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Spatio-temporal analysis of currents in the Abidjan estuarian bays

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Abstract

The analysis of current data collected during spring tidal periods in the Ebrié Lagoon estuary has allowed for an assessment of the spatiotemporal behavior of current speeds and directions. Results indicate that current speeds throughout the lagoon are generally low (< 1 m/s). Current speed typically decreases with depth. The average velocity profile over the water column exhibits a sawtooth pattern. Indeed, at approximately 2 meters depth in some areas and 5 meters in others, a significant decrease in average velocity is observed, followed by an increase before decreasing again regularly to the bottom. This variation is attributed to salinity fluctuations in the water column.

The current regime is influenced by the shape of the area. At the entrance of Cocody Bay, currents are alternating. At the entrance of Bietry Bay and Banco Bay, they exhibit a rotary character with an alternating tendency.

In Bietry Bay and Cocody Bay, the water column moves synchronously, whereas at the entrance of Banco Bay, there is vertical shear in the current.

Keywords: Ebrié Lagoon; Hydrodynamics; Tide; Depth; Time; Direction; Speed; Velocity sticks

1. Introduction

The Ebrié Lagoon estuary is located in southeastern of Côte d'Ivoire, more specifically in the Abidjan region. This lagoon plays a significant role in the country's economy as it is home to the Autonomous Port of Abidjan (PAA). Like all estuarine zones, it is subject to intense anthropogenic activity. This has resulted in alterations to water circulation, pollution in certain areas, sedimentation of bays, and the closure of its initial outlet in the Grand-Bassam region. Hydrodynamically, this lagoon is strongly influenced by ocean tides and the discharge of its tributaries.

Studies on the currents in this lagoon, conducted by Lemasson et al. (1981), Guiral and Lanusse (1984), Guiral et al. (1989), Affian (2003), Monde (2004), and Wango (2009), have provided a general overview of current behavior. The objective of this study is to use Matlab, a powerful computational tool, to analyze data from a Doppler current meter (current speeds and directions). This methodology aims to provide more precise information on the behavior of currents along the water column in this lagoon.

2. Methodology

The estuarine zone of the Ebrié Lagoon encompasses numerous bays. To study the currents in several of these bays, a measurement campaign was conducted by the Autonomous Port of Abidjan during spring tides. A Doppler current meter, model DCM12, was deployed at the entrance of three bays (Bietry Bay, Banco Bay, and Cocody Bay) and in the

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Vridi Canal (Figure 1). The current meter recorded both water level variations (m) and current data (direction in degrees and speed in m/s) along the water column over a three-day period at each station.

Figure 1 Location of the study stations

Current data was analysed using Matlab through a script containing formulas to calculate and represent velocity sticks for each cell in the water column.

In order to plot the velocity stick, it is broken down into its eastward (U) and northward (V) components according to the following formulas:

$$U = Vit.\sin(\theta); \quad \ldots\ldots\ldots\ldots\ldots(1)$$

$$V = Vit.\cos(\theta); \quad \ldots\ldots\ldots\ldots(2)$$

with:
$\theta = \pi * Dir / 180$ (Conversion of directional data from degrees to radians)
U: The East-West velocity component (U) indicates the direction of the flow: positive for Eastward flow, negative for Westward flow.;
V: The North-South velocity component (V) indicates the direction of the flow: positive for Northward flow, negative for Southward flow;
Vit: Scalar velocity (m/s).

The plotting of velocity sticks provides information about currents (direction, sense, intensity, and time).

Direction and sense of the current: Velocity sticks have both a direction and a sense. The sense of the velocity sticks is indicated by their arrowhead. The direction of the velocity sticks is read clockwise (Figure 2).

