea (Polonsky *et al.*, 1997).

Weather in Europe, extending well into Eurasia, is to a large extent determined by conditions in the North Atlantic, and in particular the North Atlantic Oscillation (NAO) quantified by the normalized anomaly of the sea level pressure difference between the Azores and Iceland (Hurrell, 1995). Severe weather in Europe occurs when the NAO index is positive. The NAO accounts for about one third of the hemispheric interannual variance, and accounts for surface temperature changes as well as evaporation-precipitation anomalies in the European and the Eastern Mediterranean regions (Hurrell, 1995, 1996; Marshall, 1997). It has been linked to sea level changes in the Caspian Sea (Rodionov, 1994), to Danube river runoff directly influencing Black Sea hydrology (Polonsky *et al.*, 1997), as well as to surface winter temperatures, precipitation and river runoff in Turkey (Cullen, 1998).

Large scale control is well expressed in long range atmospheric transport patterns, suggested by the simultaneous occurence (Li *et al.*, 1996; Andreae, 1996) and parallel dependence on the interannual NAO patterns (Moulin *et al.*, 1997) of the transport of aerosol dust from the Sahara desert into the Mediterranean and tropical Atlantic regions. An exceptional case studied during the first half of April 1994 (Özsoy *et al.*, 1998; Kubilay *et al.*, 1998), has illustrated the role of large scale controls. Atmospheric blocking in the Atlantic had triggered upper air jet interactions and meridional circulations on a hemispherical scale (Figure 2a-c). These interactions resulted in large scale subsidence and cyclogenesis resulting in an anomalous pattern of dust simultaneously transported towards the subtropical Atlantic and the eastern Mediterranean regions, leading to maximum dust concentrations in 30 years of measurements in Bermuda and similarly high values in Erdemli (Özsoy, *et al.*, 1998). It is most interesting that the average sea level pressure was characterized with the typical dipole pattern of the NAO (Fig 2d), with a corresponding high index value of ~ 4, suggesting significant

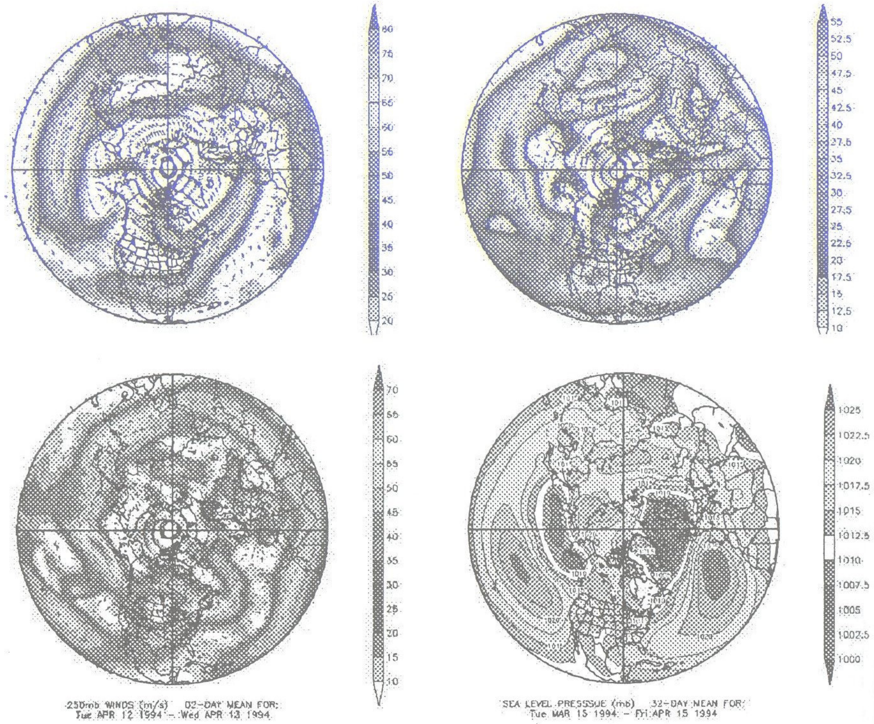

Figure 2. Northern hemisphere upper atmospheric circulation showing the evolution of the polar and subtropical jets. $250hPa$ wind speed (shading) and direction (vectors) based on two day averages for (a) March 31 - April 1, (c) April 4 - 5, 1994, (c) April 12 - 13, 1994 and (d) the monthly average sea level pressure for the period March 15 - April 15, 1994. The source for the data is NOAA Climate Diagnostic Center (plotting page web adress http://www.cdc.noaa.gov/HistData/

links between high index NAO circulation and the anomalous dust event. In addition to the links with NAO, the Atlantic dust flux also appears well correlated with the African drought and the ENSO (Prospero and Nees, 1986).

