Journal of Marine Systems 142 (2015) 75–95

Contents lists available at ScienceDirect

Journal of Marine Systems

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

The role of the wind in the formation of coherent eddies in the Gulf of Eilat/Aqaba

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ARTICLE INFO

Article history:
Received 17 February 2014
Received in revised form 13 September 2014
Accepted 15 September 2014
Available online 5 November 2014

Keywords:
Oceanic eddies
Surface currents
Wind measurement
Vortices

ABSTRACT

Rare surface cyclonic eddies have been observed using a high frequency radar system in the northern part of the Gulf of Eilat/Aqaba. These surface eddies appear during fall and winter months and are absent during the rest of the year. Using an oceanic general circulation model and a regional atmospheric model (providing atmospheric wind with high spatial and temporal variability), we investigate the role of atmospheric wind in the formation and appearance of these eddies, by analyzing three cases in detail and by conducting idealized sensitivity experiments. For all three cases, the model simulates the development of a coherent eddy with similar characteristics as the observed ones, including width, intensity, and life-time. Generation of one of the coherent eddies occurs in a process similar to lid-driven cavity flow, in which eastward current at the southern open-boundary of the rectangular-shaped area of the head of the gulf drives the cyclonic circulation within the cavity. Other cases of eddy formation involve strong, northward flowing currents along the eastern boundary of the northern gulf. In all cases, weaker winds are favorable for the appearance of these eddies at the surface.
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1. Introduction

A high-frequency (HF) ground-based radar system has been operating on the northern part of the Gulf of Eilat/Aqaba (hereinafter the gulf), providing high-resolution measurements of surface currents since August 2005. While surface circulation in the northern gulf is mostly chaotic and unorganized, coherent cyclonic eddies are evidenced in the HF radar observations a few times a year from November to April (Gildor et al., 2010). These eddies are characterized by a basin-wide diameter of 5–6 km (Fig. 1), and typically persist for around a day. During eddy events, surface currents are stronger than the typical velocity (10–20 cm s^{-1}) and can exceed 100 cm s^{-1}.

Submesoscale coherent eddies in coastal regions can be generated by a variety of processes. Based on observations and modeling, previous studies have suggested various factors for eddy formation, such as the effect of bottom topography or irregular structure of the coastline (Kim, 2010; Zimmerman, 1981), spatial patterns in the wind field (Chavanne et al., 2002; Hu et al., 2011; Oey, 1996; Oey et al., 2001), shear flows (Shapiro et al., 1997) and the interplay of these factors with stratification and tidal forcing (Takeoka and Murao, 1993; Vethamony et al., 2005). Berman et al. (2000) used a wind-driven numerical model to show the existence of a chain of cyclonic and anticyclonic eddies, semi-permanently residing along the main axis of the gulf. The locations and sizes of these eddies vary seasonally, with three cyclonic eddies in the northern half of the gulf in winter and spring, and a cyclonic eddy with a 10-km diameter in summer. Observational evidence of these eddies was suggested by Manasrah et al. (2004), based on current measurements collected along the gulf during February and March 1999. In observations from the northern part of the gulf, an anticyclonic circulation with a diameter of about 5–8 km has been identified (Manasrah et al., 2006). In contrast to observations, eddies in the model of Berman et al. (2000) were a permanent feature of the circulation and the northernmost eddy was located about 10 km south of the northern boundary of the gulf. In the present study, the focus is the rare eddies that appear within the northern 10 km of the gulf.

Gildor et al. (2010) first identified these coherent eddies in HF radar observations of the northern gulf, and suggested that the circulation producing these eddy events might be the geophysical equivalent of lid-driven cavity flows, where a fluid bounded within a rectangular domain is driven by an external current along one of the boundaries. Using a simple reduced-gravity model with idealized geometry, Gildor et al. (2010) show that a coherent eddy with characteristics similar to the observed eddies in the gulf developed in the simulation within a few hours, as a result of a driving current at its southern boundary. The northern eddy shown in the Berman et al. (2000) model generates as the driving current at the southern open boundary of the cavity. However, the simplified model of Gildor et al. (2010) neglected the effects of winds, tides and irregularities in the coastline and bathymetry characteristic of the gulf.

One objective of this study is to test whether the lid-driven cavity flow mechanism, as suggested by Gildor et al. (2010), can be reproduced in a complex Ocean General Circulation Model (OGCM) with realistic

