

Spatial and Temporal Monitoring of the Ivorian Continental Shelf Surface Current Fronts: Maximum Cross-Correlation (MCC) Technique Application

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ABSTRACT: To have a better understanding of the sea surface current of the Ivorian continental shelf at local scale, Maximum Cross Correlation (MCC) method was applied on chlorophyll concentration data at 1.1 Km resolution, extracted on selected MODIS satellite imageries acquired from the orbiting AQUA satellites. Images from MCC were thereafter filtered to produce a composite vectors image mapping sea surface current in the second half of the year (end of Major Warm Season, Major cold Season, Period of transition and Small Warm Season). The study highlights three surface current direction which are Eastward (Guinea current), westward and South-North. The South-North hit the coast and splits in two currents. The splitting area therefore corresponds to the divergence area with eastward current on right side and westward current on left side. The westward current on left side meets the Guinea current to create the convergence area. The South-North surface current give more understanding of the real origin of the westward surface current.

KEYWORDS: Ocean surface current, Remote sensing, Ocean color, Maximum cross correlation, Continental shelf, Ivory Coast.

I. INTRODUCTION

Mapping coastal surface current structure is very important because water motion to a certain extent is the basis of the pelagic species distribution (fisheries activities) on one hand and the pollutant substance distribution (oil exploitation) on the other hand. Previous studies [1] with in-situ data from oceanographic campaigns described two ocean currents on ivorian continental shelf. The first is the eastward Guinea current occurring at the surface and the westward Guinea

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counter-current which occurring at sub-surface (under the Guinea current, between 15 and 80 m in depth). Later, Colin et al.[2] always with in-situ data mentioned some dispersed registration of westward current at the surface in the second path of the year. To understand the registration of these westward surface current, Mobio [3] used ocean color 1 km data to mapping Ivorian continental shelf current. Its study highlighted through remote sensing data a real westward current at the surface with the eastward current. The main objective of this study is to confirm the westward current at the surface and find out the origin of this westward current using maximum cross correlation (MCC)method.

The ivorian continental shelfs included in the large marine ecosystem of the Guinea Gulf that extends from Guinea Bissau to Cape Lopez in Gabon (Fig. 1). This gulf is delimited by the sea front of fourteen countries including an island country (Sao Tome and Principe). The area of interest of this study is located between latitudes 3° N and 5,5 ° N and longitude 7 ° W and 4 ° W.

