Variability of the Black Sea dynamics observed by space altimetry

Gennady Korotaev[1], Temel Oğuz[2], and Chester Koblinsky[3]

ipdop@fossil.ukrcom.sebastopol.ua; Oğuz@ims.metu.edu.tr; koblinsky@gsfc.nasa.gov
[1] *Marine Hydrophysical Institute Sevastopol Crimea Ukraine*
[2] *Institute of Marine Sciences Erdemli Turkey*
[3] *Goddard Space Flight Center Greenbelt USA*

Abstract- Seven years Topex/Poseidon and ERS altimeter data set is applied for the analysis of the Black Sea dynamics on time scale from few days to years. The wind-driven nature of the seasonal and interannual variability of the circulation is explained. It is shown that the regional air-sea coupling induces the seasonal cycle of the surface wind stress curl. Intense mesoscale variability is evident from analysis of currents and sea level variations. Space altimeter data confirms semi-permanent nature of marginal anticyclones. The pattern of anticyclonic mesoscale eddies is changed significantly from one year to another. However eddy statistics obtained during the seven years of observation demonstrates regular annual cycle. The Rim Current jet meandering regions and areas of intense transfrontal transport by means of detachment of meanders are identified.

Keywords- Black Sea, variability, circulation, altimetry

Introduction

Major information about the Black Sea dynamics for many years came from hydrographic surveys and episodic current measurements from buoys. However the last decade gave the space altimetry as a new and very efficient tool of observations of marine circulation. Modern altimeters measure the sea surface elevation with the accuracy four centimeters (Koblinsky et al. 1999) providing unique possibility to observe multi-scale oceanic processes.Although measurements are designed mainly for observation of oceanic processes, it was shown by Korotaev et al. (1998, 1999, 2001) that a joint use of the Topex/Poseidon and ERS altimetry provides accurate information about the Black Sea dynamics. We are using here the continuous altimeter observations from the spring of 1992 until the end of 1998 preprocessed according to the algorithm of Korotaev et al. (2001) to study seasonal, interannual and mesoscale variability of the Black Sea circulation.

Seasonal variability of the basin-scale circulation

Surface geostrophic currents derived from altimetry (Korotaev et al. 2001) manifest obviously annual cycle of the basin circulation. The Rim Current is the most intense in winter-spring seasons. Summer circulation attenuates significantly and in the autumn season the Rim Current usually brakes on the set of mesoscale eddies. Seasonal variability of currents is well presented in the temporal evolution of potential and kinetic energy. A linear one-and-a half layer model of the wind-driven circulation and decomposition of the altimeter sea level to the empirical orthogonal functions (EOF) are applied by Korotaev et al. (2001) to explain seasonal variability of the Black Sea currents. The scheme of the seasonal cycle of circulation is shown on Fig.1. Increase of the cyclonic vorticity of the surface wind in January produces intensification of the upwelling on the bottom of Ekman layer, which induces the rise of pycnocline. The shallowest pycnocline observes a quarter of period (i.e. three months) after the most intense wind stress curl. However the rise of pycnolcline in the central part of the basin should be compensated by its deepening near the coast just due to the conservation of the fluid volume. The deepening of pycnocline occurs above the continental slope where the geostrophyc balance should be broken for the onshore velocity component. The displacement of the pycnocline near the coast is significantly higher than its rise in the open sea as the volume of fluid replaced in the center of the basin should be preserved along the beach. Therefore the slope of pycnocline toward the coast increases significantly at the beginning of spring. The intensity of the Rim current, which is in geostrophic balance, is highest at the same time. The weakening of the wind stress curl in summer vice versa is accompanied by the deepening of pycnocline in the open sea ant its rise near the coast.

