INTEGRATION OF REMOTE SENSING TECHNOLOGIES INTO ARCTIC OIL SPILL RESPONSE

By

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Abstract

Identifying the tools and pathways to successful integration of landscape level science into decision-making processes is vital for quality environmental stewardship. Remote sensing information can provide critical facts to decision makers that historically were only available via manned airplane flights and ground truthing expeditions. Remote locations like the Arctic are well suited for monitoring with remote sensing tools due to the lack of transportation infrastructure and communications bandwidth. Remote sensing tools can be valuable when monitoring specific Arctic targets like ocean going vessels, sea ice, coastal erosion, off-shore resource development infrastructure, and oil spills. This dissertation addresses how to mount a more efficient and informed response to Arctic oil spills by capitalizing on available RS tools. I posed three research questions to frame this work, 1) What remote sensing tools are currently available, as compared to those currently used in the Incident Command Structure of an oil spill response? 2) Are there barriers to additional remote sensing tool use for oil spill response support? 3) What process changes can improve or increase remote sensing data use in oil spill detection and response? I conducted a four-phased, exploratory sequential mixed methodological study to examine current remote sensing capacity and solutions to expand remote sensing use in support of oil spill response. Phase One defined the remote sensing tools available to support oil spill response, identified how those tools are being used in support of oil spill response actions, and was used as the foundational research to inform the following phases of the study. Phase Two used cloud-processing resources to establish an automated oil detection pipeline. Phase Three addressed human-driven barriers to remote sensing tool use identified in phase one through remote sensing tool training, knowledge coproduction, and remote sensing data integration into oil spill response exercises. Synthesizing all components of Phases One, Two and Three, a remote sensing protocol for the use of unmanned aircraft systems in support of oil spill response was developed and integrated into U.S. Coast Guard operational policy in Alaska to complete Phase Four of this research. This research identifies opportunities and solutions that support improved Arctic oil spill response decision-making through the application of remote sensing data and information.
I dedicate this dissertation to the great State of Alaska.

“Fight the good fight.”
Buffy the Vampire Slayer
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Preface

This six-chapter dissertation is one of the outcomes of my 30-year journey of learning about the implications of oil spills both in terrestrial and marine environments. Inspired to become a scientist by the 1989 Exxon Valdez oil spill, I obtained my B.S. in Natural Resources, focused on Ecology. Following science to Alaska, I then earned a M.S. in Biology focused on the molecular components of microbial degradation of crude oil. This learning journey led to my desire to identify ways to better prevent, respond and mitigate oil spills in America’s waters using remote sensing tools and to the body of work presented here.

All of the research presented in this dissertation was conceived, designed, conducted, analyzed and written by myself, with methodological and editorial guidance from my committee chairs Franz Meyer and Sarah Trainor, and from my co-author for Chapter 3, Chris Stoner. Chapter 2 will be revised for submission to the peer-reviewed journal, Environmental Science and Policy. Chapter 3 has been published in Proceedings of the IEEE OCEANS 2017 - Anchorage, AK. Chapter 4 is formatted for an unmanned aircraft special issue of Remote Sensing. Chapter 5 has been published as a Geophysical Report to preserve the integrity of the protocol itself for future applications, the content of which has been integrated into Alaska’s Arctic and Western Alaska Area Contingency Plan.

I am deeply grateful to my entire dissertation committee, Andy Mahoney, Nettie La Belle-Hamer, Olivia Lee, Sarah Trainor, and Franz Meyer, for the many hours of discussion, project scoping, experimental attempts, gut-wrenching decisions, and over all patience and encouragement during this process. My exceptionally gracious partners in the U.S. oil spill response community made this research possible through their direct participation in the interview and survey processes and by supporting my access to oil spill exercises and experts. I could not have performed this work without the encouragement and help of these partners, specifically, Chris Hall (Alaska Clean Seas), Catherine Berg (National Oceanic and Atmospheric Administration), James Nunez (US Coast Guard), Matt Hbbie (US Coast Guard), Jereme Altendorf (US Coast Guard), Oscar Garcia-Pineda (WaterMapping, LLC), Scott Pegau (Oil Spill Recovery Institute)
and Nancy Kinner (University of New Hampshire). I will forever be indebted to their faith in my research.

Thank you to my leadership team, Mark Myers, Larry Hinzman, Nettie La Belle-Hamer, Bob McCoy, and Cathy Cahill for encouraging me not only to begin, but much more emphatically, to finish this degree. My deepest thanks to my mentors, Anupma Prakash, Elena Sparrow and Joan Braddock, for listening and providing sage advice applicable to any situation I could think of. I am thankful for the patience of my co-workers and their continued support across all of the projects that I have worked on since the beginning of this degree. My friends have been stalwart supporters, helping me through delays and frustrations, self-imposed and otherwise, during the course of this degree. I only hope you all know how much I have appreciated, and needed, this bolstering, and I will forever be thankful. To my third base coach, Bill Schnabel, I do not think I would have made it over home plate without your shouts and demands of forward progress. Last, my deepest gratitude is extended to my parents, my children and my husband for enduring me and this degree for the last six years.
Chapter 1: General Introduction

1.1 Background

A new world of commerce is being thawed from the ice of the Arctic. A 25% increase in vessel traffic over the past six years attributed to fishing, shipping, tourism, resource exploration and resource development in the Arctic (Arctic Council, 2020) is tied to increases in economic opportunities and environmental transformations. As Arctic conditions change, identifying the tools and pathways to successful integration of landscape-level science into decision-making processes is vital for quality environmental stewardship. Remote sensing (RS) information, can provide critical facts to decision makers that historically were only available via manned airplane flights and ground-truthing expeditions. The RS targets associated with increased vessel activity in the Arctic that are well suited for monitoring with RS tools are individual vessels, sea ice, coastal erosion, off-shore resource-development infrastructure, and oil spills.

The essential elements to effective RS surveillance of non-accidental discharges of oil have been understood for over 20 years, and include (Engelhardt, 1999)

- Early identification of target anomaly and rapid verification;
- Delivery of alert warnings and image data in operational real time to allow interdiction;
- Image products tailored in their complexity to specific user-information requirements;
- Image products compatible with and readily accessible to the software and hardware systems of the end user;
- Integrated data formats for multiple images;
- Compatibility and non-conflicting hand-over of surveillance image services to emergency response for interdiction or emergency response;
- Data security, safe data-handling protocols, and appropriate archiving.
These requirements are clear, but are these RS surveillance elements integrated into regular Arctic observations? Do these observations support the identification of accidental oil discharges as well? Who is using these products, and what decisions are they making based upon what they are learning from them?

Though there is no substitution for field-based observation of small-scale ecosystem processes, some landscape level examinations can be conducted using RS techniques that reduce risk to Arctic industrial operators, scientists, and community members. In support of planning mandates for resource development, operational components of spill responses, and natural resource damage assessments, this research directly addresses some of the suggested research and technology priorities as outlined by the Interagency Coordinating Committee on Oil Pollution Research (ICCOPR) in the *Oil Pollution Research and Technology Plan (OPRTP)*. This research is also intended to support the United States Coast Guard (USCG) Arctic Strategy Initiatives (USCG, 2019) by identifying RS informational tools and integration strategies to enhance Arctic operations and exercises and strengthen marine environmental response in the Arctic.

**Research Overview**

This dissertation is focused on **how RS tools can be capitalized on to better respond to Arctic oil spills**. The research inquiry synthesized themes central to the use and potential use of RS tools in the marine oil spill response setting. Three questions were defined to frame these themes into queryable components:

1. What remote sensing tools are currently available, as compared to those currently used in incident command structure (ICS) of an oil spill response?
2. Are there barriers to additional RS tool use for oil spill response support?
3. What process improvements can be undertaken to increase RS data use in oil spill detection and response?
This research identifies opportunities and solutions to support Arctic oil spill response decision-making through the application of RS data and information.

1.2 Methodology approach

1.2.1 Interdisciplinary approach

Using fundamentals of grounded theory, an interdisciplinary, four-phased approach, with a mixed-methods research design was implemented to examine current RS capacity and solutions to expand RS use in support of oil spill response. Grounded theory is rooted in the systematic, yet flexible, guidelines for analyzing qualitative information and constructing theory about processes and actions from the data itself (Charmaz, 2014; Ritchie et al., 2014).

- Phase One defined the RS tools available to support oil spill response and, how those tools are being used in support of oil spill response actions; this phase also informed the following phases of the study.
- Phase Two removed a set of data-driven barriers to RS use discovered during Phase One, by establishing an automated oil-detection pipeline using cloud-based processing resources.
- Phase Three addressed human-driven barriers to RS tool use by exercising the three determined components of RS tool acceptance from phase one; training, knowledge coproduction, and data integration.
- Phase Four of this research synthesized all components of phases one, two and three, to develop a RS protocol for the use of unmanned aircraft systems (UAS) in support of oil spill response integrated into U.S. Coast Guard operational policy in Alaska.

The interdisciplinary knowledge base required to complete this research included a deep technical understanding of RS data and applications for oil spill response support focused on Alaska, communication strategies to become embedded in the oil spill response community of Alaska, and the qualitative capacity to synthesize information from broadly disparate sources to effect policy change in Alaska oil spill
response. As such this work draws upon the applied fields of geophysics, social science, and public policy research.

1.2.2 Research design and mixed methodology

This study was undertaken through the lens of a pragmatic worldview, using exploratory sequential mixed methods research based upon grounded theory. This worldview forms from actions, situations and consequences, which in this case were those affiliated with RS tool use during marine oil spill response. Research under this worldview focuses on a problem and the full understanding of the problem within the social, historical and political context, and is often used to identify potential solutions to that problem (Creswell, 2014).

Exploratory sequential studies are initiated through a qualitative exploration of a particular problem (*how RS tools are currently used*), followed by the development of an instrumental solution (*facilitating additional RS tool use*), and concluding by administering the developed instruments to the relevant sample of the population (*RS protocol integration into policy*) (Creswell, 2014).

A thorough examination of RS tools available to support oil spill response decision-making provided the framework for the *qualitative* analysis of current uses of RS data in an oil spill response. Knowledge gained about current RS use and barriers to that use was used to develop two, methodologically distinct (one *quantitative* and one *qualitative/quantitative*), solutions for integrating additional RS tools into the oil spill response framework. Finally, the development and application of the protocol for UAS use during oil spill response with and for the Alaskan oil spill response community functionally administers this research to this partner population.

1.2.3 Use and barriers to use of remote-sensing tools

The first recorded RS assessment of an oil spill was performed by a human observer, using a handheld video camera to record the Exxon Valdez oil spill (EVOS) (Skinner & Reilly, 1989). Airborne and satellite-based RS tools beyond hand-held cameras and video recorders became available after EVOS but were not widely used in operational oil spill detection until the Deepwater Horizon oil spill (DWHOS) incident in
2010 (Leifer et al., 2015; Leifer & Simecek-beatty, 2012; Lubchenco et al., 2012). The years following the DWHOS have revealed that remotely-sensed data has the potential to increase the efficiency of decision-making during an oil spill response (Leifer et al., 2015; Muskat, 2014). The USCG is charged to use the best available technologies to meet the mission needs of the U.S. Department of Homeland Security (USDHS), inclusive of responding to oil spills (USCG, 2018), and in support of that mandate, the National Oil and Hazardous Substances Pollution Contingency Plan (Code of Federal Regulations, 1980) defines the role of the National Oceanographic and Atmospheric Administration (NOAA) as coordinator of scientific activities during oil spill emergencies. The decision-maker’s perception of the information need (data saliency) often influences data usability in any given scenario (Meadow et al., 2015), but tactical versus strategic science requirements are not always easily understood by scientists (Machlis & Ludwig, 2014; Machlis & Mcnutt, 2010), creating a disconnect between RS data demand and supply.

This qualitative study (Chapter 2 - Use and Barriers to use of Remote-Sensing Tools in Arctic Oil Spill Response) is an examination of how remote-sensing data and tools are utilized during an oil spill response. A literature review of available RS tools was undertaken to define the RS tools with the potential to be used to support oil spill detection. Interviews composed of open-ended questions about RS information for decision-making were conducted with 25 members of the U.S. oil spill response community, over half of whom had Arctic experience. Individual interviews revealed the current utilization of RS imagery and tools, challenges, and pathways to the successful integration of RS products in the oil spill response structure. The information gathered during these collection efforts was analyzed and used to synthesize recommendations for effective integration of remotely sensed information into Arctic marine oil spill planning and response activities.

1.2.4 Automated oil spill detection using cloud computing

Computer processing for large volumes of data, including for data sets that require large amounts of computing power to manipulate, or for large data sets that need to be processed quickly, are well-suited for cloud-based computing solutions.
Cloud-computing provides on-demand, scalable, delivery of computing power, database storage, applications, and other infrastructure technology resources through a cloud services platform with pay-as-you-go pricing (Griffith, 2016). Synthetic aperture radar (SAR) is a satellite- or airplane-based, remote-detection sensor that has the ability to image the earth through clouds, smoke, precipitation and night (Woodhouse, 2006). SAR data are voluminous, with data products ranging in size from roughly 150 MB to 4 GB, though larger and smaller data sets exist. Data sets of this size require large computing capacity to process the raw signal into an image and also for construction of secondary products created through algorithms and models. SAR has been demonstrated to remotely sense oil on water and has been used as an essential oil spill tracking tool (Girard-Ardhuin et al., 2003; Jha et al., 2008; Leifer & Simecek-beatty, 2012; Li & Li, 2010; Topouzelis et al., 2007; Tunaley, 2010). Based on the oil detection potential of SAR, semi-automated oil spill detection algorithms using SAR data have been developed for ocean surfaces (Garcia-pineda et al., 2013; Jones et al., 2012; Solberg et al., 2007; Solberg & Brekke, 2004; Topouzelis et al., 2007). Oil spill detection algorithms have the potential to support oil spill response by early detection of oil slicks on the water, which in turn can support an earlier response to the slick, potentially reducing associated environmental damage from marine oil spills.

Supported by the responses of interview respondents familiar with SAR, the second part of this research (Chapter 3 - Cloud-based Oil Detection Processing Pipeline Prototype for C-band Synthetic Aperture Radar Data) is a quantitative proof-of-concept study that examines the potential of cloud-based computing to support the semi-automated detection of oil spills in the Arctic for operational use. The operational objective of this research is to support the fast generation of oil spill detection maps, via a prototypical design and deployment of an automated oil detection processing pipeline using SAR data in the Amazon Web Services (AWS) cloud-computing environment. Using C-band SAR data from the Sentinel-1A satellite, and the oil-detection algorithm derived from Solberg et al., (2007), I generated a geographic information system (GIS)-ready, automated oil spill detection product, deliverable to multiple end users from AWS. This work demonstrated the ability to apply oil detection algorithms to SAR data in a cloud-based environment to create oil spill footprints for integration into an
operational data delivery system, specifically the NOAA-maintained, common operational picture.

1.2.5 Integration of UAS into Arctic oil spill response

Unmanned aircraft systems can support the critical mapping needs of an oil spill response, but are not a consistent data source in incident command posts (ICP) of Alaskan oil spill responses. Successfully integrating UAS into operational settings requires the synthesis of federal, state, municipal and tribal regulations. It also requires the use of correct RS sensors for specific cases to collect data decision makers care about and can act upon. The value of UAS-based data on the environment is clear, but the integration of the data into decision-making in the short and long-term is pocked with gaps in understanding and efficiency. The integration of these data sets into the ICP of an emergency response is additionally hindered by the lack of uniform flight and data collection protocols to make the data available to decision makers.

This mixed methods study (Chapter 4 - Integrating Small Unmanned Aircraft Systems into Alaskan Oil Spill Response – Applied Case Studies and Operational Protocols) was designed to understand how RS data and UAS are currently used as part of oil spill response exercises, specifically in Alaska. The study evaluated the attitudes oil spill responders and their perceived familiarity with UAS applications in support of an oil spill response, and identified how to legally, safely and logically use UAS to support Alaskan oil spill response. I was embedded in the ICP of five Alaskan oil spill response exercises as a UAS Technical Specialist, UAS subject matter expert, and participant observer. Observations were conducted during the exercises to determine current RS and UAS use during oil spill response activities in Alaska. A set of pre- and post-exercise surveys were designed and delivered to participants in four oil spill exercises to evaluate the responders’ attitudes and perceived familiarity with UAS applications in support of an oil spill response. As a result, a set of recommendations for UAS integration into an ICP and a UAS operational protocol was developed for the use of small (less than 55 pounds) UAS to legally, safely and logically support oil discharges or hazardous substance release responses and exercises in Alaska.
1.2.6 Protocol for using UAS during an oil spill response or exercise

A variety of UAS are available to support response activities with potentially valuable real time data. Determining the precise aircraft, sensor payload and flight patterns depend on both the operational need for surveillance and the ability to navigate regulations. In support of UAS integration into America’s airspace, the Federal Aviation Administration (FAA) has defined general protocols for the commercial use of small UAS in 14 CFR Part 107. However, these regulations do not address any other concerns associated with flight of these small aircraft, such as shared operational airspace within a temporary flight restriction area, or regulations for flight over animals that fall under state or federal management.

In the final portion of this research (Chapter 5 - Protocol for Using UAS During an Oil Spill Response or Exercise), the protocol described was developed for the use of small UAS in support of responses and exercises in Alaska involving oil discharges or hazardous substance releases. These specific types of environmental responses are authorized by the National Oil and Hazardous Substances Pollution Contingency Plan 40 CFR Part 300, also known as the National Contingency Plan (NCP). The NCP establishes the National Response System (NRS) and this protocol describes the roles and responsibilities for UAS integration into the incident command structure (ICS) of authorized NRS actions that may include UAS flight requirements and UAS-relevant agency requirements in the presence of marine mammals, seabirds and shorebirds. This protocol was developed with input from the USCG, NOAA, the National Marine Fisheries Service, U.S. Fish and Wildlife Service, and the State of Alaska Department of Fish and Game. The protocol was designed to fit within the context of the ICS of oil spill response activities in the U.S. as practiced by the USCG during actions authorized by the National Response System as defined under 40 CFR Part 300, the National Contingency Plan. It has been integrated into the USCG and State of Alaska, Arctic and Western Alaska Area Contingency Plan, a primary guidance document for oil spill response activities in Alaska.
1.3 Organization of the dissertation

This dissertation is composed of four research chapters (Chapters, 2, 3, 4, and 5), each designed for peer-review by fellow scientists as journal publications or conference proceedings, or by agency and industry partners during the public comment process for area contingency plan integration. The four research chapters are framed by this explanatory introduction (Chapter 1) and the conclusions drawn from this work, inclusive of suggestions for future applied research to support oil spill response (Chapter 6).

1.4 Literature cited


Jones, C. E., Holt, B., & Minchew, B. (2012). Deepwater Horizon Oil Slick Characterization with UAVSAR.


Chapter 2: Use and Barriers to Use of Remote-Sensing Tools in Arctic Oil Spill Response

2.1 Abstract

Remote-sensing (RS) tools capable of detecting marine oil spills continue to increase in availability, accuracy, and precision, expanding the capacity for timely observations of oil spills in support of effecting efficient responses. To ascertain the current use of RS tools and any barriers to their use in oil spill response, open-ended interviews of members of oil spill response, science-support, and decision-making teams were conducted. Interview content analysis revealed the current utility of RS tools for oil spill response support, as well as the data-driven and human-driven barriers to be addressed for more thorough integration of RS data. The analysis was used to support recommendations to enhance the operational use of RS geospatial data for emergency response decision-making, and for gaining acceptance of these tools throughout the broader oil spill response community.

2.2 Introduction

2.2.1 A Brief History of Oil Spill Remote Sensing

Detection of oil spills in the marine environment has been traditionally dominated by human observers from aircraft or watercraft. At the onset of the Exxon Valdez oil spill (EVOS) in 1989, the first assessment of the situation was performed via boat, and the second a few hours later by a human observer in a helicopter using a handheld video camera to record the unfolding disaster (Skinner & Reilly, 1989). Manual surveys like these are highly credible but are manually intensive (NOAA, 2016) and spatially limited, with a high human-risk component. A lower-risk option is to use remotely sensed data captured via unmanned aerial or aquatic platforms.

Starting in 1972, the unmanned, polar-orbiting satellite Landsat began providing images of the earth from space using multiple spectral bands (optical data) for

observations. The first synthetic aperture radar (SAR) mission to observe earth, Seasat, was carried out in 1978 (JPL, 2020), followed in 1991 by the European Remote-Sensing Satellite (ERS-1) platform carrying a C-band SAR, propelling RS science and application development for non-optical monitoring of the earth. These advances in RS technologies have expanded the ability for detection of marine oil spills well beyond the capacity of shore-based or airplane-based human observers (Leifer et al., 2015), but were not widely applied to oil spill detection until the Deepwater Horizon oil spill (DWHOS) in 2010 (Leifer et al., 2012; Lubchenco et al., 2012).

During the DWHOS, massive amounts of RS data from all available sensors were collected over the spill, particularly after the implementation of the International Charter on Space and Major Disasters, a cooperative data-sharing agreement for satellite observations of the earth. The enactment of the charter enabled the collection of a large archive of images that could have been used during the response but that was largely bypassed until the restoration stage of the spill was in progress (Osofsky, 2013; Leifer et al., 2015). During the response to the DWHOS, decision makers relied on trained aerial observers to identify potential actionable oil due to their familiarity with the observers and the information they provide (Leifer et al., 2015). The years following the DWHOS have revealed that remotely sensed data has the potential to increase the efficiency of decision-making during an oil spill response (Leifer et al., 2015; Muskat, 2014), but it is not clear if this potential has been realized.

2.2.2 RS Tools Available to Support Oil Spill Response

Critical for assessing RS tool integration into oil spill response is an understanding of what RS tools are available to support oil spill response activities and what RS tools are currently being used, as well as how they are being used and by whom. Numerous RS systems are available for detecting oil in the marine environment, though not all environmental conditions are conducive to sensor detection of oil. Using
an assortment of sensors and RS platforms to detect oil in the marine environment allows for the detection of oil in the broadest set of conditions.

Table 1 identifies the RS tools that are available for ocean-based oil observations under various ice conditions present in the Arctic based on the literature review referenced in Appendix A. The “open water” column in the table represents how these tools can be used to observe oil in ice-free, non-Arctic locations. The sensors in Table 1 are grouped by platform, or the vehicle that can carry them, and by the spectral components of the data they collect. Platforms can either be aerial (satellites, airplanes, unmanned aerial systems (UAS)), water-based (boats, submarines, autonomous underwater vehicles), or land-based in their data-collecting design. The technical readiness level (TRL) of the sensors is also indicated, and represents an estimate of technological maturity of the sensor on a scale from 1 to 9, from prototype to commercially available product (Panetta & Potter, 2016). One of the variables of the TRL calculation is the relative availability of data products for end user consumption.

The sensors in Table 1 have been demonstrated to have different benefits and drawbacks for oil spill detection in the Arctic based upon their fundamental spectral characteristics and TRL. Other RS tools exist that can be part of a sensor suite for detecting various components of oil on water and in mixed-ice conditions (e.g. microwave radiometers), but their data are either difficult to process
and integrate into decision-making or are not available on the scale that can support the kinds of decision-making required during a marine oil spill response.
Table 2.1. Oil spill detection sensors, supporting platforms and relative capacity under Arctic conditions. The "**" indicates sensor is used on all platforms, and includes human observers, purple brackets aerial platforms (satellite, airplane, UAS), blue brackets ocean vessels (ships and underwater vehicles), black brackets shore-based platforms. Technical readiness level “TRL” indicates the BSEE scale of readiness. “Yes” and “No” indicate if a sensor can detect oil under the defined conditions; unknown or variable sensor capacity for a condition is indicated in orange. “COP-ready” represents if data products from the sensor are available in a GIS-ready/common operational picture-ready format, or if the data needs to be processed to create a COP-ready product “On-demand”. References listed in Appendix A.

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Benefits</th>
<th>Drawbacks</th>
<th>TRL</th>
<th>Open water</th>
<th>Water/brash ice mixture</th>
<th>Fresh oil under ice</th>
<th>Encapsulated oil (1-6 cm)</th>
<th>COP-ready</th>
</tr>
</thead>
<tbody>
<tr>
<td>Visible – Direct observations, cameras</td>
<td>Intuitive</td>
<td>Weather dependent</td>
<td>9</td>
<td>Yes</td>
<td>Yes</td>
<td>No above</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Synthetic Aperture Radar/SLAR – Backscattered signal or signal phase</td>
<td>All weather; day/night; footprint definition</td>
<td>Cannot image through ice; false positives</td>
<td>6/7</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>On-demand</td>
</tr>
<tr>
<td>Infrared</td>
<td>Footprint definition</td>
<td>Weather dependent; false positives</td>
<td>6/7</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
<td>On-demand</td>
</tr>
<tr>
<td>Multispectral - MODIS</td>
<td>Footprint definition</td>
<td>Weather dependent</td>
<td>7</td>
<td>Yes</td>
<td>Yes</td>
<td>No above ? below</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Hyperspectral</td>
<td>Footprint definition; emulsion composition</td>
<td>Processing intensive; weather dependent</td>
<td>4</td>
<td>Yes</td>
<td>Yes</td>
<td>No above ? below</td>
<td>No</td>
<td>No</td>
</tr>
<tr>
<td>Fluoresensor – polarized</td>
<td>Detection through water &amp; some ice</td>
<td>Point/line sweeps; may be weather dependent</td>
<td>6/7</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>On-demand</td>
</tr>
<tr>
<td>Acoustic – Narrowband, Broadband, Multibeam</td>
<td>Detection through water &amp; some ice</td>
<td>Processing intensive</td>
<td>5</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Condition dependent</td>
<td>On-demand</td>
</tr>
<tr>
<td>High-frequency Radar</td>
<td>Ice and oil detection</td>
<td>static locations</td>
<td>8</td>
<td>Yes</td>
<td>Unknown</td>
<td>No</td>
<td>No</td>
<td>On-demand</td>
</tr>
<tr>
<td>Ground Penetrating Radar</td>
<td>Detection through ice and snow</td>
<td>Needs to be in contact with ice/snow surface; water sensitive</td>
<td>6/7</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Dogs</td>
<td>Weather independent</td>
<td>Need to be in contact with ice/snow surface</td>
<td>5</td>
<td>No</td>
<td>No</td>
<td>Yes</td>
<td>No</td>
<td>No</td>
</tr>
</tbody>
</table>
2.2.3 Oil Spill Detection Challenges

RS oil spill detection challenges range from basic weather conditions such as clouds, to diurnal cycles preventing visible spectrum observations, to the interpretation of the data or the information product. Optical sensors are very easy to interpret but are only available during daylight hours and in decent weather conditions, which is also the case for sensors that are multispectral, hyperspectral, infrared, and fluorosensing. Sunglint is the angle at which the sun is shining on the oil slick and is key to the observation of oil by multispectral sensors (Hu et al., 2009; Jackson & Alpers, 2010). SAR can image through night and some precipitation (Woodhouse, 2006), but it can be hard to interpret correctly, as are the other radar-based sensors in Table 1 (high-frequency radar, sonar, and ground penetrating radar).