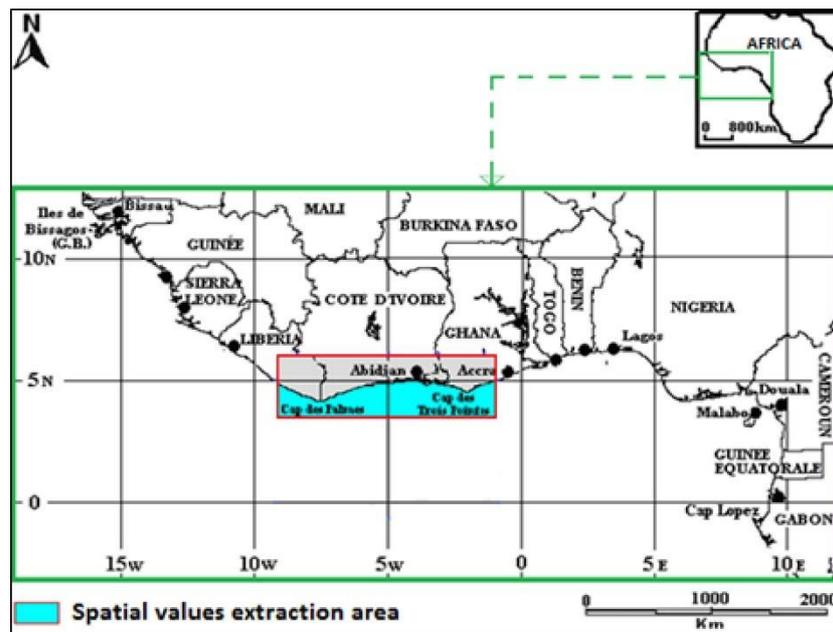


Fig. 1. Localization of the ivorian continental shelf

Sea surface temperature (SST) along the ivorian continental shelf is characterized by significant variations. These thermal variations allowed Morlière[4]to define four marine seasons (Fig. 2): the small cold season (SCS), from January to February; the major warm season (MWS), from March to June; the major cold season (MCS), from July to September and the small warm season (SWS), from November to December. Between the MCS and the SWS, there is a transition period which is the month of October. The MCS is characterized by the presence of an intense upwelling along the coast.

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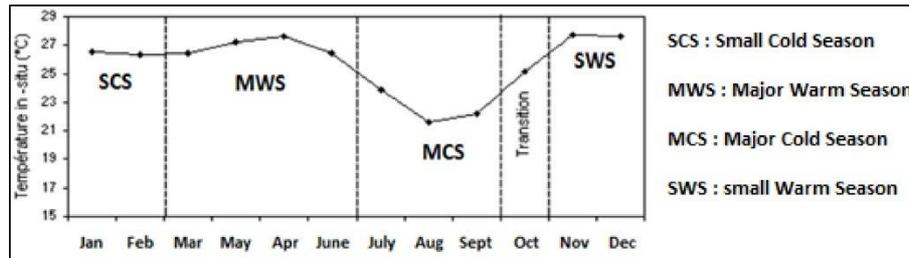


Fig. 2. Sea surface temperature variation defining different marine seasons of Ivorian continental shelf

II. LITERATURE SURVEY

Originally developed for monitoring meteorological clouds[5], the method of maximum cross correlation (MCC) has been successfully applied to thermal 1.1 x 1.1 km resolution images for mapping the East Australian current [6], the Gulf Stream [7], the California Current [8] and the coastal waters of British Columbia[9]. Garcia and Robinson [10] well as Tokmakian et al. [8] have successfully calculated the velocities of surface waters by applying the method of MCC to chlorophyll concentrations extracted from images of CZCS (Costal Zone Color Scanner) visible band. Similarly, Crocker [11] and Crocker et al. [12] have successfully applied the MCC method to both temperature and chlorophyll MODIS images of 1.1 x 1.1 km resolution to describe the ocean surface currents of the coast of California and the Gulf of Mexico. However, the application of the MCC method to thermal images is inoperable when surface temperature gradients are low, which is common in the equator waters where the Ivorian continental shelf is located.

III. PROPOSED METHODOLOGY

The methodology applied in this study is based on the maximum cross correlation (MCC) technique which has been developed in several studies.

III.1. Data

The data used in this study are ocean color (chlorophyll concentration) level 2 images with 1.1 km of spatial resolution from MODIS sensor (AQUA satellite). These images have a size of 1024 pixels out of 1024 lines.

Images used are images of June, July, August, September, October, November and December from year 2010 to 2014. This period follows the first study period (2003 to 2009). Images of the second half of the year are used due to previous studies [3][13] that showed at Ivorian continental shelf surface, the Guinea counter-current (westward current generally (in literature) occurring below the surface).

Ocean color (OC) images are acquired at the NASA website (<http://oceancolor.gsfc.nasa.gov>).

III.2. Maximum cross correlation (MCC) method

The MCC method is an automated procedure that tracks the movements of patterns across sequential images by cross correlating a pattern template subwindow in an initial image within a specified search window in a second image[9].

The displacement vector between the two sequential images is defined to have its origin in the center of the initial pattern subwindow in the first image and its endpoint at the center of the subwindow location with the MCC in the second image (Fig. 3). The velocity vector is calculated using the time separation between the sequential images. The use of MCC for generating ocean surface currents from feature tracking in thermal infrared (IR) and OC imagery is well established [6][11][12][3].

