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Research Article

Characterization of the Boreal Summer Upwelling at the Northern Coast of the Gulf of Guinea Based on the PROPAO *In Situ* Measurements Network and Satellite Data

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The boreal summer upwelling along the northern coast of the Gulf of Guinea (GG) is characterized using new *in situ* sea surface temperature (SST) from onset sensor and satellite TRMM Microwave Imager (TMI) datasets. This study aims to encourage intensive *in situ* SST measurements at the northern coast of the Gulf of Guinea. It shows good agreement between daily *in situ* SST and TMI SST and similar coastal upwelling onset date, end date, and durations calculated using both datasets. Interannual evolution of the onset date at four stations along the northern coast of GG indicates that the upwelling can be initiated at one cape or simultaneously at both the cape of palms and the cape of three points. It can be also initiated eastward towards Cotonou or globally off all the northern coasts of GG. Nonsignificant trend is found on upwelling onset date and end date variability. Moreover, this study shows that SST is significantly warm or cold some years. Ocean conditions during these years are related to known physical processes.

1. Introduction

Coastal upwellings are characterized by seasonally low sea surface temperature (SST). They generally result from the response of the coastal ocean to alongshore winds, leading to the production of a relatively intense current with a small offshore and a large alongshore component [1]. This causes the pumping of cooler and nutrient-rich waters from the subsurface to the ocean surface. Upwelling areas are economically important even though the global area constituted by these regions is less than 1% of the global ocean [2]. Moreover, coastal upwellings have a great impact on local climate. Particularly, the coastal ocean surface conditions in the Gulf of Guinea situated in the northeastern equatorial Atlantic influence the West African climate [3]. Understanding the ocean dynamic of this region is then of great interest, (i) firstly because the Gulf of Guinea is the principal source of the water vapour which constitutes most of the precipitation on the continent. For example, Gu and Adler [4] linked the rainfall peak in May along the coastal area of the Gulf of Guinea to the seasonal forcing of the ocean. Eltahir and Gong [5] observed that the intensity of the West African monsoon depends on the meridional gradient of the static humid energy in the boundary layer between the ocean and the continent. (ii) Secondly, this tropical Atlantic area has the largest SST seasonal amplitude of about 5–8°C [6]. A coastal upwelling is observed each year along the northern coast of the Gulf of Guinea during the boreal winter and summer periods, that is, from January to February and from June to October, respectively, off Côte d'Ivoire and Ghana [7, 8]. June and October correspond to transition periods where an upwelling could be observed. These months are characterized by a progressive fall of SST in June and a return of warm water in October corresponding, respectively, to the beginning and

(a) (b)

Figure 1: (a) An autonomous onset sensor TIDBIT (model 5, version 2) used to measure coastal SST data. (b) A view of sensor installation by technicians at Sassandra site (Côte d'Ivoire) (Courtesy of PROPAO).

the end of the upwelling. However, the end of the upwelling could be sometimes observed at mid-October [9].

Satellite SST data have been extensively used for global oceans monitoring. These studies cover the Mauritania coastal zone [10], the Senegalese upwelling [11], and the northern coast of the Gulf of Guinea [9, 12, 13]. For example, Aman and Fofana [12, 13] used SST data from Météosat satellite to characterize the seasonal upwelling variability along the coast of Côte d'Ivoire. No study was undertaken using *in situ* coastal data since these measurements stopped in the earlier 1990s. The last studies were those of Verstraete et al. [14], Arfi et al. [15], Picaut [16], and Colin [17]. These works showed that (i) the cooling is firstly induced by the large-scale structure of the Guinea current off the continental shelf which tilts the thermocline towards the coast and then is amplified by the increase of the zonal wind component at the coast [17]. (ii) Secondly, the study of the mean sea level reveals a wave with a 15-day period throughout the year. This oscillation clearly appears during the upwelling season [16]. And, (iii) an annual cycle is found in mean sea level amplitude of about 20 cm at Tema, Takoradi, and Abidjan [15].

This paper proposes to use two datasets derived, respectively, from satellite measurements and new *in situ* SST records from onset sensors moored along the northern coast of the Gulf of Guinea. The study aims to test the ability of the SST derived from the onset sensors to characterize the northern coastal upwelling. It will allow using these new *in situ* measurements along the northern coast of the Gulf of Guinea in coming works linked to fisheries and to climate. For instance, Binet [18] showed that *Sardinella aurita* migrates towards the surface and the shore during the upwelling period. Ali et al. [9] highlighted the influence of the coastal upwelling on the precipitations along the northern coast of the Gulf of Guinea. However, given the short time series available with the onset sensors (during 2005–2011), satellite measurements will be used to achieve this work. SST measurements with onset sensors are monitored by the Regional Program of Physical Oceanography in West Africa (PROPAO) and now by the Jeune Equipe Associée à l'IRD named Analyses Littorale, Océanique et Climatique au nord du Golfe de Guinée (JEAI ALOCGG). The objectives of this program are to study the coastline and coastal erosion, the ocean conditions in the Gulf of Guinea and tropical Atlantic, the regional climate, and the role of the Gulf of Guinea in regional conditions. This project provides an opportunity to create a regional databank which could contribute significantly to the understanding of the complex mechanisms of this upwelling.

Section 2 presents the onset sensors data and the satellite measurements. Section 3 outlines the validation of the onset sensors SST as a good candidate to study the northern coastal upwelling of the Gulf of Guinea. The upwelling characterization is also undertaken using its onset date, its end date, and its duration. Section 4 describes the variability of this phenomenon. The summary and conclusion are provided in the last section.

2. Data and Method

Two types of data are used in this study to characterize the coastal upwelling at the northern coast of the Gulf of Guinea: SST records from onset sensors and satellite SST measurements from Tropical Rainfall Measuring Mission Microwave Imager (TRMM/TMI).

