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Mean Flow and Variability in the Upper Portion of the East Sea Proper Water in the southwestern East Sea with APEX Floats

Homan Lee, Tae-Hee Kim, Ji-Ho Kim, Jang-Won Seo and Yong-Hoon Youn

Marine Meteorology and Earthquake Research Laboratory Meteorological Research Institute, Seoul 156-720, Korea

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Drift data from 17 Argo profiling floats in the East Sea are used to understand the mean flow and its variability in the upper portion of the East Sea Proper Water (UESPW) (around 800 m). The flow penetrates into the Ulleung basin (UB) through two paths: an extension of the southward flowing of the North Korean Cold Water along the east coast of Korea and between Ulleung Island and Dok island. Flows at 800 m are observed in the range of from 0.2 to 4.29 cms-1 and the variability in the north of the UB is larger than that in the south of the UB. In the UB, cyclonic flows from 0.3 to 1.6 cms-1 are observed with the bottom topography. We found that the mean kinetic energy (MKE) and the mean eddy kinetic energy (EKE) are 1.3 and 2.1 cm2s-2 respectively.

Key words : ARGO float, East Sea, Upper portion of the East Sea Proper Water, Mean kinetic energy, Mean eddy kinetic energy

1. Introduction

The deep water in the East Sea, called the East Sea Proper Water, is characterized by homogeneity in temperature and salinity. This characteristic makes it difficult to deduce the deep flow field from the dynamics. Sudo[1] and Senjyu and Sudo[2] revealed that the Proper Water consists of at least two water masses: the upper portion and the deep water. The former, the upper portion of the East Sea Proper Water (UESPW), is defined as having at a 300-1000 m depth with a potential density of 27.32~27.34 kgm^{-3} as a mode water formed by winter convection off the Primorye coast west of 136 °E between 40 °N and 43 °N.

Recently, the CREAMS (Circulation Research of the East Asian Marginal Seas) project, first launched in 1993, has intensified the oceanographic studies and detected the detailed subsurface structure of the water mass in the East Sea[3~10]. Chang et al.[11], Lie et al.[12], and Shin et al.[13] have studied the mean circulation pattern in the East Sea from direct current measurements. And a schematic diagram of the deep water circulation in the East Sea was suggested by Shin et al.[14] from a number of deep sea current data directly observed by current meter moorings.

A new observation instrument, called the Autonomous Lagrangian Circulation Explorer (ALACE)[15,16], is developed for the measurement of the current in the submerged water[17]. Some research has used neutrally buoyancy floats, for example, the RAFOS[18] float, for deep cross equatorial flow in the Atlantic[19], and ALACE for mid-depth circulation in the tropical and South Pacific[20] and for intermediate depth circulation in the tropical Atlantic[21]. In the East Sea, Park[22] and Danchenkov et al.[23] studied the circulation at 800 m from APEX, and Park et al.[24] devised a new method to remove the errors in the estimated location and time from APEX, and estimated the velocity at the depth of 800 m after processing to minimize some types of errors.

In this paper, APEX (Autonomous Profiling

Corresponding Author : Homan Lee, Marine Meteorology and Earthquake Research Laboratory Meteorological Research Institute, Seoul 156-720, Korea
Phone : +82-2-847-2495
E-mail : homann@metri.re.kr

Explorer) floats deployed by the Meteorological Research Institute (METRI) of the Korea Meteorological Administration (KMA) and the Korea Ocean Research & Development Institute (KORDI) have been used to describe the mean flow and variability of the UESPW (at about 800 meter) in the southwest East Sea.

2. Data

As part of ARGO (Array for Real-time Geostrophic Oceanography) program, METRI launched three floats in 2001, and five floats in 2002 in the southwestern East Sea. Two of these floats drifted onto the continental shelf within the span of about three months and another two floats launched in 2002 ran out the Ulleung Basin (UB). And eleven floats, equipped with SBE-41, were deployed by the Ministry of Maritime Affairs & Fisheries (MOMAF) through KORDI. In this study, APEX data obtained in and around the UB within about two years have been analyzed (Table 1).

