SEMIDIURNAL TIDAL CURRENTS MEASURED WITH OCEAN SURFACE RADAR AROUND ISAHAYA BAY MOUTH IN ARIAKE SOUND, JAPAN

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1. INTRODUCTION

Ariake Sound, in Kyushu Island of western part of Japan and connecting the small bay, Isahaya Bay, in the northwestern (Fig. 1) is strongly affected by large semidiurnal tide of which amplitude ranges from 3 to 5 m [3]. While Ariake Sound exhibits highly productive, red tides have occurred more frequently around the northern area of Isahaya Bay Mouth, causing damage to the fisheries, recently [1]. The accurate and fine-scale tidal currents variability is generally important to evaluate water quality because estuary attributes such as salinity and temperature distributions are strongly affected by the tidal mixing and tidal exchange [4]. The motivation of the present work is the observation of fine-scale Semidiurnal Tidal Current (STC) variations around Isahaya Bay mouth in Ariake Sound with Ocean Surface Current Radar (OSCR), which enables us to measure surface currents with a high spatial and temporal resolution.

2. MEASUREMENTS AND TIDAL ANALYSIS

In order to continuously monitor STC around Isahaya Bay mouth in Ariake Sound, two units of Digital Beam-Forming type OSCR (DBF-OSCR) were deployed at St. A (St. B) on the western (eastern) coasts of Ariake Sound (Fig. 1) from April to December 2007. Each one unit of DBF-OSCR alternately transmited for 15 minutes interval at VHF of about 41.9 MHzand alternately measured a 13 minutes averaged radial components of the surface velocity along eight beams, which are blue (red) lines from St. A (St. B) in Fig. 1, with resolution of 30 minutes in time, 13-17 deg. in azimuth, and 500m in range, along radial beam direction of 500m from 1.5km to 25km and with velocity resolution of about 2.13 cm s^{-1} [2].
In order to isolate four major tidal constituents (K_1, O_1, M_2, S_2), A standard harmonic tidal analysis was applied to time series of the surface radial component for a period of roughly 5 of 8 months, which is due to data-missing for machine maintenances and troubles. The tidal currents are mapped on a fixed about 500m grid by interpolations and combination of the radial tidal constituents isolated by the harmonic analysis. The interpolations and combinations, however, do not use the constituents at the radial beam point at which the acquisition ratio of the valid radial velocitis to whole observations is less than 75 %.

3. TIDAL VARIABILITY AND TIDAL EXCHANGE TRHOUGH ISAHAYA BAY MOUTH

The distribution of observed M_2 tidal ellipses (Fig. 2a) in the whole domain shows near rectilinear of which semi-major axes align with coastlines in Ariake Sound; The tidal currents flow approximately north-south along the western and eastern coastlines in Ariake Sound and approximately east-west perpendicular to the Isahaya Bay Mouth around the Bay Mouth.
The co-amplitude distribution (Fig. 2a) of the semi-major axes shows (1) that tidal currents range from 18 cm s^{-1} to 60 cm s^{-1}, and (2) that the tidal currents in the southeastern region is four times as fast as that in the northwestern. The co-phase, referred to the moon's transit at 135° E, distribution (Fig. 2b) shows (3) that the phase varies from 150° to 170°, (4) that phase of about 170° around Oura tide station (black triangle in Fig. 2b) [3] leads about 90° from the pahse (258°) observed from sea level at Oura station, and (5) that the phase of the western region is 10-20° earlier than that of the eastern region in Ariake Sound. These results (4) and (5), probably including result (2), are consistent with the tidal response in semi-enclosed bay; the phase difference between the current and sea level is representative of a standing wave pattern, which has the difference of 90° in phase, and the phase lag between the western and the eastern is due to the earth's rotation. The depiction of the latter phase lag, has been often calculated in semi-enclosed bay, would have been difficult without current observations with high resolution in space and time by Ocean Radar technique.
In order to evaluate the tidal exchange through Isahaya Bay mouth, z-z' line including line-L1, L2, and L3 (Fig. 3a) along Isahaya Bay Mouth is defined and the vector of M_2 tidal current constituents are decomposed into an orthogonal component

(u') perpendicular to z-z' line in line-L2. The amplitude of u' is linearly increasing from 9cm s^{-1} in the north to 26cm s^{-1} in the south along the line-L2 (Fig. 3b). Besides, the phase of u' is nearly constant and leads about 90° from that of tidal level at the Oura tide station.

The volume transport induced by the M_2 semidiurnal tide is evaluated with the amplitude of tidal elevation and the orthogonal components u'. The total volume transport (VT), entering from Ariake Sound to Isahaya Bay, from a low tide to a high tide is calculated with integration of tidal level amplitudes, which is 155cm at Oura tide station in Fig. 2a, over the bay area, amounting to about 2.5×10^8 m^3. The volume transport of the M_2 semidiurnal currents through the line-L2 (VT-L2) is calculated to be 1.7×10^8 m^3 by the sum of the product of the depth, the unit width and the integration of u' harmonic function at each point in line-L2 with ignoring the phase of these velocities and the tidal elevations. If the volume transport through the narrow line-L3 is assumed to be nearly zero because the u' components are decreasing from the south to the north in line-L2 and u' component at the northernmost is considerably small, the volume transport through line-L1 (VT-L1) is determined to be 0.8×10^8 m^3. The amplitude of the transverse-averaged u' component in line-L1 is evaluated to be about 28cm s^{-1} calculated from the VT-L1 with the width and the averaged depth of line-L1. The amplitude of u' in line-L1 is comparable to the u' amplitude at the southernmost in line-L2 (Fig. 3b). The volume transport, including VT-L1, from the southern coast to the center (No.18 in Fig. 3a) of Isahaya Bay mouth reaches approximately 80 % of the total transport calculated with tidal levels, representing that the south part in the Isahaya Bay Mouth account for the most of the tidal exchange induced by semidiurnal M_2 tide.