2.1. Data. The Regional Program of Physical Oceanography in West Africa (PROPAO) *in situ* measurements network is composed of several onset sensors moored along the coasts of Lagos (Nigeria), Cotonou (Benin), Takoradi (Ghana), and Sassandra (Côte d'Ivoire). The sensors have been installed at Cotonou in 2005 and 3 years later (2008) in the other stations. They are autonomous sensors TIDBIT (model 5, version 2) with a temperature range from -5°C to $+37^{\circ}$C and an accuracy of $\pm 0.2^{\circ}$C (Figure 1). These sensors are calibrated at the Institut Français de Recherche et d'Exploitation de la Mer

(IFREMER) at Brest (France) before the first use. The calibration involves the correction of the measured hourly SST dataset by a 6-degree polynomial function for each sensor or for each event which can be an immersion or a withdrawal. The corrected datasets are archived on the PROPAO website (http://www.nodc-benin.org/fr/propao/). They are sent to the Centre de Recherche Halieutiques et Océanologiques of Benin (CRHOB) by different partners (Department of fishery (DOF) of Ghana, Nigerian Institute for Oceanography and Marine Research (NIOMR), Centre de Recherches Océanologiques (CRO) of Côte d'Ivoire, and Centre de Recherche Halieutique et Océanologique of Benin (CRHOB)). In this study, hourly SST data are averaged to obtain daily dataset for homogeneity with daily satellite measurements which will be used later. Only the onset sensor data at the station of Cotonou are used because of their relative long time series (2005–2011) compared to the other stations. Moreover, their onset sensor time series have already been tested for calibration; those of the other stations should be done soon.

The signatures of the coastal upwelling events are analyzed using the daily SST derived from the TRMM Microwave Imager (hereafter TMI) sensor [19] from May 1 to November 30 to fully integrate the upwelling season [7, 8] during the period 1998–2011. TMI is a nine-channel passive microwave radiometer with operating frequencies ranging from 10.65 to 85.5 GHZ which provides a nearly complete dataset sampling between ±38° latitude. This product is available daily at 3-day running average. Optimal interpolation is used to fill points with no data, thus yielding a complete data coverage over the ocean. The lowest frequency channel of this radiometer yields SST images even in the presence of nonrain clouds, in contrast to infrared radiometers that require cloud-free condition. The additional channel at 10.7 GHZ allows measuring SST with a good precision during strong averse of tropical areas [20]. Some studies [21–23] have shown the good quality of the TMI dataset whose new version has been validated by comparison with moored buoys data [24]. In this study, the 14-year daily SST data are obtained from Remote Sensing Systems (ftp://ftp.discover-earth.org/sst/daily/tmi/) from 1998 to 2011 at 0.25° × 0.25° spatial resolution. TMI SST are then extracted at each grid point close to PROPAO stations (Cotonou (6.22°N–2.26°E), Takoradi (4.88°N–1.75°W), Abidjan (5.19°N–4.02°W), and Sassandra (4.95°N–6.08°W)) (Figure 2). Ali et al. [9] observed that the upwelling extends from the coast to 4°N. But it could extend beyond [8]. Those offshore TMI grid points can then document the beginning date of the major upwelling (hereafter onset date), the vanishing date of the phenomenon (hereafter end date), and its duration during the boreal summer.

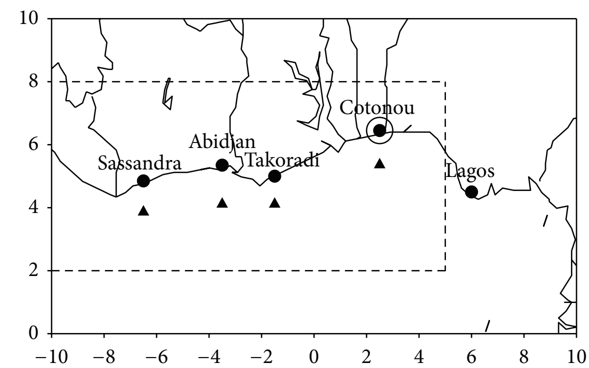

Figure 2: PROPAO network of sensors. The rectangle shows the oceanic zone. The stations (dots) and the nearest TMI grid points are shown (triangles). The sensor position of Cotonou is encircled.

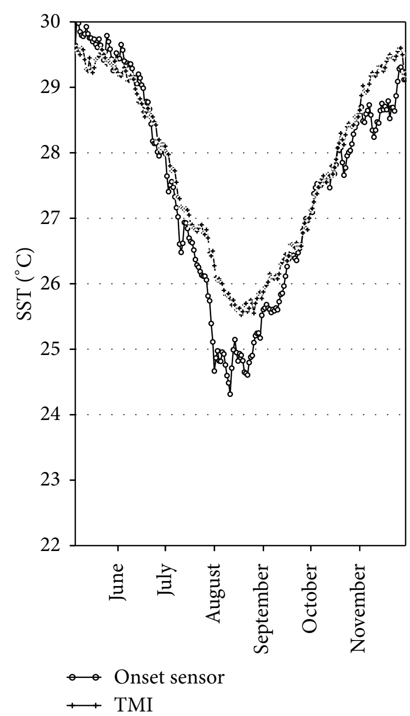

Figure 3: Daily climatology of SST from May 1 to November 30 in 2005–2011 from the onset sensor at Cotonou and from TMI at a point close to the station. SST thresholds 24°C, 25°C, 26°C, 27°C, and 28°C are plotted.