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http://dx.doi.org/10.1016/j.jmarsys.2014.09.006
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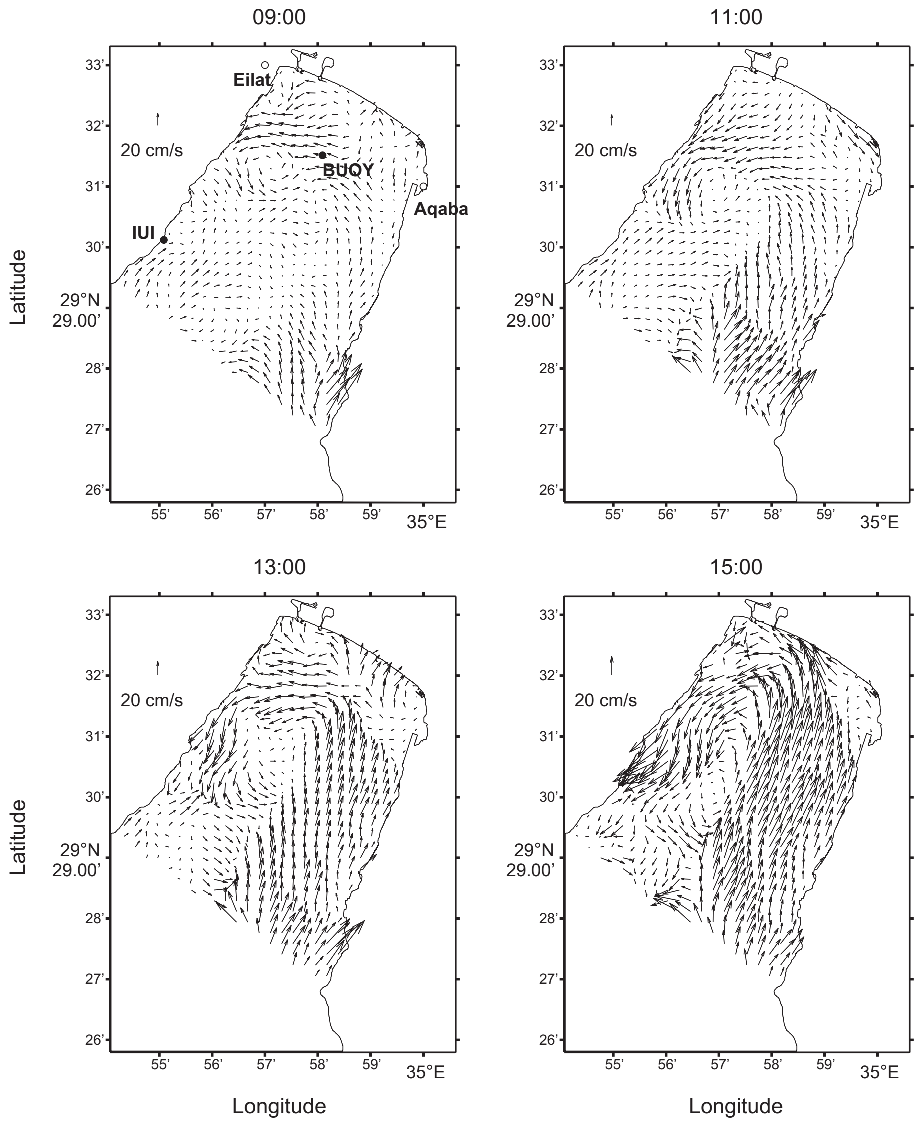

Fig. 1. HF radar surface current observations reveal the appearance of a basin-wide, coherent cyclonic eddy in the northern gulf during 29 November 2005. Snapshots are taken every 2 h between 09:00 (top-left) and 15:00 (bottom-right), local time. Two meteorological stations are marked on the top-left map: the coastal station at the Interuniversity Institute for Marine Sciences (IUI) (labeled: IUI) and the meteorological buoy, deployed in October 2010 (labeled: BUOY). The vector field represents surface current measured by the HF radar after filtering and gap filling as described in Lekien and Gildor (2009).

bathymetry and atmospheric wind. Our second objective is to examine the role of the wind in the generation of the observed eddies. To achieve these objectives, we use a high-resolution OGCM driven by atmospheric wind from a regional atmospheric model. While previous modeling studies of the gulf have mostly focused on the dynamics of the large-scale circulation (Berman et al., 2000; Biton and Gildor, 2011a,b), we focus on resolving the physical mechanism of submesoscale features, characterized by length scale of *O(1)* km and time scale of hours to days. Atmospheric data collections in this region are rather limited, with only a few stations available along the gulf. However, a recently collected meteorological data from three nearby stations in the northern gulf, two coastal stations and a moored station located near the center of the gulf, demonstrate the high temporal variability and the possibility of large spatial variability in the wind even over a short distance (much smaller than the atmospheric Rossby radius), apparently due to the strong orographic effects. The observed variability in the wind field can provide an explanation for the formation of cyclonic eddies in the northern gulf, considering their irregular nature. Realistic wind patterns with the sufficient spatial and temporal resolution can be obtained by a regional atmospheric model.

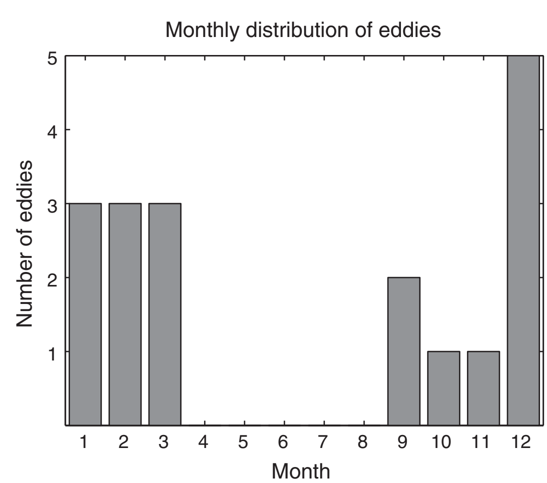

Fig. 2. The number of coherent eddies per month observed at the head of gulf throughout a period of five years, between September 2005 and September 2009. Observational data was collected using the HF-radar, at a spatial resolution of 300 m and temporal resolution of 30 min. The eddies appear from December to March.

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