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Director NMIO View:

Rear Admiral Robert Sharp, USN

As both the Director of the National Maritime Intelligence-Integration Office (NMIO) and the National Intelligence Manager for the Maritime Domain (NIM-Maritime), I am pleased to present Volume 12 of NMIO's Technical Bulletin. This is the second volume published during my tenure at NMIO, and offers me the perfect opportunity to highlight the wonderful work being done by some of our brightest minds in academia.

NMIO's science and technology (S&T) strategic guidance from the Director of National Intelligence is to engage academia, think tanks, the private sector, and foreign governments to help the maritime community to better understand the implications of emerging technologies. This edition of our Technical Bulletin is an opportunity to share with the global maritime community recent Science Technology Engineering Math (STEM) research initiatives across a vast array of focus areas, all related to enhancing maritime domain awareness.

Our future leaders, professors, and university researchers are best positioned to pursue the next great technological advancements that address some of our greatest maritime challenges. The NMIO Technical Bulletin is one of our key vehicles to promote enhanced maritime domain awareness and information sharing, and so we are pleased to present Volume 12, our special academic edition, with articles from universities around the world.

Improved productivity resulting from technology innovation has been a major driver of economic growth, changing the way we live in astonishing ways. Innovative technology is allowing us to have myriad tools to improve our collective situational awareness for enhanced detection, interdiction, surveillance, enforcement, and mitigation of the threats and challenges we face in the maritime domain. STEM education has a wide-range of disciplines and is often regarded as an awesome playground to have fun, be creative, share ideas and work together to tackle some of the most challenging issues of present and future. STEM skills are more critical to the workforce than ever imagined, and significant strides have been made towards making student and professor educational experience more robust, utilizing computers and emerging technology while understanding the human factors and ergonomics for safe and effective use of these advancements. Research and development opportunities undertaken at universities worldwide have broad applicability to a range of maritime endeavors. In a technology-driven economy, the future of STEM education will help guide research and policy, allowing students to solve challenges, which in turn allows them to engage with industry and governments in preparation for future career opportunities.

NMIO continues to advance information sharing requirements across the Global Maritime Community of Interest (GMCOI). Your valued contributions positively affect the safety of the maritime domain. As we continue to innovate, we must remember to communicate, coordinate, and collaborate broadly across the GMCOI, in order to be successful in maintaining safe and secure use of the maritime domain for all.

I would like to thank those authors who invested their valuable time between teaching and studies to contribute to this edition of our Technical Bulletin. The articles contained herein capitalize on our relationships with all levels of academia partners. I encourage other stakeholders to become more involved in this community publication, by submitting articles to help us broaden the topics and regions covered in this product.

Please enjoy the tremendous articles in this 12th volume of the NMIO Technical Bulletin on a variety of STEM topics related to the emerging technological advancements used in the maritime domain, policy and information sharing perspective. I look forward to continuing to work collaboratively with the community of interest to address challenges and opportunities of common concern!

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Contributions welcome: We welcome contributions from all Global Maritime Community of Interest stakeholders, both domestic and international. In submitting your article, please highlight who you are, what you are doing, why you are doing it, and the potential impacts of your work. Please limit your article to approximately two to three pages including graphics. Articles may be edited for space or clarity.

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SECURING CYBER-DEPENDENT MARITIME SYSTEMS AND OPERATIONS

Jason Jaskolka, Stanford University; **John Villasenor**, University of California, Los Angeles

Safety, security, and reliability of computer systems and networks are becoming a permanent fixture in the daily news. Systems today are comprised of broad communication networks with many distributed and interacting components linked in complex ways. Each component is responsible for providing some information, or controlling some element of the system. These complex distributed systems play a vital role in nearly every critical infrastructure sector, as well as in other critical industries.

In the Maritime Transportation Sector (MTS), complex distributed systems are used for tasks including determining shipping loading/unloading schedules, optimizing container movement and storage, and controlling physical system components.[1] The MTS is an integral part of the global economic landscape, accounting for nearly 80% of the world's trade by volume.[2] Therefore, disruptions to the operation of these systems due to cyber-attacks or failures can have a far-reaching and crippling impact on the national and global economy.

Ensuring that systems vital to the operations of maritime ports, vessels, and navigation support, are robust against existing and emergent cyber threats is among the top priorities for governments and facility operators. In this article, we report on results from our current research effort sponsored by the U.S. Department of Homeland Security (DHS) as part of the Critical Infrastructure Resilience Institute (CIRI). CIRI is based at the University of Illinois at Urbana-Champaign and supports (using funds from DHS) research projects at a number of different universities and national labs, including Stanford University, where the work we describe here is being performed. Broadly speaking, our research aims to develop a framework to help understand and address the evolving cyber threats that are faced by critical infrastructures, including maritime systems and operations.

A LATENT AND LOOMING THREAT

Despite the extensive testing and verification applied to individual components of many critical systems, cybersecurity vulnerabilities resulting from component interactions that may be unfamiliar, unplanned, or unexpected often go undetected. These kinds of interactions are called implicit interactions.[3] Cyber incidents resulting from implicit interactions are often the result of system design flaws arising from the complexity of modern systems and networks. As the size and complexity of systems continues to grow, the ability to adequately characterize, analyze, and assess the full range of system behaviors is becoming increasingly unmanageable.

The exploitation of implicit interactions can have severe consequences in terms of the safety, security, and reliability of a system and its operations. For example, implicit interactions allow for system components to interact in unintended—and often undesirable—ways, which can give rise to unpredictable, and potentially unsafe and/or insecure system behaviors. Furthermore, they can provide a means for compromising the integrity or availability of critical information required for safe and reliable system operations, or even for leaking confidential information to unauthorized parties. Unfortunately, implicit interactions are often only made visible, or known, after a system experiences an attack or failure. Therefore, the ability to identify, understand, assess, and eventually mitigate implicit interactions is greatly needed if we expect to have cyber-resilient systems.

SUSCEPTIBILITY OF MARITIME SYSTEMS AND OPERATIONS TO IMPLICIT INTERACTIONS

Modern ports and vessels rely on hundreds of interacting cyber-dependent systems and components—a number of which are summarized in Figure 1—to operate with impressive efficiency and reliability.

Figure 1: A selection of the interacting cyber-dependent systems and components found at a typical maritime shipping port.
Photo Credit: Ajepbah [CC-BY-SA-3.0 DE], via Wikimedia Commons

The benefits of employing cyber-dependent systems within the MTS are indisputable. However, the use of such systems also comes with risks. The components and subsystems within a maritime port or vessel are often large and complex in their own right. In addition, the vast majority of them are interconnected, thus making maritime ports and vessels exceedingly large and complex distributed systems. It is because of this sheer size and complexity that maritime ports and vessels are often considered "sitting ducks" due to their susceptibility to cyber-attacks. Exploitation of unforeseen linkages within and among these systems, whether due to malicious and targeted attacks, or even simple misuse or failure, can have devastating impacts including:

a. Injury or death to operators, passengers, or the general public;

b. Disruptions to the transportation system and its operations;

c. Physical damage to affected equipment and systems;

d. Loss of sensitive information; and/or Harm to the marine environment.

The susceptibility of maritime systems and operations to threats from implicit interactions has been demonstrated in the past. For example, in January 2014, the NCC Group, a cybersecurity and risk mitigation firm, showed that the Electronic Chart Display and Information System (ECDIS) could be penetrated and manipulated.[4] Several security vulnerabilities could enable an attacker to read, download, replace, or delete any files needed by the ECDIS. To make matters worse, the ECDIS is interconnected with numerous other important systems such as radar, automatic identification systems (AIS), anemometers, and fathometers, among others. In turn, these systems are typically connected to the shipboard network which allows them to have far-reaching effects on other important systems. Given this connectivity, a compromised ECDIS aboard one vessel could potentially be penetrated and manipulated to provide invalid position information to the vessel's AIS, which can then be communicated to other nearby vessels and port operators, and may ultimately result in a collision.

This example brings a new light upon the old adage that "a chain is only as strong as its weakest link" in that any unauthorized access, either directly or via one of the multiple systems linked to the ECDIS, can enable attackers to interact with the shipboard network and everything to which it is connected. Therefore, all of the possible linkages between the wide range of systems and components in maritime ports, vessels, and operations must be well-understood to prevent the presence and exploitation of implicit interactions.

ADDRESSING THE ISSUE OF IMPLICIT INTERACTIONS

As explained above, there is a need to ensure that systems vital to the operations of ports, vessels, and navigation support, are robust against existing and emergent threats.

We are currently engaged in a research effort targeted at developing rigorous and practical approaches for addressing the issue of implicit interactions, and for advancing cybersecurity assurance and intrinsic resilience in distributed systems and networks. Our methodology is based on formal methods, which are mathematically-based techniques for specifying, developing, and verifying software and hardware systems. The use of these methods and techniques is highly desirable when developing systems with high standards of safety, security, and reliability.[5] Consequently, as a critical infrastructure sector, maritime systems and operations fall directly within this category of systems. Moreover, in recent years, DHS has encouraged the adoption and development of formal methods in scenarios when they can be demonstrably effective.[6]

Figure 2: The ECDIS is a cyber-dependent system installed on the bridge of a vessel as a supplement—or often a replacement—of paper chart navigation.
Photo Credit: Michael Krahe [CC-BY-SA-4.0], via Wikimedia Commons

To date, we have developed approaches for identifying the existence of implicit interactions in distributed systems, [3,7] and for determining how existing implicit interactions can be exploited to mount cyber-attacks. We have also developed metrics and measures to aid in assessing the potential severity, and evaluating the exploitability, of identified implicit interactions to more accurately assess the threat that they pose to the overall safety, security, and reliability of a given system.

We are currently developing a framework with which we can assess the potential impact that a cyber-attack mounted upon an implicit interaction can have on the operation of a complex distributed system. For example, we want to determine whether an attacker exploiting an implicit interaction can merely turn a light on and off on a control panel, or delete some or all of the container tracking information at a shipping terminal, or cause a collision to sink a vessel. These are just a few of the vastly different possible results of a cyber-attack on maritime ports, vessels, and operations. Knowing which is possible—and more likely—for a given system is a critically important piece of information that can be used to assess where and how to focus efforts, and spend valuable resources, on mitigating the existence of particular system vulnerabilities.

Based on the results of the above-mentioned analyses, we intend to develop mitigation approaches that can help in eliminating the existence of implicit interactions within existing critical systems, and providing sound recommendations for designing and developing future systems that avoid the potential threat posed by implicit interactions.

IMPACT AND IMPORTANCE OF THIS WORK

Existing approaches for establishing principles or specifications for cyber risk management or response activities are limited by the absence of a comprehensive foundational understanding of the dynamics, interactions, and therefore potential weaknesses of critical infrastructure systems.[8] Our research efforts aim to develop a better understanding of the increasingly distributed, complex, and richly connected critical infrastructure environment. In particular, we are focussed on enhancing the understanding of the linkages between system components in an effort to study the integrity, sustainability, reliability, and vulnerabilities of complex systems.

More broadly, we are working to advance the state-of-the-art in the tools and methods for achieving security-by-design and cybersecurity assurance for critical infrastructure systems. Among other benefits, the methods and approaches that we are developing will make it far more practical to address cybersecurity at early stages of system development. This will provide substantial savings in terms of the costs associated with minimizing cybersecurity vulnerabilities, and recovering from the effects of cyber-attacks and failures. Furthermore, the methods and approaches being developed will provide critical infrastructure designers, owners, and operators with actionable information that can drive design, implementation, and cyber-assurance decisions for critical systems and components, as well as mitigation strategies and policies for cybersecurity.

While our current research efforts are primarily motivated by the goal of identifying and analyzing cybersecurity vulnerabilities in critical infrastructure systems, the methods and techniques we are developing can be applied more broadly as well. For example, they can also be used to analyze the impact of unforeseen dependencies arising in complex supply chains, organizational structures used in command and control, as well as logistics, and in many other applications.

CONCLUDING REMARKS

As maritime ports and operations continue to increasingly depend on the connectedness of cyber-dependent systems and networks, there is an ever-growing need to proactively identify, analyze, assess, and defeat cyber threats to the interests of the U.S. and its global partners. The larger and more complex our modern systems and networks become, the more intellectually unmanageable they become, which inevitably leaves them susceptible to security vulnerabilities, particularly those resulting from previously unknown, unforeseen, or unexpected linkages within and between systems and components (i.e., implicit interactions). These kinds of issues are only going to be exacerbated in the future by the prospect of remote-controlled and autonomous ships, where the connectedness and complexity of the systems and components will vastly increase.

We need to develop a better understanding of the complex distributed systems that we build, and we need to design these systems with intrinsic resilience to be able to manage and combat the evolving and emerging cyber threat landscape that they face. Our current research efforts can help address some of these challenges by providing an enhanced understanding of the hidden complexity and coupling in the complex distributed systems that are so heavily relied upon by the nation's critical infrastructure.

We would welcome the opportunity to engage with members of the U.S. maritime sector to discuss ways in which the methods we have developed can be used to improve maritime system security, safety, and reliability.

ACKNOWLEDGEMENTS

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HUMAN CENTERED DESIGN KNOWLEDGE FOR MARITIME DESIGNERS; ENOUGH PREACHING, TIME TO PRACTICE

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BACKGROUND

Maritime transport services represent approximately 90% of world trade, turning the shipping industry into the backbone of the current world economy. Though the maritime industry is growing daily in terms of technology, regulations, capacity, and safety, there are still a significant number of accidents that occur at sea. It has been estimated that 60−80% of all casualties at sea are the result of operator error. According to the United Kingdom Protection and Indemnity Club, this costs the maritime industry US$540 million every year. However, it is prudent to investigate the cause for these errors by considering them as symptoms, or starting points of investigations, rather than concluding that these errors occurred solely due to the operators. Researchers found that the underlying cause for most of these errors is often linked with Human Factor (HF) issues that mainly relate to the shortcomings of designs.

Design shortcomings affect crews' mental workload, ability to sleep, and level of physical stress during their sea time. As an example, layout design of accommodations can adversely affect the quality of crew rest, the level of restoration that seafarers achieve during their non-working hours, and the degree of the mental wellbeing they experience. These conditions can influence human performance by increasing physical and mental fatigue that could ultimately lead to operator error. A root cause analysis was conducted in HF perspective for the sixty-six deaths caused in British-flagged ships during the years 2003 and 2012. It found that in 64% of the cases, the risk of fatality could have been mitigated during the early design stage of the ships. Therefore, the early stages of a ship's design present practical opportunities for mitigating or reducing the potential for operator error, by addressing the potential risks that a ship and its crew would otherwise face when the ship enters into service. In light of this, there is a growing awareness in the marine industry that HF needs to be considered in ship design if seafarers are to operate ships safely and effectively. Knowledge of HF and user involvement can be applied to ship design through a Human Centered Design (HCD) approach.

Despite the potential benefits of an NCD approach to ship design, however, according to relevant literature ship design practice today does not show explicit consideration of a HCD approach. It was found that maritime designers' lack of awareness and understanding of HF issues and HCD is the highest contributing factor for this situation. Furthermore, researchers emphasized that, though maritime designers' education and training programs are piling up with a wide range of subjects, the majority of these are heavily biased towards the technological field. However, there was no study found in the literature that was conducted to evaluate maritime design students' understanding of HF issues and the HCD approach, and the importance of integrating the concepts into their education system.

MOVING ON − THE HCD KNOWLEDGE OF MARITIME DESIGN UNDERGRADUATES

To begin the research discussed in this article, a classroom survey was first conducted at the Australian Maritime College (AMC) to evaluate maritime design students' HCD awareness and understanding. Two cohorts of final-year maritime design undergraduates − sixty students altogether − participated in the survey. Findings from both cohorts validated the statements given by the researchers that maritime design education systems lack subjects related to maritime HCD. One of the recurring themes found during the survey was that the majority of students suggested using designers' 'common sense' to design user-friendly ships, which is an embarrassing defensive attitude showed by future ship designers. Thus, it was identified that there is a great need to transfer maritime HCD knowledge into the maritime design undergraduate syllabus, to be taught in a systematic and engineering-oriented fashion. Furthermore, students studying maritime HCD should be encouraged to carry their knowledge forward into future design teams so that these concepts can be more fully implemented in future maritime design.

HOW TO DISSEMINATE HCD KNOWLEDGE?

The practice of a design project and its pedagogical structure, which is Problem-Based Learning (PBL), is well-tested and globally implemented in engineering education. Accordingly, referring the established pedagogical structure of small group design projects, authors developed a theoretical framework to systematically transfer maritime HCD knowledge into maritime design education and to motivate students to utilize the knowledge in design projects. The framework was developed by connecting the student-centered pedagogies: PBL and Peer-Led Team Learning (PLTL), with Vygotsky's Zone of Proximal Development (ZPD) theory and the Scaffolding concept (see Figure 1). ZPD is the distance between (1) the student's actual development level as determined by independent problem-solving and (2) the student's level of potential development as determined through problem-solving under adult guidance, or in collaboration with a more knowledgeable other.

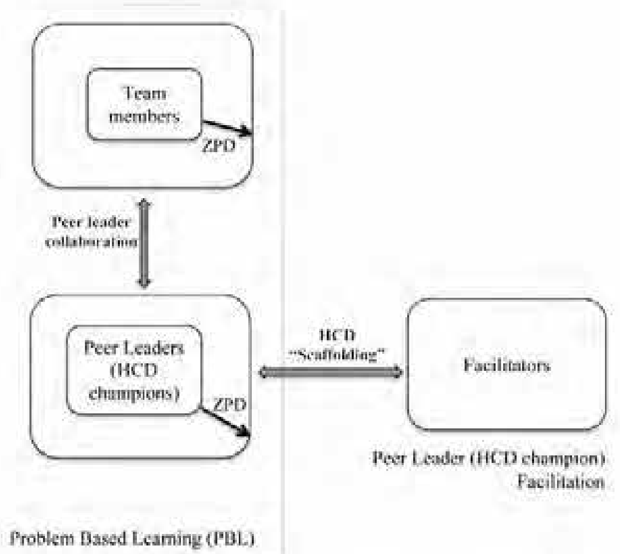

Figure 1: Theoretical framework – PLTL and PBL pedagogies linking with cognitive development theory, Vygotsky's ZPD, and the Scaffolding concept.

