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Variability of atmospheric deposition of dissolved nitrogen and phosphorus in the Mediterranean and possible link to the anomalous seawater N/P ratio

Z. Markaki [a], M.D. Loÿe-Pilot [b], K. Violaki [a], L. Benyahya [b], N. Mihalopoulos [a,*]

[a] Environmental Chemical Processes Laboratory, Department of Chemistry, University of Crete, P.O. Box 2208, 71003 Heraklion, Greece
[b] Ecole Normale Supérieure, Unité Biogéochimie Marine, Montrouge, 92120 France; now at: Ecole Normale Supérieure, CERES-ERTI, 75005 Paris, France

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ABSTRACT

Atmospheric deposition of Total Dissolved Nitrogen (TDN) and Phosphorus (TDP) was studied in bulk deposition samples simultaneously collected at several locations around the Mediterranean, during one year period (June 2001–May 2002). Dissolved Inorganic Phosphorus (DIP) and Nitrogen (DIN) atmospheric deposition fluxes ranged from 243 to 608 µmol $m^{-2}y^{-1}$ and from 18.1 to 47.7 mmol $m^{-2}y^{-1}$ respectively, presenting an important spatial variability within the basin.

Wet deposition was found to be the main factor controlling DIN deposition in the Mediterranean. The amount of DIN deposited during the wet period was 2–8 times higher than that deposited during the dry season. It was estimated that about 65% of the total DIP was deposited during the wet period. Dust events as well as regional biomass burning were also found to contribute significantly to the DIP deposition. A significant percentage of the TDN and TDP of the samples were in organic form with Dissolved Organic Phosphorus (DOP) and Nitrogen (DON) accounting for 38% and 32% of TDP and TDN respectively.

DIN/DIP molar ratio of the bulk deposition varied depending on the location of the sampling site in the Mediterranean basin, presenting an increasing trend from the Western (60) to the Eastern Mediterranean basin (105). This variation is similar to that observed in the seawater column, indicating an important link between atmospheric deposition and seawater productivity of the area.

1. Introduction

The Mediterranean Sea is known to be among the most oligotrophic areas in the world (Redfield et al., 1963; Sournia, 1973; Bethoux et al., 1998). Especially the Eastern basin is considered to be an ultra oligotrophic system as compared to the Western basin (Krom et al., 2003). Studies performed in the area proved that it is not only nutrient depleted but it is also highly deprived in P relative to N (Krom et al., 2005). An unexpectedly high N/P molar ratio has been observed in Mediterranean deep water (20:1–28:1), significantly higher than the normal oceanic Redfield ratio (16:1) (Mc Gill, 1965, 1969; Coste and Minas, 1967; Coste et al., 1988; Berland et al., 1980; Krom et al., 1991) and displaying an eastward increasing trend from about 20:1–24:1 in the Western to 28:1 in the Eastern Mediterranean.

The atmospheric deposition of nitrogen and to a lesser extent of phosphorus has been recognized as significant in the Mediterranean region. The atmospheric nitrogen flux to the whole Mediterranean Sea is equal to the riverine input (Martin et al., 1989; Loÿe-Pilot et al., 1990a,b; UNEP/WMO, 1997). Krom et al. (2004) presented a detailed nutrient budget for the Eastern Mediterranean where atmospheric inputs of DIN and DIP account for 61% and 28% of the total budget of N and P respectively.

As a consequence, the atmospheric deposition is expected to strongly influence the marine P and N cycles and the trophic status of the Mediterranean Sea (Migon et al., 1989; Loÿe-Pilot et al., 1990a,b; Bergametti et al., 1992; Guerzoni et al., 1999; Herut et al., 1999, 2002; Kouvarakis et al., 2001; Ridame and Guieu, 2002; Markaki et al., 2003). The atmospheric input to the Mediterranean Sea displays a high N/P ratio for dissolved or soluble inorganic forms (Migon et al., 1989; Herut and Krom, 1996; Ridame et al., 2003), which could be one possible reason of the high N/P ratio in deep sea waters (Guerzoni et al., 1999; Kouvarakis et al., 2001; Ridame et al., 2003; Krom et al., 2004). This high N/P ratio in the Eastern Mediterranean could be retained within the system by the absence of significant denitrification in either the sediments or intermediate water (Krom et al., 2004). The above observations emphasize the need for a better characterisation of the atmospheric deposition of nutrients such as N and P, in the marine Mediterranean ecosystem.

Despite the importance of atmospheric deposition in biogeochemical cycling of N and P in the Mediterranean, no simultaneous data from various locations around the Mediterranean have been collected so far. In addition, the potential role of organic forms of N and P has been not considered. Especially for DON (Dissolved Organic Nitrogen) recent estimates (Spokes et al., 2000; Cornell et al., 2003; Mace et al.,

* Corresponding author.
E-mail address: mihalo@chemistry.uoc.gr (N. Mihalopoulos).

