Deep-Sea Research I 97 (2015) 80–91

Contents lists available at ScienceDirect

Deep-Sea Research I

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

Seasonal and interannual variability of the Black Sea eddies and its dependence on characteristics of the large-scale circulation

A.A. Kubryakov [a,b,*], S.V. Stanichny [a]

[a] Marine Hydrophysical Institute, Sevastopol, str. Kapitanskaya, 2, Sevastopol, Russia
[b] Saint-Petersburg State University, Saint-Petersburg, Russia

ARTICLE INFO

Article history:
Received 18 July 2013
Received in revised form
9 December 2014
Accepted 19 December 2014
Available online 29 December 2014

Keywords:
Mesoscale eddies
Large-scale circulation
Seasonal and interannual variability
Black Sea
Satellite altimetry
Rim current
Energy cascade
Eddy formation
Baroclinic instability

ABSTRACT

Mesoscale eddies in the Black Sea basin are investigated by automated eddy identification method (winding angle) using satellite altimetry data for 1992–2011. Seasonal and interannual eddy variability is strongly affected by the intensity of basin-scale circulation. Weakening of large-scale circulation in response to the decrease of the wind curl leads to the baroclinic instability of the Rim current and enhanced formation of mesoscale anticyclones. Increasing wind curl and circulation induce intensive formation of mesoscale cyclones. Intense developed large-scale circulation leads to the decrease in the number of both cyclonic and anticyclonic eddies. Eddies properties (orbital velocity, energy and lifetime) on the interannual time scales also depend on the intensity of the large-scale circulation. It was shown that the most powerful and long-lived anticyclones are generated in years with intense currents, right after the currents begin slowing down, which is related to the transfer of energy from large- to meso-spatial scales. Mechanisms of eddies formation and dissipation are discussed.

1. Introduction

The Black Sea is a semi-enclosed Northern Hemisphere basin with one narrow connection to the Mediterranean basin through the Bosporus strait and the Marmara Sea. General circulation of the Black Sea (Fig. 1) consists of the following major components: the cyclonic Rim Current encircling the basin along of the continental slope; the western and eastern cyclonic gyres, and a number of anticyclonic mesoscale eddies located between the Rim current and the coast (Oguz et al., 1993; Ginzburg et al., 2002; Korotaev et al., 2003; Zatsepin et al., 2003). Cyclonic mesoscale eddies are also often observed in the left of the Rim current (e.g. Latun, 1989; Krivosheya et al., 1998; Zatsepin et al., 2003). Typically, they occur coupled with more intense anticyclone eddies. Anticyclonic eddies can be more rarely observed not only near the coast, but also in the center of the basin (Zatsepin et al., 2003).

In most cases the Black Sea eddies are linked with the Rim current and move in cyclonic direction following the main flow (see for example Ginzburg et al., 2002). But in some areas mesoscale eddies are trapped, thus forming quasi-stationary Batumi eddy, Sevastopol eddy, and others (Oguz et al., 1993) (Fig. 1). The Batumi and Sevastopol eddies are the most pronounced, thus better studied quasi-stationary features of the Black Sea mesoscale circulation.

On the seasonal to interannual time scales, the wind stress curl is the primary forcing that drives the basin-scale circulation, as has been shown by simulations (e.g. Stanev, 1990), in-situ observations (Zatsepin et al., 2010), and satellite data (Korotaev et al., 2003; Ilyin et al., 2012). As the Black Sea is an almost closed basin, current kinetic energy should redistribute between large- and meso-spatial scales or dissipate. Such relative simplicity of the basin energetics and abundance of intense mesoscale eddies can clarify the mechanisms of interaction of large- and mesoscale circulation, basing on the Black Sea example.

Seasonal variability of the Black Sea eddies has been investigated using hydrological data (e.g. Titov, 1992; review in Ivanov and Belokopytov, 2013), altimetry data (e.g. Korotaev et al., 2003), numerical simulations (e.g. Staneva et al., 2001), laboratory experiments (Blokhina and Afanasyev, 2003; Zatsepin et al., 2005; Elkin and Zatsepin, 2013), and satellite measurements in optical and infrared bands (Ginzburg et al., 2002; Karimova, 2011 and others). The clearest point, which is confirmed by satellite and hydrological observations, is the intensification of anticyclone activity in the warm period (Titov, 1992; Zatsepin et al., 2003; Karimova, 2011;

* Corresponding author at: Marine Hydrophysical Institute, Sevastopol, str. Kapitanskaya, 2, Sevastopol, Russia. Tel.: +79787411045.
E-mail addresses: arskubr@gmail.com (A.A. Kubryakov), sstanichny@mail.ru (S.V. Stanichny).