3. Similarities in Regional Cooling Patterns

There is a significant degree of synchronism displayed between the Levantine, Black and Caspian Seas, in terms of the air and sea surface temperatures displayed in Figure 3. This is because of the proximity of the three regions, but also a result of the possible large scale controls discussed above, and by Özsoy and Ünlüata (1997). In the same Figure, comparisons are also made with the NAO and SO indices and with solar transmission (an indicator of volcanic dust in the atmosphere). Some cold years appear

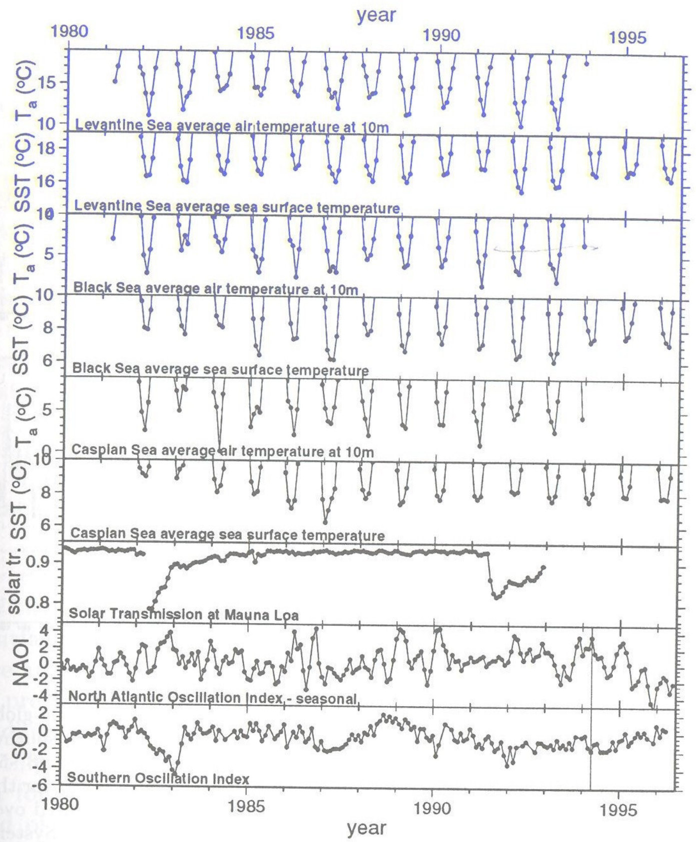

Figure 3. Time series of average air (ECMWF/ERA re-analyses, 6 hr forecast temperature at $10m$ height) and sea surface temperatures (ESA ERS1/ATSR derived monthly averages) for the Levantine, Black and Caspian Seas, Solar transmission at Mauna Loa, and the climatic indices NAOI (seasonal averages) and SOI, for the last two decades.

linked with negative values of the SO Index in Figure 3 (*e.g.* 1982-83, 1986-87, the 1990's), often cited as ENSO years (*e.g.* Meyers and O'Brien, 1995). Similarly, some years (1983, 1986-87, 1989-90, 1992-93) are characterized by high NAO indices.

Relatively cooler winters are detected in the years 1982-83, 1985, 1987, 1989, 1991 and 1992-93 in Figure 3. Some of the cold years correspond to well known cases of convection and deep water formation in the regional seas (*e.g.* from recent data *in 1987*: dense water intrusion into the Marmara Sea from the Aegean, Beşiktepe *et al.*, 1993; deep water formation in the Rhodes Gyre region, Gertman et al., 1990; main pycnocline erosion in the Black Sea, unpublished data; *in 1989*: extensive LIW formation in