2.2. Method. Figure 3 shows the daily climatology of the *in situ* SST at Cotonou and of TMI SST at the point close to this station (see Figure 2) during 2005–2011. The SST thresholds at 24°C [18], 25°C [25], and 26°C [9] and two arbitrary thresholds (27°C and 28°C) are also represented on the graph. The threshold 24°C is too low to detect the upwelling period with both datasets. The threshold at 25°C exhibits the upwelling season durations of about 26 days. The duration of the upwelling season reaches 50 days, 84 days, and 110 days, respectively, for 26°C, 27°C, and 28°C which is consistent with several works [7–9, 16]. The differences between the climatological means make a constant threshold quite irrelevant for characterizing the upwelling onset and end dates. Another hypothesis for not using a fixed threshold could be the complexity of the upwelling at all the northern coast of the Gulf of Guinea. For example, the threshold used to characterize the upwelling at the coast of Côte d'Ivoire and

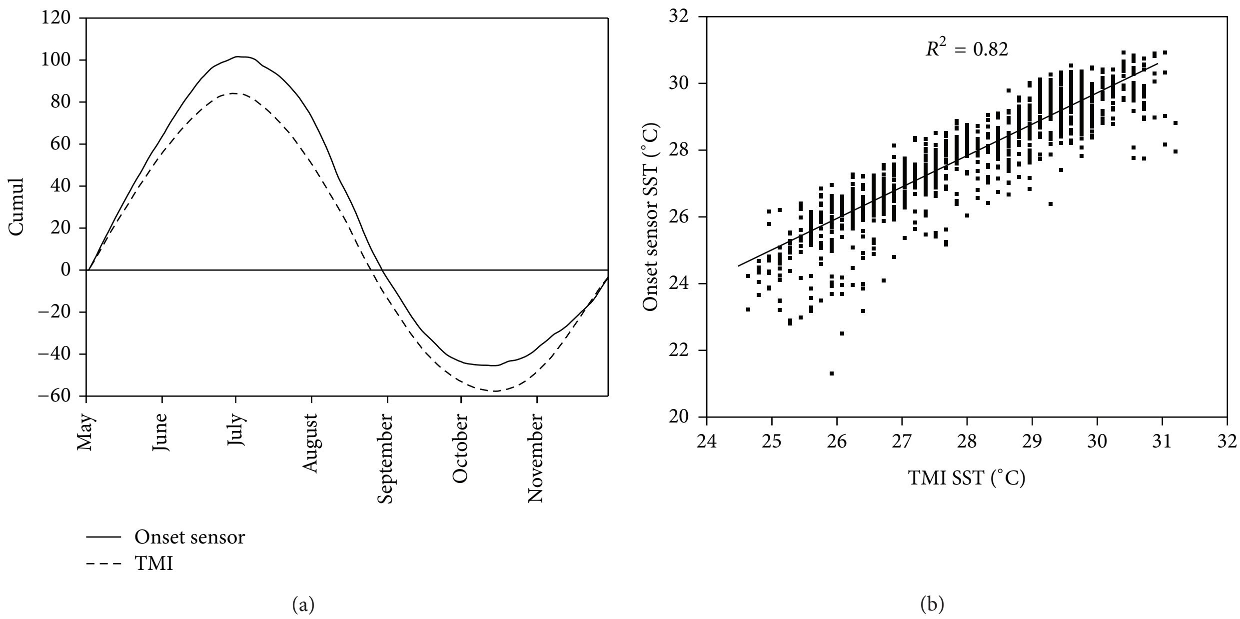

Figure 4: (a) Climatology of the cumul in 2005–2011 of TMI SST at 2.625°E; 5.375°N close to Cotonou and of the onset sensor moored at 2.26°E; 6.22°N. (b) Linear regression between daily SST of onset sensor and of the point close to the station of Cotonou.

Ghana is not the same at Benin. This value ranges between 24°C and 26°C off Côte d'Ivoire and Ghana while it is about 26°C or 27°C off Benin (data not shown).

To overcome the choice of the SST threshold for the upwelling characterization period, a cumul method which is an adaptation of the method of Liebmann and Marengo [26] is used. It is used to find the major upwelling season onset date, its end date, and its duration during the boreal summer period. Once, SST are averaged between the onset date and the end date for each year to study the upwelling variability. This allows characterizing objectively the upwelling period from both datasets.

For a given year and within the corresponding upwelling period (from May 1 to November 30), annual mean and standard deviation of SST are performed through (1) for each station. Then, daily standardized anomalies (instead of simple anomalies used by Liebmann and Marengo [26]) are calculated to provide the same statistical weight to all SST values and to eliminate seasonality. The initial value of the cumul (which is an adimensional value) is taken as the standardized anomaly at May 1. The cumul at May 2 represents the sum of the standardized anomalies at May 1 and at May 2. The following cumuls are calculated as the sum of the standardized anomaly of the current day and those of the previous days. This method is summarized in (2). These calculations are applied for each year and for the daily climatology which represents the mean SST of the same calendar days, leading to 214 daily mean values. The maximum (resp., minimum) of the cumul curve versus the date indicates the onset date (resp., end date) of the upwelling season. The duration of the phenomenon is obtained by differencing the Julian days of the end date and of the onset date. It will allow studying the variability of the upwelling season at the northern coast of the Gulf of Guinea. consider

$$\overline{\mathrm{SST}} = \frac{1}{N}\sum_{i=1}^{N}\mathrm{SST}_i,$$
$$\sigma = \sqrt{\frac{\sum_{i=1}^{N}\left(\mathrm{SST}_i - \overline{\mathrm{SST}}\right)^2}{N}}, \quad N = 214 \text{ days}, \tag{1}$$

$$\mathrm{cumul}\,(k) = \sum_{i=1}^{k}\frac{\left(\mathrm{SST}_i - \overline{\mathrm{SST}}\right)}{\sigma}, \quad k = \text{current day},$$
$$i = \text{initial day}, \ \sigma = \text{standard variation}. \tag{2}$$

