Coordination of GIS and Remote Sensing Response to the Deepwater Horizon Oil Spill in Louisiana

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Abstract: *On April 20, 2010, the Deepwater Horizon oil rig leased to British Petroleum (BP) exploded in the Gulf of Mexico releasing 5000 barrels of oil daily. The BP Deepwater Horizon Incident Command Center in Houma, LA, was put into place to help coordinate response efforts. The command center has been a focal point of collaboration on mitigation efforts as well as GIS mapping efforts. The U.S. Coast Guard established its Incident Command Center initially in Robert, LA and then moved to downtown New Orleans. This research reports on interviews with respondents federal, state, academic, and commercial respondents to the disaster conducted in order to identify:1) what kinds of GIS and remote sensing data were being used to assist in the emergency response, and 2) how effectively GIS data had been exchanged amongst groups working on the response effort. Results indicate a unique response effort led a commercial enterprise with support from federal agencies. These initiatives involved many state and federal agencies as well as use of cutting edge GIS and remote sensing technologies. These results may provide insight into how GIS response may be best coordinated for effective data sharing amongst federal, state, and local responders to oil spills.*

Introduction

On April 20, 2010, the Deepwater Horizon oil rig leased to British Petroleum (BP) exploded in the Gulf of Mexico releasing an estimated 5000 barrels of oil daily based on National Oceanographic and Atmospheric Administration (NOAA) estimates. Since then a very large oil slick reached the Louisiana shore near the Chandeleur Islands and projected to affect miles of Louisiana coastline as well as potentially the coasts of Mississippi and western Florida. While BP has been engaging in efforts to contain the spill its excessive depth at nearly 5000 feet underwater has made containment difficult. BP has also been engaging in surface methods of containment including the use of booms, chemical oil dispersants, and assistance from local shrimpers in monitoring the plume.

A massive response from federal, state, and local officials followed to monitor the myriad environmental, economic, and social impacts of the spill, which has been compared to 1979's Ixtoc blowout in Mexico's Bay of Campeche as well as the Exxon Valdez spill of 1989. In order to assist in the environmental mitigation efforts, the Deepwater Horizon Incident Command Center in Houma, LA, near New Orleans, was put into place to help coordinate response efforts. The command center was a focal point of collaboration on response as well as GIS mapping efforts. This study reports on interviews held with agencies involved in the response with particular focus on how the use of GIS and remote sensing aided the response. Similarly to previous work (Pine 1993, Pine 1997, Pine 2008), the aim of this study is to provide another insightful case study on how GIS response can be best organized to coordinate effective data sharing amongst federal, state, and local responders. Findings from this research build upon previous studies of how GIS and other technologies may be best coordinated in the context of large scale environmental disasters such as very large oil spills (Pine 2006a, Pine 2006b). In particular, this study compares GIS used in disaster response in relation to previous disaster response in Louisiana (Curtis *et al.* 2006a, Curtis *et al.* 2006b, Mills *et al.* 2008).

Background

At 11:00 PM Central Time on April 20th, 2010, an explosion occurred on the Deepwater Horizon drilling platform located approximately 50 miles southeast of the Mississippi River Delta. NOAA estimated that 700,000 gallons of #2 fuel oil or marine diesel fuel were spilled in the Gulf of Mexico. The semi-submersible drilling platform had a crew of 120 persons aboard with eleven members of the crew perishing in the incident.

The Deepwater Horizon was constructed by Transocean Ltd., a Switzerland based company with 20,000 employees worldwide, and leased to British Petroleum. Transocean Ltd. is the world's largest offshore drilling contractor and the leading provider of drilling management services worldwide with a fleet of 139 mobile offshore drilling units. The company owns or operates a contract drilling fleet of 45 High-Specification Floaters (Ultra-Deepwater, Deepwater and Harsh-Environment semisubmersibles and drill-ships) and other assets utilized in the support of offshore drilling activities worldwide (Transocean 2010).

The National Response Team (NRT), an organization of sixteen federal departments and agencies responsible for coordinating emergency preparedness and response to oil and hazardous substance pollution incidents, was activated in response to this event. A coordinated group of federal partners has been overseeing BP's response to the spill including the United States Coast Guard, Departments of Homeland Security, Commerce, Interior and the Environmental Protection Agency. A Command Center was established for the spill in Robert, Louisiana at a Shell Oil Company Training Center. This command center was moved to downtown New Orleans in June, 2010. An investigation of the incident has been initiated by the U.S. Coast Guard (USCG) and the Mineral Management Service (MMS) who share jurisdiction.

