Continental Shelf Research 31 (2011) 37–46

Contents lists available at ScienceDirect

Continental Shelf Research

journal homepage: www.elsevier.com/locate/csr

Research papers

Decadal variability and scales of the sea surface structure in the northern Ionian

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ARTICLE INFO

Article history:
Received 17 March 2010
Received in revised form
3 November 2010
Accepted 7 November 2010
Available online 18 November 2010

Keywords:
Physical oceanography
Sea level
Inter-annual variability
Vorticity
Northern Ionian Sea

ABSTRACT

The variability and scales of the sea surface structure of the northern Ionian Sea from January 1993 to December 2007 were studied by means of altimeter remotely-sensed weekly Sea Level Anomaly (SLA) objective maps. Variability in the sea surface structure was addressed by means of empirical orthogonal function (EOF) analysis and, assuming an exponential correlation model, scales of the SLA field were quantified as e-folding distances of the SLA autocorrelation function. The variability in the sea surface structure, described by the first three EOFs, which cumulatively explain 60.3% of the data set variance, is characterized by a large-scale structure with variability on a time scale of ~10–13 years and, on shorter scales, an eddy system with variability on an annual scale. The variability in the large-scale structure describes an overturning of the SLA field, which took place in 1997, and determines a reversal of the geostrophic upper-layer circulation. As the large-scale circulation transition takes place, time-dependent spectral analysis of EOF coefficients shows a redistribution of the spectral energy from inter-annual to semi-annual and monthly components. Spatial scales display variability on an annual and inter-annual time scale. On the annual time scale, variability in spatial scales is characterized by longer values in summer–fall and shorter in winter–spring. Inter-annual variability in spatial scales is demonstrated by a remarkable drop in the values during fall in the period 1998–2000. We propose an explanation of the variability in horizontal scales in terms of the redistribution of water masses and related modifications of the vertical structure of the water column associated with different regimes of the basin-scale circulation.
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1. Introduction

The northern Ionian (Fig. 1) is an important area as it represents the crossroads between different water masses originating in the western and in the eastern Mediterranean. For this reason, over the last two decades the oceanographic community has paid increasing attention to this basin.

Dense and oxygenated waters of Adriatic origin spread into the Ionian deep layer, whilst the intermediate layer is influenced by salty and warm waters coming from the Levantine and Aegean basins. Through the Sicily Strait, the relatively fresh water of Atlantic origin (Modified Atlantic Water; MAW) enters the Ionian, propagating eastward and, occasionally, northward towards the Adriatic Sea. The routes of the MAW in the Ionian in the late 1980s to early 1990s have been reported by Malanotte-Rizzoli et al. (1997, 1999). According to these authors the MAW from the Strait of Sicily formed a broad anticyclonic meander crossing the entire Ionian.

Pinardi et al. (1997) performed a numerical simulation and showed that the observations reported by Malanotte-Rizzoli et al. (1997) were the result of a surface circulation reversal from cyclonic to anticyclonic, which took place in 1987, the result of anticyclonic wind stress and heat fluxes in the previous winter.

In 1991, the intermediate and deep layers of the Ionian Sea were occupied by an anticyclone, which confined the Levantine Intermediate Water (LIW) to the eastern basin and prevented the northward flow along the northeastern boundary of the Ionian. Consequently, the LIW was replaced by waters of Cretan origin (Cretan Intermediate Water, CIW; Malanotte-Rizzoli et al., 1999). During the early 1990s the eastern Mediterranean deep convection cell experienced significant variations. The area of dense water formation, originally located in the Adriatic, shifted into the Cretan Sea. This phenomenon, termed the Eastern Mediterranean Transient (EMT; Roether et al., 1996), affected the Ionian circulation over the entire water column (Malanotte-Rizzoli et al., 1999; Borzelli et al., 2009; Gačić et al., 2010); it ended in the second half of the 1990s (Roether et al., 2007).

Vigo et al. (2005) and, more recently, Criado-Aldeanueva et al. (2008), using a long series of remotely sensed altimeter data over the Mediterranean, showed a sea level variability consistent with a reversal in the Ionian circulation from anticyclonic to cyclonic.

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doi:10.1016/j.csr.2010.11.001

