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Investigation of the influence of the background ocean current on flow measurements using the UVP method

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Seabed surveys were carried out in the Okinawa Trough area and the Izu-Ogasawara area to assess the flow state of hydrothermal jets at hydrothermal deposits using UVP measurements. It is known that background ocean currents are added to the measured jet velocity as a bias component in one-dimensional UVP measurements. This study investigated the effect of background current among several types of measurement data with seabed current component variations. Correction equations for the seabed current component were then developed and the effect of seabed currents on flow estimation was evaluated. The possibility of quantitative flow measurement under the influence of seabed currents based on UVP measurements for several jets was then assessed by comparing velocity and flow data.

Keywords: Ultrasonic Velocity Profiler, hydrothermal vent, jet flow

1. Introduction

Hydrothermal deposits can be found at deep sea globally and have attracted attention as candidates of potential new resources. The amount of material deposited from hydrothermal vents could be estimated from the composition and flow rate of the hydrothermal fluid since the key physical phenomenon is transport of material from seabed via hydrothermal fluid. The aim of this study is to clarify the flow behavior of the hydrothermal fluid using experimental mechanics, and as part of this, quantitative measurements of the flow field using the UVP method are being carried out [1]. Velocity measurements of hydrothermal jets have been carried out several times in the past, showing the validity of qualitative measurements [2]. On the other hand, there are also concerns about the influence of the actual environment, such as seabed-specific currents [3] and temperature changes in the jet stream [4], in flow estimation based on time-series measurement data.

This paper discusses two topics; firstly, the relationship between measurement data using the UVP method and the influence of ocean currents on measurements, and secondly, a method for estimating flow rates by subtracting background current velocity information considering distribution of the UVP measured jet velocity profiles.

2. Measurement methods

UVP measurements were carried out at hydrothermal vents in the Izu-Ogasawara and Okinawa Trough areas during the KS-22-12 voyage in the Izu-Ogasawara area from 14 August 2022 to 23 August 2022 and the KR-18-14 Leg 1 voyage in the Okinawa Trough area from 18 October 2018 to 30 October 2018, respectively. The dives were conducted during the KR-18-14 Leg 1 voyage in the Okinawa Trough area from 18 to 30 October 2018. The research was conducted with the mother vessel Shinsei Maru and the ROV Hyper Dolphin, and the mother vessel KAIREI and the ROV KAIKO Mk-IV, respectively, with measurement equipment, etc. as payloads.

Peacock UVP (Ubertone) as well as a control PC are installed in a pressure-resistant vessels and deployed to the deep sea. The device is remotely controlled and monitored from the mother vessel. Two pressure balance type ultrasonic transducers (frequency: 3.6 MHz, active diameter: 10 mm) are used for the UVP measurements.

Research dives were conducted at the Sunrise deposit (approx. depth: 1,300 m) in the Myojin knoll of the Izu-Ogasawara region and at north Iheya area (approx. depth: 1,000 m, points: C9023A and C9023E) in the Okinawa Trough region. Measured hydrothermal vents at the Sunrise deposit had clear fluid exhibiting formed chimney around the vents while those at the north Iheya region had typical “black smoker” appearance. Measured maximum temperature reached 138 °C at the Sunrise deposit, 299 °C at C9023A, and 45°C at C9023E.

3. Measurement results

3.1 Measurement of jet velocity by UVP

The ultrasonic beam line was set so that velocity profile at jet axis can be measured with a certain inclination angle, which is required to obtain axial velocity component with UVP. The measurement device was shifted with the manipulators of the ROV. The angle is stored as a pitch of Peacock UVP to the data file on the control PC. Even though the measurement device is rigidly fixed with the manipulators during the measurements, velocity profile varies over the time due to the aforementioned background current or slight motion of the ROV.

