12-2016

Maritime Advanced Geospatial Intelligence Craft for Oil Spill Response: Selected Resources and Annotations

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Selected Resources and Annotations

prepared for the
Marine Advanced Geospatial Intelligence Craft (MAGIC) Team
December 16, 2016

This document was prepared for the MAGIC consortium

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Abstract — This selection of resources highlights the utility of Unmanned Surface Vehicles (USV) for use in marine spill response. Each entry is followed by a brief summary and evaluation of the source (i.e., the annotation). Most annotations will define the scope of the source, list significant cross references, and identify relevant USV capabilities. There is no attempt to provide actual hypotheses, data, or graphics, especially concerning cited articles published in refereed journals. The purpose of the annotation is to inform the reader of the relevance, accuracy, and quality of the sources cited. Relevance relates to the citation's presentation of capabilities that improve marine spill response operations. Significant interest involves the use of sensors that characterize the environment to support oil spill cleanup operations. The diversity of resources is especially relevant since no two oil spills are the same owing to the variation in oil types, locations, and weather conditions. The development of USVs for oil spill monitoring, cleanup, and science reduces some of the dependence on expensive ship time.

Contents

I. Introduction

This document is a selection of resources highlighting the utility of Unmanned Surface Vehicles (USVs) to investigate the impacts of the oil, dispersed oil, and dispersant on the ecosystems of the Gulf of Mexico and affected Gulf Coastal States in a broad context of improving fundamental understanding of the dynamics of such events, the associated environmental stresses, and the public health implications. The works described in this document highlight innovations related to USVs that improve response, mitigation, detection, characterization, and remediation associated with oil spills and gas releases. Each entry is followed by a brief summary and evaluation of the source, the annotation. Most annotations will define the scope of the source, list significant cross references, and identify the relevant environmental conditions. There is no attempt to provide actual hypotheses, data, or graphics, especially concerning cited articles published in refereed journals. The purpose of the annotation is to inform the reader of the relevance, accuracy, and quality of the sources cited. Relevance relates to the citation's presentation of (a) technology developments, (b) physical distribution, dispersion, and dilution of petroleum and associated contaminants, (c) environmental effects, (d) biochemical evolution, and (e) impacts. This annotated bibliography supports those interested in using USVs to study the effect, and the potential associated impact, of hydrocarbon releases on the environment and public health, as well as to develop improved spill mitigation, oil detection, characterization and remediation technologies.

II. Purpose

There are three main purposes behind this document. First, the annotations serve as a starting point for the development of a Maritime Advanced Geospatial Intelligence Craft (MAGIC) for use by a consortium that includes the public, private, and academic sectors. The annotations help educate program managers on the use of USVs for marine spill response and force scientists and engineers to consider various authoritative methods to consider automation, navigation, and environmental loads in development of a fully integrated and operational MAGIC. Second, the document provides a clear understanding about what scientific advances have been applied to build and operate USVs. After reading and critically analyzing sources, the program managers will be able to determine what issues there are and what methods applied researchers need to employ to characterize the coastal zone. Scientists and engineers involved in trade studies may also benefit from past investigations. Finally, this complete and comprehensive overview of engineering and marine science related to USVs is being published using Scholarworks@UNO in order to benefit other scientists and engineers involved in acquisitions, design, testing, and evaluations. There is an emphasis on marine science in this document. At the time of this writing, no comparable list of resources exists that is relevant to the use of USVs for marine spill response.

III. Peer-Reviewed Articles

1. Asl, Samira Daneshgar, Dmitry S. Dukhovskoy, Mark Bourassa, and Ian R. MacDonald, 2016. Hindcast Modeling of Oil Slick Persistence from Natural Seeps, Remote Sensing of Environment, Vol. 189, pp. 96-107. http://dx.doi.org/10.1016/j.rse.2016.11.003

The authors explain remote sensing techniques to detect hydrocarbon fluxes from natural seeps and anthropogenic releases into the Gulf of Mexico. Trajectories of the oil slicks were investigated using models and observations. Results from the numerical experimentation were assessed using a wind-powered USV, the SailDrone. Important findings included the use of SAR to observe oil slicks in the northern GoM, general short residence times (6.4 hours) of oil slicks, wind speeds > 7 m/s as the dominant factor reducing the residence-time of surface oil, and that oil slicks tend to persist more than 30 hours in low wind and strong current conditions.

2. Leifer, Ira, William J. Lehr, Debra Simecek-Beatty, Eliza Bradley, Roger Clark, Philip Dennison, Yongxiang Hu, Scott Matheson, Cathleen E. Jones, Benjamin Holt, Molly Reif, Dar A. Roberts, Jan Svejkovsky, Gregg Swayze, and Jennifer Wozencraft. 2012. State of the Art Satellite and Airborne Marine Spill Remote Sensing: Application to the BP Deepwater Horizon Oil Spill, *Remote Sensing of Environment*, Vol. 124, pp. 185-209.

This paper reviews the fundamentals of remote sensing from an oil spill cleanup perspective. The authors emphasize the use of airborne and spaceborne passive and active remote sensing data for spill and impact monitoring. While imagery analysis is confounded by weather, oil emulsification, and scene illumination geometry, the authors describe how airborne and satellite imagery analysis was used successfully. Oil slick thickness and oil-to-water emulsion ratios were derived quantitatively for thick (>0.1 mm) slicks from Airborne Visible/Infrared Imaging Spectrometer (AVIRIS) data using a spectral library approach based on the shape and depth of near infrared spectral absorption features. Satellite, visible-spectrum broadband data of surface-slick modulation of sunglint from Moderate Resolution Imaging Spectroradiometer (MODIS) allowed extrapolation to the total slick. The paper also described use of the Uninhabited Aerial Vehicle SAR (UAVSAR) for pattern discrimination related to a combination of oil slick thickness, fractional surface coverage, and emulsification (see https://uavsar.jpl.nasa.gov/). The paper points out that some types of imagery analysis (e.g., hyperspectral imagery analysis) where too slow to be useful. Rapidly produced information was key to response utilization and are a must for oil spill response.