Admiral Thad Allen was appointed as National Incident Commander and charged to work closely with the Coast Guard and the Departments of Homeland Security, Defense, Interior, Commerce as well as the EPA. Admiral Allen continued as the Commandant of the U.S. Coast Guard until May 25, 2010. It should be noted that this is not the first assignment of Admiral Allen to the Gulf of Mexico. In 2005, he was designated the Principal Federal Official for Hurricane Katrina response and recovery operations in Louisiana, Mississippi and Alabama. This assignment was broadened to include the response to Hurricane Rita in 2005. Other federal partners in this response include the U.S. Fish and Wildlife Service, National Park Service, CDC, USGS, OSHA and USDA.

Under the leadership of DHS Secretary Janet Napolitano, the BP Oil Spill was designated on April 29th as a Spill of National Significance. NOAA's Emergency Response Division within the Office of Response and Restoration of the National Ocean Service, has been on the scene of the spill from the start, providing coordinated scientific weather and response services to federal, state and local organizations. NOAA spill specialists advised the U.S. Coast Guard on cleanup options as well as risks of the spill to sensitive marine resources in the Gulf of Mexico.

As of June 2010 nearly 38,000 personnel were engaged in the response to the spill and protecting the shoreline and wildlife. Over 6,580 vessels were participating in support of the response including skimmers, tugs, barges, vessels of opportunity, and recovery vessels. Ninety-eight aircraft were also engaged in the response. Over 2.7 million feet of booms were deployed in the spill and 28 million gallons of oily water was recovered. It is also estimated that 9.9 million billons of oily water have been burned (Deepwater Horizon Response 2010).

Methods

The methods used in this rapid response research included site observations and interviews with GIS personnel and government administrators at the two major response sites. In addition, other government agents involved in the response were interviewed about the effectiveness of using GIS to aid the response. Experts from the State of Louisiana emergency response and environmental agencies were also interviewed about the GIS needs in order to determine how well the GIS and remote sensing teams performed at the Command Centers. Similar to methods used in previous work (Jensen 2008), text analysis was also performed on media coverage of the event with specific focus on GIS analysis, mapping, and data collection needs across the impact area of Louisiana, Mississippi, and Florida.

Two sets of interviews were conducted as part of this examination of how GIS and remote sensing data are being used in the response. Interviews were held at two locations, the Incident Command Center located in downtown New Orleans and the BP Operations Command Center in Houma, LA. The main research questions to be addressed based on interviews at the Command Centers were: 1) what kinds of GIS data were being used to assist in the emergency response of this major environmental disaster, 2) how effectively had GIS data been exchanged amongst groups (federal, state, local, commercial) working on the response effort, and 3) what best practices can be developed for oil spills based on lessons learned from the quick response to this disaster.

This study used the qualitative methods of observations and face-to-face interviews at the study sites in Houma and in New Orleans (Creswell 2009). Since this data relied upon behavioral observation at the study sites as well as interviews, our observations were certainly affected by our presence. As Montello and Sutton (2006) warn, full disclosure of activities and uses of data was unlikely to have been elicited from one visit to the study sites, particularly at the BP Incident Command Center where the investigators were entering into a site with many GIS and emergency response professionals working under high stress conditions. The study methodology was also informed by Yin's (2003) scientific approach to assessing if hypotheses are true for case studies through gathering and analysis of evidence. In this case, the two major hypotheses examined were: 1) GIS and remote sensing data significantly aided in the response and clean-up; and 2) GIS and remote sensing data were shared among the participating agencies effectively to meet the information needs of the response team.

Results from Interviews

1. Access to Remote Sensing Data Partner Agencies

In designating the Deepwater Horizon as a Spill of National Significance, the USGS began receiving daily remote sensing data from international partners who can provide remote sensing data. The activation of the International Charter brought remote sensing data to federal, state and local responders through a common Internet site. Under the International Charter, response agencies can use the data in response operations at no cost. Users of the remote sensing data must comply with a set of requirements such as acknowledging the source of the data in maps or images released by agencies during the response.

International Charter participating agencies that have contributed to the Gulf Coast response include:

Canadian Space Agency (CSA) - Radarsat1, Radarsat2
European Space Agency (ESA) - Envisat, Meris
Japanese Space Agency (JAXA) - ALOS Palsar
Argentina Space Agency (CONAE) - SAC-C
Disaster Monitoring Constellation (DMCii) - DMC
USGS - Landsat
USAF EagleVision - SPOT
French Space Agency (CNES) - SPOT
German Space Agency (DLR) - TerraSARX

In addition, response agencies also received remote sensing data from the US National Geospatial-Intelligence Agency (NGA) including IKONOS, Quickbird, Worldview, GeoEye, and CosmosSkymed imagery.