Look-alike phenomena in RS images that are not oil can be currents, eddies, organic films, rain cells, upwelling/downwelling zones, and shear zones (Brekke & Solberg, 2005; Topouzelis et al., 2007). But these features often can be discriminated based upon shape, and whether that shape is indicative of a slick produced by man or nature (Brekke & Solberg, 2005). Temperature equilibrium between the oil and the water achieved with time reduces the efficacy of thermal sensors (Fingas & Brown, 2012; Puestow et al., 2013). Regardless of the source, false positives and uncertainty in RS data can cause false impressions of oil presence/absence, resulting in frustration and inefficiencies in oil spill response if not addressed (Brekke et al., 2014; Dufek et al., 2019; Leifer et al., 2012; NOAA, 2016; DHS, 2014).

Knowing where and how to access RS data and what hurdles need to be overcome to acquire it is key for RS use but is not common knowledge. Numerous data sets in multiple formats are freely available to theoretically support oil spill detection, but few investments have been made in fine tuning the application of these data sets to oil spill response decision-making. Latency in data delivery to the end user is a challenge when data are needed quickly for decision-making. Data can be delayed from the time of their collection from hours to months depending on the complexity of both the data and the data processing required to make a useable product for decision-making.
Delivery of the data also can take a large amount of time if bandwidth is limited and data need to be delivered manually via hard drive or some other manual storage device (Cutter, 2003; Leifer & Simecek-beatty, 2012).

The DWHOS took place in the Gulf of Mexico, where waters are deep, sea ice is non-existent, and communication networks, both formal and informal, are ubiquitous. In the largest oil-producing region in the U.S. Arctic, waters where oil production currently takes place are shallow, sea-ice is present in varying concentrations and forms, and few communication networks exist other than the informal. As the Arctic becomes increasingly ice-free, more vessel traffic along America’s Arctic coast is increasing the likelihood of an oil spill in this remote region. The ability to identify, track, and respond to oil spills quickly to prevent impacts to coastal communities as well as the ocean environment is an escalating concern (NRC, 2014).

The Arctic is a region of active weather immersed in darkness half of the year, is under a variable sea ice regime, is very sparsely populated, and is restricted by a lack of bandwidth for data transfer to decision makers in rural Alaskan hubs. Spaceborne and airborne RS imagery can provide information over these remote locations but are also somewhat limited in Arctic applications by many of these conditions. Spectral sensors that rely on daylight and cloud-free days do not provide key information about the ocean surface in darkness or in areas where storms are frequent. SAR can image these areas through clouds and in the dark, but the imagery can be misleading if look-alike phenomena are present. In SAR imagery, oil can look like new, undeformed, sea ice, and other look-alike phenomena such as eddies, algae, and wind effects (Brekke et al., 2013; Brekke et al., 2014; Topouzelis, 2008). Weathering processes such as emulsification, natural dispersion, and dissolution also contribute to increased uncertainty in oil slick identification.

Oil and oil emulsions can become encapsulated as a layer within the developing sea ice sheet, where the oil is only released through vertical rise via brine channels, or through the ablation of the ice from the top of the encapsulated oil (Oggier et al., 2020;
Fingas & Hollebone, 2003). If the ice floe containing the encapsulated oil has been tracked throughout the winter, the area of oil surfacing, and thus the point to focus remediation efforts, can be anticipated and can be targeted for clean-up. If however, the floe is not tracked, the oil could be released to the environment as the ice moves and melts during break-up conditions. RS tools can be used to support both ice floe and released-oil tracking in the Arctic, until both are dispersed into the water column with time and wave energy. The importance of RS information for detecting and tracking oil products released in the Arctic marine environment now and into the future cannot be overemphasized.

2.2.4 Federal Oil Spill Response Management

2.2.4.1 Incident Command

RS tools used to detect and track oil spills during an oil spill inform the Incident Command (IC) of the response about the oil itself, whether the IC is being directed by the responsible party or the U.S. Coast Guard (USCG). The USCG is the federal agency responsible for oversight of marine oil spill responses in U.S. territorial waters. The USCG is charged to use the best available technologies to meet the mission needs of the U.S. Department of Homeland Security, inclusive of responding to oil spills (USCG, 2018). The 33 CFR 155 series in the Code of Federal Regulations addresses the requirements vessel operators and USCG regulators must adhere to during a marine oil spill response. Under these regulations, ocean vessel owners/operators responsible for an oil spill must provide aerial oil tracking to support oil spill assessment and cleanup activities by trained personnel who can interpret the aerial imagery; there is no mandate on what specific aerial observational technologies must be employed. Many RS technologies can be used to meet these directives, but efforts to integrate RS have varied, and response plans often rely upon existing, proven technologies (manned aircraft with a trained aerial observer). The mandate for aerial observations in 33 CFR 155 is to collect the information for documentation and decision-making in the Incident
Command Post (ICP) during a spill response, but moving from the known to the new is not accomplished easily or quickly.

2.2.4.2 NOAA’s SSCs

The National Oil and Hazardous Substances Pollution Contingency Plan (Code of Federal Regulations, 1980) defines NOAA’s role as coordinator of scientific activities during oil spill emergencies. NOAA acts as a liaison between the scientific community and the Federal On-Scene Coordinator (FOSC) (typically USCG) through their 12 scientific support coordinators (SSC). NOAA SSCs are operational scientists, responsible for consuming scientifically technical information and providing concise summaries and recommendations for operational decisions. SSCs are also responsible for the coordination of both mission-critical and non-mission-critical scientific activity during oil spill response actions (Shigenaka, 2014). The SSC is the primary data translator and data provider to the IC during an oil spill response. NOAA provides keystone scientific services and products to SSCs during a spill, as well as all interested parties. Data resulting from site overflights carrying trained aerial observers, oil fate calculations, oil trajectory analysis, and mapping provide the standard to which all other RS data are compared.

2.2.4.3 Broader Science Support

Scientific support for oil spill response operations is not limited to the SSCs, though they are the coordinators of the additional science support. Science support can be in the form of data collectors, processors, visualizers, archivists, and interpreters. These roles can be filled by contractors, academics, agency representatives, or others trained to identify and deliver data to the ICP. Science support personnel may be present in the ICP as subject matter experts and are often managed through the Environmental Unit of the ICP, where many of the science questions are asked during an oil spill response. Science support staff who maintain data visualizations are often in the Situation Unit, where the common operational picture (COP) is maintained. These
support roles are critical for providing RS data to the SSC and the decision makers in the ICP.

However, tactical versus strategic science requirements are not always easily understood by scientists wanting to support an emergency response (Machlis & Ludwig, 2014; Machlis & Mcnutt, 2010). Presenting science-based solutions to decision makers during a response has been identified as less than ideal (Leifer et al., 2015; Osofsky, 2011) and a negative impact on the credibility, saliency, legitimacy, and acceptance of the scientific tool presented. Credibility describes the scientific adequacy of the technological advancements (products, tools, methods, etc.) being promoted to meet the given need. The science or product saliency refers to the relevance of the scientific assessment, product, or tool to the needs of the decision makers (White et al., 2010). Does it provide actionable knowledge (Von Lubitz et al., 2008)? The decision maker’s perception of the information need (data saliency) often influences data usability in any given scenario (Meadow et al., 2015). Legitimacy is the perception that the scientific product has been respectfully produced and that it is unbiased and fair (Meadow et al., 2015; White et al., 2010). It is unclear if these perceptions are preventing further use of RS data for decision-making during oil spill response actions, or if there are data-driven facets to RS use that have prevented further RS tool integration.

2.2.5 RS Data Lifecycle During an Oil Spill Response

Oil spills are usually quite small, quickly cleaned up within 24 hours using manual and mechanical means, and damage assessment is straightforward (ADEC, 2007). In these circumstances, RS data are rarely needed. When that is not the case, and the spill is large enough to warrant the use of RS data, an ICP is established to manage the response. The ICP is where all decisions about the response are made and where RS is used to support those decisions (USDHS, 2014).

RS data use is facilitated by a variety of roles in the ICP, in that many different people work with the data at different points in the data life cycle. In the ICP, airplane and UAS-based data collections are coordinated through the Air Operations Chief, who is responsible for the safe management of the air space. In this case, a data collection
request is submitted by a member of Operations (OPS), the Environmental Unit (EU) or from the Wildlife Branch of OPS, for flights over a particular area of the response. These situational awareness requests can be specific for information about oil location, footprint of the spill, wildlife in the area, or other observations. Recently, UAS have been used for some of these observation missions, and the data-collection coordination is very similar to that of manned aircraft, with the addition of the UAS-specific legal requirements. There is an inherent lag between an overflight data request and the actual launch of an aircraft to collect the data, introducing latency into the life cycle.

Once the data has been collected from an airborne platform, the data will be transferred to the Situation Unit for posting to the COP (USDHS, 2014), be that a computer-based interface, a paper or magnetic map, or a combination of all three. A COP is a shared display of relevant information, used in the ICP, for decision-making during a response. Most COPs include a map with varying layers of geospatial data and informational sets relevant to the specific response (USCG, 2004), but they may also include bookkeeping components, resource staging and availability. Through the COP, RS data has the greatest likelihood to be seen and used for resource allocation during a response. The Environmental Response Management Application (ERMA) managed by the NOAA, is a COP that allows for GIS-like data fusion of available historical and real time information layers for data visualization and map creation in support of decision-making. ERMA hosts numerous RS data sets that are updated in real time, and near real time, plus serves as an active archive during a spill response for geospatial data sharing and archiving. Additionally, ERMA houses non-public datasets that may contain sensitive information contributed by the responsible party in a given oil spill, with access limited to approved information managers. Private COPs are also available, and the most frequently used commercial COP is offered by The Response Group.

RS data are used during an oil spill response to locate the oil, determine if it is actionable, identify any apparent resources immediately at risk, identify specific wildlife sightings, and ascertain the effectiveness of any already deployed response tactics. In some cases, the RS data require additional processing and interpretation before they are committed to the COP, introducing additional latency in the data-delivery portion of
the RS data life cycle. RS data collected from a satellite platform typically enter the command post though the SSC into the ICP. The SSC receives the data and the analysis from data experts at NOAA National Environmental Satellite, Data, and Information Service (NESDIS). Though there are many different data providers, NOAA NESDIS provides data to the IC already formatted for the COPs often in use during federalized oil spill response actions, allowing for straightforward integration into the response.

RS data interpretation normally takes place in the EU, or by EU science-support personnel from outside of the command post. Interpreters of the data are responsible for discerning false positives within the data as much as they are responsible for identifying oil and various oiled features. Once the data have been supplied to the decision maker, the decision maker then uses the interpreted data in consultation with the SSC to analyze and coalesce RS information with the other data needed to make their decision. Over an ocean, actions resulting from that data have an additional lag of up to 24 hours, increasing unreliability and uncertainty—and reducing saliency of the product (Cutter, 2003).

2.2.6 Research Objectives

This study was designed to understand the uses and barriers to use of RS tools by oil spill responders. This research was driven by two working hypotheses:

Hypothesis 1 (H1): Freely available, satellite-collected, RS data products are being used to inform tactical responses to oil spills.

Hypothesis 2 (H2): If there is a primary barrier to RS use in oil spill response, it is that data are not delivered in a format that is easily consumable by the COP in the command post.
These hypotheses were used to define the specific objectives of this research to understand **what RS data are currently used in a federalized oil spill response (RO1)**, to understand how those data are used (RO2), to recognize if barriers exist preventing additional use of RS data and tools (RO3), and if barriers exist, identify ways to overcome RS data use barriers (RO4).

To address these hypotheses and research objectives, members of the U.S. oil spill response community were interviewed about their experiences using RS data on previous oil spill responses. The open-ended interviews were used to identify a) the current use of RS tools and imagery in the Incident Command Structure (ICS) of oil spill responses, b) perceived or concrete barriers to additional use, and c) ways forward for additional RS tool integration. The results of the analyses of these data were used to define the recommendations to enhance the operational use of RS geospatial data for emergency-response decision-making.

### 2.3 Materials and Methods

Project protocols including interview questions were submitted to the University of Alaska Fairbanks Institutional Review Board (IRB) to ensure respect for persons, and guarantee beneficence and justice toward the human subjects involved in the research. This study was determined to be exempt from additional IRB review and procedures due to the impersonal nature of the interview questions (Appendix A & B). A pilot study designed to evaluate the interview questions, question delivery, talk-to-text software, and coding software was performed in March of 2016 prior to data collection. This study was minimal in sample size (three individuals), as it was designed to test the interview process and not to determine sample size. As a result of the pilot study, interview questions were revised for clarity, and talk-to-text software was eliminated in favor of human transcription of recorded interviews.
2.3.1 Interview Data Collection

Interviews of 25 individuals who have worked on oil spill responses and/or in the field of oil spill research were conducted between February and July of 2017 to assess facets of major RS-data-and-imagery-use themes in the ICS of an oil spill response. The interview tool was chosen for data collection due to the open-ended capacity of interview questions, allowing for possible insights not often captured under the structure of a survey. The interview tool is limited by the perception of the interviewee, which may impact accuracy of recalled transactions, a ubiquitous bias of the tool. Interviews were conducted over a six-month period in an effort to collect a "snapshot in time" of the interviewees' collective experiences before any other significant events took place that could have influenced one part of the interview pool over another. Questions focused on the overall functional structure of RS data use during a spill response, RS data use during oil spill response actions, and any personal and professional experiences with using the data. The interviews were open-ended, allowing for emergent themes to present themselves throughout later analyses (Appendix D).

Purposive sampling of members of the Alaskan oil spill response community identified initial interviewees (Ritchie et al., eds., 2014). The "snowball" technique of interviewee identification, also known as chain-referral sampling, was employed for identifying additional interviewees not otherwise directly accessible by the research team. This technique relies on initial interviewees providing suggestions of other potential interviewees who could provide value to the study (Mosley, 2013; Naderifar et al., 2017; Seidman, 2013). Interviews were conducted until response saturation to the standardized interview questions was observed. Response saturation was identified through response convergence by multiple interviewees (Yin, 2011) and determined to be reached when additional interviewees did not provide new unique responses to the questions, and no new themes emerged from the responses (Charmaz, 2014; Guest et al., 2006). The potential for sampling bias using this methodology is low for homogenous populations (Charmaz, 2014; Naderifar et al., 2017), as interviewees suggest others who may have similar roles or experiences. The typical number of interviewees identified using the snowball technique to be adequate in representing a
homogeneous population has been previously determined to be 12 (Charmaz, 2014; Guest et al., 2006), and increases with population heterogeneity.

The interviewees fell broadly into two categories by roles assumed during a typical oil spill response as either, 1) members of the Incident Command (IC) responsible for decision-making in support of oil spill response, and 2) the scientific support personnel working to support oil spill response decision makers using RS data, as highlighted in Table 2. Roles of the interviewees on specific oil spill exercises or responses did not cross over between these two main categories, in that members of the IC may fill a different role within the IC for different incidents, but they are always members of the IC. Members of the IC for oil spill responses under the operational control of the federal government, i.e. federalized, marine-based oil spill responses, are predominantly representatives of government agencies at the federal and state level. Non-federalized spill response IC are often staffed by members of the responsible party, with federal and state agency participation more as advisers and overseers of the response. All of the interviewees representing IC in this study were from federal (USCG, EPA) and state agencies, not private industry. Scientific support roles can represent the government, industry, or academia, and are there to respond to the needs of the NOAA SSC. The scientific support interviewees included federal and private (but contracted by the federal government) data collectors, providers, and interpreters represented by NOAA, members of academia, Transport Canada, and state agencies. The NOAA SSC roles typically bridge science support and IC but were included with the other members of science support during analyses as they are not the decision makers in IC.

All interviewees had at least 10 years of experience working on oil spill response actions, with 20 of the 25 (80%) interviewees having worked on oil spill responses throughout their careers. Eighty percent of the interviewees had worked on the DWHOS in 2010, which was the largest oil spill any of the interview participants had worked on, with an estimated 210 million gallons of crude oil released into the Gulf of Mexico (McNutt et al., 2012). Participants worked on other large-scale emergency response actions, such as Hurricane Katrina in 2005 (28% of the interviewees), the 2004 Selendang Ayu grounding off the Alaskan coast that released 338,000 gallons of bunker
fuel (ADEC, 2007) (20% of interviewees), and the 2015 Refugio oil spill of approximately 128,000 gallons off the coast of California that an additional 20% of interviewees directly referenced. All other spills and responses brought up by interviewees were smaller in volume and activity than these four significant response actions.

Interviewees were also asked specifically about their experience in responding to oil spills in Arctic environments (Table 2). The definition of Arctic for this study was any area north of the Aleutian Islands of Alaska, and above latitude 66° in the circumpolar north. Arctic participants were key to understanding nuances of RS applications in less populated places, with no road access, and limited observational conditions (daylight, no precipitation, little to no wind, etc.), as well as to ascertain the current status of RS applications that included some degree of ice cover.

<table>
<thead>
<tr>
<th>Role</th>
<th>No Arctic Experience</th>
<th>Arctic Experience</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>Incident Command</td>
<td>3</td>
<td>8</td>
<td>11</td>
</tr>
<tr>
<td>Scientific Support</td>
<td>6</td>
<td>8</td>
<td>14</td>
</tr>
</tbody>
</table>

*NOAA SSCs are included with Science Support in this study, though they have an advisory position in IC.

Interviews were conducted mostly via phone (22 of the 25 interviews) due to the geographic diversity of interviewees as compared to the research team. Three face-to-face interviews were conducted. Interviews were recorded and transcribed using professional transcription services (VoiceBase, Inc.), after which each transcript was manually edited for detailed accuracy against the audio recording before analysis.

Interview response saturation was observed after interviewing 25 members of the oil spill response community who self-identified into two broadly homogeneous categories of interview participants based on role in response actions, members of the IC (11), or part of the scientific support team (14). This response saturation indicated that a sufficient number of interviews were collected using the snowball technique of referral to represent these two different, but interconnected, oil spill response
communities (Charmaz, 2014; Guest et al., 2006). Twenty-five interviews has also been shown to be a suitable number to support phenomenological studies (Creswell, 2014) like this one, where the phenomena are oil spill responses and exercises.

2.3.2 Interview Data Analysis

Categorical content analysis of the interviews was performed through qualitative coding of the transcriptions and subsequent interpretation of coded content for RS data uses and barriers to use. Qualitative data coding is the process of methodically classifying qualitative data through abstraction, or disassembly of text and reassembly through interpretation (Ritchie et al., 2014; Saldana, 2016; Yin, 2011). A code in qualitative analysis is a word or short phrase that represents either the direct or indirect attribute of language-based data (Saldana, 2016), and is used as a categorical bin that raw data can be divided into for analysis. This process began with data familiarization through review of all data (the verbatim interview transcripts) for transcription errors and response content. A set of 12 descriptive codes were developed by synthesizing the interview questions, key variables of the study, and literature about RS lessons learned during the DWHOS event (Leifer et al., 2015; McNutt et al., 2012; Muskat, 2014). Of these 12 codes, three of them, Availability; C,S,L; and Interpretation, were defined as preliminary “Barriers/boons to use” for RS tool integration using the above code criteria. Each transcribed interview was manually coded using the 12 primary codes defined in Table 3. Annotations, subdivisions of the primary codes, and emergent topics were identified throughout the process for integration into the second round of coding.
<table>
<thead>
<tr>
<th>Preliminary code</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Availability</strong></td>
<td>Reasons RS tools used or not used due to availability; Reasons knowledge from data/tool not avail for d-m</td>
</tr>
<tr>
<td>(Barriers/boons to use)</td>
<td></td>
</tr>
<tr>
<td><strong>C, S, L</strong></td>
<td>Credibility, saliency, legitimacy; interviewee stated preconceived notions and bias about data (how collected, how processed, who involved, certainty of data)</td>
</tr>
<tr>
<td>(Barriers/boons to use)</td>
<td></td>
</tr>
<tr>
<td><strong>Data-sharing platform</strong></td>
<td>The way data are presented for d-m consumption</td>
</tr>
<tr>
<td><strong>Format</strong></td>
<td>What format the data arrived in; if manipulation was required for data use; specific formats types; good/bad</td>
</tr>
<tr>
<td><strong>How data are being used</strong></td>
<td>How are the RS data being used? What are d-m trying to understand by using RS data?</td>
</tr>
<tr>
<td><strong>ICS practices</strong></td>
<td>Discussion of ICS organizational structure and protocols</td>
</tr>
<tr>
<td><strong>Integration</strong></td>
<td>Integration mandates, attempts, fail-safes into response</td>
</tr>
<tr>
<td><strong>Interpretations</strong></td>
<td>Knowing how to use the data, knowing what data means, knowing false positives</td>
</tr>
<tr>
<td>(Barriers/boons to use)</td>
<td></td>
</tr>
<tr>
<td><strong>It would be really cool if...</strong></td>
<td>New RS data and tools d-m want but don’t have; kinds of RS data people really want or daydream about</td>
</tr>
<tr>
<td><strong>Mandate</strong></td>
<td>Use or disuse of RS data based on policy mandate</td>
</tr>
<tr>
<td><strong>Role</strong></td>
<td>Role of interviewee in spill responses and drills, past/present</td>
</tr>
<tr>
<td><strong>RS platform</strong></td>
<td>RS platform used to carry sensors in data collection</td>
</tr>
<tr>
<td><strong>Teaching or learning preferences</strong></td>
<td>How people want to learn about RS data and tools</td>
</tr>
<tr>
<td><strong>What data are being used</strong></td>
<td>The specific RS products and sensors being used as reference data for d-m</td>
</tr>
<tr>
<td><strong>What people want to learn about, operationally</strong></td>
<td>The specific, existing RS tools or images that interviewees want to learn more about</td>
</tr>
</tbody>
</table>
Secondary coding of the interviews was performed digitally using NVivo 12 Plus qualitative data analysis software tool (©QSR International Pty Ltd). Secondary coding offered the opportunity to confirm initial code analysis, to divide the initial code categories into subcategories where appropriate, and to incorporate emergent codes revealed during preliminary coding of the interviews. Emergent codes represented information that did not correspond directly with the existing codes but were described by multiple interviewees when responding to interview questions. An example of an emergent code would be the code, “You don’t know what you don’t know,” which was used when interviewees were unable to discuss specific RS tools due to a lack of exposure. Other emergent codes included where the data were coming from, discussion points, key interviewee quotes, and geographical locations of concern for future oil spills.

Barriers to RS tool use were explored through content analysis of the categorized data after secondary coding. This analysis revealed that the preliminary codes designed to capture the potential barriers to RS use were insufficient, and Data Integration was identified as an additional barrier or boon. Additional distinctions about RS-use barriers teased from the interview content at this stage was the need to add data consumers, and data establishment as sub-codes to Data Integration. During this analysis, it also became evident that interviewee perceptions of credibility, saliency, and legitimacy were distinct and warranted division into their own primary codes. The final codebook of the analysis is available in Appendix E.

The independent variables of analysis for the coded interview data were the role of the interviewee during spill response actions, and if the interviewee had Arctic oil spill response or exercise experience. Dependent variables of analysis were the codes that described what kind of RS data are used, how it is used to inform decision-making, and what barriers to use exist. Barriers to RS use were divided into data-driven barriers to RS as defined in Appendix F, and the following human-driven barriers to RS use:

- **Legitimacy** – Legitimacy describes the establishment of fairness and perceived lack of bias in the production of the RS information, but also fairness in its analysis for oil spill response support. Legitimate data has not been influenced by
beliefs or value systems during collection and analysis, and is unbiased in its content (Cash et al., 2010; Meadow et al., 2015; Weichselgartner & Kasperson, 2010; White et al., 2010). Interview text was coded under Legitimacy if interviewees expressed concern over data collection methods, the data collectors, or other variables that can be described as personal measures of legitimacy.

- **Credibility** – Credibility refers to the recognition that the RS data being discussed or used is authoritative, believable, and trusted. Often credibility addresses the scientific adequacy of the technical evidence and arguments about the RS data or tool (Cash et al., 2010; Leifer et al., 2015; Weichselgartner & Kasperson, 2010; White et al., 2010). Interview text was coded under *Credibility* if interviewees expressed skepticism about the authoritative nature of RS data.

- **Saliency** – The salience of scientific knowledge is determined by its relevance and/or utility to a stakeholder. Saliency deals with the relevance of the RS data or assessment to the needs of the decision makers (Cash et al., 2010; Leifer et al., 2015; Lemos, Kirchhoff, & Ramprasad, 2012; Von Lubitz et al., 2008; Weichselgartner & Kasperson, 2010; White et al., 2010). Interview text was coded under *Saliency* if interviewees described the data as being not helpful, or useful for the particular response, or for their role in the response.

Some factors directly influencing these coded variables were specifically asked about during the interviews, including product format, data access, and the vertical hierarchy of decision-making during a response, while others emerged during the interview analysis process. Collected information from interviewees was dissected in two ways based on role and prior Arctic experience. Interviewees tend to repeat themselves when trying to validate a point, or when referencing the same scenario multiple times (Seidman, 2013). To avoid the influence of repetitive statements on analysis, percent frequencies of unique response codes of individual interviewees as components of the entire interview pool were calculated to develop the analytical visualizations.
2.4 Results

2.4.1 Reported Geospatial Data Use

Interviewees were asked what RS data they used as part of their roles in oil spill responses in which they had previous involvement. One interviewee had no experience using RS data or tools, so results about RS use were based off of the remaining 24 interviewees.

2.4.1.1 What RS Data Are in Use

Figure 2.1 describes the different kinds of RS and other geospatial data that are currently used during oil spills, as reported per role and Arctic experience of the interviewees. All interviewees were asked specifically about their use, or lack of use, of

![Bar Chart](image.png)

**Figure 2.1.** Specific RS data and geospatial information used in oil spill response. SAR to support oil spill response; all other sensor types were indicated independently by interviewees.
Interviewees identified a thorough suite of RS data products that were in use during oil spill response. The most common RS data type used by all interviewees was visible imagery (R, G, B spectral data), as either photos or videos. This data type is the most ubiquitous in society at large as well, and is intuitive for people to interpret quickly, though not always accurately. Photos also are the primary data product of the human aerial observers who are still a mainstay in all significantly sized oil spill response actions.

SAR was the second most used sensor, according to interviewees. SAR played a pivotal role during DWHOS and was used to develop synoptic oil spill maps daily that were used in briefings to both the response community and the public. The extensive use of SAR can also be attributed to the massive size of the DWHOS (McNutt et al., 2012), which was provided at no-cost among the satellite-based RS data available over the area due to the enactment of the International Charter on Space and Major Disasters. The DWHOS was such a large, and long-lived, oil spill event, that all interviewees who reported prior RS use had worked on it in some capacity.

Non-specified imagery, data having no description of exactly what kind of sensor was used in its capture, was mentioned by many interviewees, as was infrared imagery. Many of the respondents talked about RS data they had heard of other people using on a response when asked about what kind of data were used. In these cases, the interviewee rarely knew the sensor type that had been used and so a separate category, Other, was created to capture this nuance.

The data types that were mentioned by less than 20% of the interviewees were a mix of the most complex (LIDAR) and most straightforward Automatic Identification System (AIS) RS data products that could be used on an oil spill response. This distribution likely represents the unique applications of each of the sensors in this group (LIDAR, aerosol data, AIS, buoy data), as none of them would be considered common for spill response applications, though their usefulness is well understood and applied in other scenarios more often.