METRI-APEX floats were programmed to surface after six and one half-day periods of drift at a depth of approximately 800 dbar but the KORDI APEX floats operated at 700 dbar (Fig. 1). During their ascent to the surface from the parking depth, temperature and salinity profiles were obtained at preset pressures and transmitted during about a half-day surface period. The transmitted data including the float status information as well as the location information were collected from the ARGOS data transmission system[25]. Afterwards they were returned to the parking depth for the next mission.

3. Results

From the pattern of flow on Plate 1, it is

Table 1. Information of APEX floats and data used in this study

Argos ID (WMO ID)	Date of Deployment	Location of Deployment		Period of Data (month)	Drifting depth (m)	Cycle (day)	Launched by
24889(2900169)	Oct. 21, 2001	37.17	130.48	3	800	7	METRI
24890(2900170)	Oct. 22, 2001	37.50	129.82	12	800	7	〃
24892(2900171)	Oct. 22, 2001	37.50	130.50	22	800	7	〃
24680(5900193)	Aug. 2, 2002	38.28	129.40	11	800	7	〃
24681(5900194)	Jul. 30, 2002	38.10	130.37	11	800	7	〃
24682(5900195)	Jul. 31, 2002	37.59	131.51	11	800	7	〃
24683(5900196)	Jul. 31, 2002	37.30	131.73	11	800	7	〃
24851(5900197)	Jul. 31, 2002	36.50	131.09	3	800	7	〃
23734(2900204)	Oct. 19, 2001	38.52	129.50	21	700	10	KORDI
18543(2900201)	Oct. 13, 2001	37.30	131.43	10	700	10	〃
18544(2900202)	Oct. 14, 2001	37.23	131.90	19	700	10	〃
18545(2900203)	Oct. 14, 2001	37.30	131.72	16	700	10	〃
04664(2900205)	〃	36.00	130.00	21	700	10	〃
04665(2900206)	〃	36.17	130.17	17	700	10	〃
04666(2900207)	〃	36.17	130.33	21	700	10	〃
04684(2900209)	Sep. 02, 2002	36.00	130.33	10	700	10	〃
04252(2900225)	Sep. 02, 2002	36.00	130.5	10	700	10	〃