3. Li, Chunyan and Eddie Weeks, 2009. Measurements of a Small Scale Eddy at a Tidal Inlet Using an Unmanned Automated Boat, *Journal of Marine Systems*, Vol. 75, Issues 1-2, pp. 150-162.

This article discusses the application of an unmanned automated boat equipped with an acoustic Doppler current profiler in field surveys at a tidal inlet. The use in the field resulted in the discovery and quantification of a small scale eddy with a diameter of 300 m with strong upwelling and downwelling zones.

4. Shih, Wei-Chuan and A. Ballard Andrews, 2008. Infrared Contrast of Crude-Oil-Covered Water Surfaces, *Optics Letters*, Vol. 33, No. 24, pp. 3019-3021. https://doi.org/10.1364/OL.33.003019

Crude oil or diesel spills may form well-defined films, but detection by visible light is challenging owing to poor contrast and wave action. Numerous researchers have experimented with detection of oil spills by using alternative wavebands. Long-wave infrared imaging provides advantages for oil spill detection in the coastal ocean since it is (a) less variable than visible light,

(b) contrast is improved (oil and diesel surface films are darker than water in the long-wave IR band and lighter than water in the mid-wave IR band), and most importantly (c) the thermal infrared radiation is emitted by the water surface itself rather than being reflected. This paper describes some of these advantages in detail for long-wave infrared imaging by examining contrasts between thin and thick oil slicks. A model was developed to characterize crude-oil-covered water surfaces, where thinner oil slicks have more negative contrast than thick films. This finding indicates that thin oil slicks would be easier to detect in the long-wave infrared bands than thicker films.

5. Guerrero-González, Antonio, Francisco García-Córdova, Francisco J. Ortiz, Diego Alonso, and Javier Gilabert. 2016. A Multirobot Platform Based on Autonomous Surface and Underwater Vehicles with Bio-Inspired Neurocontrollers for Long-Term Oil Spills Monitoring. *Autonomous Robots*, Vol. 40, Issue 7, pp. 1321-1342.

This article describes robotic systems that are capable of improving current oil spill cleanup procedures. Experiments with an Autonomous Underwater Vehicle, an Unmanned Surface Vehicle, and the entire BUSCAMOS-Oil monitoring system are described. Buscamos is Spanish for "we look for." The innovative system provides a long-term monitoring capability that includes search and identification and dissemination of information on coverage, direction and speed of the oil spill.

6. Vasilijević, Antonio, Dula Nad, Nikola Stilinović, Nikola Mišković, and Zoran Vukić, 2016. Application of an ASV for Coastal Underwater Archaeology, *Journal of Maritime & Transportation Sciences*, Vol. Special Issue 1, No. 1, pp 179-186.

The Unmanned Surface Vehicle *PlaDyPos* can be deployed with a variety of payloads for seafloor imaging and remote-sensing in shallow waters (< 40m deep). High-resolution imaging and remote-sensing software were used to produce photomosaics and micro-bathymetry maps of the seafloor, as well as performing precise geo-referencing for an archaeological site. Data are archived, manipulated, and displayed using a Geographic Information System. *PlaDyPos* was developed at the University of Zagreb.This lightweight USV is easily deployed and recovered. *PlaDyPos* uses a Robot Operating System (ROS) for control, communication, telemetry and acoustic and optical data logging. ROS is a collection of tools, libraries, and conventions that aim to simplify the task of creating robot behavior across a wide variety of robotic platforms. Payloads include the ARIS EXPLORER 3000 imaging sonar, NavQuest 600 Doppler Velocity Log, and Bosch FLEXIDOME IP starlight 7000 Vandal Resistant camera for visual imaging. (For additional information on PlaDyPos see https://labust.fer.hr/zari/labust/equipment/pladypos.)

7. Weeks, Eddie, Chunyan Li, Harry Roberts, Richard F. Shaw, Nan Walker, 2011. A Comparison of an Unmanned Survey Vessel to Manned Vessels for Nearshore Tidal Current and Transport Measurements. *Marine Technology Society Journal*, Vol. 45, No. 5, pp. 71-77.

In this article, an experiment was conducted and discussion was given to compare the performance of manned boat and Unmanned Surface Vehicle (USV) in coastal ocean surveys. Instrumentation included an acoustic Doppler current profiler, echo sounder, a side-scan sonar, and a chirp sonar. The USV was able to resolve tidal and subtidal current velocity profiles by repeating a planned route continuously over at least a tidal cycle. The USV demonstrated endurance, energy efficiency, ease of operation, and capability of coverage of shallow areas close to shore.

8. White, Helen K., Robyn N. Conmy, Ian R. MacDonald, and Christopher M. Reddy. 2016. Methods of Oil Detection in Response to the Deepwater Horizon Oil Spill, *Oceanography*. Vol. 29, No. 3, pp 76-87. http://tos.org/oceanography/assets/docs/29-3_white.pdf

This articles describes challenges in detecting oil and its subsequent dilution owing to physical, chemical, and biological processes. Oil detection technologies were described and recommendations were made that included (a) greater collection of surface samples for chemical and physical analyses, (b) better characterization of surface oil samples so that the interpretation of satellite data can be improved, (c) improved spatial, temporal, and spectral resolution for satellites, and (d) longer sampling and duration of analysis for unmanned vehicles, and (e) better availability and correct outfitting of ships with hydrographic equipment composed of real-time, two-way cabled CTD rosettes capable of full ocean depth sampling with, at a minimum, dissolved oxygen sensors, hydrocarbon (not pigment) fluorometers, and transmissometers, as well as particle size analyzers. Research results and new capabilities need to be transitions to oil spill responders.

