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"Interannual and Decadal Ocean Climate Variability in the Eastern Mediterranean Region"

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INTERANNUAL AND DECADAL OCEAN CLIMATE VARIABILITY IN THE EASTERN MEDITERRANEAN REGION

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Importance of Ocean Climate Variability on Decadal Time Scales

Because geophysical systems are often non-linear, dissipative systems, there is a good chance that they develop chaotic oscillations. On climate time scales, it is quite possible that a system can catastrophically jump from one state to another as a result of a small change in inputs, though the inputs would seemingly have little effect on the result. Such changes may occur very rapidly, for example, as demonstrated by ice core records for glacial/interglacial transitions.

It is therefore necessary to understand the natural variability in such systems to establish their sensitivity to change, and to understand what causes the observed variations, in order to develop a sense for what to expect under some adverse changes of greater magnitude. Furthermore, comparative studies of simultaneous behaviour of different parts of a system (different seas in this case) yields information on common causes of climatic change.

We describe such variability and common processes in the Eastern Mediterranean, with a similar motive.

Levantine Sea

Buoyancy fluxes from the sea into the atmosphere during cold outbreaks in winter leads to the formation of Levantine Intermediate Water (LIW) in the northern Levantine Sea. The LIW is then modified by dispersion as it is transported across the Mediterranean at intermediate depths of 200 - 300m, and descends to 1000-1500m as it exits from the Gibraltar Strait into the Atlantic Ocean, where it modifies a large water mass of global significance.

Compared to the LIW, the origin of the deep waters in the Eastern Mediterranean are less clear. While it is generally accepted that the Bottom Water (deeper than 2000m) is formed by waters cooled in the shallow Adriatic Sea, it is recognised that the more heterogeneous Deep Water (DW) in the 1000 - 2000m depth range could have multiple sources.

On the average, the residence time of the Mediterranean waters is on the order of 100 years. The fact that the entire sea is efficiently ventilated suggests that it is also very sensitive to climate variability; similarly the Mediterranean system can have an impact on local climate more significantly than its size suggests.

There is some evidence of long term warming effects in the deep waters of the Western Mediterranean Basin (Bethoux, *et al.*, 1990). In parallel, there is also an increase in nutrient levels in deep water (Bethoux, 1989), possibly resulting from anthropogenic inputs.

Various hypotheses have been advanced to date to explain the formation of LIW: isopycnal sinking of dense water from cyclonic regions (Ovchinnikov, 1984; Ovchinnikov and Plakhin, 1984), convection at continental shelf/slope regions (Bruce and Charnock, 1965; Georgopoulos *et al.*, 1989), convection in anticyclonic eddies (Brenner *et al.*, 1991), Ekman flux convergence near the coasts (Feliks, 1991), and wide-area convective overturning (Sur, *et al.*, 1992; Lascaratos *et al*, 1993). The heterogenous distribution of LIW in the Levantine Sea is maintained by these source mechanisms and complex dynamics (Özsoy *et al.*, 1989, 1991, 1993).

The possibility of Deep Water formation in the cyclonic Rhodes Gyre region (Ovchinnikov, 1984) Rhodes Gyre region, has been confirmed by recent observations (Gertman *et l.*, 1990; Sur *et al.*, 1992). In contrast to the analogous deep convection events in the west (Gascard, 1991), pre-conditioning is not essential for deep convection in the Rhodes Gyre region, a permanent cyclonic region of the Eastern Mediterranean.

The new observations of Sur *et al.* (1992) suggest that LIW and DW can simultaneously be formed in northern Levantine region, as suggested by Lascaratos *et al* (1993). However, this can only occur during severe winters, subject to interannual or decadal climate variability.

Garrett *et al.* (1992) indicate that the Mediterranean region is one of the areas of the world where interannual climatic variability seems to be the strongest. Variability in atmospheric forcing, as well as the prevailing oceanic circulation patterns (Özsoy *et al.*, 1991, 1993) could lead to the observed interannual dependence.

Such qualitative changes in the northern Levantine circulation have been detected in 1986/87, when deep convection in the Rhodes Gyre (Gertman *et al.*, 1990) coincided with drastic changes in the circulation, with the consequence of the northern Levantine being flooded by Atlantic Water (AW), which normally occupies the southern region (Özsoy *et al.*, 1991, 1993). Similar events of deep convection leading to changes in the basin-scale circulation have been demonstrated in the Western Mediterranean (Crepon *et al.*, 1989; Barnier *et al.*, 1989). These changes in the modality of circulation could in turn lead to changes in climate as a result of ocean-atmosphere interaction.

In the case of the 1992 mixing event, a large atmospheric anomaly in the region seems to have played an important role. It is known that a large negative atmospheric temperature anomaly, with a deviation of -3°C from climatic means, calculated over a period of several months, occurred in the Eastern Mediterranean, following the eruption of the Mt. Pinatubo volcano (Halpert *et al.*, 1993).

