Greek Argo: Towards monitoring the Eastern Mediterranean – First deployments preliminary results and future planning

D. Kassis (1, 2), L. Perivoliotis (1) and G. Korres (1)

(1) Institute of Oceanography, Hellenic Centre for Marine Research. dkassis@hcmr.gr

(2) *Department of Naval Architecture and Marine Engineering, National Technical University of Athens*

Abstract: The Greek Argo initiative initiated its activities in 2010 with the first successful Greek float deployment in the Cretan Sea. During the last two years, the Greek-Argo infrastructure has become a member of Euro-Argo ERIC and therefore fully aligned with the key objectives of the European infrastructure. During the upcoming years Greek Argo aims to fill gaps in under-sampled sea areas of the Eastern Mediterranean basin such as Aegean, Ionian and Western Levantine Seas.

Within this work Greek Argo's new monitoring capacities and future planning are presented. We additionally present preliminary results from previous deployments showing the level of variability and signals of different origin water masses at subsurface and deep layers for Ionian and Cretan Seas. Furthermore, additional features of these areas are described as data analysis reveals intermediate layers circulation subsystems, a dynamical behavior of the basin's upper thermocline and intermediate/deep water masses spatial variability. A first assessment is also presented regarding biochemical profiles recorded from the float in the Cretan Sea which is the first autonomous profiler with a dissolved oxygen sensor in the basin.

Keywords: Regional Seas, TS profiles, Dissolved Oxygen, Profiling Floats

1. INTRODUCTION

Being the first in-situ, global ocean-observing network in the history of oceanography, autonomous profiling floats have been expanding into regional seas providing crucial information for their dynamic processes. Lately, the expansion of the so-called Argo Network into Regional Seas has upgraded monitoring and forecasting activities in enclosed sea basins giving the opportunity of more enhanced studies of the mesoscale and sub-mesoscale dynamics dominating in such areas. This evolution is the outcome of the combined efforts of the new formed Euro-Argo Research Infrastructure www.euro-argo.eu and several multinational initiatives. Since the second half of 2012, Greece has established national contribution to the ARGO project. The Greek Argo infrastructure www.greekargo.gr is funded by the National Strategic Reference Framework (NSRF) while it is a member of the Euro-Argo ERIC and therefore fully aligned with the key objectives of the European infrastructure.

The Greek Argo initiative aims to contribute to an enhanced monitoring over Aegean and Ionian seas as well as Eastern Mediterranean region in general. The Aegean and Ionian basins present high variability and transitional characteristics as water masses of different origin meet and interact. The physical characteristics and circulation patterns of the wider area have been studied since the 80's. The results reveal the significant role of these two basins in the hydrology of the Eastern Mediterranean which affects the circulation and balance of the wider region in both seasonal and inter annual timescales (Ovchinnikov 1984; Georgopoulos et al., 1989; Theocharis et al., 1990; The POEM Group, 1992; Robinson and Malanotte-Rizzoli 1993; Theocharis et al., 1993; Roether *et al.*, 1996; Pinardi and Masetti 2000). The three major water masses of the area are namely: the Modified Atlantic Water (MAW), that can usually be identified as a subsurface minimum of salinity between 30 and 200m depth, the Levantine Intermediate Water (LIW), that is identified by its salinity maximum in the layer between 200 and 600m depths and a colder and less saline transitional water mass in the layer between 700 and 1600m. The interaction between these two basins is also important for the dynamics of the area and a subject of study. Research in the past showed that the Levantine origin Cretan Intermediate Water (CIW) which is formed in the South Aegean basin and is slightly denser than (LIW), enters Ionia basin by a northward flow through the west Cretan Arc Straits. (Nittis et al., 1993; Zodiatis 1993b; Astraldi et al., 1999; Kontoyiannis et al., 1999; Lascaratos et al., 1999; Theocharis et al., 1999a; Tsimplis et al., 1999; Vervatis et al., 2011). During 2009 and 2010, an incident of high salinity intermediate water branches reaching into the Ionian Basin was indicated with characteristics similar to the CIW (Kassis et al., 2012).

2. OPERATIONAL PLAN - ACTIVITIES

The operational action plan of Greek Argo infrastructure included the purchase and deployment of 25 new floats for the next years, covering in that way semantically the future medium term monitoring needs of the whole region. In this plan many factors were taken into account in order to achieve the best monitoring results. Mainly, the deployments were planned so as to cover understudied basins of the region such as Aegean, Eastern Ionian and Western Levantine, in regard with the complex topography of each area and its general circulation features that are the main factors of float losses. An interesting statistic outcome of the Greek Argo strategic planning was that the lifetime expectancy of the floats for the wider region of the Eastern Mediterranean Sea appeared to be 20% less than of those in the Western part, mainly due to complex bathymetry and topography of the region.