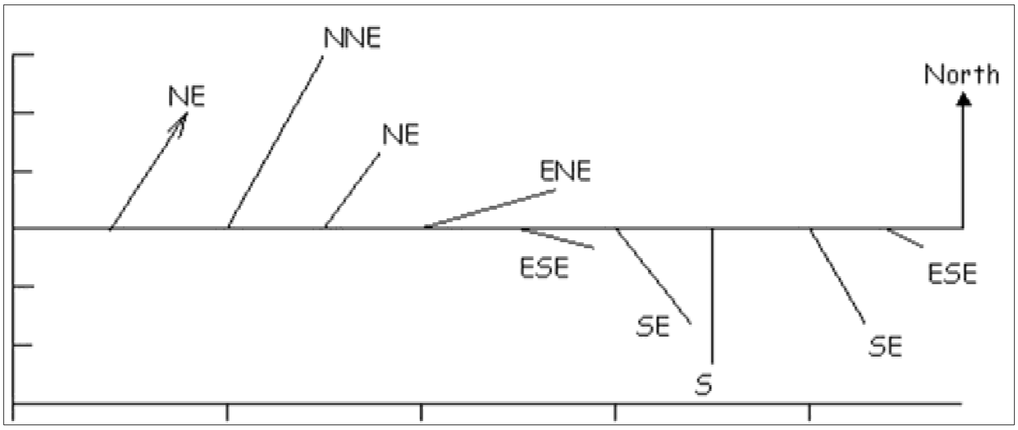

Figure 2 Interpretation of velocity stick directions and senses

Current velocity: A common error is to directly project the velocity stick onto the Y-axis to estimate its magnitude. The correct approach involves rotating the velocity stick to be parallel to the Y-axis before making the measurement (Figure 3). Alternatively, the stick length can be measured directly using a ruler and scaled according to the graph's axis. In both cases, the length of the velocity stick is proportional to the current intensity.

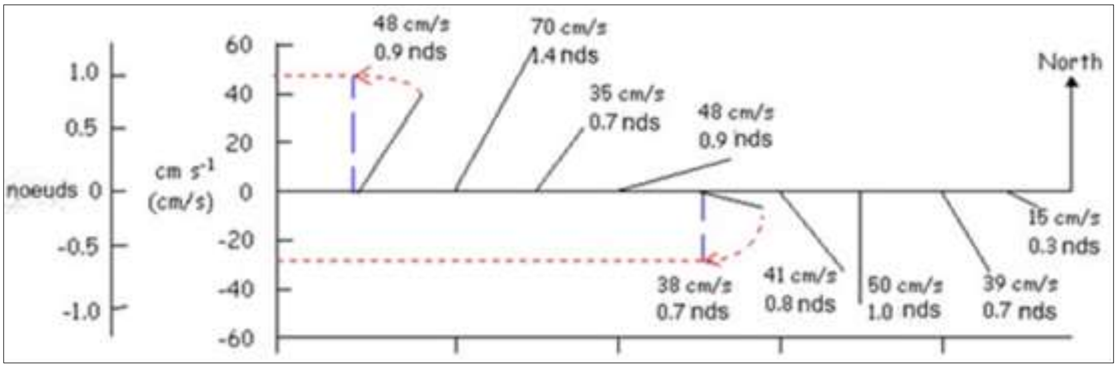

Figure 3 Current intensity estimation in velocity stick plots

Time: The X-axis is calibrated with time units. The origin of each velocity stick corresponds to the timestamp of the measurement (Figure 4). To identify this timestamp, project the stick's origin vertically onto the X-axis."

