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Dynamical structure and wind-driven upwelling in a summertime anticyclonic eddy within Funka Bay, Hokkaido, Japan

Daisuke Takahashi[a,*], Kazuo Kido[b], Yoshinori Nishida[c], Naoto Kobayashi[d], Naoyuki Higaki[b], Hideo Miyake[e]

[a]Center for Marine Environmental Studies, Ehime University, 2-5, Bunkyo-cho, Matsuyama 790-8577, Japan
[b]Department of Marine Geoscience, Geological Survey of Hokkaido, 3-1, Chikko, Otaru, Hokkaido 047-0008, Japan
[c]Hokkaido Wakkanai Fisheries Experimental Station, 5-15, Suehiro 4 Chome, Wakkanai, Hokkaido 097-0001, Japan
[d]Faculty of Fisheries, Hokkaido University, 3-1-1, Minato-cho, Hakodate, Hokkaido 041-8611, Japan
[e]Graduate School of Fisheries Sciences, Hokkaido University, 3-1-1, Minato-cho, Hakodate, Hokkaido 041-8611, Japan

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Abstract

We conducted hydrographic observations in 2002 to investigate the anticyclonic eddy that emerges every summer in Funka Bay, Hokkaido, Japan, and elucidate dynamical structure and wind-driven upwelling within the eddy. The anticyclonic eddy has a vertical scale of 32 m and is characterized by a strong baroclinic flow and a sharp pycnocline with a concave isopycnal structure. The sharp pycnocline occurs below a warm and relatively low-salinity water termed summer Funka Bay water (FS), which is formed by heating from solar radiation and dilution from river discharge in summertime Funka Bay. Flow of the anticyclonic eddy rotates as a rigid body at each layer, and the horizontal scale and rotation period of the eddy in the surface layer are about 15 km and 2.2 days, respectively. The dynamical balance of the anticyclonic eddy is well explained by the gradient flow balance. The contribution of centrifugal force to the gradient flow balance is about 27%. Therefore, the effect of the nonlinear term associated with centrifugal force cannot be neglected in considering the dynamics of the anticyclonic eddy in summertime Funka Bay. In addition, upwelling of subsurface water was observed in the surface layer of the central part of the eddy. The formation mechanism of this upwelling is consistent with interaction between horizontal uniform wind and the eddy. This upwelling is driven by upward Ekman pumping velocity related to the horizontal divergence of Ekman transport. In summertime Funka Bay, there are two wind effects that affect the anticyclonic eddy: a decay effect of the upwelling of subsurface water resulting from horizontal uniform wind (mainly northwesterly wind), and a maintenance or spin-up effect of horizontal non-uniform wind (mainly southerly–southeasterly seasonal wind) with negative wind stress curl.

Keywords: Anticyclonic eddy; Gradient flow; Ekman pumping; Upwelling; Funka Bay

1. Introduction

Funka Bay, in southwestern Hokkaido, northern Japan, is connected to the northwestern Pacific

*Corresponding author. Tel.: +81 899278179; fax: +81 89927984.
E-mail address: d-taka@dpc.ehime-u.ac.jp (D. Takahashi).

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Ocean by an 85 m-deep sill on the southeastern extension of the bay. A narrow continental shelf exists outside of Funka Bay, beyond which the bottom topography deepens abruptly. Behind the sill, the bay has a circular shape, with a diameter of about 50 km, and a bowl-shaped bottom topography with a mean depth of 59 m and a maximum depth of 95 m. The land topography around Funka Bay is mountainous and complex, with most of the immediate area descending steeply into the bay from heights in excess of 200 m. The bay mouth is bounded by Komagatake (>1000 m elevation) to the south and Mts. Orofure and Washibetutake (>900 m elevation) to the north. The bay mouth is located in the southeastern part of Funka Bay, and the longitudinal axis of Funka Bay is aligned northwest–southeast (Fig. 1).

Scallops and kelp are widely cultivated in Funka Bay, and the area is also utilized as a nursery ground for pollock. Coastal areas with depths shallower than 50 m (total area is 212.2 km^2; 10% of Funka Bay) are used to cultivate scallops, which is one of the most important fisheries in Funka Bay (Mida and Fuji, 1985). In summertime (June–July), scallop larvae floating in the surface layer within Funka Bay are transported to the coastal area by

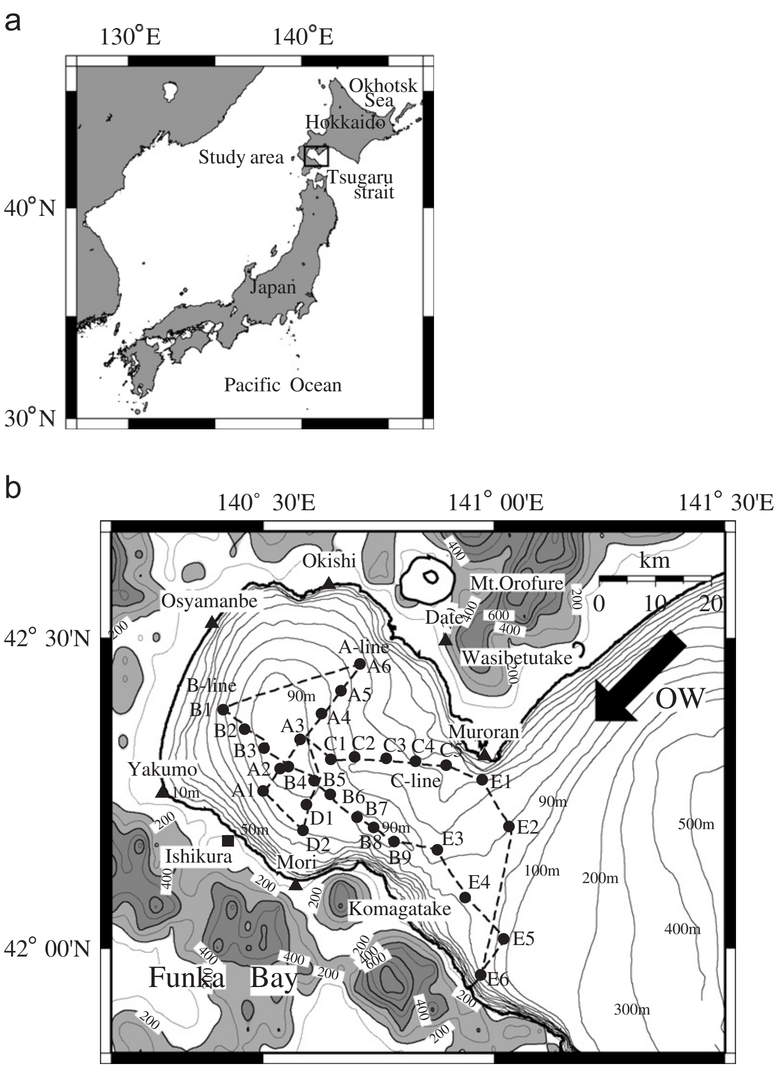

Fig. 1. (a) Location map of Funka Bay. (b) Bathymetry map of Funka Bay, showing land topography around Funka Bay, shipboard ADCP observation lines (dashed lines), station positions on the CTD casts (solid circles), wind stations (Mori, Yakumo, Osyamanbe, Date, and Muroran; solid triangles), and the city of Ishikura (solid square). Contour intervals for land topography are 100 m. Light shaded areas represent land topography between 200 and 400 m, whereas heavy shaded areas show land topography in excess of 400 m. OW is Oyashio water.