# Description of the mechanism leading to the development of hypoxic/seasonal anoxic area In Amvrakikos Gulf, Western Greece


Krystallia Kountoura[1] and Ierotheos Zacharias[1]

[1]University of Ioannina, Department of Environmental and Natural Resources Management, Agrinio, Greece.

E-mail: kkountoura@cc.uoi.gr, izachari@cc.uoi.gr



University of Ioannina

European Geosciences Union General Assembly 2011

Vienna | Austria | 03 – 08 April 2011


## Introduction

The environmental problem of hypoxia has increased its occurrence in estuarine and coastal areas, daily as only the last 50 years, more than 400 hypoxic zones have been reported all over the world (Diaz and Rozenberg 2008).

In coastal regions, the occurrence of coastal hypoxia can be a natural phenomenon, human influenced, or a result of complex interactions between climate, weather, basin morphology, circulation patterns, freshwater inflows, stratification, mixing and nutrient loadings (Levin et al. 2009, Pena et al. 2010).

Amvrakikos Gulf, one of the most important wetlands in Europe and particular in Greece, is a shallow and semi-enclosed embayment, in Western Greece.

The mean depth of the gulf is equal to 26 m (fig. 1), while its maximum depth is equal to 63 m, at the eastern site of the gulf. Its only link to the open Ionian Sea is a narrow strait, the Preveza channel, which is about 600 m wide, its length is equal to 3 km and its mean depth is 8.5 m.

The study area receives the freshwater input from two rivers, Arachthos and Louros, with important water discharges.

