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Decadal biogeochemical history of the south east Levantine basin: Simulations of the river Nile regimes

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ABSTRACT

The south eastern Mediterranean is characterized by antiestuarine circulation which leads to extreme oligotrophic conditions. The Nile river that used to transport fresh water and nutrients into the basin was dammed in 1964 which led to a drastic reduction of fresh water fluxes, and later, changes in Egyptian agriculture and diet led to increased nutrient fluxes. In this paper we present the results of simulations with a biogeochemical model of the south eastern Mediterranean. Four experiments were conducted: (1) present day without riverine inputs; (2) Nile before damming (pre-1964); (3) post-damming 1995 Nile; and (4) fresh water and nutrient discharges of Israeli coastal streams. The present day input simulation (control run) successfully reproduced measured nutrient concentrations, with the exception of simulated chlorophyll concentrations which were slightly higher than observed. The pre-1964 Nile simulation showed a salinity reduction of 2 psu near the Egyptian coast and 0.5 psu along the Israeli coast, as well as elevated chlorophyll a concentrations mostly east of the Nile delta and north to Cyprus. The spring bloom extended from its present peak during February–March to a peak during February–May. The 1995 Nile simulation showed increased chlorophyll a concentrations close to the Egyptian coast. The Israeli coastal stream simulation showed that the effect of the Israeli coastal stream winter flow on chlorophyll converged to control concentrations within about one month, demonstrating the stability and sensitivity of the model to external forcing. The results of this study demonstrate the significance of fresh water fluxes in maintaining marine productivity, which may have large scale effects on the marine ecosystem.

1. Introduction

The Mediterranean sea is the largest (ca. 2,500,000 km^2) and deepest (average 1500 m, deepest 5250 m) marginal sea on earth. It is connected through the Straits of Gibraltar in the west to the Atlantic Ocean, and in the east to the Marmara and Black Seas at the Dardanelles, and, more recently through the Suez Canal to the Red Sea and Indian Ocean. A shallow ridge at the Straits of Sicily divides it into the western and eastern basins. The eastern Levantine basin, the region of interest in this work, is located at the southeastern corner of the Mediterranean (Fig. 1). The main characteristics of this marine region include: anti-estuarine thermohaline circulation, counter-clockwise long-shore current, high summer surface temperature and salinity, and extreme oligotrophic conditions. The precipitation:evaporation ratio decreases on a west-to-east gradient, which intensifies all of those characteristics.

The eastern Mediterranean water masses are formed by Atlantic water flowing eastward through the Straits of Gibraltar and the Straits of Sicily, warming and evaporating, and increasing in salinity from 36.15 at Gibraltar to 39 in the eastern Levantine (Maillard and Balopoulos, 2002). The modified Atlantic water, as well as the locally formed saline Levantine surface water, cools and sinks during winter, forming the Levantine intermediate water, which flows westward at depths of 200–500 m. Surface and intermediate water of the Levantine basin are subjected to seasonal changes, with surface water temperature ranging approximately from 16 to 28 °C and salinity approximately from 38.7 to 39.3. During summer, a sharp seasonal thermocline and halocline are formed to a depth of about 100 m.

Levantine waters are known to be highly oligotrophic (Azov, 1991; Berman et al., 1986; Gitelson et al., 1995; Krom et al., 1991). In fact surface nutrient concentration is below the detection limit for conventional methods and therefore, our knowledge of surface concentration is sketchy at best. The oligotrophy is caused by an entry of nutrient-poor Atlantic surface water at Gibraltar and further nutrient consumption within the surface eastward flow. This process leads to the formation of a nutrient depleted layer deepening on a west to east gradient (Pujo-Pay et al., 2011). The eastern Mediterranean is characterized by high deep water N:P ratio of ca. 23 and surface P limitation (Kress et al., 2005; Krom et al., 1991, 2005; Thingstad et al., 2005; Zohary and Robarts, 1998). Phytoplankton are N and P co-limited during summer.

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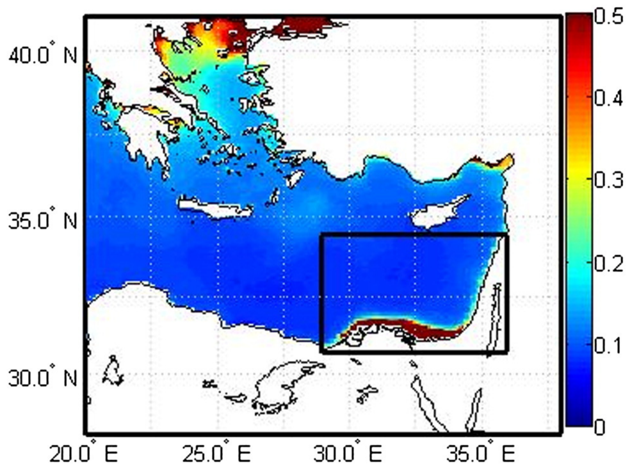

Fig. 1. East Mediterranean mean SeaWiFS chlorophyll concentration (1997–2010) map. The model domain is marked by a black rectangle at the southeastern corner.