3. Upwelling Characterization Using *In Situ* and TMI SST

Figure 4(a) illustrates the climatology of the cumul of TMI SST at a grid point (2.625°E; 5.375°N) close to the station of Cotonou (see Figure 2) and of the *in situ* SST at this station (6.22°N–2.26°E) during 2005–2011. The Cotonou station is used because of its longer *in situ* SST time series compared to those of Sassandra and Takoradi, whose time series start in 2008. Both curves show similar boreal summer upwelling onset date and end date even though the data are recorded from different sources. The cumul values of *in situ* SST are higher than those of SST derived from TMI. The linear regression fit between both daily SST datasets is also plotted (Figure 4(b)). The coefficient of determination is 0.82 and is significant at 95% confidence level. The good agreement

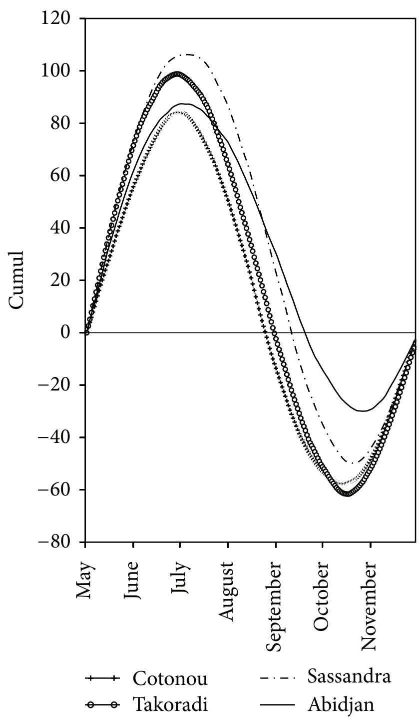

Figure 5: Daily climatology of the cumul from TMI SST in 1998–2011 for the four nearest grid points of PROPAO network stations.

between the results of both datasets is interesting as they are from different sources and from different sites of measurements. It allows concluding that *in situ* SST data could be used to study the upwelling at the northern coast of the GG. Then, it is highly recommended to use the acquisition of *in situ* SST measurements based on onset equipment as (i) it appears very useful for the coastal upwelling characterization and since (ii) satellite data are not available near the coasts. However, given the shorter time series of the *in situ* SST, TMI SST will be used in the following sections.

Figure 5 shows the climatology of the daily cumuls from TMI SST during 1998–2011 period for the four nearest grid points of PROPAO network stations. The maximum and the minimum of the cumul curve versus the date represent, respectively, the boreal summer upwelling onset date and end date. The SST climatological value which corresponds to the maximum of the curve is about 26°C (data not shown). This result concurs with those of Arfi et al. [15] and Ali et al. [9]. This threshold allows an early detection of the cooling areas if SST is spatially plotted.

The boreal summer upwelling off Sassandra and Abidjan begins approximately at July 3 and ends at October 17 while it begins at June 28 and ends at October 13 off Takoradi and Cotonou. The upwelling at the four sites lasts 15 weeks. These results are consistent with those of several authors [7–9, 16] who noted similar duration of the upwelling season. The upwelling signal appears firstly off Cotonou and off Takoradi coasts approximately one week before its westward extension to Abidjan and Sassandra [16]. This westward extension is associated with a semiannual oscillation [27].

Table 1: Onset date as Julian day for the four nearest grid points of PROPAO network stations. Underlined dates show upwelling initiation eastward towards Cotonou. Bold dates refer to initiation at one cape while bold and italic dates refer to initiation at both capes.

Year	Cotonou	Takoradi	Abidjan	Sassandra
1998	182	**170**	179	178
1999	186	188	212	213
2000	172	180	186	181
2001	174	183	194	181
2002	184	188	193	194
2003	176	**169**	172	181
2004	177	***167***	169	***167***
2005	176	**166**	174	168
2006	188	***185***	188	***185***
2007	177	178	186	196
2008	178	180	182	**175**
2009	195	189	190	**187**
2010	184	**174**	186	180
2011	173	186	187	190

Its origin could be more eastward off Nigeria or Cameroon coast. A simple calculation of the appearance velocity of the phenomenon, for example, between the two capes (Takoradi: 1.75°W; 4.88°N and Sassandra: 6.08°W; 4.95°N) separated by 4.33° of longitude, gives 78 cm/s when considering a 1-week lag between the two maxima of their respective curves of cumul. This velocity is consistent with the speed of a coastally trapped Kelvin wave travelling at 70 cm/s [16].

4. Boreal Summer Upwelling Variability at the Northern Coast of the Gulf of Guinea

Figure 6 presents the interannual evolution of the upwelling onset date (black curve) and of the end date (red curve) versus the years for all stations. Linear regression fits are superimposed on the graphs. Nonsignificant trend of upwelling onset date (late onset date at Cotonou and Takoradi and early onset date at Abidjan and Sassandra) is noted for all stations. Nonsignificant trend (based on the Student test) of upwelling end date lasts at Takoradi, Abidjan, and Sassandra while early upwelling is noted at Cotonou. For example, the upwelling season lasts until November in 1999 for Cotonou, Abidjan, and Sassandra stations while it vanishes in early 2004 for all stations (mid-August at Cotonou, at the end of September at Takoradi, Abidjan, and Sassandra). The curve of the upwelling onset date points out two main cases concerning the beginning of the phenomenon (Table 1). The first case shows that the upwelling initiates eastward at Cotonou and extends westward in 1999, 2000, 2001, 2002, 2007, and 2011. This case represents 43% of all years. This observation is consistent with Picaut [16] who showed that the signal of the boreal summer upwelling at the northern coast of the Gulf of Guinea mainly propagates from east to west. However, the causes of this propagation are poorly known. The westward extension of the upwelling may be slower some years. For example, the upwelling extends from Cotonou to the other