2.1. Float deployments

During 2010, HCMR procured (using internal funds) and deployed a PROVOR-CTS3 float initiating the Greek Argo programme. The float was deployed in the Cretan Sea during June 2010, its lifetime ended in May 2012 after a successful recovery and redeployment operation in November 2011. Between October 2013 and November 2014, 7 new deployments were achieved from HCMR's Argo operational team. The first deployment took place in October 2013, under the framework of PERSEUS FP7 project, in the Cretan Sea at approximately 15nm north-west of Heraklion port. The float was lost 6 months after in the South-east straits of Aegean basin but it was detected and recovered by the port authorities under the guidance of Greek Argo operational team. The float is a PROVOR DO type being the first float in Aegean equipped with a dissolved oxygen sensor additional to standard CTD float's instrumentation and is to be redeployed in the same region. In November 2013 and March 2014, two NOVA type standard CTD floats were deployed in the Northern and Central Ionian basin in the framework of IONIO Interreg-III project, being the first Greek Argo floats in Ionian Sea. During the last 3 months of 2014, 4 additional deployments were accomplished by the Greek-Argo team. The floats were purchased by the Greek Argo RI and were deployed in the North, Central, South Aegean and South Ionian accordingly. All floats integrate an Iridium satellite telemetry system which provides a dual telecommunication capability allowing modification of the configuration in real-time, while the one in Central Aegean comprises an additional Dissolved Oxygen sensor. The deployments information and current location of the 6 operating Greek floats are presented in table 1 and figure 1.

All floats are following the recommendations of MedArgo (Poulain et al., 2007). More specifically, the drifting depth is 350 m which is near the depth of the Levantine Intermediate Water (LIW) core. The cycle length is set to 5 days in order to obtain useful estimates of currents, as longer cycles are not able to represent the circulation in the vicinity of the intricate coastlines of regional Mediterranean Seas.

TYPE	WMO	DATE OF DEPLOYMENT	LAT	LON
NOVA	6901887	13/11/2014	36.25	21.50
NOVA OXYGEN	6901886	12/11/2014	37.08	23.91
NOVA	6901885	08/10/2014	35.79	25.12
NOVA	6901884	07/10/2014	36.92	24.25
NOVA	6901883	14/03/2014	38.14	20.24
NOVA	6901882	28/11/2013	39.91	19.32

Table 1. Deployments of the active Greek floats in the Aegean and Ionian basins.

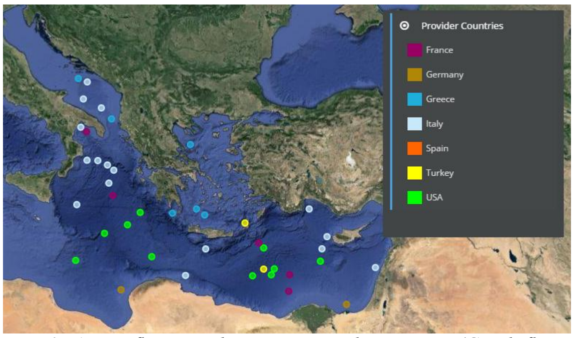

Fig. 1. Active floats in the Eastern Mediterranean (Greek floats with blue dots) www.greekargo.gr *(February 2015)*

Moreover, the assimilation of profiler displacements becomes inefficient to correct modelled velocities if the cycle length is longer than the typical Lagrangian integral time scale characteristic of the circulation at 350m (Molcard et al., 2003). The profiling depth for this configuration is set to 1000m and due to irridium telecommunication technology a maximum time of 30min is estimated to be the surface time for the localization and data transmission.

3. FEATURES PRESENTED

The analysis of the so far acquired profiles and trajectories shows a variety of hydrodynamic features of the monitoring areas. In the Cretan Sea, the recorded trajectories depict complex circulation patterns with a number of different in size and intensity mainly cyclonic subsystems.

