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Measuring Flow Velocity with Acoustic Doppler Current Profiler in the Commodore Channel Lagos, Nigeria: *Implication for Understanding Channel Dynamics*

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Abstract
This study is conducted to investigate the flow characteristics in the Commodore channel. The Commodore channel is situated along the barrier bar complex of the Nigerian coastal zone. The dimension of the channel is 0.5 to 1 km wide and 10 km long. Numerous lagoons within the barrier bar complex connects the Atlantic Ocean through the Commodore channel. The construction of stone moles and dredging operation have significant impact on the stability and flow velocity and this has induced siltation and erosion problems at different sections of the channel and its adjacent beaches. In this study, we deployed the Teledyne RD instrument (1996 - 2010), Work-horse Sentinel Acoustic Doppler Current Profiler to measure water flow pattern along the Commodore channel. The equipment comprises of four beams transducer with transmitting frequency of 300 kHz. The ADCP was mounted on a boat and deployed with its transducer facing down to collect current velocity datasets along twenty transect lines covering the channel section. We processed and analysed the raw field data with Win-River and Matlab softwares to produce streamwise current velocities and depth average (DAV) profiles of selected transect lines representing the channel entrance, mid-stream and up-stream respectively. Our results shows variations in flow velocities within the different channel area. The streamwise flow velocities along the channel mouth was slightly higher than the velocities along the middle and upper reaches. Maximum flow velocity of 1.00 m/s were recorded within the channel centre while minimum flow velocity of 0.11 m/s usually occurred along the boundaries of each transect. This implied that the channel centre are areas of high energy associated with strong current while the channel banks are areas of low energy associated with weak current.

Keywords: *Acoustic Doppler Current Profiler, Commodore channel, Depth average velocity, Streamwise velocity.*

Introduction

The Commodore channel is an intricate parts of the barrier bar complex situated in the western Nigeria's coast. The Lagos lagoon and other creeks and lagoons within the barrier bar complex connect the Atlantic Ocean through the Commodore channel. The channel is depicted by flow reversal condition that is driven by tide and density current. Stone moles were constructed along the Commodore channel to attenuate the impact of waves from the Atlantic Ocean and these includes; the training moles, the west mole and the east moles. The construction of those moles distorted the dynamic flow of water and sediment accretion along the channel. This sediment build up obstruct the movement of vessel in and out of the Lagos harbour (Smith, 1979). The construction of moles and other anthropogenic activities like dredging operation have significant impact on the stability and flow velocity and have created siltation and erosion problems at different sections of the channel. The characteristic of flow velocities generally affect the morphodynamics, nutrients circulations and sediment transport processes in water bodies. The knowledge of flow velocity is utilized by oceanographers, geoscientist and coastal engineers in the design and construction bridges, dams and flood protection (Hlavčová et al., 2016; Jeneiová et al., 2016; Peksová Szolgayová et al., 2017). The geoscientist also used flow velocity condition to make inferences on energy of deposition, provenance, sediment transport dynamics and tidal fluxes (Holmes and Garcia 2002, Dinehart and Burau 2005b, Klein 2003). ADCPs have also been used for characterization of mean velocity and turbulence intensity in rivers (Lemmin & Rolland, 1997; Barua & Rahman, 1998). The ADCP instrument has wide application in deep sea and coastal environments in measurement of current velocity for the purpose of aquatic habitat assessment, hydrodynamic modelling and runoff processes (Dinehart et al., 2005; Christensen and Herrick, 1982; Simpson and Oltmann, 1993; Oberg and Mueller, 2007b).

Principles and working operation of the Acoustic Doppler Current Profiler has been described in (Gordon, 1989). Basically the ADCP measures water velocity by utilizing the principle of Doppler effect. Acoustic sound signals is being emitted through the instrument beams and the return reflected signal is also received by the beams (Oberg and Muller 1994). The difference in frequencies between the emitted and reflected acoustic signals is used to evaluate the velocity of water. Measurements were divided into vertical cells or bins in which each cell constitute flow vector at a definite depth. An internal flux gate compass is built inside the device that keep the position of the instrument relative to the earth's magnetic. This paper focused on measurement and analysis of current velocity dataset that were collected using a boat mounted ADCP. The main objective of the study is to determine streamflow and depth averaged velocities (DAV) with a view to understanding the flow characteristics through the Commodore channel.

