Integrated Ocean Observing Systems as a source of scientific information for supporting oil spill response – From Gulf of Mexico to Gulf of Guinea

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ABSTRACT

As of 2013, the Gulf of Guinea produces about 5.5 million barrels of oil per day – more than 60% of the total daily crude oil production in sub-Saharan Africa. Potential oil spills and their impact on the environment and the economy are of concern. As was seen in the Deepwater Horizon oil spill in 2010, information from the United States Integrated Ocean Observing Systems (IOOS®) was key in the response. A robust IOOS-like system in the Gulf of Guinea could support oil spill response and enhance the existing Global Ocean Observing System for Africa (GOOS for Africa). There is great potential within the Gulf of Guinea for regional stakeholder resources to coordinate systematic metocean and coastal data, and share these data across the West, Central and Southern African countries. Through such coordinated efforts, the society benefits from the development of a "blue economy" and from improved disaster response more than from individual observations. Drawing from the examples in the Gulf of Mexico, the paper integrates the lessons from IOOS types of assets into useful response efforts for the Gulf of Guinea area. Responders, decision makers, scientists and the public all benefit from improved access to environmental information and forecasts. We include a "mock up" of how an IOOS asset would support scientific spill response in the Gulf of Guinea.

1.0 INTRODUCTION

The fragile nature of marine environmental resources and the increasing stressors on them have necessitated innovative management strategies that mainly centre on the coordinated integration of major factors; viz:

- Zhang and Kitazawa (2016) recently developed an integrated multi-trophic aquaculture to simulate physical, biochemical and ecological interactions and assessed its bio-mitigation effects in a marine environment.
- An integrated environmental mapping and monitoring concept was demonstrated for sites such as ‘deep-water coral reefs’ to outline the key stages from survey to ‘selection of parameters, sensors, sensor platforms, data collection, data storage, analysis and to data interpretation for reliable decision making’ (Nilssen et al., 2015).
- Wu et al. (2012) utilised fuzzy integrated assessment method to assess the ecological quality status of three semi-enclosed coastal areas in the Sansha, Luoyuan and Tong’an Bays in the Western Taiwan Straits.
- In the New Caledonia’s lagoon (2004–2008) of the French Pacific territory, attempts have been made to implement integrated coastal zone management (David et al., 2010).

These synopses serve to illustrate the growing development of integrated systems and approaches for managing ocean resources and the blue economy thereof. This is especially critical for developing nations.

Therefore, effective oil spill contingency planning and response require a systematic understanding of baseline to real-time environmental and oceanographic conditions. While the Gulf of Guinea area in the South Atlantic Ocean has about 22 countries at different stages of oil and gas development and blue economy initiatives, no formidable framework exists for coordinating ocean observing systems or formal data sharing practices. Integrated marine pollution response can be leveraged in the Gulf of Guinea by taking a cue from rather well established frameworks in the United States, European Union (EU) and elsewhere. For example, major oil companies like Shell, ConocoPhillips and Statoil in 2011 signed a data-sharing agreement for the Arctic with the National Oceanic and Atmospheric Administration (NOAA). Under this agreement, the Alaska Ocean Observing System, which is part of the United States Integrated Ocean Observing System (U.S. IOOS®), integrates data from industry with other data from academic and other public sources to provide comprehensive oceanographic and environmental data available in the Chukchi Sea area (McCammon 2013). A similar agreement was reached with Shell in the Gulf of Mexico.

1.1 Importance of the Problem

The United Nations Environment Programme (UNEP) recently sited in Nigeria the headquarters of the Regional Coordination Centre (RCC) to combat marine pollution in West, Central and Southern Africa (i.e. the Gulf of Guinea Area) as shown in Figure 1. The RCC is hosted by the National Oil Spill Detection & Response Agency (NOSDRA). This is a significant mandate, as oil development occurs along the west African Coast from Senegal to Angola. This has the advantage of a single point to disseminate integrated data widely.

Figure 1: Map of Africa showing the coastal country boundaries (from Mauritania to South Africa) covered by UNEP's Regional Coordination Centre of the Abidjan Convention for combating marine pollution.