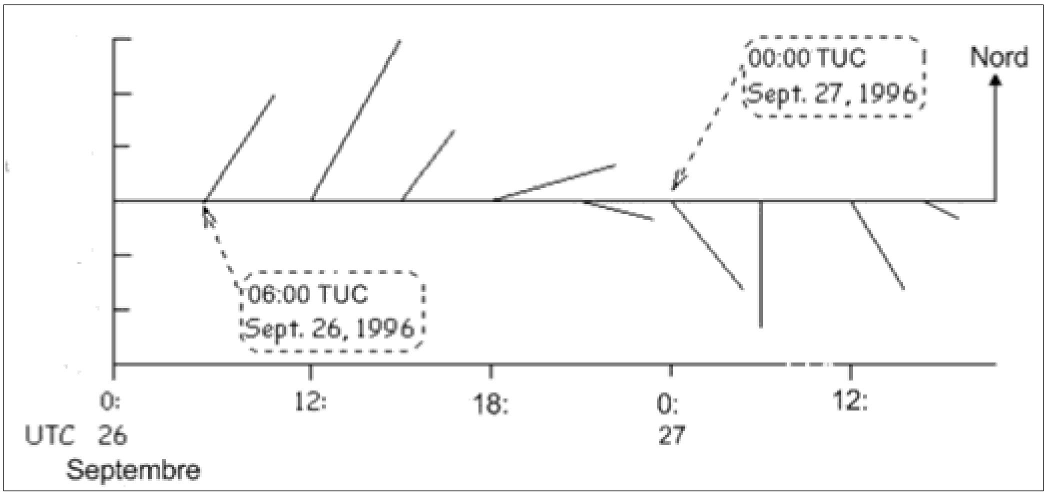

Figure 4 Time interpretation in velocity stick plots

3. Results and discussion

The analysis of velocity data shows that currents are weak throughout the lagoon. At all points, the velocity is less than 1 m/s.

3.1. Vertical velocity profile

The vertical profile of the mean velocity shows that, in general, the mean velocity decreases with depth (Figure 5). Current velocities in the lagoon are low. The highest velocities are observed at the surface. However, it is noted that the mean velocity profile has a sawtooth pattern. It is formed by three or four parts depending on the area. Indeed, from the surface to about 2 m depth, there is a decrease in the mean velocity which then increases until about 1.5 or 2 m lower before decreasing again regularly to the bottom.

A minor increase in mean velocity is detected at approximately 6 meters depth in Bietry Bay. In Banco Bay, the decrease in velocity occurs in two phases: a first phase characterized by a slight decrease from the surface to a depth of 2 meters, and a second phase that is more marked from 2 meters to approximately 5 meters depth.