9. Zhang, Yanwu, Michael A. Godin, James G. Bellingham, 2012. Using an Autonomous Underwater Vehicle to Track a Coastal Upwelling Front, *IEEE Journal of Oceanic Engineering*, Vol. 37, No. 3, pp. 338-347. DOI: 10.1109/JOE.2012.2197272

This article describes the use of a large Autonomous Underwater Vehicles outfitted with antennas for Iridium and Argos satellites, GPS, and line-of-sight radio-frequency communications to find and track ocean features such as fronts where there are different physical, chemical, and biological characteristics. The paper describes a couple of algorithms that can be used to autonomously detect and track an upwelling front (e.g., based on the horizontal gradient of the vertical temperature difference between shallow and deep depths or by recognize that it has departed from a stratified water column and entered an upwelling water column, or vice versa). In this paper the AUV was deployed for up to two days and provided high-resolution pictures of various parameters such as temperature and salinity. The navigation software allows the autonomous underwater vehicle to use real-time information (e.g., on the fly calculation of horizontal variability) to modify its course to ensure sufficient coverage of the frontal region.

IV. Trade Publications, Technical Papers, Conference Proceedings, etc.

10. Arnone, Robert, Brooke Jones, Inia Soto Ramos, Mustafa Cambazoglu, and Stephan Howden, Ocean Weather Laboratory - Identifying Events and Abnormal Bio-optical and

Physical Properties in the Gulf of Mexico. presented at Gulf of Mexico Oil Spill and Ecosystem Science Conference 2017, New Orleans, LA, 6-9 February 2017.

The dynamic biological and physical conditions within the Gulf of Mexico (GoM) have been identified by the Ocean Weather Laboratory as an interaction of the river discharge and the offshore currents. Ocean properties derived from VIIRS satellite ocean color (Chlorophyll and Bio-Optics) and Sea Surface Temperature (SST) products and physical properties from ocean-circulation models (currents, SST and salinity) were used to identify dynamic changing properties. Methods were developed for characterizing the degree of environmental changes in the GoM which are defined using the Dynamic Anomaly of bio-optical and physical environmental properties. Results have identified locations where normal and abnormal bio-optical and physical ocean properties occur to determine ecological and physical hotspots in the GoM. The locations of the environmental anomalies and abnormal events in the GOM can be validated with USV data.

11. Arnone, Robert, Ryan Vandermeulen, Inia Soto Ramos, and Kevin Martin. Applications of VIIRS Ocean Color for Real Time Adaptive Sampling, Poster Presentation at NOAA –STAR / NESDIS JPSS annual Science Meeting, College Park, Maryland, 24-28 August 2015, Available online. URL: http://www.star.nesdis.noaa.gov/star/meeting_2015JPSSAnnual_posters.php, Accessed December 13, 2016.

Methods used at the Ocean weather Laboratory to couple daily satellite and circulation models are defined with new products that can be used for adaptive sampling. This includes defining the uncertainty between HYCOM and NCOM and the satellite products, information which could be collected by Unmanned Surface Vehicles.

12. Arnone, Robert, Ryan Vandermeulen, Inia Soto Ramos, Mustafa Cambazoglu, Stephan Howden, Greg Jacobs, and Alan Weidemann. Ocean Weather - Interaction of Physical and Bio-Optical Processes Across a River Plume Dominated Shelf in the Gulf of Mexico, presented at 2016 Ocean Sciences Meeting, AGU/ASLO/TOS, New Orleans, LA, 21-27 February 2016.

Several events of water mass exchange across the shelf shows dynamic pathways between the offshore Gulf of Mexico waters and coastal waters. The Ocean Weather Laboratory is defining real time physical and bio-optical processes by using several circulation models coupled with ocean color satellite products. The dynamic circulation across the Mississippi Shelf which is associated with river plumes is shown to have a strong influence on the surface bio-optical response as observed in satellites. Daily similarity and differences between these models with satellite observations defines the confidence and uncertainty for capturing the dynamic cross shelf processes. Improved methods using data collected from Unmanned Surface Vehicles can support and provide enhanced monitoring of the bio-physical ecosystem with the models and satellites data.

13. Arnone, Robert, Ryan Vandermeulen, Inia Soto Ramos, Mustafa Cambazoglu, Stephan Howden, Greg Jacobs, Jeff Book, Travis Miles, and Alan Weidemann, Defining Dynamic Bio-Optical Physical Events Across the Miss Shelf and the Influence of Freshwater Plumes, presentation at the 2016 Gulf of Mexico Oil Spill & Ecosystem Science Conference, 1-4 February 2016, Tampa, Florida.

The dynamic circulation of the Mississippi Shelf (MS) is shown to have a strong influence on the surface bio-optical response as observed in satellites. Several dynamic events occurred within 2015 that identify the interaction of the offshore water masses and pathways across the MS shelf to the coast. Surface and vertical bio-optical and physical properties from ship confirmed the satellite and models locations of the plumes. Unmanned Surface Vehicles would provide significant influence for validation of models and satellites.

14. Arnone, Robert, Ryan Vandermuelen, Percy Donaghay, Haoping Yang, 2016. Surface Biomass Flux Across the Coastal Mississippi Shelf, in *Proceedings SPIE: Ocean Sensing and Monitoring VIII*, Vol. 9827, Baltimore, Maryland, 17 - 21 April 2016, Hou, Weilin W. and Robert A. Arnone (Eds.), SPIE, doi:10.1117/12.2240874.

The exchange of water masses across the Mississippi shelf was used to determine the chlorophyll flux for an eight-month period in 2013 through the major Mississippi River discharge period in Spring and Fall. Circulation models (NCOM and HYCOM) and Suomi National Polar-orbiting Partnership (SNPP) satellite chlorophyll products were used to monitor the changes in the shelf transport and surface biological impact. The physical and biological response of cross shelf exchange was observed in rapidly changing dynamic movements of river plumes across the shelf as identified by the models and satellite products. Support from an Unmanned Surface Vehicle would provide improved capability to the exchanges across the shelf.

15. Arnone, Robert, Ryan Vandermuelen, Sherwin Ladner, Michael Ondrusek, Charles Kovach, Haoping Yang, and Joseph Salisbury, 2016. Diurnal Changes in Ocean Color in Coastal Waters, in *Proceedings SPIE: Ocean Sensing and Monitoring VIII*, Vol. 9827, Baltimore, Maryland, 17 - 21 April 2016, Hou, Weilin W. and Robert A. Arnone (Eds.), doi:10.1117/12.2241018. http://dx.doi.org/10.1117/12.2241018.