Black Sea

The spreading of the Mediterranean effluent into the Black Sea follows a very particular pattern of boundary mixing (Özsoy *et al.*, 1993). The Mediterranean water first spreads onto the shelf and becomes diluted by entraining the overlying Cold Intermediate Water. Then, descending the continental slope, it generates a pattern of intrusions and secondary circulations up to a depth of 500m, aided by the double diffusive ambient environment of the Black Sea interior, and the temperature-salinity anomalies of the sinking slope water. This, in turn, sets up a larger scale vertical circulation contributing to the mixing in the basin interior, across the halocline.

Winter convection leading to CIW formation is most effective within the upper part of the Black Sea, reaching depths of about 200 m or more. Comparison of recent data with historical profiles often indicate changes, especially in the potential temperature - salinity (θ - S) relationship (*e.g.* Murray *et al.*, 1991, Ivanov *et al.*, 1994).

Long-term data (more than 40 years in duration) suggest strong climatic changes in the features of this convective region (Sur *et al.*, in preparation), with synchronism suggested with the adjacent seas (Özsoy *et al.*, 1992). For example, an extreme event of cooling evidently took place in 1987, when similar effects were also noted in the surrounding seas, *e.g.* dense water intrusion into the Marmara Sea from the Aegean (Beşiktepe, 1991), and deep water formation in the Rhodes Gyre region (Gertman *et al.*, 1990). It is tempting to note that an extraordinary productivity event between May 1986 and July 1988 was detected from radioactive dating of fresh bottom sediments in the 'fluff layers' (Moore and O'Neill 1991). CIW formation with extreme properties was repeated in 1992, when deep water formation recurred in the Rhodes Gyre region (Sur *et al.*, 1992). These observations suggest important roles of climate in the heat stored and exchanged with the atmosphere, and the nature of this interaction should be investigated further.

Marmara Sea

Interannual changes are common in the Turkish Straits System, situated between two large basins much affected by the climatic fluctuations. Because its oceanography is either largely determined by *the conditions in the adjacent basins, and because the atmospheric* forcing has much in common between the individual basins, the Turkish Straits System sensitively responds to such changes.

For example, the fresh water inflow into the Black Sea is known to possess large seasonal and interannual variations; the seasonal discharges of large rivers (*e.g.* the Danube) can change by a factor of 3 between the minimum and maximum values (Sur *et al.*, 1994). More significantly, the changes in fresh water influx seems to result in interannual sea-level changes in the Black Sea, controlled by the flow through the Turkish Straits.

Salinity measurements suggest that low salinity waters created by the discharges of major rivers in the northwestern Black Sea reaches the southwest coast. The minimum salinity occurs in the March - August period, subject to significant differences in the timing and salinity value from one year to the next (Sur *et al.*, 1994).

Long-term variations are evident in sea surface temperature recorded at several stations in the Marmara region, with strong correlation between minimum and maximum temperatures at different stations (Özsoy *et al.*, 1986). Extremely cold temperatures of 3°C were observed in Florya during the winters of 1944 and 1954. Waters of $\sim$ 2°C were observed along the Black Sea entrance at Kumköy during 1954, at the same time when ice floes reached the Bosphorus from the north (Acara, 1958).

Evidence suggests that the mixing of the upper layer waters also depends on the long-term variations of weather. For example, we have seen that the upper layer salinity in the Marmara Sea reached a maximum of 30 during February 1987 as compared to the usual 25-27 observed during other winter periods. The near-surface ($5m$) salinity and temperature in the middle of the eastern basin of Marmara, shows this exceptional increase of salinity as compared to the winter months of other years. Baştürk *et al.* (1990) showed an increase in upper layer nutrients during the same year. The winter of 1987 was particularly severe, leading to deep mixing events in the entire region, including an exceptional deep water formation event in the Rhodes Gyre region of the Eastern Mediterranean (Gertman *et* *al.*, 1990) and a deepening of the main pycnocline in the Black Sea, (H. İ. Sur, personal communication). An extraordinary productivity event during the same period (between May 1986 and July 1988) was detected from radioactive dating of fresh bottom sediments at the bottom of the Black Sea (Moore and O'Neill 1991).

Exchanges through the Turkish Straits

The two-layer flows through the Bosphorus and Dardanelles Straits determine the fluxes between the Black Sea and the Mediterranean Sea.

The fluxes through the Bosphorus depend on the short term and seasonal variability of the strait dynamics, operating in the full range of possible forcing and flow configurations, *i.e.* blocked flows of the upper and lower layers, short term transients, and seasonal and interannual response to the net water budget of the Black Sea, which in turn, has highly variable elements (Oğuz *et al.*, 1990; Latif *et al.*, 1991; Özsoy, 1990; Özsoy *et al.*, 1992).

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