Two Internet sites have been established to distribute remote sensing data including a secure site to the above data that is limited to public agencies engaged directly in support of the oil spill response. The site is arranged by data providers and by date of data acquisition. A second Internet site was established for other users who wanted access to information about the spill. This site is a public one and arranged by data providers such as NASA, NOAA, US Army Corp of Engineers, and USGS. The public site includes remote sensing data such as AVIRIS, LANDSAT, MODIS, MERIS, and NESDIS data. Agencies such as NOAA, NASA, and USACE have been called on to fly photo missions along the coast in support of the spill response. These images are compressed files and listed by date of distribution. The directories also include some images that have been processed by collaborators and image metadata is also provided within the folders. Figure 1 below is a true color image of April 29, 2010 from the Terra-1 MODIS satellite provided by the Louisiana State University Earth Scan Lab.

Fig. 1. Terra-1 MODIS true color image (April 29th, 2010) provided by the LSU Earth Scan Lab.

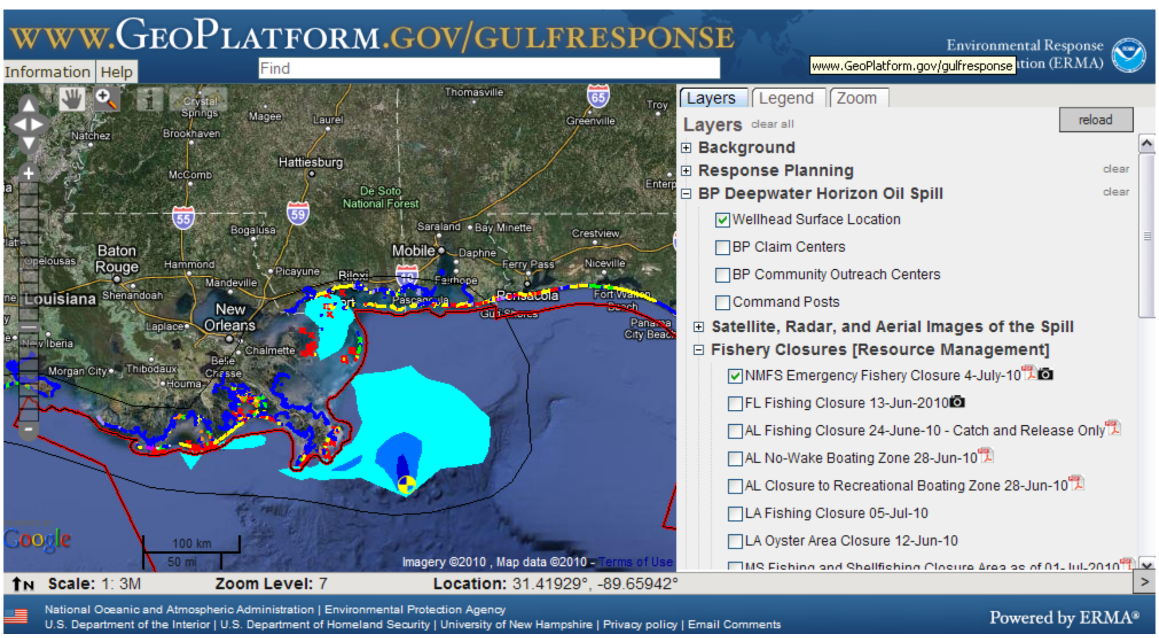

Fig. 2. Gulf Response GeoPlatform through NOAA's ERMA (2010).

2. *Gulf Response GeoPlatform*

NOAA has developed the Internet mapping resource Environmental Response Management Application (ERMA). This Google-based Internet mapping program was developed by staff from NOAA's Emergency Response Division within the Office of Response and Restoration and the University of New Hampshire's Coastal Response Research Center. The Internet mapping program allows public access to many of the layers being used by public, private and non-profit organizations engaged in the oil spill response and restoration. Over 300 data layers are available to the public through the ERMA site (see Figure 2). Many of the layers were generated by agencies involved in the response including fisheries closures, shoreline cleanup and assessment team (SCAT) results, navigation caution areas for mariners, data buoys, tides, water levels wildlife areas including refuges, management areas, marine protected areas or sanctuaries, shellfish habitats, restoration projects. In addition, federal and state agencies have provided NOAA with critical information for the Gulf of Mexico including navigational fairways and nautical charts, bathymetry contours, high resolution historical coastal imagery and LIDAR data.