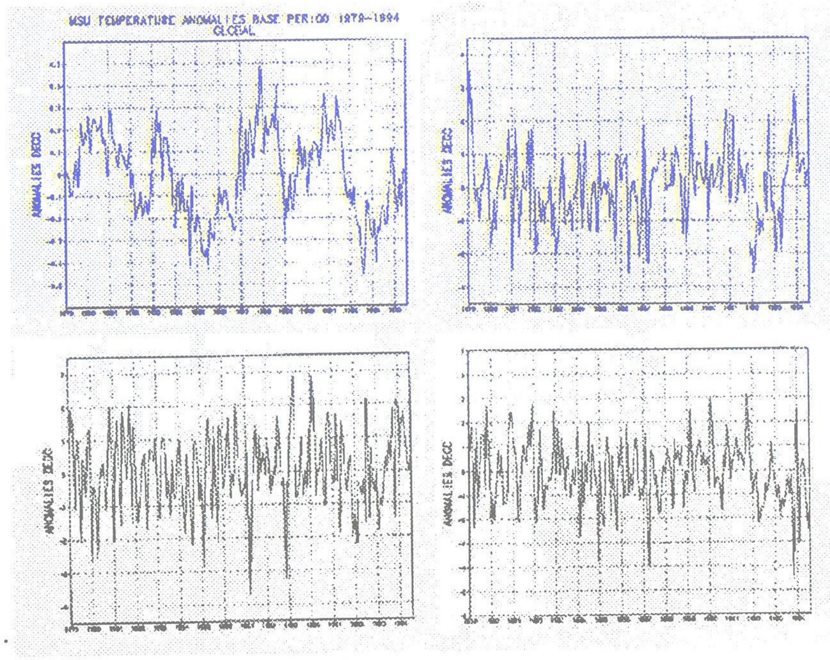

Figure 4. Average lower tropospheric temperature anomalies for (a) the globe, (b) the Rhodes Gyre region of the Levantine Sea (33°-37°N and 26°-32°E), (b) southwest Black Sea (41°-43°N and 27°-31°E), (c) northern Caspian Sea (45°-47°N and 48°-53°E). The measurements were obtained from the Microwave Sounding Unit (MSU) for the 0-5.6km layer of the troposphere (grid resolution 2.5°) and the anomalies calculated over the base period of 1979-1995 are produced by the Global Climate Perspectives System (GCPS) at the http://www.ncdc.noaa.gov/onlineprod/prod.html web address.

northern Levantine Sea (Özsoy *et al.*, 1993); *in 1992 and 1993*: Black Sea Cold Intermediate Water (CIW) formation and pycnocline erosion, Ivanov *et al.*, 1997a,b; simultaneous intermediate and deep water formation in the Rhodes Gyre region of the Levantine Sea; Sur *et al.*, 1992, Özsoy *et al.*, 1993). There are also some surprises: the year 1987 is one of the coolest years in all three seas, but there is no corresponding decrease of air temperature in the Caspian Sea. Secondly, while the air temperature displays various anomalous years in the Caspian Sea, the sea surface temperature does not respond to it very effectively, except the year 1987, unlike the pattern observed for the other two seas.

Cooling in the lower troposphere (Figure 4a) occurred globally in 1992-1993 (Spencer and Christy, 1992), following other cooling periods of 1982, 1985-86, 1989 in the last two decades. Significant drops of Temperature

drops of 1-2°C occurred in the entire region extending from the Rhodes Gyre of the Levantine Sea to the southern Black Sea and the northern Caspian Sea (Figures 4b-d). An event of global climatic significance (Fiocco *et al.*, 1996) the eruption of Mount Pinatubo volcano in June 1991, resulting in stratospheric warmings (Angell, 1993), decreased solar energy inputs (Dutton and Christy, 1992; Dutton, 1994) and anomalous temperatures (Halpert *et al.*, 1993; Boden *et al.*, 1994) in the entire northern hemisphere in 1992-93. Anomalous cold temperatures appeared in the Middle East in very similar spatial patterns during the winters of 1992 and 1993, covering the Black Sea, eastern Mediterranean, and African regions in both years (Özsoy and Ünlüata, 1997). In Turkey, the winter of 1992 was the coldest in the last 60 years (Türkeş *et al.*, 1995), and in Israel, it was the coldest in the last 46 years (Genin *et al.*, 1996).

4. Surface Fluxes

To study the effects of climate variability in the three seas, the loss terms of the surface fluxes are computed from uniform quality, decadal atmospheric re-analysis data obtained from the ECMWF at 1° resolution (mean sea level pressure, 10m wind, 2m atmospheric and dew point temperatures and cloudiness, produced every 6 hr intervals from 6hr global forecasts), and monthly average sea surface temperature based on ERS1/ATSR satellite data for the period 1981-1994. The air-sea fluxes are calculated by a method of iteratively reconstructing the atmospheric variables at 10m height from ECMWF supplied fields based on Monin-Obukhov turbulent boundary layer theory, then using bulk formulae to compute the wind-stress, moisture flux, sensible (q_s) and latent (q_l) heat fluxes (Launiaien and Vihma, 1990; Vihma, 1995) as well as the longwave radiation (q_b) fluxes (Bignami *et al.*, 1995). The values are then averaged over the sea domain and a month to produce the values in Figure 5, where the standard deviations are also marked.