Coastal processes can change on hourly time scales in response to tides, winds and biological activity, which can influence the color of surface waters. These temporal and spatial ocean color changes require satellite validation for applications using bio-optical products to delineate diurnal processes. Data from WAVCIS (wave-current information system) and an unmanned surface vehicle can define this variability which can affect the oil degradation process.

16. Cruz, Nuno A. and Jose Carlos Alves, 2008. Autonomous Sailboats: An Emerging Technology for Ocean Sampling and Surveillance, 6. pp, in *Proceedings of Oceans 2008*, Quebec City, QC, Canada, 15-18 September 2008, IEEE, doi:10.1109/OCEANS.2008.5152113.

Autonomous sailboats that use wind energy for propulsion and control the sails and rudders without human intervention have the ability to travel for long distances, even though at modest velocities. The authors describe advantages in collecting ocean data and list some risks such as collision and vulnerability to extreme weather. Research and development with autonomous sailboats has been promoted through programs such as (a) the Microtransat challenge (see http://www.microtransat.org/), (b) the World Robotic Sailing Competition (see http://www.roboticsailing.org/), and (c) SailBot (see http://sailbot.org/).

17. Gilabert, Javier, João Sousa, Zoran Vukić, Georgios Georgiou, Francisco López-Castejón, Antonio Guerrero, Pedro Calado, Nikola Mišković, Antonio Vasilijević, Dan Hayes, and Daniel Martínez. Underwater Robotics Ready for Oil Spills, 8 pp. in *Interspill 2015 Conference Proceedings*, Amsterdam, Netherlands, 24 - 26 March 2015, Interspill, Available online. URL: http://bit.ly/2htHy3R. Accessed December 11, 2016.

Multivehicle robotic technologies can be applied to use autonomous underwater vehicles (AUVs), unmanned aerial vehicles (UAVs) and unmanned surface vehicles (USVs) to mitigate oil spills. Robotic capabilities complement existing remote sensing and modeling capabilities. Environmental intelligence from these devices across the spill combined with hydrodynamic modeling provided updated maritime domain awareness for decision making. Experiments have included a network of four AUVs, two UAVs, and one USV to detect and track oil spills. The *PlaDyPos* USV with four thrusters and developed at the University of Zagreb was used for the surface component of the system. Sensors included fluorometers for crude and refined oil identification. Communications included an acoustic modem and Wi-Fi.

18. Giron-Sierra, Jose. M., Alina T. Gheorghita, Guillermo Angulo, and Juan F. Jimenez, 2014. Towing a Boom with Two USVs for Oil Spill Recovery: Scaled Experimental Development, in *Proceedings of 13th International Conference on Control Automation Robotics & Vision (ICARCV)*, Singapore, 10-12 December 2014, IEEE, DOI: 10.1109/ICARCV.2014.7064577

Spill oil is contained with booms and collected from the water using surface skimmer equipment. There are various types of booms that can be used either to surround and isolate a slick, or to block the passage of a slick to vulnerable areas (e.g., the intake of a Reverse Osmosis Water Purification Unit or open-ocean aquaculture cages). Most booms rise up out of the water about a meter. Others are designed to sit flush on tidal flats those designed for deep water have skirts which hang down about a meter below the waterline. Skimmers float across the top of the slick contained within the boom and suck or scoop the oil into storage tanks on nearby vessels or on the shore. These booms and skimmers are sea state limited. This article discusses the use of two unmanned surface vehicles (USV) for towing a boom, in order to do oil spill containment and displacement operations. The USVs are controlled from a ground station and kept in parallel formation.

19. Jones, Brooke, Robert Arnone, and Inia Soto Ramos. Enhanced Monitoring Products of Dynamic Environmental Conditions in Gulf of Mexico to Enable Optimal Sample Collection. accepted for presentation at Gulf of Mexico Oil Spill and Ecosystem Science Conference 2017, New Orleans, LA, 6-9 February 2017.

A dynamic anomaly product derived via integration of ocean-circulation models, satellite ocean color products, and in situ measurements aims to provide researchers and managers enhanced monitoring capabilities for the Gulf of Mexico (GOM). The dynamic anomalies indicate changing conditions relative to time-sensitive variability, allowing managers to identify comprehensive sampling schemes, to interpret *in situ* data collected within the context of environmental conditions, and to identify data gaps due to undersampling. Data from a USV can be used to better understand these anomalies and reveal events that can impact the ecosystem.

20. Ramos, Inia Soto, Robert Arnone, Mustafa Cambazoglu, Greg Jacobs, Ryan Vandermeulen, and Stephan Howden. Characterization of the 3-Dimensional Mississippi River Plume using a High Resolution Circulation Model Coupled with Ocean Color Imagery and Field Data. Presented at 2016 Ocean Sciences Meeting, AGU/ASLO/TOS, New Orleans, LA, 21-27 February 2016.

The Mississippi River Plume (MRP) is responsible for creating a highly dynamic environment in the northern Gulf of Mexico (nGOM). It is also responsible for the transport of rich-nutrient waters, physical and biological connectivity between the nGOM coastal waters to the deep ocean and other regions within the Gulf, and in cases of unfortunate events such as the Deep Horizon Oil Spill it may contribute to the transport and fate of hydrocarbons. A USV platform can be instrumented to provide data to support the location and tracking of the MRP and determination of its impact on oil transport.

21. Talks, T. 2012. Podcast: TED Talks series - Cesar Harada: A Novel Idea for Cleaning Up Oil Spills. Available online. URL: https://www.ted.com/talks/cesar_harada_a_novel_idea_for_cleaning_up_oil_spills. Accessed December 8, 2016.

Researcher Cesar Harada who founded the open-source *Protei Project* discusses the use of an articulated sailboat to protect the oceans from pollution. The low-cost "Ocean Blimp" remotely controlled sailboat trails oil absorbent material for oil spill cleanup.

22. Edwards, John. Rutter *sigma* S6 Oil Spill Detection and Monitoring System, Sea-Image Corporation, Available online. URL: http://www.sea-image.com/rutter_osd1.htm, Accessed December 9, 2016.