Scientific support staff interviewed acknowledged using RS data more than members of the IC and were consistent in their recognition of the need for multiple kinds
of sensors, used to examine the same phenomenon, to give the richest data set for decision-making. Science support teams are responsible for interpreting the RS data, and made it clear through the interviews that the more data sets they have available covering an area, the better interpretation they can provide to the decision makers in IC. Interviewees with Arctic experience reportedly used RS data more than those without Arctic experience. However, uniformly, their experience with RS use during oil spill response activities were all in non-Arctic settings. Only those interviewees with Arctic experience indicated use of AIS transponder tracking of boats and buoy data as part of response activities. Conversely, only responders not experienced in the Arctic described aerosol data as important RS data during a response.

2.4.1.2 Data Platforms

The platform on which the sensors were mounted was indicated for some of the sensors, but not consistently enough to be correlated to the sensors used. Platforms used during the response to carry RS sensors included satellites, airplanes, helicopters, UAS, underwater remotely operated vehicles (ROVs), and poles in a static location.

Airplanes and satellites were the dominant RS collection platforms as described by 92% and 80% of the interviewees respectively. Airplanes and helicopters were used to carry human observers collecting photos or videos, and by a number of different, contracted data providers that carried suites of sensors, most commonly visible, infrared and side-looking radar. Satellite-based sensors were the only ones that could provide a large enough field of view to gain an understanding of where all of the oil had gone during the large DWHOS, and were lauded by most members of the scientific support team for their ability to provide a synoptic view of the oil spill. UAS were discussed in every interview based upon a set of UAS specific questions; however, interviewees specified that the potential use of UAS to support oil spill response was academic and non-operational in their prior experiences.
2.4.1.3 How RS Data Currently Used

![Data usage chart](image)

**Figure 2.2.** How RS data are currently being used in support of oil spill response based on percentage of interviewees by role.

Interviewees were asked how they used RS information during a response or exercise, and their answers were binned into the 15 categories identified in Figure 2.2. RS data usage for oil spill response was also parsed by role (member of IC or member of scientific support team). General definitions for each use are included in Appendix E Figure Variable Definitions.

In general, members of the scientific support team used RS data more than members of IC (Figure 2.2). This result reflects the nature of the work performed by the two different groups of interview respondents, as many members of the scientific support team are charged with either handling data directly or supporting the interpretation of the data. The two instances where IC used RS data more than the
scientific support team members was for Communications support and Air monitoring, also reflecting the natures of the two different roles. Members of the IC are responsible for briefing the media, governmental leaders, and the public (USDHS, 2014), and they often incorporate maps and other visualizations of the incident to clarify the discussion. In support of a safe operational environment, air monitoring is used to detect the level of harmful chemical components in the air as a result of the pollutant or from the response. This information was used for tactical decision-making and for ensuring worker and public safety, both of which fall under the purview of the IC. The two RS data uses that were most similar between the two categories of interviewees were determining Situational awareness, and Tactics monitoring, though members of the scientific support team used RS data more than IC in both of these circumstances as well.

2.4.2 Barriers to RS Use in Oil Spill Response

Barriers to RS use during an oil spill response emerged throughout the interviews, most markedly during discussion about data availability, data format, and other successes or failures when using RS data during an oil spill response or exercise. The interview data show that the use of RS data and tools in oil spill response is limited by interwoven data-driven and human-driven barriers, as barriers to RS data use were consistently described as a combination of interdependent data-driven and human-driven barriers preventing the efficient use of RS data and tools during response actions. Data-driven barriers were defined as tangible components of the data that are influential on RS data usage. Human-driven barriers were defined as those that hinged on an interviewee’s perception of RS data based on their experience or hearsay. Interviewees did not distinguish between data- and human-driven barriers to RS use directly, but described scenarios of both data- and human-driven barriers being simultaneously influential on their RS use experiences. To represent the interconnected nature of the barriers, the data-driven barriers in Figure 2.3 are tied to their underlying human-driven barriers by color. Central nodes (parent nodes; Saliency, Legitimacy, Credibility, Interpretation, Data Integration, Availability) represent primary codes of the study that, when analyzed for content, were identified as barriers or boons to RS data
use. The secondary nodes (child nodes), represent codes that interviewees identified as contributing factors to the central barrier nodes, but were not discrete barriers in themselves.

2.4.2.1 Data-driven barriers to RS integration

One of the working hypotheses of this research was that RS data were not being presented to oil spill response decision makers in formats that are easily consumable by the COP, the primary data-sharing platform, and that this formatting issue was the primary barrier to RS use in oil spill response (H2). The barriers to RS use that were identified through the open-ended responses of the interviewees indicated data format for the COP was only one of many different quantitative and qualitative barriers to RS use during an oil spill response, and that most of the barriers were interconnected (Figure 2.3). Data-driven barriers to RS use fell into three primary categories represented by the primary nodes in Figure 2.3: Availability, Data Integration and Interpretation. The Interpretation node represents both data- and human-driven barriers to RS use, and is discussed with the human-driven barriers.
Figure 2.3 – Barriers to RS use in oil spill response. The width of the circle outline and the intensity of circle shading represent number of interviewees identifying the category as barrier; the more respondents, the darker the category color shade and the thicker the outline. All Data Integration and Availability responses were subcategorized into the child nodes; Interpretation contains responses in both the parent node and child nodes. Data-driven barriers are represented by solid circles and human-driven barriers by dashed circles.
2.4.2.1.1 Availability

Data availability was identified by interviewees as a major challenge to RS data use. Availability is characterized by the variables that influence data access. The factors contributing to RS data availability challenges were not uniformly distributed across interviewees, and included some individuals who indicated there were no barriers to their RS data access. Respondents described these variables with a negative connotation, except for those who described having No Availability Issues. Variables impacting data availability are defined in Appendix E and are represented as some of the data-driven barriers on Figure 2.3.

Of the barriers to RS availability, Latency was the most often cited barrier to data availability. Ninety-two percent of Interviewees cited latency from the point of RS data collection over the ocean to its arrival in the ICP as effectively making the data obsolete for quality decision-making. Additional latency details were discussed (post-processing complexity, satellite repeat cycle, crew mustering, etc.), but all were found to be components in the larger latency-from-collection-to-decision-making problem.

Cost was a concern for 76% of respondents, though no specific questions about cost were posed. Components of Cost identified by interviewees were broad and included the cost of the data itself, software to process the data, vendor operations, training requirements, and costs of maintaining any infrastructure needed to support RS data. A number of interviewees tied cost to latency (e.g. “time is money”), and some indicated that only industry could afford RS data. Several interviewees in scientific support knew which RS data sets were available to them at no cost, a nuance that emerged in discussions about where the data had come from.

Access to restricted data sets held by either government agencies or by private entities was categorized as a Clearance barrier to access and was cited by all of the science support interviewees and some of the members of IC, or 72% of total interviewees. Data sets from classified government satellites in earth orbit theoretically have the capacity to provide high-resolution imagery over areas where the publicly available satellites have lower-resolution coverage. Clearance to access these types of high-resolution data sets was the barrier scientific support recognized as a clearance
issue. Clearance to access data held privately by the responsible party of an oil spill was also described but quickly dismissed by interviewees as not a critical barrier due to data-sharing agreements normally signed by agencies and industry during an oil spill response.

Coverage over the area of interest by RS data was identified as a barrier to availability by 60% of the interviewees. Satellite coverage by earth-observing satellites over a given area is limited by orbital and sensor characteristics of the satellites (Ferretti, 2014; Sabins Jr., 1987). Satellite-based coverage issues were often tied to data Latency issues by interviewees. Coverage issues associated with airplanes were not highlighted, as basic knowledge of deployment breadth of these aircraft were commonly understood. There were no specific coverage issues discussed regarding UAS either, likely due to the lack of operational integration of these tools. Coverage issues associated with either water-based or static platforms were not discussed by interviewees.

The 44% of interviewees who mentioned Weather and 24% who mentioned Bandwidth as barriers to availability had sufficient background knowledge about RS data to recognize these two categories as potential problems. Weather acts as a barrier to platform launch and data collection for most of the RS data that interviewees described using in Figure 2.3. The most common interfering phenomena are clouds and wind, but weather is not always a barrier to RS data use. None of the interviewees mentioned daylight hours as a barrier for RS availability, even though over half of them had previously worked in the Arctic on responses that took place in the winter, and daylight is required for the functioning of many of the observation sensors described by the interviewees.

For scientists performing raw data processing and data delivery to the ICP, Bandwidth is a significant barrier to data availability. RS data in raw form tends to be large in volume, with most RS data besides traditional photos, being in the multiple MB or GB range. The large data volume requires proportionally sufficient bandwidth to transfer from one location to another, bandwidth that is often unavailable in remote locations. The interview data show this nuance is not understood by people who do not
work with RS data sets, and was not indicated as a barrier by interviewees who were members of the IC.

Sixty-eight percent of interviewees had Access Knowledge about the data. Members of the science support teams knew where to get the data, or were the providers themselves. Members of the IC who were using the data for decision-making did not typically know of available data sources besides those provided by NOAA NESDIS, nor was it a significant concern to them. The positive perspectives expressed by interviewees in the IC and scientific support about Access Knowledge and No Availability Issues fundamentally differed from each other, and were also in conflict with all of the other perceived barriers to availability that were negatively expressed by the interviewees. It was common to hear from members of the IC that they had no RS data-availability issues; they just asked their SSC for information, and it was supplied. As such, these interviewees possessed Access Knowledge by knowing who to call to get science information, and have No Availability Issues because the SSC was able to provide them what they were looking for. Alternatively, members of the science support team have different Access Knowledge, in that they know to get the data from data providers such as NESDIS, or an airborne data vendor, or through the COP, and they have No Availability Issues because they know all of the data portals from which to harvest the data. Regardless of perspective, 68% of respondents said they had Access Knowledge on how to acquire the data, and 62% of respondents said they has No Availability Issues in gaining access to the data.

2.4.2.1.2 Data Integration

Data integration differs from Availability in that it incorporates the logistical components of data access once the data are in hand, such as format- and data-sharing platforms (COPs). Definitions for the data-integration subcategories can be found in Appendix F and their interpreted relationship to Availability and Interpretation in Figure 2.3.

Data Origin was described as a key variable to data integration by 100% of the respondents. Having confidence in the RS data quality, or data Credibility, was
intertwined in interviewee discussions about *Data Origin*. COPs, briefings, and information sharing platforms were grouped as RS data-Sharing Platforms, and were important components of data integration for 92% of the interviewees. Having data accessible in a format that did not require additional processing, or that was compatible with the COP, or were just easily consumed by decision makers was an important component of RS data *Format* for 84% of respondents. However, only 36% of interviewees indicated that *Ingest & Processing* was an important component to data use, even though *Format* is directly tied to whether additional *Ingest & Processing* would be required for data integration. Having known *Consumers* of the data (people who would actually use the data for decision-making) was important to 80% of respondents. *Establishment* of the data products as one of the usable tools during an oil spill response, as opposed to working with a prototypical data set or data source, was important to 64% of the interviewees.

2.4.2.1.3 Interpretation

Unlike the other parent nodes represented in Figure 2.3, *Interpretation* holds distinct data points about the interpretation requirements of RS data and tools. RS data often needs to be translated, or interpreted, by a subject matter expert, or a member of the response team who has been trained to interpret the information at hand. Failure to provide data-interpretation support will limit the availability of RS data to be used to accelerate the response efforts of an oil spill response. As such, *Interpretation* is both a human- and data-driven barrier to RS data use. The child nodes under *Interpretation* are defined in Appendix E and F.

Of all the interview language coded under barriers to *Interpretation*, the actual interpretation of the data was identified by 88% of interviewees as the biggest barrier to RS use in this group of codes. This was not described as a problem for the visible RS data (photos and videos) and for those data collected and relayed by a human visual observer, as no specialized training was required for their interpretation. Having a subject matter expert (SME) as a member of the science support team on-site who
could interpret the data was important to many interviewees, as members of the IC typically had no training that was applicable to RS data interpretation.

*Knowing how to Manipulate* the data was recognized as a skill and need by 72% of the interviewees, and was the only other node under the *Interpretation* node that could be considered both a human- and a data-driven barrier. RS data manipulation requires a deeper level of understanding and expertise than interpretation alone and is the narrowest portion of the RS use bottleneck. Manipulating the data in this case meant knowing how to ingest it, perform some degree of post-processing on it, and present it to the decision makers of IC in a usable way, ideally in the COP.

Sixty percent of interviewees described being disappointed in the level of *Resolution* offered by RS products. Resolution as a function of pixel size was never expressed as such, but it was clear that was the issue when interviewees complained of not being able to “zoom in” enough to distinguish two closely spaced objects in an image (Sabins Jr., 1987).

*False Positives* and *Uncertainty* were noted problems by over half of respondents, representing both IC and the scientific support teams. When these two data-driven barriers were discussed during interviews, interviewees often tied the two barriers directly to data *Credibility*. *False positives* resembling oil hindered specific response missions during DWHOS (Garcia-Pineda et al., 2013; Leifer et al., 2012, 2015), and were of concern to 56% of interviewees. Interviewees described having limited expertise in the ICP to tease false positives out from the actual oil signatures, and the most commonly described solution to this problem was to send a human observer in a helicopter or airplane to confirm the presence of oil (Figure 2.3). The word “uncertainty” in this context references a qualitative scale of uncertainty that decision makers are interested in being informed about. Unlike the calibrated qualitative scales of confidence and likelihood used for Intergovernmental Panel on Climate Change reports (IPCC, 2005), interviewees wanted this uncertainty expressed as low, medium, and high uncertainty in the interpretation of the RS data. The 52% of the respondents who did mention uncertainty as a barrier to RS data use were adamant about how important it was and wove it into most of the discussion.
Algorithm Use was the least important barrier to interpretation of RS data, and was described by only 44% of the interviewees. Interview language about Algorithm Use referenced the capacity of algorithms to expand oil spill detection applications or trajectory modeling capacity.

2.4.2.2 Human-driven barriers to RS integration

The obstacles to RS data use described as data Credibility, Saliency, Legitimacy, and Interpretation (section 2.3.2), were the human-driven barriers to RS data use as described by interviewees. These human-driven barriers were infrequently described without referencing interconnected data-driven barriers.

2.4.2.2.1 Legitimacy

The Legitimacy of RS data refers to trusting that the information is impartial and fair, and that it was produced in a respectful and unbiased manner (Cash et al., 2003; White et al., 2010). Sixty percent of all interviewees directly described the Legitimacy and illegitimacy of data and data providers, as well as the challenges of interpretation (88%). Seven IC members, representing 28% of the total interviews, indicated data Legitimacy was a concern for them. These IC members were more likely to use data coming from sources they know, as opposed to those they do not (e.g. contracted vendor for the responsible party), and placed an emphasis on trust in the data’s origin. For example,

“It all comes down to trust. If you trust the individual who is giving you the information, whether it's legal information, or if it's operational information, or if it's visual information, it's all trust.” (Member of Incident Command)

Legitimacy was distinctly important to nine of the interviewed science support team members, representing 36% of the overall interview pool. The members of the science support team who self-identified as RS data providers understood the appearance of data integrity influencing Legitimacy, and the importance of transparency to create trust in the data:
"We were very transparent, but we’re also transparent about what we’re able to do." (Science Support Team Member)

The data driven-barriers that interviewees most often correlated to Legitimacy were child nodes of Interpretation, especially when the importance of knowing the uncertainty of data coming from different sources was described:

"Knowing more about the source of the data and the uncertainty associated with it, just whatever it is, I would consider all of that. But I would happily receive it and use it to the extent that I felt appropriate once I knew more about the data." (Member of Incident Command)

Knowing that the data were repeatable and reliable per interpretation were also concerns for interviewees representing both scientific support and the IC, but these components of Legitimacy were described through their respective lenses of data provider versus consumer, i.e. science support versus IC. Science support team members were concerned with creating or synthesizing repeatable data products. For example,

“At a minimum, you’re consistent with your other data products that you created on and off for the last however many years. It’s a level of control that I do understand.” (Science Support Team Member)

On the other hand, members of the IC were concerned with receiving data that was repeatable:

“If it is reliable and repeatable, and somebody can explain it to me, then it’s useful to me.” (Member of Incident Command)

These slightly different perspectives on reliability and repeatability highlight how these two distinct groups interact differently with the RS data, as well as that these components support RS data Legitimacy for both groups during a response. However, the emphasis of these interviewees on reliability and repeatability also echoes the interwoven data-driven barriers within Data Integration of Origin and Interpretation that
influence the perception of data *Legitimacy* and *Credibility* by members of the response community.

### 2.4.2.2.2 Saliency

Data *Saliency* addresses the perceived need for the data as determined by its relevance and/or utility to stakeholders in the IC (Cash et al., 2003; White et al., 2010). The human-driven barriers attributed to *Saliency* were discussed by interviewees as scenarios highlighting the relevance of RS data in the oil spill response. Eighty percent of interviewees indicated the importance of *Saliency* in respect to RS data, and these responses were evenly represented members of the IC and the science support teams. The fundamental concerns about data *Saliency* are represented in the following interview quotes:

> "Ultimately, it again goes back to the appropriate application of the technology to the situation." (Science Support Team Member)

In this instance, the interviewee refers to the *Saliency* of the application of the data, as compared to the *Saliency* of the data itself as highlighted by a different member of the science support team,

> "And if we don't deliver something of sufficient resolution that doesn't support them making that decision, we're just wasting their time." (Science Support Team Member)

Interviewees representing members of the IC also recognized the importance of salient RS information to execute an efficient response, but viewed through the lens of informed decision-making,

> "It's important to minimize impact and protect the environment and protect public property. So any tool that would be at our disposal to use, yeah, I would definitely be interested in taking a look" (Member of Incident Command)
However, members of the IC also recognized that not all data was salient to the decisions at hand, mirroring the concerns of the science support team about providing data that is not directly applicable to the specific situation,

“Sometimes it may be all you have. So do you really want to look a gift horse in the mouth so to speak? … But also what else do I have to look at? Is there anything else more reliable? I think that’s a consideration, and rarely do you have multiple sets of imagery that you can integrate into your COP. So I think it’s, what’s the best, what’s the best horse in the stable as far as with reliability?” (Member of Incident Command)

The prevalence of **Saliency** in the interview responses was also remarkable in that data **Saliency** was consistently connected to data-driven barriers that impact **Saliency**. This connection of data **Saliency** to **Latency** as a data-driven barrier was distinctly described by seven individuals, representing 35% of the interviewees noting **Saliency** as a barrier to RS use.

“I think most of the time we’ve received stuff a week late on average. It doesn’t help us as much. We need real time information to make real time decisions.” (Member of Incident Command)

Though data **Latency** influenced the **Saliency** of RS data in this interview pool, it was only one of the components of **Saliency** brought to light during the interviews. Specific RS data applications described in Figure 2.3 that supported quality decision-making also influenced data **Saliency**. Specifically, interviewees also brought up key determinations about the oil in the environment that could increase **Saliency**:

“When we can start reliably differentiating [oil] thickness, I think that’s going to give a whole new level of utility to [the] satellite industry.” (Science Support Team Member)

Qualitative components of the data were described as influencing **Saliency** but were also directly tied to data-driven barriers in context. In this example of this interweaving of themes, the **Format** element of **Data Integration** was described as an
influence on data Saliency by a member of the IC who had worked on emergency response actions for over 20 years:

“… you need to provide high enough quality of information and an easily digestible format.” (Member of Incident Command)

Tying multiple data-driven barriers tied to Saliency is also highlighted by this interviewee, in this case by connecting Saliency to Scale, Resolution, Ingest & Processing, and Latency:

“The question of scale and utility of the derived data really become critical. How you capture sufficient resolution and then making that product available in such a fashion that it can either be ingested into something or used independently to support decision-making. So a lot of it is timing, but most of it comes around the appropriate delivery and timely delivery of whatever data are being collected.”

(Science Support Team Member)

The recognition of data-driven barriers to RS use was consistently tied Saliency by the interviewees indicates that improvements made to data components that influence Saliency will increase the overall data Saliency in the oil spill response community.

2.4.2.2.3 Credibility

Descriptions about how reliable or scientifically adequate the RS data were to the interviewee were coded as Credibility (David W. Cash, Jonathan C. Borck, 2003; White et al., 2010). Data Credibility was indicated as important to 84% of the interviewees, representing 32% of the members of IC and 52% of science support team members interviewed overall. Credibility of RS data was described positively in reference to consistency associated with calibration and other quality data practices by science support team members. For example,
"I don't care if you're flapping your arms, you're Mary Poppins with an umbrella, UAV, an airplane with a pilot, piloted aircraft, satellite, or God. As long as it's calibrated, you've shown what you can do, you've proven what you can do, and it meets your data quality objectives, good to go." (Science Support Team Member)

Conversely, Credibility was described negatively based on problems also attributable to data consistency or lack thereof:

“The problem with any data management in a response, is the numbers never agree. The numbers will never be uniform, especially if you have reports coming in from multiple locations.” (Member of Incident Command)

This described frustration with data inconsistency reducing RS data Credibility was also identified by members both of the IC and science support team as a barrier that could be overcome through analysis and expert interpretation of the RS data:

“I think if there were an intermediary who could provide experienced analysis, that would buffer, increase these people's confidence.” (Science Support Team Member)

Members of the IC also understood that Credibility was achievable through interpretation by someone familiar with the data products who was also able to report data accuracy:

“Yes, provided the technicians can describe how accurate the data is, how it's collected, how it's put together. I understand this debate.” (Member of Incident Command)

These perceptions of data Credibility as a surmountable, human-driven barrier from both the science support community and the IC of responses also demonstrate how data-driven barrier of Interpretation—specifically the interpreted level of data Uncertainty—can heavily influence data Credibility. When expert Interpretation and analysis was not available for RS products, Credibility was achieved by “ground truthing” RS data using human observers in manned aircraft. The use of human
observers can be perceived as verifying the *Credibility* of the data but also indicates a fundamental lack of *Credibility* for stand-alone RS data products:

“Unless provided us with synoptic pictures and we can have some confidence that it’s not a false positive. And the best way to do that, at this point, is oftentimes with a trained observer. That’s why I keep thinking of it, at least in today’s context, as a recon tool. A recon-level tool which is maybe good enough for some initial information, but it’s going to need to be ground truthed somehow, probably.” (Science Support Team Member)

These data demonstrate that until clear RS data *interpretation* can be provided for each RS product entering the ICP during a response by either an expert or a well-defined RS product, the human-driven barrier of *Credibility* will persist, and human observers will continue to be the most credible data source for observed oil characteristics.

### 2.4.3 Preferred Learning Methodology

Interviewees were asked if they wanted to learn more about RS tool applications to support oil spill response activities, and if yes, to identify their preferred methods for learning about the tools. Figure 2.4 represents the preferred learning or training methods indicated by the interviewees. Three individuals grouped into IC were not interested in learning more about RS tools, as RS tools were described as “outside of my wheelhouse”; these individuals were still pooled for learning preference, and their responses are included below.
Figure 2.4. Preferred learning methods for members of the oil spill response community. Interviewees were not limited to one response.

Workshops were the preferred method of receiving new information by 64% of the interviewees, followed by Hands-on training opportunities, popular with 48% of the respondents. There was a steep decline in interest for the other learning methods listed, even though Discussions with subject matter experts and small groups of engaged responders was very positively described as a way 24% of the interviewees had learned about RS tools in the past and would like to learn by in the future. Self-driven methods such as reading or independently researching a topic were less popular than Workshops and Hands-on training, with only 16% of interviewees indicating this preference, which was the same percentage for those wanting to learn from Seminars (16%). Webinars could also be considered as a self-driven learning methodology but were only mentioned by 12% of the respondents. Demonstrations dedicated to particular RS topics were of interest to 8% of the interviewees, and large-scale Conferences, such as the International Oil Spill Conference with multiple vendors and expertise highlighted, were attractive learning options for only 4% of the interviewees.
2.5 Discussion

During the interview process, it quickly became clear that the two working hypotheses, \(H_1\): All freely available, satellite-collected, RS data products are being used to inform tactical responses to oil spills, and \(H_2\): If there is a primary barrier to RS use in oil spill response, it is that data are not delivered in a format that is easily consumable by the COP in the command post, were myopic in form and function. However, the objectives, to understand, 1) what RS data are currently used in a federalized oil spill response (RO1), 2) how those data are used (RO2), 3) to recognize if barriers exist preventing additional use of RS data and tools (RO3), and if barriers exist, 4) identify ways to overcome RS data use barriers (RO4), were broad enough to remain valid throughout the study. The open-ended nature of the interview tool was thus critical for capturing the range of responses about RS data use during oil spill response actions by interviewees, as well as the perceived barriers to that use.

This study revealed that science is employed throughout an emergency response. However, \(H_1\): Freely available, satellite-collected, RS data products are being used to inform tactical responses to oil spills, was only partially correct. Interviews conducted with 25 members of the oil spill response community to understand what RS data are currently used in a federalized oil spill response (RO1) (Figure 2.1), revealed that very few satellite-collected RS products were used with any regularity after the conclusion of the DWHOS. The satellite-obtained RS data that are being used are normally verified by sending a human aerial observer in a manned aircraft, highlighting a lingering credibility and legitimacy issue for RS tool use. Some manned aircraft and UAS missions are currently used to collect RS data during regional oil spills lasting more than a day. However, the integration of these tools into the COP is not guaranteed, nor is the activation of a COP for the response phase of the oil spill.

RS data were used by different members of the response in both quantitative and qualitative ways (RO2) (Figure 2.2). Quantitative measures of the oil location, oil thickness, and aerosol particulates, were synthesized by science support team members to make qualitative assessments about oil trajectory, resources at risk, and effectiveness of deployed response tactics. These assessments were presented to
members of the IC to support their need for situational awareness, tactical decision-making, and communications support through the lens of a COP or large paper maps.

The second project hypotheses, **H2: If there is a primary barrier to RS use in oil spill response, it is that data are not delivered in a format that is easily consumable by the COP in the command post, was not confirmed.** According to interviewees (section 2.4.2.1.2), data-sharing platforms are not limited to COPs, and RS data were made available through COPs, briefings, and other non-geospatial platforms to members of the ICP. As such, data that were not properly formatted for a COP were not the primary nor an insurmountable barrier to RS data use by interviewees. However, formatting data sets for integration into ERMA, the COP maintained by NOAA, should be considered as a best practice to achieve greater visibility of RS data by NOAA and members of the IC reliant on the NOAA SSC for information, but it will not prevent RS data from being referenced. Multiple other data-driven and human-driven barriers to RS data use were also found to exist (RO3) (Section 2.4.2.1 and 2.4.2.2, Figure 2.3), and solutions to overcome them are discussed below (RO4).

### 2.5.1 Influence of Role on RS Use

All but one of the interviewees in this study used RS data in some capacity, but RS data are not one size that fits all, in that different users have different data needs based on their role in the response. Interviewees working in different temporal parts of the response were using the data differently, and had different data requirements due to their role.