The comparison of fluxes in the three different seas shows coincidence between the active periods of Black Sea and Levantine Sea, and a lesser degree of sychronism between them and the Caspian Sea. On the other hand, the Black Sea and Caspian Sea momentum fluxes are larger, more seasonal and more variable than the Levantine Sea, where the larger events come in interannual pulses. The sensible heat flux increases from the Levantine Sea to the Black Sea, reaching a maximum in the Caspian Sea.

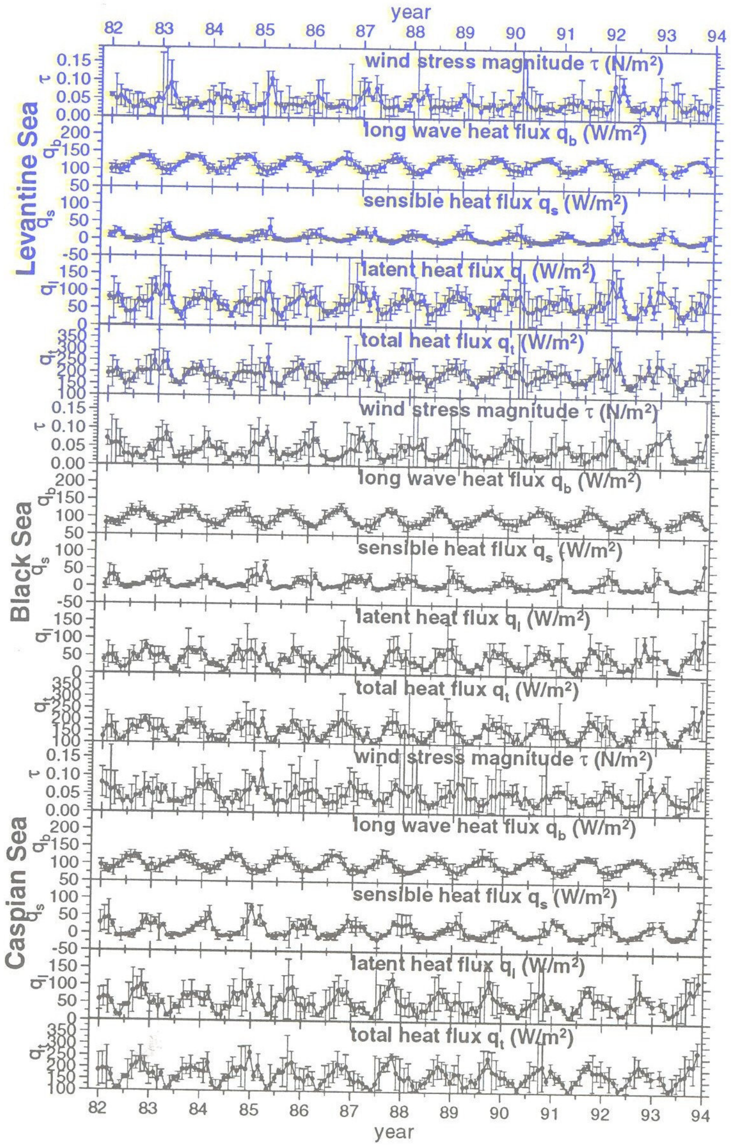

Figure 5. Wind stress and heat flux components for the Levantine, Black and Caspian Seas computed from the ECMWF re-analysis, 6 hourly forecast fields. The values are averaged over each basin and over one month periods. The error bars denote one σ standard deviation.

5. Changes in the Eastern Mediterranean

5.1. THERMOHALINE CIRCULATION

The mean residence time varies considerably from $\sim$100 years for the Mediterranean and shorter for the Caspian, to $\sim$2000 for the Black Sea. The

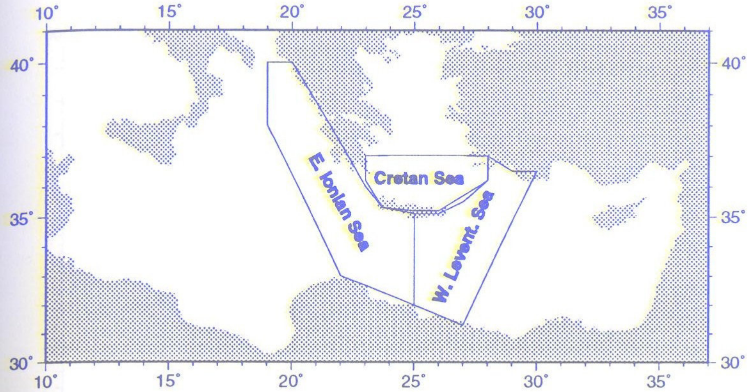

Figure 6. Areas chosen for deep water analyses in the western Levantine, eastern Ionian and Cretan Seas