As of 2013, the general Gulf of Guinea area produces about 5.5 million barrels of oil per day – more than 60% of the total daily crude oil production in sub-Saharan Africa. Given the law of improbable incidents as demonstrated through the Poisson probability distribution formula (see Anderson et al., 2012), it is justifiable to raise concerns upfront about 'low frequency-high impact' incidents e.g. Spills of National Significance (SONS) and crucially, how environmental conditions in the Gulf of Guinea might influence response efforts. During the 2010 Deepwater Horizon (DWH) oil spill in the Gulf of Mexico, U.S. IOOS played a prominent role in the operational response phase (Section

3). With this, fundamental questions about oil behaviour in the Gulf of Guinea (per Anifowose and Beegle-Krause, 2015) need urgent attention, viz:

i. How will ocean circulation in the Gulf of Guinea transport and disperse fractions of oil at the surface and through the water column?

ii. What spatial extent could suspended deep-bottom coated sediments reach and the temporality of concentration?

iii. Will deep-bottom oil residue eventually come to shore and how long could it take to arrive at shore?

iv. For a deep offshore well blowout, should Subsurface Dispersant Injection (SSDI) be used with naturally low dissolved oxygen in the deep water?

The above questions cannot be effectively addressed without coordinated integration of oceanic environmental data across all the Gulf of Guinea member countries. Opportunities for this are yet to be fully explored and may be achieved through support from the Global Initiative for West, Central and Southern Africa (GI WACAF), which is a partnership between the International Maritime Organization (IMO) and International Petroleum Industry Environmental Conservation Association (IPIECA). At the individual country level, the collection of environmental data that could feed into the regional scale would need to be systematic and of reasonable quality (see Anifowose et al. 2016). This is not without data availability and accessibility challenges, particularly in less studied areas. A robust system in the Gulf of Guinea will enhance oil spill response, safe industry operations and the existing Global Ocean Observing System for Africa (GOOS for Africa).

Also, mangroves are abundant in western Africa, and mangroves are the habitat most sensitive to oil spills (Hoff and Michel, 2014). Oiling can rapidly kill a mangrove, though mangroves can equally suffer sub-lethal effects from oil spills. The complexity of mangrove areas makes protecting mangroves from oil spills, cleaning mangroves of oil and restoring mangrove habitat very challenging. Regional ocean observing system data connected to operational oil spill forecasting could provide more timely and detailed predictions for the location, tidal excursion and timing of any offshore oil moving into an area of coastal mangroves. The recent advancements in operational coastal modelling, particularly finite element models, and ocean observing / remote sensing mean that detailed models of flow through mangrove areas is within the realm of possibility. These could be used in oil spill trajectory models to aid in planning, preparedness and response.

2.0 CIRCULATION IN THE GULF OF GUINEA – A CURSORY VIEW

A sizeable volume of freshwater and sediments are regularly discharged into the Gulf of Guinea shelf by at least 12 major rivers (Folorunsho et al. 1998). In order to predict where an oil spill will travel, hindcasts and/or forecasts of wind and currents are used in oil spill trajectory models. All major oil spill models can use external 4D (x,y,z,t) circulation forecasts, and longer hindcast fields can be used for oil spill response planning and drills. What is also important to recognize is that though government, academic and industry can use the same types of data in oil spill trajectory models, the questions of interest to these groups are not necessarily all the same. During a spill, each entity wants an oil spill to be cleaned up as efficiently and quickly as possible. However, each has a different stakeholder and a relationship with the public. Hence there is much overlap, but one organization could not support all the needs of the other two.

The Gulf of Guinea poses some challenges in ocean observing and forecasting. The eastern equatorial Atlantic Ocean circulation is more complex than the eastern equatorial Pacific Ocean. Both have similar equatorial currents (surface westward currents related to the gyres) generally similar to the larger ocean basin gyres in the North Atlantic and the South Atlantic. There is also an equatorial undercurrent in both the Atlantic and Pacific Ocean, though the Atlantic undercurrent changes drastically as the African continent influences the overall circulation along the eastern portion. As these surface and subsurface currents travel eastward, some of the currents are redirected north and south before reaching the coast (Bourlès et al, 2002). The Atlantic also exhibits El Niño-like variability (Zebiak, 1993, Keenlyside and Latif, 2007), and warm events lead to increased rainfall on the northern Gulf of Guinea (Carton and Huang, 1993). More intense trade winds lead to deepening of the thermocline on the west side of the equatorial South Atlantic. As these winds relax, this warm pool of water travels toward Africa, depressing the thermocline in the entire Gulf of Guinea. These events are similar to the Pacific El Niño, so have been termed "Benguela Niño", Guinea Niño (see Binet, Gobert and Maloueki et at, 2001). These complexities and inter-annual variability point toward the need for systematic ocean observing for improved prediction of the trajectory and fate of any significant oil spill. A spill in the same place a few years later would behave radically differently than the first spill, which may confound oil spill responders without quality trajectory forecasting. More detail on the complexities and the large marine ecosystem of the Gulf of Guinea are available in McGlade et al. (2002).