As illustrated in Figure 1, this framework contains three parties: peer leaders, team members, and facilitators. Peer leaders are student volunteers from each design project team with a high level of motivation in learning and applying HCD during the design process, and are also ready to train under facilitators to become more capable peers in HCD within their group. Authors named these peer leaders 'HCD champions.' Design project team members are the students from each group who are working with HCD champions within a PBL environment. Facilitators are the researcher, maritime HF specialists, and field experts including experienced seafarers and naval architects.

Within this framework, the HCD champions are facilitated through maritime HCD lecture sessions, workshops, and consultation sessions. This facilitation process, referred to as 'Scaffolding,' is the path that can help learners reach their potential development. HCD champions are then working with their respective design project teams focusing on usability aspects of their designs while ensuring the effective transmission of HCD knowledge to the team members so as to, in turn, draw the team members towards their potential development in maritime HCD. Thus, within this framework, HCD dissemination flows from the facilitator to the HCD champion and then through to team members. Although the team members are not receiving direct support from the facilitators as the HCD champions do, the whole design team may participate in group facilitation sessions. To learn the effectiveness of this research study, Action Research – combining Action (what researchers do to solve an issue or to improve the current practice) with Research (how researchers learn from the action and understand the effectiveness of the action) – was selected as the methodological framework.

SCAFFOLDING – PRACTICING WHAT WE PREACH

Students who enrolled in the design project unit for the academic year 2015 at AMC were the first cohort of this study, which was facilitated through a planned HCD Scaffolding program during the year-long first action cycle (September 2014 to September 2015). The Scaffolding program consisted of:

- HCD-related onboard activities during a five-day voyage on the AMC research vessel (see Figure 2)
- weekly lecture series; Topics covered maritime HCD, HF, ergonomics, steps of HCD cycle, HCD guidelines, and HCD evaluation methods (see Figure 3)
- HCD workshop sessions (see Figure 4)
- guest lecture sessions from seafarers
- field expert consultation sessions (see Figure 5)
- distribution of HCD Scaffolding material

In order to investigate how the above actions contributed to the improvement of student HCD knowledge, the following data collection techniques were used during the study: maintaining a researcher's journal, interviewing HCD champions, distributing an internet questionnaire to team members, and reviewing design project reports. The Scaffolding program of the first year was revisited and revised in light of what was learned through a review of the data, and the cyclic process was then repeated as the second action cycle with the cohort of the academic year 2016 (September 2015 to September 2016). Both action cycles were conducted based on the theoretical framework developed.

Figure 2: Photos taken during an onboard activity (a) Assembling the stretcher; (b) Door obstructions while carrying the stretcher down to the engine room; (c) Strapping in the patient; (d) Discussing different ways of carrying the patient; (e) Stretcher with patient – almost vertical due to poor design of the stairs – and the struggle to turn the stretcher due to inadequate landing space; (f) Door obstructions while carrying the patient to the main deck.

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Figure 3: (a) Students performing familiarization session on working nature in a ship bridge – inside ship simulator with HF specialist; (b) Usability expert conducting a seminar in the classroom on context of use.

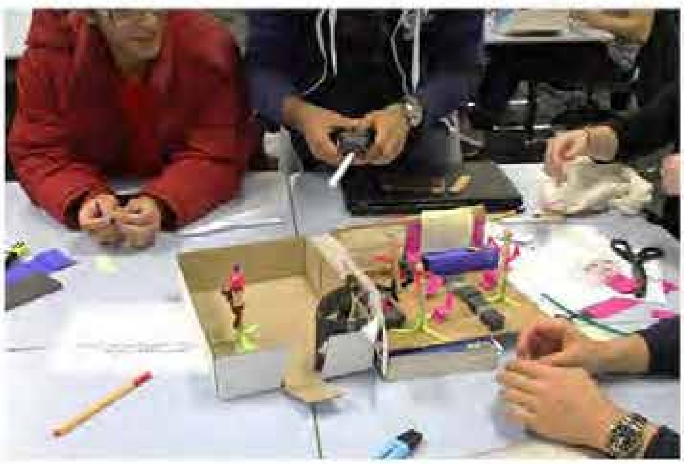

Figure 4: HCD champion and team members preparing their lo-fi prototype for the given scenario – ship engine room crew preparing for arrival in port.

Figure 5: HCD champion and team members having discussions with field experts – Master mariners, Submariner, Chief engineer – during their design process.

DID THE SCAFFOLDING PROGRAM AND THE THEORETICAL FRAMEWORK MAKE ANY CHANGE?

Findings revealed that the Scaffolding program made a significant contribution to elevating the HCD knowledge of the maritime undergraduates, pushing them to their ZPD. Thus, their HCD knowledge after the Scaffolding sessions eventually became the new (heightened) limits of their independent understanding of HCD before they enter the workforce as design engineers. In addition, the theoretical framework can be used to create skillful and unique maritime designers who can influence their colleagues and carry forward the knowledge into their future design teams. Findings after the onboard activities stimulated the students' awareness of HF issues and HCD knowledge and showed the importance of these hands-on activities to the Scaffolding approach. In addition, the onboard stay was remarkably influential in changing the students' previous 'common sense' perspective on HCD. Furthermore, introducing HCD success and failure stories, as well as organizing consultation sessions with experienced seafarers, showed a notable contribution towards the students' development.

It can be concluded that the systematic approach followed in this research study is a promising way to integrate HCD knowledge into maritime engineering education. The results proved the effectiveness of the concept of utilizing the HCD champion to efficiently disseminate HCD knowledge into the design teams. Through the Scaffolding facilitation sessions provided by the HCD champions, the team members were able to understand the importance of HCD concepts, and were inspired to use these concepts during their careers. Some team members were willing to master these concepts to become champions in the future. Thus, the HCD champion concept can be identified as a prudent approach to accelerating the rate of spreading the HCD knowledge within the maritime industry.

Findings of this research further confirm the emphasis made by previous researchers: the maritime design education system does not currently provide students with enough knowledge and experience to understand and appreciate user requirements and the user perspective. In order to meaningfully include maritime HCD knowledge into the maritime design education system, the attitudes and traditional norms of the education system must evolve as a precondition for effective knowledge transfer. Likewise, the maritime educational institutions and responsible faculty members worldwide must acknowledge the significance of integrating HCD knowledge into maritime education. Therefore, it can be concluded that the requirement of introducing HCD knowledge and non-technical skills into maritime design curriculum should be addressed globally in order to prepare socially-conscious maritime designers.

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NIGHT-TIME SATELLITE IMAGERY OBSERVATION OF HUMAN ACTIVITY IN DISPUTED AREAS OF THE SOUTH CHINA SEA

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ABSTRACT

Human activities associated with dredging and reclamation around South China Sea (SCS) coral reefs were analyzed by using Day-Night Band (DNB) data to measure the mean intensity of lights at night in the regions defined around each of the several areas investigated. A slight increase in DNB mean intensity was observed at the beginning of dredging at Subi Reef and Mischief Reef. Similarly, a sharp reduction in DNB mean intensity was observed at the end of dredging at Subi Reef and Mischief Reef, but not as clearly at the Fiery Cross Reef. Judging from these changes in the DNB mean intensities, we estimate that dredging at Subi and Mischief Reefs occurred over a period of about 6 months at each location. We also compared the distribution of fishing boats in the region, before and after reclamation activities, and found that the most significant change in fishing behavior is that fishing boats are no longer detected within 12 nm of the artificial reefs. The fishermen appear to avoid these newly created "territorial waters," but continue to fish in the adjacent waters where the concept of exclusive economic zones or maritime median lines between nations does not appear to be recognized.

1. INTRODUCTION

The South China Sea (SCS) is the second largest semi-enclosed sea in the world, hosting a large marine ecosystem with terrestrial inputs from rivers [Dang, 2012; Pomeroy, 2012; Witter, et al., 2015] (Fig.1a). Most of the fishery resources in the SCS are either highly migratory or trans-boundary stocks, such as scad, mackerel, and tuna [Dang, 2012]. In the Philippines, the Fisheries Act categorizes fisheries as either municipal or commercial areas [Witter, et al., 2015]. Commercial fishing vessels of more than 3 gross tons can only operate legally in fishing areas further than 15 km from shore [Pomeroy, 2010; Muallil, et al., 2014; Witter, et al., 2015], and use advanced fish tracking devices (such as sonar) and "super lights" (submerged green LED lights) to attract fish at night [Muallil, et al., 2014]. Commercial fishing vessels are prohibited within the municipal waters or coastal waters extending from the shore up to 15 km seaward [Muallil, et al., 2014]. The waters around the Spratly Islands, given their abundant fishing resources, have long been traditional fishing grounds for fishermen from China, Taiwan, Vietnam, Malaysia and the Philippines [Dang, 2012]. The SCS has been under heavy fishing pressure for more than 30 years [Witter, et al., 2015]. Monitoring fishing activities in the SCS has been difficult, owing to the sheer number of vessels and the lack of reporting requirements for fishing vessels. This paper discusses the use of DNB imagery to monitor the presence and location of fishing vessels in the SCS, independent of vessel broadcasts, as well as its use for monitoring island-building activities.

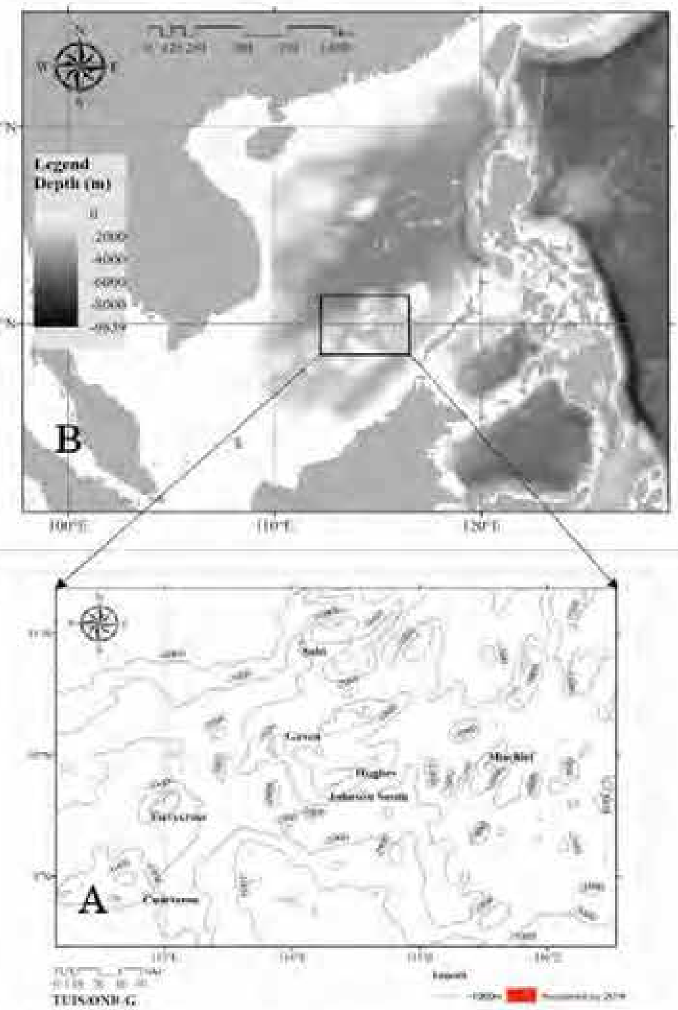

Fig.1 The bathymetry map of the South China Sea (A), and coral reefs reclaimed by the Chinese government as of 2016, including Mischief, Cuarteron, Johnson South, Hughes, Gaven and Subi Reefs (B).

The DNB of the Visible and Infrared Imaging Radiometer Suite (VIIRS) on the Suomi-National Partnership Project (Suomi-NPP) satellite has been used to observe the global distribution of lights at night [Johnson, et al., 2013; Levin & Zhang, 2017; Levin, 2017]. The primary mission of the DNB is to provide visible and near-infrared spectral (500 to 900 NM) imagery of the Earth over illumination levels from full sunlight to quarter moon [Cao & Bai, 2014; Ma, et al., 2015; Kyba, et al., 2015]. The radiance observed by DNB ranges from a minimum radiance of 3 nW cm-2 sr-1, which has a minimally sufficient signal to noise ratio, to a maximum of 100 nW cm-2 sr-1, which is the saturation level of DNB instrument [Cao & Bai, 2014]. At night, the DNB maintains a nearly constant pixel footprint of 742 m of a side, where the subpixels are aggregated in both the scan and track directions according to a complex scheme to achieve the near constant resolution of 742 by 742 meters across scan and along track [Cao & Bai, 2014; Elvidge, et al., 2015].

The DNB data has been applied to the analysis of urban activities from street lights [Levin & Duku, 2012; Zhang, et al., 2013; Miller, et al., 2013; Katz & Levin, 2016; Levin & Phinn, 2016], the recognition of fishing boats from lights for fishing [Miller, et al., 2013; Straka, et al., 2015; Elvidge, et al., 2015], and metrological applications that monitor cloud distributions associated with fronts and typhoons [Miller, et al., 2012; Miller, et al., 2013; Hawkins, et al., 2014; Ma, et al., 2015; Walther, et al., 2015a; Walther, et al., 2015b; Wang & Cao, 2016]. The first two applications, to urban and fishery lights, are restricted by the moonlight reflected by clouds. This same reflected moonlight is sufficiently strong for about half of the 29.5-day lunar cycle to be used for the last application, monitoring cloud distributions [Miller, et al., 2013].

A better understanding of active point sources of light at night will potentially open up new opportunities for more quantitative applications of the DNB, including object tracking, and monitoring the stability of both the instrument and the environment [Cao & Bai, 2014]. Because the spatial footprint of the DNB is large enough that several boats could be present in a single pixel, a validation effort would be required to define the types of boats that are detected, in terms of the installed wattage of lighting, lighting types, shielding present on the lights, and orientation of the lights while in operation [Elvidge, et al., 2015].

We developed the DNB mean intensity analysis method discussed below, where we collected and averaged light from an area (5 km radius) which was based on the size of dredging and reclamation projects on the coral reefs in the SCS. Using this method, the increases in light intensity correlated well with the beginning of dredging activities. Pixel-based analysis did not work to detect the change of activities, since the location of dredges and construction vehicles continually changed.

In the absence of agreement on the geographic extent and ownership of the Spratly Islands and their surrounding waters, fishermen of one country do not know where to stop and sometimes unconsciously operate in the areas that should belong undisputedly to another state [Dang, 2012]. The distribution of fishing lights was monitored as a function of distance from the coral reef. This study revealed that fishermen no longer approach within 12 NM of recently constructed islands.

2. DATA AND METHOD

2.1 DNB MEAN INTENSITY METHOD

DNB imagery was used for this study to detect the temporal change in activities around the islands. Tokyo University of Information Sciences operates an X-band direct downlink receiving station on the Miyakojima Island to capture the data from Suomi-NPP. Signals received by this station cover the northern half of the SCS. The DNB and M12BT data are extracted from the scientific raw data record of VIIRS in real-time, combined to form the data for one day's observation covering the study area, and projected onto the map. The M12BT data, which is given as the brightness temperature, are utilized along with DNB data to identify the presence of clouds. Although an empirical method for identifying lights from fishing boats in the presence of lunar light reflected by clouds has been developed [Asanuma, et al., 2016], the data for this study is selected from imagery acquired during periods of low lunar illumination to eliminate reflected moonlight, which is noise when studying light associated with island-building activities.

The intensity of light around the islands where island-building was occurring was monitored to record and understand the temporal changes in light intensity during dredging, construction and post-construction activities. Instead of pixel-based analysis of DNB data, analysis in this study used the average radiance calculated from the DNB signal within an area surrounding each reef, as the reefs became islands. The region of interest for each area was defined by a circle with a 5 km radius (covering 78.5 km2) around the center of each reclaimed landmass; this was large enough to cover dredging operations, runways, and other anthropogenic features such as buildings and roads. Figure.2 shows the circular area over the Mischief Island. Each square shaped pixel on Fig.2 corresponds to one pixel of DNB from VIIRS, which covers 742 by 742 meters. The ArcMAP zonal statistics function was applied to get a DNB mean intensity from each circular zone. As clouds are not distributed uniformly within a scene, finding a cloud-free condition on one reef does not mean an equally cloud-free condition for other reefs. Several days before and after the new moon was used and, on the actual day of the new moon, clouds obscured the ground and blocked reception of light from sea-level activities.

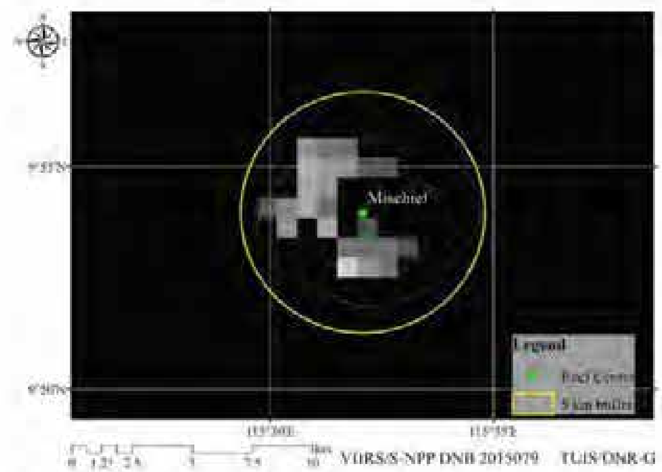

Fig.2 5 km buffer over Mischief Island to obtain DNB mean intensity on March 19, 2016.

2.2 ANALYSIS OF THE DISTRIBUTION OF FISHING LIGHTS AROUND RECLAIMED AREAS

The spatial distribution of fishing lights was analyzed in and around the reclamation projects over the course of time. Whereas permanently submerged reefs have no territorial waters associated with them, islands may have a territorial sea stretching out 12 NM from their baseline (usually the low water mark); however, the rights associated with man-made islands are very much in question. This aspect of the study was intended to shed light on actual behavior, presumably reflecting the fishermen's perception of the balance between their rights and risks. The SCS study area includes seven such man-made islands, shown in Figure 3. Around each, we have drawn a 12 NM radius circle defined from the baseline of the reclaimed area. In some of these, there remains an ambiguity on the baselines, as the coral reefs that are exposed at low tide, and are within 14 miles of the island may extend the territory associated with the man-made feature. Mischief and Subi reefs are straight-forward, having been reclaimed by covering most of a single coral reef. Other reefs, such as Gaven, Chigua and Johnson South, are more complicated, having both reclaimed land and as-yet unreclaimed portions of the original reef. In this analysis, the lunar light-free and cloud-free DNB data were used to study the spatial distribution of fishery-related lights in the SCS.