Study Area

The Commodore channel is an intricate parts of the barrier bar coastal system that connects the Lagos lagoon and other creeks to the Atlantic Ocean. Heavy merchant vessels enters and exits the Lagos harbour through the Commodore channel, making it a major navigational route for commercial and economic activities within the Nigeria's territorial waters (Figure 1). A distinct characteristic of the channel is flow reversal condition which is also accompanied by density current.

Materials and Method

Field Design

Field work for this study was carried out in June 2019 by team of research personnel from the Marine Geology/Geophysics Department of the Nigeria

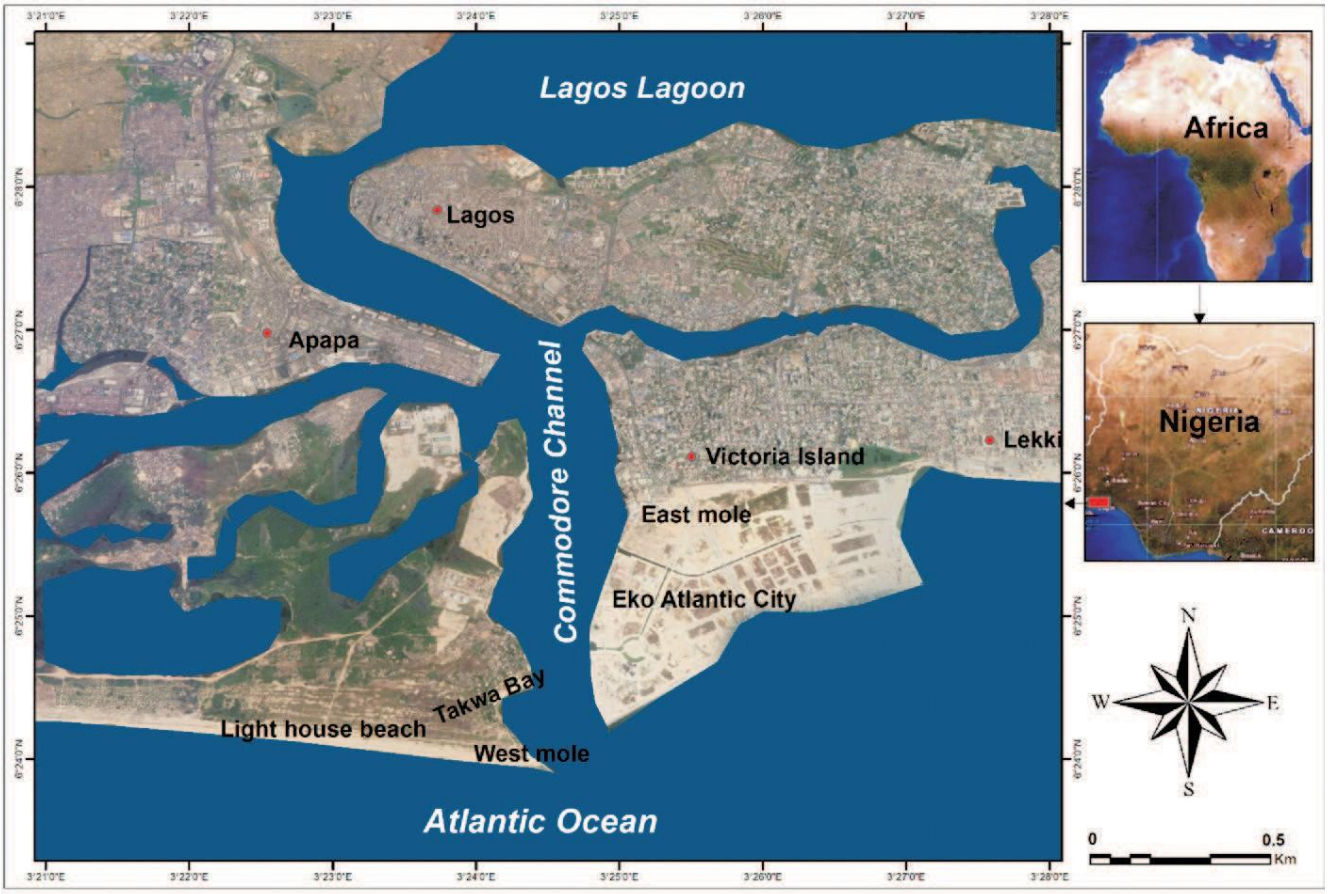

Fig. 1: Location of the Commodore channel area (after, Google, 2019)

Institute for Oceanography and Marine Research. (Figure 2a). Field procedure and data acquisition were designed such that twenty transects lines spaced at 100 m apart covering the study area were created and digitized on Google Map (Fig. 2b).

Instrumentation and Deployments

The Work-horse Sentinel Acoustic Doppler Current Profiler (ADCP) was used for the acquisition of water current dataset. The ADCP transducer consists of four beams which are aligned at 20 degrees with the vertical and transmitting frequency of 300 kHz. An internal flux gate compass that maintained the instrument position relative to the earth's magnetic field was incorporated into the device. One ensemble was measured each second, and each ensemble is divided into separate bins in which each bins constitute flow vector at definite

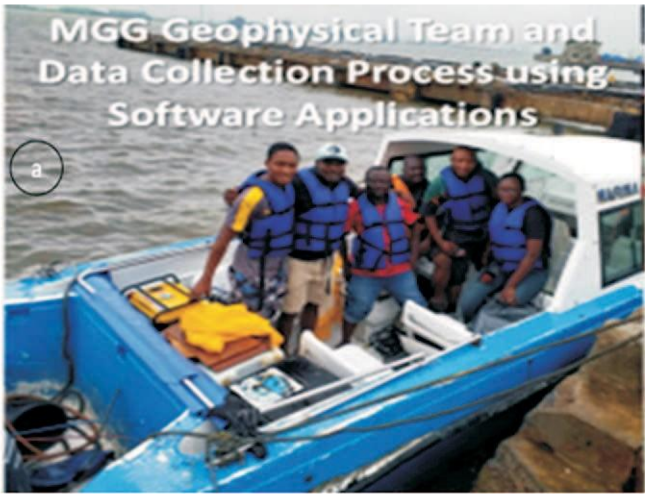

Fig. 2a: Research Personnel on board

Fig. 2b: Digitized transect lines

depth. On navigating to the study area, the ADCP was fastened to a hard steel base and then secured firmly to a hinge at the side of the survey boat. The transducer was positioned 1 m away from the boat engine in order to minimize errors due to external noise (Fig. 3a). Also, for data quality assurance the speed of the boat was maintained at 1 - 2 m/s and offsets distance to the banks were observed.