Deepwater oil development in western Africa is in a different deep ocean regime than in the Gulf of Mexico or coastal Brazil. Beegle-Krause et al (2016) showed that a deepwater well blowout on the eastern side of the mid-Atlantic Ridge system could lead to subsurface hypoxia. This is due to the difference in deepwater ages (time since at last at the surface) between the two sides of the equatorial Atlantic. In areas of the oil development in the South Atlantic Basin (Brazil), the lower oxygen water is 25 years old, while on the eastern side (Africa) the low oxygen water is 50-100 years old. A simulated realistic well blowout resulted in two deep hypoxic layers below 1000 m depth. Thus, the decision of whether or not to use Subsurface Dispersant Injection (SSDI) could lead to lower DO levels, becomes more complex, especially in places like the Gulf of Guinea. Eutrophication and DO depletion has been a problem along the Gulf of Guinea (Awosika and Ibe, 1998).

2.1 The Case for Integrated Ocean Observing System (IOOS) Development in the Gulf of Guinea

Copeland (2008) introduced the concept of "Common Operational Picture" as important to military operations for understanding different types of information that vary spatially over an area of operation, leading to a more organized and transparent response structure. Common Operational Picture debuted operationally for oil spills during the DWH oil spill with the public launch of the NOAA and University of New Hampshire collaboration of Emergency Response Management Application (ERMA®) for the Gulf of Mexico. ERMA® Deepwater Gulf Response[1] contains all the operational and assessment data for the DWH oil spill in a user-friendly geospatial interface.

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[1] http://response.restoration.noaa.gov/maps-and-spatial-data/environmental-response-management-application-erma/erma-gulf-response.html

Chang (2006) discusses the "fragile" relationship between the Pacific and Atlantic El Niño events, and that these Atlantic events effect primarily the Gulf of Guinea, demonstrating that an IOOS in the Gulf of Guinea would improve observation and forecasting of these changes. Analyses of the significant economic benefits of U.S. IOOS to their coastal areas have been documented in Hauke (2010). These societal benefits that range from oil spill response to economic improvement would also have benefit in the Gulf of Guinea and would allow prediction on many time scales from long-term changes in climate to immediacies of operational support incidents such as search and rescue and oil spills.

2.2 Available Observing Assets in the Gulf of Guinea Today

Ahanhanzo (2006) details the evolution of Global Ocean Observing System (GOOS) Africa following the 25th Session of UNESCO's Executive Council of the Intergovernmental Oceanographic Commission in 1992, to which the World Meteorological Organization, the UNEP and the International Council of Scientific Unions (ICSU) later committed themselves. Figure 2 shows that GOOS Africa was established in 2011 with 36 member states and that efforts are underway to establish a Regional Ocean Observing Framework System (ROOFS-Africa).

The Global Ocean Observing System

GRA: GOOS Africa

GOOS Africa is administered through the IOC Sub-Commission for Africa and the Adjacent Island States. Sub-Commission officers are defacto officers of GOOS Africa, and represent the African Member States in their relations with the GOOS Regional Alliances.

Website: N/A
Established: 2011
Type: Network of regional organization
Membership: 36 Member States
Contact: Mika Odido, Secretariat, IOC (IOC Africa Sub Commission)

Governance

The Bureau of the Sub-Commission comprises the Chair and three Vice-Chairs elected by the Sub-Commission, and shall serve in accordance with the Guidelines for the Structure and Responsibilities of the Subsidiary Bodies of the Commission. A proposed Regional Ocean Observing Framework System (ROOFS-Africa) to better coordinate ocean observing and operational oceanography across African nations is currently under development.

Figure 2: Current status of GOOS Africa.
Source: http://www.goosocean.org/index.php?option=com_content&view=article&id=43&Itemid=143. Accessed on: 20 March 2017.

There is also the Prediction and Research Moored Array in the Tropical Atlantic (PIRATA) operated by France, USA and Brazil. PIRATA is an experimental program dating back to 1997 with a number of data collection points as shown in Figure 3, and it is a platform that could be extended to support additional sensors.