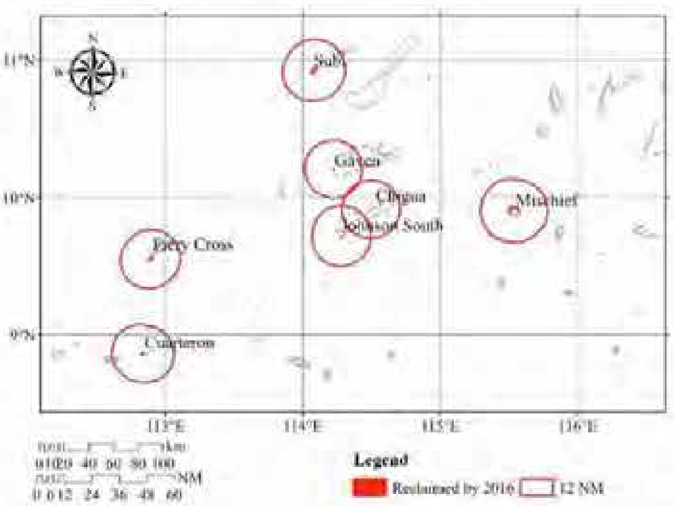

Fig.3 Reclaimed coral reefs by the Chinese government (■) and estimated territory of 12 NM (□).

3. RESULTS

3.1 DREDGING AND RECLAMATION ACTIVITIES.

Fiery Cross Reef, Subi Reef, and Mischief Reef were selected to study the possibility of analyzing temporal changes in activities around these islands that could be detected by DNB. Fig.4-A, -B, and -C are plots of the time series of DNB mean intensity from 2014 to 2016 for Fiery Cross Reef, Subi Reef, and Mischief Reef, respectively.

Data from Fiery Cross Reef (Fig.4-A) showed a DNB mean intensity at or near 0 nW cm-2 sr-1, until August of 2014. The DNB mean intensity then increased gradually up to 4 nW cm-2 sr-1 from September of 2014 to June of 2015, and a slightly higher level, around 6 nW cm-2 sr-1, was observed in November of 2016, with some month-to-month variation observed around that time. The first dredger adjacent to the reef was observed on August 14 of 2014, in high-resolution aerial imagery posted by the Center for Strategic International Studies Asia Maritime Transparency Initiative (AMTI) [AMTI, 2016]; this corresponds to the period of the increased DNB mean intensity observed in September of 2014. The DNB mean intensity reached 4 nW cm-2 sr-1 in June of 2015, followed by a significant dip, corresponding to the time when the AMTI imagery showed the finished coastline and the last observed presence of the dredgers. Dredged material was deposited over the existing coral reefs to create 677 acres (2.74 km2) of island by March of 2015 [AMTI, 2016]. Surface structures and a runway were constructed following the dredging and deposition. A civilian aircraft conducted the first-ever landing on the new airstrip on Fiery Cross Reef on January 2, 2016 [Tiezze, 2016].

Data from Subi Reef (Fig.4-B) showed a DNB mean intensity at or near 0 nW cm-2 sr-1, until January of 2015, which corresponds to the period when the first dredgers at Subi Reef were observed in high resolution aerial imagery, on January 26, 2015 [AMTI, 2016]. The DNB mean intensity then increased gradually up to 8 nW cm-2 sr-1 from February to June 2015, and reached around 10 nW cm-2 sr-1 in November 2016, although considerable variation was observed. The coastline of Subi Reef had been altered, assuming its final polygonal shape, with a protected harbor, by June 2015. The last dredgers were observed on September 3, 2015, after 976 acres (3.95 km2) of island had been reclaimed [AMTI, 2016; Tiezze, 2016]. Buildings and a 3000-meter runway were then constructed. A civilian plane landed on Subi Reef for the first time on July 12, 2016 [AMTI, 2016; Xinhuanet, 2016], while the highest DNB mean intensity, around 11 nW cm-2 sr-1 was recorded in August of 2016.

Data from Mischief Reef (Fig.4-C) showed a DNB mean intensity at or near 0 nW cm-2 sr-1 until January of 2015, corresponding to the arrival of the first dredger, which was observed at Mischief Reef on January 25, 2015 [AMTI, 2016]. The DNB mean intensity then increased gradually up to 6 nW cm-2 sr-1 from February 2015 to June of 2015, and then to 10 nW cm-2 sr-1, observed in November 2016, although month-to-month variations were observed. Dredging and deposition operations continued until the middle of 2015. Aerial photography showed the last dredgers on June 10, 2015, at which point the final coastal line bounded 1367 acres (5.53 km2) of reclaimed island [AMTI, 2016; Macias, 2016]. The buildings and a 3000-meter runway were then constructed. The highest DNB mean intensity around, 15 nW cm-2 sr-1, was observed in August of 2016, following the first use of the runway by a civilian plane that landed on Mischief Reef on July 12, 2016, the same day as the first landing on Subi Reef [AMTI, 2016; Macias, 2016].

All three coral reefs were quite dark until the dredging started. The pace of dredging operations may depend on operational factors as well as the area to be reclaimed. Dredging operations at Fiery Cross Reef lasted about 10 months. Dredging at Subi Reef and Mischief Reef lasted only 6 months, although the final area reclaimed for each was larger than the area reclaimed for Fiery Cross Reef.

The beginning of dredging is clearly observed as an increase in DNB mean intensity at all reefs. At the end of dredging operations, DNB mean intensity at Subi Reef and Mischief Reef dropped noticeably, while the corresponding change at Fiery Cross Reef was not clear.

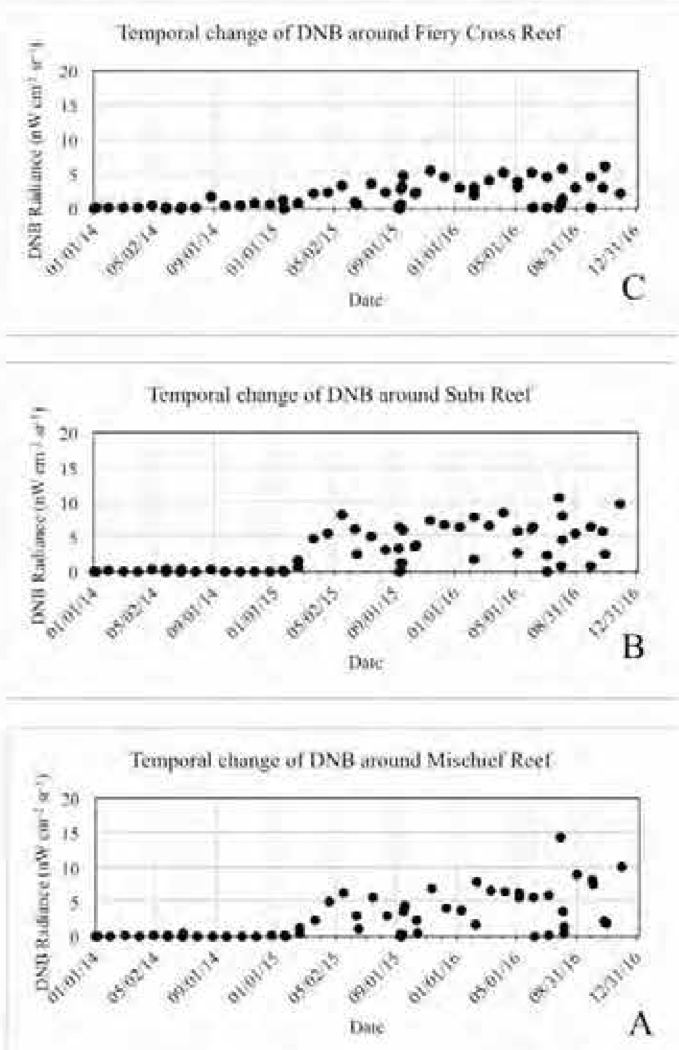

Fig. 4 Time series of DNB mean intensity of Fiery Cross Reef (A), Subi Reef (B), and Mischief Reef (C) from 2014 to 2016.

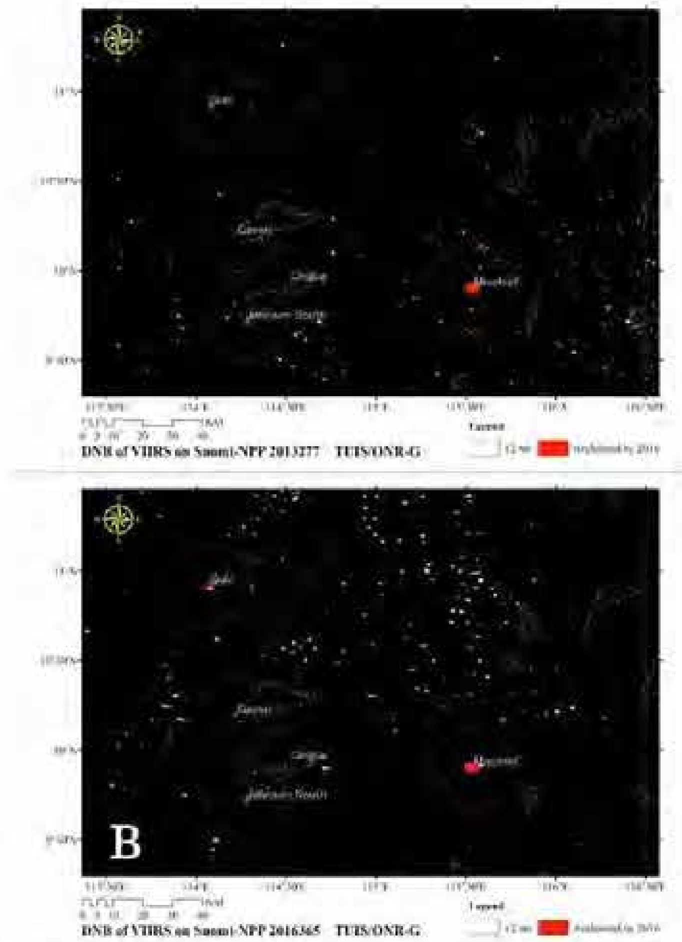

Fig.5 Distributions of fishing lights near the Subi, Gaven, Chigua, Johnson South, and Mischief Islands on October 4, 2013 (A) and December 30, 2016 (B). Circles on the figure are drawn 12 NM from the baseline of reclaimed islands.

3.2 DISTRIBUTION OF FISHING BOATS BEFORE AND AFTER OF RECLAMATION

Figs.5-A and B exhibit the distribution of fishing lights near the Subi, Gaven, Chigua, Johnson South, and Mischief Islands on October 4, 2013 and December 30, 2016, respectively. In Fig.5-A, the fishing lights are seen both outside and inside the red circles, which show the 12 NM range from the baselines of reclaimed areas and small stations which existed even prior to the reclamation activities. In contrast, Fig.5-B shows fishing lights only outside of the red circles. Fishermen know their own location at night from GPS as well as from lighthouses on the islands. The lighthouses, which are 50 m high, were built on each reclaimed island by the Chinese government. The lights from the lighthouses can be seen at a distance of about 18 NM from the fishing boats (limited by the Earth's curvature).

4. DISCUSSION AND CONCLUSION

The lights associated with the dredging and reclamation activities around several SCS reefs were analyzed with DNB mean intensity in a region around each area of interest. A slight increase in DNB mean intensity was observed at the beginning of dredging at Subi Reef and Mischief Reef. Similarly, a sharp reduction in DNB mean intensity was observed at the end of dredging at Subi Reef and Mischief Reef, but that drop in intensity was not as clear at Fiery Cross Reef. It is estimated that the dredging period at Subi and Mischief Reefs were about 6 months each, judging from the changes of DNB mean intensities. Although abrupt changes in DNB mean intensity were not observed at Fiery Cross, it is estimated that the dredging period at Fiery Cross Reef was about 10 months, which is longer than dredging at Subi or Mischief Reefs. The area of Fiery Cross Reef was 2.74 km2, which is smaller than either Subi Reef or Mischief Reef, which are of 3.95 and 5.53 km2 respectively. The number of dredgers is unknown, but a gradual increase in the number of dredgers may correlate with the steady increase in DNB mean intensity noted in January 2015, when dredging operation started at these reefs.

All three reclaimed reefs had ground facilities and runways built by August 2016. The major source of lights detected by DNB can be attributed to those ground facilities, but not lights along runways. A steep increase of DNB mean intensity on Subi Reef and Mischief Reefs may be explained by lights from the ground facilities, while at Fiery Cross Reef, with less extensive ground facilities, the data showed a less obvious inflection in the DNB mean intensity time series at the end of the dredging period in June 2015.

The comparison of the spatial distribution of fishing boats before and after the reclamations indicate that the most significant change following the reclamation activities was that fishery boats stayed more than 12 miles away from the newly constructed islands. The fishermen avoided the territory but continued working in adjacent waters, although no agreement on exclusive economic zones and intermediate lines between nations in the SCS region existed. For the question raised by Dang, This research suggests that the fishermen decided on their own to approach only as far as they could while avoiding disputes over the fishery resources.

The DNB data from the Suomi NPP satellite has proven to be a useful tool for monitoring island dredging and reclamation and other nighttime activities, such as fishing, in the SCS.

5. ACKNOWLEDGEMENT

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THE GEORGETOWN INSTITUTE OF DIPLOMACY:
AN IDEAL FELLOWSHIP LOCATION FOR EXPLORING THE SYNERGY BETWEEN DIPLOMACY AND MARITIME DOMAIN AWARENESS

Steven Keating, National Security Law Fellow, Georgetown University, Institute for the Study of Diplomacy

One does not routinely see "diplomacy"[1] in the same sentence as "Maritime Domain Awareness"[2] (MDA). A common misconception is that diplomacy only takes place in formal meeting rooms,[3] and MDA activities solely occur in intelligence/military settings. In reality, however, diplomacy and MDA are interdependent force multipliers that function in a system of international law to advance national security objectives.

In 2016, I was selected for an Office of the Director of National Intelligence (ODNI) National Security Law (NSL) Fellowship to research security issues related to the maritime domain.[4] Established in 2015, the ODNI fellowship program was designed to further the professional development of Intelligence Community (IC) attorneys and expand the scholarly literature on legal topics of interest to the IC. An ideal location for achieving these two objectives is the Georgetown University Institute for the Study of Diplomacy (ISD), which brings together experienced diplomats, academics, and other practitioners to explore global challenges. The purpose of this article is to: (1) introduce the vital relationship between diplomacy and MDA, and (2) briefly highlight why an ODNI-sponsored fellowship at the Georgetown ISD is a worthy investment for the IC.

DIPLOMACY AND MDA

In today's global economy, a nation's success is often determined by its strategic use of the maritime domain. More than 70% of the earth's surface is covered by water,[5] and over 90% of the world's trade is transported by ship.[6] The maritime domain is a mega-set of things, places, risks, and opportunities—the geopolitical competition over which can lead some nations to violent conflict.[7] Geospatial intelligence[8] (GEOINT) is a critical component of MDA because GEOINT enables a nation to geolocate its assets and those of other nations. The location of assets in the maritime domain determines a nation's rights and responsibilities under international law. Leveraging timely MDA, supported by GEOINT, places a nation in a stronger posture to practice effective diplomacy in advancing its interests. For example, in December 2016, the U.S. State Department reportedly issued a formal protest to China following its seizure of an underwater autonomous glider in international waters within the South China Sea.[9] Accurate MDA intelligence of the glider's location at the time it was seized justified this démarche to China.

Described as both a process and a desired end-state,[10] MDA is a concept embraced by the international community, including the United Nations.[11] Because (like the maritime domain itself) MDA is global, efforts to achieve it necessitate multidisciplinary, interagency, and international coordination. The success of MDA therefore depends upon cooperative partnerships. Although much emphasis has been placed upon the utility of technology and automation of big data analytics in MDA,[12] the human factor is indispensable. Christian Bueger and Amaha Senu of Cardiff University in Wales stated this fact when they wrote, "What is most important in the US understanding of MDA is the emphasis put on not just gathering of 'big data', but also on the sharing of information across states and organizations."[13] Productive information sharing is

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[1]Diplomacy is defined as "the art and practice of conducting negotiations and maintaining relations between nations[.]The U.S. Department of State, Online Diplomatic Dictionary. See https://diplomacy.state.gov/discoverdiplomacy/references/169792.htm - D (last visited Apr. 1 2017).

[2]MDA is defined by the United States, as "the effective understanding of anything associated with the maritime domain that could impact the security, safety, economy, or environment of the United States." The White House, The National Maritime Domain Awareness Plan (NMDAP) for the National Strategy for Maritime Security (2013) at 2. https://www.hsdl.org/?view&did=747691 (last visited Apr. 1, 2017).

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[4]The Maritime Domain is defined as "...all areas and things of, on, under, relating to, adjacent to, or bordering on a sea, ocean, or other navigable waterway, including all maritime-related activities, infrastructure, people, cargo, vessels, and other conveyances." The White House, 2013, The National Maritime Domain Awareness Plan (NMDAP) for the National Strategy for Maritime Security, at 2. https://www.hsdl.org/?view&did=747691 (last visited, Mar. 31, 2017).

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[8]"Geospatial intelligence" means the exploitation and analysis of imagery and geospatial information to describe, assess, and visually depict physical features and geographically referenced activities on the earth. Geospatial intelligence consists of imagery, imagery intelligence, and geospatial information." Also called GEOINT. 10 U.S.C. § 467(5) (2017).

[9]See W.J. Hennigan, China Seizes U.S. Underwater Drone in South China Sea, Prompting a Formal Complaint, L.A. Times, Dec. 16, 2016, http://www.latimes.com/nation/politics/trailguide/la-na-trailguide-updates-china-seizes-submarine-drone-in-south-1481910244-htmlstory.html. (last visited Apr. 12, 2017).

dependent upon trust-based relationships with foreign nations; diplomacy can improve international information sharing and thus enhance the quality of MDA.[14] The State Department has committed to "leverage its diplomatic resources and influence, while coordinating closely with other components of the United States government, to promote and enhance close cooperation among sovereign nations…"[15] For example, over the past few years, the State Department has been very active in regional capacity building to enhance MDA in Africa[16] and South East Asia.[17] Another "human factor" benefit that diplomacy brings to MDA is the unique placement and perception of diplomats to discern how a foreign leader's intentions to act in the maritime domain might affect the United States.