Prior to deployment, we connect the cable of the ADCP to the field computer and activate the data acquisition software installed on the Computer to enable communication with the instrument (Fig. 3b). After communication was established we configured the ADCP by entering the appropriate parameters such as baud rate, comports, water temperature, salinity, maximum/secondary water depth, and transducer depth. We synchronized an external GPS with the WinRiver software and mount it directly over the ADCP transducer in order to record the position of each pings. After the general settings were completed and the instrument started pinging, we then lowered the ADCP into the water and deployed to measure the water velocity along the established transect lines as the boat traverses the channel.

Fig. 3a: ADCP deployed in water

Fig. 3b: Field data acquisition computer

Data Analysis

Data analysis was done using MATLAB software in accordance to United States Geological Survey (USGS) guide lines. First, we downloaded the raw acoustic data stored in the ADCP WinRiver software as ASCII file format. Secondly, we inputted the ASCII file into MATLAB platform and processed the data into various units consisting of the ensembles in numbers, flow velocity magnitude in cm/s, direction of flow in degrees, discharge in m^3/s, the Northing (U) and Easting (V) velocity components in degrees, the bed elevation or depth of the channel in meters, distance across the channel in meters, and the heading, pitch and roll output of the boat among others. Finally, using quiver algorithms on the velocity mapping toolbox in MATLAB, we produced components of streamwise current and the depth averaged velocities (DAV) profiles for the entire channel section.