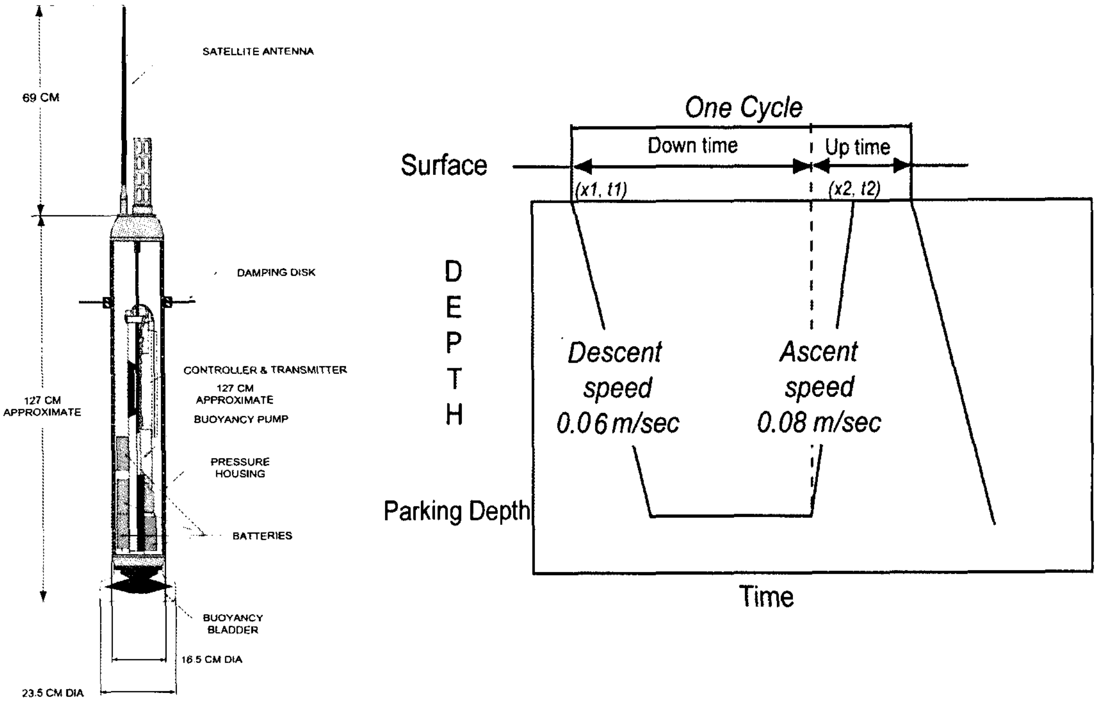

Fig. 1. APEX schematic (left panel) and an observation cycle of the profiling float (right).

apparent that flows at 800 m are spatially complex. Flows at 800 m generally are parallel to the coast with southward or southeastward flow and they are directed between Ulleung island and Dok island after sinking around the polar front[10,26].

Deep currents were observed at 620 m and 790 m depths off the mid-east coast of Korea from the end of August to November 1986. The deep currents were observed to be moving to the southeast with an average speed of about 3 cms^{-1}[12]. From Chang et al.[11], a strong deep mean flow of 6.2 cms^{-1} was directed near the seabed (about 1200 m) and the mean kinetic energy (MKE) was larger than the eddy kinetic energy (EKE). In the southeastern part of the UB, the flow of 1～8 cms^{-1} was observed at a 1000 m depth during the period from June 1999 to June 2000 and attained the maximum speed in winter[13]. In this study the mean flows off the coast and east of Ulleung Island had a mean speed of 2.4 cms^{-1} and 0.8 cms^{-1} over the period of observation, respectively. In the UB, cyclonic flows from 0.3 to 1.6 cms^{-1} were observed along with the bottom topography.

To compute the mean vectors and variability of the Lagrangian flow at 800 meters, we grouped the data in 0.5° x 0.5° square grids. We calculated the vector averages and kinetic energy of the mean velocity on all boxes containing more than 2 vector values and represent the mean velocity in each box on Plate 2. The MKE and EKE were calculated in the same way as McClean et al.[27] did in the North Atlantic and Kundu and Allen[28] off the Oregon coast.

If the zonal velocity is denoted as u (cms^{-1}), and the meridional velocity as v (cms^{-1}), then MKE (cm^2s^{-2}) is

$$MKE \equiv \frac{1}{2}(\overline{u}^2 + \overline{v}^2)$$

where $\overline{u}$, $\overline{v}$ denotes a simple average taken over all the data in 0.5° x 0.5° bins. The EKE is defined by