Fig. 1 and Fig. 2 show examples of the mean velocity distribution classified by the pitch angle and the direction of the current velocity in the UVP measurements. Fig. 3 shows the average velocity distribution every 10 seconds at C9023E as an example of time-series variation. The standard error of the velocities and the echo amplitude profiles at each condition are shown in Fig. 4 - Fig. 9. Figures are titled according to the conditions. In each figure, "With current" indicates that the current were observed within the range of ±15° relative to the measurement line, while "Without current" means that no background current was observed.

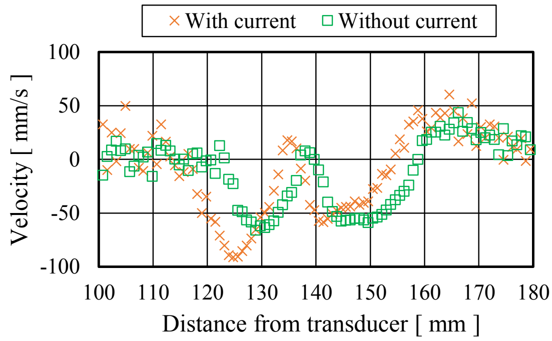

Fig. 1 Velocity profile at Sunrise deposit, angle of 4°

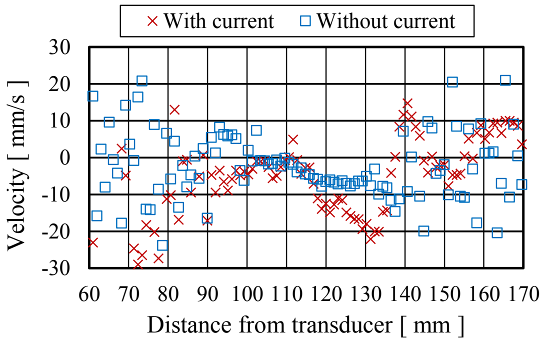

Fig. 2 Velocity profile at C9023A, angle of -13°

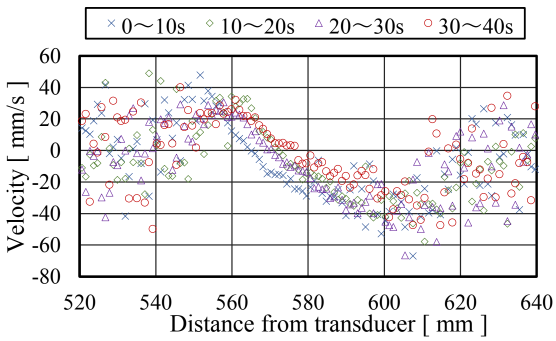

Fig. 3 Velocity profile variation at C9023E

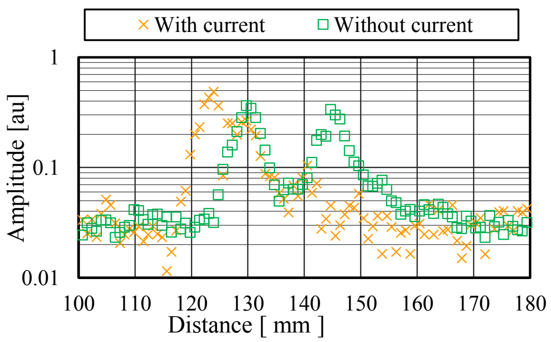

Fig. 4 Amplitude profile at Sunrise deposit, angle of 4°

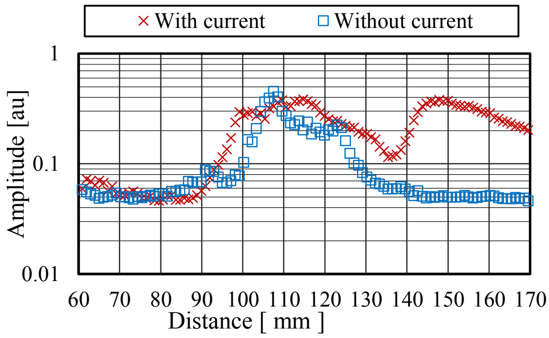

Fig. 5 Amplitude profile at C9023A, angle of -13°

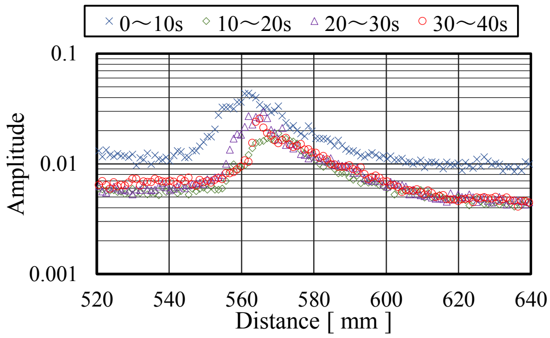

Fig. 6 Amplitude profile variation at C9023E

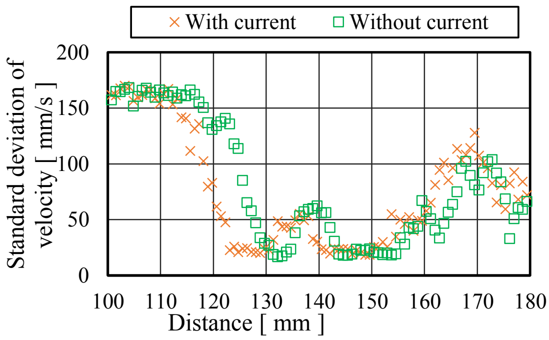

Fig. 7 Standard deviation of velocity profile at Sunrise deposit, angle of 4°

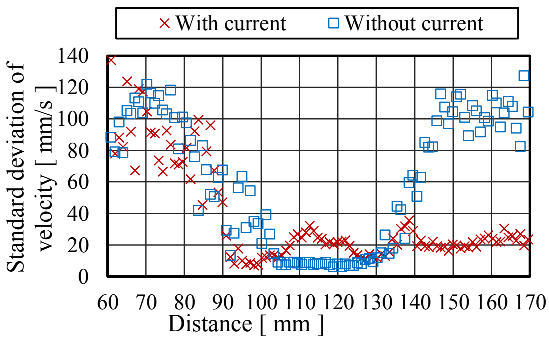

Fig. 8 Standard deviation of velocity profile at C9023A, angle of -13°

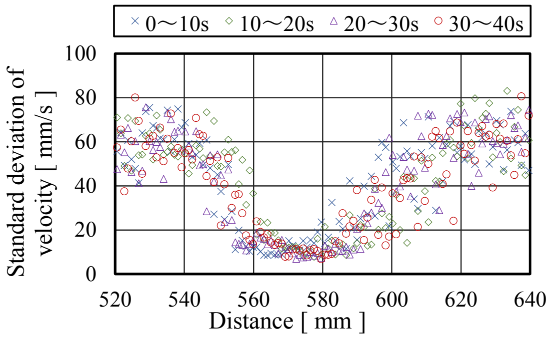

Fig. 9 Standard deviation of velocity profile variation at C9023E