3.2 Deployments in the Cretan Sea

Regarding mesoscale circulation in the basin, the dominant eddies of the upper layers are the West Cretan anticyclone and the Cretan cyclonic gyre forming a dipole that converge in the centre of the basin (Theocharis et al., 1999a). The latter is recorded from the 1st Argo float's orbit after its deployment during the summer of 2010 which follows a cyclonic path of an approximately 30 km radius indicating a significant westward displacement of the eastern cyclone. The perfect fit of the float's path after a comparison against satellite altimetry and the derived geostrophic velocity field, confirms the existence of the cyclone with a signal from surface down to deeper intermediate layers where the float was drifting (350m). After a similar comparison with the Aegean Sea hydrodynamic model output, on a run that is not assimilating data from this specific float, a good representation of the cyclone is shown (fig. 2).

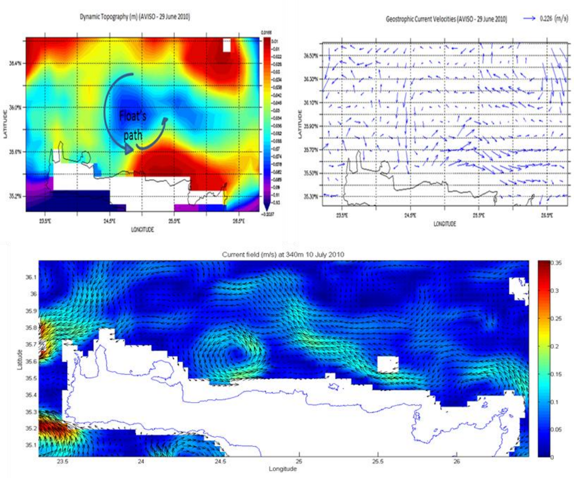

Fig. 2. Satellite SSH vs 6900795 trajectory (upper left); Sea Surface Geostrophic Velocities (upper right); Poseidon hydrodynamic model output of monthly average current field at 340m depth during July 2010.

The model is based on the Princeton Ocean model (POM) and was initially developed as part of the Poseidon-I system (Korres et al., 2002).

The altimeter products were produced by Ssalto/Duacs and distributed by Aviso, with support from Cnes (http://www.aviso.altimetry.fr/duacs/)

The second float deployed in the area was a PROVOR-DO type (WMO 6901881), which operated for 6 months (November 2013 – March 2014) before its signal was lost in the Eastern straits of the Cretan basin. During the first two months of its operation, its trajectory overlapped with the path of 6900795 float. A comparison of the measured profiles for two sub-regions (South-center and South-east) between 2011 and 2013 shows significant alternation of the physical properties. In 2011, the intermediate layers (100 – 600m) are presented saltier and slightly warmer than what has been recorder in the end of 2013. At surface and subsurface layers the picture is reversed with higher salinity values recorded in 2013 especially in the South-central part of the basin (fig. 3). The large salinity averaged differences (~0.1 psu) of the intermediate layers between the two periods, result in the discrete water masses signals in the T-S diagram constructed using the profiles of each float in the two different sub-regions (fig. 4). The high-salinity core water (S > 39.1) with characteristics similar to CIW, that occupied these layers during 2011, is replaced by water masses in the same density range (29.10–29.2 kg·m−3) indicating a LIW intrusion wich associated with temperature and salinity in the ranges of 14–15 ^{o}C and 39.02-39.07 psu, respectively. This is also supported from the comparatively low dissolved oxygen concentration recorded in the layers below 100m during November-December of 2013 from the PROVOR-DO float which conducted a West-east transect following the Cretan coastline. A spur of dissolved oxygen maximum (215-220 μmkg^{-1}) highly correlated with the boundaries of the halocline is recorded while the underlying layers present values below 205 μmkg^{-1} (fig. 5). This can be associated with inflowing LIW from the northwestern Levantine Sea which is poorer in oxygen, than the intermediate and deep waters of the Cretan Sea (Souvermezoglou et al., 1999).

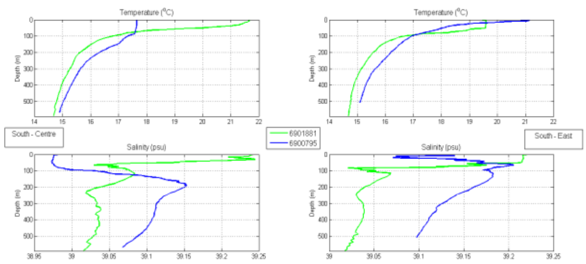

Fig. 3. Average Temperature (up) and Salinity (down) profiles for the years 2011 (blue) and 2013 (green) for the Central (left) and the Eastern (right) part.