Mediterranean 'conveyor belt' (*i.e.* the 3-D thermohaline circulation, partly connected to the North Atlantic through the Gibraltar Strait), could have global impact, by regulating water masses and overturning in the North Atlantic (Reid *et al.*, 1994; Hecht *et al.*, 1996), with a potential, yet speculative contribution (Johnson, 1997a,b) to the triggering of paleoclimatic transitions (Broecker *et al.*, 1985).

The conceptual schemes of Mediterranean thermohaline circulations (*e.g.* Robinson and Golnaraghi, 1994) have been drastically changed by the discovery of deep water formation (a) through dense water outflow from the Aegean Sea, and (b) simultaneously with LIW in the Rhodes Gyre core. It is now evident that the 'conveyor belt' circulation in the entire Mediterranean is undergoing changes. Increases in the deep water temperature and nutrients (Bethoux *et al.*, 1989; Bethoux, 1989, 1993) appear coupled to the annual deep convection patterns (Gascard, 1991; Madec and Crepon, 1991; Send *et al.*, 1996) in the western Mediterranean.

The real surprise has recently come from the eastern Mediterranean, where deep water was found to form in the center of the permanent Rhodes Gyre, simultaneously with LIW on its periphery (Gertman *et al.*, 1990; Sur *et al.*, 1992; Özsoy *et al.*, 1993) with a recurrence interval of a few years depending on cooling. Furthermore, a climatically induced switching in the closed cell 'conveyor belt' is now evident. The classical scheme of deep water renewal by dense water (fresh, cold) outflow from the Adriatic Sea (Roether and Schlitzer, 1991; Schlitzer *et al.*, 1991; Roether *et al.*, 1994), have been replaced by the dense water (salty, warm) outflow from the Aegean Sea (Roether *et al.*, 1996), starting in the early 1990's. The event has been detected for first time since the beginning of oceanographic observations,

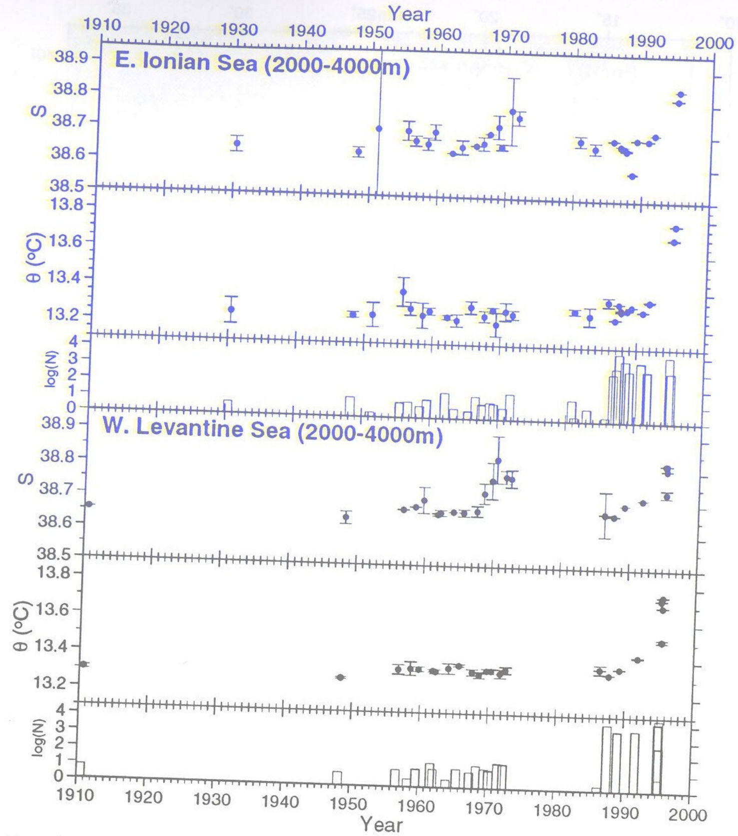

Figure 7. Average salinity, potential temperature, and log number of observations in the depth interval of 2000-4000m in the western Levantine, eastern Ionian Sea areas. The error bars denote standard deviation. The averages are obtained from individual data sets contained within the combined MODB / POEM data and grouped into 1 year intervals falling within the specified depth range.

although intermediate depth ($\sim$ 1,000-1500m) Aegean intrusions of lesser magnitude were well known (Roether and Schlitzer, 1991).