Results

The streamwise current and depth average velocities profiles along the survey lines have been presented (figure 4 to 9). Transect 1 and 2 represent the channel entrance or mouth, transect 8 and 9 represent the middle reach or mid-stream while, transect 15 and 20 represent the upper reach or up-stream. All velocity values are interpreted in m/s S.I. unit. The streamwise velocity is the flow velocity recorded as the boat navigates along and across channel area. The depth averaged velocity (DAV) showed the effective velocities averaged over the entire depth of the water column within a transect cross-section. The streamwise velocity maps are shown as filled contour layers with the secondary flow vectors overlain (Figure 4a to 9a), while the depth average velocities are shown as vectors, with arrow-head indicating direction of flow (Figure 4b to 9b). Since the Commodore channel geometric configuration is rectilinear with North-South directional fluxes, the quiver vectors pointing towards the north direction represent flood tidal flow or discharge, while the quiver vector pointing towards the south represent the ebb tidal flow or discharge respectively.

Transect 1 (Channel Entrance)

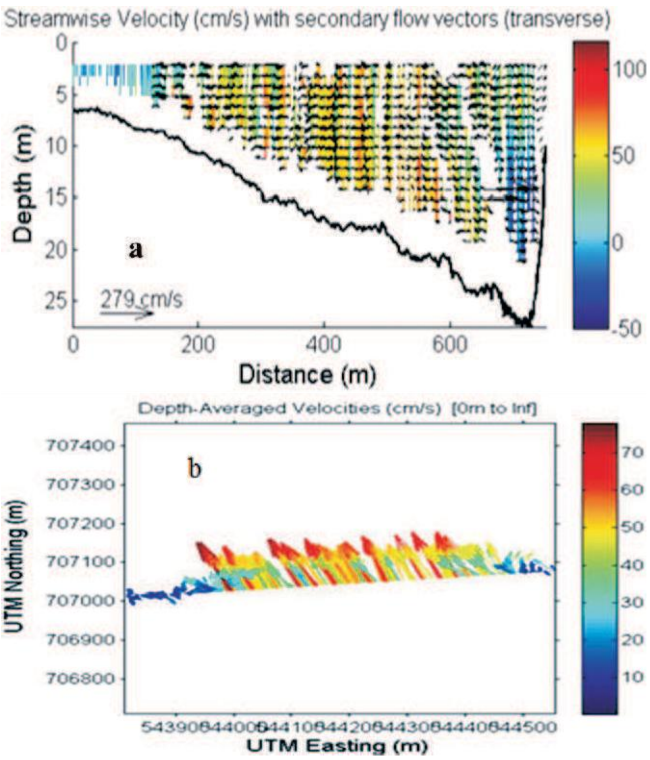

Fig. 4: (a) Streamwise velocity profile, **(b)** Depth average velocity profile

Transect 2 (Channel Entrance)

The current velocity magnitude along transect 2, varied between 0.2 to 0.7 m/sec over a depth ranged of 3 to 10 m. Maximum and minimum velocity of 0.65 and 0.35 m/s was recorded along the left and banks of the channel section (Figure 5a). The depth average DAV, was pointing south indicating an ebbing tidal flow direction (Figure 5b).