THE GEORGETOWN UNIVERSITY INSTITUTE FOR THE STUDY OF DIPLOMACY

An ideal establishment in which to study national security issues, such as the relationship between diplomacy and MDA, is the Georgetown ISD. The ISD is an integral part of the Edmund A. Walsh School of Foreign Service. Directed by a retired career diplomat, Ambassador Barbara K. Bodine, the ISD "brings together diplomats, other practitioners, scholars and students from across and beyond Georgetown University to explore global challenges and evolving demands of diplomatic statecraft, to better understand the nexus of theory and practice, and to enhance and expand an appreciation of the role of diplomacy as a critical tool in national policy."[18]

The leaders of the ISD have real-world, diplomatic experience applying MDA to statecraft in matters such as MDA capacity building and counter-piracy activities.[19] In addition to its leadership, the ISD hosts a total of six diplomatic, IC, and military fellows. These fellows are all experienced practitioners in their particular areas of expertise; some of them have recent experience with MDA-related issues, such as territorial disputes in the South China Sea and migrant flows in the Mediterranean. Collaborating on a daily basis with the leaders and fellows of the ISD enhances an attorney's understanding of the critical connections between diplomacy, MDA, and the law.

The Georgetown ISD provides access to a wealth of campus resources, including the library, faculty and MDA-related events. The ISD is located on the main campus of Georgetown University in Washington, DC, one block from the Lauringer Library, which contains 2.3 million volumes. Online services facilitate electronic research for both legal and multidisciplinary databases. Another invaluable resource is the Georgetown University faculty, which includes recognized experts in Asian maritime affairs, environmental security, and the Law of the Sea. Fellows have the opportunity to observe classes and serve as guest lecturers. In addition, Georgetown hosts world leaders and respected scholars for events directly related to MDA. For example, the university recently sponsored the following three events: (1) Our Ocean, One Future Leadership Summit (attended by United Nations officials and the Secretary of State), (2) a speech by the former President of Kiribati on the impact of rising sea levels to low-elevation island states and the use of diplomacy to seek long-term adaptations to territory loss, and (3) a multi-panel discussion by scholars on "Maritime Tensions in Asia: Dangers, Diplomacy, and Defense."

In addition to cutting-edge symposia at Georgetown University itself, the ISD's location is in close proximity to the following organizations that have sponsored MDA-relevant events: The Arctic Research Consortium, The Center for Strategic and International Studies, and The National War College. One of the most valuable workshops I attended was the Eyes north—Ears Open: Anticipating and Responding to The New Arctic Security Landscape, held in Washington on February 1-2, 2017. This workshop was organized by the National Maritime Intelligence-Integration

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[10] Joseph L. Nimmich; Dana A. Goward, Maritime Domain Awareness: The Key to Maritime Security, 83 Int'l L. Stud. Ser. US Naval War Col. 57, 65 (2007) at 63.

[11] See United Nations, International Maritime Organization Amendments to the International Aeronautical and Maritime Search and Rescue Manual, MSC.1/Circ. 367, May 24, 2010, http://www.imo.org/blast/blastDataHelper.asp?data_id=29093&filename=1367.pdf (last visited Apr. 1, 2017).

[12] John Mittleman, Operational Aspects of Maritime Domain Awareness, NMIO Technical Bulletin, Vol. 11 (October 2016) at 4. See also Ionnis Parisis, The Maritime Dimension of European Security: Strategies, Initiatives, and Synergies, Tufts University, Fletcher School of Law and Policy Working Paper 1/2015, Feb. 2015 at 53.

[13] Christian Bueger & Amaha Senu, Knowing the Sea: The Prospects and Perils of Maritime Domain Awareness, from Web Portal, Piracy Studies.Org: The Research Portal for Maritime Security, Jul. 8, 2016,
http://piracy-studies.org/knowing-the-sea-the-prospects-and-perils-of-maritime-domain-awareness/
(last visited Apr. 1, 2017).

[14] See Van Jackson, et al., Center for New American Security, Networked Transparency: Constructing a Common Operational Picture for the South China Sea (2016) at 43, https://s3.amazonaws.com/files.cnas.org/documents/CNAS Report-COP-finalc.pdf (last visited Apr. 4, 2017).

[15] United States Department of State, International Outreach and Coordination Strategy for The National Strategy for Maritime Security (2005) at 1. https://www.state.gov/t/pm/rls/othr/misc/255321.htm (last visited, Apr. 2, 2017)

[16] U.S. Department of State, U.S. Counter Piracy and Maritime Security Action Plan, https://www.state.gov/t/pm/rls/othr/misc/255332.htm (last visited Apr. 3, 2017).

[17] Prashanth Parameswaran, America's New Maritime Security Initiative for Southeast Asia: A look at the Southeast Asia Maritime Security Initiative as it gets underway, The Diplomat, Apr. 2, 2016, http://thediplomat.com/ 2016/04/americas-new-maritime-security-initiative-for-southeast-asia/ (last visited April 11, 2017).

[18] The online Description of The Georgetown Institute for the Study of Diplomacy presents a succinct mission statement for the ISD. See https://isd.georgetown.edu/ (last visited Mar. 31, 2017).

[19] Ambassador Linda Thomas-Greenfield, serving as the Senior State Department Fellow at the ISD, was recently the Assistant Secretary of State for African Affairs, where she was keenly aware of the importance of MDA to maritime security in Africa and U.S. national security objectives.

Office (NMIO). Participants included Canadian and U.S. representatives from academic, diplomatic, intelligence, law enforcement, military, and public policy communities. This collaborative workshop epitomized the international, multidisciplinary, and human-networked nature of MDA.

CONCLUSION

The ODNI-sponsored NSL Fellowship at the Georgetown ISD is a worthy investment for the IC because selected fellows have an exceptional opportunity to grow professionally while conducting legal and policy research in a broad range of disciplines of value to the IC. In terms of my own professional development, the NSL Fellowship has: (1) expanded my practical knowledge of both the customary and conventional international Law of the Sea, which is increasingly consequential to the security challenges facing the United States in the 21st Century; (2) furthered my awareness for how GEOINT is used by MDA stakeholders and how the provision of GEOINT can be improved to maximize MDA; and (3) increased my legal understanding of the dynamic synergy between diplomacy and MDA—how MDA can empower diplomacy and how diplomacy can facilitate the capacity building essential for maximizing international security consistent with international law.

The expertise I have gained during this NSL fellowship will significantly improve my ability to provide optimal legal advice on matters related to potential maritime domain flashpoints, such as: maritime territorial disputes, maritime terrorism, piracy, and natural resource exploitation in the Arctic Ocean. Clearly, the many opportunities, resources, and networking available through the Georgetown ISD make it an excellent choice for future ODNI-selected attorneys to pursue professional development and conduct research in areas of high impact to the IC.

ABOUT THE AUTHOR

Steven G. Keating is an IC National Security Law Fellow at the Georgetown University ISD. He is an Assistant General Counsel for the National Geospatial-Intelligence Agency, where he has focused on intelligence oversight, maritime law, and international law. He holds a B.S. in Marine Transportation from the U.S. Merchant Marine Academy and a J.D. from Campbell University. He is a retired captain in the U.S. Navy Reserve and a U.S. Coast Guard licensed officer with a decade of maritime experience on a variety of operational and research platforms.

UNIVERSITY OF WASHINGTON CoSSaR STUDENTS ADDRESS REAL-WORLD STEM PROJECTS TO ENHANCE NATIONAL SECURITY, SAFETY AND RESILIENCE

Established in 2014, the Center for Collaboration for Safety, Security and Regional Resilience (CoSSaR) is a joint venture among the Human Centered Design and Engineering (HCDE) Department, the College of Engineering, and the Applied Physics Laboratory at the University of Washington. CoSSaR establishes a multi-disciplinary environment where professionals from a wide range of entities (Federal, State, County, City, Tribal, International, Public and Private) team with university experts to align strategies, processes and investments in systems for security, safety and resilience. Undergraduate and graduate level students are encouraged to collaborate with the CoSSaR team. Students are regularly employed as research assistants on active CoSSaR grants, and have the opportunity to put theory into practice under directed research group (DRG) classes that award credit for their participation in safety, security and resilience projects.

CoSSaR projects span the areas of security and law enforcement, disaster management, community engagement, and resilience. Examples of past and current projects include:

- Maritime Operations Information Sharing Analysis (MOISA) examined and analyzed the Puget Sound information-sharing environment for security and safety.
- Project Interoperability in the Puget Sound (PIPS) linked interoperability tools and concepts to mission requirements by building on the MOISA analytical work and CoSSaR's state and regional partnerships in the maritime domain to improve information sharing and safeguarding.
- Canadian-U.S. Maritime Information Sharing Pilot Project (CANUS) supports installation of a new information capability on the U.S.-Canadian border and is assessing the benefits of the new capability compared to current operations.
- Modeling Post-Disaster Housing Recovery is developing and applying new data and computer modeling methods to simulate post-disaster housing recovery. New computer models will enable policy-makers and planners to quantify the benefits and tradeoffs associated with possible pre- and post-disaster housing interventions.
- Effective Preparedness Messaging is a collaboration with the "Global Disaster Preparedness Center" (GDPC) at the Red Cross. CoSSaR is working to enhance the design and delivery of information to motivate and enable people to take actions to prepare for and cope with emergency situations.

Student involvement is a critical part of each of these projects. Taken as a whole, this portfolio of projects provides invaluable training and experience to the next generation of security and safety professionals. Following in their own words are descriptions of some of these experiences.

BEIER JIA –SENIOR, ELECTRICAL ENGINEER

As an undergraduate student, I participated in the qualitative analysis of a rich real-world text database comprised of observations collected during a regional earthquake exercise studied by CoSSaR under the PIPS project. The qualitative analysis consisted of using grounded theory to code these observations for examples of breakdowns in information sharing. The challenging piece of the analysis was to determine how to accurately categorize each excerpt according to its breakdown type. My confidence grew as I became more familiar with the categories and the observations. During the group discussion, we eliminated uncertainty regarding how to code the observations and continued to refine our categories, so that our research team arrived at an adequate level of agreement.

I really enjoyed working in this group full of talented undergraduates and graduate students facilitated by knowledgeable professors. Even though I am not majoring in HCDE, all other members were always very kind and patient in answering my questions. Their encouragement has been more of a help and motivation than they can ever know. I was recently accepted into several graduate programs. The experience I received as a member of the qualitative analysis group provided me with a depth of knowledge in research methodologies and practical teamwork experience, which I will use in my future graduate work.

ROBIN MAYS - PHD STUDENT, HCDE

CoSSaR has offered a rich platform for interacting with a wide range of agencies active in seeking to build resilience in communities throughout the world. In my focus on humanitarian response systems, I have been able to formally partner with European faculty and students on the cutting edge of information systems design and with humanitarian practitioners doing some of the most impactful work around the world for helping vulnerable communities in need.

First, with leading researchers at the European Research Center for Information Systems (ERCIS), we took on the challenge of proposing a new way to design technology for organizations committed to humanitarian and human rights law, where traditional design methods have previously failed. We investigated new collaborative design methods that are just beginning to redefine how we meet the demand for public ownership and community resilience. Second, with Red Cross/Red Crescent (RCRC) professionals, we have delved into the nexus of where public messaging meets technology. Through the use of human-centered design, we are developing key design principles for translating how the long established effective messaging of the RCRC can be best translated into effective design of digital tools and games for community resilience and readiness.

Picture 1: Robin Mays and Professor Mark Haselkorn in Lisbon, Portugal at a STEM security conference. STEM related research stretches across the globe.

Under CoSSaR, I am grateful for the opportunity to bring much-needed collaborations across the practice-academic divide, from leading experts in humanitarian work around the world to those leading the future of technology design. These successful experiences are nurturing long-term principles and partnerships for working across communities, government agencies, non-profits, for-profits and academia in the area of future resilience.

DHARMA DAILEY – PHD CANDIDATE, HCDE

Through CoSSAR, I have participated in empirical research on Puget Sound's safety and security professionals' information sharing practices as well as training and exercises. Understanding the "as-is" information sharing practices of safety and security professionals is foundational to making improvements to information sharing that support their mission. This grounded understanding is also instrumental to the research I have been conducting to understand how technologies like social media are changing how the public shares, produces, and receives information in times of crisis.

DEREK HULING – MASTERS-LEVEL RESEARCH STAFF, COSSAR

For the past two years I have been working with Dr. Scott Miles under a Washington State Sea Grant Hazard Resilience and Climate Adaptation Grant. Working with other engineering departments, coordinating and participating in resilience workshops, and developing decision support tools for practitioners has helped to focus my research interests, as well as providing tools and insights into the state of resilience in the Pacific Northwest.

Our preliminary simulation development work indicates a strong path for continuing research in evaluating and modeling infrastructure recovery using discrete-event simulation. This work will be continued under a grant awarded by the NSF under the CRISP program. CoSSaR's collaborative mission and access to premier faculty, staff, and resources creates an ideal environment from which to continue this research.

TOM WILSON – PHD STUDENT, HCDE

Working as part of a CoSSaR DRG, I have gained experience in conducting qualitative analysis of rich, real-world data gathered during the Cascadia Rising Disaster Exercise--the nation's largest emergency management exercise. The Cascadia Rising Disaster Exercise sought to test regional resilience along the Cascadia Subduction Zone, as an earthquake followed by a tsunami is one of the most complex disaster scenarios that emergency management and public safety officials face in the Pacific Northwest. As a Research Assistant within CoSSaR, I have been involved in analyzing observational data collected during the exercise, in particular focusing on the cause and effect of barriers to information sharing faced by state and Federal participants. Our findings will be used in future CoSSaR projects aimed at improving our understanding of information sharing during emergent events.

In other work with Dr. Kate Starbird, I've been investigating how online rumoring behavior varies by language during an emerging crisis event. Specifically exploring a rumor from the 2015 Paris attacks, I analyzed how Twitter rumoring behaviors varied across two languages: French, the primary language of the affected population; and English, the dominant language of Internet communication. This work offers insight into potential limitations of previous research of online rumoring, which often focused exclusively on English language content, and demonstrates the importance of considering language in future work.

MELISSA BRAXTON, MS, PHD CANDIDATE, HCDE/USER EXPERIENCE DESIGNER, 18F

Through COSSAR, I have had the opportunity to travel all over the Puget Sound region and engage directly with stakeholders throughout the large and diverse maritime safety and security community. Working directly with community members and software developers, I was able to apply human centered design methodology to co-design systems that support this community.

One particular project I was involved in focused on understanding how Puget Sound Federal and local port partners collaboratively plan and schedule their resources (e.g. crew, vessels) to accomplish interagency missions. Understanding these work processes is critical for many purposes, not the least of which is in the application of evidence-based human-centered methods. The need for a human centered approach here is given impetus by the pending introduction by Department of Homeland Security Science & Technology of a new planning and scheduling capability that will affect the way the region currently works.

Picture 2: Melissa Braxton participates as a panelist at a STEM related event with senior leaders in the community

In addition to (1) providing a better understanding of planning and scheduling work processes, and (2) helping us design enhancements to how this work is accomplished, my activity with CoSSaR also helps address a known need for a repeatable process to incorporate port partners' input into the design of future systems to support interagency operations.

SARAH YANCEY, MPH, MPS, RESEARCH SCIENTIST, COSSAR

As a staff research scientist with the CoSSaR team, I have endless opportunities to further my professional interests and expertise in emergency management, regional security and resilience, and public health via several active CoSSaR projects. As a recent graduate (MPH-2013 and Masters of Homeland Security-2016), CoSSaR provides a platform for enhancing my more specialized professional skills via our unique work in the regional maritime sector, the arctic domain, and the regional security arena.

Currently, I work on the NMIO-funded CANUS project. On this project, I work with Dr. Mark Haselkorn and Dr. Sonia Savelli as the leaders of the Assessment Working Group, which meets regularly with participating stakeholders to establish and evaluate measures of effectiveness during the "as-is" and "to-be" operational situations.

In addition to CANUS, I currently serve as co-PI with Dr. Haselkorn on a collaborative research project to evaluate effective traffic incident management (TIM) along the Seattle I-5 Corridor. Co-funded by the Washington State Department of Transportation and the Seattle Department of Transportation, this initiative brings TIM stakeholders (regional transportation entities, first responders, law enforcement, non-profits and academia) together to identify processes, technologies and other inputs to improve TIM and reduce congestion along the Seattle I-5 Corridor.

Overall, my transition from student to CoSSaR staff research scientist has offered countless benefits via professional networking, advanced skill development in the Puget Sound regional security and safety arena, and the invaluable opportunity to successfully grow as a research scientist.

Student participation in CoSSaR projects brings them into collaboration with government sponsors, agency professionals, and regional leaders. This results in professional relationships that benefit them beyond the length of the project. For example, Melissa Braxton's collaborations in MOISA and PIPS have led to a cutting edge position at 18F, a unit under the Government Services Administration focused on bringing human centered design techniques to the Federal government.

The thrust of the students' statements presented here emphasize how much their work with CoSSaR has contributed to their evolving careers. However, we, the CoSSaR leadership, feel fortunate to have worked with this cohort of bright, innovative, and committed students. We are confident that they will go on to provide important service to their country and the world, even as they establish fulfilling careers for themselves. Innovative centers like CoSSaR at the University of Washington serve many purposes, not the least of which is their ability to attract the best and the brightest STEM students to engage in exciting, real-world impactful research.

Picture 3: Sarah Yancey engages with fellow STEM students

VESSEL DETECTION AND CLASSIFICATION BY SPACEBORNE SYNTHETIC APERTURE RADAR FOR MARITIME SECURITY AND SAFETY

Kazuo Ouchi, Former Professor: National Defense Academy, Japan

ABSTRACT:

In the field of synthetic aperture radar (SAR) technology and applications, strong interest, in recent years, is focused on the maritime domain awareness (MDA), and the present article is a summary of the current status and future trend of vessel detection and classification by spaceborne SAR. To date, a number of algorithms of vessel detection have been proposed and used routinely in practice. Here, several major algorithms are illustrated, including the conventional constant false alarm rate (CFAR) and recent polarimetric analyses. Unlike vessel detection, the algorithms of vessel classification are still under development partly because of coarse spatial resolution and partly because of shortage of SAR images corresponding to each vessel category as reference data for comparison. However, with increasing number of spaceborne SARs with finer resolution, a few operational algorithms have been proposed. In this article, the principal theories and future trend of vessel classification are described with examples.