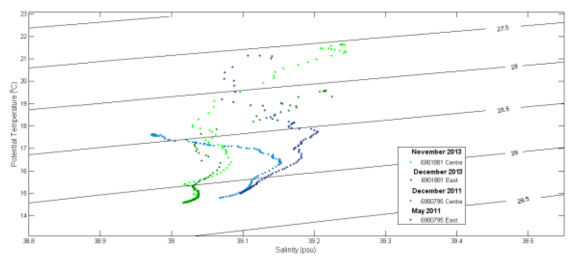

Fig. 4. Θ-S diagram for the Central (2011 light blue, 2013 light green) and the Eastern (2011 dark blue, 2013 dark green) part.

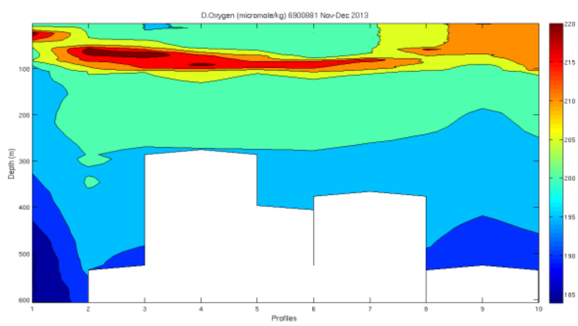

Fig. 5. Dissolved oxygen concentration measured by 6901881 float during a centre to east transect.

3.2 Deployments in the Ionian Sea

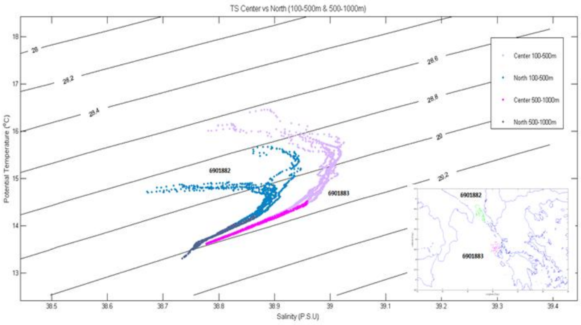

Fig. 1. Figure captions shall be written in italic 8 pt font with consecutive numbering even if they are maps or photographs

4. CONCLUSIONS

The first Argo measurements in the two basins show significant variability with signals of different origin water masses at subsurface and deeper layers. In the Cretan basin, mesoscale circulation patterns together with a number of smaller mainly cyclonic subsystems are traced in the floats trajectories. Regarding the upper layers, the westward displacement of the Cretan cyclone together with an inter-annual variability in the salinity signal, traced all along the central part of the basin until the South-east, are the most important presented features. For the Ionian basin …

The new-formed Greek Argo infrastructure can play a significant role through additional float deployments that will fill gaps in under-sampled sea areas of the Eastern Mediterranean basin such as Aegean, Ionian and Western Levantine Seas. This network of profiling floats is, for the first time, providing continuous profiles of physical and biochemical parameters from enclosed basin such as Aegean Sea. The use of these data will have short and long term benefits such as more comprehensive surveys of sea water processes and interactions and more enhanced operational forecasting and climate studies.

Acknowledgements

This work has been supported by the "Greek Research Infrastructure for Observing the Oceans – GREEK ARGO" project (ERDF 2007-2013) and the IONIO Interreg-III project funded by the European Territorial Cooperation Operational Programme "Greece-Italy" (2007 – 2013).

REFERENCES

Astraldi, M., Balopoulos, S., Candela, J., Font, J., Gacic, M., Gasparini, G.P., Manca, B., Theocharis, A. and Tintoré J. (1999). The role of straits and channels in understanding the characteristics of Mediterranean circulation. Progress in Oceanography 44 (1– 3), 65–108

Georgopoulos, D., Theocharis, A. and Zodiatis, G., (1989). Intermediate Water formation in the Cretan Sea (S. Aegean Sea). *Oceanologica Acta*, 12, 4, 353-359.

Kassis D., Nittis K. and Perivoliotis L. (2012). Hydrodynamic variability based on the multi-parametric POSEIDON Pylos observatory of the south Ionian Sea. *Ocean Sci. Discuss*., 10, 883–921, 2013 doi:10.5194/osd-10-883-2013.

Kontoyiannis, H., Theocharis, A., Balopoulos, E., Kioroglou, S., Papadopoulos, V., Collins, M., Velegrakis A. F., and Iona, A., 1999. Water fluxes through the Cretan Arc Straits, Eastern Mediterranean Sea: March 1994 to June 1995. *Progress in Oceanography*, 44, 511-529.