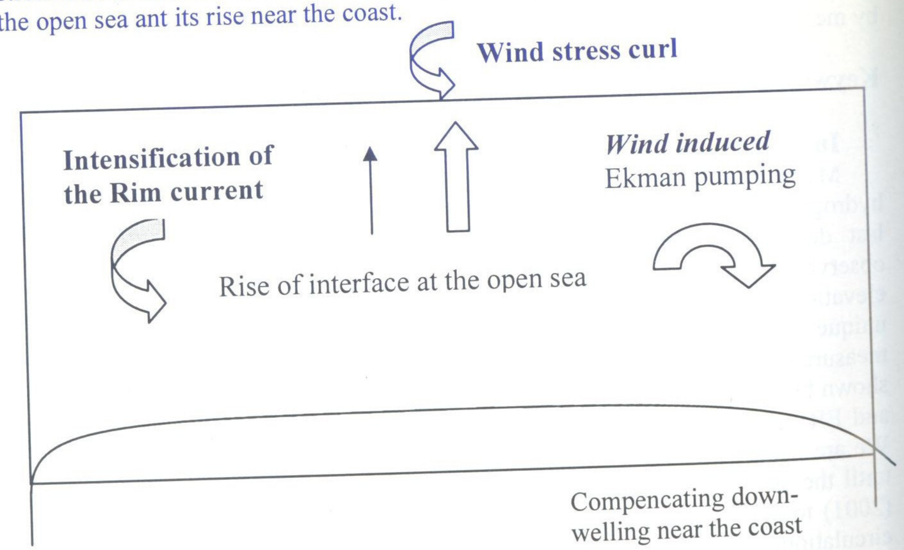

Fig. 1. Qualitative explanation of the wind-driven seasonal cycle of the Black Sea circulation

Coupling of the Black Sea and atmosphere in frame of the seasonal cycle

The seasonal variability of currents is explained by the annual cycle of the wind stress curl. The question arises what is the reason of seasonal variation of the wind stress curl? Observations show that the phases of the wind stress curl cycle

are in a good consistency with the phases of the air-sea temperature difference. Therefore we could assume that the winter warming of the atmosphere by the sea creates a localized source of heat, inducing cyclonic circulation in the atmosphere (Gill, 1982).

The problem of the atmospheric circulation in a coupled system of the sea, land and atmosphere under the influence of the varying annually solar radiation is considered by Korotaev (2001) for evaluation of the offered mechanism. The simple configuration of the Black Sea permits to consider an axially symmetric problem of the atmospheric circulation above the landlocked round sea. For the sake of simplicity the model of isothermic, dry, adiabatic atmosphere is considered.

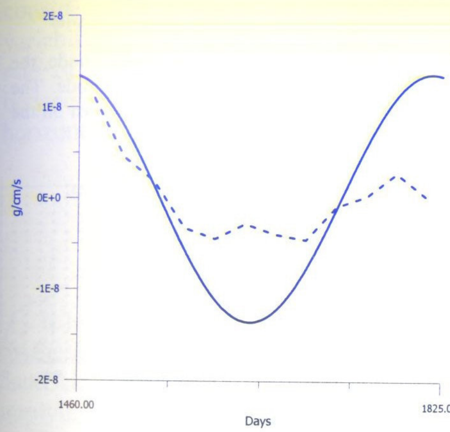

Fig. 2. Simulated (solid line) and observed (dash line) vorticity of the wind stress.

Despite of the simplicity, the model describes qualitatively well the shift of phase between oscillations of temperatures of the sea and the atmosphere. The annual cycle of the wind stress vorticity averaged over the basin area is presented in Fig. 2 according to the model simulation and based on observations in the Black Sea. The model correctly describes a phase of the averaged wind stress curl variability. Thus, the model simulation shows that the difference of thermal capacities of the water and the land could provide the moonson-like seasonal modulation of the wind stress curl.

The proposed theory indicates the significance of regional air-sea interaction but does not provide an explanation how the local warming of the atmosphere could be more important then the larger scale processes. Let consider EOF decomposition of the climatic surface wind field over the Black Sea basin to clarify the question. Three first modes describe 73% of the total energy. Annual cycle of the amplitude of each mode is shown on Fig. 3. The spatial structure of these modes is shown on Fig. 4. Two most energetic modes correspond to the almost uniform wind oscillation. The third mode has absolutely another structure and describes the cyclonic-anticyclonic motion above the Black Sea. Curves on Fig. 3 present also the vorticity of the surface wind above the Black Sea reproduced by each mode. They show that the vorticity of the surface wind is described mainly by the third mode while the impact of the first and the second modes is negligible. The cyclonic phase is in winter and anticyclonic phase is in summer. Thus we assume that the seasonal cycle of the Black Sea circulation reflects regional coupling of the sea and atmosphere.