The changes in deep water first became evident when an unusually warm, saline water mass below 1000m was detected south of the Island of Crete during summer 1993 (Heike *et al.*, 1994; A. Yılmaz, pers. comm.). Anomalous heat fluxes were detected in the deep sediments of Ionian Sea deep brine lakes in 1993-94, capped by a double diffusive interface in contact with the new deep water (Della Vedova *et al.*, 1995), suggesting a fresh transient event. Although an exact date for the Aegean dense water outflow can not be established, observations suggest a strong pulse in 1992-93, superposed on a background trend starting in the late 1980's.

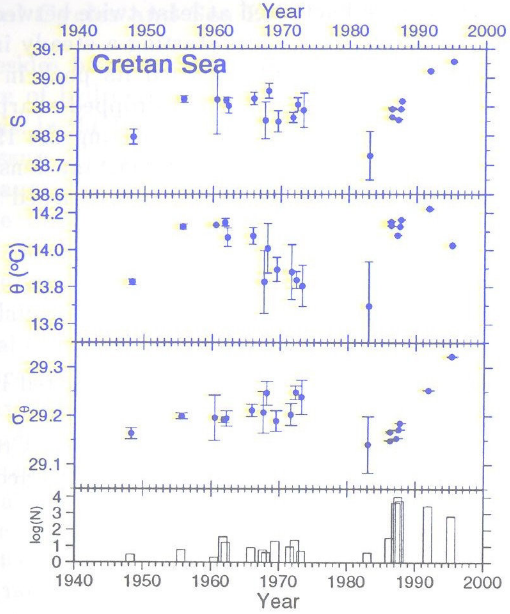

Figure 8. Average salinity, potential temperature, σ_θ density and log number of observations in the depth interval of 1000-2000m in the Cretan Sea. The error bars denote standard deviation. The averages are obtained from individual data sets contained within the combined MODB / POEM data and grouped into 1 year intervals falling within the specified depth range.

An analysis of the MODB historical data base (Brasseur *et al.*, 1996) combined with the last 10 years of Physical Oceanography of the Eastern Mediterranean (POEM) data was made by Özsoy and Latif (1996) to address the effect of Aegean outflow in the observed changes in deep water. For this purpose, the three regions adjacent to the Aegean - Eastern Mediterranean junction (Figure 6) were selected.

The average properties in the depth range of 2000-4000m, with the 95 % confidence limits are shown in Figure 7 the western Levantine and eastern Ionian boxes (Figure 6), together with the number of observations in each annual cluster. The vertical resolution, accuracy and coverage of the measurements increased in the second half of 1980's (POEM program). If we disregard the large salinity changes associated with measurement drift in the 1960's and 1970's, and trust the relatively more accurate temperature measurements, an increase in deep water temperature (and possibly salinity) is evident in both regions in the late 1980's, topped by a rapid increase during 1992-95.

In the Cretan Sea deep water (maximum depth $\sim$2000m), both temperature and salinity have fluctuated at least twice between minimum and maximum values in the last 60 years, starting a steady increase after the mid 1980's (Figure 8). The salinity reached its peak in 1995, while the temperature first increased until 1991 and dropped sharply in 1991-95 to yield a rapid and steady increase in density during the 1980's and 1990's, which is quite different than the relatively constant density values of the previous three decades. Similar conclusions were reached by Theocharis *et al.*, (1996) with regard to Cretan Sea.

5.2. NEAR-SURFACE CIRCULATION

Upper ocean variability has been most readily detected in the circulation of the main thermocline and in the physical properties of the intermediate and surface waters both in the western Mediterranean (Crepon *et al.*, 1989; Barnier *et al.*, 1989) and the eastern Mediterranean (Hecht, 1992; Sur, *et al.*, 1992; Özsoy *et al.*, 1993).