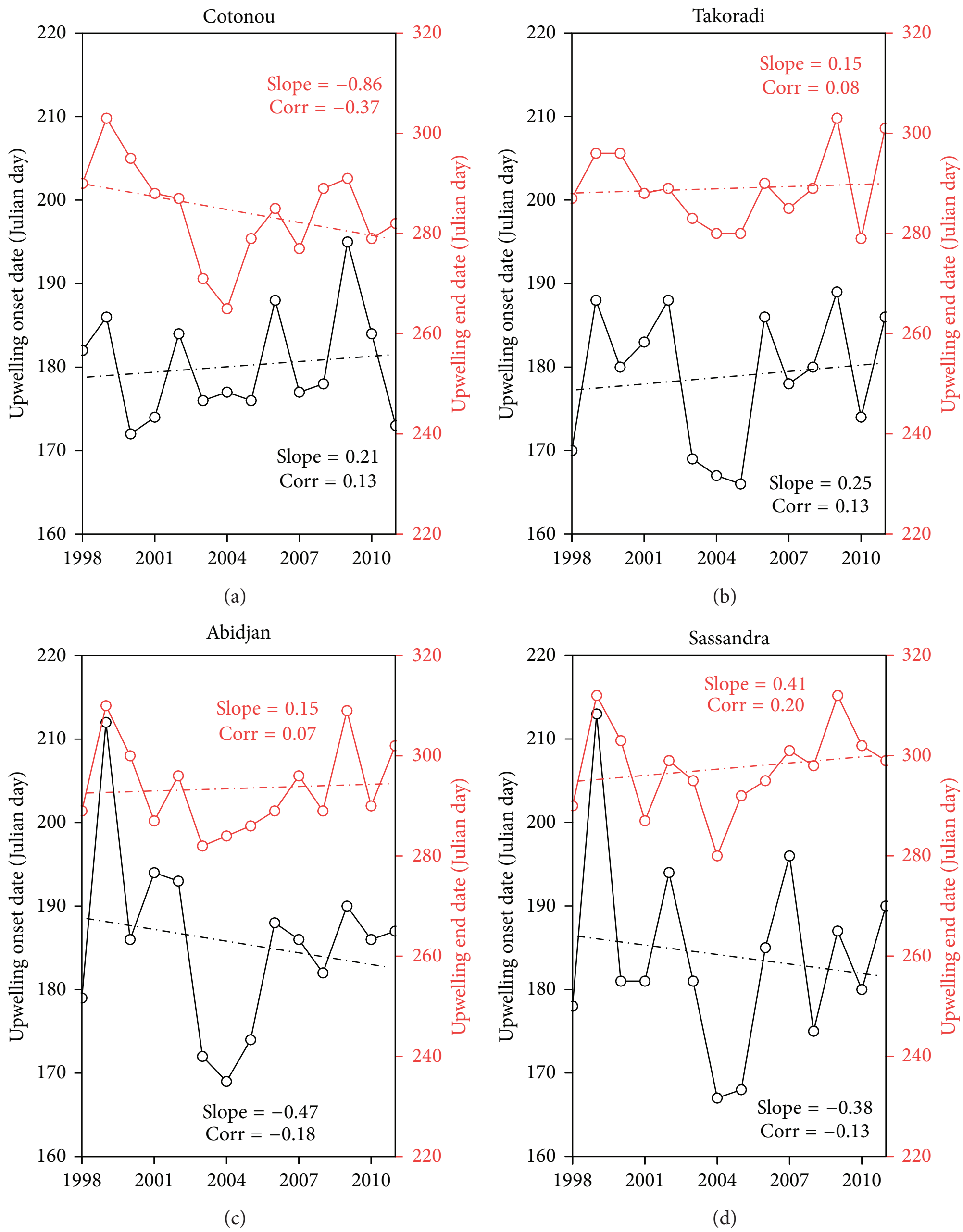

Figure 6: Interannual evolution of the onset date (black) and of the end date (red) of the great upwelling season in 1998–2011 of each station. The linear regression fit is superimposed on the graphics. The date is expressed in Julian days.

stations in 2 weeks during 2011. These remarks could be related to the initiation of a lower upwelling (see Figure 8). The second case relates to the upwelling initiation at cape of three points close to Takoradi and/or at cape of Palmas close to Sassandra. The phenomenon can be initiated at one cape and then extends both sides of it. This case occurs during 1998, 2003, 2005, 2008, 2009, and 2010 and represents 43% of all years. During 2004 and 2006 (14% of the 14 years studied), the upwelling appears simultaneously at both capes and then extends to other stations. These last two situations are similar to the cape effects described by Marchal and Picaut [28]. They could be explained by the dynamical interaction between the Guinea current and the cape of three points which induces a lower slope of the thermocline upstream of the cape and an accumulation of warm water downstream of it. This could also be amplified by the eastward orientation of the capes. However, these different cases show the complexity of the study of the upwelling at the northern coast of the Gulf of Guinea for which several mechanisms may contribute to its initiation. These could be (i) local and remote actions of the wind that induce the role of equatorial and coastal Kelvin waves [29–31], (ii) the potential role of the Guinea current