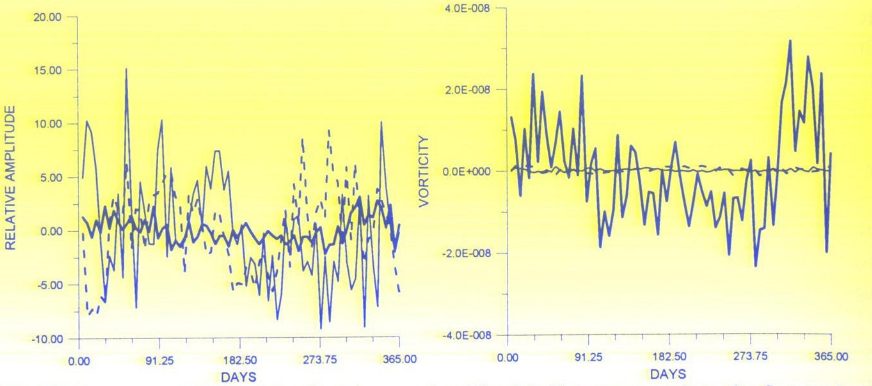

Fig. 3. The temporal EOF of the first three modes. The thin line corresponds to the first mode, the dash line corresponds to the second mode and the solid line corresponds to the third mode. The temporal evolution of the energy of the surface wind where prevails the first mode is shown on the left plot. The wind vorticity is presented on the right one where the third mode dominates.

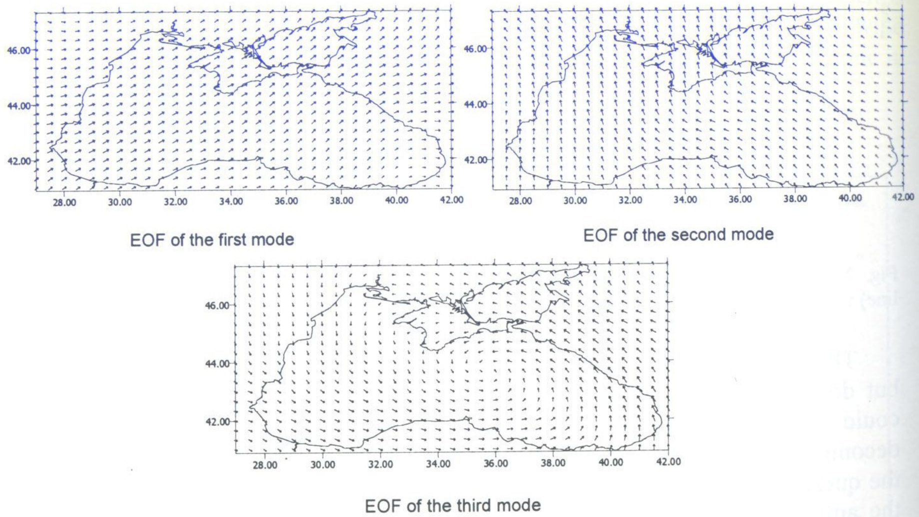

Fig. 4. The spatial components of the three most energetics EOF. The first mode is on the upper panel, the second mode is in the center and the third mode is on the bottom.

Interannual variability of the Black Sea circulation

The Black Sea circulation manifests significant interannual variability, which is evident from the evolution of the potential and kinetic energy (Korotaev et al. 2000). Annual mean energy as well as the amplitude of seasonal variation varies few times from one year to another. Interannual variability is observed also in the structure of the Black Sea circulation (Korotaev et al. 2002b). The winter pattern of the circulation is more or less similar for different years. However the intensity of

the western and eastern gyres varies significantly from one year to another. Much more changes could be found in summer – fall. The low level field in 1993 and 1994 is replaced by a few larger scale gyres in 1995 and even by the basin-wide cell in 1996.