Rutter's *sigma* 6 Oil Spill Detection (OSD) and Monitoring System provides reliable early detection and tracking to oil spill response and clean-up resources to aid an efficient and successful cleanup operation. The *sigma* 6 OSD monitoring system gives an enhanced two-dimensional image of oil slicks on the sea surface and can be connected to an existing installed radar transceiver. The system provides a high-resolution image with 4096 video intensity levels for each pixel, detecting small contrasts between the sea surface and oil slicked area.

23. Vasilijevic, Antonio, Pedro Calado, Francisco Lopez-Castejon, Dan Hayes, Nikola Stilinović, Dula Nad, Filip Mandić, Paulo Dias, Joel Gomes, Juan Carlos Molina, Antonio Guerrero, Javier Gilabert, Nikola Miskovic, Zoran Vukić, João Sousa, and Georgios Georgiou. 7 pp. Heterogeneous Robotic System for Underwater Oil Spill Survey, in

Proceedings of MTS/IEEE OCEANS 2015: Discovering Sustainable Ocean Energy for a New World, Genova, Italy, 18-21 May 2015, IEEE, DOI: 10.1109/OCEANS-Genova.2015.7271492.

This paper describes the use of several autonomous underwater vehicles (AUV), an unmanned surface vehicle (USV), and an unmanned aerial vehicle (UAV) to locate and map the 3D spatial extent of an oil spill. Once this information is transmitted to the ground station it can be incorporated into trajectory spill models, merged with aerial imagery, or applied to improve other decision aid products. A demonstration of the use of *in situ* and remote sensors mounted on unmanned vehicles to quantify an oil spill was simulated with Rhodamine Water Tracing dye and conducted in Croatia from September 22 to October 2, 2014. Two-way acoustic and WI-FI communications were used between platforms and the ground station. The set up facilitated visualization of real-time concentration data.

24. Wang, Jianhua, Fuxin Ren, Zhenyi Li, Zhao Liu, Xiang Zhao, and Yongshen Yang. Unmanned Surface Vessel for Monitoring and Recovering of Spilled Oil on Water, 4 pp. in Proceedings of OCEANS 2016. Shanghai, People's Republic of China, 10-13 April 2016. IEEE, doi: 10.1109/OCEANSAP.2016.7485405

This paper discusses rapid response to oil spills with the *HaiTeng 01* Unmanned Surface Vehicle (USV). The USV is a planing craft fixed with multiple video cameras to measure the oil spill and a bow-mounted skimmer. Communication to the USV is based on a wireless LAN to guarantee real-time transmission of eight channels of video, command instructions, and state data for both the USV and spilled oil recovery system. Experiments in Shenzhen Bay were successful in demonstrating high speed response, transmission of video, operations of the hydraulic dynamic inclined plane skimmer, and collection of approximately 1000 liters of spilled oil.

V. Data Repositories, Imagery Libraries, and More

25. ASTER Spectral Library. National Aeronautics and Space Administration, Available online. URL: http://speclib.jpl.nasa.gov/. Accessed December 8, 2016.

The Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) is an imaging instrument onboard Terra, the flagship satellite of NASA's Earth Observing System (EOS). In support of spectral studies, the ASTER spectral library is a collection of spectra from the Jet Propulsion Laboratory, Johns Hopkins University, and the United States Geological Survey. The ASTER library provides a comprehensive collection of over 2400 spectra of a wide variety of materials covering the wavelength range 0.4 - 15.4 μm.

26. Coupled Ocean/Atmosphere Mesoscale Prediction System, Monterey Marine Meteorology Division, Naval Research Laboratory, Available online. URL: http://www.nrlmry.navy.mil/coamps-web/web/home. Accessed on December 2, 2016.

The Coupled Ocean/Atmosphere Mesoscale Prediction System (COAMPS®) has been developed by the Naval Research Laboratory. The atmospheric components of COAMPS are used operationally by the U.S. Navy for short-term numerical weather prediction for various regions around the world.

27. GCOOS (Gulf of Mexico Coastal Ocean Observing System), Coastal Studies Institute, Louisiana State University. Available online. URL: http://gcoos.tamu.edu/. Accessed December 13, 2016.

As the Gulf of Mexico component of the U.S. Integrated Ocean Observing System, GCOOS provides observations and products needed by public, private, and university sectors. GCOOS provides current conditions in the Gulf of Mexico and the data and information can support maritime operations such as marine spill response.

28. Gulev, Sergey, Vika Grigorieva and Andreas Sterl, Global Atlas of the Ocean: based on VOS observations. Available online. URL: http://www.sail.msk.ru/atlas/index.htm. Accessed on December 2, 2016.

This Atlas was developed by oceanographers and scientists from the P.P.Shirshov Institute of Oceanology, Russian Academy of Science (Moscow), Southampton Oceanography Centre (Southampton) and Royal Netherlands Meteorological Institute (De Bilt) through funding from the European Union under INTAS grant 96-2089. The primary interest was the quantification of wave fields coming from different sources, i.e., *in situ* measurements of waves, voluntary observing ship sea state data, remotely sensed waves, and modeling output. This resource is particularly valuable since the investigators re-processed Comprehensive Ocean Atmosphere Data Set (COADS) Releases 1a and 1b, which cover respectively the periods 1950- 1979 and 1980-1997. Oceanographers from Neptune Sciences also re-processed COADS data owing to formatting problems and decoding values. For example, swell period codes were changed in 1968, but this change was not accepted simultaneously by all nations and owners of marine vessels.

29. International Comprehensive Ocean-Atmosphere Data Set (ICOADS). Available online. URL: http://icoads.noaa.gov/. Accessed on October 26, 2007.

The International Comprehensive Ocean-Atmosphere Data Set (ICOADS) is an archive of data that is stored in an ASCII format. Records are accessible through an online request interface that permits subsetting in space, time, and by parameter. The total period of record is currently 1784-May 2007 (Release 2.4). ICOADS data are made available as surface marine reports and monthly summary statistics. Marine reports contain individual observations of meteorological and oceanographic variables, such as sea surface and air temperatures, wind, pressure, humidity, and cloudiness. Summary statistics such as the mean and median are calculated for each of 22 observed and derived variables, using 2° latitude x 2° longitude boxes back to 1800 (and 1°x1° boxes since 1960). This database of observational records (surface marine reports from ships, buoys, and other platform types) has been used by numerous authors (McDermid et al., 1997; Naval Research Laboratory, 1994 and 1995; and Nichols and Earle, 1997) to develop statistics within specific regions such as Marsden squares. The Marsden squares, which are grid cells of 10° latitude by 10° longitude between 80°N and 70°S latitudes, provide a convenient location to pull data such as wave heights, wave periods, and wave directions.