Those interviewees who were part of the very first phase of the response did not use RS data at all. These responders work from GPS coordinates relayed over a phone or radio, send a team to respond, and help define the type of response that will follow next. During the next part of the active response phase, decision makers in the IC need information relatively quickly and regularly to make informed resource allocation decisions, or verify effectiveness of tactical decisions already made (Figure 2.2), like boom placement or team deployments. These decision makers described wanting data products in as close to real time as possible so that their decisions are still relevant to
the oil situation when applied in the field. These decision makers were also more concerned with accuracy than they were precision; thus, a low-resolution image delivered quickly in a format they can consume may suit their needs well.

During this active response phase, part of the science support team is working to provide the IC with the RS information they need to make informed decisions, while another part of the science team is using RS data to create trajectory models of where the oil will be in the near future. Members of the scientific support team often interface with RS data before the decision makers in IC. These scientists work to support the SSC through collection, interpretation, and display of the RS data, and the SSC summarizes and presents those data to IC (section 2.4.1; Shigenaka, 2014). In section 2.4.2.1.2, interviewees acknowledged that RS integration into the ICP is almost always based upon the formal introduction of RS data by the SSCs and their support scientists, be them from academia or agency. Decision makers in the IC incorporate the synthesized information presented from the SSC with all of the other information available to them to make decisions about response actions.

Precision is paramount to the modeling scientists, and they use many different RS data sources and direct observations to create their predictions (Deqi et al., 2009; French-McCay et al., 2018; Lubchenco et al., 2012; Yan et al., 2018). The interviewees who used RS data to create trajectory models also placed less of an emphasis on the need for common formats for two likely reasons: They were performing more complex data processing functions that required complex processing software not suited for the ICP, and when they were done with that processing, they knew how to manipulate the data product into a common format likely consumable by a COP.

The active response phase of an oil spill event is followed by the damage assessment phase (Burger, 2008; Burlington, 2002). RS tools are used during the assessment phase to determine the extent of damage resulting from the oil spill and the supporting response effort. RS users during the damage assessment phase want high resolution, well calibrated, archived, synoptic data, and they are willing to wait months for it (Lubchenco et al., 2012; Muskat, 2014; Weidhaas et al., 2016). In addition to the RS data on the oiled area of interest, these scientists also work with numerous
observational and RS baseline data sets (Beyer et al., 2016; Burger, 2008; Burlington, 2002; Nixon et al., 2016). Meeting the needs of these different RS data users during a response can be achieved through coordinated data collections from multiple sensors and platforms, followed by detailed data cataloguing and archiving. However, addressing the combinations of data-driven barriers attributable to *Interpretation* and *Availability* highlighted in Section 2.4.2.2.2 and the interwoven human-driven barriers of *Saliency* will be key to the success of multi-sensor solutions.

### 2.5.2 Arctic Applications

Of the 16 interviewees who had Arctic experience, all recognized the potential value for RS in the Arctic, especially due to the remote nature of the environment and the related transportation barriers to oil spill reconnaissance for response. The collected data show that they also all understood the extreme challenges of oil spill detection and effective response when the oil spill was in or under the Arctic sea ice. Interviewees who had Arctic response experience did describe routinely sending out manned aircraft with trained aerial observers to gain situational awareness of emergency response scenarios in the Arctic (Figure 2.1). Aerial observers collect aerial photography and location information of the hazard via GPS points, and they perform interpretations about actionability (NOAA, 2016), which would be considered direct sensing, not remote (Woodhouse, 2006). Interviewees with Arctic experience did not reference using RS tools other than aerial observers and AIS as part of the Arctic responses they had worked on (Section 2.4.1.1). The reasons for this lack of RS tool use in the Arctic response environment are unclear but may be a result of the smaller-sized oil spills typically experienced in America’s Arctic environment (ADEC, 2007), as RS tools over Arctic areas are known to exist and responders have worked with them in lower latitudes.

The development of Arctic RS tools for oil spill response tends to be determined by funding availability rather than an emergency need (Torrice, 2010). The science support community continues experimenting with different sensor and platform pairing solutions to detect oil in Arctic environments (Bassett et al., 2015; Bradford et al., 2008;
Brekke et al., 2013; Makysm et al., 2014; Fingas & Hollebone, 2003; Wilkinson et al., 2015), and Arctic-based responders have been experimenting with UAS due to their real time data-delivery capacity and broad marketplace availability (C. Hall, personal communication).

Weather is commonly perceived to be a major contributor to the availability of RS data in the Arctic (Beamish et al., 2020; Du et al., 2019; Fingas & Brown, 2012). Precipitation, clouds, no clouds, wind events, and humidity are major drivers of data usability for airborne RS assets, as is the darkness of Arctic winter. In the Arctic, temperature, in conjunction with these other phenomena, is a major influencer on RS data acquisition as well. Airplanes, UAS, and the sensors themselves need additional outfitting to be able to operate in temperatures below freezing, which are often encountered in the Arctic (Kramar & Määttä, 2018; Thibotuwawa et al., 2019). An additional hurdle of weather is the operation of these sensor platforms by humans, who also have limited capacity to tolerate cold temperatures or unsafe weather conditions for flight. Weather is not always a barrier, and less than half of the interviewees indicated this was an inhibition to RS data availability (Section 2.4.2.1.1). Weather challenges can sometimes be overcome by working with multiple data sets from different platforms over the area of interest when available.

2.5.3 Overcoming Barriers to RS Use in Oil Spill Response

Fundamental research into RS tools and new uses to support environmental management is important, but the translation of that research into the operational environment is a key dynamic that also needs to be addressed. In the operational environment of oil spill responses, barriers to RS use include interwoven perceptions and realities experienced by the oil spill response community as shown in Section 2.4.2. Most of the barriers to RS use identified in this study are not entirely static, in that data-driven barriers to RS use can be improved upon with the investment of time and financial resources, and human-driven barriers can be reduced through training and the production of RS data tools tailored for oil spill response support. The interviewee-identified barriers to operational RS use in support of oil spill response cannot be single-
handedly addressed by any one team at any one time. Instead, interview results indicate barriers to RS use need to be considered and addressed through the development and integration of operational RS tools through holistic planning strategies undertaken by multidisciplinary teams as demonstrated by a member of the science support team here:

“And I think we’re better served when we have the end users as well as the data producers and providers and analysts together filling each other’s requirements and limitations so that we can collectively work towards effective solutions.”

(Science Support Team Member)

Kalluri and others previously demonstrated the importance of the RS tool-development life cycle for transitioning RS science products into operational tools with the data end users as part of the NASA Synergy Project (Gilruth et al., 2006; Kalluri & Gilruth, 2004; Kalluri et al., 2003). Their end user focused road map to move from applied science algorithms to operational data products can be used as a guidance document to address the same types of problems in the oil spill response operational community. The process begins with systematic identification of user needs, followed by prototype development, concluding with an iterative cycle of production and deployment of solutions.

2.5.3.1 Investment in RS Systems

The infrastructure to support effective use of RS in an oil spill response is spill-location specific, and is a constant challenge in rural and isolated locations that make up most of America’s Arctic. When oil spills happen in relatively remote locations, ICPs are located in hub communities that can support the associated infrastructure and personnel of a response which can be quite far from the spills. A portion of the interviewed science support team members consistently described the reliance of ICPs on the available bandwidth to receive and disseminate information in Section 2.4.2.1.1, and the impacts of bandwidth limitations on latency and data saliency in Section 2.4.2.2.2. RS data sets are typically voluminous, and require significant bandwidth to
remotely deliver to the ICP. The bandwidth to deliver large RS data files to and from remote locations is limited and can effectively stall RS data arrival to decision makers, reducing the saliency of the data due to an inability to deliver it. Investing in communication infrastructure to expand bandwidth in rural locations will support RS data use in a timely fashion. These kind of infrastructure investments often originate at the regional or statewide level, and require a substantial planning and monetary commitment.

Improvements in local bandwidth performance are not always realistic. To expand the use of RS data sets in bandwidth limited environments, science support team members can perform additional data processing to create smaller data products that are more easily shared over these kinds of connections. In this case, costs would be shifted to support operational scientists in RS data manipulation, as opposed to hardware and software solutions to the bandwidth problem. Unprocessed or raw RS data are typically in a unique format and is large in volume, ranging from several MB to multiple GB. Through post-processing, these RS data sets are reduced in size by creating more concise data products that can be displayed through a COP or other interface. Processing the data into smaller volume data products can take place almost anywhere the computing resources are available if the smaller data products in the KB to MB range can be delivered over low bandwidth connections.

The bandwidth limitations and the RS data processing costs described by interviewees as data-driven barriers could also be circumvented by working in a cloud-based computing environment using minimal bandwidth. Processing large RS data sets typically requires sizable investments in on-site computer hardware and its subsequent maintenance. Cloud computing differs from on-site computing in that the hardware on which the processing is taking place is located off-site and is accessible via the Internet. Computing costs are calculated on the amount of computing or archiving required for any given project; as such, the user pays only for the portion of the services that are used (Griffith, 2016). Delivering data products to multiple users from the cloud is achieved through direct downloads, and server-to-server connections from the cloud storage locations to local machines, such as those supporting the COP in the ICP.
Interviewees identified challenges of data interpretation associated with the resolution of satellite-based RS data over small-scale oil spills but did not identify solutions to problems associated with resolution other than to gain access to “military grade” data. Alternatively, these challenges can be overcome through investments in sensor technology prior to deployment. Satellite-based sensors tend to have larger fields of view than airborne RS platforms, which can create challenges for small target identification (Martin, 2004). Deploying sensors capable of collecting greater-detailed imagery through increases in the mechanisms of spatial resolution will allow for greater RS data use for smaller spills. Observation platforms that fly closer to the earth (airplanes, UAS, underwater ROVs) also have the potential for higher data resolution, but are still subject to processing and interpretation limitations.

An often-under-costed component of integration is quality long-term data management and archiving. As previously described, RS data are voluminous, but as with all components of the administrative record for any oil spill event, needs to be made available for the damage assessment and litigation phase of the oil spill. Those RS data sets that are supported through all facets of integration from ingest to archive need sufficient metadata to be located and retrieved for future analyses. Thorough and deliberate archiving reduces costs associated with recreating data sets from raw sources and supports the establishment of RS tools in the oil spill response tool kit utilized by a broad swath of the oil spill response team.

Costs associated with RS data acquisition vary by platform, sensor, and collection agency. Acquiring RS data collected from commercial or classified governmental satellite-based sensors requires money or clearance. Developing partnership agreements among these data providers and the oil spill response science support teams led by NOAA could remove cost as a barrier for satellite-based RS tool development and implementation with commercial assets. An alternative straightforward solution to data costs limiting access is to provide science support teams the funding to purchase commercial satellite-based data sets. This funding would need to be consistent and maintained for data product development and support, but also for all subsequent steps to integration, interpretation training, and use for decision-making.
Investments in **algorithm** preparation to support semi-automated oil spill detection using RS data could also reduce the costs of using RS data. Cost savings in this case would be realized in the long term by reducing the human hours required to manually review imagery for the presence of oil by shifting the initial review to a computer. This workflow would also decrease latency associated with initial data interpretation, as algorithms can be tuned for performance and speed, and computing power can also be increased to speed up oil-screening analysis. There are numerous algorithms for performing these detections using SAR imagery (Ajadi et al., 2018; Brekke et al., 2013; Garcia-pineda et al., 2013; Solberg & Brekke, 2004). SAR is a good candidate sensor to apply semi-automated detection algorithms due to its sensor qualities of being able to image at night and though most precipitation events. To isolate a robust algorithm and promote its integration into the RS data workflow would be a multi-faceted, and likely multi-year, endeavor that in itself would be expensive.

Oil spill detection algorithms are not currently operationally integrated, and are not typically used by the interviewed members of the science support teams. To capitalize on these detection algorithms, creating a COP-consumable end-product or visualization of the model output will allow decision makers to integrate these data geospatially. Developing methods to represent the uncertainty on the secondary manual review that would be required of suspicious areas in RS imagery would also need to be part of the algorithm integration process.

2.5.3.2 **Training**

Lack of trained personnel to interpret RS data emerged as a theme in the interviews as to why RS data were not used more in oil spill response (Section 2.4.2.1.3). According to the interviewees, the primary tool used by IC for oil spill response decision-making is a map, normally a paper one. Paper maps are intuitive geospatial visualizations that do not require electricity or bandwidth to display and rarely a subject matter expert to interpret. Anyone can write on a map, but only trained personnel can manipulate a COP, creating a gap between response team members trained to use these technologies. Interviewees from the IC repeatedly indicated their
preference and trust for the paper map. One interviewee highlighted the importance of a paper map in the ICP as a conversation starter to build rapport among the members of the ICP; another interviewee likened it to a coffee table book that folks were drawn to as there was nothing else really interesting to see in the ICP. However, focusing decision-making on a paper map makes integrating RS data sets more difficult, unless they are integrated in the COP and a paper version of the COP map is printed out for decision-making. The interviewed members of the IC understood the value of being able to use multiple data layers for decision-making but were more interested in data that were the easiest to interpret and that provide the most certain picture relevant to the response at hand.

Interviewee responses about RS data visualization needs as described in Sections 2.4.2.1.3 indicated that one training that will positively impact a broad audience of responders would be COP training for RS data set use. The shared display of relevant information in a COP is widely used in the ICP to support decision-making and information archiving during U.S. maritime oil spill response efforts (USCG, 2004). The two COPs repeatedly referenced by interviewees were the GIS-based NOAA COP interface ERMA and the COP offered by The Response Group (TRG). TRG holds the contract to support USCG response operations, but ERMA is the COP used by the USCG’s data providers at NOAA. Training decision makers how to utilize visualizations from the COP and how to interpret principal RS data may reduce the technological data gap between the science support team and the IC, as was the case during the NASA synergy project (Kalluri & Gilruth, 2004; Kalluri et al., 2003), but should be weighed against other IC duties that would be impacted by additional duties. Training members of the IC about RS tools and visualizations may also increase overarching data credibility in this community through increased RS tool familiarization. Basic RS tool familiarization highlighting RS tool support needs, what different information RS tools can offer, and what limitations exist for different RS tools, will likely also reduce responder frustrations described in Section 2.4.2.2 through managed data expectations.

The key methods for learning identified by participants of this study are workshops and hand-on training experiences (Figure 2.4). Training for decision makers
and spill responders to use RS data can increase RS data use in the short term; however, consistent investment and integration of this training into institutional best practices is needed for the long-term adoption of RS tools. Investment in a long-term knowledge-maintenance program inclusive of regular refresher training will reduce bottlenecks of interpretation expertise, effectively increasing RS saliency (Cash et al., 2003; Machlis & McNutt, 2011; Muskat, 2014; Weidhaas et al., 2016). Having in-house experts who are able to use RS data quickly, confidently, and easily can also serve as a model or peer-to-peer training mechanism to enhance technology acceptance (Osofsky, 2011).

Providing training during a response is neither ideal nor feasible. Additionally, institutional organization of the response and the responders’ day-to-day roles outside of the response may not provide the leeway or mechanism to provide training on how to use RS products (Kalluri et al., 2003). Training programs on how to quickly and effectively use the RS data product should be identified and ideally conducted prior to the disaster by a trainer versed in both oil spill responder needs (Lemos et al., 2012). There are additional costs to upgrade the technology, and to spend the time learning and practicing with the new technology, that need to be included when budgeting for increasing RS data use.

2.5.3.3 Response Integration

Interview data indicate that the usefulness of RS data tends to be recognized by people working on oil spill responses but is still not integrated into each response. Often this is because of the size of the spill (Scale) and the subsequent response. Most oil spills are too small to be visualized using satellite-based RS tools as they are in the 10s to 100s of gallons range (ADEC, 2007), which does not translate into a large footprint, and most are cleaned up without the need to collect any RS imagery. The DWHOS was the first U.S. oil spill event where satellite-based RS data that could support oil spill response was incorporated into the response in support of decision-making. Interest in using these tools on responses since then has also been limited by satellite coverage based upon orbit limitations (see interview results discussed in Section 2.4.3.1.1).
Earth-observing satellites tend to be either geostationary satellites that are effectively static in location or polar-orbiting. Polar-orbiting satellites operate between 500-800 km above the earth’s surface, with orbital paths from pole-to-pole, shifting with the rotation of the earth (Ferretti, 2014; Sabins Jr., 1987). Some of these satellites are able to position sensors to observe specific locations of the earth but are still limited in their ability to image an individual area by the constraints of their orbital cycles. Without the ability to image the area of the oil spill at a minimum of once a day, interviewees said that the utility of these tools for tactical decision-making is reduced during the response stage of the spill.

Integrating RS data into a COP or other data sharing application is crucial for providing RS data to the greatest number of users during an oil spill response (see discussion in Section 2.4.2.1.2). Interviewees identified the component of data format as key to the ability to quickly ingest the data into a COP. RS image acquisitions from either an airborne or spaceborne platform need to be downloaded, ingested, and processed to be meaningful products for decision makers. Any required data post-processing needs to be completed prior to delivery of the product to the end users, who in this case are the decision makers in the oil spill response ICP. The time and complexity of these processes will vary by RS data type, which links this barrier to latency.

Data integration into the COP allows for the layering of multiple data sets and opportunities to increase data confidence through data cross referencing, an ideal situation that was also described by interviewees (Section 2.4.2.1.2). Supplying RS data to the situation unit of the ICP in a COP-ready format will reduce latency and increase RS data use. Establishment of freely available satellite-collected imagery from the visible and microwave regions of the electromagnetic spectrum into the COP will provide baseline data sets to support planning and tactical decision-making, while simultaneously reducing latency normally associated with their integration. The use of a COP is not ubiquitous on all oil spill responses and drills, thus integration and sharing of RS data will be somewhat limited in those circumstances. For these smaller responses, real time data feeds, such as UAS data, can be shared locally among the response
team members. Even if the baseline data are not in a COP, it is possible to move toward digital maps and the integration of small RS data sets locally into those digital displays.

Other data integration components that were identified by interviewees as either barriers or confusion points for the use of RS data during an oil spill response are improvable. Knowing where to access RS data outside of the COP can be taught, eliminating accessibility issues as barriers to RS use. RS data providers can and should incorporate uncertainty and other potential limitations of the data, as deploying resources against data of undeclared certainty often end in frustration and a loss of legitimacy for that data product and/or that data provider. This was a described source of frustration for by multiple interviewees, and has been previously reported by Cutter (2003), Leifer et al. (2015), Machlis & Ludwig (2014), and Weidhaas et al. (2006), and others.

Most RS data enter an oil spill response ICP through the NOAA SSC. As such, provision of better science to support the SSC will increase the efficiency and effectiveness of the response. Currently, science support relationships are primarily based on the “who-you-know-and-trust” model (Section 2.4.2.1.2; Machlis & McNutt, 2011), which can potentially limit exposure to new and useful oil spill response support tools across all phases of a response. It is important to formalize cross-discipline partnerships in science and create multiple lines of communication between the science community at large and the operational scientists supporting an oil spill response prior to any disaster or emergency event (Gilruth et al., 2006; Leifer et al., 2015; Lemos et al., 2012; Machlis & Ludwig, 2014). Investing in the formalization of these partnerships may expand the RS tools available for oil spill response, while reducing human-driven barriers associated with unknown RS data providers.

It is vital that any RS tools that are integrated or considered for integration into oil spill response COPs be practiced with during oil spill response exercises and drills, just as with all of the other tactics employed during an oil spill response. RS tool practice during oil spill response exercises and drills was directly identified by interviewees as an important component to RS tool integration:
“So, the more we do this, the better we can become at serving that decision support need and, to me, it's one of the things that I've taken out of Deepwater Horizon, and has given me very significant professional interest of how we can better use tools and technology to address the science.” (Science Support Team Member)

It is not common to employ all possible tools in the oil spill response toolbox during drills and exercises, as time is often limited and the regulatory objectives of the exercises are normally the top priority. However, this lack of practice reduces the exposure of these tools to decision makers, effectively maintaining the technology gap. The new tools that are successful during a response are those that have been practiced with during drills.

2.5.3.4 Increasing the Legitimacy, Credibility and Saliency of RS Data in Oil Spill Response

Interviewed members of the IC were more likely to use data coming from sources they know, as described in Section 2.4.2.1.2 and 2.4.2.2.1. Key to the perceived Legitimacy of the science being promoted is the development of relationships between the scientists and the end users or stakeholders based on trust. There are different ways to create this trust (phone calls, academic conferences, journal publications), but the establishment of common ground, with a focus on the mission and a recognition of expertise over pedigree (Machlis & Ludwig, 2014) will relax the barriers between scientists and the response community. Clear communications, feedback mechanisms, iterative discussions, and efforts to understand the end user perception of the problem were found to be foundational to legitimacy establishment and is consistent with published literature (Meadow et al., 2015; White et al., 2010). Formalization of relationships between the data provider and the user is important to bolster actionable discussions and solutions to RS data use in oil spill response. The formalization of these partnerships also implies a level of accountability on behalf of scientists and the stakeholders (Kalluri & Gilruth, 2004; Kalluri et al., 2003).
Credibility describes the scientific adequacy of the technological advancements (products, tools, methods, etc.) being promoted (Graneheim et al., 2017; Meadow et al., 2015; White et al., 2010). Credibility to interviewed members of the science support team is dictated by quantifiable variables, such as sensor calibration. Credibility to interviewed decision makers in IC is knowing what the data are trying to tell you and what their limitations are. A large threat to Credibility of science in a decision framework is the level of uncertainty in the data. This indicates that it is important for scientists to be very straightforward about the level of uncertainty that comes along with a data product, especially if that product is to be used in decision-making specifically to allocate resources (Kalluri & Gilruth, 2004; Gary E Machlis & Ludwig, 2014). RS data products are often perceived as “oversold” by the RS scientists who work with RS data every day, as they have learned how to work around data errors and conduct additional levels of processing to create seemingly straightforward data products. Because of poorly understood uncertainty as an influential factor for RS data credibility, interviewees stated human aerial observers are still used extensively to “ground-truth” RS data over a spill.

Credibility is also influenced by latency. The latency introduced at each step of the data lifecycle decreases the utility of RS data during the response phase of a marine oil spill response, which in turn further decreases the Credibility of those data. What needs to be made clear is that these products may not be as reliable as hoped due to reasons such as lag time between data acquisition and data product dissemination, which may cause the data to be stale by the time it reached the hands of a decision maker. If the “old” data are acted upon as if it was real time information, resources, time, and energy will be squandered, and frustrations will run high. Situations like these reduce the credibility of the data and the scientist immediately, and happened frequently during the DWHOS response (C. Hall, personal communication). Interviewees described access to real time data as a solution to reduce confusion and frustration associated with latency. In reality, real time data still possess the same components of uncertainty as non-real time data, and are not a requirement for all data users in an oil spill response. Real time data delivery can be critical in acute circumstances but may be
overwhelming for the data infrastructure available, and it should be balanced against the monetary and temporal costs associated with additional computer processing.

RS data Saliency refers to the relevance of the scientific assessment to the needs of the decision makers (White et al., 2010). Key to the salience of RS products to the interviewees was accuracy, timeliness, and resolution of the RS data (Sections 2.4.2.1.1, 2.4.2.1.3, and 2.4.2.2.2), and how that related to their role in response. Saliency discussions reiterated the need for different data for different users on different time scales (i.e. response phase versus damage assessment phase), as well as the need to fit in the framework of decision-making during an emergency response (Leifer et al., 2015). Oftentimes, scientists will produce a scientific product rather than an operational product, effectively increasing the barrier to use by not meeting the needs of the end user (Leifer et al., 2015). Salience of the science is reduced further when a product is touted that is not needed. There is no lead coordination entity to drive tactical scientific research in the U.S. (Machlis & Ludwig, 2014); thus in time of emergencies, it falls upon the NOAA SSCs to assemble applicable science that could support the response. Formal scientific integration into spill response decision-making could include changes in the organizational structure of a spill response (Machlis & Ludwig, 2014), creating space for mobilized scientists to be able to support tactical scientific applications.

Two of the interviewees who have been involved in oil spill response for decades pointed out that scientists have been trying to integrate RS tools into oil spill response for the last 20 years, and they have had some success (Figure 2.1). However, the reliance on human aerial observers for validation of RS products indicates this integration is not complete. Perception of data usefulness, trustworthiness, and applicability will determine the level of human-driven barriers to the integration of RS data for oil spill response. The best practices pivot around the concepts of scientific credibility, saliency, and legitimacy by the end user community, which will lead to greater levels of end user participation, shared accountability, and co-adaptive management solutions (White et al., 2010).
2.5.3.5 Insurmountable Barriers to RS Use

Not all of the interview-identified barriers to RS use in oil spill response support can be overcome with time and money. Wind, clouds, and precipitation can obscure RS observations of oil on the ocean surface (Martin, 2004; Sabins Jr., 1987; Woodhouse, 2006), while operationally limiting the use of airplane and UAS platforms. Satellite platforms are not directly subject to weather limitations, but the sensors they carry are limited by their spectral properties and the interaction of those properties with clouds and precipitation. Spectral characteristics of RS sensors reliant upon cloud-free conditions to collect images of the earth cannot be improved, but other sensors that are not as heavily influenced by weather, such as SAR, can be leveraged to fill observational data gaps introduced by weather or darkness.

The coverage of an area of interest by satellite-based RS imagery is limited by the temporal and spatial resolution of the satellite, which was also tied to latency by interviewees. Temporal resolution describes how long it takes for the satellite to return to image a given point on the earth, and it is dependent on the satellite orbital characteristics—as compared to spatial resolution that refers to the size of each pixel representing an area of the earth’s surface (Ferretti, 2014; NASA Earthdata, 2020; Sabins Jr., 1987). Some improvements to temporal resolution can be achieved through the design of satellite-based sensors that can be tasked to collect data at different angles with various fields of view. Similarly, increasing the spatial resolution of new sensors is also improvable with significant investment. Both of these improvements would make satellite-based RS information more valuable for the smaller, more common oil spills. These improvements are not achievable with single satellite-based sensors currently in orbit, which are static in their temporal and spatial resolution characteristics. However, satellite-based coverage can be augmented by synthesizing data from suites of sensors currently in orbit, but that augmentation would require a significant investment of resources for either the purchase of data sets from multiple commercial vendors or for training RS technicians in data-fusion techniques.

Clearance to access high-quality data sets collected by governmental entities will remain restricted. The International Charter on Space and Major Disasters (the
Charter) is a worldwide collaboration through which satellite data from 61 different satellites, operated by 17 different international space agencies, are made available for the benefit of disaster management. The Charter was enacted during the DWHOS, thus clearance was not an issue for that response. However, the Charter does not apply to day-to-day operations or oil spills that do not impact large areas or many people.

Observational RS data will continue to have false positives in the imagery, as look-alike phenomena will continue to exist. Data processing techniques and algorithms can be developed to increase discrimination of false positives but will not eliminate their fundamental existence. Discriminating false positives through manual interpretation of RS data, data cross referencing, and confirmation overflights by aerial observers will continue to be required to reduce uncertainty in RS imagery.

The barriers to RS use that cannot be overcome through some level of applied effort are few. Determining and addressing the motivation preventing the reductions in these barriers will help to identify specific pathways to overcome them.