Peak positions of the velocity and echo amplitude profiles show good agreements. The measurements are carried out to the natural fluid without adding any tracer particles. Hydrothermal fluids, however, have macroscopic temperature variation in the measurement volume of UVP as well as particle deposition. These small speckles are thought to be working as tracer for UVP measurement. The migration of the velocity and the echo amplitude peaks suggests that measurement line have altered against axis of jet flow due to background ocean current or ultrasonic bending according to temperature profile along the beam. Note that because of these reflection mechanisms, amplitude peak does not necessarily mean the location of jet flow.

Amplitude profiles of C9023E shown in Fig. 6 fluctuate over time and thus beam position against the jet axis shall also be altered. However, there is no significant change in the shape of the velocity profile. In Fig. 1, peak velocity increases when ocean currents were observed. contrast, the data at the Sunrise deposit show an increase in the maximum velocity. Additionally, peak velocity for C9023A shown in Fig. 2 and standard deviation shown in Fig. 8 have both increased when currents were observed. These differences are thought to be caused by the influence of the bottom currents at the time of measurement, and as the influence increases, the variation of the data also increases. The shape of the amplitude profile for C9023A shown in Fig. 5 changes significantly when there is an influence of the bottom currents. This suggests that the shape of the jet flow itself may be significantly distorted by bottom currents.