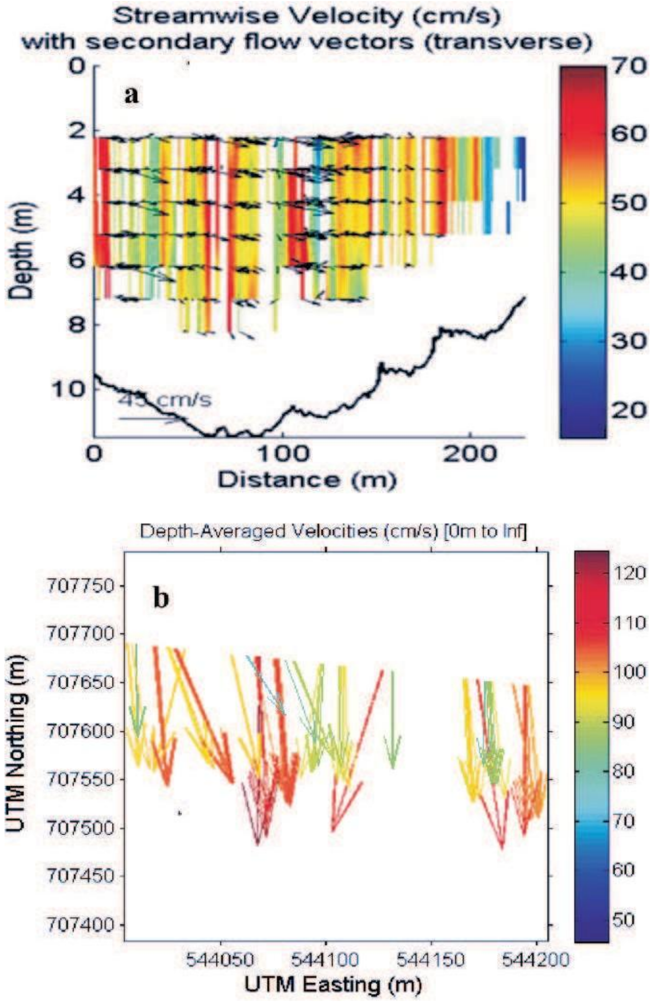

Fig. 5: (a) Streamwise velocity profile, (**b)** Depth average velocity profile

Transect 8 (Mid-Stream)

The current velocity along transect, showed a uniform velocity magnitude of 1.0 m/s over a depth ranged of 2 to 20 m the channel cross section (figure 6a) The depth average velocity DAV, was pointing north indicating a flood flow direction (Figure 6b).

Transect 9 (Mid- Stream)

Analysis of the current velocity profile showed a

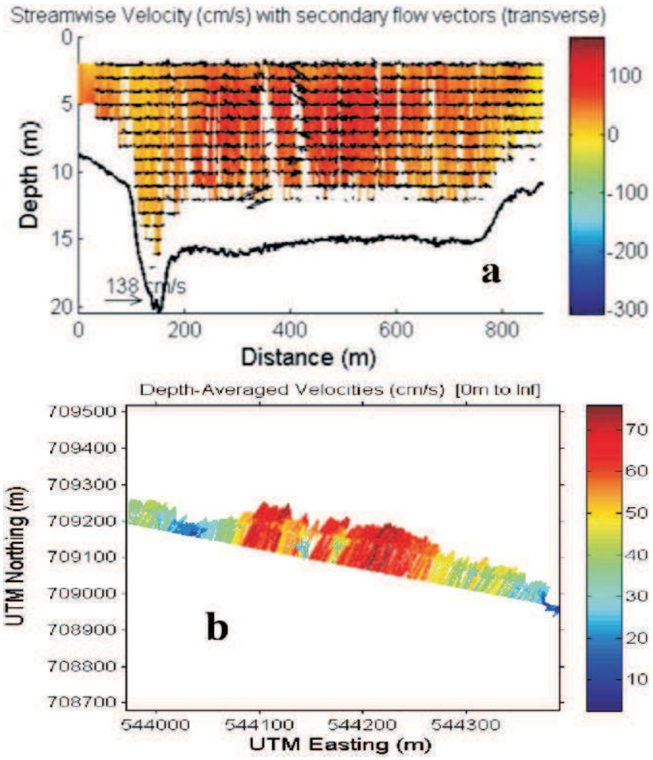

Fig. 6a: (a) Streamwise velocity profile, **(b)** Depth average velocity profile

velocity magnitude of between 0.1 to 0.5 m/sec, over a depth ranged of 2 to 15 m. Maximum velocity was recorded within the channel centre while minimum velocity was recorded along the channel banks (Figure 7a). The depth average velocity DAV vectors was pointing north indicated a flood flow direction (Figure 7b).