30. Large Marine Ecosystems of the World, National Oceanic and Atmospheric Administration, Available online. URL: http://www.lme.noaa.gov/, Accessed on December 2, 2016.

Large Marine Ecosystems are regions of ocean space encompassing coastal areas from river basins and estuaries to the seaward boundaries of continental shelves and the outer margins of the major current systems. They are relatively large regions on the order of 200,000 km2 or greater, characterized by distinct: (a) bathymetry, (b) hydrography, (c) productivity, and (d) trophically dependent populations. On a global scale, 64 LMEs produce 95 percent of the world's annual marine fishery biomass yields. Within their waters, most of the global ocean pollution, overexploitation, and coastal habitat alteration occur. For 33 of the 64 LMES, studies have been conducted of the principal driving forces affecting changes in biomass yields. They have been peer- reviewed and published in ten volumes (http://www.lme.noaa.gov). Based on lessons learned from the LME case studies, a five module strategy has been developed to provide science-based information for the monitoring, assessment, and management of LMES. The modules are focused on LME: (a) productivity, (b) fish and fisheries, (c) pollution and health, (d) socioeconomics, and (e) governance.

31. OceanColor Home, Goddard Space Flight Center, NASA, Greenbelt, Maryland. Available online. URL: http://oceancolor.gsfc.nasa.gov/. Accessed on December 2, 2016.

This website provides information on ocean color satellites such as MODIS (or Moderate Resolution Imaging Spectroradiometer) and SeaWiFS (or Sea-viewing Wide Field-of-view Sensor) as well as the associated data analysis systems available for the processing, display, analysis, and quality control of ocean color data. Imagery may be retrieved using a browseable web interface or through FTP. Various links provide users with access to instructions and data organized by satellite. These satellites are useful in detecting sea surface temperatures and the amount of phytoplankton in the water, which can be meaningful for many land and coastal ocean classification applications. Scales would be on the order of kilometers.

32. United Nations Atlas of the Oceans, Available online. URL: http://www.oceansatlas.org/. Accessed on December 2, 2016.

A continuously updated database that contains information relevant to the sustainable development of the oceans and the state of ocean resources. The database provides descriptive information on the history, physical characteristics, biology, and ecology of the oceans, including maps and statistical information.

33. WAVCIS (wave-current information system), Coastal Studies Institute, Louisiana State University. Available online. URL: http://www.wavcis.lsu.edu/index.asp. Accessed December 13, 2016.

WAVCIS is system of meteorological and oceanographic sensors deployed from platforms such as oil rigs and models that can be used to characterize sea state, surface current and meteorological conditions along coastal Louisiana. SeaPRISM radiometers are also included and are integrated into the NASA AErosol RObotic NETwork (AERONET). AERONET provides a long-term, continuous and readily accessible public domain database of aerosol optical, microphysical and radiative properties for aerosol research and characterization, validation of satellite retrievals, and synergism with other databases. WAVCIS is a component of the Gulf of Mexico Coastal Ocean Observing System (GCOOS).

34. Wave Information Studies, Coastal and Hydraulics Laboratory, U.S. Army Corps of Engineers. Available online. URL: http://wis.usace.army.mil/. Accessed on December 2, 2016.

A Wave Information Study (WIS) produces hindcast data generated from numerical models such as WISWAVE and WAM that are driven by climatological wind fields overlaid on grids containing estimated bathymetries. The major parameters are significant sea height, dominant sea period, sea direction, sea swell height, sea swell period, and sea swell direction. Regions of primary interest to the U.S. Army Corps of Engineers are adjacent to the United States' Atlantic, Gulf of Mexico, and the Pacific Coasts.

35. World Ocean Database 2013, National Oceanographic Data Center, National Oceanic and Atmospheric Administration, Available online. URL: http://www.nodc.noaa.gov/OC5/WOD13/, Accessed on December 2, 2016.

The World Ocean Database 2013 is an archive of data from Conductivity-Temperature-Depth (CTD) casts, water bottle and bucket collections, plankton net tows, and most recently, data collected from instrumented autonomous underwater vehicles and gliders. Observations mostly relate to the water column and include variables such as temperature, salinity, oxygen (dissolved oxygen, apparent oxygen utilization, and percent oxygen saturation), dissolved inorganic nutrients (phosphate, nitrate, and silicate), chlorophyll at standard depth levels, and plankton biomass sampled from 0 - 200 meters. The database has codes for wave direction, wave height, sea state, wind force, wind direction, weather condition, etc. Some of the data in this archive can be used to complement satellite imagery exploitation and may be useful in assessing heat flow in the ocean, especially as it relates to engine cooling.

VI. Key Research Centers and Organizations

36. Bureau of Ocean Energy Management (BOEM). Available online. URL: https://www.boem.gov/. Accessed December 9, 2016.

An independent agency established in 2010 under the United States Department of the Interior to manage development of U.S. Outer Continental Shelf energy and mineral resources in an environmentally and economically responsible way. Activities focus on the extraction of offshore minerals, which includes exploration and development of oil and gas resources, the bureau is also responsible for "non-energy minerals" (primarily sand and gravel) excavated from the ocean floor.

37. Bureau of Safety and Environmental Enforcement (BSEE). Available online. URL: https://www.bsee.gov/. Accessed December 9, 2016.

An independent agency established in 2011 under the United States Department of the Interior to promote safety, protect the environment, and conserve resources offshore through vigorous regulatory oversight and enforcement. Activities include inspection, investigations, summoning witnesses and producing evidence, levying penalties, canceling or suspending activities, and overseeing safety, response, and removal preparedness.