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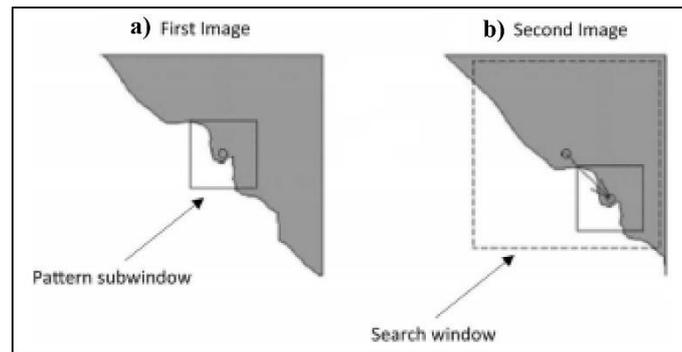


Fig. 3. MCC method illustration (a) Selection of the pattern by the subwindow (b) Tracking of the pattern within the search window

One of the requirements for MCC to work well is that the time separation between the sequential images should not be large enough such that the features being tracked decorrelate significantly. Mobio[3] showed that, for sequential ocean color (OC) images at resolution of 1 km, the MCC method can perform well for time separations up to 48 h between them.

The MCC method is not applicable to thermal images when surface temperature gradients are low, which is common in the equator waters where the Ivorian continental shelf is located. This is the reason of the choice of the OC images for this study.

The other two main parameters that control the MCC method are the sizes of the template subwindow and the search window. The size of the template subwindow should be large enough to contain enough pixels to define a pattern; however, the larger of the subwindow size is, the more it smooths out the structure of the flow. Thus, the template subwindow size has to be defined by keeping in mind a balance between the above two factors. Based on the work of Crocker [11] and our personal experience, it appears that the window of 22 x 22 pixels (24.2 x 24.2 km) is the best window size (minimum size) to contain oceanographic structures and produce coherent vectors.

The search window in the second image is set to resolve the maximum expected velocity which is 0.8 m/s [14][1] in our study area. So, the search window size is 63 pixels (69.3 km) for images separated by 24 hours, or 126 pixels (138.6 km) for images separated by 48 hours.

The search window is moved in the second image with an overlap of 11 pixels (half the size of the time gate), selected value to ensure that most of any structure which would be spread over two windows is taken into account.

A raw velocity field output from the MCC method contains vectors at every grid point, with diverse values of cross correlation. Postprocess filtering has to be applied to the raw vector field to get a vector field that depicts the geophysical characteristics of ocean surface currents. As a first step, a minimum correlation cut-off value is used to remove vectors that result from low values of pattern cross correlation. Vectors associated with single-pixel displacement or having a magnitude larger than a defined threshold value are also removed. Finally, a nearest neighbor filter is used to ensure spatial coherence. For each grid point in the vector field, the target vector is compared with all the other vectors in its immediate neighborhood. The comparison can be made in many ways; the most common method is to use difference thresholds for u-component and v-component magnitudes and direction, and the number of neighborhood vectors violating any of these thresholds is determined. If the number of neighborhood vectors that exceed the defined difference thresholds is greater than a specified limit, the target vector is flagged and discarded.

So, to be approved, any vector must have a high correlation coefficient (greater than 0.8) and have a velocity equal or less than a known maximum velocity (0.8 m/s in our case study). In addition, at least two of eight vectors surrounding the vector involved must have a velocity of up to 0.1 m/s more or less than the velocity of the vector involved.

The result of this process is individual current vector fields image from two sequential OC images.

To have a monthly image (Composite vectors image), individual current vector fields images from one month are superimposed to increase the spatial coverage (and to reduce the cloud cover damaging effect) and depict the mean flow.

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IV. RESULTS AND DISCUSSIONS

IV.1. Results

After treatment and processing of the data four (4) different season current field have been observed and described in this study: Major warm season (MWS) current field, Major cold season (MCS) current field, Period of transition current field and Small Warm Season (SWS) current field.