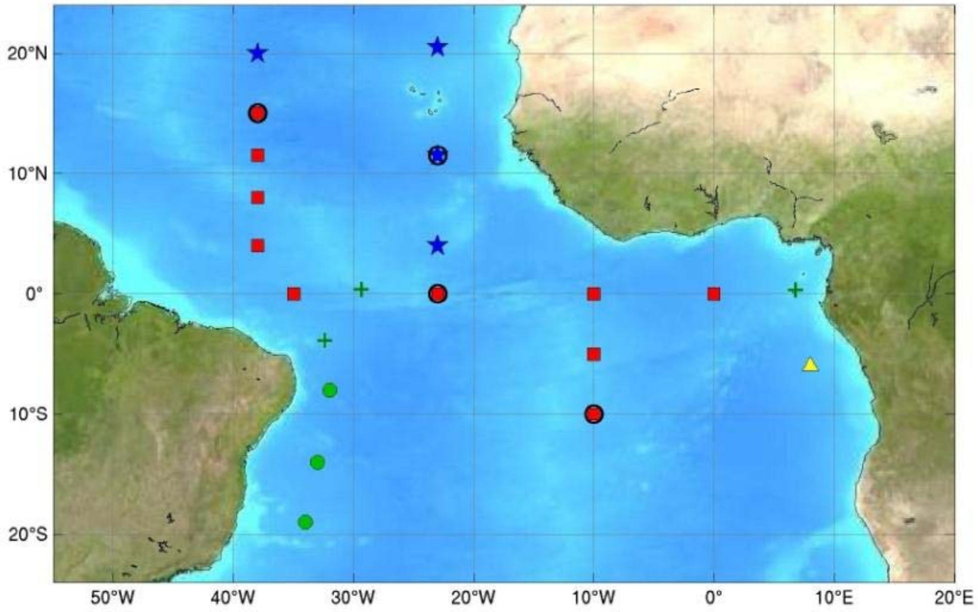

Figure 3: Map of the South Atlantic Ocean showing the PIRATA backbone of ATLAS buoys (red squares), Northeast Extension (blue stars), Southwest Extension (green circles), Southeast Extension pilot project (yellow triangle), and island-based observation sites (green crosses). Buoys with barometers and the ability to estimate net heat flux are indicated with black circles. Also current meter moorings are maintained at 23W-Equator (PIRATA-international) and 10W-Equator (PIRATA-France, initially installed in relation with the EGEE/AMMA and TACE/CLIVAR programs). Source: http://www.brest.ird.fr/pirata/pirata.php. Accessed on: 20 March 2017

3.0 LESSONS LEARNED IN INTEGRATING FEDERAL, STATE AND ACADEMIC SCIENCE ALONG THE PATH TO U.S. IOOS

The DWH oil spill began on April 20, 2010, in the Gulf of Mexico on the BP-operated Macondo Prospect. Following the explosion and sinking of the Deepwater Horizon oil rig, a sea-floor oil gusher flowed for 87 days, until it was capped on July 15, 2010. Throughout the Federal government, NOAA and other agencies stepped up to the response, as did State agencies from Texas to Florida under the U.S. National Response Framework. The efforts of these multiple agencies were coordinated by the Incident Command System (ICS) designed to quickly stand up full operational support. During an oil spill, including DWH, NOAA's Office of Response and Restoration (OR&R) works with the NOAA National Weather Service to provide incident weather forecasts and trajectory modeling for U.S. Coast Guard response efforts (MacFayden *et al*, 2011, Beegle-Krause *et al*, 2011) while NOAA's National Environmental Satellite, Data and Information Service (NESDIS) provides satellite monitoring of the oil (Streett, 2011). The Environmental Protection Agency (EPA) officially approves any chemical dispersant application for oil spills (Venosa *et al* 2014).

Data sharing and integration is essential for successful disaster response. By 1997, Unidata had developed data formats to allow easy sharing of complex environmental data, particularly large numerical circulation model output, and began distributing netCDF (network Common Data Format) libraries. Since the late 1970s, the concepts leading to U.S. IOOS development were being formulated while collaborations between Federal scientists and University or private data providers increased. The BP Thunderhorse riser break in 2003 and the responses to Hurricanes Katrina and Rita in

2005 pushed NOAA OR&R to expand from in-house tools for quickly developing regional coastal circulation models to making individual arrangements with universities to access their ocean circulation models in the event of an oil spill. These efforts eventually led to the NOAA OR&R GOODS system.