38. Coastal Data Information Program, Ocean Engineering Research Group, Scripps Institution of Oceanography. San Diego, CA. Available online. URL: http://cdip.ucsd.edu/. Accessed on December 2, 2016.

The Coastal Data Information Program (CDIP) is an extensive network for monitoring waves along the Pacific coasts. CDIP provides a database of publicly-accessible environmental data for use by coastal engineers and planners, scientists, mariners, and boaters. CDIP has been a leader in developing best practices for ocean observing systems, especially with and forefront of coastal monitoring, developing numerous innovations in instrumentation, system control and management, computer hardware and software, field equipment, and installation techniques. Such resources can directly support or augment environmental characterization efforts.

39. Field Research Facility, U.S. Army Corps of Engineers, Duck, NC. Available online. URL: http://www.frf.usace.army.mil/. Accessed on December 2, 2016.

The Field Research Facility (FRF) is located on the Atlantic Ocean near the town of Duck, North Carolina. It is a model coastal observatory where instruments are deployed to measure waves, winds, tides, and currents. Central to the facility is a 560m (1840 ft) long pier and specialized vehicles. The FRF is a key location for basic and applied research on the coastal ocean, especially barrier island coast types. Products produced by the FRF include observations of environmental factors such as waves, tides, and currents, climatologies, bathymetry, and descriptions of experiments. From the FRF website, users may access Wave Information Studies, numerical hindcasts of wave climate for coastal waters in the United States.

40. Gulf of Mexico Research Initiative (GoMRI). Available online. URL: http://gulfresearchinitiative.org/. Accessed December 9, 2016.

GoMRI was established on May 24, 2010. It is BP's commitment to provide $500 million in funding over the course of 10 years for independent scientific research related to the Deepwater Horizon incident. The goal of GoMRI is to improve society’s ability to understand, respond to, and mitigate the impacts of petroleum pollution and related stressors of the marine and coastal ecosystems, with an emphasis on conditions found in the Gulf of Mexico. Knowledge accrued will be applied to restoration and to improvement of the long-term environmental health of the Gulf of Mexico. Funding has been awarded to a variety of organizations such as Louisiana State University, University of South Florida, the Northern Gulf Institute, Alabama Marine Environmental Sciences Consortium, and the National Institutes of Health. In excess of $110 million has been awarded to research consortia, some include the university, government, and industry sectors.

41. Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX), Available online. URL: http://shoals.sam.usace.army.mil/. Accessed on December 2, 2016.

The Joint Airborne Lidar Bathymetry Technical Center of Expertise (JALBTCX) mission is to perform operations, research, and development in airborne lidar bathymetry and complementary technologies to support the coastal mapping and charting requirements of the US Army Corps of Engineers (USACE), the US Naval Meteorology and Oceanography Command, and the National Oceanic and Atmospheric Administration (NOAA). JALBTCX staff includes engineers, scientists, hydrographers, and technicians from the USACE Mobile District, the Naval Oceanographic Office (NAVOCEANO), the USACE Engineer Research and Development Center (ERDC), and NOAA National Geodetic Survey. These personnel plan and execute survey operations using the Compact Hydrographic Airborne Rapid Total Survey (CHARTS) 36 system and industry-based coastal mapping and charting systems. CHARTS includes a lidar instrument and a hyperspectral imager.

42. Littoral Acoustic Demonstration Center (LADC), University of New Orleans, Available online. URL: http://ladc.uno.edu/. Accessed December 8, 2016.

LADC was founded in June 2001 as a consortium of scientists from universities and the Navy. The Center conducts ambient noise and marine mammal acoustic measurements and analyses in shallow water. Researchers have used acoustic means to estimate marine mammal populations and have assessed environmental impacts to beaked whales using data collected near the Deepwater Horizon oil spill. These techniques are especially important since beaked whales are difficult to identify visually. Species that have been identified acoustically include Blainville's (*Mesoplodon densirostris*), Cuvier's (*Ziphius cavirostris*), and Gervais' (*Mesoplodon europaeus*) beaked whales. LADC research has since been broadened to include airgun calibration measurements.

43. National Data Buoy Center (NDBC), National Weather Service, National Oceanic and Atmospheric Administration, Stennis Space Center, MS. Available online. URL: http://www.ndbc.noaa.gov/. Accessed on December 2, 2016.

The National Weather Service's NDBC website contains real-time and historic meteorological and oceanographic data from moored buoys and Coastal-Marine Automated Network (C-MAN) Stations.

44. Ohmsett: Oil and Hazardous Materials Simulated Environmental Test Tank, Bureau of Safety and Environmental Enforcement. Available online. URL: http://www.ohmsett.com/. Accessed December 2, 2016.

Ohmsett, located in Leonardo, New Jersey, provides a full-scale oil spill response equipment testing, research, and training facility. The primary feature of Ohmsett is a large, above ground, concrete wave test tank measuring 667 ft long, 65 ft wide and 11 ft deep. The tank is filled to a depth of 8ft with 2.6 million gallons of crystal clear salt water. Variables such as waves, temperature, and oil types are able to be controlled. The mission of Ohmsett is to strengthen awareness of oil spill pollution prevention and response methods, while at the same time remaining committed to the well-being of its customers, employees, and associates.

45. United Kingdom Hydrographic Office, Admiralty EasyTide, Available online: URL: http://easytide.ukho.gov.uk/EasyTide/EasyTide/index.aspx. Accessed on December 2, 2016.

Admiralty EasyTide and TotalTide are tide and tidal current prediction programs for over 7,000 tide stations and 3,000 tidal current stations, worldwide. Admiralty TotalTide is a “for official use only” tide and tidal prediction CDROM version of EasyTide that may be obtained through coordination with the National Geospatial-Intelligence Agency. A TotalTide license is for one year, which benefits from the UK Hydrographic Office’s annual updating of their worldwide harmonic constant database. Some tide and current terms in this software are slightly different than those used by the National Oceanic and Atmospheric Administration. Tide and current terms are defined in NOAA’s Tide and Current Glossary.