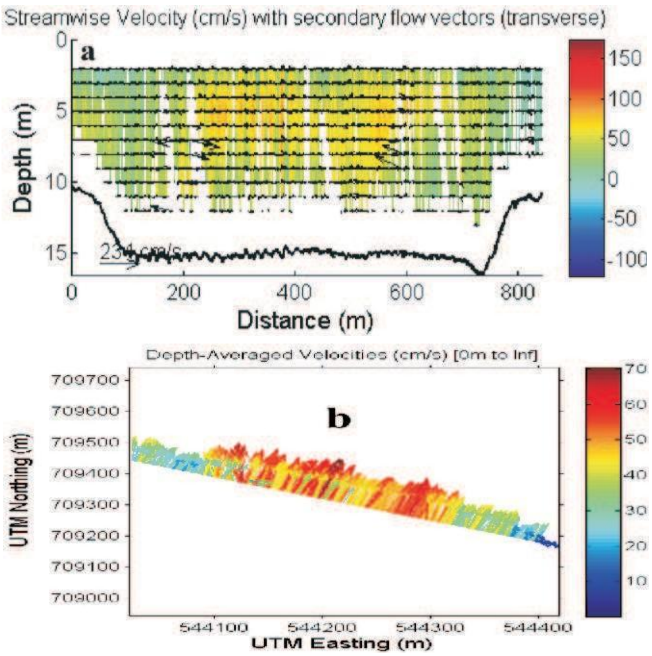

Fig. 7: (a) Streamwise velocity profile , **(b)** Depth average velocity profile

__Transect 15 (Up-Stream)__

Current velocity profiles along transect showed velocity magnitude that varied between 0.1 to 0.5 m/sec over a depth range of 2 to 15 m (Figure 8a). The depth average velocity DAV vectors was pointing south indicating an ebbing tidal flow direction (Figure 8a).

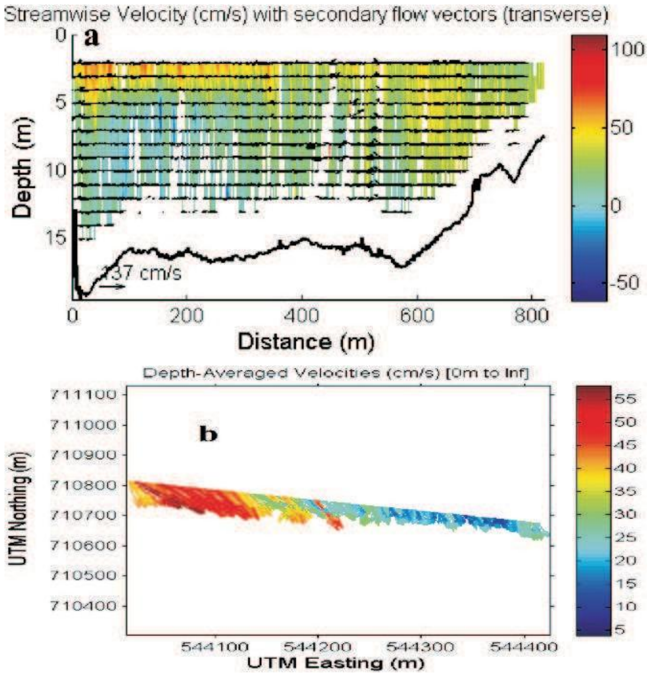

Fig. 8: (a) Streamwise velocity profile, **(b)** Depth average velocity profile

__Transect 20 (Up-Stream)__

The current velocity profiles showed velocity magnitude of between 0.2 to 0.8 m/sec over a depth ranged of 2 to 16 m. The velocity magnitude increases with depth across the channel (Figure 9a). The depth average velocity DAV, was pointing north indicating a flooding flow direction (Figure 9b).

