Measurement of deep currents by ADCP attached on the real-time deep seafloor observatory

Kyohiko Mitsuzawa, Japan Marine Science and Technology Center (JAMSTEC) Seattle Office
810 Third Ave., Suite 632, Seattle, WA 98104
kyom@jamstecseattle.org

Ryoich Iwase, Kenji Hirata, Hitoshi Mikada, Deep Sea Research Dept., Japan Marine Science and Technology Center (JAMSTEC)
2-15 Natsushima-cho, Yokosuka, 237-0061, Japan
iwaser@jamstec.go.jp, hiratak@jamstec.go.jp, mikada@jamstec.go.jp

Riyo Otsuka, Marine Works Japan, LTD
1-1-7 2F Mutsuura, Kanazawa-ku, Yokohama, 236-0031, Japan
riyo@mwj.co.jp

Abstract - Three systems of real-time deep seafloor observatory were deployed in the northwest Pacific around Japan. The first system was deployed in the Sagami Bay, 7km off Hatsushima Island, central Honshu in 1993. It was developed as a proto-type of the cable end station for the comprehensive seafloor monitoring network. The observatory was renewed in March 2000. The ADCP was installed in the observatory at a renewal. The second system was deployed at the landward slope of the Nankai Trough, 120 km off Cape Muroto, Shikoku, in March 1997. Third system was deployed at the landward slope of the southern Kurile Trench, 220 km off Kushiro, Hokkaido, in August 1999. The observation system consists of bottom seismometers, Tsunami pressure gauges and the cable end station which composed of several environmental monitoring instruments. ADCP (RDI BBADCP 150 kHz) is attached on the cable end station as the bottom current monitoring instrument. Measurement data of each observatory are transmitted to the land station in real-time using a submarine electro-optical cable. Bottom current profiles are measured as ranges of about 440 m in the Sagami Bay, about 150 m in the Nankai Trough, and about 360 m in the southern Kurile Trench using the ADCPs.

Following phenomena were obtained as results and topics of the observation.

1) Deep exchange flow, which was divided in the internal boundary, was observed in the Sagami Bay.

2) As the features of the deep currents, the southwestward current can be observed on the landward slope in the Nankai Trough.

3) The strong bottom eddies were observed on the slope in the southern Kurile Trench.

I. INTRODUCTION

The first real-time deep seafloor observatory was deployed in Sagami Bay, central Honshu, in 1993. In this area, a plate boundary between the Philippine plate and North American plate is forming the Sagami Trough. Colonies of white clams (*Calyptogena soyoae)* were found at a southeastward slope in the Sagami Trough off Hatsushima Island at depths of about 1100 m in 1984 by manned submersible "Shinkai 2000". The colonies are raised by the cold and warm seepages contained with hydrogen sulfide and methane. The seepages, which come from along the submarine faults, are considered to have some relations among the volcanic and seismic activities in the Sagami Bay. The observatory was deployed in the white clam colony, about 7 km off Hatsushima Island at a depth of 1174 m to monitor the relations among biological activities associated with the seepages and the volcanic, seismic activities. The observatory was developed as a proto-type of a cable end station for a comprehensive seafloor monitoring network [1]. The system including submarine electro-optical cable with a length of 8 km was completely renewed in March 2000 after six-year continuous observation by first observatory.

After a major earthquake in January 1995 at Kobe, Hyogo Prefecture, the Japanese government planned to construct the ocean seismic observation networks in the subduction zone around Japan. The second observatory was developed under the comprehensive seafloor monitoring network program in JAMSTEC from 1995 to 1996. It was deployed at the landward (southward) slope of the Nankai Trough in March 1997, when observation and measurement were started. The cable end station with ADCP (Acoustic Doppler Current Profiler) was installed at the end of the submarine cable with a length of 125 km, 120 km off Cape Muroto, Shikoku at a depth of 3572 m [2]. The purpose of the observatory is not only building up precise ocean seismographic networks but also monitoring of the deep sea environmental changes such as deep currents and temperature. From the point of physical oceanography, it was a good opportunity to measure and understand the structure and time changes of deep currents around Japan.

The third system was deployed in August 1999 at the landward (southward) slope in the southern Kurile Trench funded under the same program of the Muroto observatory, which purposes are to monitor seismicity, tsunami and geophysical and oceanographically phenomena in the southern Kurile subduction zone, which the Pacific plate subducts

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beneath the North American plate. The cable end station was installed at the end of submarine cable with a length of 240 km, 220 km off Kushiro at a depth of 2630 m [3].