3.2 Results and discussion of jet and current data analysis

For axisymmetric jets, it is well-established that the axial velocity component exhibits an axisymmetric “even function” velocity profile while the radial velocity distribution is characterized by an odd function due to jet spread and entrainment. Schlichting's theoretical equation, which describes the velocity distribution of a free jet in laminar flow, provides a theoretical solution. However, it should be noted that Schlichting's equation is applicable to laminar flow conditions whereas the hydrothermal jet is typically turbulent. Consequently, the velocity distribution deviates from that theoretical equation. Previous research has demonstrated that the axial velocity distribution of the jet conforms to a Gaussian distribution [5]. Thus, an axial velocity profile can be described by Eq. (1):

$$V_z = b \times \exp\left(\frac{-(x-a)^2}{2 \times \left(\frac{1}{2}c\right)^2}\right) \ [\,\mathrm{mm/s}\,] \qquad (1)$$

where a is the position of the center of the jet, b is the maximum velocity in the velocity distribution area, and c is the jet width. In order to incorporate the effect of bottom currents, we modified equation to Eq.(2):

$$V_Z = (b') \times \exp\left(\frac{-(x-a')^2}{2 \times \left(\frac{1}{2}c'\right)^2}\right) + d \quad [\,\mathrm{mm/s}\,] \qquad (2)$$

where a' is the value that takes into account the effect of the position of the center of the jet and the deviation of the center position due to the bottom current, b' is the result of the maximum velocity and the shape change due to the deviation from the peak width position, c' is the result of the shape change due to the deviation from the peak jet width position, d is the velocity effect of the bottom current, and V_Z is the axial velocity.

In UVP measurements, the transducer is inclined to the vertical axis of the jet. Therefore, assuming the axial velocity component is dominant compared to the radial velocity component, the radial velocity distribution will be an odd function from the jet axis [5]. Therefore, by taking the average of the velocity components at equidistant points from the axis, the radial velocity component is cancelled out and the axial velocity component can be synthesized. Subsequently, performing least squares fitting with Eq. (2), parameters of the jet and the bottom current velocity are estimated. Finally, flowrate is estimated by integrating the equation as shown in Eq. (3).

$$Q = 2\pi b' \left(\frac{c'}{2}\right)^{\mathbf{2}} \qquad (3)$$

R^2 values of fittings and obtained parameters are shown in Fig. 10 to Fig. 14 and Table 1. "Radial distance" in figures indicates the distance from the central axis of the jet estimated through fitting. Time-series ensemble averaged velocity is plotted. Estimation results show that the flow rate is affected by fluctuations of the bottom currents. The decrease of flow rate is caused by UVP beam line misalignment as the jet itself moves away due to the current and UVP could not capture the center of the jet axis. The fitting results also indicate that the jet parameters can be estimated by proposed method in this study. However, the predicted bottom current velocities, especially at station C9023A, are slower than the other case measured at Sunrise deposit. Considering the low R^2 value shown in Fig. 13, original velocity profile shown in Fig. 2 and amplitude profile shown in Fig. 5, this measurement could have been including multiple hydrothermal jets in one measurement line. Furthermore, current velocity could have velocity profile depending on the distance from the seabed. Since current proposed model is applicable to the simple jet condition, it would be required to improve the methodology so that complicated actual situation can be precisely assessed in the future.