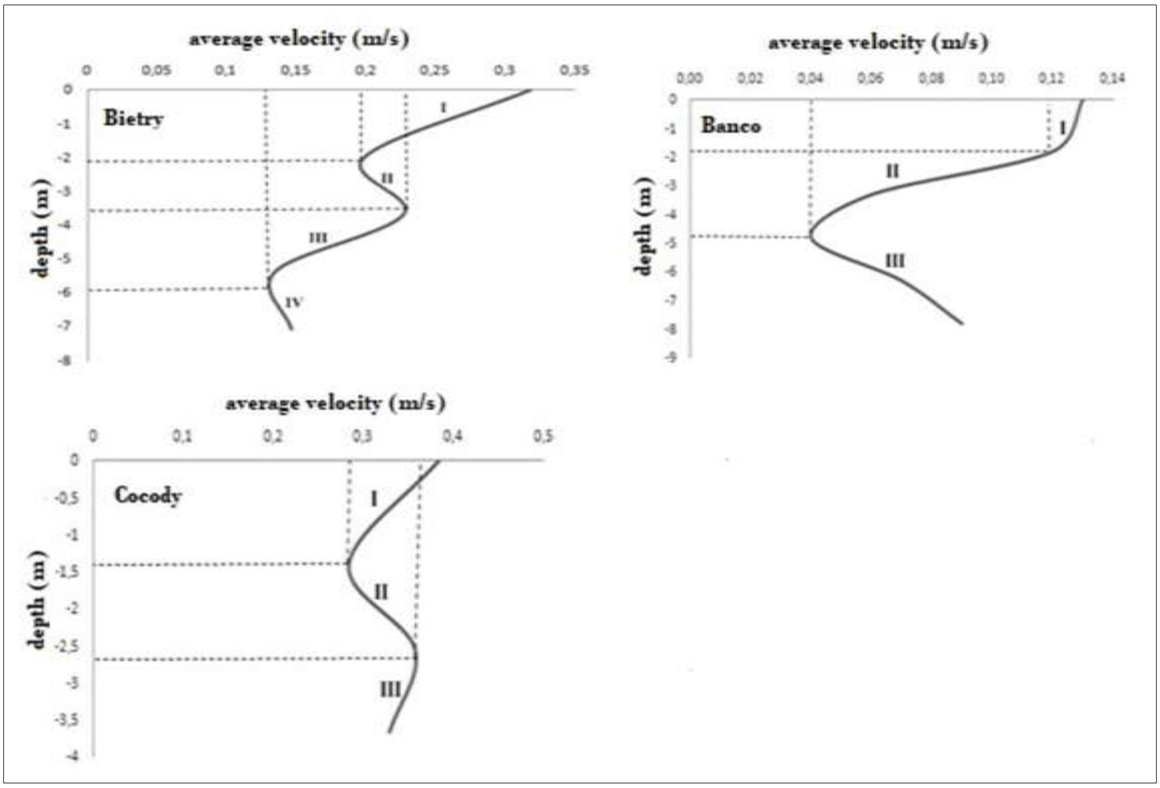

Figure 5 Vertical variation of mean velocity in Bietry, Banco, and Cocody bays

These variations in velocity with depth could be due first to the effects of wind on the surface, which accelerates the currents, and then to variations in salinity in the water column, which causes the increases and decreases in velocities.

3.2. Spatiotemporal evolution of velocity stick

The length and orientation of velocity sticks provide information about the evolution of current speed and direction over time.

In the Bietry Bay, both at the surface and the bottom, there is no preferential direction; rather, we observe a certain disorder in the orientation of the sticks (Figure 6).