2.5.4 Limitations to this Research

This research provided a foundational understanding of RS tool use and barriers to use in the U.S. oil spill response community, but a number of components not pursued as part of this work could be considered as limitations to this research.

The interview tool used to ascertain RS use during oil spill response is limited by the perception of the interviewees based on their past experiences. In this research, interviewees focused their experiential responses on the DWHOS event and several emergency response actions in the U.S. Arctic and sub-Arctic, and they did not emphasize oil spill response experiences from other areas around the U.S. where oil production and transport occurs. Interviewees were all from North America (24 of the 25 were from the U.S.) and did not have the experience to describe the different RS tool-integration strategies into oil spill detection and response by other countries in both Arctic and non-Arctic locations around the world, though significant ocean monitoring programs using RS tools exist worldwide.
No interviews were conducted with individuals who were actively working for private oil industry companies, though some interviewees had been contracted by private industry in the past. Interviewees represented members of U.S. and state governments or their scientific support teams. Only members of the governmental oil spill response community were interviewed, inhibiting a thorough understanding of how private organizations use RS tools to detect or respond to oil spills. A number of interviewees speculated Cost was not an issue for oil companies using RS tools, but how the RS tools were being used by industry directly was not explored. The composition of the interview pool was intentional so that an understanding of how government policy and procedures either hindered or bolstered the use of RS data in government-led response actions could be understood. What was not explored was how to change policies and protocols in an effort to change or influence oil spill response law in the U.S. or individual states beyond the current mandates in the CFR to use “best available technologies” to support oil spill response actions. Instead, policy and protocol explorations identified how grassroots integration efforts could be leveraged into formal policy and protocol establishment.

This study focused on what RS tools were being used and what barriers to additional RS tool use existed, if any at all. The focus was not on efforts undertaken by people in academia, government, or industry to better support oil spill response activities with RS tools, nor the methods these groups are employing to integrate additional RS tools into oil spill response activities. Each interviewee had opportunities throughout the discussion and afterward to discuss other efforts being undertaken to further integrate RS tools, but the only mention of other integration efforts was from the science support team members who were also data providers. These interviewees referenced the problems they encountered when delivering data to, and interpreting data in, the ICP, but they did not mention any efforts to improve this process being undertaken by either themselves or other data specialists in the field. It is possible other groups in the U.S. are attempting additional RS tool integration, and their methodologies could be quite effective, but these efforts were not discussed by the interviewees, nor were they readily apparent in policy documents referenced for oil spill response actions in the U.S.
2.6 Conclusions

This study examined which RS tools were available to support oil spill response actions in both Arctic and non-Arctic settings, how those tools were being used to support decision-making, and what barriers existed to their use.

The numerous RS tools that are available to support oil spill response through detection of oil and other targets in both Arctic and non-Arctic environments are not fully utilized in these contexts. The open-ended interviews with 25 members of the U.S. oil spill response community revealed that only a portion of the RS tools available for these efforts were used or otherwise integrated into oil spill response decision-making. Aerial photographs and other optical data sets were utilized the most to support acute oil spill response decision-making, while SAR was used to provide the synoptic view of larger oil spills through time and damage assessment. The scale and the temporal nature of oil spill response actions were drivers for how the data were used by different members of the response, and they demonstrated that not all oil spill responses benefit from RS tool use. For example, small oil spills are cleaned up quickly and do not need RS data for detection and long-term monitoring. Ultimately, human observers in aircraft trained to identify actionable oil spills and to ground truth information provided by RS tools remain the most trusted oil detection data sources.

RS tools were used broadly during responses to observe oil locations in support of situation monitoring and decision-making. Members of the IC and the scientific support teams generally used RS data to answer similar questions but differed in that science support prepared and interpreted the data for the decision makers in the IC. For larger oil spills, tactical response actions were defined by the confirmed information from the RS imagery and the derived trajectory analyses.

Barriers to tool use described by interviewees were categorized as data-driven or human-driven, which enabled analysis of potential strategies to overcome them. Data-driven barriers to RS data use were grouped into the three overarching categories of Availability, Data Integration, and Interpretation. Subcomponents to each of these categories were determined by the interview responses, but were not ubiquitously
influential to RS tool use. Saliency, Legitimacy, and Credibility emerged from the interviews as the primary human-driven barriers to RS tool use. These human-driven barriers were intertwined with the data-driven barriers to RS tool use when described by interviewees, such as the commonly cited dependence of data Saliency on data Latency, demonstrating the complex nature of perception about the use of RS technologies to support oil spill response.

It may be possible to overcome many of the barriers to RS tool use identified here through investments of time and resources. However, some data-driven barriers are insurmountable, such as weather, but these are few in comparison to those that can be improved upon. Due to the interwoven nature of the identified barriers to RS use, efforts to increase the credibility, saliency, and legitimacy of RS data use during an oil spill response will also likely be linked to reductions in data-driven barriers.

Motivation to increasingly use RS information for decision-making during oil spill response to improve oil spill response can be generated through policy or by individuals. Capitalizing on collaborative opportunities among scientists and oil spill responders may increase both of these modes of motivation and should be explored as part of the effort to increase the efficiency of oil spill response actions in the maritime environment.
2.7 Literature Cited


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Chapter 3: Cloud-based Oil Detection Processing Pipeline Prototype for C-band Synthetic Aperture Radar Data

3.1 Abstract

Processing large data sets on a cloud-based platform greatly reduces the costs normally associated with the required computing infrastructure due to its on-demand availability and scalability. Cloud-based computing can therefore be leveraged to speed operational delivery of large data sets to research scientists and decision makers in an emergency response, specifically during a marine oil spill response. Amazon Web Services (AWS) offers a suite of cloud computing services that compose a scalable, on-demand, computing platform to perform small to very large processing jobs without investment in on-site hardware and data support infrastructure. Synthetic aperture radar (SAR) data is a processing intensive, remote-sensing data product, that often requires additional secondary-processing to be formatted for general consumption as a GIS-ready product or other commonly consumable format. SAR has been shown to be effective for the identification of oil spills on water by using either the backscattered amplitude of the signal or the specific components of the signal phase. Oil detection algorithms have been developed for use with both SAR signal-based detection methods, but few have been operationalized, i.e. integrated into an operational service environment or the common operational picture of an oil spill response. An adaptation thresholding oil spill detection algorithm modified from Solberg et al., 2004 has been incorporated into the Sentinel-1 Toolbox, on-demand, processing tool suite available from the European Space Agency (ESA), and is accessible to users via downloadable Python scripts. Adaptive thresholding is a straightforward amplitude-based, supervised, oil classification methodology that focuses the analyses on the shape of an anomalous feature, the contrast of that feature from the background water, and the homogeneity of the processed SAR image. In this experiment, the oil spill detection python scripts based on the Solberg et al., 2004 segmentation thresholding algorithm were

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constructed and downloaded from the ESA Sentinel Toolbox, and integrated into a prototypical processing pipeline in the AWS cloud-computing environment to determine the operational feasibility of performing oil spill detection using SAR in a cloud-processing environment. SAR images were staged to a Simple Storage Service (S3) object storage bucket in AWS, as was the oil detection script downloaded from ESA. Sample SAR images staged to the AWS S3 bucket were a matrix of both satellite-collected C-band SAR data (Sentinel-1A and Sentinel-1B) downloaded from the Alaska Satellite Facility, and simulated SAR data containing different kinds of oil slicks, ocean surface anomalies due to winds and currents, and combinations thereof. Processing took place in a scalable AWS Elastic Compute Cloud (EC2) computing instance, using AWS CloudWatch functions to call and run the algorithm scripts against the sample SAR data to create a GIS-ready product deliverable to multiple end users from S3 bucket at the end of this prototypical processing pipeline in AWS. End users only require log in credentials to download the GIS-ready products from the oil detection processing pipeline. This work demonstrates the ability to apply oil detection algorithms to SAR data in a cloud-based environment to create oil spill footprints for integration into an operational data delivery system, and the common operational picture of a marine oil spill response.

3.2 Introduction

Processing solutions for large volumes of data, or for data sets that require large amounts of computing power to manipulate, have historically required sizable investments for on-site computer hardware and its maintenance. In the current era of Big Data, data processing solutions have expanded to include cloud computing and other data services. Cloud computing is different than local computing in that the servers on which the processing is taking place are located off-site, and are accessible via the Internet. Cloud computing provides on-demand, scalable, delivery of compute power, database storage, applications, and other infrastructure technology resources through a cloud services platform with pay-as-you-go pricing (Griffith, 2016).
Cloud computing requires a level of trust in the service providers managing the processing servers, in that effective processing and data preservation will be accessible well into the future. These assurances are available at a cost that is scalable to the user’s computing and archiving needs. Computing costs are calculated on the amount of computing or archiving required for any given project, i.e. the user pays only for the portion of the services that are used.

Delivering data products to multiple users from the cloud is achieved through direct downloads, and server-to-server connections from the cloud storage locations to local machines, reducing sharing time through centralization. By providing products in a Geographical Information System (GIS) -ready format, the operational utility of the cloud-based processing can be fully leveraged. One application of this functionality is in support of the common operational picture of a marine oil spill response. The common operating picture is an interactive data visualization based on GIS technology that is compiled to support situational awareness of an emergency response in an accurate, timely, and geo-referenced format. This data suite and visualization of it is used to support communications (briefings) and resource allocations throughout an emergency response (OGC, 2015). By providing oil detection maps to the common operational picture of a given oil spill response, decision makers would be able to access timely oil spill footprint and location information, along with the other geospatial data necessary for decision-making during a spill response.

Synthetic aperture radar (SAR) is a satellite or airplane based, remote detection sensor, that has the ability to image the earth through clouds, smoke, precipitation and night (Woodhouse, 2006). SAR data is voluminous, ranging in data product size roughly from 150 MB to 4 GB (ASF, 2017), though larger and smaller data sets exist. Data sets of this size require large computing capacity to process the raw signal into an image, but also for construction of secondary products created through algorithms and models.

SAR has been demonstrated to remotely sense oil on water and has begun to be used as an essential oil spill tracking tool (Girard-Ardhuin et al., 2003; Jha et al., 2008; Leifer & Simecek-beatty, 2012; Li & Li, 2010; Topouzelis, 2008; Tunaley, 2010). SAR detection of oil on water is most commonly accomplished by measuring changes in the
backscattered signal from water, where oil is visualized as dark features in a SAR image (Topouzelis, 2008; USDC, 2004). Other more computationally intensive and accurate SAR oil detection methods use the SAR signal phase to calculate differences among the dielectric constants of the oil and the surrounding water (Brekke et al., 2014; Jones et al., 2011). Based on the oil detection potential of SAR, semi-automated oil spill detection algorithms using SAR data have been developed for ocean surfaces (García-Pineda et al., 2013; Jones et al., 2011; A. H. S. Solberg et al., 2007; A. S. Solberg & Brekke, 2004; Topouzelis, 2008). Numerous methodologies, software packages and scripts drive these algorithms, some components of which are more effective than others at discriminating oils from the background ocean and other look-alike phenomena.

Adaptive thresholding is a straightforward, supervised oil classification methodology that focuses the analyses on the shape of the anomalous feature, the contrast of that feature from the background water, and the homogeneity of the processed SAR image (ESA, 2017). Using calibrated SAR images, a speckle filter is initially applied. The processing steps of this method include masking the land out of the SAR image leaving only ocean pixels for the remaining analyses. Dark spot detection is then performed by adaptive thresholding of the backscatter information of the pixels in the remaining image. The dark spot containing pixels are then clustered and eliminated based upon the minimum threshold cluster size, leaving the pixels most likely to contain oil as the output. A version of this algorithm is freely available through the European Space Agency’s Sentinel-1 Toolbox, and is relatively computationally inexpensive for detecting oil in SAR imagery.

This experiment was designed to create an effective oil detection processing pipeline using SAR data in a cloud computing instance to create an operational product that could be used in oil spill response decision-making. The integration of a SAR-based, oil detection algorithm was chosen for this pipeline experiment for two reasons; 1) to demonstrate the scalability of the AWS processing environment to process and deliver voluminous SAR data sets, and 2) to experiment with the fast generation of easily deliverable oil spill detection maps in a common format for decision makers in the Unified Command/Incident Command System of an oil spill response.
The key research questions of this experiment were: **What are the benefits to detecting oil in SAR imagery using cloud-based computing?** **What are the costs to deliver the products of the processing pipeline to a common operational picture data manager in the short- and long-term?** **Where are the stumbling points to implementing a cloud-based prototypical processing pipeline?** The results of this study will determine the operational feasibility of providing long-term monitoring of the oceans using semi-automated oil spill detection techniques processed in and delivered from the AWS cloud.

### 3.3 Materials and Methods

Amazon Web Services (AWS) is a cloud services platform that owns and maintains the network-connected hardware required for off-site processing and archiving services (Amazon, 2017), and was the cloud service provider used for this experiment. AWS offers a secure location to share and collaborate in the sciences, and may provide faster and cheaper data processing and delivery potential than on-site hardware. Voluminous SAR data and proprietary secondary processing algorithms designed for SAR, are ideal candidates for processing in this secure and scalable location.

To examine the speed and efficacy of processing and delivery of informational products derived from publicly available SAR oil detection algorithms in the AWS cloud processing environment, a prototypical oil spill detection pipeline (Figure 3.1) was established in the AWS cloud processing environment. **Leveraging built-in AWS services for logging, monitoring and computing, the prototypical pipeline receives SAR data, automatically initiates processing of that data by scaling up computing resources to meet demand in processing in the queue, analyzes the SAR image for likely oil, delivers the resulting oil detection products, and turns itself off.**

Sample SAR data sets were staged in a Simple Storage Service (S3) Input Bucket in the AWS cloud. An Amazon Machine Image (AMI) was created that contained the Sentinel-1 Toolbox installed as well as required libraries and functions, along with a SAR oil detection algorithm as an xml file formatted for the Sentinel-1 Toolbox. S3
buckets function as storage, built to store and retrieve any amount of data in any format (Amazon, 2017). Amazon Simple Queue Service (SQS), designed to send, store, and receive messages between AWS software components at any volume, was used to generate queued messages when new data arrived in the S3 Input Bucket. SQS activity was monitored by CloudWatch services, a monitoring service for AWS cloud resources and applications. CloudWatch collects and monitors log files, sets alarms, automatically

![Image of data flow diagram](image.png)

**Figure 3.1.** Oil spill detection processing pipeline prototype data flow; **S3 Input Bucket** – SAR image upload site, **SQS Message Handler** – Watches the input bucket for new data and creates message when it arrives, **CloudWatch** - Alarm system to watch the SQS for new data messages, scales EC2 nodes as needed, terminates EC2 nodes when processing complete, **Auto-scaling EC2 Nodes** - Launched using AMI that contains oil spill detection algorithm, pulls data from S3 Input Bucket, processes file using oil spill detection algorithm, then terminates activity when job complete, **S3 Output Bucket** – Output GeoTIFFS of potential oil spill in SAR input image; download site.

reacts to changes in AWS resources, and controls the state of Elastic Compute Cloud (EC2) scalable computing instances (Amazon, 2017).

In this prototype, under the direction of CloudWatch services, when new data arrival messages were generated in the SQS queue, CloudWatch would tell the Auto-Scaling EC2 group to increase the amount of nodes needed, which would then launch EC2 nodes in accordance with the number of jobs needing to be run. Data for
processing was fetched to the running EC2 instances and processing would commence using the Sentinel-1 Toolbox and oil spill detection algorithm steps specified in the xml. Processing was completed on m3XL EC2 nodes (4 cores per EC2, 8 threads of execution per core, 15 Gb of writing capacity, 80 GB on-hand memory), that launched when new SAR data was added to the S3 input bucket. After the detection algorithm was successfully applied to the given SAR data, the resulting output was then stored in an S3 output bucket, until it was retrieved. The Auto-scaling group would then terminate the EC2 node once the processing was completed for that job, thereby scaling down the group to only the number of jobs still available for processing. The analyses were monitored for time and used to determine the scalability of secondary SAR processing in the cloud.

The auto-scalable EC2 cluster used in this experiment was designed to add new compute nodes to the cluster each time an oil spill detection job was detected by CloudWatch. The flexible capacity to add or remove EC2 computing resources on-demand in minutes is some of the greatest power that can be harvested from the AWS cloud environment. Costs for processing also scale with the instances (you only pay for the processing and data management solutions that you actively use), as well as to which AWS region and market your computing resources are “housed”. Additionally, the Amazon Spot Market allows the user to define the maximum amount of compute costs that they are willing to pay, and their jobs are processed when the real time market value for AWS processing drops to the defined maximum cost threshold. The benefit of working in the Spot Market is that processing costs are very low when the maximum threshold cost is set to a low value. However, the low paying jobs are run only when the market dips to the low rates, usually during off-peak hours, increasing the time to receive a data product. The Spot Market was utilized in this prototypical pipeline. The Spot Market maximum bid price was set in the Auto-Scaling group so that EC2 m3XL nodes would automatically be launched well below market rates. If the going market rate for EC2 m3XL nodes was above the rate set in the Auto-scaling group, then the job would wait until the price fell to at or under the Auto-scaling maximum rate of $0.25/hour. This tunable price setting allowed for much cheaper compute resources than market rate cloud processing.
Sample SAR images for the demonstration were a matrix of different kinds of oil slicks, ocean surface anomalies due to winds and currents, and combinations thereof. The sample images were C-band SAR were from the satellite platforms Sentinel-1A and Sentinel-1B identified and downloaded from the Alaska Satellite Facility.

Figure 3.2. Graph of the processing steps employed in the oil spill detection algorithm from the Sentinel-1 Toolbox.
The oil spill detection processing steps were configured using the Sentinel-1 Toolbox from the European Space Agency. Within the Sentinel-1 Toolbox, users are able to build processing graphs for various SAR Level 2, post-processing techniques that can be downloaded as executable xml for processing outside of the Sentinel-1 Toolbox environment. The oil spill detection algorithm built in to the Sentinel-1 Toolbox is based off of the Solberg et al., 2004 segmenting thresholding algorithm, but with the flexibility for users to adjust various parameters specifically to their data set if desired. The Sentinel-1 Toolbox algorithm is an adaptive thresholding algorithm that allows for oil feature detection without the requirement of a reference database to compare the clustered pixels to. This can be considered a drawback and may increase the likelihood of look-alike phenomenon being classified as oil. Similarly, weather conditions heavily influence the backscatter of the ocean, and can also cause oil spill look-alike phenomena. The adaptive thresholding algorithm used in these tests did not integrate weather conditions into the final classification step, also increasing the likelihood of a misidentification of an oil spill look-alike phenomenon.

The processing graph developed for the prototypical processing pipeline (Figure 3.2) used the default parameters when processing inside the Sentinel-1 Toolbox environment. In this pipeline, the SAR data set is pulled from the S3 bucket and delivered to the processing nodes. Processing begins when the data is read and radiometric calibration applied to the backscatter values of the SAR images. A speckle filter to reduce regular noise in the SAR image is part of the calibration. A land-water mask is then applied to mask out the land, narrowing the area of the image for analysis by algorithm to the water where the oil would be located. The oil spill detection steps follow masking, and is primarily defined as dark spot detection in the image by the algorithm. Clustering of dark formation pixels is the last step of the analytical sequence, followed by the elimination of pixel clusters that are smaller than the defined minimum cluster size, which in this case was 0.1 Km. In other words, only dark pixel clusters greater than 100 m are identified as possible oil spills using the default parameters of the algorithm. The oil detection product image is then written to the S3 output bucket as a GeoTIFF, where it was downloaded by permissioned users for analysis.
Time and the external dependencies of the AWS Spot market processing availability for the algorithm to run on a given set of test data was measured, and analyzed to determine if these factors would inhibit effective integration of the algorithm into an automatic or real time data processing situation.

3.4 Results

This experiment was able to demonstrate the scalability of the well architected AWS processing environment to process voluminous SAR data to deliver a GIS-ready oil detection product in a cost-effective way. The benefits of processing these SAR data sets in the cloud are realized through a number of operational ways. The oil detection algorithm was kicked off simply by uploading SAR data into the S3 input bucket for analysis. Notification of complete data processing was received via email to subscribed users within an average of one to two hours after product upload, and the data products could then be downloaded from the S3 bucket, in either a command line or the AWS online interface. The simple process as designed reduces barriers to oil spill detection by creating a stable and easy environment for more novice science users to take advantage of cloud resources.

The architected scalability of the EC2 processing nodes allows for the processing of multiple SAR images simultaneously, or not, as required. This is an important benefit to demonstrate for an operational system that could be processing data for large-scale ocean monitoring efforts for initial oil detection, or for processing large amounts of data during short periods of time, like during an oil spill response. As SAR data was added to the S3 input bucket, CloudWatch services would spin up additional nodes to meet the new processing demand. Once all of the data from the input bucket was processed, all of the nodes would terminate, eliminating costs of running idle, a significant long-term cost saving measure.

Using the AWS Spot Market was a cost benefit to the experiment, and would realize the most processing savings for large-scale processing efforts. Original pipeline development was via a single on-demand EC2 m3.2XL node utilizing that operated at an average cost of $12/day, or $0.53/hour. After analyzing the required compute needs,
the pipeline prototype was switched to m3XL auto-scalable EC2 nodes, and into the Spot Market, with a maximum cost threshold of $0.25/hr (on-demand EC2 cost for m3XL node is $0.26/hr). These two modifications alone reduced processing costs to less than one dollar a day, though the greatest volume of data of the experiment was being processed (Figure 3.3).

Figure 3.3. AWS processing costs for the prototypical oil spill detection pipeline development and testing.

Visual analysis of oil detection products from the Sentintel-1 Toolbox run in the AWS cloud, compared to the same oil detection products from running Sentinel-1 Toolbox in a local environment, indicate that results are generally comparable (Figure 3.4). However, preliminary analysis of the output products for accuracy in detecting oil in a marine environment appeared to be quite low. Quantitative analysis of the products in comparison to control products of known oil volume and location will provide the percentage accuracy value for this algorithm, after which the determination of operational usefulness of this specific algorithm can be determined. The prototypical processing pipeline for detecting oil in SAR imagery successfully managed the storage, transfer, processing and temporary archiving the large SAR data sets that were used in this experiment. The algorithm used for oil detection fit easily into the AWS prototypical pipeline as designed, and SAR data sets were analyzed for oil simply by uploading
them to the S3 input bucket, and then downloading GeoTIFF output a few hours later from the S3 output bucket.

Figure 3.4. Algorithm output comparison. Comparison of a) SAR intensity image, b) output from the Sentinel-1 Toolbox oil detection algorithm run in prototypical processing pipeline in the AWS environment, and c) output from the Sentinel-1 Toolbox oil detection algorithm run on a desktop computer.
3.5 Discussion

There are many benefits of AWS computing that were realized performing this experiment, though few of them were captured during the first implementation of the prototypical pipeline. The AWS cloud-processing environment and the supporting AWS tools are available to anyone with a credit card, however the design and implementation of the resources in a functional pathway is not. To gain the greatest traction in AWS, working with a computer engineer that is eager to try new services and explore processing hiccoughs will increase the likelihood for a successful implementation of processing in the AWS cloud. Similarly, scientists and other users that need to access the prototypical pipeline need to be trained in the organization and functional differences between cloud-based versus locally hosted processing and archiving, so that they can gain some level of trust in processing and archiving data in the AWS cloud. The differences between the two processing environments are logical, and benefits of AWS processing of large data sets understood, but a level of credibility and saliency of cloud-processing needs to be demonstrated to these users before they will commit to off-site data processing and archiving in the cloud.

To make this pipeline useful in an operational setting, detection products would be delivered to the input S3 buckets when available from SAR data providers (e.g. ASF), to support oil spill detection and monitoring. Post oil detection processing in the pipeline, data products should be pushed from the S3 output bucket to a common operational picture used during an oil spill response. The barriers to this end-to-end oil spill detection pathway are limited to funds required to maintain the pipeline, run the pipeline, and align the data sharing agreements among the stakeholders. It is also important to note that S3 is a short-term data archiving solution meant to support objects that are being actively moved into and out of storage. Though costs of data archiving in S3 are in the range of $.02/GB/month (Amazon, 2017), AWS offers a variety of mid- and long-term, more cost-effective, data archiving solutions that would need to be explored if large volume data products are intended to be archived in the AWS cloud for the long-term.
The Amazon Spot Market was utilized for this prototypical pipeline, where market rates are determined by overall demand for AWS compute resources. The Auto-scaling group was configured to automatically launch the EC2 m3XL processing nodes would automatically when work was in the SQS queue but below typical going market rates. If the going market rate for EC2 m3XL nodes was above the rate set for the Auto-scaling group, then the job would wait until the price fell to or under the Auto-scaling maximum rate. Though this tunable price setting allowed for much cheaper compute resources than market rate cloud processing, it would be a hindrance to fast data delivery during an actual emergency response. Converting the pipeline to full market rate resource access would allow for consistently available compute nodes to support rapid data processing and delivery to decision makers, though at a greater cost.

The application of automated algorithms for SAR processing and GIS-ready data delivery in a cloud-based processing environment is also relevant in the absence of oil in terms of SAR applications to monitor the environment. The SAR process flow proposed here could be used with multiple types of algorithms to detect other phenomena with SAR imagery, such as sea ice detection and tracking, long-term forest fire effects, wind speed and many other ecological applications. By reducing the post-processing required by the operational end user, the potential exists to increase the use cases of SAR data in multiple decision-making arenas.

The GIS-ready, SAR-based, oil detection products from this cloud-based pipeline could be made available to oil spill response data managers through the common operational picture interface maintained by National Oceanic and Atmospheric Administration, Environmental Response Management Application (ERMA), as well as privately managed common operational pictures, such as those utilized by industry. Clear communication with oil spill stakeholders on the existence, utility and availability of these data products would be a first step to the integration of the entire pipeline as a data delivery mechanism for spill response. A workshop to interface with engaged oil spill stakeholders in industry, agency and academia, would offer a forum for open communication, and the establishment of saliency and credibility of this oil detection pipeline for detecting and monitoring of the marine environment for oil spills.
The amplitude-based, adaptive thresholding algorithm employed here performs oil classification based on the shape of anomalous features that are in contrast from the background water. Using the Sentinel-1 Toolbox algorithm with default parameters caused only dark pixel clusters greater than 100 m will be identified as possible oil spills. This minimum pixel cluster size will likely eliminate many oil slick features, such as those from a moving ship release, and may retain false-positives such as a large, low-wind areas in a SAR image. It is possible to tune cluster size to a smaller area to capture some of the smaller possible slicks, at the risk of oversensitivity and additional false-positives. Analyses of the output images from the experiment for accuracy of the algorithm for the detection of oil from SAR imagery is a separate effort that is underway.

A similar and perhaps more accurate method from which adaptive thresholding is modeled in this case, is segmentation thresholding. Segmentation thresholding classifies as oil or a look-alike feature by comparing the image to an oil spill description database. In a controlled environment, database of oil spill features is developed by training the algorithm to different oil spill and look-alike feature scenarios, and capturing the descriptive variables for future comparison. The accuracy of this analysis can be enhanced with the addition of weather information, but is typically about 75% effective in correctly identifying oil from look-alike features. It is possible to integrate a database of oil spill descriptions and other variables for image reference into the AWS pipeline used in this experiment. The increase in cost would be realized in EC2 processing time, which would depend on the efficiency of the database integration into the processing model.