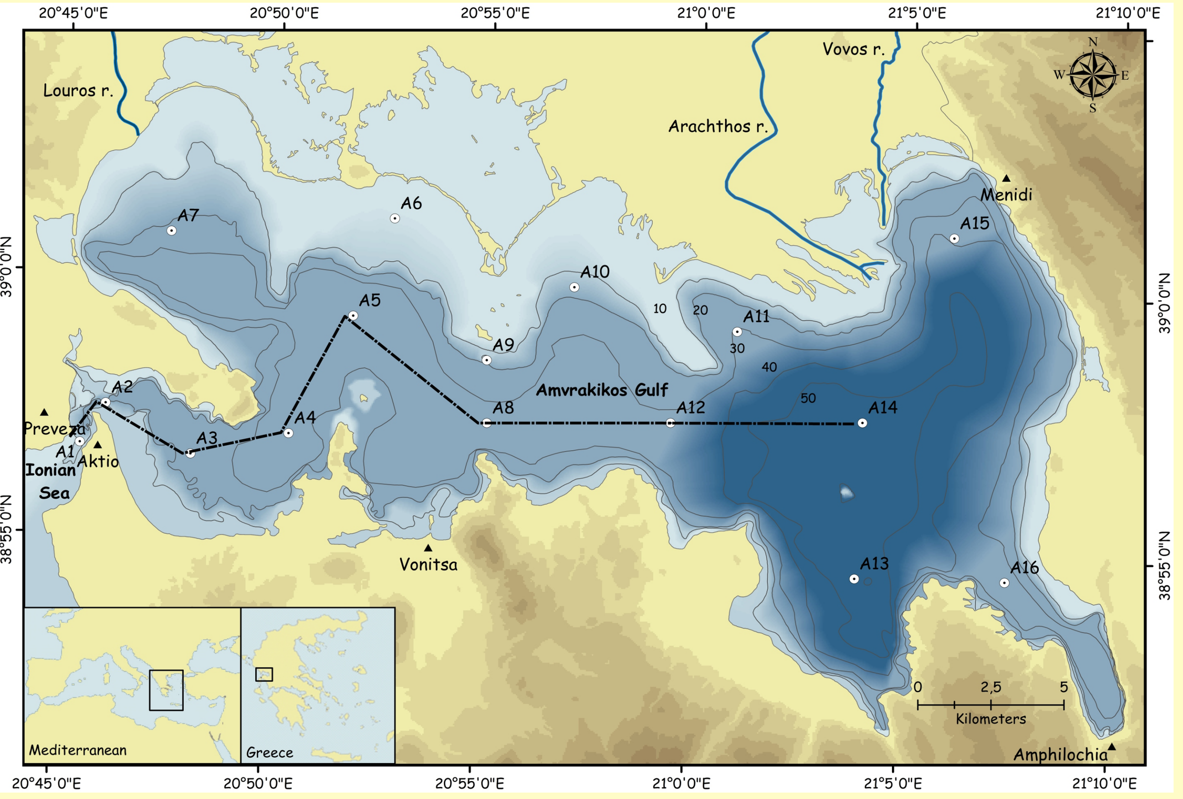


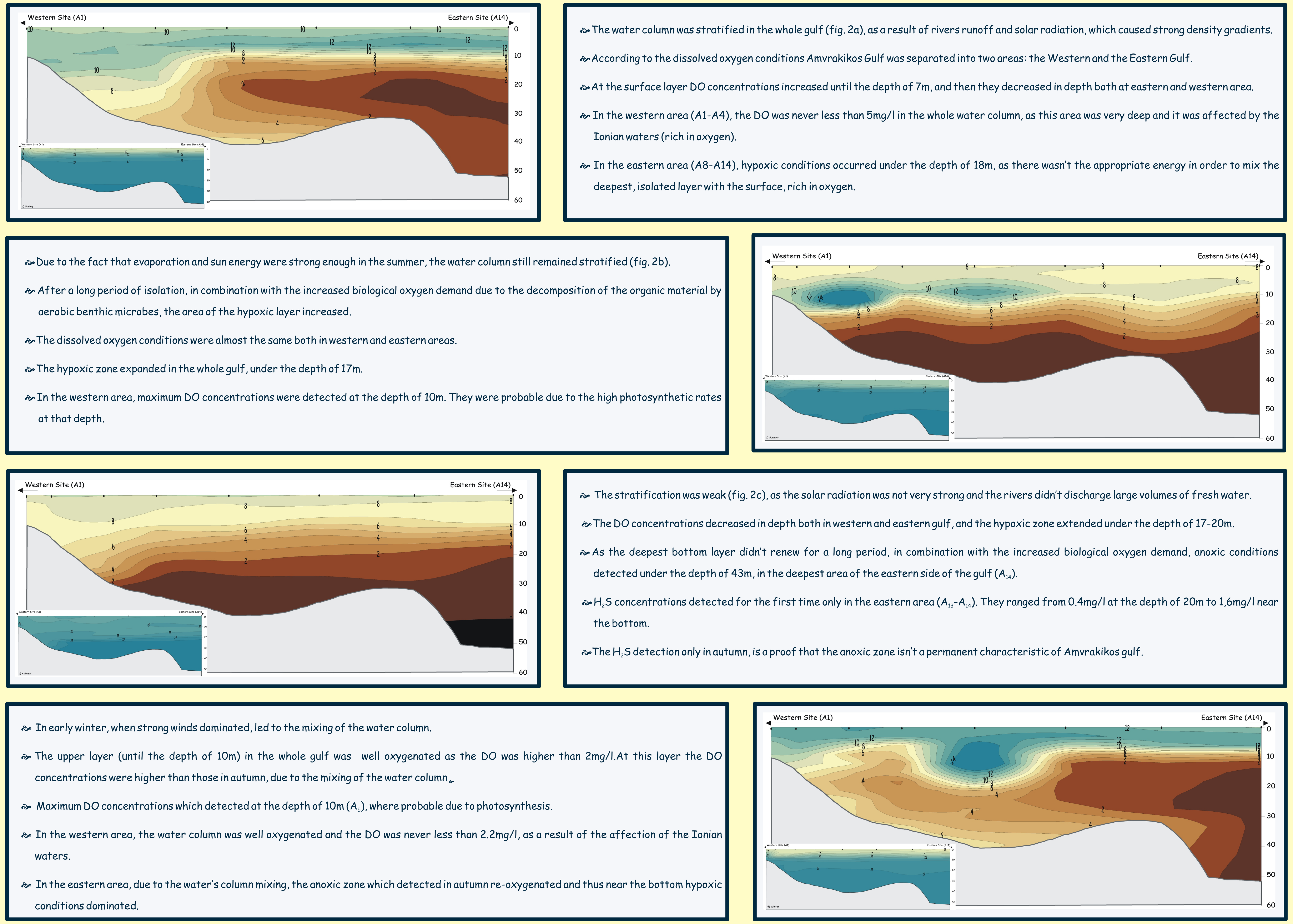

Fig. 1.Amvrakikos Gulf and sampling stations (dots). The dashed line represents the transect $A_1$-$A_{14}$.