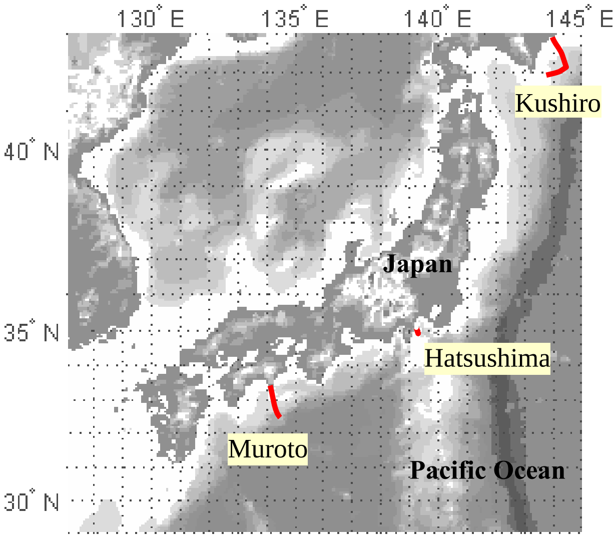

Fig. 1. Map of deployment areas of observatories. Red lines indicate the cable routes.

II. INSTRUMENTATIONS

The real-time deep seafloor observatory basically consists of three-component ocean bottom seismometers and precise pressure sensors as Tsunami gauges and a cable end station which composed of geophysical and environmental monitoring instruments such as a CTD, ADCP, electro-magnetic current meter, video camera with underwater lights, hydrophone and heat flow temperature probes [4]. The picture of cable end station deployed off Cape Muroto is shown in Fig. 2. The components of other two cable end station are basically same as the Muroto observatory.

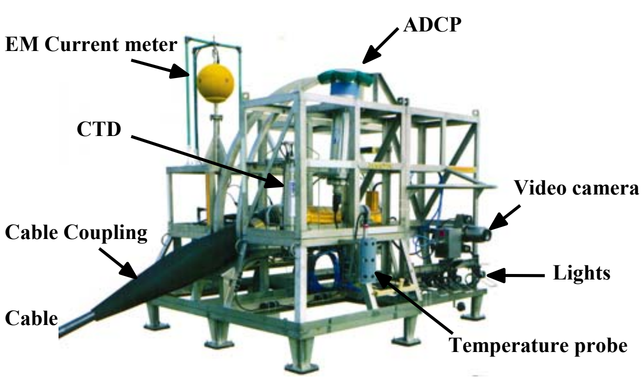

Fig. 2. Cable end station of Muroto observatory.
The cable end station consists of several environmental instruments such as an ADCP, CTD, video camera and heat flow temperature probes. Size of the frame is 230(W) × 285(L) × 276(H) cm. The frame was made of Titanium-alloy.

All data and telemetry commands to and from the observatory are transmitted in real-time using submarine electro-optical cable between instruments and land stations. Power for the underwater instruments is supplied from land station by using a constant current power supply system. Several instruments such as a CTD, ADCP can be controlled from the operation room in JAMSTEC Yokohama Institute for Earth Sciences, using a NTT digital network of 256 kbps.

A direct reading 150 kHz Broadband ADCP from RD Instruments is mounted in the cable end station, keeping the up-looking direction by a gimbals assembly. The transmitting sound into the water from four transducers with 20-degree beam angle are scattered by suspended particles, planktons, etc. The Doppler shift between the source sound and scattered sound is used to calculate the velocities of the particles or planktons which are moving correspondence with currents. Transducers heights are setting about 2 m above the seafloor. The ADCPs are set to measure every 1 minute in Hatsushima observatory and every 30 minutes in Muroto and Kushiro observatory. The setting parameters of ADCPs are shown in Table 1.

Table 1
Setting parameters of ADCP

RD Instruments Direct Reading Broadband ADCP	
Frequency	150 kHz
Depth of transducer	1170 m*1
	3570 m*2
	2630 m*3
Time per ensemble	1 min.*1
	30 min.*2&*3
Time between pings	2 sec.*1
	3 sec.*2&*3
Pings per ensemble	20*1
	30*2&*3
Blank after transmit	400 cm
Number of depth cells	60*1
	36*2
	48*3
Depth cell size	800 cm

*1 Hatsushima, *2 Muroto, *3 Kushiro

III. OBSERVATIONS

A. Vertical measurement ranges of ADCP

The vertical measurement ranges vary with depending on the acoustic backscattering conditions of the water column. The backscattering conditions are different in the area and depth, the deeper area in the ocean is generally becoming the less backscattering particles in the water column. The mean vertical measurement ranges of each ADCP are shown in Fig. 3. The ranges of ADCP of the Hatsushima observatory is as almost three times as the Muroto's measurement ranges. Deep water in the Sagami Bay contains more backscattering particles than other two sites. One of the reasons is as near the coast where a lot of particle is supplied from the river including organic matters produced by human activities.