KEY WORDS: Synthetic Aperture Radar (SAR), Vessel Detection, Classification, Maritime Domain Awareness

1. INTRODUCTION

In the last several decades, vessel detection and classification by synthetic aperture radar (SAR) attracted much attention for its allweather and day-and-night abilities of acquiring radar imagery. These characteristics are useful particularly for the maritime domain awareness (MDA) associated with vessel traffic control, fishery, illegally operating vessels including piracy, smuggling and those intruding territorial waters, and monitoring of ocean environment such as oil spills. In general, most of vessels use the automatic identification system (AIS), vessel monitoring system (VMS), or long-range identification and tracking of ships (LRIT) for reporting and inter-exchanging their information such as their identifications, positions, and designations. However, some vessels are not willing to use such systems, and therefore, it is necessary to detect and identify these "dark" vessels from space using SARs and/or electro-optical sensors.

During the early stage of research on vessel detection, airborne SAR were used, although several attempts were reported using the data by the SEASAT-SAR, the first of its kind of spaceborne SAR aiming at the ocean monitoring launched in 1978. Since then, a substantial number of spaceborne SARs have been launched, and the spatial resolution has been improved; new technologies have also been developed including radar interferometry and polarimetry (Ouchi 2013). Along with the advance in SAR technology, vessel detection using SAR imagery has been advanced, and a number of ship detection algorithms have been proposed and used in practice (Arnesen and Olsen 2004; Crisp 2004; Greidanus and Jackson 2005; Stasolla et al. 2016; Vachon et al. 2014).

The most popular and used algorithms are the conventional CFAR (constant false alarm rate) with a suitable clutter model and adaptive threshold model (without clutter model). Other algorithms include those based on the sub-look (multi-look) spectral analyses, standard deviation filter, wavelet transform, and others. The methods based on polarimetric SAR (PolSAR), and along-track interferometric SAR (AT-InSAR) data have also been proposed as alternative approaches.

The progress of vessel classification is slow compared with vessel detection partly because the spatial resolution of spaceborne SARs was not fine enough to describe the images of vessels in detail, and partly because the number of SAR images of a same category was not enough to be used as reference data. In recent years, however, the spatial resolution of some spaceborne SARs has become as fine as a few meters and even sub-meters, and the images of vessels can reveal the fine structure of vessels. Further, with increased number of spaceborne SARs and development of numerical simulation, data banks have been accumulated, resulting in several algorithms for vessel classification and recognition. At present, the main approach to vessel classification is based on the feature-based template matching using parametric vectors extracted from SAR and reference images. Although under development, the methods based on PolSAR data, pattern matching and machine learning have been proposed.

In this article, the main algorithms of vessel detection are summarized, followed by those of classification with some examples.

2. VESSEL DETECTION

2.1 PRINCIPLES OF VESSEL DETECTION BY SAR

SAR is a side-looking imaging radar using the microwave, and the frequency bands of the current spaceborne SARs are X-band to L-band corresponding respectively to the wavelengths of 2.4-3.8 cm (12.5-8.0 GHZ) and 15-30 cm (2.0-1.0). The principle of vessel detection is based on the different backscattering processes from vessels and sea surface. As in Figure 1, the dominant radar backscatter from the sea surface is the single-bounce surface scattering;

while that from a vessel consists of the surface scattering as well as double-bounce and multiple-bounce (volume) scatterings. Thus, the image amplitude (or intensity) of the sea surface is, in general, smaller than that of the vessel.

Figure 2 is an example showing the images of vessels acquired by the L-band SAR onboard the Japanese PALSAR satellite. The white "dots" correspond to vessels, where HH implies that the transmitted signal is with horizontal polarization and the reception is also horizontal polarization (co-polarization). HV means that the transmission is with horizontal polarization and vertical polarization reception (cross-polarization). As in Figure 2, vessel detection is best performed with HV-polarization data where the radar backscatter from the sea surface is smallest among other two polarization combinations. The cross-polarization data are not always available in practice, so that HH-polarization data are often used for their smaller radar backscatter from the sea surface than VV polarization.

2.2 VESSEL DETECTION ALGORITHMS

As mentioned in the preceding section, a number of vessel detection algorithms have been proposed to date.

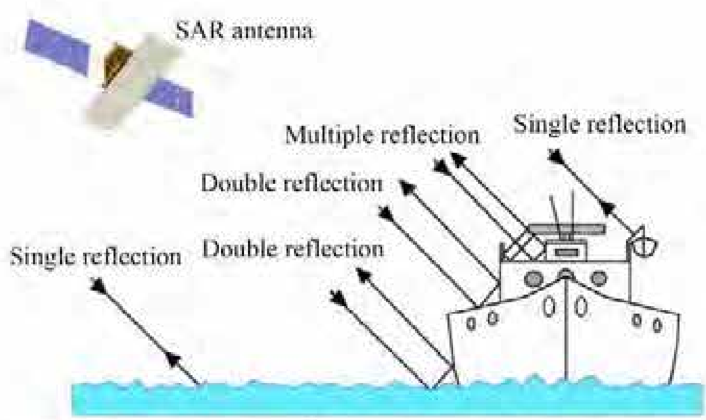

Figure 1. Different backscattering processes from a vessel and sea surface.

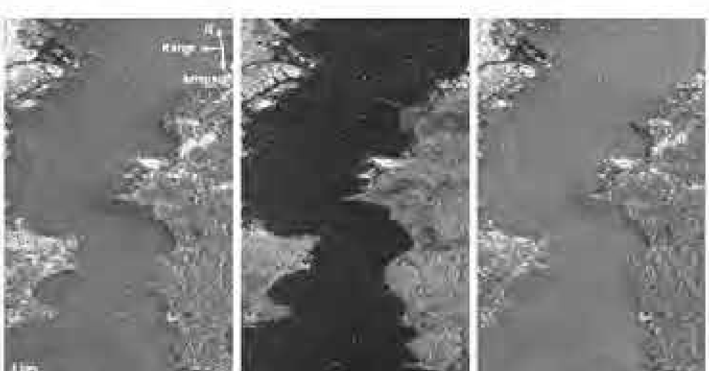

Figure 2. ALOS-PALSAR L-band SAR images of Tokyo Bay (09.10.2008). From left to right: HH-, HV-, and VV-polarization amplitude images. Yokohama is located on the top-left.

The following algorithms can be considered as the main approach to vessel detection.

1. CFAR with a clutter model
2. Adaptive threshold
3. Sub-look coherence, entropy, and generalized likelihood ratio test (GLRT)
4. Standard deviation, median, and wavelet transform filters
5. Polarimetric analyses
6. AT-InSAR

Table 1 shows selected institutes and algorithms of vessel detection. Note that not all systems are operational, and some systems are commercially available so that detailed algorithms are often classified. In some algorithms such as SIMONS, a vessel classification algorithm is applied after detection in the processing chain (Margarit and Tabasco, 2011).

Table 1. Selected institutes and ship detection algorithms.

Institute	System	Algorithm
JRC/TNO (ESA/Netherland)	SUMO	CFAR with K-distribution
QinetiQ (UK)	MaST	Adaptive threshold
Veridian Systems Division (USA)	-	Adaptive threshold
CCRS/MDA/DRDC (Canada)	OMW OceanSuite	Modified CFAR with K-distribution
CLS (France)	SARTool	CFAR
NOAA/NESDES (USA)	AKDEMO	CFAR
Kongsberg/FFI (Norway)	MEOS NRTSAR	CFAR with K-distribution
Edisoft/ISEL Lisbon (Portgual)	VDC Software/ SUMO	Adaptive threshold / Sub-look
MSS/MELCO (Japan)	VESSELFINDER/ HuygensWorks	Standard deviation filter
GMV Aerospave & Defense (Spain)	SIMONS/SIDECAR	Wavelet transform filter
eOsphere Ltd. (UK)	R&G	Median filter/ Pauli decomposition
Open University/ NDA (UK/Japan)	Not in operational	Notch filter/ Sub-look CFAR

SUMO: Search for Unidentified Maritime Objects, MaST: Maritime Surveillance Tool, OMW: Ocean Monitoring Workstation, AKDEMO (Alaska SAR Demonstration), MEOS: Medium Earth Orbit Satellite, AEGIR (Aegir is the name of a sea god in the old Scandinavian myth), SIMONS: Ship Monitoring System

2.2.1 CFAR

As the name stands, CFAR is a technique to detect targets with a constant false alarm rate irrespective of the variant parameters such as the mean and standard deviation of a probability density function (PDF) of the background clutter (El-Darymli et al. 2013). Thus, the CFAR algorithm assumes a probability pfar of false alarm required by a user, and compute the threshold value z_T from

$$p_{far} = p(z > z_T) = \int_{z_T}^{\infty} p(z)dz \qquad (1)$$

where p(z) is the PDF of the background clutter, and z is the image intensity or amplitude. For most of SAR images of sea surface, however, the mean and variance of clutter vary from an area to another, so that the shape of p(z) also changes, and, for a fixed z_T , p_{far} is no longer constant. In the CFAR algorithm, p(z) is made invariant by changing variables. For example, the traditional CFAR assumes a Rayleigh clutter, and is known as the cell-averaging CFAR. The Rayleigh distribution is given by

$$p(z) = \frac{2z}{\sigma_z^2} \exp\left(-\frac{z^2}{\sigma_z^2}\right) \qquad (2)$$

where σz is the standard deviation (SD). The mean of the reference pixels is $<z>=\pi^{1/2}\sigma_z/2$. Now, define a new variable as z'=z/< z >=2z/(π1/2σz), and express the image in terms of z'. Then, from the relation p(z)dz = p(z')dz', the following PDF can be obtained.

$$p(z') = \frac{\pi z'}{2} \exp\left(-\frac{\pi}{4} z'^2\right) \qquad (3)$$

Equation (3) is now independent of σz. The required threshold z_T for a preset false alarm p_{far} can then be computed by substituting Equation (3) into Equation (1), and targets can be detected with a constant p_{far} by applying this threshold to the SAR image. Here, the example of Rayleigh clutter is shown for brevity. However, in practice, sea clutter does not always obey Rayleigh distribution, but often obeys Weibull, log-normal, or K- distributions depending on SAR data and sea states, and accordingly non-Rayleigh CFAR is generally used for SAR data.

With reference to Table 1, the SUMO developed by JRC (Joint Research Center) uses a fast CFAR algorithm with a Kdistribution noise model. Similar algorithms were adopted by CLS (Collecte Localisation Satellites) and CCRS (Canada Center for Remote Sensing), and FFI (Norwegian Defence Research Establishment). The OMW developed by CCRS is essentially the same as the OceanSuite of MacDonald, Dettwiler and Associates (MDA) Ltd. and Defence Research and Development Canada (DRDC) (Vachon et al. 2014).

2.2.2 ADAPTIVE THRESHOLD

Adaptive threshold is used by QinetiQ, Kongsberg, FFI, Veridian Systems Division and Edisoft, in which the constant value c is adaptive depending on the SAR data, areas, and sea states. The MaST, for example, uses a boxcar moving window similar to CFAR as in Figure 1, where the mean and standard deviation within the signal and background windows are computed, and the threshold value is determined by comparison of these statistical quantities.

$$z_T = <z> + c\,\sigma_z \text{ or } z_T = c(<z> + \sigma_z) \qquad (4)$$

Thus, the algorithm is similar to the conventional CFAR, but does not assume any background noise model. It should be mentioned that the information on the MaST was available only in the website (Crisp 2004), which the author could access in 2011. But, the site is not available now maybe because of sensitive military applications.

2.2.3 STANDARD DEVIATION, MEDIAN, AND WT FILTERS

In the method of standard deviation filter developed by MSS (Mitsubishi Space Software), the standard deviation of each range line or a boxcar are first computed and subtracted by the mean. Since the images of vessels have larger SD values than those of sea surface, they are enhanced and can be detected easier than from the original pre-filtered image.

The R&G of eOphere applies a median filter to a single polarization amplitude image, followed by morphological filtering. In this system, the Pauli decomposition analysis is adopted if polarimetric data are available.

The algorithm of SIMONS (Margarit et al. 2011) is based on the discrete wavelet transform (WT) with the Harr wavelet. The algorithm is essentially target enhancement by noise reduction through the addition of the local mean and detected edges in different directions over neighbouring image pixels.

2.2.4 SUB-LOOK SPECTRAL ANALYSES

The sub-look approach requires two or more multi-look images, and the inter-look correlation property within a moving window is examined, i.e., the images of a vessel are correlated between looks, but those of sea surface are uncorrelated (Hwang and Ouchi 2010; Marino et al. 2015). The advantage of this method, unlike others, is the images of ships need not to be bright as long as they are correlated between looks. The disadvantage is that the resolution is degraded by sub-look processing. There are several different techniques in this approach, including the original sub-look coherence, sub-look entropy, GLRT (Generalized Likelihood Ratio Test), and others (Marino et al. 2015).

The sub-look coherence is defined as

$$\gamma = \frac{|\langle A_1 \cdot A_2^{*T} \rangle|}{\sqrt{\langle A_1 \cdot A_1^{*T} \rangle \langle A_2 \cdot A_2^{*T} \rangle}} \qquad (4)$$

where A_j (j =1,2) are the complex sub-images, ^{*T} means taking the complex conjugate transpose, and the angular brackets imply taking the spatial average within the moving window. An example of the intensity-based original sublook algorithm (Hwang and Ouchi 2010) is shown in Figure 3, where the image of a vessel embedded in clutter is enhanced and made visible in the coherence output

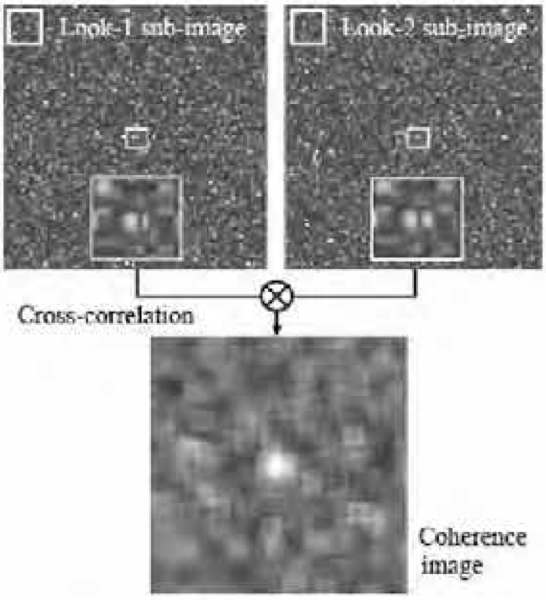

Figure 3. The original intensity-based sub-look spectral analysis for ship detection.

The sub-look entropy is defined as follows. Denoting the vector of N sub-images by $A=[A_1, A_2, A_3, \ldots, AN]$, the covariance matrix can be calculated as [C] = <A A*T>. Then, the entropy H is computed from

$$H = -\sum_{j=1}^{N} p_j \log_N p_j \qquad (5)$$

where pj is the probability for j-th scattering process,

$$p_j = \frac{\lambda_j}{\lambda_1 + \lambda_2 + \lambda_3 + \cdots + \lambda_N} \qquad (6)$$

and λ_j is the j-th eigenvalue obtained by the diagonalization of [C].

The GLRT is a new algorithm derived under the assumption of Gaussian clutter. However, it is robust such that it can be applied to compound-Gaussian clutter, e.g., Kdistribution often used to model sea clutter.

The validity of these techniques was examined using extensive SAR data over the European seas and Tokyo Bay with AIS data, indicating that on average the GLRT outperformed the other detectors for the images of small SNR as reported by Marino et al. (2015). The problem is that GLRT requires a certain numbers of sub-look images, resulting in substantial loss of resolution, so that it may not be suitable for detection of small ships.

2.2.5 POLARIMETRIC ANALYSES

The theory of PolSAR is well known (Lee and Pottier, 2009) and used mainly for classification over land and biophysical information retrieval in forestry and agriculture. For vessel detection, the principle is the different scattering mechanisms by vessels and sea surface as illustrated in Figure 1. As mentioned previously, the microwave backscatter from the sea surface is generally due to single-bounce surface scattering (except multiple-bounce scattering from breaking waves at high sea states and at large incidence angles), while that from ships is due to double- and multiple-bounce scattering.

In the mode-based three-component and four-component scattering power decomposition analyses, the total image intensity is decomposed into the surface, double-bounce, and volume (and helix in the latter) scattering components. Although the theories require further strict validation, the techniques can be used for vessel detection.

Figure 4 on the left is the color composite representation of the polarimetric PALSAR images of Figure 1, showing different backscattered power by different scattering processes. This difference in the scattering process can be enhanced by the four-component decomposition analysis as shown on the right of Figure 4. The helix scattering (the process that a linearly polarized incidence wave becomes a circulary polarized wave upon reflection) is not shown for brevity. In the decomposed image, the sea surface appears blue indicating surface scattering, and the land area appears predominantly green as a result of multiple-bounce volume scattering from forests. Urban areas of structure aligned orthogonal to the angle of beam incidence (range) direction shows double-bounce scattering in red color by the ground and buildings. Vessels on the water appear also red and green due to the double-bounce and multiple-bounce scattering from the strcture of vessels (see also Figure 1).