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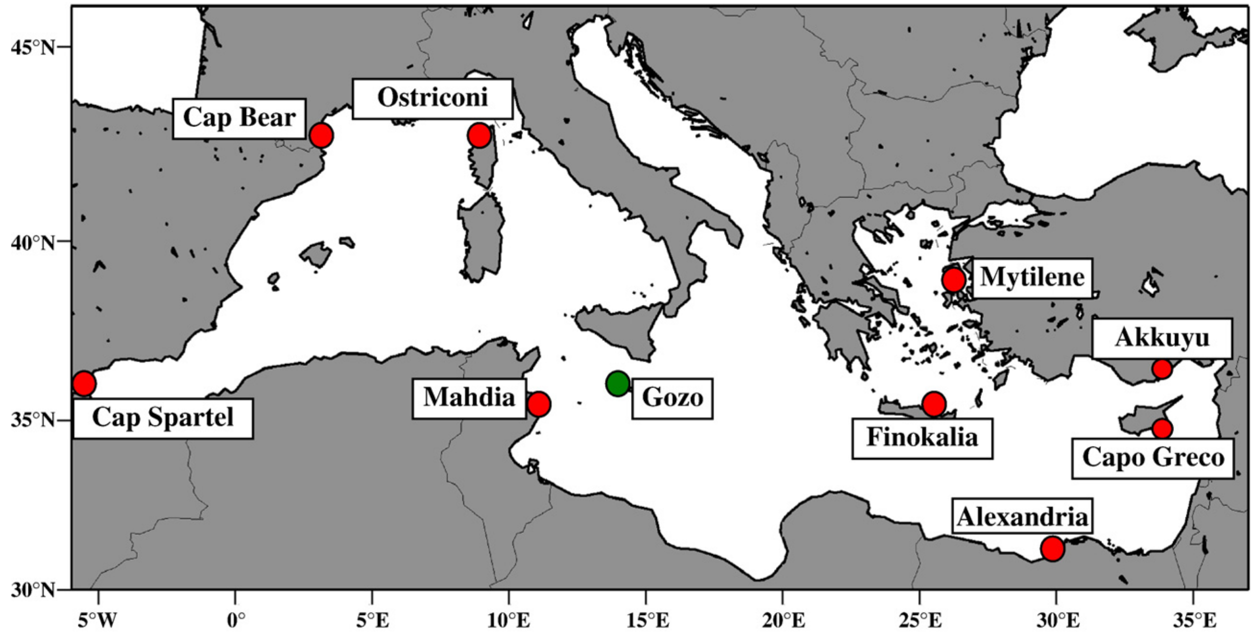

Fig. 1. Location of ADIOS sampling sites in the Mediterranean.

2003) reported that it can account for 20 to 60% of the total DIN flux. Finally no effort has been made to link the increasing seawater N/P ratio from the west to the east with the atmospheric deposition.

This work tries to fill these gaps by reporting results on the temporal and spatial variability of the atmospheric deposition of Total Dissolved Nitrogen (TDN) and Phosphorus (TDP) based on data simultaneously collected at several locations around the Mediterranean, during one year period.

2. Sampling and analysis

2.1. Sampling sites

Ten sampling stations were implemented in the frame of the ADIOS EU funded project along the northern and southern coasts of the Mediterranean Sea in order to take into account the main sources and deposition regimes over the Mediterranean basin (Fig. 1) (Guieu et al., 2010-this issue). The selected sites were chosen to

Table 1
Main characteristics of the ADIOS sampling sites.

	Station coordinates	Altitude	Geological substrate	Vegetation	Local soil conditions	Vicinity of human settlements	Distance to the sea
Morocco Cap Spartel	35°47N . 05°54 W	326 m	Silicic sandstones	Low shrubland	Soil covered by vegetation	5 km NW of the town of Tangier	1500 m
France Cap Bear	43°31N . 03°09 E	100 m	Gneiss	Low shrubland and bare rocks	Soil covered by vegetation and rocks	20 km from the town of Perpignan	500 m
France Corsica Ostriconi	42°40N . 09°04 E	60 m	Granite	Low shrubland and bare rocks	Soil covered by vegetation and rocks	A few houses, 500 m	800 m
Tunisia Mahdia	35°25N . 11°02 E	10 m	Sands and gravels	Olive plantations and low vegetation	Building terrace	2 km from the town of Mahdia	200 m
Malta Gozo	36°04N . 14°13 E	160 m	Limestone sand	Low shrubland and rocks	Soil covered by vegetation and rocks	Small villages to the South	400 m
Greece Crete Finokalia	35°20N . 25°40 E	130 m	Limestones and marls	Low shrubland	Soil covered by vegetation	Small village at 2 km	250 m
Greece Lesbos Mytilene	39°02N . 26°36 E	100 m	Serpentinites and peridotites	Low shrubland	Soil covered by vegetation	10 km from the town of Mytilene	1000 m
Egypt Alexandria	31°12N . 29°53 E	12 m	Sands and alluvial fans	No	Building terrace	Upwind of the town of Alexandria by N winds	100 m
Cyprus Cavo Greco	34°57N . 34°05 E	40 m	Limestones	Few vegetation	Hard rocks	Broadcast station at 200 m No village in the vicinity	800 m
Turkey Akkuyu	36°08N . 33°32 E	50 m	Limestones and marls	Shrubland	Soil covered by vegetation	A few houses at 1 km No village in the vicinity	300 m