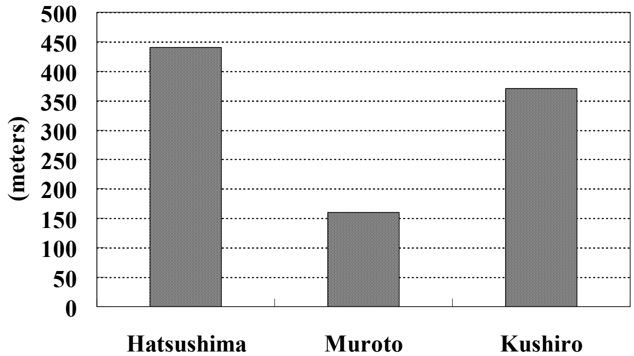

Fig. 3. Vertical measurement ranges of ADCPs.

B. Results of Hatsushima observatory

Deep current measurement using the ADCP mounted in the Hatsushima observatory was started in March 2000. The vertical measurement range of the ADCP reaches about 440 m above the seafloor at a depth of 1170 m, which means it has good measurement conditions compare with other two sites. However, we sometimes lost data of the ADCP by biological disturbance at the Hatsushima observatory. Several crabs, a kind of golden king crab (*Paralomis multispina*), climb up the ADCP and block acoustic transmission pass from transducers (see Fig. 4.).

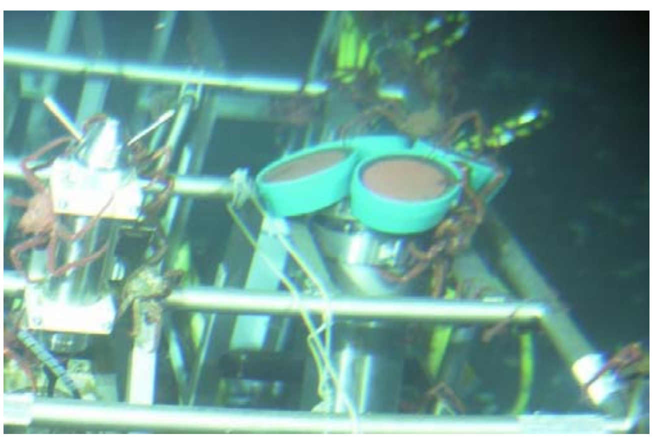

Fig. 4. Biological disturbance for current measurement. Several crabs climb up ADCP and disturb acoustic transmission from transducers. The picture was taken by the Shinkai 2000, dive #1323 on November 28, 2002.

Current structure in the Sagami Bay sometimes indicated the Kuroshio Current effect. In the deep sea area, counterclockwise currents as ranges about <20 cm/sec with semi-diurnal changes are generally observed off Hatsushima. The Kuroshio water sometimes forms internal boundary as a thermocline at a depth of about 800 m, during flowing Kuroshio water into the Sagami Bay. Deep exchange flows, divided by internal boundary, were observed by ADCP measurement of Hatsushima observatory. Fig. 5 shows deep exchange flow between upper and lower layers of the boundary was observed in September 2000.