In addition to the layers developed during the response and provided by public agencies, users may open MODIS satellite images for specific dates following the spill, shoreline over flight imagery, buoy information, current wind, wave, NEXRAD radar, HF radar and NWS warnings. Response information was also provided on this site including oil spill trajectories (near and off shore), satellite interpretations for potential oil foot print, fisheries closures, predicted environmental conditions (wind, wave and precipitation), navigational caution areas for mariners, and Environmental Sensitivity Index data for Texas, Louisiana, Mississippi, Alabama, and Florida. Government agency field studies including field photos and impacts on wildlife are also included.

The ERMA mapping utility which comes in both a public access and responder version provides responders with critical information that can be accessed and used to support many different response needs. Since map layers can be edited and controlled by either a response command center or a NOAA program office, the information can be kept up to date as often as new information becomes available.

For response agencies, a private secure web mapping resource allows many users access to an extensive library of remote sensing data from U.S. and international providers as noted above and provided through the International Charter. Although an extensive library of data layers has been made available over the Internet by USGS in a disaster, this is the first time that users of the data can see products as they become available. For example, responders might review RADARSAT images of the spill over the duration of the incident, focus on a specific area of the spill and then download the data to their computer. Users thus have the capacity to view the many remote sensing data layers using the Google Mapping utility for responders and either directly download the data or go to the web based data library maintained for the oil spill by USGS to obtain appropriate files.

The Internet based mapping utility and geospatial library is a significant development over past attempts to obtain, store and distribute data. As part of the Hurricane Katrina response, FEMA supported the development of the Katrina and Rita Geospatial Data Clearinghouse (Curtis *et al.* 2006; Mills *et al.* 2008). The site was developed at Louisiana State University in support of the hurricane response in the Gulf of Mexico. ERMA has successfully addressed data access and distribution issues that first surfaced in the response to Hurricanes Katrina and Rita in 2005. ERMA provides access to critical geospatial data in a common format, along with metadata on the information in the site and in a timely basis.

3. Use of GIS and Remote Sensing Data for Responders

The Incident Command Center in New Orleans is directed by the U.S. Coast Guard and provides strategic direction for federal agencies engaged in the oil spill response. NOAA's (2010) public outreach efforts through the web are illustrated in Figure 3. Contact was made with staff with NOAA's Emergency Response Division within the Office of Response and Restoration. The interview was conducted with Ms. Kari Sheets who was deployed by the National Weather Service in Maryland to provide GIS support to the Command Center. During the two-hour interview, Ms. Sheets provided many valuable observations on the use of GIS and remote sensing data in the federal agency support of the response.