In the case of an actual oil spill, it is anticipated that products such as these would be integral in mapping the extent and transport of oil in Arctic waters. These data would reduce human risk associated with mapping spilled oil through their remotely sensed acquisition, allowing for data fusion mapping techniques and oil fate and transport model enhancement. The GIS-ready format would also allow spill managers and responders functional access to these products for spill response decision-making. Finding a good algorithm to create accurate detection products will increase the value of the pipeline products to oil spill data stakeholders.
3.6 Conclusions

The oil spill detection pipeline as prototyped here was determined to be efficient, easy to use, and cost effective for processing and short-term archiving of SAR data products. Development and implementation of the pipeline was supported through AWS built-in tool and architecture techniques, eliminating the need for custom coding to configure the processing pipeline. Using these AWS resources allowed for quick development and iteration on the processing pipeline prototype.

In an operational setting, being subjected to price-defined computational access may be detrimental during any number of real time emergencies, thus operational use cases may not lend themselves well to this AWS Spot Market model. However, for periodic processing and single, medium to large-scale data processing efforts, being able to skip hardware investment and spend directly on processing in a scalable way would allow efficient fund expenditure without the overhead of processing hardware that will become obsolete within three years.

Further analysis of oil detection algorithms for use with SAR imagery is necessary before the pipeline can be recommended for operational use for marine oil spill detection. The pairing of an accurate oil spill detection algorithm and this prototypical processing pipeline could be the defining demonstration needed for operational use cases to move from under the desk to up in the cloud.

3.7 Literature Cited


Chapter 4: Integrating Small Unmanned Aircraft Systems into Alaskan Oil Spill Response – Applied Case Studies and Operational Protocols

4.1 Abstract

Unmanned aircraft systems (UAS) can support the critical mapping needs of an oil spill response but are not a consistent data source in incident command posts (ICP) of Alaskan oil spill responses. The integration of these data sets into the ICP of an emergency response is limited by the lack of uniform flight and data collection protocols, but are flight protocols the only limiting factor to UAS-integration? To understand how UAS can be integrated into the incident command structure (ICS) of oil spill responses and exercises, the lead author was embedded in the ICP of five Alaskan oil spill response exercises as a UAS Technical Specialist, UAS subject matter expert, and participant observer. Observations were conducted during the exercises to determine current remote-sensing (RS) and UAS use during oil spill response activities in Alaska. A set of pre- and post-exercise surveys were designed and delivered to participants in four oil spill exercises to evaluate responders’ attitudes towards and perceived familiarity with UAS applications in support of an oil spill response. As a result, a set of recommendations for UAS integration into an ICP and a UAS operational protocol was developed for the use of small (less than 55 pounds) UAS to legally, safely and logically support oil discharges or hazardous substance release responses and exercises in Alaska. The protocol was designed to fit within the context of the ICS of oil spill response activities in the U.S. as practiced by the USCG during actions authorized by the National Response System as defined under 40 CFR Part 300, the National Contingency Plan, and has been integrated into the USCG and State of Alaska, Arctic and Western Alaska Area Contingency Plan, a primary guidance document for oil spill response activities in Alaska.

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3 Garron, J. and S. Trainor. *In preparation.*
4.2 Introduction

Societal demands for real time information access can be supported by synthesizing currently available tools into known operational paradigms. Integrating new mapping technologies into the ICP of Alaskan oil spill response activities is an operational opportunity for synthesizing new data collection tools and informational products to increase oil spill response efficiency—an important aspect of reducing environmental impacts of oil spills. Current use of mapping and remote sensing tools incorporated with oil spill response exercise observations and surveys about unmanned aircraft systems (UAS) can be used to identify ways forward for integrating UAS collected data into the oil spill response lexicon.

4.2.1 Geospatial Support of an Oil Spill Response

Data used to support informational requests in the command post of an oil spill response reflects the wide variety of data sources available. The geospatial component of oil spills is often represented through paper or digital maps displaying data from disparate data sources. For oil spill response activities large enough to warrant the initiation of an incident management team, most of these maps are synthesized in a geographical information system (GIS) environment (Cutter, 2003; Ivanov & Zatyagalova, 2008; Muskat, 2014), many of which also serve as the foundation of the common operational picture (COP). GIS maps, and ideally the centralized COP of a spill response, display data that were not digitally collected in a synthesized way with data that were collected digitally. Non-digital data can include verbal reports of oiled animals, oil locations, and resources at risk, relayed via radio using latitudinal and longitudinal coordinates collected by aerial observers with global positioning systems (GPS) and appropriate training (NOAA, 2016). Non-digital data can also include field sketches from shoreline clean-up assessment technique (SCAT) teams (National Oceanic and Atmospheric Administration, 2007), observations from the field (C. A. Yan et al., 2015), and traditional ecological knowledge (TEK) (Bethel et al., 2014; Close & Hall, 2006; Huntington, 2000) of the area of interest.
Digital mapping tools are almost synonymous with RS tools. RS tools are defined by their capacity to detect targets from a distance (Sabins Jr., 1987), utilizing sensors designed to collect information about a target through electromagnetic observations or in situ sampling. RS tools also allow for the characterization of the environment in which an oil spill can or has occurred in remote areas that would otherwise be inaccessible, are extremely challenging to get to, or are inherently environmentally sensitive to human disturbance (Chou et al., 2010; Giordan et al., 2017; Murphy et al., 2017). Such tools can be used to support oil spill response activities without exposing people to the numerous dangers and environmental concerns associated with assessing an oil spill directly (Adams et al., 2014)(Adams et al., 2014). RS instruments became prominent in oil spill response activities during the Deepwater Horizon oil spill response (DWHOS) due to the remote location of the response, and the size of the spill (Jones et al., 2012; Leifer et al., 2012). To support the visualization of data from these RS tools, the web-based GIS COP from the NOAA application, ERMA, was also introduced as a response support tool during the DWHOS. ERMA is a GIS-based platform for mapped resources to be synthesized in a geospatial environment. Since the DWHOS event, ERMA has been used to integrate many disparate data sources, both static and real time in form, allowing for the synthesis of digitally and non-digitally collected data to be visualized together in support of decision-making (NOAA, 2018).

The mapped data used to support an oil spill response tends to fall into three distinct categories; resources at risk, situational awareness, and navigation.

1) *Resources at risk* are area-specific vulnerabilities that could be impacted by the oil spill or the response (USDHS, 2010). The natural habitat of the area that could be impacted by the oil, the people and animals reliant on that habitat for survival, archeo-cultural resources (known/unknown), critical infrastructure, and economically viable natural resources (fish, water quality, aesthetics, etc.) could all potentially be among the resources at risk. Many of these resources are known traditionally, but may not be mapped for baseline conditions prior to the oil spill event.
2) Situational awareness is a broad term describing the perception of the elements in a given environment within time and space, the comprehension of their meaning, and the projection of their status in the near future (Endsley, 2011). Situational awareness of an oil spill event normally includes 1) defining the extent and location of the oil spill (footprint), 2) identifying the oil spill source and ideally how thick the oil is, and 3) identifying the most immediate concern for response. RS data collected in support of situational awareness can be used for volume estimates and tactical strategies at the time of observation, and will likely be used as a variable in trajectory modelling for potential oil impacts to the environment (Lubchenco et al., 2012).

3) Navigation is a critical component of any response, and normally requires some kind of area map. Determining access to the oiled area as well as to areas where equipment and personnel can be staged can be a significant challenge, especially in remote, poorly mapped areas, like Alaska. Tactical decisions about response methodologies are based on the situational awareness and the navigation thresholds for the particular environment.

Using UAS to collect data in support of these critical components of an oil spill response has not been fully explored in an operational setting, though the potential is apparent.

4.2.2 Airborne Remote Sensing Tools to Support an Oil Spill Response

4.2.2.1 Platforms

An RS platform is the vehicle that carries the sensors (i.e. the payload), on-board computers, and power supplies. These platforms can be aerial (satellite, airplane, unmanned aerial vehicle) or nautical (boats, submarines, autonomous underwater vehicles) in nature. RS platforms are used to collect data in areas that are not normally accessible via ground transportation, and in some cases, to transmit information to the location where decision makers can access the informational product, such as an ICP.
Above the earth’s surface, satellites and airplanes have the capacity to operate for long periods of time, cover large areas in one mission, carry multiple sensors, and provide large data sets rich with information. However, satellites and airplanes have large start-up costs associated with their deployment, may be limited in their abilities to transmit data in real time, and may not provide publicly available data sets. Small UAS are by definition less than 55 lbs. (Code of Federal Regulations, 2016), and are comparatively easy to transport into a disaster area to support the acquisition of relatively high-resolution images over small areas with little lead time (Giordan et al., 2018; Huang et al., 2017). Commercial, off-the-shelf UAS offer low cost solutions for geospatial data acquisitions over small areas (Giordan et al., 2018; Yan et al., 2015), and can be used to supply the immediate situational awareness that is critical during the first phases of an emergency response (Lubchenco et al., 2012). High-resolution data delivered in real time has been a need identified by the oil spill response community for years (Cutter, 2003). Real time (i.e. live), or near-real time (less than 60 minutes after collection), UAS-based data collections to support decision makers during an emergency response are now being widely leveraged (Garcia-Pineda et al., 2020; Giordan et al., 2018; Gowravaram et al., 2018; Parscal et al., n.d.), but uniform protocols for integrating UAS flights in support of emergency response actions were not previously defined.

4.2.2.2 Sensors

Many other RS sensors and platforms can be used to visualize real time ocean conditions or to support oil spill response (Janzen et al., 2019; Muskat, 2014; Sweeten et al., 2014), and efforts are underway to miniaturize and specialize sensors used to support oil spill response for UAS (Watts et al., 2012). Situational-awareness flights tend to rely on easily interpretable sensors like electro-optical (EO) systems and long wave infrared (LWIR) to discriminate targets from background signals. EO sensors operate in the visual (red, blue, green) part of the electromagnetic spectrum, and are the most familiar RS products available, with outputs as pictures or videos. Most commercial, off-the-shelf UAS are outfitted with an EO sensor as their payload. LWIR sensors can be economical (less than $10,000), with data relatively easy to process into
a product for decision makers to consume, but these sensors tend to be of lower resolution than RGB data available for a similar cost (Yao et al., 2019). Miniature multispectral sensors are being used for centimeter scale mapping of the oil location (Gowravaram et al., 2018; Hunt & Stern, 2019; Sankey et al., 2017; Yao et al., 2019), and also to determine oil spill thickness (Garcia-Pineda et al., 2020).

The amount of time required to process remotely sensed data during an emergency response will heavily influence whether a specific sensor and resulting data set will be used for tactical decision-making (Giordan et al., 2018). Specialized sensors often have specialized data-processing flows that require a large amount of computing capacity, and large amounts of bandwidth to deliver data from one location to another. Other sensors are available for support in oil spill response, but require more involved integration with the UAV platform and more complex post-processing of the collected data after flight completion than the EO, LWIR, and multispectral, commercial, off-the-shelf sensors. Hyperspectral sensors are able to discriminate specific kinds of oils using discriminatory spectral information, but can also be used to describe environment health and whether baseline conditions have been disrupted by an oil spill (Adão et al., 2017; Hruska et al., 2012; Sankey et al., 2017; Yao et al., 2019; Zhong et al., 2018). Similarly, light detection and ranging (LIDAR) sensors provide high resolution, three-dimensional depictions of targets, at a high energetic and hardware cost (Rhee et al., 2018; Sankey et al., 2017; Yao et al., 2019). Synthetic aperture radars are also being miniaturized for use on a UAV. These sensors are valuable for mapping large areas for oil impacts and to support trajectory modelling efforts, but they also require large amounts of energy to run and to process the collected data (Hruska et al., 2012; Koo et al., 2012; Lort et al., 2018; Yan et al., 2018; Yao et al., 2019). Choosing the correct UAS platform and sensor package requires including the operational capacity to create informational products for decision makers from the system, and also the capacity to image the spatial extent of the area of interest in a timely fashion under FAA operational guidelines.
4.2.3 Decision makers in the Incident Command Structure of an Oil Spill Response

Emergency response actions often include the establishment of an ICP and an incident management team (IMT). These IMTs are organized using the FEMA defined ICS (USDHS FEMA Emergency Management Institute, 2018), a hierarchy of defined roles and supporting responsibilities for incident management. The roles within an ICS-defined IMT fall into five functional categories: Incident Command, Operations, Planning, Logistics, and Finance, with a sixth section, Intelligence, included under extremely complex circumstances. These sections are led by a section chief, and contain a variable number of subordinate roles depending on the specifics of the

Figure 4.1. ICS organizational chart [41].
emergency response (Figure 4.1) (USDHS, 2014). The USCG Incident Management Handbook (USDHS, 2014), designed to assist in the use of ICS during response operations and planned exercises, defines these roles relevant to the National Oil and Hazardous Substances Pollution Contingency Plan 40 CFR Part 300, also known as the National Contingency Plan (NCP)(Code of Federal Regulations, 1980). The ICS exists to support quality decision-making by the Incident Command (IC). The Incident Commander and the supporting IC staff use the information provided to them from the Operations, Planning, Logistics and Finance Sections to run the response or exercise. In oil spill responses and exercises large enough to have an IMT, Incident Command is where the Federal on Scene Coordinator (FOSC), State on Scene Coordinator (SOSC), and the Scientific Support Coordinator (SSC)–roles that are not filled by the responsible party–will be incorporated.

The Operations Section is responsible for developing the tactical response to the emergency. During oil spill response activities, the Operations Section determines where the oil is, what resources (equipment and personnel) are required to respond to the spill, where to stage those resources, where to deploy them from and how. Within the Operations Section is the Air Operations Branch (Air Ops). Air Ops is responsible for managing the airspace and the aircraft operating within the area of interest. Often a temporary flight restriction will be put in place, which also is under the managerial authority of the Air Ops Branch Director, though the FAA maintains ultimate control of all airspace in the U.S.

The branches of the Planning Section provide the information to directly support the Operations Section. The Environmental Unit within this section is often where federal, state, and municipal agencies have representatives embedded as resource specialists during a response or exercise, and where natural resource concerns are integrated into the response. The Environmental Unit coordinates any specialized permits required to support the response or exercise and enters into any required consultations for response activities, such as Section 7 consultation requirements of the Endangered Species Act, or Section 106 of the National Historic Preservation Act. The Situation Unit also falls under the Planning Section, and is where the COP and all other
geographical information is gathered, disseminated and archived for the response. This geographic information includes the relevant environmental sensitivity index (ESI) maps (summaries of resources that are at risk if an oil spill occurs nearby), bathymetric and topographic data, ownership status and locations where response resources are staged. Imagery and data collected during a response are made available to decision makers through the integration and display of that data as information by the Situation Unit. The Planning Sections is often where any subject-matter experts or technical specialists unique to specific components of the response will be integrated into the IMT.

Decision makers in the various sections of an ICS-based IMT have different information requirements, both in type and mode of display. Maps are one of the primary ways to convey information to and among decision makers in an emergency response, they often serve as the base layer of the COP, and are referenced both in hard copy and digitally during response activities (Garron, observational data, 2018). The three critical types of information conveyed via maps in an oil spill response or exercise are, resources at risk, situational awareness and aids to navigation. As such, maps are not required in the Finance Section, and have limited applicability in the Logistics Section. Maps are more consistently used for decision-making in the Operations Section, the Planning Section and by the IC staff directly (USDHS, 2014). In the Operations section, maps are used to support tactical decision-making and navigation, for instance where to deploy response teams to/from, what response equipment could work within the area of interest, and where resources can be staged for additional response support. In the Planning Section, maps are most heavily used to identify and support resources at risk of impact from the oil spill or the response. Using UAS to help create or augment these maps has not been widely integrated into oil spill response operations, though the technologies are well suited for the provision of near real time data in the dynamic setting of a marine oil spill.
4.2.4 Credibility of New Technology in an Oil Spill Response

Existing research on the introduction of new techniques or tools into communities offers insights into how they can be best introduced to communities of oil spill responders. The introduction of new techniques or tools calls for understanding of how they can be integrated to provide the greatest value and cause the greatest efficiencies in a given community. Also important is the perception of the value and efficiencies the new technique or tool can bring to the community. The long-term successful integration of new technologies into a decision-making scenario requires buy-in from the end user community (Kalluri et al., 2003). Perceptions of data quality and the level of uncertainty of those data, acknowledged or not, can influence the operational context of its use (Kalluri et al., 2003; Lemos et al., 2012; Von Lubitz et al., 2008). Integrating end user feedback into protocol development in real time establishes trust, increases efficiency, and ensures clear communication between the researcher and the end user (Dilling & Lemos, 2011).

Established relationships between scientists and members of a response team allow for a deeper understanding of responder needs and how science can be used to meet them (Weidhaas et al., 2016). Knowledge coproduction leverages these relationships, and focuses research on topics most important to the given user community, increasing the likelihood of usable data or data product creation for that community (Dilling & Lemos, 2011; Meadow et al., 2015). Coproduction of science products (or protocols) with the end user community also increases the credibility of the product (or protocol) itself, inherently increasing the likelihood of adoption in that community (Meadow et al., 2015; White et al., 2010).

In some cases, the integration of new tools to support an oil spill response is mandated. The USCG is charged to use accepted best management practices to meet the mission needs of the USDHS, inclusive of responding to oil spills (USDHS, 2014). UAS can support the requirements of CFR 155.1035 (Code of Federal Regulations, 2018b) in that they can be used to acquire the required information for reporting the location of an oil spill incident: details of the pollutant itself, including estimates of oil
discharged or threat of discharge; weather and sea conditions on scene; and current condition of the vessel responsible for the oil discharge.

Under 33 CFR § 155.1050 (Code of Federal Regulations, 2005), commercial vessel owners/operators in the marine environment must provide aerial oil tracking to support oil spill assessment and cleanup activities by trained personnel who can interpret the aerial imagery. There is no mandate on what specific aerial observational technologies must be employed, only that aerial oil-tracking resources must be capable of arriving at the site of a discharge in advance of the arrival of response resources, and for a distance up to 50 nautical miles from shore. They also must include appropriately located aircraft and personnel capable of meeting the response time requirement for oil tracking, as well as; sufficient numbers of aircraft, pilots, and trained observation personnel to support oil spill operations. Observation personnel must be trained in the protocols of oil spill reporting and assessment, including estimation of slick size, thickness, and quantity—but the tools of assessment of these observations is not specified. UAS also can be used to provide information essential for the protection of the marine environment, including details on the quantity, extent, and movement of the pollution; whether the discharge is continuing; and actions taken with regard to the discharge. Regardless of the method of introduction, the tools that will be successful in supporting an oil spill response are those that have been used and practiced with during drills and exercises.

4.2.5 Applicable Policies for UAS in Oil Spill Response

The FAA is responsible for the management of U.S. airspace and is obligated to integrate increasingly present UAS safely into U.S. airspace. UAS operational requirements are added and removed by the FAA on a regular basis, and as in manned aviation, they pivot around the qualifications of pilots and types. For small UAS (less than 55 lbs. total weight), FAA regulations are defined for UAS flights performed by civil (Code of Federal Regulations, 2016) or public (Code of Federal Regulations, 2018b, 2018a) UAS operators (pilots). Flight waivers required to deviate from these regulations during an emergency can be applied for by qualified pilots. If standing Certificates of
Authorization (COAs) or Part 107 waivers for an area of operations are determined insufficient for UAS flights in support of a given response or exercise, Emergency-Certificate of Authorization (E-COA), can be requested through the Special Governmental Interest (SGI) amendment process via the Emergency Operation Request Form ([https://www.faa.gov/uas/advanced_operations/emergency_situations/](https://www.faa.gov/uas/advanced_operations/emergency_situations/)). During emergency response activities, a temporary flight restriction (TFR) over the area of operations can also be requested from the FAA, allowing for UAS flights in the area of interest under the direct control of the emergency response Air Ops Branch Chief.

Other federal agencies, and many state agencies, are creating their own policies and guidelines for UAS use over the lands, waters and animals for which they are trustees. Agency rules range from the prohibition of launching, landing or operating UAS (USDOI, 2014), to restriction free zones in Class G airspace. Most commonly, a special use permit is required for UAS activities in actively managed areas like national wildlife refuges, or state-managed critical habitat areas, the bounds of which will depend on the agency and resource under scrutiny. Cybersecurity standards also play a role in defining missions. In January of 2020, the US Department of Interior grounded its entire UAS fleet except when required for emergency response operations due to concerns about data integrity (USDOI, 2020). These types of concerns and related restrictions will dictate the usability of UAS in the airspace over these public assets, as well as the collected data and its management.

Guiding the discussion on how to safely integrate UAS into operational settings requires the synthesis of federal, state, municipal and tribal regulations, while also recognizing that capitalization of RS requires the use of the correct sensor to collect the data decision makers care about and can act upon. The value of UAS-based data collection about the environment is clear, but the integration of the data collected by the sensors into decision-making in the short and long-term remains pocked with gaps in understanding and efficiency.
4.2.6 Research Objectives

The central research question of this work is, how can UAS be integrated into the ICS of oil spill responses and exercises? Three objectives were identified as requirements to address the central research question.

**Objective 1:** Understand how RS data and UAS are currently being used as part of oil spill response exercises, specifically in Alaska.

**Objective 2:** Evaluate the attitudes oil spill responders and their perceived familiarity with UAS applications in support of an oil spill response.

**Objective 3:** Identify how to legally, safely and logically use UAS to support Alaskan oil spill response.

To answer the central research question and address the research objectives, the lead author was embedded as a UAS Technical Specialist into the command post of five Alaskan oil spill response exercises as a participant observer during 2018. Observations were conducted during the exercises to determine current RS and UAS use during oil spill response activities in Alaska. The use of small UAS was simulated as part of these exercises to identify specific UAS applications for oil spill response, and UAS data management guidelines in support of data use and accessibility. A set of pre and post-exercise surveys were designed and delivered to participants in four oil spill exercises to determine a) attitudes about UAS and RS data before and as a result of the exercises and b), if decisions were being made using UAS collected RS data, and what they were. Federal, state, tribal and municipal requirements and guidelines for UAS activities were compiled with the information gathered from the 2018 oil spill response exercises to create an operational protocol for how to legally and safely use UAS to support oil spill response (Garron, 2019).

This research is a response to the call for long-term research studies to provide tools to increase ICS effectiveness in incidents involving water resources as called for by Weidhaas et al., 2016, and was designed to contribute to the body of knowledge.
about the capacity of UAS flight and data integration to support emergency response, specifically oil spill response in Arctic and sub-Arctic regions of America.

4.3 Materials and Methods

Access to industry-led oil spill response exercises was required to accomplish this work. Partnerships were developed with oil and gas industry corporations operating in Alaska, which allowed access to the ICP and IMT of the five Alaskan oil spill response exercises evaluated. The lead author was an invited UAS Technical Specialist (UAS-TS) in oil spill response exercises and conducted mixed methods research as participant observer in the exercises, embedded in the IMT in either the Operations Section or the Planning Section (USDHS, 2018) as a participant observer (Given, 2008). The embedded UAS-TS also performed the role of UAS subject matter expert, as would be the case in an actual response, answering questions about the capacity of the simulated UAS being used as part of the response, and what responders could and could not do with the technology, i.e. training members of the IMT on operational limitations of UAS technology.

4.3.1 UAS Integration into Alaska Oil Spill Response Exercises

For four of the exercises, the researcher performed the role of UAS-TS, as participant observer and as a member of the Air Ops team, within the Operations Section of the IMT. Working directly under the Air Ops Branch Director, the UAS-TS researcher was responsible for all coordination that involved UAS. These responsibilities included UAS team activation, FAA coordination for emergency UAS flights, synchronizing manned and unmanned aircraft in and around the simulated TFR airspace designated as part of the oil spill exercise, safely integrating UAS-based observational data collection, and incorporating UAS into the required ICS Air Operations Summary form (ICS-220). For the fifth exercise, the UAS-TS was embedded in the Planning Section as a UAS subject matter expert, with the only responsibility being to simulate the integration of UAS into SCAT, inclusive of flight planning within the
SCAT plan. The largest part of these roles was coordinating requested UAS overflights while integrating flight preferences from natural resource trustee agencies NOAA, NMFS, USFWS, the State of Alaska Department of Fish and Game (ADFG), the Alaska State Historical Preservation Office (not on-site during exercise), the industry-led Wildlife Branch of the IMT, and other subject matter experts in the IMT.

4.3.1.1 Simulated UAS data collection

Simulated UAS missions were used in all of the exercises to address four kinds of requests: wildlife observations, SCAT support, oil spill footprint assessment, and tactical deployment observations. Simulated wildlife observation requests were made to determine if any marine mammals were nearing the “hot zone” (area of spilled oil often characterized by extensive volatile compounds), if any animals were already oiled, if there were known animals that could be impacted by migrating oil, and if critical habitat had been or could be impacted by migrating oil. In two of the five exercises, the wildlife and habitat observations were formalized as part of the SCAT surveys. SCAT requires the estimation of spill sizes, volumes, and habitat type. For the exercises where simulated UAS were used for SCAT support, UAS were used to canvass large areas of Alaskan coastline that would have been either inaccessible by foot or to assess habitat that was so highly sensitive that UAS assessment of whether any oil had made landfall had far less impact to the habitat than actually walking on the shoreline habitat would have had. Oil spill footprint assessments were requested to determine if the oiled area was increasing or decreasing in size, and where the oil had migrated to since the last simulated overflight. The tactical observation requests were paired with footprint assessment overflights to observe the efficacy of the simulated oil spill response tactics deployed as part of the exercise, and to plan response tactics for the next operational period.

Prior to each simulated flight, the UAS-TS worked with the natural resource trustees to define the mission plan which included where the simulated UAS flights would take place, what type of aircraft would be used, how high they would fly, what the primary observation target was, and how data would be communicated and delivered to
the command post from the field. The agreed-upon flight plans were used during the exercise scenario, with the agency-defined specific conditions integrated into the next iteration of the UAS protocol as lessons learned after each exercise. For all of the exercises, simulated UAS flights were reported to the exercise controllers who then decided what conditions were observed, or information collected, during the simulated flights. The simulated flights were used to develop and refine the UAS operational protocol (Garron, 2019), and initiate discussion with agency-based, wildlife-resource trustees to understand real and perceived concerns with UAS overflights.

4.3.1.2 UAS-collected baseline data

UAS-collected baseline data was used for two of the five exercises using UAS of opportunity (i.e. already in possession by the oil spill response organizations supporting the exercises). This effort relied exclusively on the use of multi-rotor, small-UAS (less than 55 lbs.), carrying off-the-shelf electro-optical (EO) sensor payloads (visible spectrum) that were intrinsically integrated with the aircraft and allowed participants in the exercises an opportunity to visualize real UAS-collected data. These data were used in the exercises as background layers for trajectory maps and the design of tactical operations. The exercises did not involve the release of any oil, nor any deployment of tactical equipment. Given that fact, use of UAS-collected data to confirm oil footprint, location or tactical effectiveness was not able to be tested. No post-processing was performed on any of the data sets prior to introduction of the baseline data sets into the command post of the exercises. All UAS-collected data used for the exercises were provided via hard drive directly to the command post GIS specialist, who was also responsible for providing the operational maps, inclusive of trajectory analyses. No data was collected or delivered in real time for the exercises as they were tabletop in nature, with no tactical deployments.