$$EKE \equiv \frac{1}{2}(u'^2 + v'^2)$$

where the prime indicates fluctuating velocity in

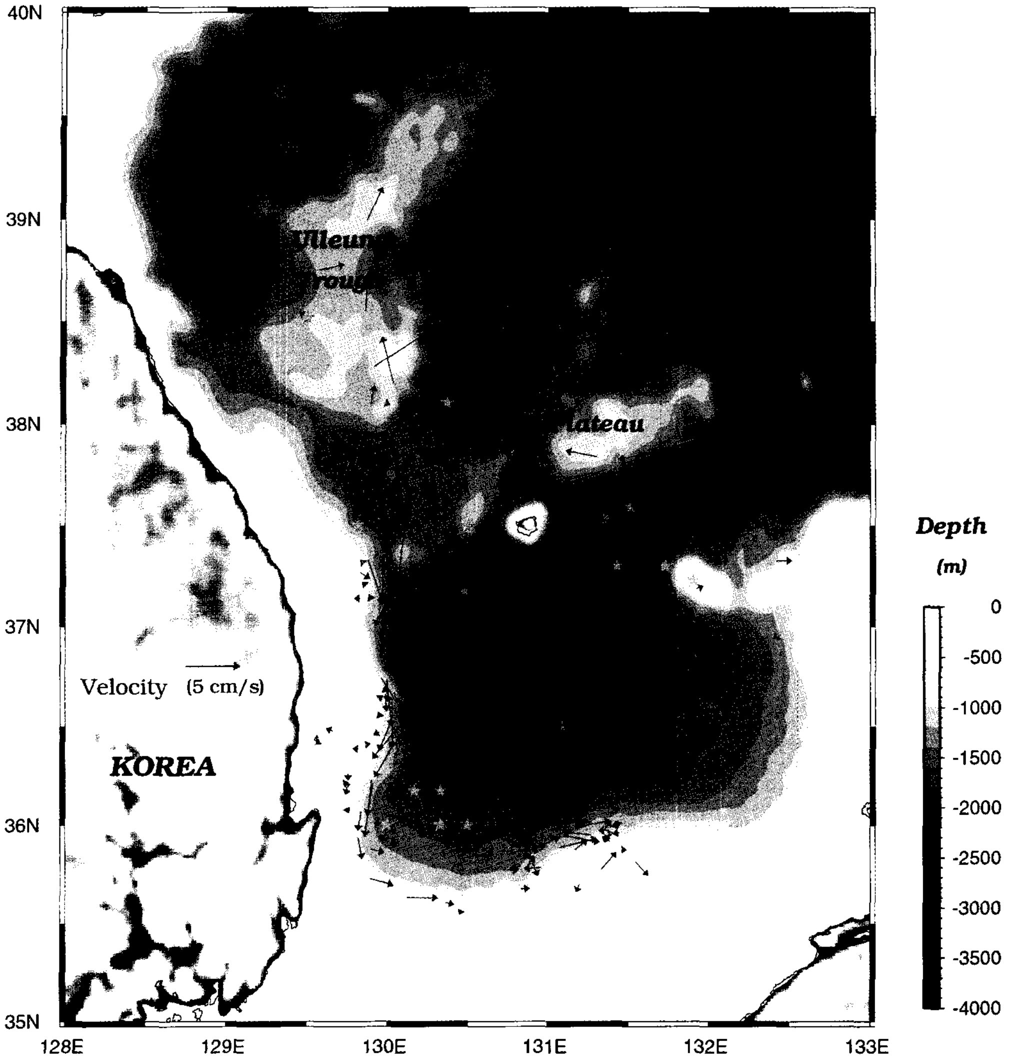

Plate 1. Bottom topography and current field at the intermediate depth (around 800 meter) observed by ARGO profiling floats. Deployment positions of floats are denoted by yellow asterisks.

bins.

The direction(θ), the axis of principal variability, was computed via

$$\tan(2\theta) = \frac{2\overline{u'v'}}{\overline{u'^2} - \overline{v'^2}} .$$

From Emery and Thomson[29], the magnitude of the variance along the major axis (minor axis) corresponds to a maximum (minimum) of D,

$$D = \frac{1}{2}\left\{\left(\overline{u'^2}+\overline{v'^2}\right) \pm \left(\left(\overline{u'^2}-\overline{v'^2}\right)^2+4\left(\overline{u'v'}\right)^2\right)^{1/2}\right\}$$

It was found that the mean MKE and mean EKE are 1.3 and 2.1 cm^2s^{-2} respectively. The variation of the deep currents in the northern part of the UB is larger than that in the southern part of the UB.

4. Discussion and Conclusions

The circulation of the UESPW was studied using profiling floats in the southwestern part of the East