Major warm season (MWS) current field

The major warm season current field is represented only by the June month.

June

On this month (Fig. 4) represented by vectors image of 15 to 17 June 2011, 01 to 03 June 2012 and 25 to 27 June 2014, it's appear three current vector directions. These currents are eastward current (in red), westward current (in blue) and South-North current (in green).

The eastward current is the Guinea current and the westward current is an opposed current at the Guinea current.

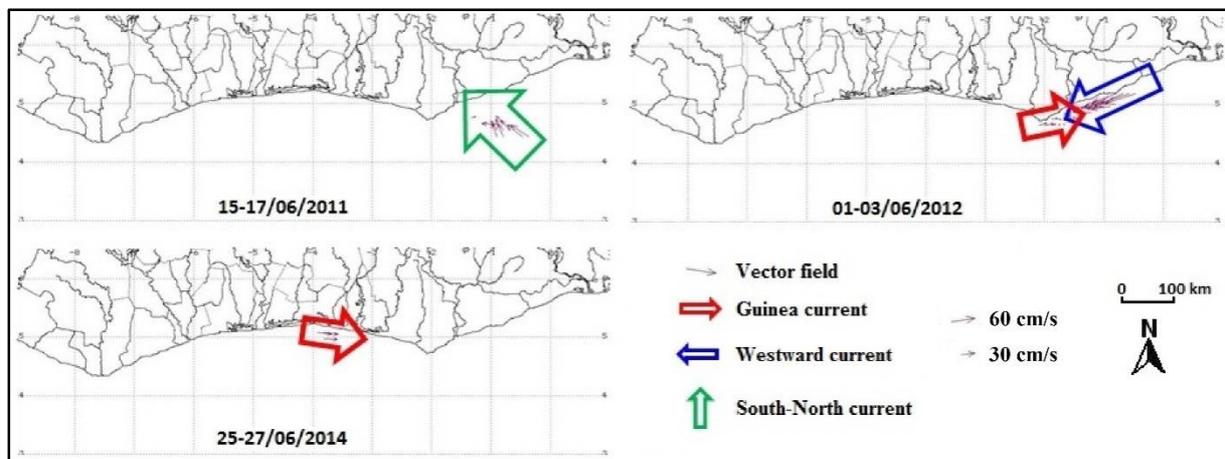


Fig. 4. June vector fields showing westward current generated by South-North current and its convergence area with Guinea current

Major cold season (MCS) current field

The major cold season current field is described by the months of July, August and September.

July

Image of 18 to 19 July 2010, composite image of July 2012, composite image of July 2013 and image of 08 to 09 July 2014 are images that showed July month surface current (Fig. 5). Current directions are eastward, westward and South-North.