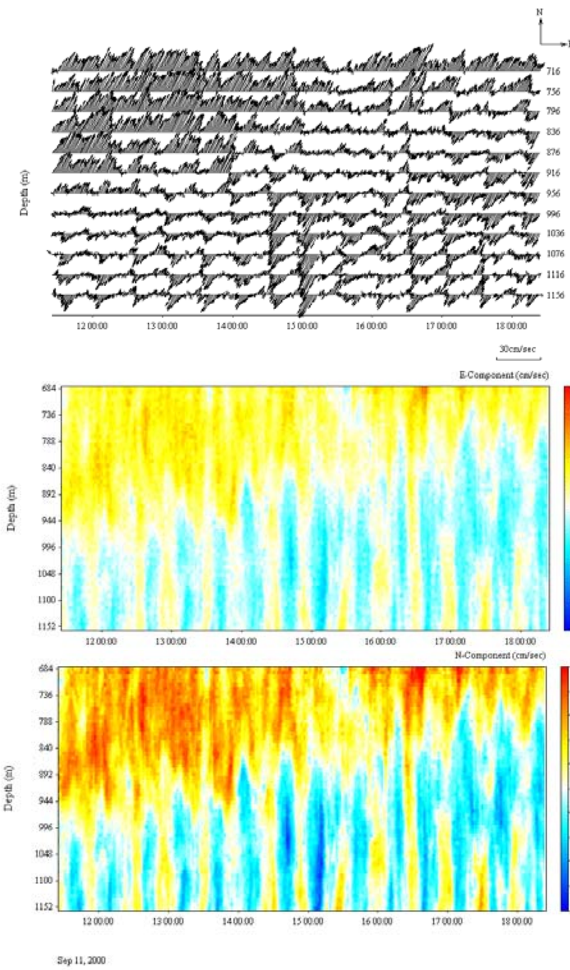

Fig.5. Time series of currents, obtained by Hatsushima observatory.

ADCP data of Hatsushima observatory, September 11-18, 2000. Data was calculated along a 25 hour running mean.
Upper figure; Stick diagram
Middle figure; Eastern component
Lower figure; Northern component

The strong westward current, which is over 1 kt along the coastline, is sometimes observed in the Sagami Bay. This current, called “Kyu-cho” in Japanese, is caused by Kuroshio water. We are investigating the relations among “Kyu-cho”, as surface strong currents, and deep exchange flows through the Kuroshio effect.

In addition, turbidity currents with bottom-surface sediment transport on the slope in the Sagami Trough, which were caused by submarine earthquake swarm between Hatsushima Island and Izu Peninsula, were observed in March

1998 and April 1998 before the observatory renewal [5]. We will expect to capture the precise structure of the turbidity currents using ADCP.

C. Results of Muroro observatory

Over six years have passed since we had started to measure the deep currents using ADCP in the Nankai Trough, off Muroto. Time series of current, which was calculated along a 25 hour running mean from January 2 to December 20, 2000 is shown in Fig. 6. Vertical measurement ranges are obtained about 150 m thickness. Maximum speed was over 25 cm/sec near the seafloor. Current was predominantly southeastward direction.

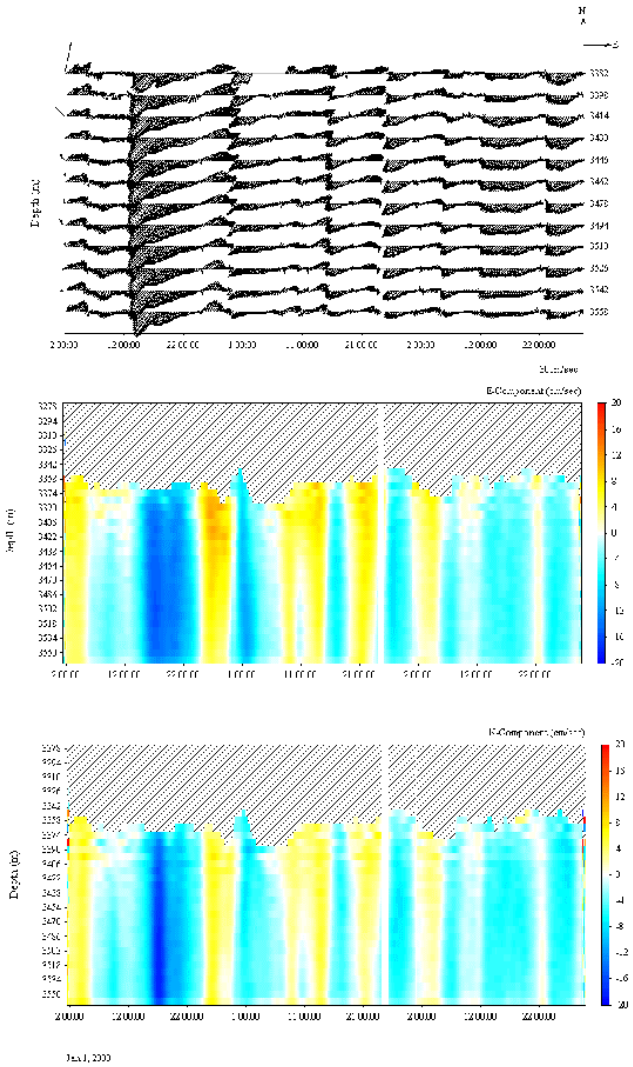

Fig.6. Time series of currents, obtained by Muroto observatory.