In the eastern Mediterranean, abrupt changes in circulation and water masses has been recognized (Hecht, 1992) as extraordinary, multi-annually recurrent events. The multiple bifurcating central jet flow joining the Asia Minor jet cyclonically east and west of Cyprus and anticyclonically along the eastern coast of Levant in 1985-86 has abruptly changed to a better organized, cyclonic flow around Cyprus in the 1988-1990 period, coincident with the Rhodes Gyre deep convection in 1987, the massive penetration of low salinity modified Atlantic water into the northern Levantine, and the disappearence of a coherent anticyclone in the Gulf of Antalya the same year and its re-appearence in 1990 (Özsoy *et al.*, 1991, 1993). The surface salinity steadily increased from 39.1-39.3 in 1985-86 up to 39.5 in 1989 and 39.7 in 1990. During the same period changes occurred in in the pattern of formation and maintenance of LIW. The LIW trapped in the Antalya anticyclonic eddy in 1985-86 disappeared together with the eddy itself in 1987. LIW with increasingly higher salinities was observed in the winter periods of the following years, reaching from $\sim$39.0 in 1989 to $\sim$39.2 in 1989-90 (Özsoy *et al.*, 1993). An increasing trend was evident in the Shikmona Gyre core salinity, temperature and density during the 1988-1994 period, with abrupt changes in the winters of 1990 and 1992 (Brenner, 1996). Salinity increases in the entire region, together with circulation changes leading to the entry of salt water into the Aegean, and blocking of LIW to spread westward by multi-centered anticyclonic region in the Southern Levantine, have been shown by Malanotte-Rizzoli *et al.*, (1998) for the POEM survey of October 1991. The changes imply a salt redistribution pattern favoring the creation of Aegean dense water outflow.

6. Hydrological Cycles and Sea Level

The sea-level, besides being a good indicator of climatic fluctuations, is a sensitive measure of hydrometeorological driving factors in enclosed and semi-enclosed seas. In the Black Sea, sea-level responds non-isostatically to atmospheric pressure and the total water budget, which are both highly variable on interannual and seasonal time scales (Sur *et al.*, 1994), strictly controlled by the variable inputs of large rivers and the dynamical constraints imposed the Turkish Straits (Özsoy *et al.*, 1998a). Simple models used to understand the time dependent response has had limited success to produce and explain sea-level variations of large amplitude in this non-tidal Sea, unless special effects of wind-setup on the hydraulics of the Bosphorus are included (Ducet and Le Traon, 1998).

In the Caspian Sea, sea-level changes depend on the regional hydrometeorological regime linked to global climate (Radionov, 1994). The sea level changes with climatic and anthropogenic components are of great economic and environmental importance for the surrounding countries. Interestingly, the sea-level change influences the residence time of the deep waters, and therefore has a direct bearing on the health of the Caspian Sea. Abrupt changes in sea-level have occurred twice since 1830's, as well as earlier in history, as the fate of Khazars occupying in its shores in the 10th century stand witness. The sea level has first dropped from a -25 m in 1930's down to -29 m by 1978, and has risen to the present -27 m after 1977. Hydrogen sulfide has been detected in deep waters prior to 1930 when sea-level was high, as a result of insufficient ventilation, limited by the decreased volume of dense water formed on the ice-covered, shallow northern Caspian shelf (average depth $\sim 2m$) under the influence of the large, variable inputs of the Volga river (Kosarev and Yablonskaya, 1994).

7. Marine Ecosystems

The marine ecosystems of interior seas are especially vulnerable, as significant changes in nutrient supplies are taking place in their confined waters. In the Black Sea, and the Caspian Sea, supplied by large rivers, eutrophication is leading to losses of habitats, species diversity, and consequent economical value (Zaitsev and Mamayev, 1997, Kosarev and Yablonskaya, 1994). The eastern Mediterranean system may be undergoing change related to the Nile river (*e.g.* Turley, 1997). Ecosystem disasters in even smaller, confined waters of the the Aral Sea, Kara Boğaz Göl, and Azov Sea, are better recognized. The introduction of extraneous species represent anthropogenic effects, either by filling a niche as in the case of the Black Sea, or through Lessepsian migration from the Red Sea, in the case of the eastern Mediteranean (Por, 1978; Galil, 1993; Gücü *et al.*, 1994;

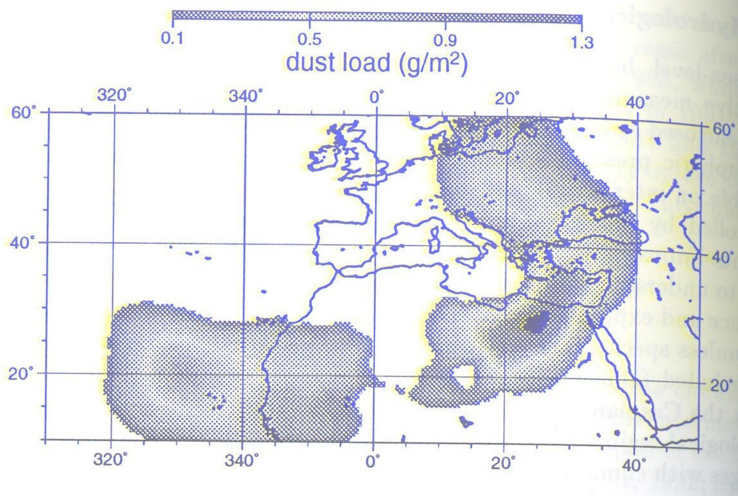

Figure 9. Model derived tropospheric dust load (g/m^2) at 18:00 on April 6, 1994.