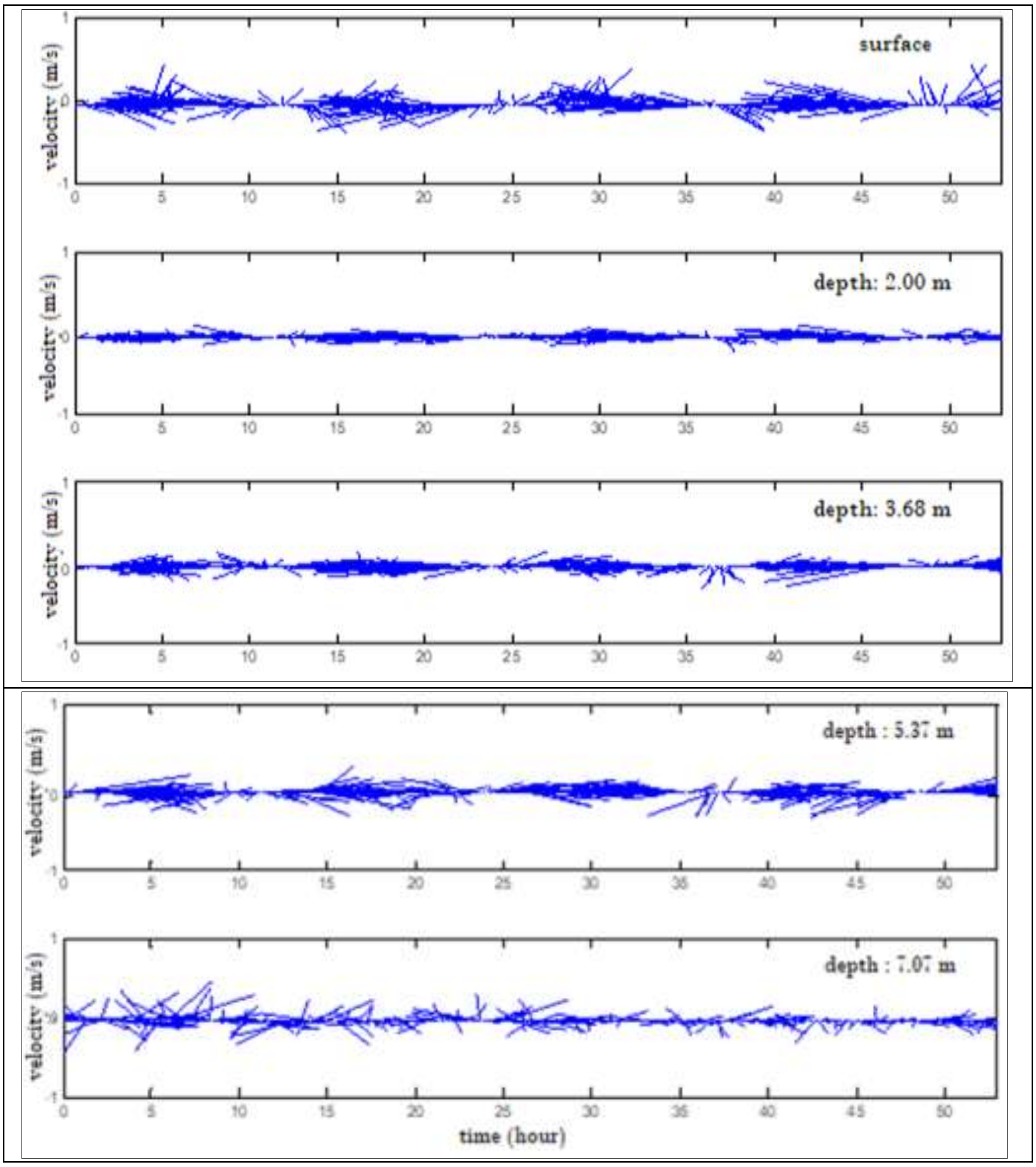

Figure 6 Spatiotemporal variation of velocity stick at the Bietry Bay entrance

This is likely due to the wind's effect on the surface and turbulent flow at depth. However, in the rest of the water column, we observe a certain orientation of the current, although it is not very apparent due to low velocity values. Broadly speaking, two groups of sticks can be distinguished, having the same direction but opposite senses; one directed E-NE corresponding to flood currents and the other W-SW corresponding to ebb currents (Figure 6). It is also noted that this ENE-WSW direction corresponds to the orientation of the bay's entrance channel: Therefore, it can be said that the currents have an alternating regime. Upon detailed observation of the sticks, it is noted that the directions are oriented differently from E-NE and W-SW: the current thus has a tendency to rotate. The superposition of the velocity stick plots on top of each other as a function of depth (Figure 6), shows that the entire water column is animated by the same movement.

At the entrance of Banco Bay, surface sticks are oriented differently compared to those in the rest of the water column (Figure 7). There are two groups of sticks with the same direction but opposite senses; the first group is directed N-W and the second S-E. At a depth of 1.80 m, flood currents are directed N-W and ebb currents S-W, whereas in the rest of the water column, there is no preferential direction along the tidal cycle. This difference is attributable to the effects of wind on the water surface. In the water column, velocity stick directions fluctuate over time, unrelated to tidal motions. Nevertheless, some flood currents oppose the ebb currents. This suggests that the current in this part of the lagoon exhibits a rotary regime with a slight alternating component.