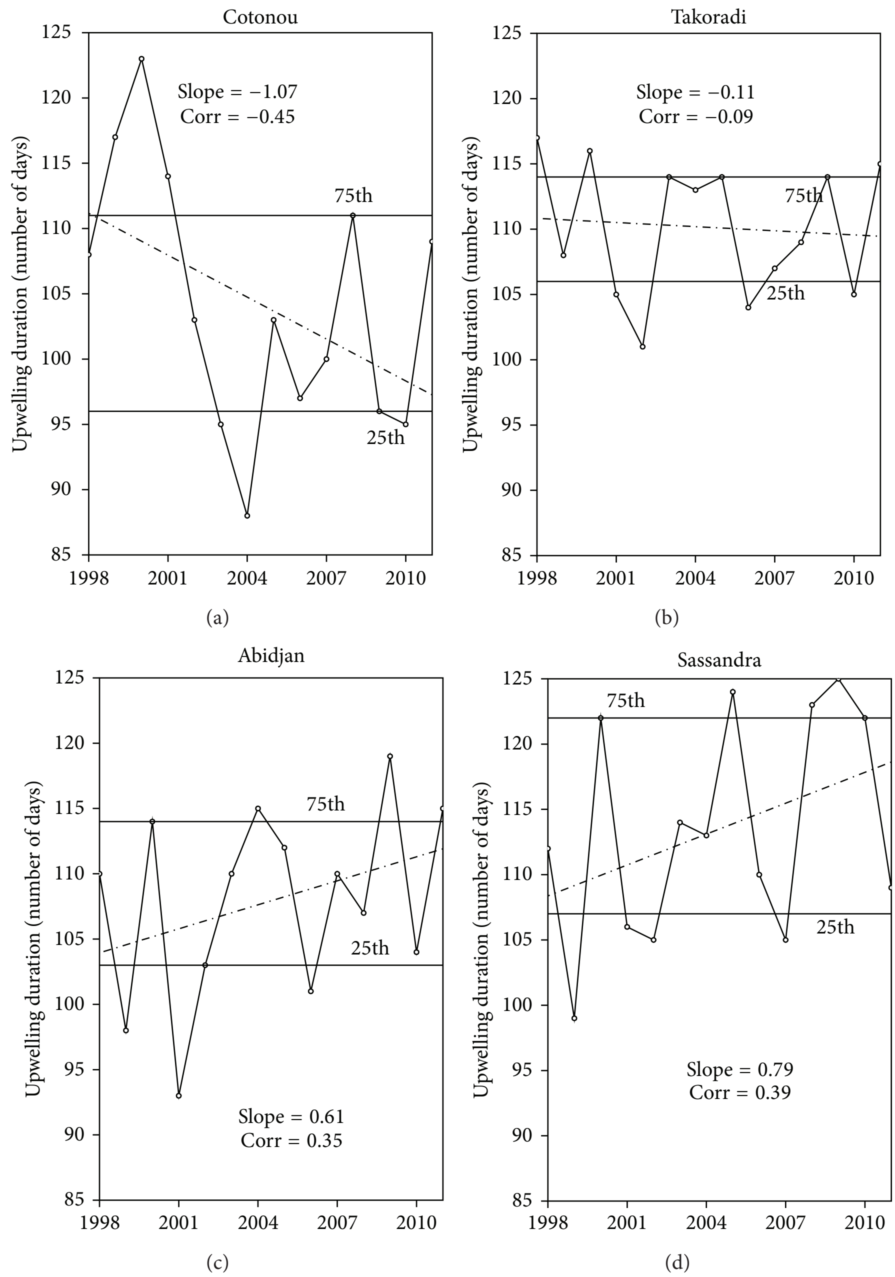

Figure 7: Interannual evolution of the duration of the upwelling season. Linear regression fit (dashed) and the 75th and 25th percentiles (horizontal lines) are superimposed.

and the cape effects [32, 33], or (iii) the coastal transport and the Ekman pumping [34].

Figure 7 shows the interannual evolution of the upwelling duration calculated as the difference between the onset date and the end date (see Figure 6) of the phenomenon. The linear regression fit indicates Nonsignificant negative trends at Cotonou and at Takoradi and Nonsignificant positive trends at Abidjan and at Sassandra showing a weak variation of the duration at all the stations. This figure shows also successive years of long or short duration of the phenomenon. The upwelling duration in the PROPAO stations network has not changed even though there are some years in which the season could be abnormally long or short. Then, the 75th and 25th percentiles of the duration distribution are computed. If a duration is higher (resp., lower) than the 75th (resp., 25th) percentile, the upwelling season is considered to be abnormally long (resp., short). Restricting the calculation to the 75th and to the 25th percentiles allows the selection of a small number of events for a more efficient analysis. The mean value for all durations higher than the 75th percentile is equal to 115 days for all stations. The mean value is equal to 102 days for the 25th percentile. Particularly, the duration reaches 122 days at Sassandra and 111 days at Cotonou. The graphs indicate a nonuniformity of the duration of the upwelling