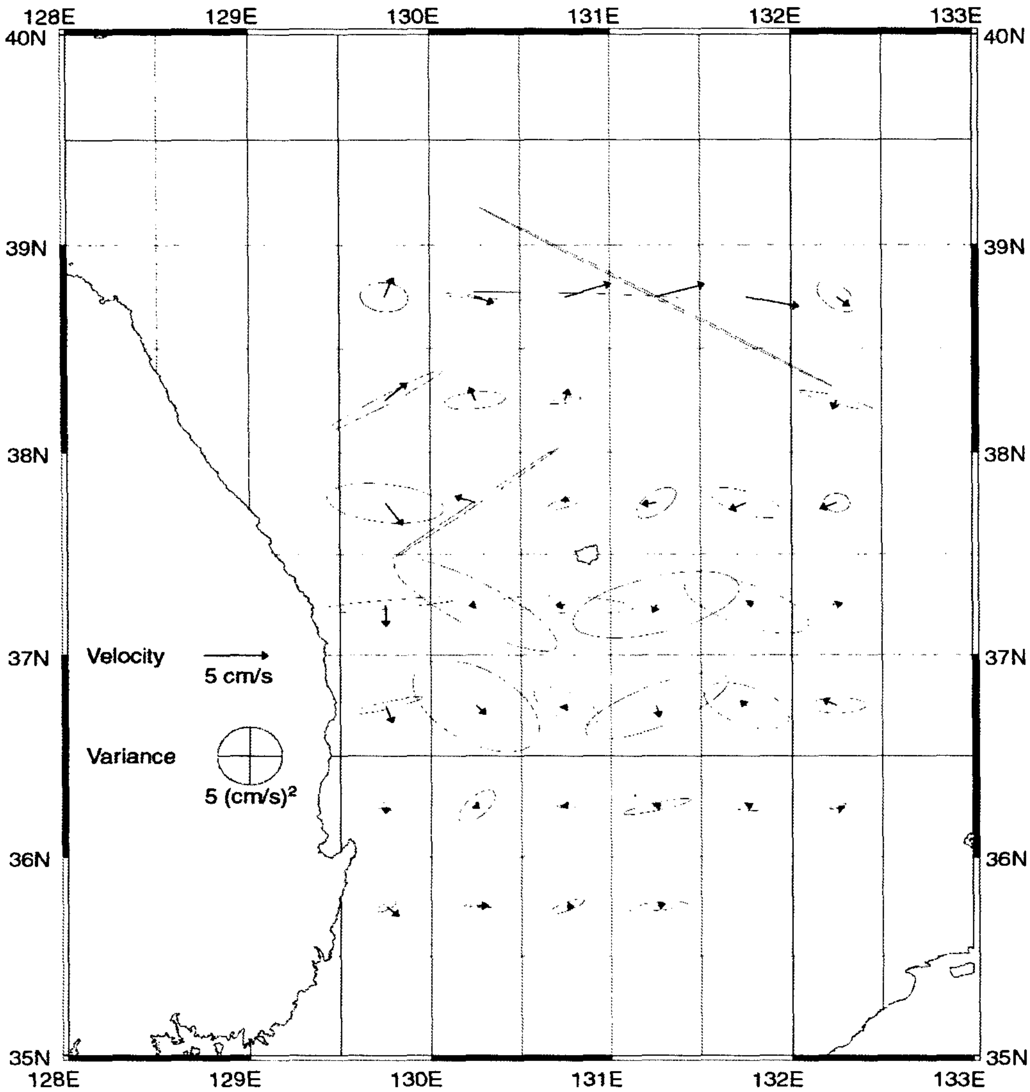

Plate 2. Mean velocity vectors ($cm\,s^{-1}$) and principal standard variation ellipses (cm^2s^{-2}) at 800 m from 0.5° x 0.5° binned.

Sea from November 2001 to July 2003.

The UESPW in the UB was formed from two intrusions: extending to the southward North Korea Cold Current flowing parallel to the coastline off the east coast of Korea, and westward flows, probably formed at the polar front parallel to 39~40 °N, between Ulleung Island and Dok Island. The entering speeds were mean speeds of 2.4 cms^{-1} and 0.8 cms^{-1} in the northwestern and eastern part of the Ulleung basin, respectively. These passages are identical to those suggested by Kim et al.[7] and the mean speed is a little weaker than that of Chang et al.[9] and Lie et al.[10] The UESPW entering the Ulleung basin flowed in the cyclonic direction along a bottom topography and had a mean speed of 0.9 cms^{-1}. It was found that the variation of the deep currents in the northern part of the UB is larger than that in the southern part of the UB.

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