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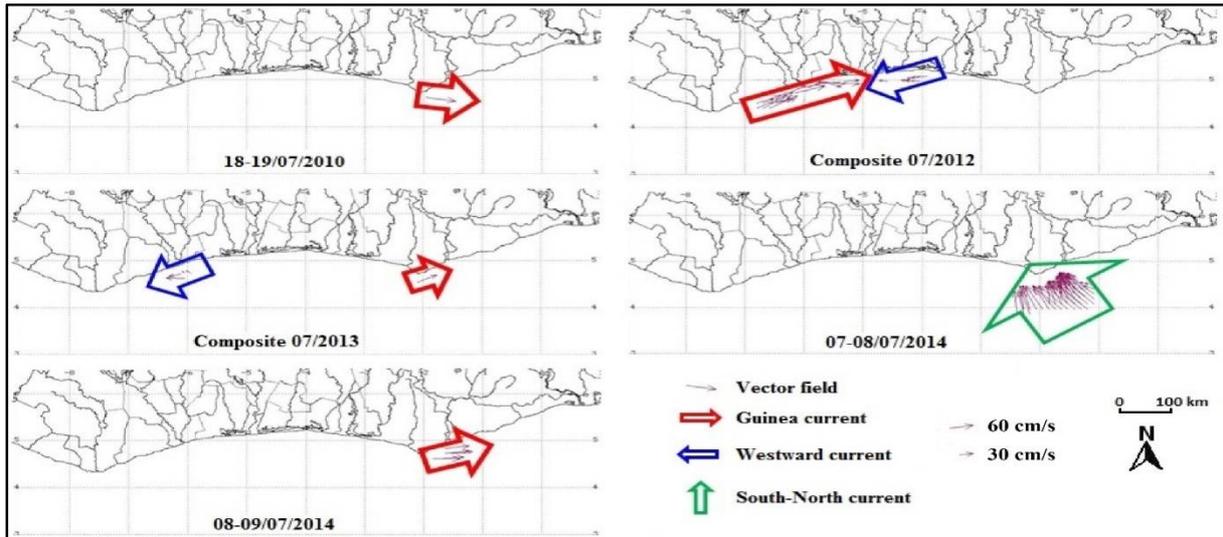


Fig. 5. July vector fields showing westward current generated by South-North current and its convergence and non-significant divergence areas with Guinea current

August

August is the second month of the Major cold season. In this month surface current is obtained with composite images of August 2010, August 2011, August 2012 and image of 20 to 21 august 2013 (Fig. 6). Three current directions are also mapped (eastward, westward and South-North).

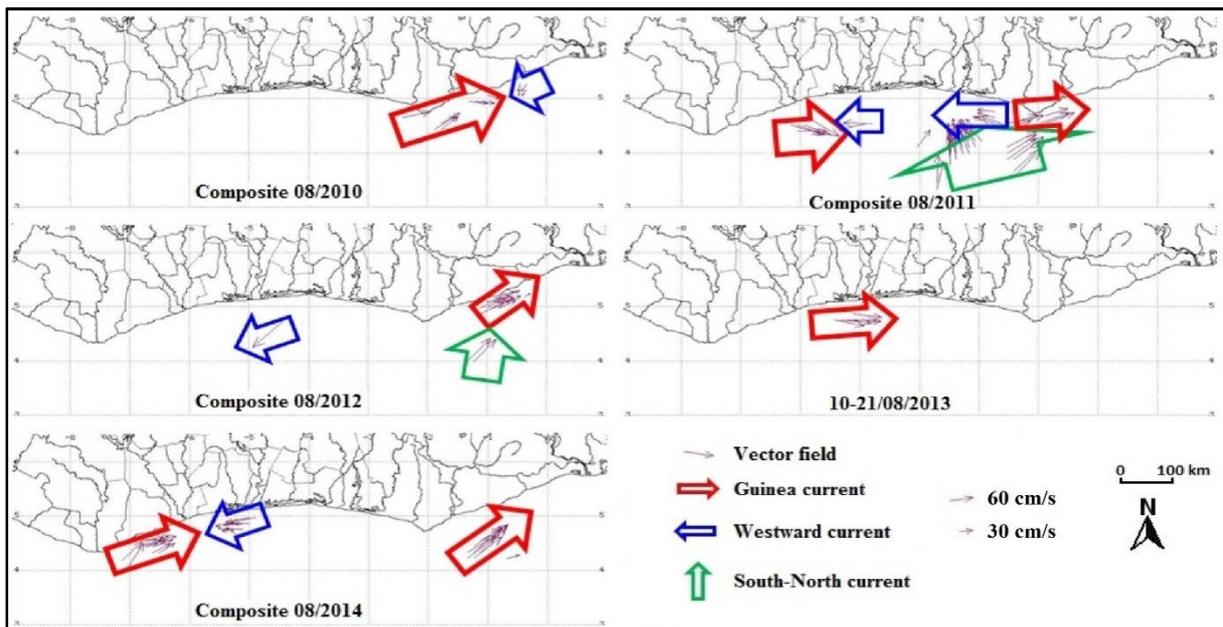


Fig. 6. August vector fields showing some convergence and divergence areas between Guinea current and westward current generated by South-North current

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September

The last month (September) of the Major cold season is represented by composite images of September 2010, September 2011, September 2012 and September 2014 (Fig. 7). The Eastward, Westward and South-North current direction are mapped.