Discussion

Results analysed showed that the streamwise velocities along the Commodore channel range between 0.1 to 0.8 m/s over depth range of 2 to 25 m. This indicated small variations in streamflow along the different channel area (channel entrance, middle and upper reaches). The velocities along the channel entrance was however slightly higher than the velocities along the middle and upper reaches respectively. The high velocity magnitude observed along the channel entrance is expected, since the channel inlet is a through flow for tidal current into the upper reaches. The strong and weak velocity magnitude observed within the centre of the channel and along the channel boundaries, implied that

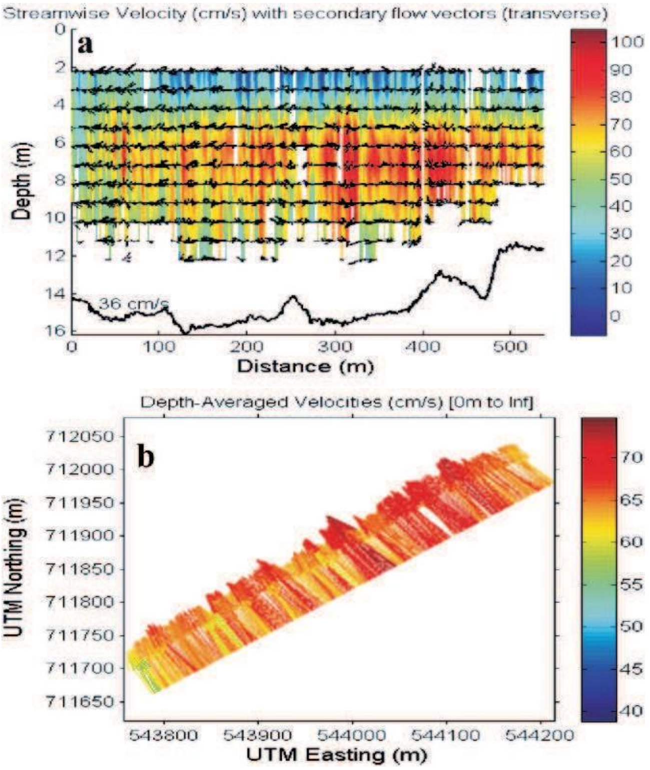

Fig. 9: (a) Streamwise velocity profile, **(b)** Depth average velocity profile

the channel centre are areas of high energy while the channel boundaries are areas of low energy. Vijverberg *et al*. (2012) and Bentum (2012) reported velocity magnitudes of 1.17 m/s and 1.13 m/s along the Commodore channel entrance and parts of the Lagos lagoon respectively. Those values were slightly different from our results however, Vijverberg and Bentum used a fixed bottom ADCP with transducer facing up to measure the current at the channel while we used a boat mounted ADCP with its transducer facing down in our measurement which we suggest to be the reasons for the differences. The Commodore channel is rectilinear in configuration and connect the Atlantic Ocean in a north south direction. Results from the depth average velocity profiles showed that flow vectors that are towards the north indicated flood flow direction while flow vectors that are towards the south indicated an ebb flow direction. Since a major characteristic of the channel is flow reversal, the change in flow velocity along the various sections of the channel will affect the sediment transport dynamics. According to Royal Haskoning (2011), the Commodore channel is in state of dynamic equilibrium and that equal volume of sediment enters and leaves the channel during flood and ebb tides. The variations in streamflow observed in this study implied that velocity magnitude amongst other variables such as depth or longshore currents can significantly impact the morphology and the distribution of sediment along the channel. Regions characterized by strong current are likely to be erosive while regions characterised by weak currents are likely to be prone to sediments accretion.

Conclusion

Flow characteristics on the Commodore channel was determined using Acoustic Doppler Current Profiler. The equipment was deployed through a low draft survey boat to measure water current along the channel section. Results obtained showed that there is no significant difference in the streamwise velocities along the entrance, mid and upper reaches of the Commodore channel during the period of study.

Acknowledgements

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