The main aim of this study, is to determine the DO conditions in Amvrakikos Gulf and the formation mechanism of seasonal anoxic zone. For this reason four sampling cruises organized (2009-2010) and the data is represented here.

## References


1. Balopoulos, E., Papageorgiou, E., 1989. Physical oceanographic characteristics and sea currents in Amvrakikos Gulf (Eastern Ionian Sea). In: Tsiavos, Ch. (Ed.), Oceanographic study of the Amvrakikos Gulf. Volume 1. Physical Oceanography. Final Report. Athens, Greece (in Greek).
2. Diaz, R.J., Rosenberg, R., 2008. Spreading dead zones and consequences for marine ecosystems. Science 321 (5891), 926-929.
3. Friligos, N., Psilidou, R., Xatzigewrgiou, E., Pappas, G., 1989. Seasonal variations on nutrients and dissolved oxygen. In: Tsiavos, Ch. (Ed.), Oceanographic study of the Amvrakikos Gulf. Volume 3. Chemical Oceanography. Final Report. Athens, Greece (in Greek).
4. Kapsimalis, V., Pavlakis, P., Poulos, S.E., Alexandri, S., Tziavos, C., Sioulas, A., Filippas, D., Lyskousis, V., 2005. Internal structure and evolution of the Late Quaternary sequence in a shallow embayment: The Amvrakikos Gulf, NW Greece. Marine Geology 222-223, 399-418.
5. Levin, L.A., Ekau, W., Gooday, A.J., Jorissen, F., Middelburg, J.J., Naqvi, S.W.A., Neira, C., Rabalais, N.N., Zhang, J., 2009. Effects of natural and human-induced hypoxia on coastal benthos. Biogeosciences, 6, 2063-2098.
6. Pena, M.A, Katsev, S., Oguz, T., Gilbert, D., 2010. Modeling dissolved oxygen dynamics and hypoxia. Biogeosciences, 7, 933-957.


## Results




- The water column was stratified in the whole gulf (fig. 2a), as a result of rivers runoff and solar radiation, which caused strong density gradients.
- According to the dissolved oxygen conditions Amvrakikos Gulf was separated into two areas: the Western and the Eastern Gulf.
- At the surface layer DO concentrations increased until the depth of 7m, and then they decreased in depth both at eastern and western area.
- In the western area (A1-A4), the DO was never less than 5mg/l in the whole water column, as this area was very deep and it was affected by the Ionian waters (rich in oxygen).
- In the eastern area (A8-A14), hypoxic conditions occurred under the depth of 18m, as there wasn't the appropriate energy in order to mix the deepest, isolated layer with the surface, rich in oxygen.

- Due to the fact that evaporation and sun energy were strong enough in the summer, the water column still remained stratified (fig. 2b).
- After a long period of isolation, in combination with the increased biological oxygen demand due to the decomposition of the organic material by aerobic benthic microbes, the area of the hypoxic layer increased.
- The dissolved oxygen conditions were almost the same both in western and eastern areas.
- The hypoxic zone expanded in the whole gulf, under the depth of 17m.
- In the western area, maximum DO concentrations were detected at the depth of 10m. They were probable due to the high photosynthetic rates at that depth.

- The stratification was weak (fig. 2c), as the solar radiation was not very strong and the rivers didn't discharge large volumes of fresh water.
- The DO concentrations decreased in depth both in western and eastern gulf, and the hypoxic zone extended under the depth of 17-20m.
- As the deepest bottom layer didn't renew for a long period, in combination with the increased biological oxygen demand, anoxic conditions detected under the depth of 43m, in the deepest area of the eastern side of the gulf ($A_{14}$).
- $H_2S$ concentrations detected for the first time only in the eastern area ($A_{13}$-$A_{14}$). They ranged from 0.4mg/l at the depth of 20m to 1,6mg/l near the bottom.
- The $H_2S$ detection only in autumn, is a proof that the anoxic zone isn't a permanent characteristic of Amvrakikos gulf.