The energy budget equation in the form

$$\frac{d(K+P)}{dt} = Gen - Diss$$

where $K = \frac{1}{2}\cdot\rho\cdot\iint\limits_S h(u^2+v^2)dS,\ P = \frac{1}{2}\cdot\rho\cdot g\cdot\iint\limits_S \xi^2 dS$

denote the basin-integrated kinetic and available potential energies, respectively is considered by Korotaev et al. [2000] to understand the nature of interannual variability of the Black Sea circulation. The energy budget equation states that the rate of change of basin-integrated total energy is balanced by the difference between the work exerted by the wind stress over the basin and dissipation due to horizontal friction in the system. They are given by

$$Gen = \iint\left[u\cdot\tau_x + v\cdot\tau_y\right]\cdot dS$$

$$Diss = A\cdot\iint h\cdot\left[\left(\frac{\partial u}{\partial x}\right)^2+\left(\frac{\partial u}{\partial y}\right)^2+\left(\frac{\partial v}{\partial x}\right)^2+\left(\frac{\partial v}{\partial y}\right)^2\right]\cdot dS\,.$$

It is remarkable that all terms of the energy budget equation can be estimated by the altimeter and the wind stress data. Temporal variations of the left and right hand sides of the equation are in relevant consistency (Korotaev et al. 2002b), implying that the basin averaged wind stress work is the major source of total energy variations.

Mesoscale variability of the Black Sea Circulation

All types of the mesoscale variability such as Rossby waves, meanders of a strong jet and eddies could be found in the Black Sea. Altimeter data shows that the intense mesoscale variability is observed along the path of the Rim Current (Korotaev et al. 2001). Continuous observation by the space altimeter during almost seven years provide unique possibility to consider different types of mesoscale variability of the basin.

Evidence of Rossby waves

It is well known that the seasonal cycle of the oceanic circulation is accompanied by the radiation of Rossby waves from the eastern coast of the basin. Rossby waves appear to reduce to zero a normal to the coast component of zonal transport. The period of radiated waves is determined by the period of flow modulation and the wavelength is found from the dispersion relation. Satellite altimetry gives direct evidence of the western phase propagation in the northern part of the Black Sea (Stanev, Rachev 1999, Korotaev et al. 2001). It is shown by Korotaev et al. (2001) that the observed signal is the superposition of the sea level reaction to the direct wind forcing and radiated from the eastern coast Rossby wave.

Mesoscale anticyclonic eddies

Basin-wide hydrographic surveys, carried out at the beginning of 90-ies in frame of the program "ComsBlack", show that the essential part of the Black Sea mesoscale variability is presented by quasi-stationary anticyclonic eddies disposed onshore from the Rim Current jet (Oğuz et al. 1994). Altimeter data provides an independent validation of the schematic picture of quasi-stationary anticyclonic eddies presented in that paper and introduces a few additional features (Korotaev et al. 2002a,b). It is shown that quasi-permanent anticyclonic eddies manifest significant intermittency. Observations indicates that the most part of quasi-permanent anticyclonic eddies have a tendency to move along the coast in the anti-clock-wise direction. Assimilation of the remote sensing altimetry and numerical simulations show that the anti-clock-wise transport of the anticyclonic vorticity is the inherent property of the Black Sea dynamics (Dorofeev, et al. 2001). The seven-year data set permits to evaluate statistics of the coastal anticyclones. It is remarkable that in spite of the well-pronounced intermittency of the life cycle of each eddy, the long-term statistic obviously shows seasonal evolution.

Transfrontal transport by mesoscale features

Intense meandering of the Rim Current induces significant transfrontal exchange of coastal and open-sea waters. It was discussed by Korotaev (1997) that the transfrontal transport is the essential mechanism for supporting of the observed surface salinity in the center of the basin. Oğuz et. al. (2002) have shown from the SeaWiFS imagery that the transport of the productive coastal waters to the open part of the basin induces the basin-wide blooming events. Altimeter data permits to identify intense trans-frontal exchange regions and to document the most typical cases.