4. CONCLUSION

The semidiurnal tidal currents around Isahaya Bay Mouth in Ariake Bay, Japan were observed with high resolution in space and time by DBF-OSCR. The distribution of the semidiurnal tidal currents were measured well-resolved in space enough to represent the tidal response in semi-enclosed bay and to evaluate the tidal exchange through the bay mouth, showing the effectiveness of Ocean Surface Current Radar.

5. REFERENCES

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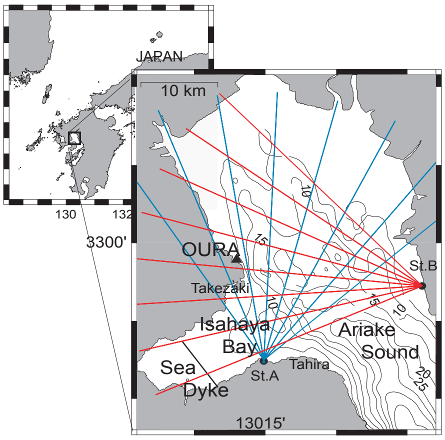

Fig. 1. Map of Ariake Sound and Isahaya Bay. Contour depth interval is 2.5m. Symbols denote locations of radar stations (black circles) and Oura tide station (black triangle). The blue (red) lines from St.A (B) denote beams on which radial currents are measured.

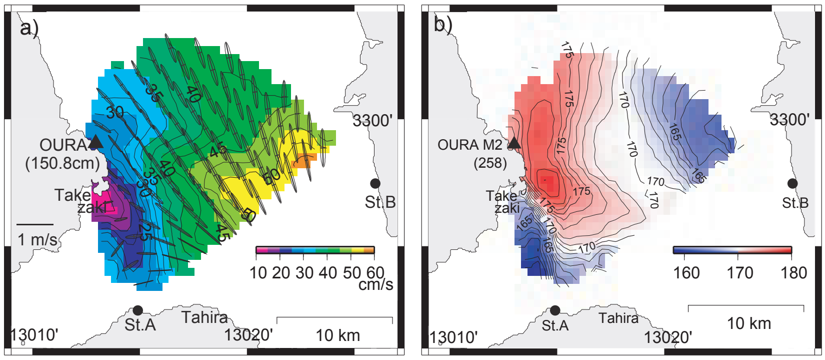

Fig. 2. M2 tidal ellipses from tidal analysis of DBF radar derived surface currents, where a) Tidal current amplitude (semi-major axis) is shown in color, and ellipses are plotted at selected cells, and b) Tidal current phase contoured at 1° interval, referred to the moon transit at 135°.

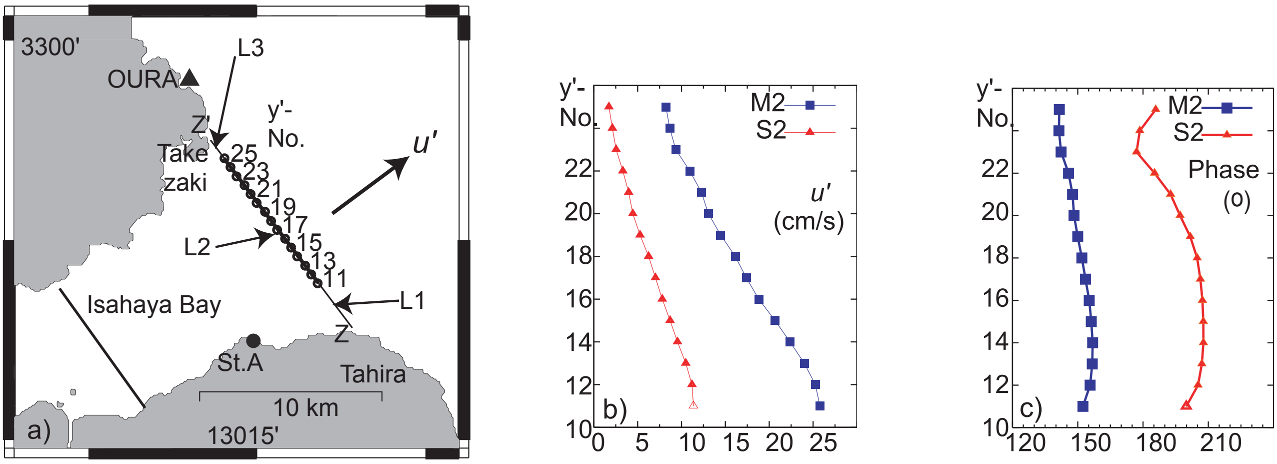

Fig. 3. M2 tidal component u' across Isahaya Bay Mouth, where a) the map around Isahaya Bay Mouth with z-z' line including line-L1, L2, and L3, b) the amplitude of u' along line-L2, and c) the phase of u' along line-L2.