3.1 Importance of Ocean Observations: An Account of U.S. IOOS During the Deepwater Horizon

This section describes the unique role observations played and how a national framework like U.S. IOOS supported the response to the DWH spill. Due to the nature of the DWH spill, continuous from the ocean floor and long duration, the United States had to adjust many of its response mechanisms. Initially it was unclear what observing assets were needed and how best to employ them. It was, however, clear that the Federal government was not able to respond alone, and would need to rely on non-federal input.

3.1.1 Need for Observations of All Types

The Incident Command Center orchestrated the daily response activity, and the typical questions that had required answers were:

- Where is the oil? And where will it be over the next three days?
- Is my seafood safe?
- What are the impacts on sea turtles and marine mammals?
- How would a hurricane impact the oil spill?
- Is the air safe?

Availability and use of ocean observing assets have changed dramatically from the IXTOC I exploratory well blowout in the Gulf of Mexico in 1979 and the TV Exxon Valdez oil spill in Prince William Sound in 1989. A wide spectrum of advanced or completely new observing assets were leveraged during the response, for example improved satellite imaging, high frequency (HF) radar and autonomous underwater vehicles (AUVs). Satellites and aircrafts were used to support weather forecasting and monitoring ocean features to not only predict where the oil would go but the effects on water conditions, spot and track oil, platforms for launching additional observing assets and measuring the presence of chemicals in the air. The Synthetic Aperture Radar (SAR) images provide excellent information about oil location and extent on the ocean's surface. NOAA developed automated methods of mapping oil spills using SAR imagery.

NOAA Ships and partner vessels from University of Miami's Cooperative Institute for Marine and Atmospheric Studies, Louisiana Universities Marine Consortium and Florida Institute of Oceanography performed an array of missions including:

- characterizing the water column in the vicinity of the wellhead and looked at impacts to protected resources.
- Took water sample and used acoustic sensors to detect submerged oil
- Conducted seafood safety sampling surveys; pelagic long-line surveys to study impacts on fish like yellow fin tuna.
- Conducted shrimp stock assessments to understand impacts of oil and dispersants.
- Bottom sediment sampling to analyze oil content.

3.1.2 IOOS Regional Associations' Support to DWH

The response to DWH showed that the U.S. IOOS business model provided a framework for delivering capacity in a crisis, in an organized and effective fashion. As the lead Federal Agency for U.S. IOOS, NOAA coordinates the 17 Federal Agencies and 11 Regional Associations (RA). The U.S. IOOS Office works with the 11 IOOS RAs that have developed a national network of Regional Coastal Ocean Observing Systems. During DWH, IOOS drew upon many of the RAs to support the response. As the Director of the US IOOS Program and a retired Captain of the United States Navy, Ms. Willis was familiar with the ICS and knew that to be effective the U.S. IOOS RAs' capabilities would need to be formally integrated and this process was started well before this incident. Dr. Jack Harlan (U.S. IOOS Office) who had a long relationship with NOAA's OR&R, served as a liaison between RAs and the formal command center. He sorted through the numerous offers of assistance and match those with the needs of the responders. In addition, Dr. Sam Walker of the U.S. IOOS Office was deployed to the ICS to orchestrate the integration on-scene.

The U.S. IOOS RA response for DWH oil spill included:

- Introduction of profiling gliders to assess the extent of the oil: Seven of the nine gliders used were provided from five US IOOS RAs and industry partnership;
- Surface currents from HF radars were used by NOAA to validate oil trajectory tracks.
- Six three-dimensional, high-resolution ocean circulation models for the Gulf of Mexico (see MacFadyen *et al,* 2011);
- Support to the ICS, including personnel
- Stand up of the sub-surface monitoring unit.

- Independent data portal that compiled glider information from Federal and non-Federal assets into a single location and provided independent analysis of the data that the ICS could readily access.

3.1.3 The HF Radar and Its Support to DWH

While the integration of these assets was seamless during DWH, it was years in the planning and as a result of having IOOS in place every day that can surge during a crisis. A good illustration of this is the use of the HF Radar data. The adage is “you can’t be exchanging business cards (or make friends) at a crisis”. This was very true in DWH, and is a key reason for drills and exercises, particularly regularly occurring U.S. Coast Guard SONS exercises. During the Safe Seas 2006 table-top exercise in the San Francisco Bay area, the first trial of using HF radar data was not considered useful by many (see Beegle-Krause et al, 2006). This changed a year later in 2007 when the container ship M/V Cosco Busan struck the San Francisco Bay Bridge tearing a 100 ft long gash in its hull over the full tanks. The U.S. IOOS HF radar systems operational in the Bay helped responders to get an accurate picture of oil movement when heavy fog prevented aerial observers from accurate oil estimates.