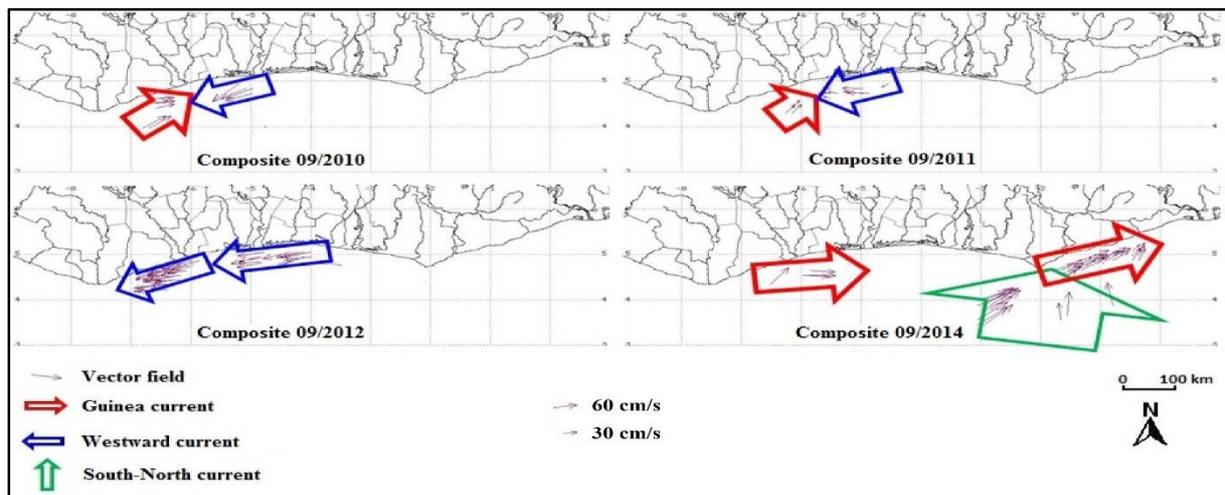


Fig. 7. September vector fields showing convergence areas between Guinea current and westward current generated by South-North current

Period of transition current field

The period of transition current field is the month of October.

October

The current field of this month is mapped using composite images of October 2010 and 2014, image of 14 to 16 October 2012, image of 08 to 09 October 2013 and image of 09 to 10 October 2013 (Fig. 8). Eastward and westward surface currents are mapped with convergence and divergence area.