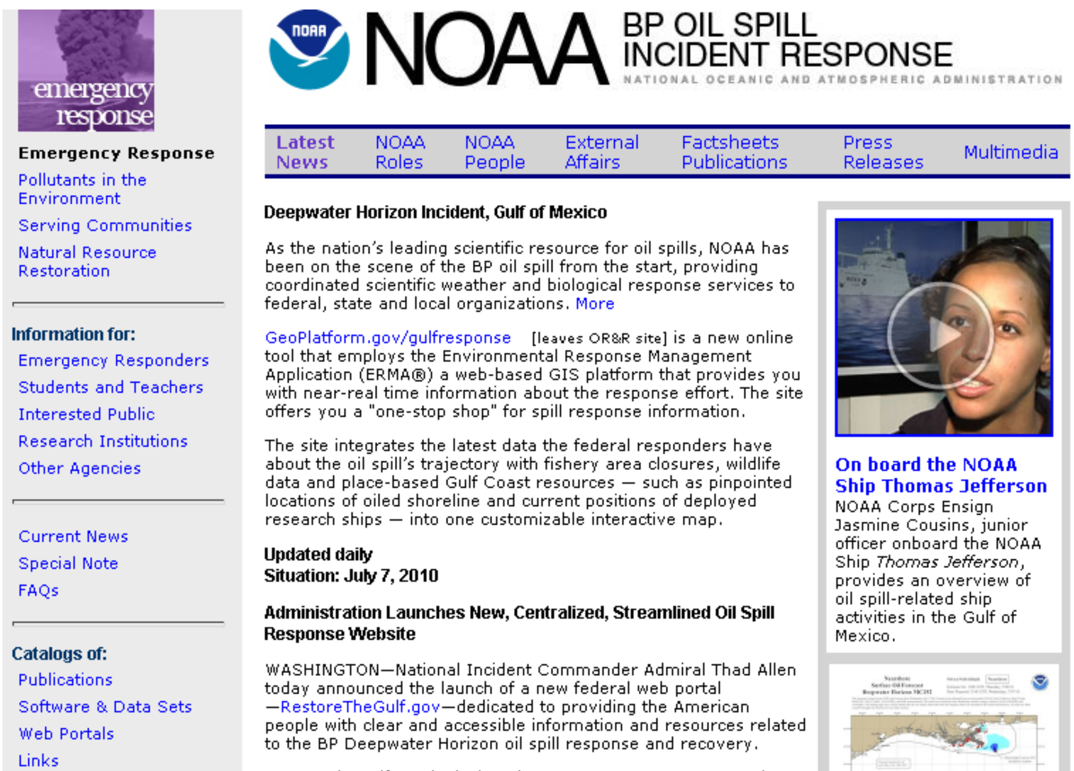

Fig. 3. NOAA's BP Oil Spill Incident Response Site (2010).

Discussion with personnel at NOAAs Emergency Response Division indicates many federal agencies and international partners supported the response from their regular duty stations throughout the U.S. Staff could access and use high-resolution as well as infrared MODIS images of the Gulf of Mexico and identify current impacted areas and the projected flow of the oil along the Gulf of Mexico. Images of the Gulf of Mexico on June 19, 2010 were some of the most useful scenes since there was minimal cloud coverage in the Gulf. For example, Figure 4 below is based on a 50 meter resolution image taken June 15, 2010 and provided by the Canadian Space Agency (CSTARS). The display of the extent of the spill's plume was provided by NOAA's National Environmental Satellite, Data and Information Service (NESDIS).

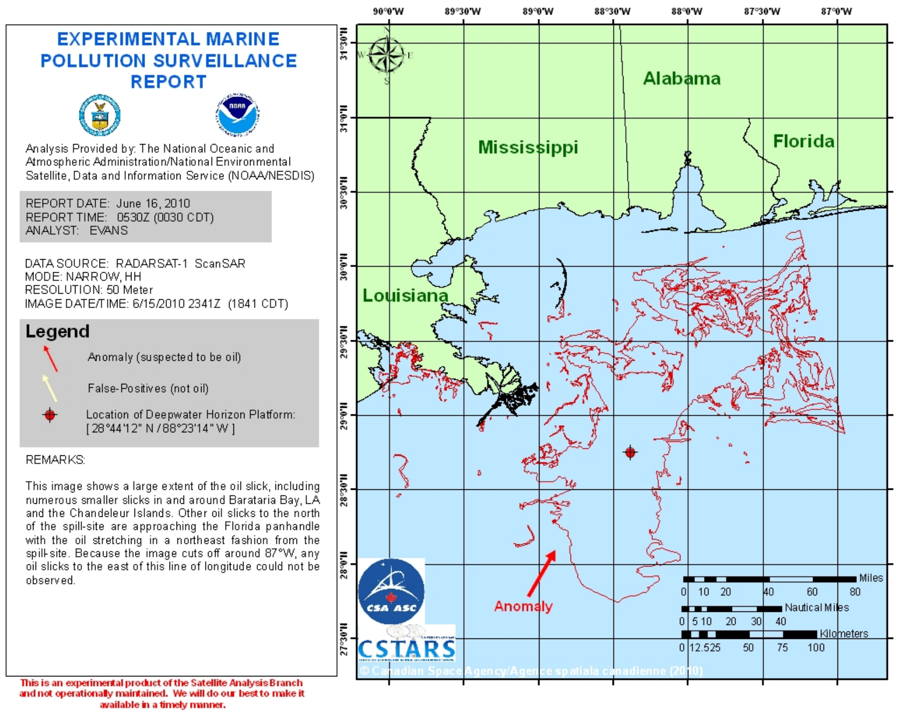

Fig 4. Characterization of the Oil Spill using RADARSAT-1 Scan SAR.