Korres, G., A.Lascaratos, E. Hatziapostolou and P.Katsafados, 2002. Towards an Ocean Forecasting System for the Aegean Sea. The Global Atmosphere and Ocean System, Vol. 8, No. 2-3, 191-218.

Lascaratos, A., Roether, W., Nittis, K. and Klein, B., (1999). Recent changes in deep water formation and spreading in the Mediterranean Sea: a review. Progress in Oceanography 44 (1–3), 5 – 36.

Molcard A., Piterbarg, L. I., Griffa, A., Ozgokmen, T. M., and Mariano, A. J. (2003). Assimilation of drifter observations for the reconstruction of the Eulerian circulation field, *J. Geophys. Res*., 108(C3), 3056, doi:10.1029/2001JC001240.

Nittis, K., Pinardi, N., and Lascaratos, A., 1993, Characteristics of the summer 1987 flow field in the Ionian Sea, J. Geophys. Res., 98, 10171-10184.

Poulain, P.-M., Barbanti, R., Font, J., Cruzado, A., Millot, C., Gertman, I., Griffa, A., Molcard, A., Rupolo, V., Le Bras, S., and Petit de la Villeon, L. (2007). MedArgo: a drifting profiler program in the Mediterranean Sea, *Ocean Sci*., 3, 379-395, doi:10.5194/os-3-379-2007 .

Ovchinnikov, I. M. (1984). Formation of Intermediate Waters in the Mediterranean Sea. *Oceanology*, 24, 2, 217–255.

Pinardi, N. and Masetti E. (2000). Variability of the large scale general circulation of the Mediterranean Sea from observations and modelling: a review. *Palaeogeography, Palaeoclimatology, Palaeoecology*, 158, 153–173.

POEM GROUP, 1992. General circulation of the Eastern Mediterranean. *Earth-Science Review*, 32, 285–309.

Robinson, A.R. and Malanotte-Rizzoli, P. (Eds.), (1993). Physical Oceanography of the Eastern Mediterranean Sea. *Deep-Sea Res*., Part II, vol. 40. Pergamon, Oxford, 300 pp.

Roether, W., Manca, B. B., Klein, B., Bregant, D., Georgopoulos, D., Beitzel, V., Kovacevic, V. and Luchetta, A. (1996). Recent changes in eastern Mediterranean deep waters. *Science*, 271, 333–335.

Souvermezoglou, E, Pavlidou, A. and Krasakopoulou, E. (1999). Temporal variability in oxygen and nutrients concentrations in the southern Aegean Sea and the Straits of the Cretan Arc. *Progress in Oceanography*, doi:10.1016/S0079-6611(99)00045-2

Theocharis, A., Papageorgiou, E. and Zodiatis, G., (1990). Flows and water mass exchanges between the Aegean and Ionian Seas through the Straits of Kithira and Antikithira (late summer 1987), Rapp. Comm. Int. Mer Medit., 32, 174.

Theocharis, A., Georgopoulos D., Lascaratos, A. and Nittis, K., (1993). Water masses and circulation in the central region of the Eastern Mediterranean: Eastern Ionian, South Aegean and Northwest Levantine, 1986-1987. Deep Sea Research II, 40, 6, 1121–1142.

Theocharis, A., Balopoulos, E., Kioroglou, S., Kontoyiannis, H. and Iona, A. (1999a). A synthesis of the circulation and hydrography of the South Aegean Sea and the Straits of the Cretan Arc (March 1994 – January 1995). Progress in Oceanography, 44, 469-509.

Tsimplis M.N., Velegrakis, A. F., Drakopoulos, P., Theocharis, A. and Collins, M.B. (1999). Cretan Deep Water Outflow in the Eastern Mediterranean, *Progress in Oceanography* (44)4 pp.531-551.

Vervatis, V. D., Sofianos, S. S. and Theocharis, A., (2011), Distribution of the thermohaline characteristics in the Aegean Sea related to water mass formation processes (2005–2006 winter surveys), *J. Geophys. Res*., 116, C09034, doi:10.1029/2010JC006868.

Zodiatis, G. (1993b). Water mass circulation between the SE Ionian – W. Cretan basins through the Western Cretan Arc straits. *Bolletino di Oceanologia Teorica ed Applicata*, 11, 1, 61-75.