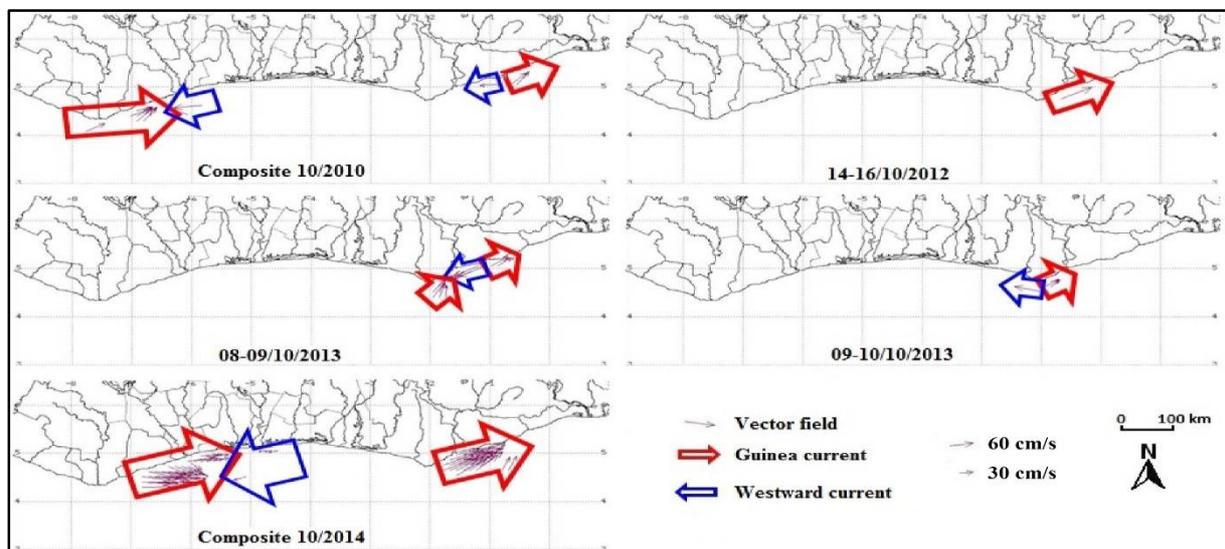


Fig. 8. October vector fields revealing various convergence and divergence areas between Guinea and westward currents

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Small Warm Season (SWS) current field

The small warm season current field is covered by November and December.

November

The Small Warm Season he's represented by November and December months. The November month surface current field is mapped by composite images of November 2010 and 2012, and image from 19 to 21 November 2014 (Fig. 9). This mapping show eastward and westward surface currents with one convergence area.

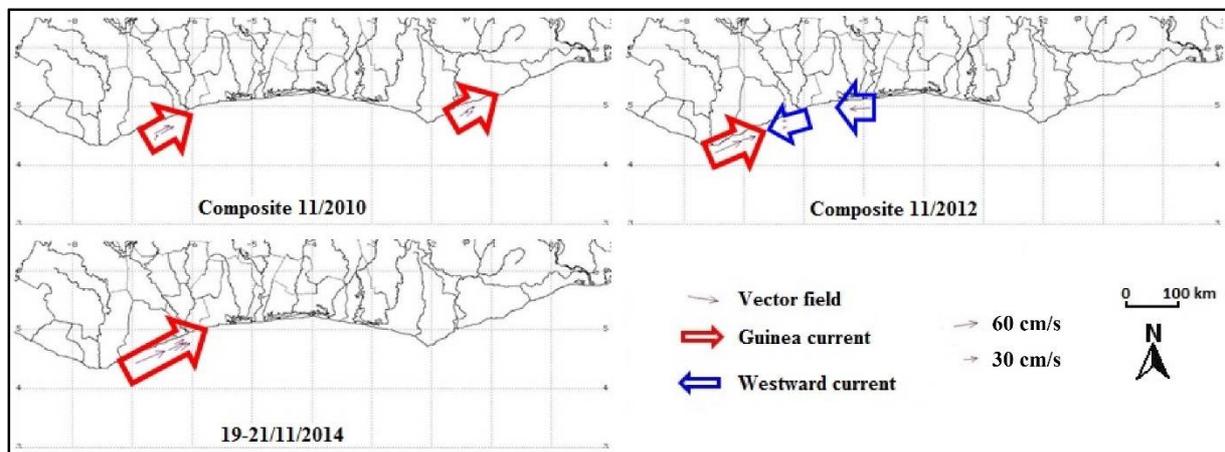


Fig. 9. November vector fields showing westward and Guinea currents convergence area

December

This month is the second month of the Small Warm Season that is represented by images from 06 to 08 December 2012 and from 09 to 11 December 2013 (Fig. 10). The mapping of the current field of this month show two surface current direction that are Eastward and Westward.