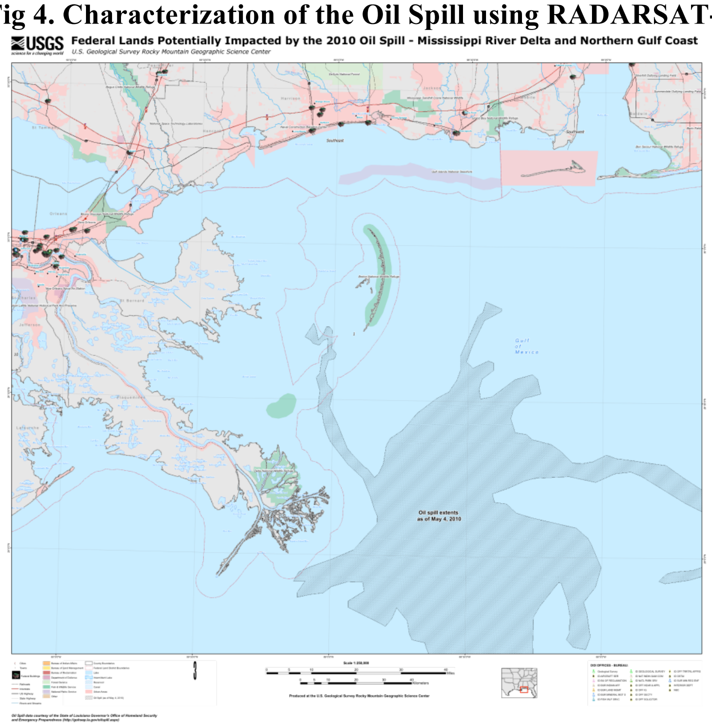

Fig. 5. Federal Lands Potentially Impacted by the 2010 Oil Spill.

Figure 5 illustrates the federal and state interagency collaborations that are part of the oil spill response. Data for the image was prepared by the USGS Rocky Mountain

Geographic Science Center with data provided by the State of Louisiana Governor's Office of Homeland Security and Emergency Preparedness.

The NGA used remote sensing images such as Figure 1 to estimate boundaries for the extent of the oil spill's plume in the Gulf. When cloud conditions would not permit assessment of oil conditions along the Gulf, satellite radar data was useful in clarifying impacted areas with significant oil accumulation. Radarsat had been noted as a valuable resource for identifying oil spills in the Gulf of Mexico following Hurricane Katrina in 2005 (Pine 2006). However, remote sensing is often not effective in areas with a low density of oil accumulation.

In an interview with GIS staff of the Command Center in New Orleans, the need for a broad network of remote sensing university labs to assist in image analysis and classification was also acknowledged. Federal agency GIS staff could coordinate the development of key data for the Command Center through conference calls or video-conferences and then work on the requested data from their normal offices. Display of the data developed for the Command Center could then be made available by way of ERMA or the secure Internet mapping program. Ms. Sheets noted that the development of ERMA had grown out of both the emergency response to the Haiti earthquake and an interagency response drill in March of 2010.

In interviews conducted with faculty at Louisiana State University on June 21, 2010, faculty members welcomed the opportunity to assist NOAA, USGS and the Coast Guard in the preparation of images for responders. Many labs such as the Earth Scan Lab at LSU receive MODIS, Landsat and other remote sensing images on an ongoing basis and have the staff expertise to review image data sets and identify images that could be useful to responders. The image library established by USGS for the oil spill response categorizes data by the provider and date of acquisition. Since atmospheric conditions can significantly influence the use of the images for responders, there is a great need to review all the data. University remote sensing labs could assist the USGS in preparing an annotated bibliography which identified which data sets and files would have usable images in the response.

The response to ERMA by senior response agency personnel was extremely positive for both the secure site used by the responders and the public site. Briefings included the use of ERMA in displaying data layers on current conditions relating to the spill. The display of different data layers using ERMA was provided in a timely manner and supported both policy and operational decisions. Emergency responders have for many years asked for timely information to deal with problems as they arise; the ERMA applications appear to be a major positive step in providing timely information for decision making.

BP established an operations center in Houma, LA to direct response and restoration operations along the Gulf of Mexico. Fortunately, BP had a very large training facility to support human resource management needs for their Gulf operations. As the BP operations in the Gulf expanded, they were able to use the offices, classrooms and other support services for the operations center. BP made a concentrated effort to supply information to the media and public through media coordinators and call centers at the site and via the Internet (see Figure 6).

Fig. 6. The Official Deepwater Horizon Response (2010) website now replaced by the Restore the Gulf website (2010).

Our orientation to the BP Operations Center and their use of GIS was provided by David Gisclair of the Louisiana Governor's Oil Spill Coordinator's Office (LOSCO). LOSCO has been a leader in Louisiana in the development of many useful documents and data layers prepared to support oil spill response and restoration efforts (LOSCO 2006). Partnerships between the Oil Spill's Office, FEMA and USGS had resulted in many data sets such as high-resolution images throughout the state for 2004 and 2008 as well as the availability of LIDAR for the entire state. In addition, LOSCO also prepared and distributed to public, private and non-profit agencies an extensive library of data layers relating to possible oil spills. Access to these data sources can be found at the ATLAS (2006) and LOSCO (2010) websites.