- In early winter, when strong winds dominated, led to the mixing of the water column.
- The upper layer (until the depth of 10m) in the whole gulf was well oxygenated as the DO was higher than 2mg/l.At this layer the DO concentrations were higher than those in autumn, due to the mixing of the water column.
- Maximum DO concentrations which detected at the depth of 10m ($A_5$), where probable due to photosynthesis.
- In the western area, the water column was well oxygenated and the DO was never less than 2.2mg/l, as a result of the affection of the Ionian waters.
- In the eastern area, due to the water's column mixing, the anoxic zone which detected in autumn re-oxygenated and thus near the bottom hypoxic conditions dominated.

Fig. 2. Vertical profiles of dissolved oxygen (mg/l) and density (inside) along transect $A_1$-$A_{14}$ in a)spring, b)summer, c)autumn and d)winter

## Conclusions

- The main reasons that make Amvrakikos Gulf prone to hypoxia/anoxia are:

### 1. Currents

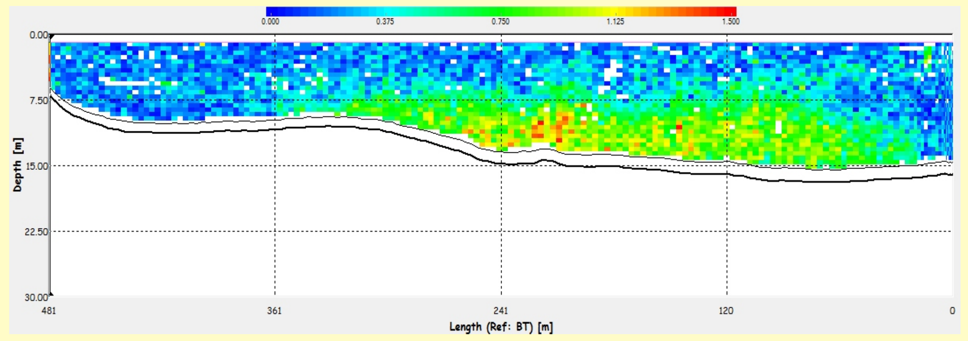



Fig. 3. Currents speed (m/s) transect in the entrance of Amvrakikos Gulf.

While the current speeds in the entrance of the gulf are very high (fig. 3), in the rest of the gulf they are very low (less than 0.02m/s) (Balopoulos & Papageorgiou, 1989). Thus, the Ionian water, rich in oxygen, can't replace the oxygen poor water which exists in the eastern area.

### 2. Physical Energy

Amvrakikos Gulf is characterized by low surface elevation (0.43m) and the wind speed is rarely higher than 10 m/s. However there can be meteorological events where the wind speed can be very strong, mainly in winter.As a result winds do not provide the system with the appropriate energy, in order to mix.

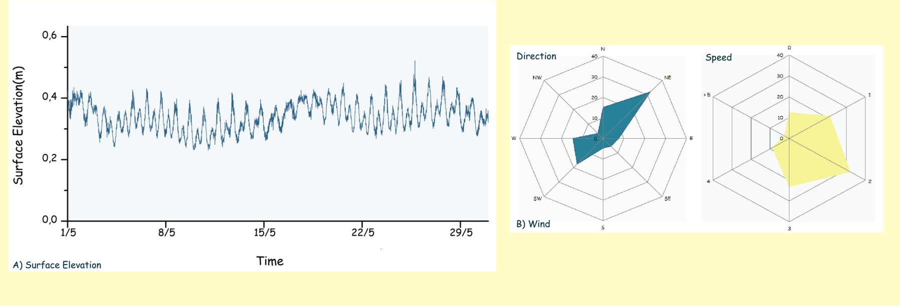



Fig. 4. A) Surface elevation (m) (May 2009) in Aktio. B) Annual wind speed and direction during 2008-2009 in Amvrakikos Gulf.