In contrast to the general Mediterranean oligotrophy, a significant near-shore increase in chlorophyll a concentrations, resulting from coastal nutrient input and recycling from the sediment, is observed throughout the eastern Levantine basin (Barale et al., 2008; Figueras et al., 2004; Gitelson et al., 1996) as shown in Fig. 1. Chlorophyll measurements show low surface concentration of 0.1 mg m^{-3} (Fig. 1) and a Deep Chlorophyll Max (DCM) of ~0.25 mg m^{-3} (Maillard and Balopoulos, 2002) at a depth of 80–120 m, which deepens eastward (Christaki et al., 2001). Levantine phytoplankton cell sizes are mostly very low with ca. 60% of the cells smaller than 2 μm (Tanaka et al., 2007; Yacobi et al., 1995). Nutrients generally enter the marine environment through discharge of fresh water (Reeburgh, 1997). Naturally, the influence of terrestrial nutrient inputs is more evident in the coastal zone, especially in oligotrophic seas where nutrients are scarce. Additionally, rivers and other point sources are progressively becoming important sources of anthropogenic nutrient enrichment to the marine environment (Shahidul Islam and Tanaka, 2004). Within the eastern Levantine basin nitrogen influx by atmospheric inputs and fresh water discharge is estimated to be 72% of the total influx (Krom et al., 2010).

The Nile river has always been a major source of water and nutrients for Egyptian land and also for the Mediterranean Levantine basin (Nixon, 2003; Sharaf-el-Din, 1977). Until 1964 the annual Nile water discharge into the Mediterranean was 43×10^9 m^3 $year^{-1}$, most of which flooded between August and October. This flood led to a massive phytoplankton bloom tens of kilometers off the Nile outfalls, increasing cell counts by two-fold from 66×10^3 cell L^{-1} to 2×10^6 cell L^{-1} (Halim, 1960). When the Aswan high dam was completed in 1965, the water discharge dropped rapidly to almost no discharge today (Rasmussen et al., 2009). The maximum discharge now occurs in January while before the Nile damming, most of the water was discharged during August to October. Prior to the construction of the Aswan dam, the Nile plume extended to the Lebanese coast during flood and reduced the salinity of coastal water by up to 6 psu (Oren and Hornung, 1972). Apart from this local effect, the deep water formation rate in the Levantine basin increased by about 30% following damming (Skliris and Lascaratos, 2004).

Damming caused a shift in the Levantine phytoplankton community structure (Kimor and Wood, 1975). El-Sayed et al. (1995) identified a drop in Egyptian fish landings following 1964, and a gradual subsequent increase to about twice the pre-damming quantities. This increase might have been partially related to changes in fishing effort, but it is also attributed to an increase in nutrient discharge to the Mediterranean resulting from Egyptian population growth, a change in Egyptian diet that became more protein-based, adoption of chemical fertilizers in Egyptian agriculture, and the construction of sewage drainage systems in Egypt that helped disperse nutrients to the Mediterranean via the coastal lagoons (Nixon, 2003). Nixon's quantifications of the potential nutrient discharge change are presented in Table 1. These estimates suggest that by 1995 the inorganic phosphorus discharged doubled compared to the pre-1964 fluxes, and the discharge of inorganic nitrogen increased to about 16 fold.

The coastal plain of Israel is transected by ten streams and their tributaries (Bar-Or, 2000). These are small rivers, with a typical catchment area of a few hundred square kilometers and lengths of tens of kilometers. The ten Israeli coastal streams have undergone a similar process to the processes affecting the river Nile and other fresh water streams in the Mediterranean (Ludwig et al., 2009). Due to water shortage and increasing population, the need for water increased and with it most water sources are now being used for human consumption. These streams are now being used as drainage for floods and for treated sewage outlet (Bar-Or, 2000). The influx of nutrients into the eastern Mediterranean via streams is second only to the discharge of nutrient by sewage treatment plants and to industrial discharge. Using the method presented by Herut et al. (2000), and data from Herut et al. (2011), we estimate the annual nutrient flux to coastal waters at 300×10^6 mol nitrogen and 50×10^6 mol phosphorus.

Computer modeling of the processes that take place in the eastern Mediterranean sea has been the subject of numerous studies, with an emphasis on hydrography (Brenner et al., 2007; Pinardi et al., 2003; Zavatarielli and Mellor, 1995). The effects of the Nile damming on the Mediterranean water masses (Skliris and Lascaratos, 2004) were simulated but never the effect of the damming on the biogeochemistry. Since the damming of the Nile is considered a major driver for changes in the Levantine basin (Rilov and Galil, 2009) and given the small number of oceanographic measurements conducted in this basin before the dam was constructed, computer simulation can help us assess the effects of the historical changes in the river Nile outflow.

In this paper we investigate the role of riverine fresh water and nutrient inputs and specifically, the effect of the historic high water and nutrient fluxes compared with the current nutrient only flux on the Levantine biogeochemistry using a version of the biogeochemical flux model (BFM, Vichi et al., 2007a, 2007b) coupled to a three dimensional circulation model specifically calibrated (Suari, 2012) for this ultraoligotrophic region.

2. Methodology

To investigate the effects of coastal streams and river discharges in the southeastern Levantine basin we implemented a coupled hydrodynamic-ecosystem model.

Table 1
Annual fluxes of nutrients to the Mediterranean via the river Nile as calculated by Nixon (2003). Pre- and post-1964 fluxes were calculated by multiplication of the upstream concentration with water discharge. Human sources include potential N and P in wastewater discharge of the Egyptian urban population and are calculated by multiplication of the typical Egyptian diet with the population.

	10^6 mol $year^{-1}$		
	P	N	Si
Pre-1964 Nile			
Dissolved	100	479	3930
Sediment	125–250	Low	
Total	225–350	479	3930
Post-1964 Nile			
Dissolved	11	14	53
Sediment	–	–	–
Total	11	14	53
Human sources			
1965	77	857	
1985	216	2930	
1995	510	7710	