Federal and state agency field staff operated from this Houma, LA site. It should be noted that data obtained by USGS from International Charter members was limited in its use and only available to public sector responders directly engaged in oil spill response activities. As a result, BP mapping staff did not have the extensive image library available for their use in the Houma Operations Center. BP staff did have access to the secure Internet mapping service at the Coast Guard – NOAA Incident Command Center in New Orleans. As a result, BP determined that they would monitor the spill in the Gulf by acquiring daily images of impacted areas. Figure 7 provides an illustration of the quality of the images obtained by daily over-flights and their potential use to direct response operations. Images obtained by BP were used exclusively within the BP GIS system and not assessable by NOAA staff in New Orleans or at other locations.

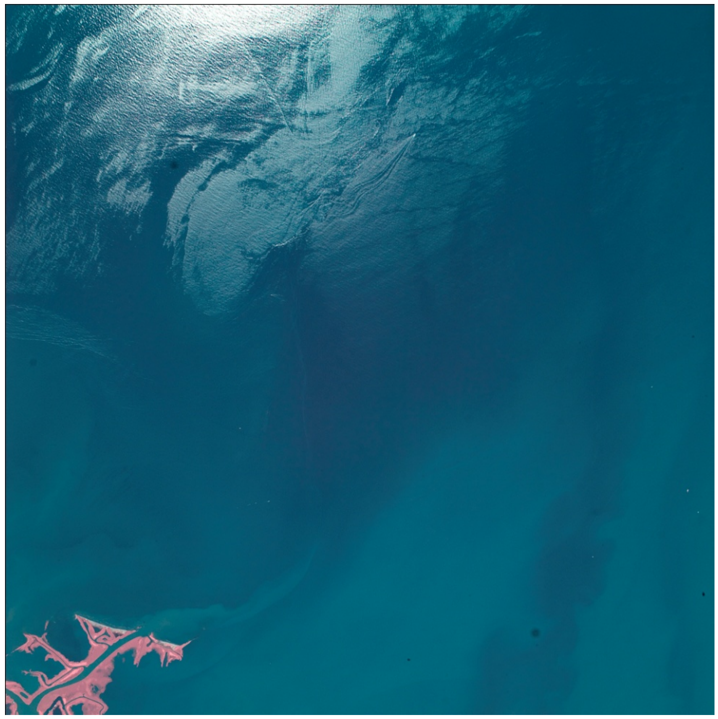

Fig. 7. High Resolution Photo of the Gulf Oil Spill, June 16, 2010.

In preparation of the BP GIS, extensive data sets from LOSCO were made available. These data sets can be obtained from LOSCO (2010) and provide an extensive base line for the potential impacts of the spill in coastal areas and included both high resolution images, LIDAR, and location information from boat launches to response resources. These data sets formed the foundation of BP's web GIS application created using ESRI's ArcServer product. This web mapping application also contained georeferenced aerial photographs of the plume's extent as well as the position and conditions of the booms used. In addition, data was collected in the field using mobile devices and uploaded directly to the spatial database. It was noted by several GIS professionals that ESRI had donated technology and professional expertise in rapidly developing a GIS for use in the response (ESRI 2010a). GIS consultants had formed the core of the spatial database development team and ran work crews working very long hours to create the GIS for the Gulf Region within a time span of a few weeks. ESRI has also been hosting a web mapping application to serve information to the public through their ArcServer application found online (ESRI 2010b). The State of Louisiana Governors Office of Homeland Security and Emergency Preparedness also had an effective means of disseminating information to the public using KML files of the plume extent and trajectory found on its website (GOHSEP 2010).

LOSCO prepared an Environmental Baseline Inventory (EBI) resource which included Louisiana's oil spill cleanup plans, response procedures, and damage assessments that all depend on one thing – reliable data. However, just collecting information isn't enough as the data must be arranged in easy to use formats that dovetail with users' needs. LOSCO developed a database that meets all of these criteria, and in the process, they are breaking new ground in mapping and information collection techniques. The EBI includes: 1) an inventory program, which overlays detailed information on a map of the State of Louisiana; 2) a sampling and analysis program, which is determining baseline soil conditions throughout coastal Louisiana; and 3) a mapping program, which makes the entire database available to users on CD-ROM and/or the Internet.