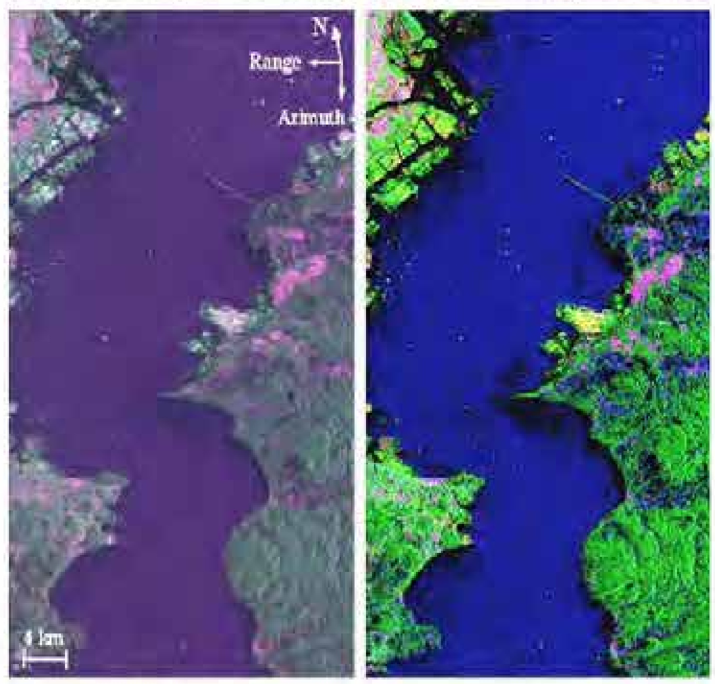

Figure 4. Left: Color composite image (HH red; HV green; VV blue) of the ALOS-PALSAR image shown in Figure 1. Right: Model-based four-component scattering power decomposition (double-bounce scattering in red; volume scattering in green; single-bounce surface scattering in blue).

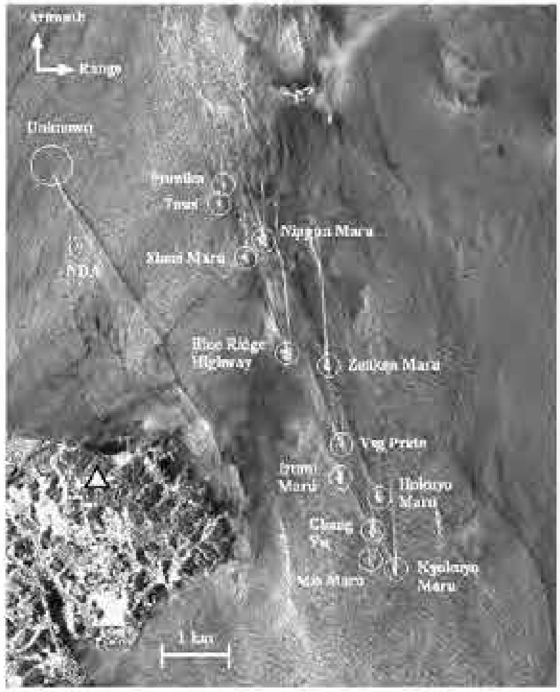

Figure 5. TerraSAR-X SpotLight HH amplitude image used for vessel detection and classification (20.09.2012).

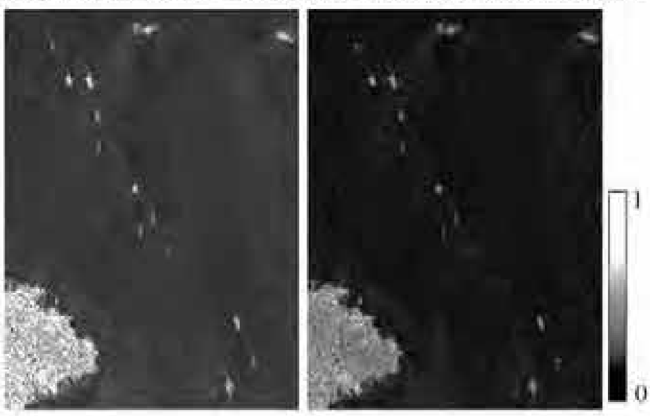

Figure 6. Left: HH/VV-polarization entropy of TerraSAR-X data in Figure 5. Right: (1- γ) coherence where γ is the degree of correlation between HH/VV-polarization images. The bright images on the top-center and top-right are small islands used as forts during the wartime.

Figure 5 is the TerraSAR-X HH/VV dual-polarization image of Tokyo Bay used for vessel detection and classification. The ground-truth data were obtained with simultaneous visual observation using a video camera from the NDA (National Defense Academy) building (triangle in the figure) and AIS data.

The HH- and VV-polarization entropy image is shown in the left of Figure 6. The entropy, which is an indication of the randomness of the radar backscatter, was computed using Equation (5) with j=2 by replacing sub-images with HH/VV co-polarization mages. H=0 corresponds to the surface scattering and H=1 implies the scattering process is random, i.e., volume scattering by forests or system noise, and also by vessels. On the right of Figure 6 is the HH/VV coherence image where the degree of correlation γ defined by Equation (4) was computed by replacing the sub-look images with co-polarization images. The values of the coherence image are reversed as (1-γ) for the visualization purpose. It can be seen that vessels can easily be detected by the entropy and coherence images as the features of the background sea surface are supressed. Detailed examination showed the best performance is obtained by the coherence image.

Other algorithms include those based on degree of polarization, notch filter with polarimetric images, and optimized polarimetric contrast enhancement.

Currently, many spaceborne SARs have polarimetric modes but less frequent data takes, and the swath is narrow in comparison with the standard modes. Polarimetry, therefore, has limited application to be used routinely for vessel detection. However, a technique known as digital beam forming (DBF) is being developed and tested with airborne SARs, enabling to extend the swath width without losing resolution. In the future, the spaceborne DBF-SAR data are expected to provide practical applications of PolSAR to vessel detection and classification.

2.2.6 ALONG-TRACK INSAR

Along-track InSAR is generally used for the velocity measurements of ocean current and moving targets on land (Romeiser et al. 2014). It can equally be applied to vessel detection and estimation of cruising speed. However, spaceborne AT-InSAR is at an experimental stage with TerraSAR-X and TanDEM-X (and by a single SAR with split-antenna), and data cannot be generally available.

3. VESSEL CLASSIFICATION

The main approaches to vessel classification by SAR are illustrated in Figure 7. The input image can either be a polarimetric or motion-compensated well-focused inverse SAR (ISAR) image. The image features of the geometrical and radiometric featres are then extracted (except the pattern matching algorithm that uses the entire image of a vessel). Classification is then made as by the algorithms based on feature-based template matching, multi-channel analyses, and machine learning.

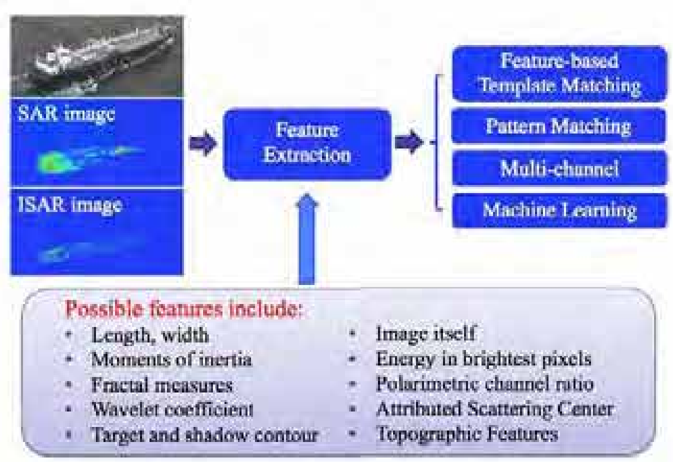

Figure 7. Flowchart of the main approaches to vessel classification.

3.1.1 FEATURE-BASED TEMPLATE MATCHING

The feature-based template matching based on the parametric vectors was developed by several institutes with different features as in Figure 7, including the GMV Spain, Lockheed Martin Canada (LMC), and National University of Defense Technology (NUDT), China.

An example of SIMONS developed by GMV Spain is shown in Figure 8. The wavelet transform is first applied to a SAR image after radiometric correction and calibration for vessel candidate detection. Each vessel image is correlated with AIS data for identification. If a vessel image is not correlated, a parametric vector is computed from the image, which consists of image length L, width W, and three radar cross sections, σB, σM, and σS, corresponding respectively to the bow, middle, and stern sections of the image. Prior to the operation, the reference parametric vectors are produced for different categories of vessels from the simulated images. Fuzzy logic is then used to classify the detected image using the SAR and reference parametric vectors.

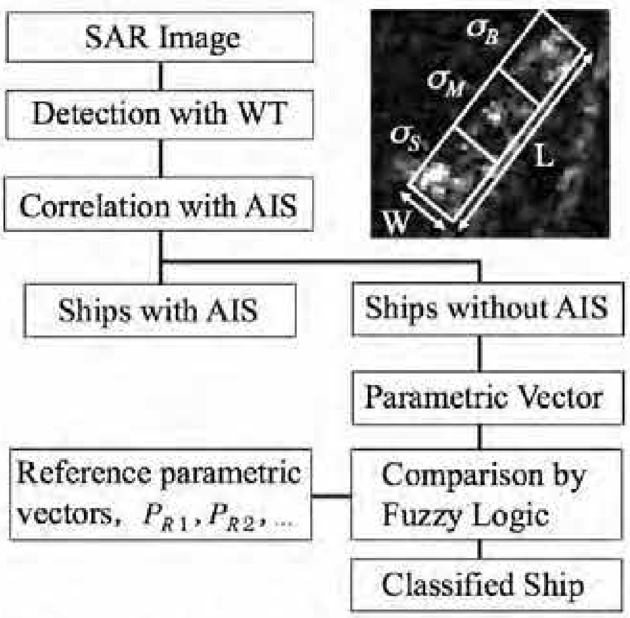

Figure 8. Basic flow of vessel classification by SIMONS based on parametric vectors.

(number): true values

Tokyo Bay Data

Name	Type	L	W	σ_S	σ_M	σ_B	Classified as
Tosci	Container	99.5 (85)	7.2 (14)	43.1	41.3	42.9	Medium Cargo
Fumika	Cargo	119.2 (73)	10.2 (12)	43.1	39.8	43.6	Medium Cargo
Shoei Maru	Oil/Chemical Tanker	112.4 (105)	9.5 (16)	43.1	41.9	40.1	Tanker
Nippon Maru	Passenger	217.2 (166)	22.5 (25)	40.6	42.4	40.4	Container
Blue Ridge Highway	Ro-ro/ Passenger	150.0 (180)	21.4 (31)	36.3	37.7	32.4	Medium Cargo
Zenken Maru	Waste Disp. Vessel	87.4 (98)	10.9 (18)	52.3	51.0	50.9	Medium Cargo
Vsg Pride	Cargo	95.2 (97)	11.0 (17)	46.2	47.8	42.9	Medium Cargo

Figure 9. A part of the classification results by the feature-based template matching of the TerraSAR-X data shown in Figure 5. The length (L) and width (W) inside the brackets are the true values of AIS data.

The accuracy of SIMONS was tested by the TerraSAR-X HH-polarization image shown in Figure 5, and a part of the results is shown in Figure 8. TerraSAR-X data with AIS in Mediterranean Sea (only 3 vessels due to strong wind condition) acquired on December 4, 2012 were also used.

Ships were categorized into 7 classes (passenger, tanker, cargo/bulk carrier/container, vehicle carrier, medium cargo, medium and small fishing boats). Although the total number of ships was 18, the classification accuracy was 89% and length estimation accuracy of 88%. These results are slightly better than those (classification accuracy ~ 70%) of the previous results using ENVISAT-ASAR data (Margarit and Tabasco, 2011) mainly because of higher resolution (3 m) than the ASAR (30 m).

A similar technique was adopted by LMC using hierarchical classification with increased number of sections of a vessel's image. No recent advance has been reported by LMC probably because the targets of interest are military vessels. NUDT China also used the same approach but with real SAR data for the reference parametric vectors. They used the sparse representation algorithm used for face recognition. Although the ship categories were only 3 (bulk carrier, container, and oil tanker), the classification accuracy was approximately 90%.

3.1.2 PATTERN MATCHING

This algorithm requires a large amount of simulated or real SAR data as template reference images, and no study, to the author's knowledge, has been reported for the purpose of vessel classification. However, if only several specific vessels are subject to classification, the amount of reference images can be reduced, and the technique is feasible. Provided that enough reference data are available and with increasing computational efficiency, the algorithm should yield considerable improvement in vessel classification.

3.1.3 USE OF MULTI-CHANNEL DATA

Multi-channel images include polarimetric images, InSAR and PolInSAR images, but again the data takes by spaceborne SARs are not frequent. Nevertheless, several techniques have been proposed as summarized as follows.

As in Figure 1, the processes of microwave backscatter from sea surface and vessels are different, so that this information can be used not only for vessel detection but also classification.

One of the PolSAR-based algorithms is the symmetric scattering characteristic method (SSCM). Symmetric targets are the scatterers having same scattering characteristics at a symmetric axis on a plane perpendicular to the radar line-of-sight. SSCM is one of the pixel-based coherent target decomposition (CTD) using image pixels having very large SNR known as the permanent or persistent scatterers. In this method, the positions and heights of coherent targets unique to individual vessel classes are estimated with the Pauli-CTD from PolInSAR data (Margarit et al. 2007). Ship classification is achieved by comparison of the measured the positions and heights of coherent targets with those simulated or real SAR reference data.

Incoherent target decomposition (ITD) is a statistical method using multiple pixels. Since ITD requires several or many pixels, it is generally applied to land targets. On the ship classification aspect, the H/α algorithm is proposed, where the entropy H is define by Equation (5) and the average alpha angle α describes the scattering processes from surface (α =0°) to dipole (α =45°) and double-bounce (α =90°) scatterings. The algorithm was tested in an anechoic chamber and airborne SAR, suggesting the possibility of ship classification.

As previously noted, there are not many spaceborne PolSAR data routinely available, and virtually no spaceborne single-pass PolInSAR data. These PolSAR and PolInSAR techniques, therefore, take some time in future to be used in practice.

3.1.4 MACHINE LEARNING

Machine learning has been used in various fields of applications including pattern recognition such as voice, face and character recognitions, medical diagnosis, search engines, and robotics. It requires a huge amount of training data and has not been applied, to the author's knowledge, to vessel classification with SAR data. There have been several reports on the military vehicle classification with airborne SAR data using the deep learning algorithm composed of multiple layers of simple neural network units. Nearly 300 training images for each vehicle were used with over 200 test images each, yielding the classification accuracy over 95% (Chen et al. 2016). With increasing spaceborne SARs, it is possible to accumulate big data, and this algorithm will then be a powerful means of vessel classification in the future.

4. OTHER INFORMATION

Other information on vessels that can be obtained by SAR includes oil spill, ship wakes, and cruising speed.

The mechanism of oil spill detection is such that oil has smaller surface tension than seawater, so that small-scale wind waves are dumped. Then, the radar backscatter from smooth surface covered with oil becomes smaller than the surrounding water, and the image appears dark. Figure 10 on the right is an example, showing a dark linear feature of oil (top-left) spilled by the broken Russian tanker Nakhodka on Jan. 2, 1997.

Oil slicks can be detected under the wind speeds 3-14 m/s. If the wind is weak, small-scale wind waves are absent and the surface becomes equally smooth irrespective of oil cover. If the wind is strong, the surface is very rough for the effect of surface tension becomes negligible. Another problem is to classify slick area from look-alikes such as windsheltered area and biogenic oil slicks. In Figure 10, for example, it is difficult to know whether the dark areas on the lower-left coast are oil slick or low-wind areas. These problems together with classification of oil types and thickness are the subject of further research.

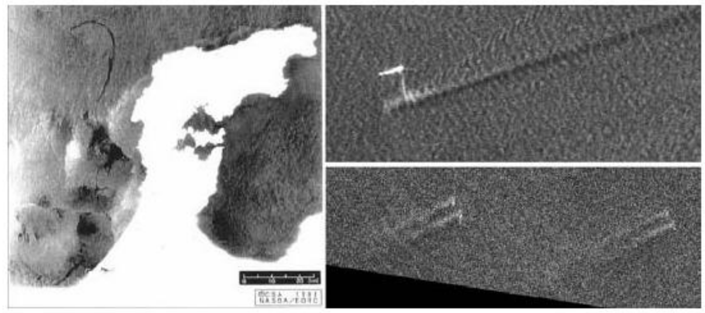

Figure 10. Left: RADARSAT image of the Noto peninsula and Japan Sea showing oil slick. Top-right: Images of a vessel and its wake in TerraSAR-X data. Bottom-right: KOPMSAT-5 image showing two pair-trawler fishing boats.

The TerraSAR-X image on the top-right in Figure 10 shows a vessel cruising away from the radar and its wake as a dark linear feature. The V-shaped Kelvin waves, although faint, can also be seen. The image of ship wake can confirm the presence of a vessel and its cruising direction. The shift of the vessel image from the wake in the vertical azimuth direction is caused by the azimuth imaging process. Fine azimuth resolution by SAR is achieved by using the Doppler return signals (Curlander and McDonough, 1991). When a SAR processor reconstruct images from the return signals, targets are assumed as stationary. Therefore, if a target is moving with a slant-range velocity component, the image is displaced from its true position. The effect is known as azimuth image shift, and the displacement is given by $-Rv/V$, where R is the slant-range distance, v and V are the slant-range velocity of a moving target and platform velocity respectively. The minus sign means the direction of shift relative to the platform propagation direction. Thus, from the shift of the image of a vessel, the cruising speed can be estimated.

If ship wakes are not visible, the cruising speed can be computed from the Fourier spectrum of the complex amplitude image of a vessel.

Finally, a mention is made on the image on the bottom-right of Figure 10. There are two images of a pair of small boats moving toward the radar, and the cruising speed is slow because of small azimuth shift. These images can then be considered as pairtrawler fishing boats.

5. CONCLUSIONS

In this article, the recent development and future of vessel detection and classification by spaceborne SAR is summarised. On the ship detection issue, a number of algorithms have been proposed and used by operational systems. The most used conventional CFAR is still a powerful technique, but other algorithms also have their own advantages, such as "invisible" vessel detection by sub-look analyses. Most of the algorithms are able to detect ships with accuracy above 80% depending on SAR resolution, sizes of ships, and also sea states. Although vessel detection is at a matured stage, further studies are required for some algorithms such as detection of small ships relative to SAR resolution and PolSAR analyses.

Despite slow progress, the technique of vessel classification is improving in recent years. The most promising method at this stage may be the parametric vector approach for it requires only feature points of ships rather than using entire images. Feature points can be extracted from single-polarization, multi-channel, and images of any other types. With increasing temporal resolution by increasing number of spaceborne SARs along with finer spatial resolution, other algorithms such as polarimetric analyses and machine learning will improve the classification accuracy in the future.