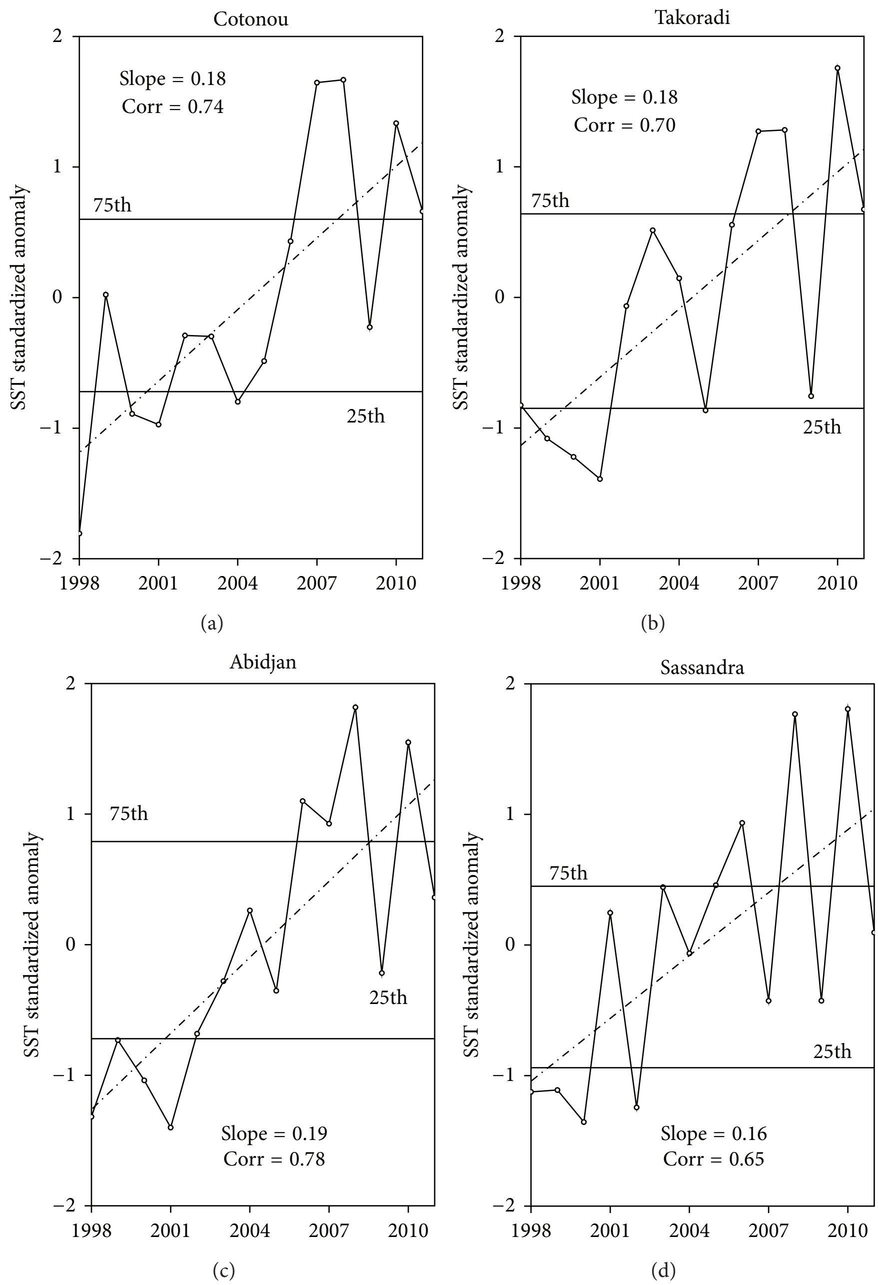

Figure 8: Interannual evolution of standardized SST anomalies during each upwelling period. Linear regression fit (dashed) and the 75th and 25th percentiles (horizontal lines) are superimposed.

season. For example, in 1999, upwelling season is the longest at Cotonou and the shortest at Sassandra and at Abidjan. In 2000, the longer duration is consistent with the results of Ali et al. [9].

Figure 8 presents the interannual evolution of the standardized SST anomaly during the selected upwelling period for each nearest grid point of the PROPAO Network stations. From the daily climatology during May 1 through November 30 of the 1998–2011 period, standardized anomalies are computed with TMI datasets. Then, annual values are calculated by averaging all daily standardized anomalies for each upwelling period based on the curve of the cumul. The 75th and 25th percentiles of the standardized anomalies are plotted too. The mean warming trend for all stations is about 0.18 standardized anomalies per year (~0.18/year). (Let us note that since standardized values are used, the unit of the performed trend value is an adimensional value versus the year.) The correlation coefficient associated with the linear regression fit is significant at 95% confidence level and is equal to 0.65, 0.78, 0.70, and 0.74, respectively, at Sassandra, Abidjan, Takoradi, and Cotonou. Abnormal cooling periods are observed at all stations from 1998 to

2001. This is consistent with Ali et al. [9] who noted higher values of their upwelling indexes for these particular years. From 2005 to 2011, significant warming occurs at all stations. Particularly, the warming is abnormally high in 2008 and 2010. These oceanic conditions could be explained by a mechanism similar to the phenomenon observed in 1984 by Colin [8]. He noted that the Guinea Current was close to the continental shelf but weak in 1984. It could not ensure a significant upward motion of the thermocline and induce a strong upwelling. This situation lasted until the upwelling period from July to September. It contributed to amplifying positive SST anomalies which resulted in a warming of the ocean surface. Figure 8 shows also nonuniformity of the warming or of the cooling. For example, significant cooling is noted from Cotonou to Abidjan in 2001 while Nonsignificant warming is observed at Sassandra. Aman et al. [35] indicated that the minimum of the sea level at São Tomé, which precedes boreal summer upwelling, was the same in 2001 and 2002 with an abnormal duration in 2001 (~2 months) than in 2002 (~1 month). This situation is associated with strong negative sea level anomalies at Cotonou, Téma (close to Takoradi), and Abidjan and positive sea level anomalies at San-Pédro (close to Sassandra). Verstraete and Park [36] and Park [37] noted also similar observations during the upwelling season in 1992. The minimum of the sea level at São Tomé is the same in 1992 and 1993. But this minimum is longer in 1992 (~2 months) than in 1993 (~2 weeks). These two situations could explain the strong cooling at Cotonou, Takoradi, and Abidjan and the warming at Sassandra in 2001.

5. Conclusion

This study aims to characterize the boreal summer upwelling at the northern coast of the Gulf of Guinea during the 1998–2011 period. Two datasets derived, respectively, from satellite measurements and new *in situ* records from onset sensors moored along the northern littoral of the Gulf of Guinea from May 1 to November 30 of each year are used.

The ability of the *in situ* SST to characterize the upwelling is firstly tested. This study compares SST provided by the TRMM Microwave Imager (TMI) sensor [19] during 2005–2011 and *in situ* SST records derived from the PROPAO stations network. An adaptation of the method of Liebmann and Marengo [26] is used to find the beginning (or onset) date of the upwelling season, its vanishing (or end) date, and its duration. The cumul values, which are a new variable performed with this method, allow being free from the use of a fixed threshold which may not fit each station's proper characteristics (mean and variance). The results show similar onset date, end date, and duration of boreal summer upwelling since both datasets are recorded from different sources. Moreover, high correlation is found between daily SST of both datasets. The coefficient of determination is 0.82 and is significant at 95% confidence level. These observations indicate a good agreement between both datasets. The use of the *in situ* SST data could contribute significantly to the characterization of the upwelling at the northern coast of the Gulf of Guinea.