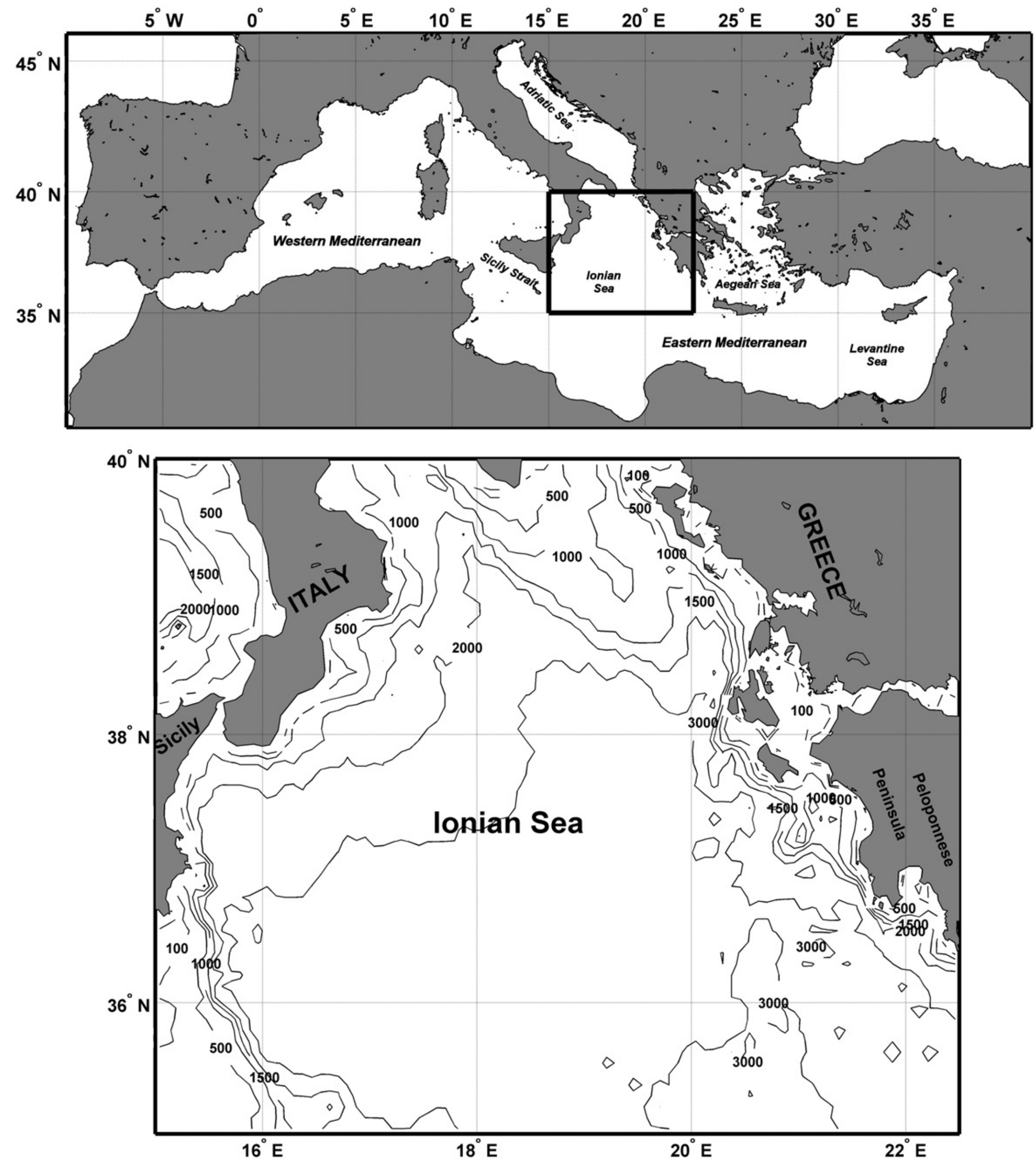

Fig. 1. Study area.

Borzelli et al. (2009) showed that this reversal was not sustained by the wind stress but could be ascribed to vorticity associated with the EMT, specifically due to redistribution of the Ionian water masses. This concept was generalized by Gačić et al. (2010), who put forward an interesting hypothesis, which explained both the reversal in the Ionian circulation and observations of decadal variations in the thermohaline properties of water masses formed in the southern Adriatic (Vilibić and Orlić, 2001). Gačić et al. (2010) conjectured that the Adriatic and the Ionian behave as a unique system (which they termed the 'Bimodal Oscillating System', BiOS), in which the Ionian circulation triggers the inflow of water masses into the Adriatic and modifies the thermohaline properties of the southern Adriatic. Modifications to Adriatic water outflow produce changes in flow patterns within the Ionian and consequent variations in the vertical stratification of the basin, which provide the vorticity source necessary to reverse the Ionian circulation. This interesting interpretation, predicated on quantitative evidence, presupposes the existence of decadal variations in the stratification regime of the Ionian. As the vertical structure of the ocean determines, through the baroclinic Rossby radius of deformation, the horizontal scales of motion, variations in the vertical structure of the Ionian would be expected to result in decadal-scale variations in the horizontal motion. Scales of the sea surface circulation are important because the ratio between horizontal scales of baroclinic motion and the internal radius of deformation determines the stability of the motion (Saunders, 1973).

Wunsch (1997) showed that, because baroclinic components intensify near the ocean surface, altimeters primarily reflect the first baroclinic mode and, thus, the motion of the main pycnocline. As the Ionian is reasonably approximated by a two-layer system, with the main pycnocline at a depth between 700 and 1000 m (Klein et al., 1999; Borzelli et al., 2009), altimeters are a valuable tool for capturing the main features of the Ionian circulation.

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