A note should be made, however, that with exception of several cases, validation is mostly made with reference to AIS data. In general, there are ships without AIS that can be detected by SAR. The resultant accuracy may then be misleading since these non- AIS ships, small boats, in particular, can be considered as false alarms. It is desirable, therefore, to make in-situ observation or use other sources of information for validation in the future study.

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CYBER POLICY: PUBLIC PRIVATE PARTNERSHIPS AND SECURING OUR CRITICAL INFRARSTRUCTURE

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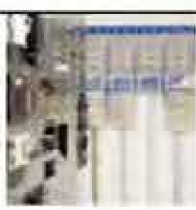
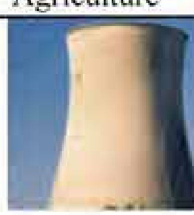
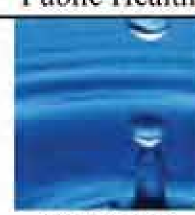
The diversity and complexity of public-private partnerships (PPP) in cyber security is uniquely problematic. The term 'cyber security' is used to refer to the integrity of personal privacy online, to the security of our critical infrastructure, to electronic commerce, to military threats, and to the protection of intellectual property.[1] While challenges in cyberspace, such as protecting individuals and upholding privacy and civil liberties are significant, the primary focus of PPP needs to be on the security of our critical infrastructure.

As defined in Presidential Policy Directive (PDD) 21, critical infrastructure is the 'systems and assets, whether physical or virtual, so vital to the United States that the incapacity or destruction of such systems and assets would have a debilitating impact on security, national economic security, national public health or safety, or any combination of those matters'.[2] (PDD 21) PPD 21 designates the following 16 sectors as critical infrastructure:

 Chemical Sector	 Commercial Facilities	 Communications	 Critical Manufacturing
 Dams	 Defense Industrial Base	 Emergency Services	 Energy
 Financial Services	 Food and Agriculture	 Government Facilities	 Healthcare and Public Health
 Information Technology	 Nuclear Reactors, Materials, and Waste	 Transportation Systems	 Water and Wastewater Systems

(https://www.dhs.gov/critical-infrastructure-sectors)

With the vast majority (~85%) of critical infrastructure is privately-owned and -operated, the responsibility for security requires a partnership between the public and private sector.[3] Some of the specific issues, identified by Busch and Givens, related to evolving governance and responsibility, legal and ethical considerations, incentivizing private sector participation, and highlights that national interests traditionally handled through law-enforcement or national defense are not aligned with the financial and reputational interests of the private sector. As Madeline Carr points out, 'Private-sector owners of critical infrastructure accept responsibility for securing their systems – to the point that it is profitable; that is, as far as the cost of dealing with the outage promises to cost more than preventing it.'

The current strategy of promoting and facilitating best practices, and fostering information sharing with the government, does not sufficiently address sophisticated threats posed by organized crime, terrorists, and hostile nation-states. Ultimately, politicians' reluctance to introduce tougher cyber security measures by law, and the private sector's aversion to being liable for national security, leaves the partnership without clear lines of responsibility or accountability.[1]

As articulated in the 2014 testimony of Steven Chabinsky, former Deputy Assistant Director of the Cyber Division of the Federal Bureau of Investigation, our public/private cyber partnerships need to be reassessed. Tackling the problems at the heart of PPP, Chabinsky recommended aligning cyber security efforts with security strategies used in the physical world, "focusing greater attention on the challenges of more quickly detecting and mitigating harm in high risk environments, while in parallel locating and penalizing bad actors." This shift in focus would strive for instant detection, attribution, threat response, and recovery, with the goal of shifting the costs of cybercrime to the offenders. In practical terms, the recommendation for alternate architectures requires substantial government leadership and private sector initiative to determine the requirements of networks, to include, "enhanced identity management, maximized intrusion detection and attribution capabilities, and prioritized actions to locate and penalize bad actors."[4]

Actions to strengthen the PPP environment, such as the US Cybersecurity Act of 2015, are positive steps to address the current problems. Underlying the legal and technical solutions, education and training of government leaders to foster a collaborative culture and engender trust with private industry is also critical to the success of PPP and building shared interests. The United Kingdom's 2009 Cyber Security Strategy provides a great context to the scope of the problem and scale of solutions required. "Just as in the 19th century we had to secure the seas for our national safety and prosperity, and in the 20th century we had to secure the air, in the 21st century we also have to secure our advantage in cyber space."[5]

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A TYPOLOGY OF COMMUNITY-BASED OBSERVING

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ABSTRACT

The need to acquire situational awareness through detection, triggering, and tracking of anomalous activities (e.g., weather events and ship transits) has never been greater. Existing technologies ranging from space-based assets to unmanned autonomous vehicles provide a depth of awareness through consistent, though homogenous, data streams but cannot convey situational context. Community-based observing networks and systems (CBONS) are a ready capability to place observed biophysical data into social context. The term "Community-Based Observing" (CBO) encompasses a range of methodologies involving collaboration between observers, researchers, and agencies, and we offer a system for classifying these efforts and approaches that highlights their utility for different purposes. We identify four types of CBO: community observing blogs/forums (COF); citizen science (CS); community-based monitoring (CBM); and CBONS. The elements of the typology include: how communities are defined and observers selected; what kinds of data and metadata are collected; how and by whom research questions are generated; how data access is addressed; and how data quality is managed. Examples within the typology are provided, and recommendations are suggested for how CBONS, specifically, can be used to enhance integrated observing networks and maritime security.

Environmental monitoring and observing has typically been a function of private industry and government agencies, ranging from space-based assets to wave gliders. However, efforts incorporating citizen involvement or engagement are becoming increasingly common and important (Kouril et al., 2015). CBO programs are tools for conducting environmental and, potentially, national security related research, but the terms used to describe such projects and how they are applied, have not been clearly defined in the literature (see Table 1) resulting in inaccuracies and confusion in usage. We define CBO as the practice of monitoring and observing environmental or linked social and environmental variables by collaborative teams of researchers and place-based observers (i.e., community members) who possess place intimacy, or local and place-based knowledge (LPBK).

CBONS rely on local individuals who act as high fidelity observers (HFOs) for data collection. HFOs can be any skilled observer, ranging from specific local residents to personnel associated with safety and security, and are characterized by a set of four criteria: a) place intimacy, b) competence, c) knowledge and d) motivation. They are trained individuals with access to both local, placed-based knowledge and hand-held technologies that enable data relays to occur securely (Alessa et al., 2016). CBONS were developed specifically for ensuring community security and on-the-ground decision support for the operator, and allow for increased domain awareness in maritime operational environments because they have specific features which other types of CBO efforts do not. CBONS provide operational context in real or near real time to inform security responses by providing forward data fusion that can ensure that search and rescue or event interdiction be enacted more precisely. To this end, they are a key tool in both the development of operator-driven policy and operational science that implements the best available science but is executed on a faster timescale than CBO for scientific purposes only (Figure 1).

Recent expert workshops hosted by the Center for Resilient Communities and Department of Homeland Security on Community-Based Observing (Seattle in November 2015) and security vulnerabilities in the Arctic (Washington, D.C. in February 2017) and along the Northern U.S. Border (Washington, D.C. in February 2017) have highlighted vulnerabilities in maritime domains due to a lack of: a) diversity in data streams; b) data access and context for operator support; and c) best practices to govern the thresholds at which responses are warranted ("triggering"). The workshops also revealed how fundamentally critical context is in interpreting data from instrumented observing networks, and how poorly we manage to acquire it. Context is critical because the criteria that describe "an anomaly" and those that trigger and guide the appropriate response by security agencies are poorly developed across both defense and security practices. CBONS are offered as a key piece to the suite of capabilities that are necessary for layered observing (Figure 2).

We intend our proposed classification to: a) provide a common language to discuss CBO science and its activities as a spectrum of observing types; and b) ensure that the security and defense communities are aware of differences in and utility of CBO methodologies.

Term	Abbreviation
Community-based Observing	CBO
Community-based Monitoring	CBM
Community-based Observing Networks (and Systems)	CBON or CBONS
Community Observer Forum	COF
Citizen Science	CS

Table 1. Terminology and abbreviations used in this paper and in the typology.

THE ELEMENTS OF THE TYPOLOGY

In order to establish a typology, we define "community" and the avenues through which observers are recruited, the types of data that are collected (quantitative or qualitative, social or biophysical, etc.), and how these data are quality assured and shared. We describe the spectrum of possibilities for each element and describe the four CBO types in terms of these elements, thus generating the typology. The key differentiating elements of CBO types are: the purpose of the CBO and intended users of products; the way in which communities are defined and observers are selected; the type of data collected; the way research questions are generated; how access to data is managed; and how the quality of data is assessed.

How are communities defined and observers selected?

"Communities" can range from all persons in an area with local or traditional knowledge of the environment, to those currently engaged in safety and security professions. Other types within the spectrum of CBOs can be distinguished by the way in which observers are recruited: in observer forums and citizen science projects, observers are self-selected (volunteers). In such cases, the community is comprised of persons interested enough to make observations. Observers contributing to CBMs and CBONS are recruited during meetings between researchers and communities, or, in the case of CBONS, observers are selected based on interests in key issues shared by both residents in situ and security agencies; such common concerns can be about the maintenance and assurance of safety and well-being. For CBONS alone, they are a group of carefully vetted and trained observers of specific phenomena. The variation in the way that "community" is defined in CBO, then, ranges from anonymous, self-selected participants of large-scale citizen science projects to known and trusted agents with a history of collaboration in CBONS (see Figure 3).

What kinds of data are collected, and what kinds of outputs are the result?

The data and metadata collected by CBO initiatives vary considerably depending on who makes observations and how standards and protocols are designed. These can range from informal, unstructured qualitative assessments from Community Observer Forums (COF) to precisely recorded quantitative observations in some CS projects. CBM and CBONS efforts often collect a range of data types, from time series of biophysical data (water quality) to highly detailed qualitative observations based on protocols co-developed by researchers and observers (events and social/cultural context).

In general, COFs have little consistency in data because the observations recorded are determined solely by individual, self-selected observers. CS provides structured data through volunteer reporting for a very specific type of biophysical variable (e.g., shorebird or beetle distributions). Compared to COF and CS reporting, CBONS programs provide verified and validated data on a robust suite of variables related to maritime domain awareness through diverse HFO selection, adaptive observer network structure, and co-developed/designed protocols and technology interfaces (see Figure 4). Some CBONS utilize hand-held technology called the Field Information Support Tool (FIST), which provides a means to standardize data collection based on inputs or variables pre-selected by analysts and operators, so that the collected information can be integrated quickly to provide situational context to operators (Figure 5); FIST is a unique and inexpensive technology initially developed by a group of deployed U.S. Marines and is currently maintained by Kestrel Technology Group, Inc.

How are CBO scientific questions formulated?

An important distinction between CBO types is in how the observed variables are determined and for what reasons, which takes place before observing begins. The differences largely stem from who initiates a CBO effort and how involved the community is in designing research questions. Citizen Science projects tend to be structured to test hypotheses generated by research scientists using crowd-sourced data; participants are not asked to take part in the creation of scientific questions, the design of protocols, or the analysis of data. Similarly, the unstructured and self-selected nature of COFs makes extensive collaboration unlikely, so observations are structured primarily by the interests of individual observers. At the other end of the spectrum are CBONS, where communities of observers and researchers share responsibility in all aspects of an observing project: questions, protocols, and metadata standards are co-produced and data is co-owned.

Who owns the data, and who has access to the data?

In all types of CBO, data is collected and reported by community members, and as noted above in some cases the protocols and questions are generated collaboratively. The data collected is about the local environment in which communities are situated, and sometimes is comprised of or informed by traditional, local, or place-based knowledge. This distinction can be especially important in the case of indigenous communities where data may relate to community wellbeing, health, and cultural identity (see Figure 6). In such cases, ownership and access to data must be negotiated, and protocols must be developed to protect the privacy of individual observers and broader communities.

Some environmental data collected by CBOs can be sensitive, and thus the communities involved in the research have final authority on who has access to data (Alessa et al., 2016). In many CS and CBM programs, the data is immediately available to researchers for analysis and publication or distribution. In CBONS, sensitive data is sometimes co-owned by a specific community or even the individual observer, and so issues of access, analysis, publishing, and distribution of data or data products must be negotiated with the community. In such cases, where data are critical to informing operators on the ground, we have developed a means to assure that data can be submitted which do not carry any details except those relevant to the mission at hand. Data ownership is correlated with the demographics of the HFOs and their communities; in some cases, proprietary data is not an issue.

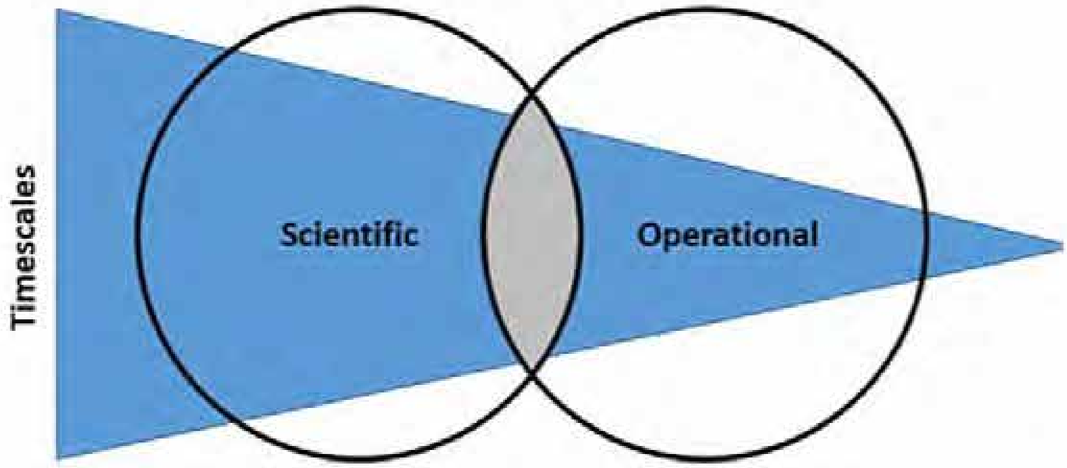

Figure 1. The timescale of scientific research and operational information needs is often at odds. Well-designed CBONS are a tool that can provide scientific information in a timeframe relevant to operational needs.

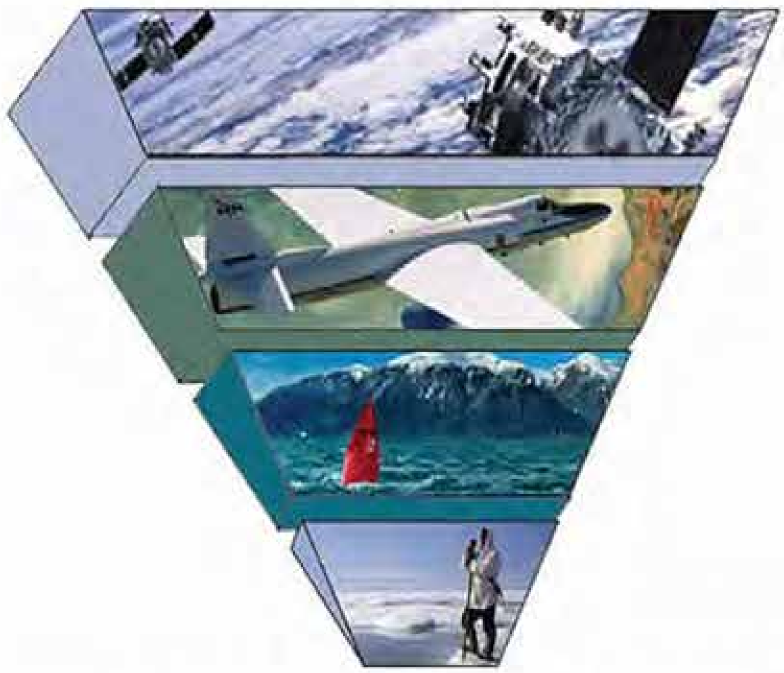

Figure 2. Layered Observing is a practice that involves the integration of data from multiple sources, including: space-based platforms; aerial platforms; surface-based sensors at land or sea; and community-based networks.

How is data quality assured?

Data interoperability refers to practices and standards ensuring that data is collected, archived, and managed in a systematic manner. This results in data (and analyses) that can be shared, aggregated, and compared across independent efforts and studies. Development of data interoperability standards has been key in joining independent biophysical observing platforms and efforts (such as ocean acidification, circulation, and CO2 enrichment) into integrated observing networks able to provide comprehensive and widely used data (Garcia et al., 2015). Interoperability standards have recently been deemed necessary in ensuring data from research can be translated into "actionable knowledge," and have also been prioritized by US federal agencies in the domains of environmental intelligence programs. Consciously addressing interoperability standards not only increases the ability of CBO projects to share data, but also encourages adoption of data standards, thereby increasing quality (see Figure 7).