ADCP data of Muroto observatory, January 1-April 3, 2000.
Data was calculated along a 25 hour running mean.
Upper figure; Stick diagram
Middle figure; Eastern component
Lower figure; Northern component

Power spectrum of eastward and northward current components is shown in Fig. 7. The main period of current change is semi-diurnal change corresponding with the M2 tide. A diurnal change is also observed.

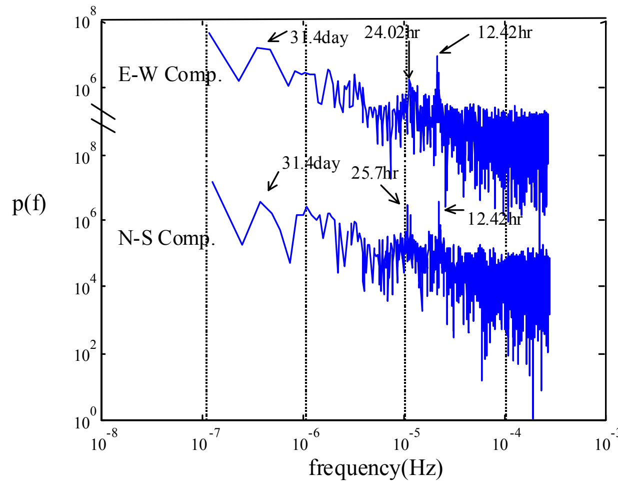

Fig. 7. Power spectrum of current.

Spectra of eastward and northward components of first layer of Muroto ADCP data calculated by FFT analysis.

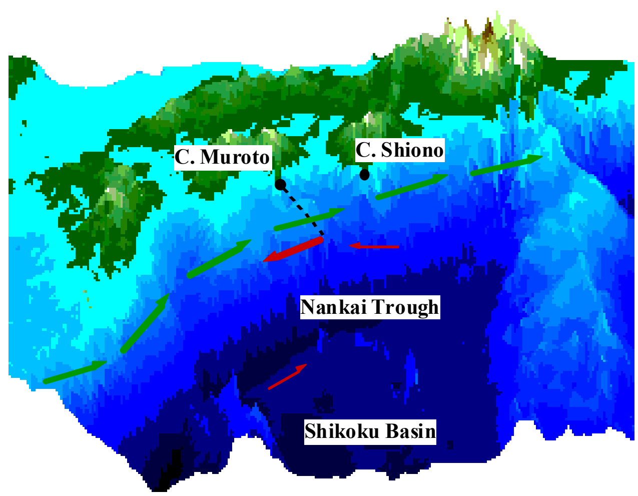

Fig. 8. Schematic features of the current system of the Nankai Trough.

Green arrows indicate the Kuroshio Current as surface current, and red arrows indicate deep sea currents. The southwestward deep currents measured by ADCP.

In this area, southwestward deep currents were suggested by Mitsuzawa and Holloway in their abyssal circulation feature [6]. Fukasawa *et al.* also reported that current direction is mainly westward on the bottom of landward slope in Nankai Trough off Cape Shiono, Kii Peninsula [7]. The results of ADCP measurements correspondent to these circulation feature. The schematic feature of the current system in this area is shown in Fig. 8. In the deep sea area of the Nankai Trough, one is forming as a deep boundary current on the southward slope, and another is forming as a kind of trench counter current on the northward slope.

C. Results of Kushiro observatory

Through three-year observation, the deep currents mainly flow northeastward along the slope in the Erimo Canyon. It was identified that current field were influenced by not only tide but also topography. The deep sea eddy, which formed by strong shear near the seafloor by topographic effect, was observed on the southward slope off Kushiro in September 9, 1999 as shown in Fig. 9.