http://dx.doi.org/10.1016/j.dsr.2014.12.002
0967-0637/

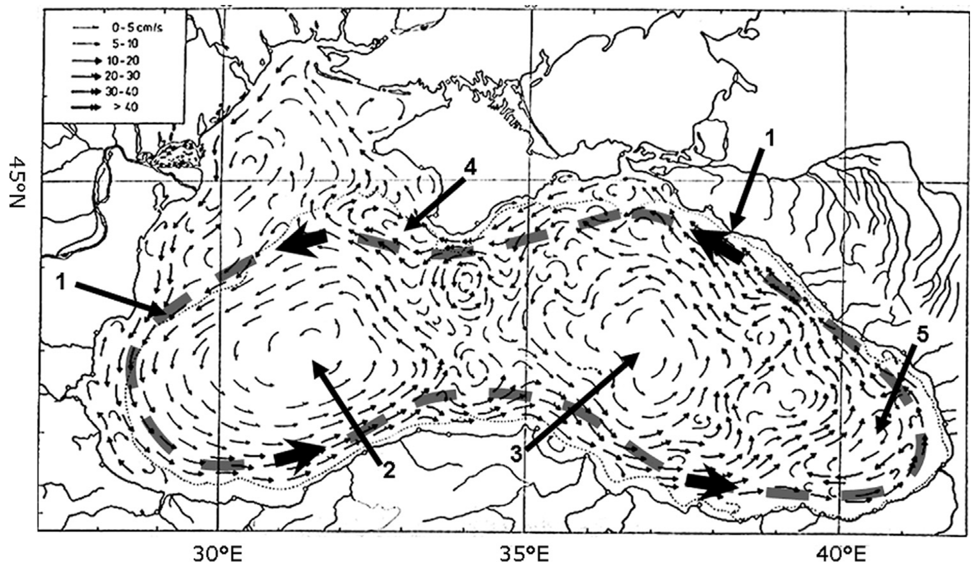

Fig. 1. Scheme of the Black Sea circulation (Neumann, 1942). 1—Rim current; 2—western cyclonic gyre; 3—eastern cyclonic gyre; 4—Sevastopol eddy; 5—Batumi eddy.

Ivanov and Belokopytov, 2013). One of the possible reasons for enhanced mesoscale activity in the summer is baroclinic instability of the Rim current during its weakening phase caused by the seasonal decrease of winds (Zatsepin et al., 2005, 2010). Some studies diverge upon the annual phase of eddy life cycle. For example, model simulations by Staneva et al. (2001) suggest that stronger Sevastopol anticyclones occur in winter while the Korotaev et al. (2003) analysis of satellite altimetry points at eddy intensification during both winter and summer. The Batumi eddy intensifies in late winter-early spring (Staneva et al., 2001; Korotaev et al., 2003) and in summer, according to Sokolova et al. (2001).

Little is known about variability of the mesoscale dynamics in the basin on the interannual time scales. (Titov, 1992) argue that the most long-lived eddies are observed in the years after severe winters. (Zatsepin et al., 2003) have found evidence that in some years an enhanced mesoscale activity can be linked to a weakening of the annual basin-scale wind curl. The (Korotaev et al., 2003) analysis of altimeter data during 1992–1999 has revealed that 1993, 1994, and 1997 are characterized by enhanced level of eddy activity in contrast with more organized circulation but weaker eddy field in 1995, 1996.

Different view on variability of mesoscale circulation in the basin can be related to the different periods of used data, existence of a temporal and spatial gaps in hydrological data and in satellite infrared or visible observations (these data relate mostly to the warm period of year (Ginzburg et al., 2002). Strong interannual changes of the Black Sea circulation can have an impact on the results of investigations (Korotaev et al., 2003). Seasonal variability of mesoscale cyclonic activity in the region has not been studied yet, as most research focuses on anticyclonic variability. Factors governing the interannual variability of mesoscale eddies of either sign are also important but not well understood.

This paper focuses on investigation of temporal variability of mesoscale anticyclones (AE) and cyclones (CE) in the Black Sea by means of automated eddy-identification algorithm from altimetry-derived data available for more than 20 years from 1992 onward. The paper is organized as follows. Satellite data is described in Section 2. Section 3 provides a short description of the method, its verification and some obtained eddy statistics. Seasonal variability of the AEs and CEs integral characteristics (total number, occupied area, kinetic energy), mean properties (lifetime, radius, kinetic energy, orbital velocity) and their relationship with the mean current kinetic energy (MKE) of the basin are investigated in Section 4. Section 5 presents the interannual variability of the Black Sea eddy characteristics. It is shown that the mesoscale circulation in the basin strongly depends on the mean flow properties on both the seasonal and interannual time scales. Discussion and conclusion are presented in Sections 6 and 7.

2. Data

2.1. Altimetry data

Regional Black Sea array of mapped altimetry sea level anomalies (MSLA) is produced by the *CLS* Space Oceanography Division and distributed by *Aviso*, with support from *Cnes* (http://www.aviso.oceanobs.com/). The 1992–2011 data is used for mesoscale eddy analysis in this paper. Regional data have an improved spatial resolution of 1/8° as compared to the coarser 1/4° resolution of the global MSLA (Le Traon et al., 2001; Pascual et al., 2006). Temporal resolution is 7 days (*delayed-time* product). MSLA data was obtained by combining altimetry measurements from different satellites using special algorithms based on optimal interpolation methods (Le Traon et al., 2001; Pascual et al., 2006).

Mean dynamic topography (MDT) data from (Kubryakov and Stanichny, 2011) was used to compute the total current kinetic energy from MSLA data. This MDT is derived by combining drifting buoys, in-situ profiles, and altimetry measurements.

Anomalies of geostrophic velocities are computed through geostrophic balance equation:

$$u' = -\frac{g}{f}\frac{\partial h'}{\partial y}; \quad v' = \frac{g}{f}\frac{\partial h'}{\partial x},$$

here u', v' are anomalies of zonal and meridional components of geostrophic velocity; h' is SLA; f is the Coriolis parameter, g is the gravitational acceleration, x, y represent longitude and latitude, respectively.

Mean kinetic energy (MKE) of total geostrophic currents was computed as

$$\mathrm{MKE} = \frac{1}{2}(\langle u^2 \rangle + \langle v^2 \rangle),$$

where

$$u = -\frac{g}{f}\frac{\partial (H+h')}{\partial y}; \quad v = \frac{g}{f}\frac{\partial (H+h')}{\partial x},$$