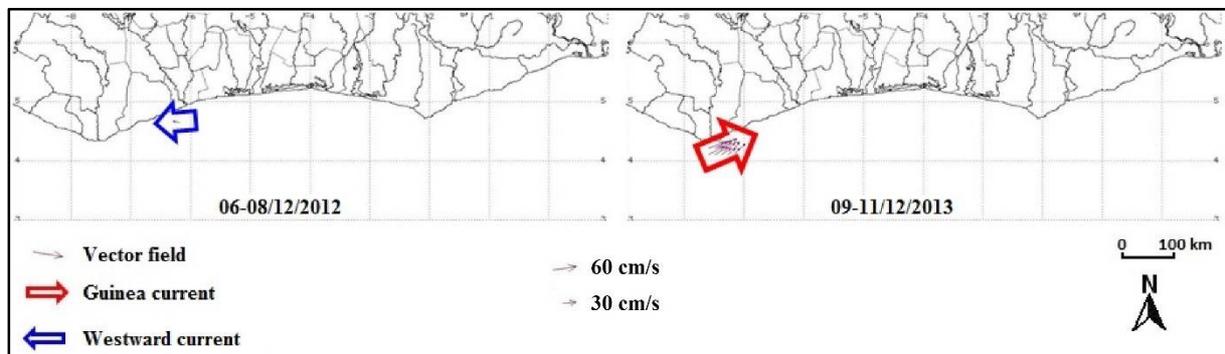


Fig. 10. December vector fields indicating the presence of westward current and Guinea current areas

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IV.2. Discussions

Images of the end of Major Warm Season and Major Cold Season show three surface currents on ivorian continental shelf. The first and second current are respectively the Guinea current (eastward) and a westward current that converging or diverging. The third current is a South-North current.

Transition period and Small Warm Season images show two surface currents (Westward and eastward) that also converging or diverging.

Lemasson and rebert[1] described during MCS, TP and SWS the Guinea Current (eastward) to the surface of the ivorian continental shelf and the counter-guinea current in the subsurface. Regarding these authors work, the eastward current showed in this study is the Guinea Current, but the westward surface current cannot be the counter-guinea current.

Colin *et al.*[2] described during these periods at surface an eastward current (Guinea current). They also describe at surface a westward current (counter-guinea current) much developed in August and September, occupying the entire Ivorian continental shelf in October and November. The study results according with Colin *et al.*[2]; Mobio[3] and Mobio *et al.* [13] studies confirm the presence of westward surface current on the ivorian continental shelf. This westward surface current would be generated by the South-North current which hit the coast and splits in two. The splitting area therefore corresponds to the divergence area with eastward current on right side and westward current on left side. The westward current on left side meets the Guinea current to create the convergence area.

On some images (Transition period and Small Warm Season), the South-North surface current don't appear. This would be due to the great cloud coverage of the study area (Equator). But the position of the South-North surface current on these images can be determinate by the following way: It is precisely located in front of the divergence zone (for the images where there is a convergence zone) and is imprecisely located at left before the westward current (for the images where there is not a convergence zone).

V. CONCLUSIONS

This study showed that the maximum cross-correlation technique can be apply to ocean color images (chlorophyll concentration) on the Gulf of Guinea in general and in particular on the ivoriancontinental shelf to estimate surface currents, despite a very important cloud cover.

This study allowed to complete previews study that apply the maximum cross-correlation technique to ocean color images (chlorophyll concentration) to estimate surface currents on the ivorian continental shelf (gulf of Guinea).

Three surface currents are mapped in the second part of the year. Two of them are already mapped in previews studies and new one in the present study. These tow surface current which are divergent or convergent are eastward surface (Guinea current) and westward surface current (which had been assimilated to the counter-guinea current appearing on the surface). The new one is the South-North surface current perpendicular to the coast where it is divided into two, creating a divergence area with an eastward surface current and a westward surface current. The westward surface current came to meet the guinea current to create convergent area. The South-North surface current is therefore the origin of the westward surface current on ivorian continental shelf.

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