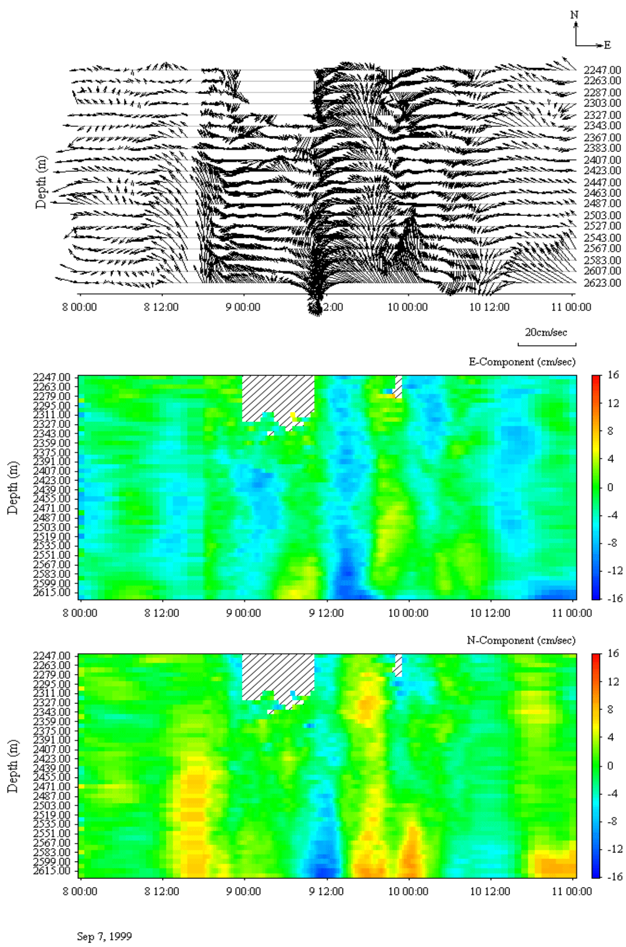

Fig.9. Time series of currents, obtained by Kushiro observatory.

ADCP data of Kushiro observatory, January 1-April 3, 2000. Data was calculated along a 25 hour running mean.

Upper figure; Stick diagram

Middle figure; Eastern component

Lower figure; Northern component

Schematic features of the current system of the southern Kurile Trench off Hokkaido are shown in Fig. 10. Oyashio Current flows from northeast to southwest as a surface current. It makes the Oyashio front located from the southeast off Cape Erimo to off Sanriku, Honshu. The cable end station was deployed at southern slope in the Erimo Canyon. Deep currents were observed along slope in the Erimo Canyon as western direction using ADCP. On the other hand, Deep Western Boundary Current (DWBC) and Trench Counter Current (TCC) are known in existing in the southern Kurile Trench. The deep westward current in Erimo Canyon may account for one of the branch currents separated from DWBC.

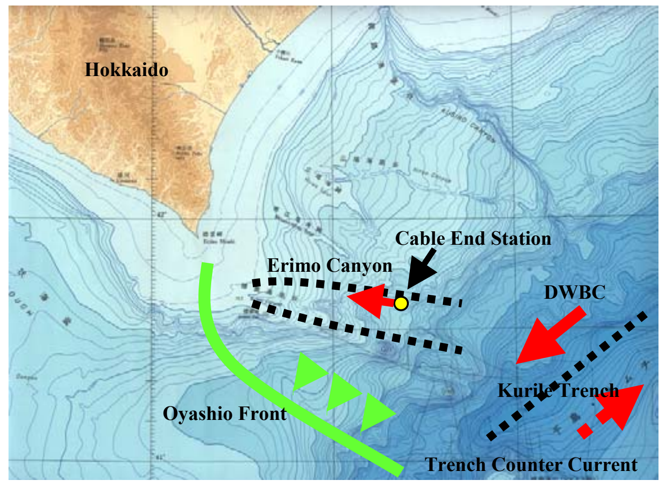

Fig. 10. Schematic features of the current system of the southern Kurile Trench

Green arrows indicate surface currents, and red arrows indicate deep sea currents.

IV. CONCLUSIONS

It has been passed over six years since we had started first real-time deep current measurement using ADCP at a depth of 3558 m in Nankai Trough. The hardware conditions of ADCP are having stable through the observations in each site. Deep current features and several interesting phenomena have been obtained.

1) Deep exchange flow, which was divided in the internal boundary, was observed in the Sagami bay.

2) As the features of the deep currents, the southwestward current can be observed on the landward slope in the Nankai Trough.

3) The strong bottom eddies were observed on the slope in the southern Kurile Trench.

It is interesting to investigate that the scale of deep sea currents and long-term changes in the deep sea area, need future study. In addition, observations are concluded to need investigation of the interaction between deep currents and surface current such as the DWBC and Kuroshio, Oyashio currents. We will expect that the deep current monitoring using ADCP lead us to understand the spatiotemporal changes of deep current system and its influence to the environmental and climate changes.

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