According to LOSCO 2010, the GIS includes data on locations of:

- transportation systems, including roads, railroad lines, and navigated waterways
- protected areas, such as wildlife refuges and bird sanctuaries
- sensitive environments, such as fish hatcheries, oyster leases, and bird colonies
- potential oil spill locations, such as oil wells, crude oil tanks, shipping lanes, oil platforms, and pipelines
- ocean currents
- past hurricane tracks
- monitoring points for the sampling and analysis program
- remedial action facilities, such as dispersant areas, in situ burn zones, in situ exclusion zones, response equipment locations, and oil reclamation and disposal facilities
- past spills over 10,000 gallons as well as those under 10,000 gallons

Summary of Findings

Despite the challenges presented to responders by the length of time required to cap the leak, GIS and remote sensing technology has been a great asset to both policy makers and those involved in response operations. The Internet Mapping Program ERMA developed by NOAA's Emergency Response Division has proven to be a valuable resource throughout the response. NOAA should be commended for this effective contribution to the response.

Both the secure and public Internet mapping resources provided by NOAA are a great improvement over previous geospatial libraries and data clearinghouses in the use of technology for viewing and using the vast GIS data sets. Users of the Google mapping utility are able to select from many data layers and display data in a useful format. The program has been found to be easy to use by both policy makers and operations personnel. It is likely that similar Internet mapping technologies will be used in future disaster response.

Use of common data sets by the public and private sectors was found to be limited. Much of the remote sensing data available to responders has significant limitations imposed by the data provider. However, some providers simply require the user give credit to the provider in images prepared in a GIS. Other data sets are limited to public sector responders and may not be accessed by private parties engaged in the response. The private sector may obtain the images, however, at a cost. Public agencies and BP contractors engaged in data collection in the Gulf Coast are using the best available GPS technology to record not only site locations, but environmental attribute characteristics. It is unclear as to the degree of data sharing by public and private parties engaged in the assessment process, but parties are at least discussing the value of data sharing.

The volume of GIS data from many sources is extensive and presents challenges to the public and private sectors for cataloging and distributing the data. Following Hurricane Katrina in 2005, public agencies identified many problems associated with using GIS and remote sensing data in the response. Issues such as common formats, documentation of data sets, and access issues were examined and strategies to address them implemented. Data distribution of GIS and remote sensing data in the oil spill response certainly reflects the productive efforts of many organizations in addressing these issues.

Support from multiple federal agencies has been extensive. For example, the USGS along with the FWS have provided baseline data for the Gulf of Mexico in anticipation of understanding the potential impacts of the spill in the coastal environment. EPA air and coastal wetlands water monitoring has been extensive. If wetland environments are heavily impacted by the spill, these agencies will be able to work with NOAA and the Coast Guard on response and restoration strategies.

The oil spill is very different from past natural disasters and the 911 terrorist attacks in 2001. Having the Coast Guard as the lead federal agency is not as unusual as operating without a federal disaster declaration. The role of BP in developing and implementing a response strategy is so very different from past disasters where agencies operate under a federal disaster declaration. Federal agencies and assets have been called in as part of the response, but state and especially university resources are not engaged. State governments and their universities have been reluctant to engage in the spill response without being tasked by BP and to say the least, BP's attention span or focus was stretched during the response.

Due to the nature of the oil spill and unique role of BP in the cleanup and restoration, local governments appear to be observers rather than key players in the disaster response. Louisiana along with some local government units have initiated efforts to protect the coastline or barrier islands. As a result, both state and local agencies have a need to be included in problem solving, the development of operational strategies, and policy determination. Unfortunately, the structure of the oil spill response did not fully engage these governmental units in the response. Access to current GIS and remote sensing data is critical in supporting state and local entities participating in the response. BP and the federal Incident Command Center may need to encourage further input by state and local jurisdictions. Providing these agencies access to information concerning the oil spill will be a critical part of the long-term engagement process.

Conclusions

Results from the evidence gathered by this study indicate that the answers to the two main research questions are: 1) GIS and remote sensing data played a key role in the monitoring of the spill and to a lesser degree the clean-up, and 2) GIS and remote sensing was effectively shared amongst BP's data specialists and federal and state government agencies to aid in the response. The oil spill response may have been more effective and efficient if BP had a GIS and remote sensing database and team prior to the event as many large oil corporations do. Yet, BP was able to effectively use GIS and remote sensing data to manage the response in an effective way. Now that the immediate need for clean-up has passed, the long-term monitoring of the environmental impacts of the spill will likely now fall to state and federal agencies (Restore the Gulf 2010). The response to this incident has been relatively unique in the sense that a corporation has primarily lead the way in response and clean-up and it remains to be seen how the GIS and imagery collected for response can be effectively harnessed for long-term environmental and socioeconomic monitoring.

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