Data for the two fall 2018 exercises were collected using the DJI Mavic Pro operated by Alaska Clean Seas. Both still images and videos were collected with visible spectrum (red, green, blue/RGB) sensors. Data was collected at nadir (0°) and oblique angles (-10° to -20°) at altitudes ranging from 200 to 390 feet above ground level and
was used as baseline data and background imagery for simulated oil spill trajectory analysis. Data collected for the spring 2019 exercises was collected using DJI Phantom 4 UAS operated by CISPRI and by the State of Alaska Department of Natural Resources at variable oblique angles. Additional sensors were not employed, as they were not available on the UAS of opportunity. All UAS pilots and UAS observers supporting these collections were certified by the FAA under 14 CFR Part 107 of the Federal Aviation Regulations as qualified UAS operators, and thus were knowledgeable about air safety and restrictions governing small-UAS flights. FAA guidance for use of small UAS during an emergency response was defined by the research team prior to the exercises and was practiced through execution for each scenario. These data were used to introduce members of the IMT to UAS-collected data sets and the type of images that could be produced from commercial, off-the-shelf UAS, and to understand how UAS-collected data would flow through the ICP without prior protocol definition.

4.3.2 Evaluation of Attitudes and Exercised Applications of UAS in Alaskan Oil Spill Response

All protocols used for collecting observational data and for survey administration as part of this research were submitted to the University of Alaska Fairbanks (UAF) Institutional Review Board (IRB) for review to ensure the rights and welfare of people who agree to participate in UAF research projects. All aspects of this research were determined to be exempt from further IRB review (Appendix F). Members of the oil spill response exercises who interacted with the research team were provided an explanatory statement of the research and the contact information for the IRB and all members of the research team if any concerns or questions were to arise from their voluntary participation in the observations and surveys. No additional contact from the participants was received by either the research team or the UAF IRB office.
4.3.2.1 Oil spill exercise observations

For each of the exercises, naturalistic observations (Given, 2008) were collected as handwritten notes about the use of UAS by the IMT of the exercise. The goal of these observations was to understand the current use of UAS in an industry-led oil spill response exercise, how UAS could be integrated into such a response, and what manned aircraft roles could be fulfilled by small UAS. These observations were made by the UAS-TS participant observer embedded in the Air Ops Branch or Planning Section of the IMT. Observations were focused on what missions the IMT was requesting of the simulated UAS teams, what real time applications UAS were tasked to support, what kinds of data were requested, and the fate of the UAS-collected data in the command post of the exercise. A final aim of conducting the observations was to note attitudes about UAS and their role in oil spill response, and if possible, how those attitudes changed after the simulated integration of UAS into the exercises.

Activity Logs (ICS 214) for all exercise participants were recorded as part of the administrative record of the analyzed oil spill exercises. ICS Activity Logs document notable actions, meetings attended, and information provided, as part of the administrative record, and are often used as reference documents in after-action reports for specific oil spill responses and exercises (USDHS FEMA Emergency Management Institute, 2018). The activity logs of the embedded UAS-TS were used as the foundation of the exercise observation notes and were both a) supplemented with additional descriptive and inferential notes collected throughout the exercises and b) noted at the completion of each exercise (Emerson et al., 2011; Yin, 2011). Observation notes were digitized, and manually analyzed using a deductive approach (Graneheim et al., 2017; Yin, 2011) framed on the research objectives to determine use of RS tools and UAS during the exercises as well as exercise participant attitudes about UAS use during the simulated oil spill response.

4.3.2.2 Survey Instrument

To evaluate the attitudes of oil spill responders and their perceived familiarity with UAS flying in support of an oil spill response, a set of pre and post-exercise surveys
were designed for participants in four production oil spill exercises. Surveys were not used as part of a fifth exercise. The surveys were also used to ascertain how decision makers on an IMT used UAS and RS data, assess requirements for those data to be used, and determine attitudes about UAS utility during an oil spill response. Survey tool analyses and the observations from these five exercises were then used to develop a set of recommendations for UAS integration practices into emergency response.

Voluntary, anonymous, surveys were administered to exercise participants for the four 2018 exercises analyzed as part of this study. All exercise participants were invited to answer the surveys via email and again in person during the exercises. Exercise participants were asked to only take the pre- and post-exercise surveys once, and were provided digital links to the surveys, as well as paper copies of the surveys on-site of the exercise. Participants were reminded once via email and in person prior to the commencement of the exercises to take the pre-exercise survey, and again at the conclusion of the exercises (in person and electronically) to take the post-exercise survey. There were 27 survey participants in the June pre-exercise survey and 19 in the June post-exercise survey, out of a total of approximately 100 exercise participants (50 for each exercise, with about 20 individuals overlapping between the two June exercises), for a June total survey response rate of effectively 27% for the pre-exercise survey and 19% for the post-exercise survey. The October exercises were much smaller due to location constraints, with an approximate total of 40 participants in each exercise, approximately 15 of whom overlapped between both October drills. There were 37 survey participants in the October pre-exercise survey and 25 participants in the October post-exercise survey, with an effective response rate of 46% (pre-surveys) and 31% (post-surveys). Electronic survey respondents had to click on a survey link in their email, which is an opportunity for the participant to abandon the effort. Similarly, some participants do not respond to surveys regardless of the materials in question. Survey participants were members of the oil industry; state and federal agencies involved with oil spill response; non-governmental organizations; and private contracting firms providing support to the IMT.
Pre-exercise surveys were designed to capture exercise participants’ previous knowledge and attitudes about UAS, and how they can be used to support an oil spill response. Post-exercise surveys measured how knowledge and attitudes changed after UAS operations were leveraged during the exercises. Questions were multiple choice and were provided to participants electronically (Google Forms for June exercises, SurveyMonkey® for October exercises) and on paper. The two delivery methods for the surveys were established as some of the participants were unable to access the electronic survey based upon account restrictions of their employer, or they preferred to respond via hard copy. Paper results were converted to electronic format for direct comparison with the results captured digitally.

All survey results were compiled in Microsoft Excel for analyses. Survey data was collected anonymously, hence pre- and post-exercise survey results were not paired by individual, and were not selectively eliminated for only answering pre- or post-exercise surveys only. The June and October exercise were fundamentally different in that the UAS data for June was entirely theoretical (no UAS-captured images or video available), whereas in October, baseline UAS data collections had been performed prior to the exercises, and the resulting footage was integrated into the exercise. This difference likely impacted post-exercise survey responses to some degree and disqualified several post-exercise survey questions from further analysis.

4.3.3 Protocol Development

As part of achieving this project’s third objective, to identify how to legally, safely and logically use UAS to support Alaskan oil spill response, a general protocol for the integration of UAS into Alaskan oil spill response and supporting exercises was developed (Garron, 2019). The protocol describes the roles and responsibilities for UAS integration into the IC structure, UAS flight requirements and natural resource trustee agency requirements in the presence of water-based or shore-based animals during oil spill response activities. The protocol, developed by Jessica Garron of UAF with direct input from NOAA, NMFS, USFWS, and ADFG, is specific for the use of small-UAS (less than 55 pounds), and was refined through practice during the five 2018 exercises.
Prior to participating in the 2018 exercises, FAA regulations about UAS the safe use of UAS during an emergency response were compiled. These requirements served as the basis for flight planning by the UAS-TS during the exercises and for the methods of engagement with the natural resource trustees embedded in the exercises. The developed operational guidelines were vetted as part of the industry-led exercises with federal, state and municipal agency representatives, and in one case industry lawyers, in real time during the exercises. Challenges, both perceived and actual, to UAS-flight and data assimilation into the command post, as well as the integration of solutions to those challenges, were observed and are discussed as part of this effort. At the conclusion of the exercises, an agency policy review about the terms of UAS use in Alaska was undertaken for each of the relevant trustee agencies overseeing Alaska’s marine environment, and integrated into the published protocol (Garron, 2019).

4.4 Results

4.4.1. Exercise Observations

4.4.1.1 Embedded UAS-TS

The embedded nature of the researcher allowed for candid observations of the oil spill response exercise setting and how the people in this setting interact and use scientific data for decision-making. UAS-TS activity logs for all five exercises, augmented by observation field notes collected as on-site jottings, as well as through reflective written descriptions at the end of each exercise (Emerson et al., 2011; Yin, 2011), documented the overall lack of detailed understanding by exercise participants about UAS capacity to support oil spill response activities. In addition to the researcher, there were one or two UAS pilots participating in each exercise, though their roles in the exercise did not include UAS operations. Positioning a member of the research team as a participant observer allowed for the both formal and informal introduction of UAS to members of the exercises who were unfamiliar with the technology, as well as for the collection of observations about UAS usage from within the ICP.
4.4.1.2 ICS Integration of UAS

UAS assets were integrated into the ICS documentation to determine what adjustments may be required in the documented requests and uses of these RS tools to support an oil spill response. UAS teams were requested by Operations, as were all other resources, through the ICS 213 Resource Request form. No alterations were made to the form to support UAS integration. Instead, estimations of contracted costs for UAS support were included in the cost burndown for the exercises, as was the case for all other requested resources. Also included was the simulated time delay in mobilizing UAS support outside of the organizations contracted to conduct oil spill responses on behalf of the responsible party. The Air Operations Summary (ICS 220) form was altered to include information about the UAS itself (make, model, N#), communication frequencies, and any relevant certificates of authorization or waivers being used. The integration of UAS into the Air Operations Summary is key to safely integrating these tools into exercise and response airspace. Treating UAS as equal to the manned assets available on a response highlighted the value of UAS as aerial reconnaissance tools that can be used interchangeably with manned aircraft for observational missions, as well as the need to consider these tools as part of the air-asset arsenal available to decision makers during a response.

For four of the case study exercises, UAS operations were coordinated through the Air Ops Branch of the Operations Section of the IC, as would be the case during an actual response. This role reported to the Air Ops Director and was responsible for receiving and coordinating the execution of UAS flight requests through Air Ops. UAS operations were coordinated out of the Environmental Unit in the Planning Section of the larger fifth exercise, where surveys were not administered. Simulated data collections during the exercises were conducted in support of three informational needs: What is the current footprint of the oil? What resources are at immediate risk? Are the deployed oil spill response tactics working? Prior to each flight, the UAS Coordinator would consult with the exercise embedded natural resource trustees. The coordination of the flights within the airspace was generally the same for each of the UAS flights,
regardless of their target data. Pre-SCAT was identified as the specific use case for UAS flights, and were coordinated through the environmental section of the Planning Branch. When used for pre-SCAT, the theory was that if the UAS encountered any oiled coastline or animals, the SCAT team would perform a formal SCAT survey.

4.4.1.3 UAS Use During Exercises

UAS were underutilized for the first two exercises in 2018. UAS missions were exclusively requested by the wildlife branch during the first two exercises, allowing for detailed discussions with federal and state resource trustees about flight parameters. Flights over animals were requested to determine what marine mammals were in the area, if any of those marine mammals were endangered species requiring section 7 consultation with USFWS, if any shorebirds were nesting or feeding along the adjacent coastline, and if any oiled animals were in the area. Supporting requirements for the trained wildlife observers using UAS were defined as part of the exercises. When trained wildlife observers were available, they were deployed with the UAS pilot teams to the ground station location to determine any impacts the physical ground station location may have on wildlife, and to review UAS-collected footage in real time via observations of UAS hand-held display, or real time data feed monitor established at the ground station. These simulated observers would be responsible for relaying geographic information about animal sightings, as well as compositional information (e.g. how many animals per group, what species in the area, heading of animals in transit, location of oiled animals), and reporting that information to regulators. During these early exercises, it was determined that the UAS pilot teams could not perform the role of wildlife observer in addition to their roles piloting and observing airspace for safe UAS operations, and the UAS protocol was written to reflect this requirement.

It was recognized that special-use permits or special-area permits would need to be acquired prior to UAS deployment as part of an exercise, and that these permits may also be required if a response last for longer than a 24-hour operational period. Similarly, when UAS flights are deployed for oil spill response exercises, additional consultation and permitting with resource trustee agencies may be required. Following
Alaska’s national response system (NRS) structure, all response activities involving NMFS’s trust species must first be authorized under the MMPA/ESA permit issued to the NMFS Marine Mammal Health and Stranding Response Program (MMHSRP). The Alaska Region Stranding Coordinator can authorize marine mammal disaster response activities, in collaboration with NMFS MMHSRP. During planned drills/exercises, mitigation and monitoring as part of an Incidental Take Authorization via Incidental Harassment Authorization (IHA) or Letter of Authorization (LOA) and project-specific Marine Mammal Monitoring and Mitigation Plan may be required. For circumstances involving direct observation of sea otters, the use of UAS must be coordinated with the USFWS Marine Mammals Management Branch in Anchorage. For flights over shorelines, coordination with ADFG is required. The most stringent flight parameters from an agency were those defined through the endangered species Section 7 consultation process relating to endangered marine mammals under the purview of NMFS.

In general, restrictions limited UAS flights in how low they could be operated over various species of concern. Discussions of molting birds, versus nesting birds, versus resting or feeding birds resulted in the overall recommendation not to fly below 150 feet when birds are present on the water’s surface or on the shoreline. This 150-foot height requirement became a generally accepted altitude for flights over non-endangered animals, including those in the coastal zone extending approximately one-half mile inland from the high-tide mark. Restrictions on how the UAS approached animals on the ground or water surface were also debated and resolved to have the least impact on animals as possible. If animals on the ground or water surface showed any kind of reaction to the presences of the UAS, the UAS was to either move off or increase altitude immediately. When UAS flights were used to identify the location of animals that had the potential to enter the hazard zone, or animals that had already been oiled but were on the move, UAS flights were still limited by minimum altitude requirements. The agreed-upon procedure for approaching animals on purpose included identifying the location of the animal at the highest altitude possible, then reducing altitude for species identification by dropping straight down until the animal could be identified. Hovering over individuals or groups of animals was to be avoided, and using UAS in the shape of
raptors was prohibited. These and other specific flight parameters—developed as a result of these face-to-face consultations and flight mission iterations—were used to design “Protocol for Using Unmanned Aircraft Systems (UAS) During an Oil Spill Response or Exercise” (Garron, 2019).

4.4.1.4 UAS Data Expectation Management

Integrating UAS into the IMT also served to educate participants about what these tools can and cannot do. The most notable overestimation of UAS capabilities concerned real time data delivery. UAS can display EO data in real time to the pilot via the hand controller of the aircraft, but that functionality is not easily translated to a command post many miles away in an area of poor communication infrastructure, common to most of Alaska. The deployment of wildlife observers in conjunction with UAS pilot teams to relay real time animal data was a result of this limitation. Similarly, when broadband networks or cellular infrastructure was lacking, data delivery to the ICP was achieved through a series of data transfers and vehicles used to transport collected imagery back to the ICP. Once those simulated data had been transferred, ingesting them into the COP became a barrier to UAS integration. All of the COPs in use as part of these exercises were GIS-based, which determined the format and metadata requirements for data assimilation. Members of the Situation Unit who were familiar with GIS applications did not have training on how to ingest raw UAS-collected images and video files that required additional processing to be consumable by a GIS. Manual data work-arounds were performed during the exercises to provide quality images to the tactical decision makers of the IC, but the value of the images collected was not fully utilized because of the lack of integration into the COP.

4.4.1.5 Legal Concerns

Legal concerns of the responsible parties (industry partners hosting exercises) for the use of UAS during a spill response or exercise were taken into consideration. Vetting of the UAS teams was a requirement for the industry partners leading the
exercises. This process was informal for the four production exercises due to the embedded nature of the research team in the Air Ops branch, but during the larger fifth exercise, the process was formal through the legal liaison of the responsible party. Simulated rogue drone operations (UAS operations from pilots not involved in the oil spill exercise) were introduced during all of the exercises, functionally forcing the exercise participants to consider the safety and legal issues associated with UAS outside of the control of the IMT. Exercise participants were limited in how they could respond to the presence of rogue UAS, just as would be the case during an actual response. In keeping with the project’s objective to identify how to legally, safely and logically, use UAS to support Alaskan oil spill response, a method was developed for managing rogue UAS operations that relied on identifying rogue UAS pilots by sending out security personnel to contact the rogue UAS operator and to have them ground their aircraft. While contact with the rogue operator was initiated, all flight operations were grounded due to a lack of direct control of the airspace until the rogue UAS was grounded and regular flight operations could continue to be coordinated through the Air Ops Branch of the IMT.

Permitting requirements for flights from state or federal lands, as well as airspace coordination over protected species and animals in general, were integrated into the UAS integration protocol after each exercise. This project also identified remaining gaps in the process of UAS integration that will need to be addressed prior to seamless integration of these remote-sensing tools into an oil spill response. Of these, the most significant are the challenges of data management for efficient use in decision-making. UAS-collected data has the capacity to be very intuitive, or very complex, and the complexities of the data and desired data product will dictate post-flight processing requirements.

4.4.2. Survey Data

Survey results are biased towards the exercise participants that were willing to respond to the survey. Of the approximated total of 180 exercise participants in the four exercises from which survey data were gathered, 36% of exercise participants took the
pre-exercise survey (64 individuals), and 24% took the post-exercise survey (44 individuals). All survey data analyses were based of the pooled responses from both the June and October 2018 exercises, though more surveys were collected, both absolutely and relatively, from the October exercises. Data analyses were performed on an individual respondent basis, based upon the unique identifier assigned to each collected response, allowing for anonymity of survey respondents to be maintained.

4.4.2.1 Relationship between survey respondent role and perceived usefulness of UAS data

![Diagram showing perceived usefulness of UAS data by role]

- **Command**
  - Not at all useful: 16%
  - Somewhat useful: 17%
  - Very useful: 50%
  - Extremely useful: 17%

- **Operations**
  - Somewhat useful: 25%
  - Very useful: 25%
  - Extremely useful: 50%

- **Planning**
  - Not at all useful: 13%
  - Not so useful: 13%
  - Very useful: 34%
  - Extremely useful: 40%

- **Logistics**
  - Not so useful: 50%
  - Somewhat useful: 50%
Figure 4.2. Relationship of usefulness of UAS data in exercise specific to participant/respondent role from pooled post-exercise surveys.

Respondents were asked to identify their role in the IMT based upon the primary branches within a typical IMT (Command, Operations, Logistics, Planning), or if they were exercise observers (not assigned to any specific section). Figure 4.2 relates the role of the respondent to their perception of UAS data usefulness to their role. Of the total respondents, 79% found UAS-collected/simulated data useful to their specific role in the exercise to varying degrees. Roles of the respondents were not broken down further than section, so it is possible that the 21% of respondents who indicated the UAS data was not useful for their specific role had no decision-making role that required the use of aerial imagery. All of the respondents who indicated they were members of the Operations section, where the UAS-TS was embedded, found UAS data useful.

4.4.2.2 Operational Data Usage
Figure 4.3. Operational data usage. Distribution frequency of previous use of aerial data (pre-exercise survey) as compared to use of UAS data in exercise (post-exercise survey). i.e. comparison of “What information are you looking for in aerial photos during a response/exercise” to “How was aerial data collected with a UAS used in this exercise”.

EO sensors were the only type of UAS-mounted sensor specifically evaluated as part of these exercises, which created the space for direct comparison of previous use of aerial imagery to the use of UAS-collected/simulated aerial imagery as shown in Figure 4.3. To understand the IMT data needs, and if UAS were able to meet those needs, respondents were asked to check all categories that applied to their prior use of aerial imagery (pre-exercise survey) and to the use of UAS imagery during the exercise (post-exercise survey). All categories of data usage were the same between the pre- and post-exercise surveys, with an optional “other” open-ended response on both. Specific “other” responses were grouped by their contextual themes: wildlife observations, situational awareness, media support.
4.4.2.3 Data Latency Requirements

Figure 4.4. Frequency distribution of acceptable data latency by role.

When asked “How ‘fresh’ does your data need to be?” over half of the total respondents (56%) indicated they needed data in less than two hours, followed by 22% of the respondents who indicated they needed their data in two to four hours (Figure 4.4). As the amount of time between collection and delivery decreased, so did the percentage of respondents accepting delayed data delivery. These trends were consistent regardless of the survey participant’s role in the IMT.
4.4.2.4 UAS Data Credibility

Figure 4.5. UAS data credibility. What would make UAS data credible (pre-exercise survey)? Still images (73%), video images (83%), human observer to ground truth (65%), knowing the pilot/operator (30%), low latency (38%), integrated into map (65%), and other, which included open-ended response space (3%).

Pre-exercise survey participants were asked what would make UAS data more credible; the results from the 60 respondents are displayed in Figure 5. This question was designed to understand participant bias towards the integration of UAS technology and resulting data streams into a spill response or exercise. Survey participants were provided answers that addressed both the UAS collection/delivery process and the UAS-collected data product, and were not limited in the number of selections they could make in their response.

Availability of basic data visualization products (still and video images) had the greatest likelihood of increasing credibility of UAS-collected data for the pre-exercise survey respondents. Having a human observer to ground truth the data collections was
as important to respondents as having the UAS-collected data integrated into a map (i.e. common operating picture); these two processes were the most favored process components that could increase UAS-data credibility among the responses available. Low latency of data is often cited as a benefit of UAS-collected data (Adams et al., 2014; Murphy et al., 2017; Thamm et al., 2013; Yao et al., 2019), but was important to less than 40% of the respondents. Knowing the operator was the least important process component to pre-exercise survey respondents. There were only two “other” responses (open-ended response opportunity) on the pre-exercise survey, both of which indicated the importance of GIS-integration capacity of the data.

4.5 Discussion

This work is an answer to the call for long-term research studies to provide tools to increase ICS effectiveness in response to oil spill incidents involving water resources as made by Weidhaas et al, 2016. To address how UAS can be integrated into the IC structure of oil spill responses and exercises, three project objectives were identified and analyzed.

**Objective 1:** Understand how RS data and UAS are currently being used as part of oil spill response exercises, specifically in Alaska.

**Objective 2:** Evaluate the attitudes of oil spill responders and their perceived familiarity with UAS applications in support of an oil spill response.

**Objective 3:** Identify how to legally, safely, and logically use UAS to support Alaskan oil spill response

The success of this project was predicated by the lead researcher taking part in the Alaskan oil spill response exercises, which was only possible by invitation from industry and agency to participate in the exercises discussed here. However, the invitation of academics into a command post of any type of response is not common, nor should it be assumed. If an oil spill occurs of large enough size or complexity to require scientific support, the Scientific Support Coordinators (SSCs) from NOAA will be the first scientists called upon to join the IMT. Additional scientific support is normally
requested by the SSC and is coordinated through them. The relationship of the SSC to the scientist and the relevance of their science to any given spill will ultimately dictate if science expertise is welcomed in the ICP.

### 4.5.1 Observations of UAS Integration

To meet **Objective 1**, *Understand how RS data and UAS are currently being used as part of oil spill response exercises, specifically in Alaska*, of this project, the lead author was embedded in the ICP of five oil spill response exercises performing the roles of UAS-TS, subject matter expert, and Participant Observer. These roles supported the identification of gaps in UAS knowledge of the response community, the education of the ICP to the appropriate and legal use of small UAS, and collection of observational data used to identify how to close those gaps in UAS application knowledge.

#### 4.5.1.1 Challenges to UAS Integration into ICS

The original goal of observing the oil spill response exercises as a Participant Observer was to determine the use of UAS-collected RS data during exercises. It quickly became clear to the research team that the responders’ understanding of UAS applications was so limited, that the embedded nature of the participant observer’s role was an opportunity to teach members of the exercise IMT some of the UAS applications to consider for future scenarios. During the first two exercises in 2018, the simulated UAS pilot teams (pilot and observer) were underutilized for tactical decision-making due to a lack of understanding of UAS capacity to support tactical requirements. In an effort to observe baseline perceptions about UAS integration into the ICP, no suggestions for UAS use were made by the UAS-TS embedded in Air Ops during these exercises. As a result, no UAS overflights for oil footprint were requested by anyone in the ICP during the first exercise. However, the wildlife branch of ops was quick to utilize the simulated real time nature of the UAS-based data collections. UAS were used by the wildlife branch to identify marine mammals nearing the simulated oil spill that would need to be
hazed away from the oil spill, identify the location of nesting shorebirds in the area of impact and projected impact, and to provide simulated real time data viewing to trained wildlife observers. This lack of awareness by the end users of new RS technology is logical, but creates a false barrier to transitioning from fundamental research to applied science, which can be overcome through direct engagement of the end user by the applied research scientist (Kalluri et al., 2003). Engagement among these interested parties can be as simple as a lunchtime seminar, or as organized as a three-day, hands-on workshop. The delivery method aside, creating opportunities for the oil spill response community to learn from applied scientists is key for the familiarization and education about these RS tools for use during oil spill response activities.

Having applied research scientists positioned within the IMT during oil spill response exercises provides benefits to both the scientist and the responder for the identification of the scientific needs of oil spill response decision makers. Embedding scientists allows scientists to see how an ICP functions, the relevance of science to specific IMT roles, and how members of the response use RS science and tools. In exchange, scientists in the ICP provide valuable insight about the RS tools or data provided to decision makers, as well as the level of uncertainty associated with each tool or data set.

The exercises used for this research demonstrated the mutual benefits of embedded scientists in the IMT specifically for supporting the integration of UAS into the ICP of an Alaskan oil spill response exercise. Embedding the UAS-TS/Participant Observer in the exercises allowed for the collection of observations about baseline RS and UAS usage, for the identification of scientific support needs that could be met with UAS during a spill response, and for the formal and informal introduction of UAS and their capacity to this community in support oil spill response activities. This model was relatively easy to adapt in Alaska, where the spill response community is small and access to oil spill researchers relatively straightforward due to previously established partnerships among industry, academia, and agencies. However, this localized model may not be sustainable at larger scales. Weidhaas et al., 2016 suggests moving beyond this “who-you-know-and-trust” model of scientific support (Machlis & McNutt, 2011) via a
more formalized scientific network, connecting the oil spill response community directly with the scientific community. Regardless of how scientists and the oil spill response community connect, allowing scientists into the ICP during oil spill response exercises will increase familiarity with UAS-based data, data collection, and data management strategies, which is key to the long-term integration of any new tool.

Other logistical considerations for UAS integration include the ICS forms required as part of the Administrative Record used to document and coordinate an oil spill response. UAS were integrated into the Administrative Record of these exercises by inclusion in the Organization Assignment List (ICS-204), Incident Organizational Chart (ICS-207), Safety Plan (ICS-2018), Activity Log (ICS-214), Resource Request form (ICS-219), Air Operations Summary (ICS-220), and the Incident Action Plan. To fully integrate UAS into ICS, the relevant ICS forms will need to be modified to include UAS and their supporting activities holistically as opposed to a case-by-case basis. Having UAS providers vetted prior to an actual response will also increase the efficiency of UAS integration into the ICP. For an actual response, UAS team vetting could include background checks, past performance records, FAA inquiries, and other formal agreements. The only mandated operational permissions for UAS flights in a TFR over an oil spill response are those dictated by the Air Ops Chief. However, all of the regulation compliance guidance provided to pilots who complete the FAA Part 107 certification will likely be a requirement to operate in the airspace of any response.