This experience strengthened the trust by NOAA OR&R in IOOS. The two offices worked through the challenges and details that resulted in real-time ingestion of the HF radar data into the trajectory models and as a validation tool. Therefore, when DWH occurred, the HF radars that were operated by IOOS’ Gulf of Mexico Coastal Ocean Observing System and the Southeast Coastal Ocean Observing Regional Association were immediately available for NOAA OR&R and used in the GNOME trajectory model (see the papers within Lui *et al* 2011).

There was also need to install temporary HF radar systems in Louisiana to provide surface current information near the mouth of the Mississippi. While this capability existed, it was not funded. This was achieved by having a network in place that included industry (CODAR Ocean Sensors), technicians and a national data infrastructure. An approach worth considering in the Gulf of Guinea.

3.1.4 Responding to Subsurface Oil During the DWH

Because of the nature of the spill, the response had to determine the extent of the subsurface plume and its trajectory as well as how to respond. The ICS set up the Joint Analysis Group to address this issue (Joint Analysis Group, 2012). Unmanned vehicles made their debut in this effort. The U.S. IOOS RAs had been using gliders and the operators were eager to assist with the crisis. The IOOS structure allowed a coordinated effort to bring a number of gliders from outside the region into the Gulf of Mexico. The gliders provided the ICS a picture of the three-dimensional water column. In addition, the gliders were outfitted with flourometers to detect the presence (or absence) of oil. This was another example where IOOS's close working relationship was employed. The use of fluorometers on gliders was new and required glider vendors, sensor vendors and the IOOS RAs to quickly coordinate deploying the gliders with the sensors and then working together to understand the results of these data. This had to be done in real-time to support the response, again made possible by having a U.S. IOOS network in place. Additional unmanned vehicles, such as the Monterey Bay Aquarium Research Institute's Gulper and Woods Hole Oceanographic Institution's robotic vehicle, which were able to dive deep and provided eyes on the blown well head were instrumental in determining the amount of oil that was released.

The U.S. IOOS Office assisted in the coordination of these assets and the U.S. IOOS data management capabilities ensured the information was available to the responders as well as the public.

Success was measured by the feedback NOAA received from the DWH Oil Spill Incident Command Center. This included statements such as: “Reduced the burden” “Informed the response.” and, important from an emergency management perspective, “Did not get in the way.” Interference by well-meaning institutions earlier in the spill had complicated the official response. U.S. IOOS provided a system for integrating multiple efforts. ERMA provided a platform to host and display all the data layers.

4.0 SUMMARY AND CONCLUSION

Two critical lessons become evident from the U.S. IOOS application and its role in the Deepwater Horizon oil spill. First, the IOOS framework and years of collaborative partnership amongst the key U.S. IOOS stakeholders played a major role in the successes recorded during the DWH oil spill response. Integration efforts began slowly through national oil spill drills and the IOOS structure and data management protocols provided a framework for collaboration. Second, the partnership was not all seamless but required coordination and communication to be successful that was enabled by IOOS.

The Gulf of Guinea nations would benefit from system similar to IOOS. With assets illustrated in Figures 2 and 3, the region, through the proposed ROOFS-Africa working with agencies like NOSDRA, can begin to evolve an IOOS similar to those deployed during the US DWH oil spill (see Section 3). Using NOSDRA as a pivot, the integration of the ocean circulation forecasts from organisations like the Nigeria Institute of Oceanography and Marine Research (NIOMR) and wind forecasts from the Nigerian Meteorological Office (NiMet) is a typical example of how individual countries in the Gulf of Guinea can contribute towards a regional Integrated OOS. This would provide support for any SONS event in the region. By connecting different country groups through data exchange coordinated by UNEP's RCC, the region will be well set up to predict and further understand the fate and effects of oil spills in the WACAF region. The importance of industry collaboration in this cannot be overemphasised, as well as the support for foundational science and detection of biophysical changes in the upper mixed layer, the upper ocean above the main thermocline and the deep ocean water in the Gulf of Guinea area where a number of countries have on-going Exploration & Production activities. U.S. IOOS is one of the GOOS Regional Alliances and, through that relationship, can assist GOOS Africa in working similarly in a regional application within the Gulf of Guinea to provide regional response. For example, this can help connect data to operational oil spill forecasting for more timely and detailed predictions of the extent and arrival time of oil spill from offshore Gulf of Guinea area into delicate coastal mangroves.

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