Yearly calculations of the boreal summer upwelling onset date, end date, and duration are computed for four PROPAO Network stations (Cotonou, Takoradi, Abidjan, and Sassandra). Since *in situ* SST time series are shorter for these stations, TMI time series have been selected for some point coordinates close to each station. It shows that the upwelling phenomenon generally starts eastward at Cotonou and Takoradi, mostly one week before its extension to Abidjan and Sassandra. Nonsignificant trend is found in the upwelling onset date and the end date, and there is nonuniformity in the duration. Moreover, the upwelling onset date reveals different areas of initiation showing the complexity of this phenomenon.

Finally, variability of the boreal summer upwelling for the four stations is studied using standardized SST anomalies. It shows significant trend. Some years are found to be significantly warm or cold and they are related to known physical process.

This work has been undertaken in the framework of the Jeune Equipe Associée à l'IRD named Analyses Littorale, Océanique et Climatique au nord du Golfe de Guinée (JEAI ALOCGG). It aims to study the coastline and coastal erosion, the ocean conditions in the Gulf of Guinea and tropical Atlantic, the regional climate, and the role of the GG in regional conditions. Our results highlight the opportunity to use the new SST *in situ* measurements from onset sensors to characterize the boreal summer upwelling at the northern coast of GG. It becomes urgent to continue the acquisition of SST data based on onset sensors along the coasts of GG because of the climate change issues since satellite measurements do not reach the coast. This project represents an opportunity for the participating countries of PROPAO Network to create a regional databank in order to contribute significantly to the understanding of the complex mechanisms of this upwelling.

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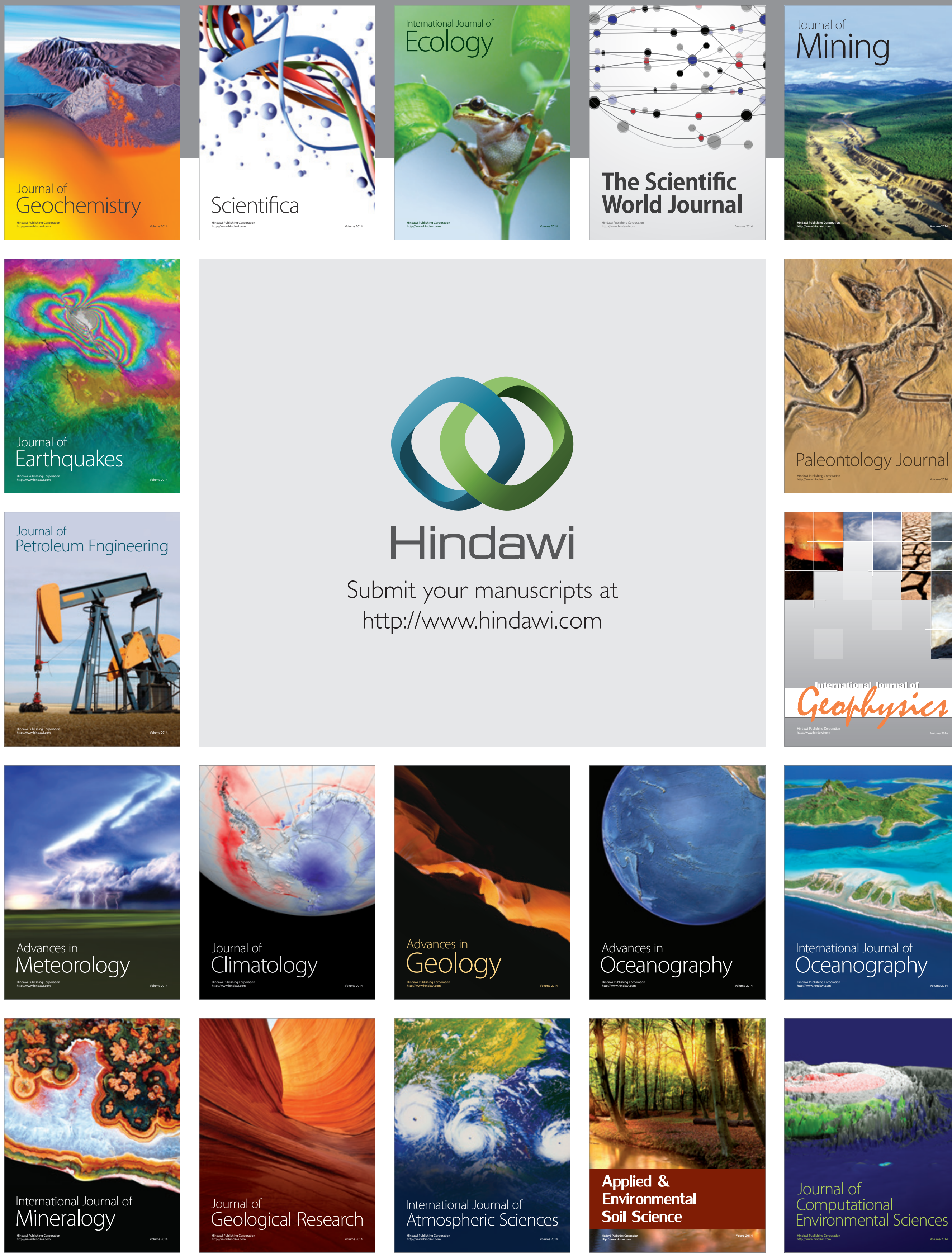
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