Kıdeyş and Gücü, 1995). On the other hand, the natural variabilities are frequently of the same magnitude as anthropogenic effects, which makes diagnosis difficult.

The basic ingredients and biological machinery of the marine ecosystems are often not sufficiently resolved (*e.g.* the sub-oxic zone in the Black Sea, Oğuz, *et al.*, *this volume*; or the roles of P-limitation and cyanobacteria in the eastern Mediterranean, Zohary and Robarts, 1996; Li *et al.*, 1993). In addition to these biochemical factors, dynamical features are of first order importance for the ecosystem. In the Black Sea, upwelling, coastal flows and river supply play important roles (Sur *et al.*, 1994, 1996; Özsoy and Ünlüata, 1997). In the eastern Mediterranean, where the surface nutrients are low, nutrient upwelling at fronts (Özsoy *et al.*, 1993), and nutrient supply in the river mouths and coasts appear significant. Ecosystem changes associated with an uplift of the nutricline following the Aegean dense water outflow are suspected in the eastern Mediterranean (Roether *et al.*, 1996), and are perhaps associated with changes in deep zooplankton (Weikert, 1996). The strong cooling and mixing in 1992-93 produced a massive algal bloom near the Rhodes Gyre (Yılmaz *et al.*, 1996; Ediger and Yılmaz, 1996), and in Eilat, where it lead to the destruction of coral reefs (Genin *et al.*, 1996). These events coincided with the enhanced pycnocline erosion (Ivanov *et al.*, 1997a,b), followed by a massive bloom (Vladimirov *et al.*, 1997) in the following summer of 1992 in the Black Sea. The bloom in the Black Sea apparently produced atmospheric non-sea-salt sulfate aerosols of marine biological origin swept southwards and detected in the Erdemli

measurements (Özsoy *et al.*, 1998c).

8. Aerosol Dust

Aerosol desert dust is important in the climate system, primarily because of its effects on heat budgets (Charlson and Heintzenberg, 1995), especially in semi-enclosed seas (Gilman and Garrett, 1994), on the heterogeneous chemistry of the tropospheric and greenhouse gases (Dentener *et al.*, 1996), as well as on the biogeochemical cycles in the marine environment (Duce *et al.*, 1991).

Dust transport is an important climatic process which is particularly active in the Mediterranean area (Guerzoni and Chester, 1996), with an increasing incidence in recent years associated with drought and desertification. The role of large scale controls in establishing conditions for transport, such as in the spectacular April 1994 case, are outlined in Section 2. The dust load for this unique case of simultaneous transport (Andrae, 1996; Moulin *et al.*, 1997) in a shallow layer across the Atlantic and within a rapidly developing cyclone towards the eastern Mediterranean and Black Sea regions, resulting in anomalously high concentrations in Barbados and Erdemli (Li *et al.*, 1996, Özsoy *et al.*, 1998b; Kubilay *et al.*, 1998) is shown in Figure 9.

Sahara dust is known to be the main source contributing to the formation of the fertile 'red soils' of the eastern Mediterranean. It is hypothesized, based on satellite observations and concurrent dust measurements (unpublished material, IMS-METU) that the transport and deposition on sea surface of eroded dust from the Sahara and Arabian deserts has an impact on short term, episodic phytoplankton blooms in the eastern Mediterranean. There is often a striking coincidence of 'high reflectivity' from the sea surface typically associated with *E. huxleyi* blooms, and the incursions of dust, supported by the coincidence of the fertilization events with high fluxes of carbonates in sediment trap obsetvations. However, the working hypothesis has to be better defined and tested with detailed observations.

9. ACKNOWLEDGEMENTS

This study benefited from a number of activities, most notably the POEM and POEM-BC, international cooperative programs, the NATO SfS Projects TU-FISHERIES, TU-BLACK SEA and TU-REMOSENS projects, as well as other work carried out by the IMS-METU. Special thanks are for the Turkish General Directorate of Meteorology for providing access to the ECMWF data on a collaborative basis.

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