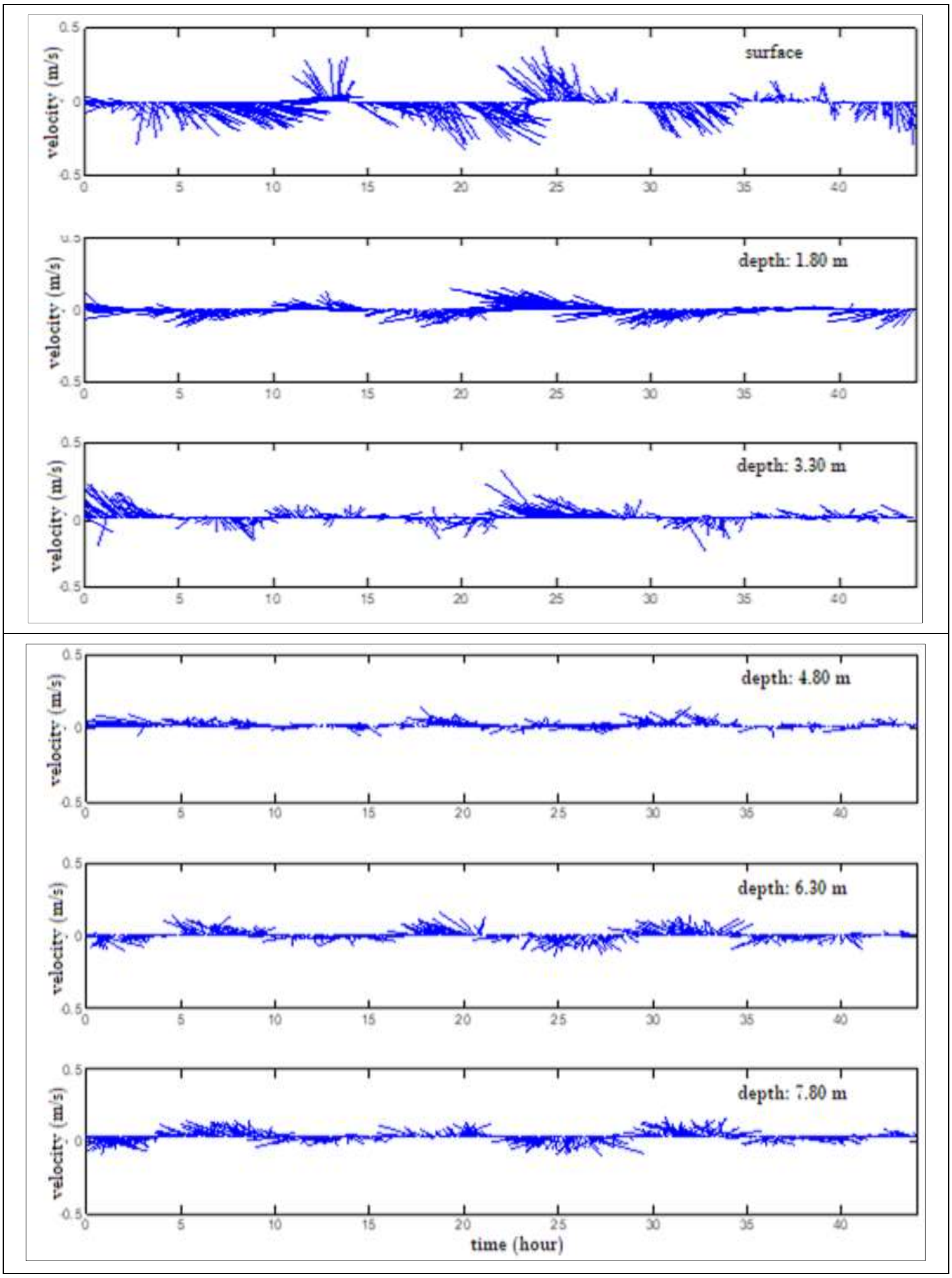

Figure 7 Spatio-temporal evolution of velocity sticks at the entrance of Banco Bay

At the entrance of Cocody Bay (Figure 8), it can be seen that the entire water column is characterized by two sets of sticks aligned NE-SW (parallel to the lagoon channel containing Cocody Bay) but flowing in opposite directions: One directed N-E (during flood tide) and the other directed S-W (during ebb tide), indicating an alternating current (Hilmi et al., 2005). The velocity vectors at different depths and at a given time "t" exhibit nearly the same direction, suggesting the absence of vertical shear and a synchronous motion of the entire water column (Figure 8).