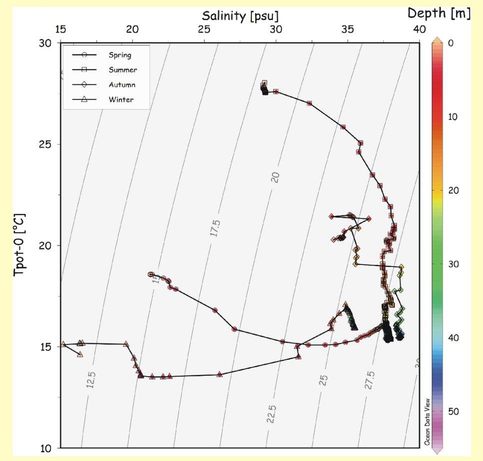



Fig. 5. T-S diagram from a representative station ($A_{14}$).

### 3. Stratification & Bottom Topography

The gulf receives freshwater inputs from Arachthos and Louros Rivers (mean water discharges 70 $m^3/s$ and 19 $m^3/s$, respectively) (Kapsimalis et al., 2005). From the observation of density distributions (fig. 2), it is clearly visible that the water column was stratified almost throughout the year due to either salinity or temperature. According to fig. 5, due to stratification the bottom mass, was isolated from spring to autumn, and it was mixed with the upper masses only in winter, as its characteristics changed.

- The formation mechanism of hypoxic/anoxic zone in Amvrakikos Gulf is the following:

Spring: Stratification, due to rivers runoff and strong solar radiation, led to the oxygen level decrease near the bottom.

Summer: The extensive isolation in combination with the increased biological oxygen demand, led to the extension of the hypoxic zone.

Autumn: The stratification in the water column was weaker, but after long isolation of the bottom water, anoxic conditions detected.

Winter: When the winds dominate, the water column mixes and finally a part of the bottom water is being re-oxygenated.

- Amvrakikos Gulf can be divided into two parts, the western and eastern area, with important differences occurring between them (fig. 6).

1. Within the western area, the water column was well oxygenated during winter and spring and hypoxic conditions occurred only in summer and autumn.
2. The eastern area was hypoxic throughout the year and anoxic conditions occurred only during autumn.

- Comparison with former studies (Friligos et al. 1989) showed that the seasonally hypoxic eastern area in 1987 converted into a seasonally anoxic area in 2009, indicating the possible degradation of the gulf's environmental state within the last 20 years.

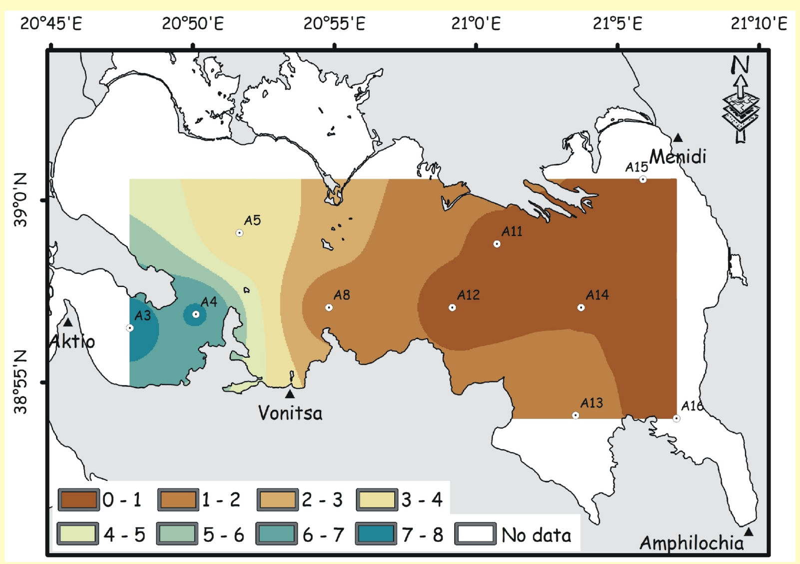



Fig. 6. DO differences between the western and eastern gulf (Spring 2009).