Summary

Altimeter data make possible to consider carefully variability of the Black Sea circulation on a very broad scales beginning from mesoscales until basin scales in space and decade in time. Mesoscale circulation derived from space altimetry seems very realistic based on the comparison with dynamical features, which are found in the imagery. Thus, reconstructed currents reproduce in a reasonable way the lagrangian transport, which is the key element of the coupling of circulation and biogeochemical cycling. Observations show the leading role of a wind-driven variability on basin scales. Moreover, the seasonal cycle of the basin-scale circulation it seems results from the regional coupling of the sea and atmosphere. The interannual variability of the basin-scale circulation is also induced mainly by wind. Therefore the regional climate changes could follow partially from the local feedbacks. For example, increase of SST intensifies the heating of atmosphere and

cyclonic winds in winter. The wind produces the increase of Ekman pumping and cooler water comes to the surface reducing SST and so on. Therefore more analysis of the local feedbacks should be done in future.

References

Dorofeyev V.L., Demyshev S.G., Korotaev G.K., 2001. Barotropic response of the Black Sea to the fluide exchange through boundaries. In: "Ecological safety of coastal zone and complex use of shelf resource", Sevastopol, p.150-158.

Gill A. 1982 Dynamics of atmosphere amd ocean. v.2 Academic Press

Koblinsky, C. J., Ray, R., Beckley, B.D., Brenner, A., Tsaoussi, L., Wang Y.M., 1999. Data set validation. NASA Rep., 2, 56 pp.

Korotaev G.K., 1997. Circulation in semi-enclosed seas induced by buoyancy flux through a strait. Proc. NATO ARW Sensitivity of North Sea, Baltic Sea and Black Sea to Anthropogenic and Climatic Changes. Kluwer Academic Publisher p. 395-401.

Korotaev G.K., 2001. The reason of a seasonal cycle of the Black Sea circulation. Marine Hydrophys. Journ. Sevastopol MHI N6 pp 14-20 (in Russian)

Korotaev, G.K., O.A. Saenko, C.J. Koblinsky, S.G. Demyshev, and V.V. Knysh, 1998, An accuracy, methodology, and some results of the assimilation of the TOPEX/POSEIDON altimetry data into the model of the Black Sea general circulation, Earth Research from Space, No.5, (in Russian).

Korotaev, G.K., Saenko, O.A., Koblinsky, C.J., Knysh, V.V., 1999. Satellite altimetry observations of the Black Sea. In S. Besiktepe et al. (eds), Environmental Degradation of the Black Sea: Challenges and Remedies NATO Science Series, 2. Environmental Security-56, 225-244. The Netherland: Kluwer Academic Publishers.

Korotaev G.K., Oğuz T., Oszoy E., 2000. Predictability of the Black Sea annual and interannual variability. In: Black Sea Ecosystem Processes and Forecasting/Operational Database Management System. Rep. of the Workshop and Project Evaluation Meeting. Istanbul, 15-18 May 2000.

Korotaev, G.K., Saenko, O.A., Koblinsky, C.J., 2001. Satellite altimetry observations of the Black Sea level. J. Geophys. Res., 106, 917-933.

Korotaev G.K., Oğuz T., Nikiforov A.A., Beckley B., Koblinsky C.J., 2002a. Dynamics of anticyclonic eddies in the Black Sea according to the space altimeter data. Earth Res. from Space N6 pp. 1-10 (in Russian).

Korotaev G.K., Oğuz T., Nikiforov A.A., Koblinsky C.J., (2002b). Seasonal, interannual and mesoscale variability of the Black Sea upper layer circulation derived from assimilation of altimeter data into a reduced-gravity model. J. Geophys. Res. (submitted).

Oğuz et al. 1994 Oğuz, T., Aubrey, D.G., Latun, V.S., Demirov, E., Koveshnikov, L., Sur, H.I., Diacanu, V., Besiktepe, S., Duman, M., Limeburner, R., Eremeev, V.V., 1994. Mesoscale circulation and thermohaline structure of the Black sea observed during HydroBlack'91. *Deep Sea Res. I,* **41**, 603-628.

Oğuz T., Deshpande A.G., Malanotte-Rizzoli P., 2002. The role of mesoscale processes controlling biological variability in the Black Sea coastal waters: inference from SeaWiFS-derived surface chlorophyll field. *Cont. Shelf Res.* **22** pp. 1477-1492

Stanev E.V., Rachev N.H., 1999. Numerical study on the planetary Rossby modes in the Black Sea. *Journ. Mar. Syst.* **21** pp. 283-306.