THE TYPOLOGY

Having described the major elements that serve to distinguish the different fundamental types of CBO, we can now compare them to each other in a more useful manner. We have organized the elements and types of CBO in a simplified manner in Table 2. It can be seen in the basic typology that

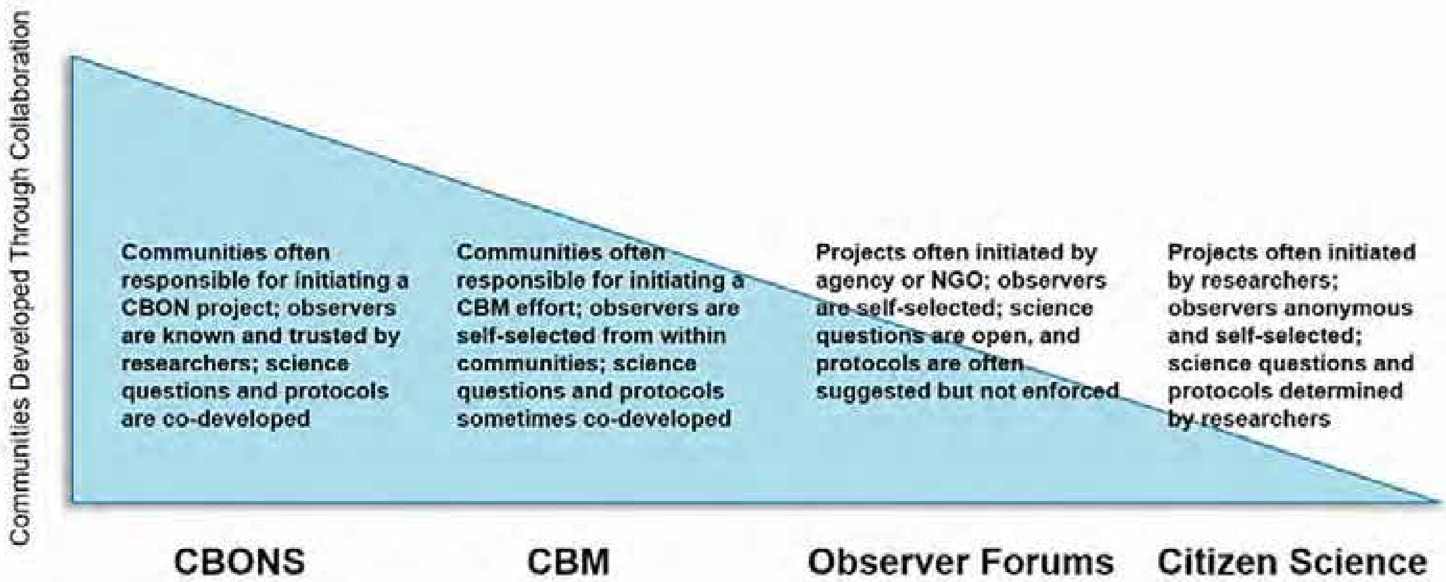

Figure 3. Degree of collaboration in CBO: CBONS and CBM are to some extent defined by their collaborative nature, where science questions and protocols are co-developed by communities and researchers; COF can be initiated by communities or researchers, but are generally only loosely structured; CS efforts tend to be organized by CS with low-degrees of collaboration other than data collection.

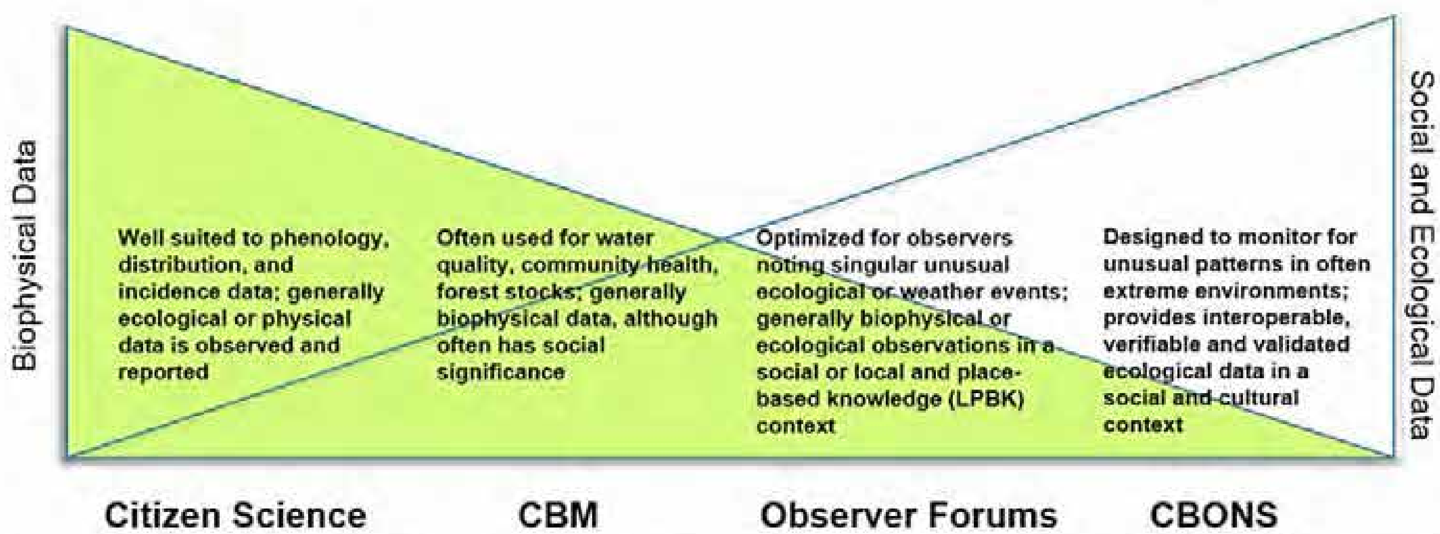

Figure 4. Data types produced by CBO: CS and CBM are very well suited to providing highly structured biophysical information across large scales; COF are useful in reporting unusual phenomena, but the unstructured nature of observations does not lead to interoperable data; CBONS are optimized to produce interoperable social and ecological data.

the complexity of programs increases from COF to CBONS, but this is accompanied by tradeoffs. Specifically, the greater degree of collaboration and co-production of knowledge in CBM and CBONS compared to COF and CS programs is achieved at the cost of more restrictive data access and longer commitment from researchers and communities. To expand on these generalizations about data complexity, and to provide greater detail on each type of CBO and how it might be used, we provide examples below.

Community Observer Forums (COF)

COF relies on observers using local knowledge to note change in environmental conditions. One example of a COF is the Local Environmental Observer (LEO) Network, dedicated to understanding and documenting the impacts of climate change in Alaska and Western Canada. Per their website, "LEO is a network of local observers and topic experts who share knowledge about unusual animal, environment, and weather events. These observations are based on local and traditional knowledge, and the experience of network members" (Alaska Native Tribal Health Consortium, 2015). COF are necessarily qualitative when it comes to data collection, because each observation stands on its own and is not generated by a validated protocol.

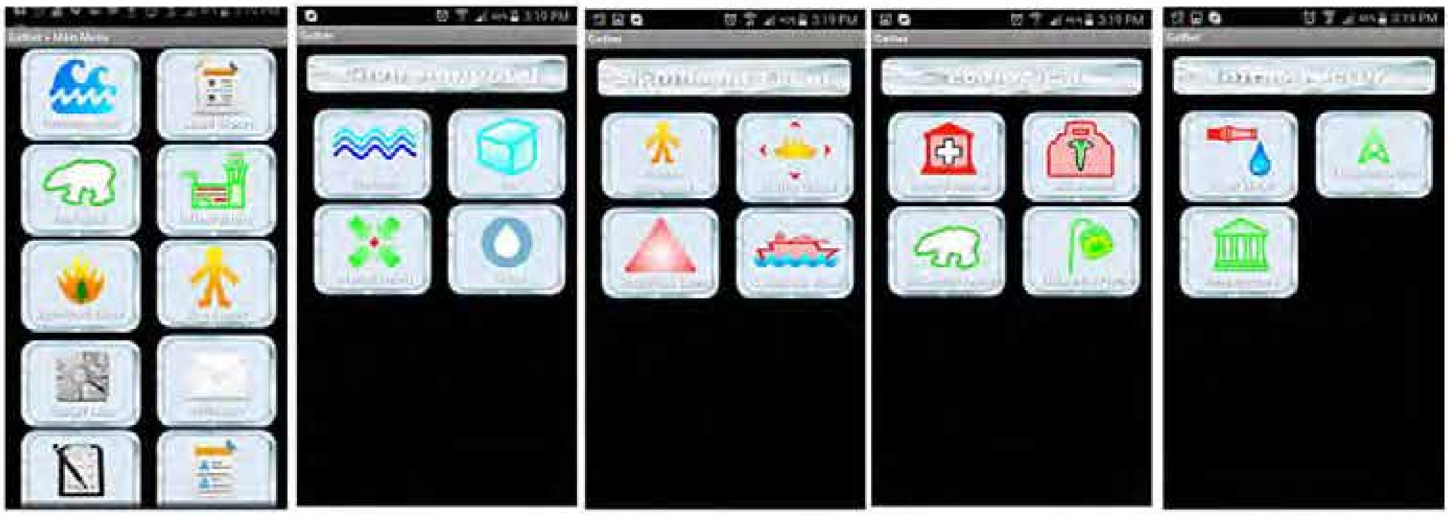

Figure 5. An example screen from the Field Information Support Tool (FIST), showing observation categories co-created with High-Fidelity Observers (HFO) from CBON-SA. In the field, an HFO can quickly select an observation type, record an observation (including GIS information, contextual information, and images or video), and then upload the observation to a fusion or command center.

Figure 6. Tymlat people ice fishing with dog, Kamchatka, Russia. ©Aleut International Association (AIA), 2012.

Citizen Science (CS)

There remain concerns about the validity of using CS in some government agencies and in the academy. Some CS projects have addressed this by assessing data quality in addition to environmental variables: For example, a dual-purpose study was conducted on the East Coast of the United States, which simultaneously measured the geographic extent, and gender of two invasive crab species and the high reliability and quality of the data collected (Delaney et al., 2008). Programs reliant on these kinds of CS observations are likely to be quantitative in orientation and driven exclusively by researcher questions. This type of program is probably best suited to answering specific, narrowly defined questions and hypotheses for which large numbers of observations are needed for analysis and statistical inference. CS can be useful in answering specific types of questions, but is not as well-suited to long-term engagement with communities as more collaborative types of CBO and is not appropriate when trust-based relationships with high-fidelity observers (HFO) are required. An example of Citizen Science is Coastal Observation and Seabird Survey Team. Data collection includes beach-cast carcasses of marine birds to establish the baseline pattern of bird mortality. The data collected helps address important marine conservation and climate change issues and protect marine resources.

Community-Based Monitoring (CBM)

CBMs vary widely depending on how they are initiated and on what phenomena are monitored. Unlike COF and CS, which tend to provide baseline or snapshots of environmental information,

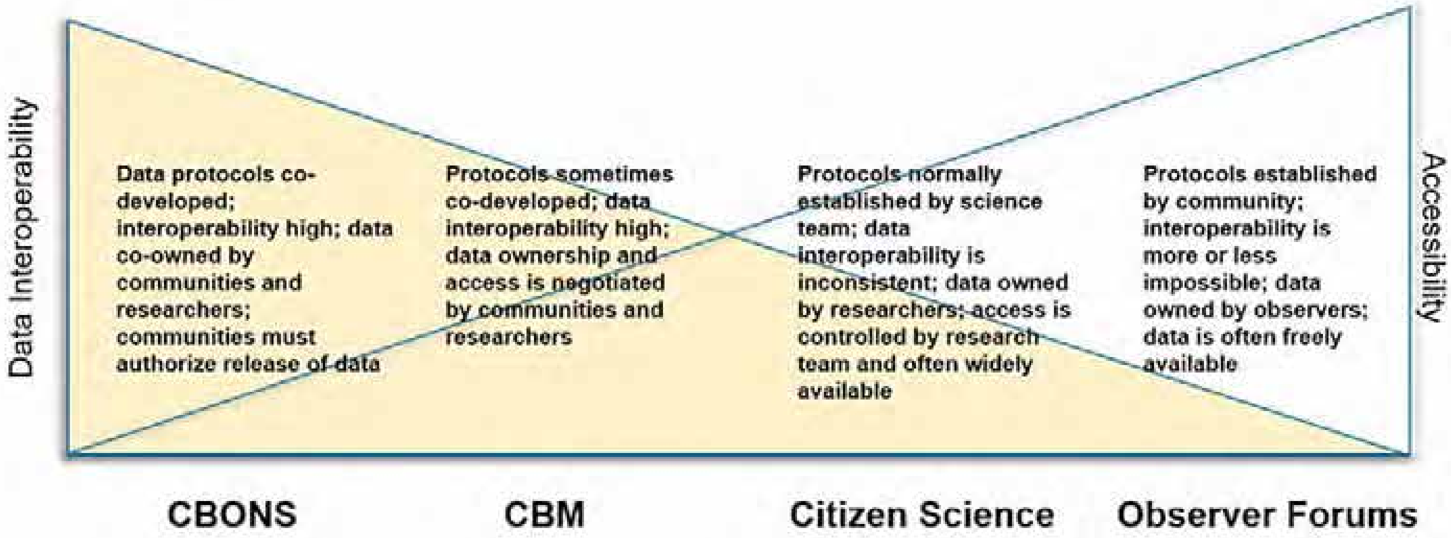

Figure 7. Data Interoperability vs. Data Accessibility for CBO: as communities and researchers collaboratively develop data and interoperability standards in CBONS and CBM, accessibility is likely to decrease as ownership claims to data by community increases. Conversely, CS and COF are likely to have more accessible data but be less interoperable, decreasing their relative value to large-scale and long-term observing.

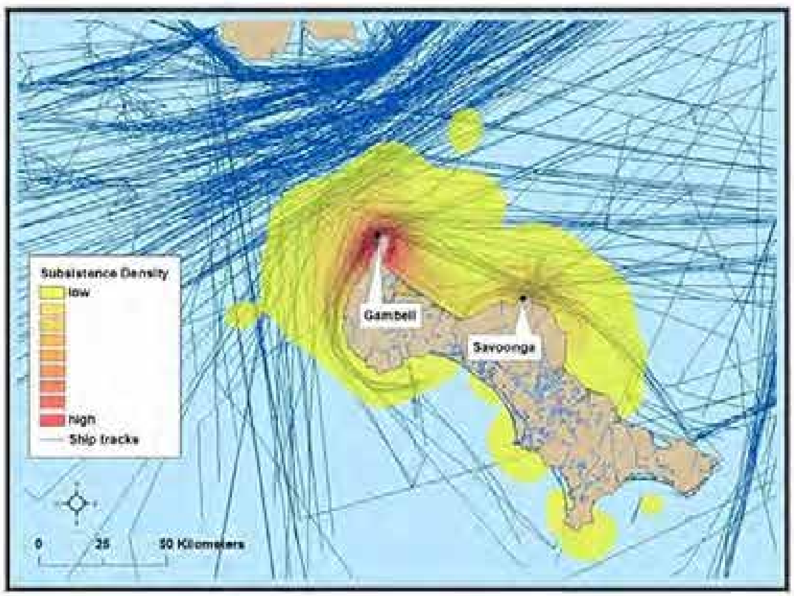

Figure 8. This map shows subsistence harvest areas from June to October 2011-2012 for bowhead whale, walrus, and seal (bearded, spotted and ringed seal) juxtaposed against shipping tracks from the same period 2011-2012. The map includes input from 108 residents of Gambell and 33 residents of Savoonga collected through a CBONS project, BSSN-CONAS. A kernel density analysis was used to display subsistence areas, and areas of direct spatial and temporal overlap with shipping are highlighted.

CBM is focused on monitoring specific environmental variables over time. They can be initiated by communities, government agencies, university affiliated researchers, or through existing or new collaborations. Many CBM programs focus on quantitative observation of specific biophysical factors, and the collaboration often involves university or government personnel training community members how to operate equipment. An example of a CBM is the Cook Inletkeeper program established in 1996 (https://inletkeeper.org/), which trains volunteers to collect water quality data for selected parameters that enhance understanding of overall environmental health. Water quality information collected by citizens is managed and analyzed in a relational database, and Inletkeeper produces annual water quality reports, which provide an overview of all citizen-collected data.

Community-Based Observing Networks and Systems (CBONS)

The fundamental distinguishing characteristic of CBONS is their ability to produce matched social, cultural, and biophysical observations. CBONS in the Arctic are a collaboration between communities, tribal government, resource management agencies, non-governmental organizations and university researchers (Alessa et al., 2015). An example of an early CBON was the CONAS program which worked with community residents in a distributed network of communities across the Bering Sea in both Alaska and the Russian Federation to systematically observe and document artic environmental and globalization changes through co-developed tools (see Figure 8). CBONS have evolved significantly to become a ready capability with structured HFO selection, data acquisition and

	Community Observer Forum (COF)	Citizen Science (CS)	Community-based Monitoring (CBM)	Community-based Observing Networks and Systems (CBONS)
Community	Self-selected, often anonymous	Self-selected, anonymous	Developed through collaboration or self-selected	Developed through collaboration
Data Type	Qualitative, unstructured data	Primarily Quantitative, highly structured	Primarily Quantitative, highly structured	Qualitative and Quantitative, highly structured
Social or Biophysical	Both Social and Biophysical	Primarily Biophysical	Primarily Biophysical	Both Social and Biophysical
Science Questions	Observer generated	Usually dictated science team	Sometimes co-developed, sometimes solely dictated by researchers or communities	Co-developed by by community observers and researchers
Data Access	Open-access, immediately available	Access controlled by science team, availability varies	Access protocols co-developed by community and researchers	Access may be limited by community in availability
Data Quality	Indeterminate	Sometimes validated, often indeterminate	Protocols Validated and verified; variable quality assurance	Validated and verified; quality assured and controlled

Table 2. A typology of Community-Based Observing (CBO) programs. In the first column are the elements capturing the variation in types of programs, and the subsequent columns have short descriptions of how those elements define the four types of CBO.

fusion protocols that are enhanced by technology-enabled real time reporting through the FIST.

CONCLUSIONS

The typology of CBO provides a means to classify and distinguish different types of community-based observing programs. Specific, real-world CBO projects often have features of more than one of the CBO types described: the categories presented here are not strictly defined and exclusive, but should be helpful in classifying different projects and in planning efforts. Integrated systems of community-based observing and monitoring systems already exist in nascent form in the Arctic, where efforts by the Arctic Research Consortium of the United States, the US Arctic Observing Network, the Exchange for Local Observations and Knowledge of the Arctic, and Snowchange (snowchange.org) are implementing or sustaining projects collecting data ranging from Indigenous Knowledge to ice, atmospheric, and distribution of fauna.

Additionally, the Department of Homeland Security's Arctic Domain Awareness Center of Excellence has a joint CRC, US Coast Guard, and Aleut International Association program called the Community-Based Observing Network for Situational Awareness (CBON-SA). CBON-SA has been founded as a test bed to demonstrate the ability to make observations relevant to Coast Guard operations in the maritime and coastal domains, but also to show that rich-media observations (video and photos in addition to GIS and contextual data) can be sent to and received in communications-austere environments. CBONS-SA is expanding to include high noise environments, specifically Ports of Entry.

CBONS are a methodology well-suited to collaborative observing in the maritime security domain, and can produce interoperable observations providing context for interpreting instrumented data from sensor, aerial, and space-based networks.

CONTACT INFORMATION

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