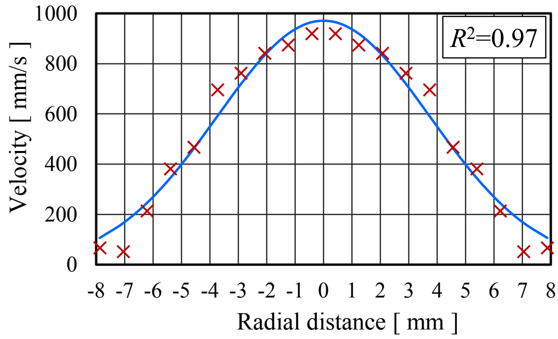

Fig.10 Fitting result for Sunrise deposit

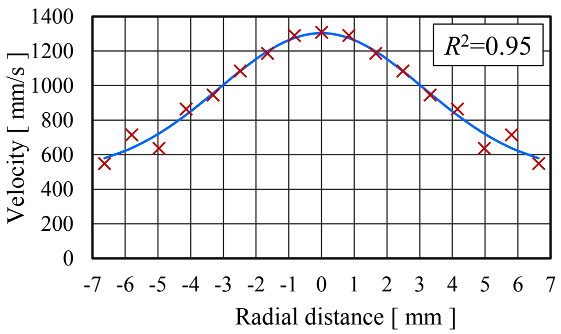

Fig.11 Fitting result for Sunrise deposit with current

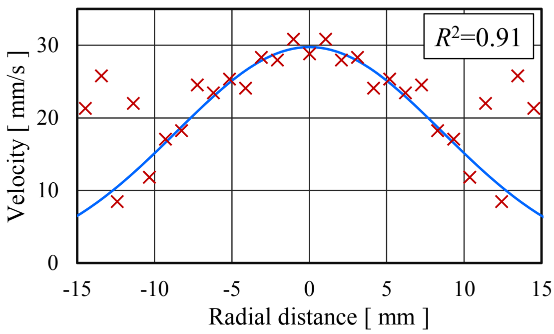

Fig.12 Fitting result for C9023A

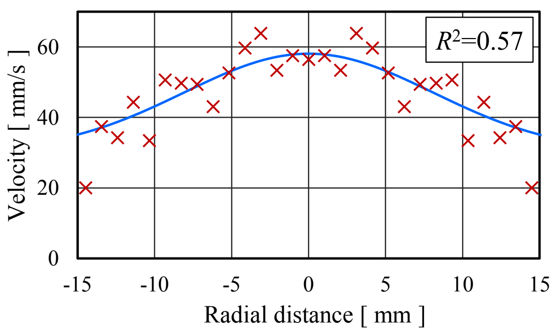

Fig.13 Another fitting result for C9023A

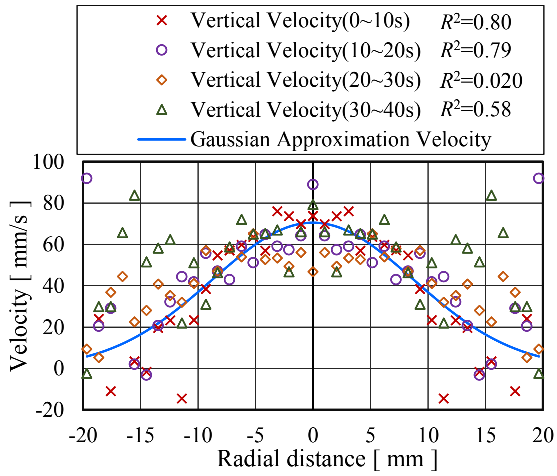

Fig.14 Fitting results for C9023E

Table 1 Estimated parameters of jets and currents

	Velocity b' [mm/s]	Width c' [mm]	Flowrate Q [L/min.]	Current [mm/s]
Sunrise 4°	971	7.49	5.14	—
Sunrise 4° w/ current	1304	6.24	4.96	34.5
C9023A -13°	29.7	17.2	0.829	—
C9023A -13° w/ current	57.1	16.1	0.686	6.78
C9023E -12°	70.5	17.6	2.05	—

4. Summary

Hydrothermal vent fluid flows were measured by UVP and flow parameters as well as bottom current effect were estimated. Estimation is performed by assuming the jet flow as an axisymmetric jet. In future work, we will continue to analyze the measurement data from other sites obtained during the previous voyages. In addition, we will conduct further analysis of the variation of the velocity distribution when the lateral direction flow affects the jet.

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