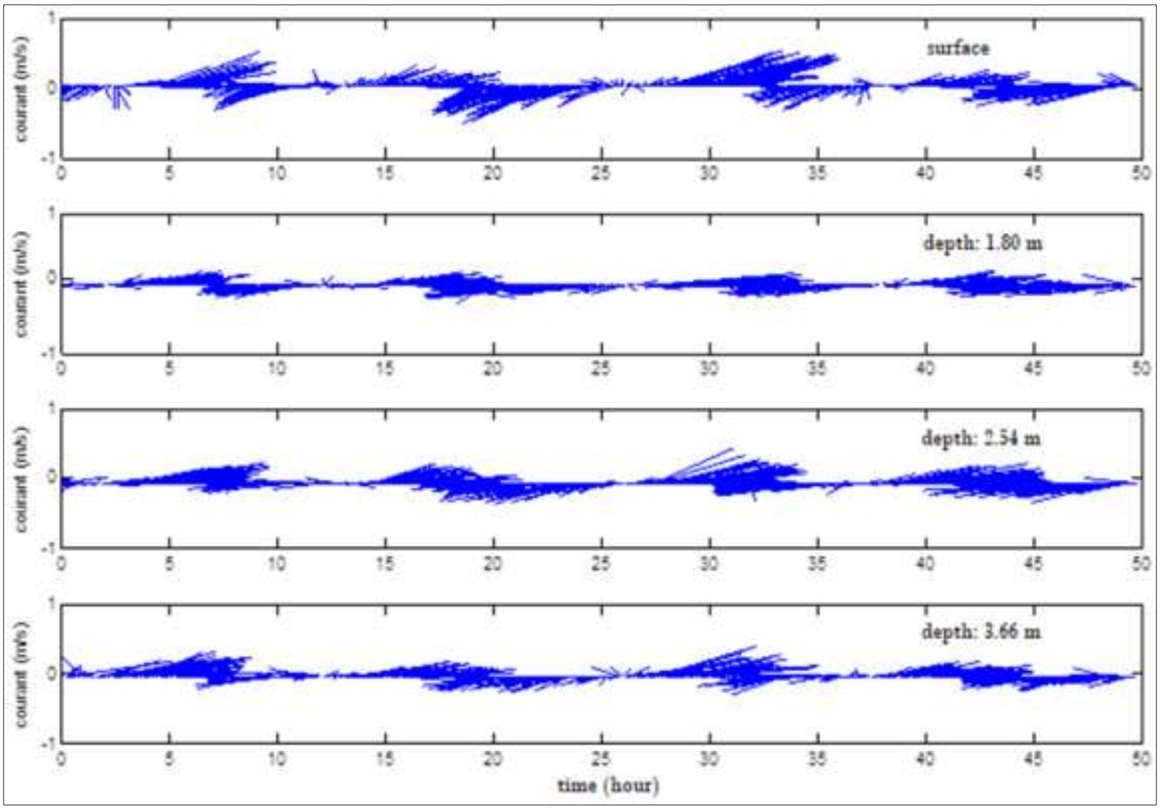

Figure 8 Spatio-temporal evolution of velocity vectors at the entrance of Cocody Bay

4. Conclusion

The current study of the estuarine bays of the Ebrié Lagoon during spring tides has shown that the hydrodynamics of this lagoon is strongly influenced by the sea tide. Current speeds are generally low throughout the entire estuarine zone (< 1m/s). The high speed values and direction variations observed at the surface (compared to values recorded in the rest of the water column) can be attributed to the wind. However, we have some reservations as wind data was not available during our study.

Current speed decreases with depth throughout the entire estuary. The evolution of the average speed as a function of depth generally forms a profile consisting of three parts: The first part is characterized by a sharp decrease in the mean current speed, the second by an increase, and the third by a steady decline in the mean current speed. A sharp decrease in mean velocity is observed around 2 meters depth. However, it should be noted that in Bietry and Banco Bays, a second significant decrease in mean velocity is detected around 5 meters depth.

Currents exhibit two distinct behaviors based on location. Within the narrow confines of the Cocody Bay entrance, the current aligns with the channel, and flow directions reverse in response to tidal fluctuations, resulting in an alternating regime. When located in a more or less extensive area, there is no preferred direction; the direction varies over time, regardless of the tidal movements: the current has a rotary or gyratory regime. "In an intermediate zone, such as at the exit of the Bietry channel or the entrance of the Banco Bay, the current adopts an intermediate regime, and the dominant regime is that of the source area. If it originates from a narrow area and enters a wider area, it will have an alternating regime with a tendency to rotate (case of Bietry Bay). Conversely, if it leaves a wider area for a narrower one, it will then have a rotational regime with an alternating tendency (case of Banco Bay).

Water column movements in the Ebrié Lagoon vary depending on the specific area. At the entrances of the Bietry and Cocody bays, the current direction is the same throughout the entire water column during the entire tidal cycle: the water column moves synchronously. At the entrance of the Banco Bay, a change in current direction is observed from a depth of 1.80 meters: there is shear in the water column.

The lack of strong currents in Abidjan's bays contributes significantly to the accumulation of pollutants in these areas.

Compliance with ethical standards

Disclosure of conflict of interest

No conflict of interest to be disclosed.

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