VII. Manuals and other Reference Sources

46. Coastal Engineering Manual, EM 1110-2-1100, US Army Corps of Engineers. Available online. URL: http://www.publications.usace.army.mil/USACE-Publications/Engineer-Manuals/u43544q/636F617374616C20656E67696E656572696E67206D616E75616C/, Accessed on December 2, 2016.

A comprehensive manual that incorporates tools and procedures to plan, design, construct, and maintain coastal projects. The six volumes include the basic principles of coastal processes, methods for computing coastal planning and design parameters, and guidance on how to formulate and conduct studies in support of coastal flooding, shore protection, and navigation projects. This manual replaced the Shore Protection Manual.

47. NOAA, Tide and Current Glossary, 2000. Silver Spring, MD: National Ocean Service, National Oceanic and Atmospheric Administration, Department of Commerce. Available online. URL: tidesandcurrents.noaa.gov/publications/glossary2.pdf. Accessed on December 2, 2016.

A detailed glossary defining terms associated with the collection, analysis, processing, and publication of data which is used for tide and current predictions. It is important that descriptive terms meaningful to Sailors and Marines by used to describe those environmental factors that impact safety and operations of amphibious craft, patrol boats, and coastal ships.

48. Wave Buoy Survey, The Johns Hopkins University Applied Physics Laboratory, Laurel, MD. Available online. URL: http://fermi.jhuapl.edu/usmc/. Accessed on December 2, 2016.

A web site providing basic information on the ease of deployment and operation of wave buoys manufactured by several different vendors. The Wave Buoy Survey was developed by Dr. David L. Porter prior to the start of the operational assessment of the Expeditionary Fighting Vehicle. It was designed so that program managers would have a location to search having objective information relevant to the utility of wave buoys to support planing craft, hovercraft, and sea state limited operations such as surf zone breaching. Dr. Porter is key oceanographer affiliated with the Office of Naval Research's Littoral Warfare Advanced Demonstration Program.

VI. Summary

This document lists numerous citations to books, articles, documents, and databases highlighting engineering and environmental factors essential for an optimal USV for marine spill response. Some of the described work was originally planned and delivered to support design and testing of USVs in various types of coasts from the tropics to polar regions. There are many other references in the literature relevant to USVs and the characterization of environmental conditions such as ambient air temperature, sea conditions (wave height, wave period, wave direction, tidal regime, and currents), and wind conditions (direction, speed, and gusts) the operation of USVs.

Many of the cited references are available from the Earl K. Long Library at University of New Orleans and online at Scholarworks@UNO. Materials related to the Maritime Advanced Geospatial Intelligence craft Project can be found at URL: http://scholarworks.uno.edu/magic/.

These background documents provide the basis for (a) developing research plans, (b) identifying the most important trade studies, (c) modernizing response planning, and (d) writing Safe Engineering and Operations Manuals for MAGIC. The overarching goal is to collect environmental intelligence that helps decision makers to decide that the best course of action (e.g., to allow the oil to break down naturally) and to develop automated techniques to improve response speed and duration. MAGIC benefits from the growing body of knowledge on the potential use of USVs to help contain the oil with booms and then collect it from the water surface using skimmer equipment. USVs might be configured to deploy dispersants that break up the oil and speed its natural biodegradation. Lastly, MAGIC may utilize this background to apply biological agents to the spill in order to hasten biodegradation.

This annotated bibliography is a starting point to build a complete design, environmental support plan, and MAGIC prototype. Basic and applied researchers from UNO, USM, LSU, NRL, MIRC, and ASV are collaborating to design the optimal ASV for marine spill response.

This information also benefits other marine scientists and engineers. Being able to access authoritative engineering and environmental information should be paramount to the planning and implementation of marine spill response operations.

The following table is provided to link the listed references to important engineering and environmental factors and there are more than 40 engineering and environmental factors from the cited works. References found in this document are categorized by the general type of study and factors. Works may be categorized in more than one cell.

Cross Reference Table

Engineering and Environmental Factors and Cited Works. References found in this annotated bibliography are categorized by the general type of study and those engineering and environmental factors of interest to MAGIC researchers. Works may be categorized in more than one cell.

Engineering & Environmental Factors	General Data and Information Resources			
	databases	remote sensing	*In situ* sensors	models
aerosols	33	2	33	
air tempera-ture	27, 29, 35, 59, 43		27, 33, 39, 43	27
bathy-metry	27, 30, 39	5, 6, 7, 41	27, 39	
breaking waves	27, 29, 39	1	27, 33, 39, 43	27
currents	27, 29, 35, 39, 43	5, 10, 11, 12, 13	6, 7, 1, 18, 23, 27, 33, 39, 43	1, 10, 11, 13, 19, 27
fluorescence	27	5	1, 8, 27, 33	
relative humidity	27, 29, 39, 43		27, 33, 39, 43	
sea surface currents	27, 29, 33, 35, 39, 43	1, 10, 11, 12, 13, 27	3, 6, 7, 9, 17, 18, 21, 23, 27, ,33, 39, 43	10, 11, 12, 23
sea surface features	1, 29, 30, 33, 35	5, 10, 11, 12, 13, 19, 22, 24, 27	3, 17, 20, 23, 27, 33	10, 11, 12, 19, 20, 23, 27, 33
spectra	24	2, 4, 33		2, 4
surf	30			

surface gravity waves	27, 28, 30, 33, 35, 38, 39, 43		16, 27, 38, 43	1, 27, 33, 34
tidal currents	27, 30, 35, 43		16, 27, 33, 39, 43	27, 33, 45
water levels	27, 29, 33, 35, 39, 43		27, 33, 39, 43	27, 33, 45
water quality	27, 30, 31, 35, 39	13, 15, 19, 23, 24, 27	8, 17, 19, 23, 27, 39, 43	19
water salinity	27, 29, 35, 39, 43	13, 14, 19	8, 9, 17, 19, 27, 39, 43	14, 19, 27
water temperature	27, 29, 35, 39, 43	13, 14, 19, 23, 27	8, 9, 17, 19, 23, 27, 33, 39, 43	9, 14, 19, 27
winds	27, 28, 29, 35, 39	27	1, 17, 18, 21, 23, 27, 33, 39, 43	1, 29, 26, 27