4.5.1.2 UAS-based Sensors to Support Oil Spill Response

A primary benefit of off-the-shelf UAS technology, is the ability to provide real time data collections for tactical operations and wildlife situational awareness. The UAS-collected data for these exercises were from the visible light spectrum, recordable by EO cameras. These cameras, capable of still-image collection as well as video, were fully integrated into the UAS of opportunity, thus making their use seamless, and their output intuitive. Most commercially available UAS can live-stream visible data (EO/RGB) as it is being collected. Whether this live-streaming is only to the pilot and the nearby observers, or to the ICP is a function of communication networks, which in
themselves are often dictated by the proximity of the area of interest to established communication infrastructure like cell networks or broadband Internet access points. In the highlighted exercises, no data were being collected during the tabletop exercises, so demonstration of real time data delivery into the command post was not achievable. However, the previously collected footage was displayed in the ICP and was used for tactical decision-making specific to the conditions observed in the UAS-collected imagery.

Many other sensors can be carried on a UAS that can support tactical decision-making during an oil spill response (M. Fingas & Brown, 2012; Huang et al., 2017; Jha et al., 2008; Messinger & Silman, 2016). Infrared sensors, finer resolution EO cameras, multispectral sensors (Dufek et al., 2019; Gowravaram et al., 2018) and hyperspectral sensors (Alam & Sidike, 2012; Andreoli et al., 2007; El-magd et al., 2014) all can answer different specific tactical questions during an oil spill response. Diurnal light cycles for human or visible spectrum observations influence which sensors are usable in dark or heavy-precipitation scenarios, as very few aircraft are outfitted with sensors able to effectively take advantage of night operations. The complex sensors capable of providing detailed information often require large amounts of energy to run and are not typically integrated in off-the-shelf UAS products, which is a risk for any operation in investment. For operational use during an oil spill, specific data collection platforms must be paired with sensors they are able to carry and power during data collection efforts, and the data processing and display considerations of those sensors need to be integrated into operations.

UAS that have been tested and established in the commercial market increase the likelihood they be used by UAS operators and data managers to create tactical informational products from the UAS-collected data for decision makers. Depending on the sensor chosen, different post-processing methods will need to be employed to provide a useful informational product for decision makers in a timely fashion. Creating an informational product that can be used by decision makers is a significant task that increases in time the more intricate the sensor and the more abstract the data. Finding an operational balance of sensors—some capable of providing easily consumable, real
time data, and others capable of providing detailed information about the spill itself in near real time—is a new wrinkle in a classic operational problem of speed versus detail. The correct sensor to use during an oil spill response is the one that is able to answer the question being asked in an acceptable amount of time for decision makers to act upon the information.

One of the most significant challenges to UAS integration is data management for efficient use in decision-making. UAS-collected data has the capacity to be very straight-forward for interpretation (e.g. RGB photos and video), or very complex (e.g. multi-dimensional hyperspectral data). The complexities of the data paired with the desired data products will dictate post-flight processing requirements. During the observed exercises, RGB data sets were the only available UAS-collected data for integration, yet data managers in the ICP who had not been trained to specifically handle UAS data were unable to integrate baseline videos or images into the GIS-based COP in use during the exercises. Manual data work-arounds were performed during the exercises to provide quality images to the tactical decision makers of the IC, but the value of the images collected was not fully utilized. This significant challenge can be overcome with training or by adding additional RS experts to the COP team, but should be addressed by all operators conducting regular oil spill drills for which they are flying UAS for situational awareness of any kind. Providing UAS-collected imagery in a format that can be easily ingested into the COP or other visualization software (e.g. ArcGIS) will also reduce barriers to integration due to the familiarity of the visualization platform (Kalluri et al., 2003).

It is likely that footage from UAS-based data collection flights will be requested by the public during future oil spill response actions, and if not supplied, collected by UAS pilots not authorized to fly as part of the response (“rogue” UAS operations). Creating a data management plan that includes the sharing of UAS-collected data, baseline or otherwise, from a given response will reduce confusion and support the development of new scientific tools and techniques to aid in future response activities (Weidhaas et al., 2016).
4.5.2 UAS Data Use Perceptions

Surveys were conducted in four of the five exercises included in this research to evaluate the attitudes oil spill responders and their perceived familiarity of UAS applications in support of an oil spill response. These surveys support the observations collected to meet project **Objective 2 Evaluate the attitudes oil spill responders and their perceived familiarity of UAS applications in support of an oil spill response**, and to identify the connections and disconnections between the perceived value of UAS data, and the actual applications of UAS data, in a Alaskan oil spill response exercises.

The June and October exercises were fundamentally different in that the UAS data for June was entirely hypothetical (no UAS-captured images or video available), whereas in October baseline UAS data collections had been performed prior to the exercises, and the resulting footage was integrated into the exercise. This difference may have impacted post-exercise survey responses to some degree, and disqualified several post-exercise survey questions from further analysis.

The UAS-collected baseline data was not integrated into the COP, resulting in less visibility and application of the UAS data for decision-making in all branches of the IMT. When UAS data was shared, it was used as background information or in support tactical deployment decisions (observation). Both still and video images collected by a UAS were available, and some images were printed and hung in the command post.

Most participants engaged in the oil spill exercises were supportive of the integration of UAS into the spill response decision-making process, and at a minimum provided quality background imagery and information for future damage assessments.

4.5.2.1 UAS Data Use

There are many people filling a variety of roles in the ICP of an oil spill, not all of which have a specific need for geospatial data products. In 2018, 79% of the participants in the oil spill exercises that responded to the survey found value of UAS-collected/simulated data to support their specific role in the command post, but what was profound was that 93% of this same pool of respondents found value in UAS data
inclusion in the overall response exercise. This result indicates generally open minds to new technology to support better response strategies, and the broad appeal of UAS and UAS-collected data to members of an IMT.

The variability in the Figure 4.3 responses between previous use of aerial data and use of UAS-simulated/collected data during the exercises indicates a lack of clear understanding about the capacity of UAS to support oil spill response, specifically through the replacement of manned overflights by optical sensors mounted to a UAS. For example, UAS can provide quality information about spill size and whether the oil spill is actionable (Garcia-Pineda et al., 2020), but participants in this exercise did not ask for those types of flights and analyses (observation). Some participants did recognize UAS capacity to support operational decision-making (Figure 4.3). UAS were understood to be valuable for identifying the location of oil, which was also the case for the respective use of aerial imagery. However, respondents’ previous use of aerial imagery to determine spill size, the actionability of the oil, and to verify deployment tactics indicates they fundamentally understand these uses for aerial imagery, but have not yet made the connection that UAS can also provide this supporting information. Exercise participants were not presented with UAS data to support these specific operational needs as part of these exercises.

The response variability in Figure 4.3 could also represent a partial sampling bias resulting from the way the questions were phrased. The pre-exercise survey question was worded to understand the respondent’s use of aerial imagery specifically, and did not include data collected and relayed directly by visual observers on an aircraft. Visual observers are often used to determine spill size, whether the oil is actionable (thickness based upon Bonn Agreement Oil Appearance Code, 2016), to identify wildlife that could be, or has been, impacted by the oil or the response, and other applications (National Oceanic and Atmospheric Administration, 2016). Information collected and relayed by visual observers does not always include aerial imagery, as much as it includes descriptions of what is seen and the geographic location of those observations. As such, many people working an oil spill response or exercise will receive the information from these aircraft-borne observers, without actually seeing any imagery of the location
where the observation is made, and thus do not actually analyze aerial imagery, or realize its potential to support decision-making during a response. Regardless of collection and relay method, all geospatial data is compiled in the Situation Unit of the IMT, for incorporation into trajectory models, operations maps, and the COP if in use. People in the IMT turn to the Situation Unit for the maps, and do not necessarily know what data was used to create the maps, nor is it relevant for operational decision-making. Having the geospatial information to make quality decisions about the response in a unified location is the requirement; UAS-collected near-real time data is one way to meet the requirement.

The use of UAS for wildlife observations as compared to a lack of wildlife observations traditionally evaluated from aerial imagery collected by manned aircraft was unexpected and represents an opportunity for expanded use of UAS. These wildlife observations were focused on real time observations conducted via colocation with the UAS pilot teams more than via the collected imagery. During the June 2018 exercises, the initial response of wildlife resource trustees was to send human observers in manned aircraft to identify the presence of animals and critical habitat relative to the oil spill and the associated response activities. This is the typical methodology employed for wildlife observations, i.e. aerial imagery is not as common as direct human observations of wildlife. As part of these exercises, the UAS Technical Specialist coordinated directly with the resource trustees as well as the wildlife branch of operations in the IMT to define flight operations that could support these wildlife objectives without sending people on an airplane to observe wildlife in real time. Not putting people in the airspace inherently increases the safety of the response or exercise. UAS costs and safety considerations were not the focus of this exercise, but some of the exercise participants specifically highlighted the benefits of UAS to reduce costs and increase safety of an oil spill response.

4.5.2.2 Data Latency

More than half the respondents to the pre-exercise indicated they needed their data in less than two hours (Figure 4.4), and another 22% needed data in two to four
hours. The large percentage of respondents needing their aerial data in less than 4 hours (78%) highlights the importance of real time or near-real time data sets for oil spill response. Though UAS are not the only remote-sensing platform capable of supplying data in near-real time/real time, they are relatively accessible to a broad community at relatively low cost. This accessibility continues to increase with time, as does interest in using UAS to support oil spill response. Demonstrating the capacity of UAS to support real time or near-real time data collections for oil spill response was part of these exercises, as were the challenges of near-real time delivery of data to the ICP.

4.5.2.3 UAS Data Credibility

Like aerial imagery and video collected from an airplane, UAS-collected optical data products are straightforward yet time consuming to interpret. Reviewing raw footage or images manually and externally to the COP adds another layer of confusion and potential delay to the process of information gathering for emergency decision-making. Increasing the visibility of the high resolution UAS-collected data in a near real time/real time collaborative space that is familiar to decision makers in the command post, (i.e. the COP), will likely raise the credibility of these collections. Supporting this hypothesis was the survey result that UAS-collected data integrated into a map was tied for the top process for making UAS-collected data more credible with human observers to ground truth the UAS-collected data (Figure 5). The fact that human ground truthing the UAS-collected data was tied for the top process to increase credibility indicates that there is still a lack of trust in this technology, or that the technology is not reliably understood. Workshops to expose oil spill responders and regulators to the value and capacity of UAS to support oil spill response will speed up the acceptance and ultimate integration (Kalluri et al., 2003) of these products and tools into the command post for response support.

Of the 53 individuals who indicated imagery products, still or video, would make UAS-collected data more credible, 41 wanted both still images and videos, and the 12 who only wanted one of the two formats, favored video imagery over still imagery. This result is significant for considering which data products would be most valuable for the
end users of the UAS-collected data. The preference for video imagery products, coupled with the process preference for map integration helps narrow the potential data products for operational consideration. These results suggest that UAS data providers consider tools like full motion video (FMV) and other georeferenced video processing methods, to support both the response and the damage assessment phases of an oil spill. When UAS-collected videos are processed to be FMV, they can be analyzed in near real time for immediate decision-making. They are also archivable and searchable by geolocation and time stamp for future analyses (ESRI, 2018). Another benefit of this video format is the ability to stop the video and analyze the frames as still imagery if preferred. Ultimately, the most effective way to develop useful data products for an end user is to include the end user in the discovery and development process (Kalluri -et al., 2003; Meadow et al., 2015; White et al., 2010).

Though low latency for data delivery was less of a priority to respondents than map integration or ground truthing the data, it was identified by 38% of the respondents as being important for UAS-collected data credibility (Figure 5), and was a requirement by 78% of survey respondents who wanted their data available in less than four hours (Figure 4.4). Real time and near-real time data delivery is one of the fundamental benefits of UAS-collected remote-sensing data over the same kinds of data collected from either a satellite or a manned aircraft. Satellites have a return interval over the same patch of earth ranging from 14 to 24-days on average, though this interval can be functionally reduced at an increased cost by using data from multiple satellites. Manned aircraft are able to fly over an area of interest more often than a satellite, but human observers on those manned flights are limited by the number of human observers available and the duration of the “duty day” for both the observer and the aircraft pilot. UAS supported by multiple pilot teams are able to fly as long as the aircraft itself remains visible and within the boundaries of any temporary flight restrictions, waivers, or general operational guidelines.

The tasking of these different remote-sensing platforms is also very different. Satellites may not be able to change their orbit or sensor look angle after launch. Deploying manned aircraft over the oil spill will be a function of available aircraft, pilots
and observers, and the funding to support additional manned airplane missions. UAS are relatively inexpensive to produce and operate in comparison to satellites and manned aircraft, and are easily taskable for multiple missions in short timeframes. What UAS-based data collections lack due to weather and synoptic vision constraints, is made up for in the benefits of safely collected reliable, repeatable, low-cost data sets, and the delivery of those data in real time or near-real time to the emergency response command post. As people become more familiar with UAS-collected data products, the low latency benefits will become increasingly exploited, and will likely continue to increase UAS credibility for oil spill response decision-making.

The lowest ranked UAS credibility indicator was knowing the UAS pilot. Responders' personal relationships with UAS pilots or operators may be important to 30% of the survey participants now (Figure 5), but these relationships will soon be irrelevant as formal vetting becomes a requirement for UAS pilots participating in an oil spill response. In the case of federal or state directed oil spill responses, formal vetting has been limited thus far to those pilots who have obtained their Part 107 certification from the FAA. On an industry-led response or exercise, UAS-pilots will be thoroughly vetted by the responsible party before they will be allowed anywhere near an oil spill under the industry’s purview. This vetting process, as defined by some of the larger oil industry corporations, is similar to the process required for manned aircraft pilots to work in support of an oil spill response.

4.5.3 Protocol Development

A protocol was developed for the use of small (less than 55 pounds) UAS in support of oil discharges or hazardous-substance-release responses and exercises in Alaska (Garron, 2019). This protocol synthesizes FAA rules and lessons learned from the case study exercises, and it provides operational guidance for UAS pilots and members of oil spill response IMTs on how to safely and legally use UAS during an oil spill response, directly addressing Objective 3 of this study: Identify how to legally, safely and logically use UAS to support Alaskan oil spill response. The protocol was designed to fit within the context of the ICS of oil spill response activities in the U.S. as
practiced by the USCG during actions authorized by the National Response System as defined under 40 CFR Part 300, the National Contingency Plan.

During the exercises analyzed in this study, UAS flight operations were coordinated through the Air Ops branch of the Operations section of the IC, as would be the case during an actual response. A TFR was put into place by the Air Ops Branch Director, allowing for direct coordination of UAS with all other air assets being utilized as part of the simulated response. When a TFR has been established, there still maybe the requirement for an Emergency Certificate of Authorization (eCOA) to access the TFR airspace. For example, if a small, fixed-wing UAS was being launched from shore, and the TFR was some distance away, a corridor would need to be set up under an eCOA for the UAS to get to the TFR. An eCOA can be used to request variances to any of the inherent Part 107 flight regulations from small-UAS, such as temporarily flying beyond visual line of sight.

The coordination of UAS flights included addressing flight requirements and requests from state and federal agencies responsible for the welfare of animal and cultural resources. Though no specific legal mandate exists requiring UAS operators to consult with agencies other than the FAA prior to flights, consultation with agency representatives during this research indicated that the lack of doing so will likely result in fines and other indirect consequences for the UAS operators and the responsible party. Fines could result from harassment of wildlife, intentionally or not, or for infractions like trespassing if operating the UAS from private, state or federal lands without prior permission or permit acquisition.
During the initial exercises, agencies requested that UAS follow the same flight requirements as mandated for manned helicopter operations. Specifically, NMFS requested flights not operate below 1,000 feet. Part 107 pilots are not allowed to fly over 400 feet per the FAA, and not all exercises required NMFS consultation. This demonstration of inconsistencies of understanding the technology and implementing the regulations was observed during the early exercises but decreased over time as resource trustees became familiar with inherent limitations of the technology and FAA regulations. By the completion of the exercise series, NMFS provided the blanket guidance for UAS usage during exercises and during actual responses. For drone use during an actual oil spill, NMFS recommends that drones stay 1,000 feet away from aggregations of marine mammals (e.g., Steller sea lion haulouts or rookeries), but if that is not practical, that the no-fly zone be removed from over the animal completely. Collection of wildlife observational data is required to enable the USCG to calculate exposure and take after the incident is over. For UAS use during an oil spill exercise, NMFS policy is that UAS operators need authorization from NMFS by way of an Incidental Harassment Authorization or research permit, both of which typically take months to acquire. If granted, UAS pilots may be allowed to fly within 1,000 feet of marine mammals under NMFS jurisdiction. This guidance may or may not be accepted outside of Alaska, and if NMFS species of concern are in the area, NMFS consultation should be conducted regardless.

Discussions with the federal and state agency resource trustees provided a training opportunity for those involved in the exercise to understand UAS capacity and to support and answer wildlife critical questions. These discussions also highlighted the limitations of UAS for animal observations compared to traditional observation.
methodology, i.e. human observers from air or shore. The exercise-based coordination effort for wildlife support led to the development of the UAS in Oil Spill Operational Protocol (Garron, 2019). Understanding the specific requirements and concerns of the wildlife resource trustee agencies (USFWS, NOAA NMFS, ADFG) allowed for flight protocols to be designed to meet the animal observational objectives while reducing disturbance impacts on the animals. Though consultation with wildlife resource trustees for flight operations will always be encouraged, the development of a standardized operational document has allowed for further expansion of the UAS tool into Arctic oil spill response (USDHS, 2018).

Trained aerial oil spill observers are responsible for assessing the appearance and distribution of oil discharged on water. NOAA’s Office of Response and Restoration (OR&R) maintains a website for training aerial observers for oil spills, an oil observation checklist and a job aid for aerial observation (NOAA, 2016). Aerial observation of oil spills and animals is distinct from the UAS Visual Observer task, which provides situational awareness to UAS pilots and operators. There is an effort underway to develop the UAS Job Aid for NOAA OR&R. It remains unclear how the analyses of oil from UAS-collected imagery will be used to substantiate or replace the traditional aerial observer analyses as this study focused on the operational components of UAS integration into a response, and not the data products that could be developed from UAS-collected data to eliminate the need for aerial observers.

This study did not focus on “rogue” UAS operations, by members of the response or otherwise, that may be operating UAS legally, but outside of the bounds of the IC structure of the response. It is recognized that rogue flights will likely occur during an actual response (rogue flights were often presented as problem injects throughout each of the exercises), but defining management strategies of these rogue aircraft and operators during an exercise can establish a basis from which to manage rogues during an actual response. The primary management tool to prevent rogue operations during an oil spill response is the establishment of a TFR over the area of operations. Part 107-certified pilots are required to check for any notice to airmen, designed to provide information essential to personnel concerned with flight operations but not known far enough in advance to be publicized by other means (i.e. real time abnormal status
indicators) that are applicable to their area of flight and through this process will be made aware of the closure in operational airspace (USDOT, 2016). Strategies to manage rogue UAS within a defined TFR during an operation includes deploying a security team to identify the operator of the UAS, and have them cease operations immediately. This method assumes the UAS is being flown with line of sight of the operator, as per Part 107 guidance, and that security teams will have physical access to the operator’s location. Jamming devices for blocking UAS operational signals are not yet commercially available, nor legal for non-governmental use: thus, if a rogue UAS is observed, the safest solution is to ground all aircraft in the TFR until the rogue UAS has left the area, voluntarily or not.

### 4.6 Conclusions

This study focused on the integration of UAS into oil spill response exercises, through participant-observer subject-matter expertise, and the development of UAS flight operational protocols. This work documents the current use of RS data and UAS in Alaskan oil spill response activities, and how those uses relate to the attitudes among the oil spill response community about the usefulness of UAS to support oil spill response activities. The UAS operational protocol developed as part of this effort (Garron, 2019), summarizes the legal and safe uses for UAS during an Alaskan oil spill response, and highlights logical ways to directly integrate UAS into response operations. The long-term goal of this research is to clear barriers between decision makers in IC and near-real time geospatial information to support quality decision-making during oil spill response activities.

Real time data availability for immediate understanding and action, streamed into a command post or Forward Operating Base is ideal for supporting operational decision-making during an oil spill response. UAS are able to support this real time need in many circumstances, and in near real time (0.25-2 hours after collection) in others. End-product requirements will dictate the post processing of the data and the speed at which it is available to decision makers, e.g. real time, low-resolution, infrared data versus three-day processed, high-resolution, hyperspectral data. It is important that
the data purveyors in a command post are able to efficiently use the data as
information, and can understand what can and cannot be accomplished with off-the-
shelf UAS and the derived data products from their image collection flights.
Understanding UAS data collection and delivery capacity will allow for realistic
expectations and support of UAS pilots to systematically collect quality data that is
wanted and can be used for change detection and other analyses in support of a
response. There is no distinct pathway for this understanding to be realized, but
relationships among industry, academia and agencies eager to share advances in oil
spill response through formal and informal discussions and learning opportunities are
the conduit.

Different UAS-based sensors will provide different data that ranges in level of
complexity to process and consume. The visible spectrum baseline data provided by
UAS for these exercises was easy to consume (photo and video formats were familiar
to members of the IMT) and of high enough quality to make tactical decisions (e.g.
boom placement in small streams). These major advantages of visible sensors should
not be overlooked when considering other RS packages capable of more detailed
analysis of the environment. There is no operational-response value in data that is too
complicated to be understood quickly by decision makers. The balance of detail versus
time will continue to improve as computing power becomes faster and more lightweight.
It is important that the computing infrastructure be in place to support voluminous RS
data sets collected during a response (or exercise), and that the end users have training
to take full advantage of the products. Uncertainty in the data products needs to be
eliminated or defined up front so credibility will not be lost. Long-term data accessibility
needs to be considered during design, implementation, and evaluation of the products if
there is to be hope of creating products that remain useable beyond the operational
response phase.

Using UAS to increase the inherent safety of an oil spill response by removing
humans from the sky is a benefit beyond data acquisition; human risk versus machinery
is not quantifiable. Practicing the integration of UAS into the airspace of an oil spill
response or exercise is paramount to the continued successful utilization of these tools.
The “Protocol for Using Unmanned Aircraft Systems (UAS) During an Oil Spill Response or Exercise” (Garron, 2019), integrates the regulations as well as the lessons learned from these exercises. Although direct consultation with federal, state, municipal, and tribal governance groups is recommended, this protocol developed as a result of exercise participation and identifies acceptable UAS flight practices in Alaska when consultation is not an immediate option.

Working with the end users to develop the questions and iterate on the solutions as a bottom-up approach to operational problems can foster tighter collaborations between the user community and the scientist (Cutter, 2003). This concept was thoroughly demonstrated by embedding the participant observer form the research team into the oil spill response exercises. Embedding a UAS-TS into the Air Ops Branch of Operations proved to be effective for safe airspace management, and for coordination with the needs of the tactical maneuvers of the Operations team. Once the operational support available from the simulated UAS was understood, the UAS were quickly integrated into routine overflights and specialized missions. There is still misunderstanding in the general operational environment on what UAS can and cannot do; thus, continued education about these tools for potential responders is important to establish and maintain. As was demonstrated during the exercises, such education could include not only basics of data analysis but also logistical challenges that help with expectation management—such as the reality that UAS may not supply real time data.

Benefits of cross-discipline partnerships for developing better response strategies cannot be overestimated. The lessons learned from previous studies about stakeholder engagement for data-product development (Dilling & Lemos, 2011; Kalluri et al., 2003; Lemos et al., 2012; Meadow et al., 2015; Von Lubitz et al., 2008; White et al., 2010), are similar to those described in this work. Stakeholder engagement needs to be foremost when developing new applications (Kalluri et al., 2003). Providing opportunities for feedback and iteration cycles will only improve the product and increase the legitimacy of the project and team. Acquiring funding to sustain the partnerships as well as the data products and services is key to long-term success.
Rogue operations, intrinsically safe UAS, citizen-created and publicly available UAS-collected data sets over sensitive targets, all need to be understood and addressed in the immediate future, prior to the next significant oil spill response. As detailed challenges about UAS integration into airspace and operations of many sorts are identified and resolved daily, the oil spill response community has an opportunity and a responsibility to take advantage of this rapidly evolving tool to support quality oil spill response decisions.

For holistic response strategy development, stakeholder engagement and training when new tools become available to support a response are critical for the long-term viability of new sensors and data products. It has been demonstrated that it can take up to five years for end users to become comfortable around a new RS tool, and that the level of comfort is heavily influenced by the end users perception of the tool’s value (Kalluri et al., 2003). Training sessions are recommended on the RS imagery and video most likely to be used for decision-making in the command post so that decision makers understand what data information is available with the RS-collection tools at hand. Response-team understanding of the benefits and limitations of customary COP software, and how UAS data fit into the COP framework, operationally and theoretically, is also key for integrating new data streams into decision-making processes. Whether these training activities are associated with an exercise, or are delivered via webinar or technical conference, is not as critical as the need of having them at all. Learning and training opportunities for staff in the ICP that work with the UAS-collected data need to be provided by any operator or responder interested in using tools beyond the human aerial observer for situational awareness during an oil spill response.

Providing opportunities for feedback and iteration cycles will only improve the product and increase the legitimacy of the technology and team. This significant challenge can easily be overcome but should be addressed by all operators conducting regular oil spill drills for which they are flying UAS for situational awareness of any kind. The new tools that are successful during a response are those we have practiced with during drills. Training and educating potential users of these data is critical for realistic integration of UAS-based tools into oil spill response activities.
4.7 Literature Cited


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Chapter 5: Protocol for Using Unmanned Aircraft Systems (UAS) during an oil spill response or exercise

5.1 Overview

The following protocol has been developed for the use of small (less than 55 pounds) unmanned aircraft systems (UAS) in support of oil discharges, or hazardous substance release, responses and exercises in Alaska. These specific types of environmental responses are authorized by the National Oil and Hazardous Substances Pollution Contingency Plan 40 CFR Part 300 (National Contingency Plan or NCP). The NCP establishes the National Response System (NRS) and this protocol describes the roles and responsibilities for UAS integration into the incident command structure of authorized NRS actions that may include UAS flight requirements and UAS-relevant agency requirements in the presence of wildlife in marine and terrestrial environments.

UAS can be utilized in an oil spill response to;

- Provide situational awareness (including tactical deployment observations)
- Map oil extent
- Identify resources at risk (including habitat)
- Identify critical infrastructure
- Determine locations of wildlife relative to the spill (e.g. species, group size, heading)
- Monitor air quality
- Other incident-specific uses approved by the Unified Command

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5.2 UAS Team Roles and Responsibilities

UAS operations are under the authority of the Federal Aviation Administration (FAA). During an emergency response, the UAS Team (FEMA, 2017c) operates under the authority of the federal or state on-scene coordinator, typically in the Air Operations Branch if/when the incident management team (IMT) is fully functional. The UAS Team is composed of UAS Pilots, UAS Visual Observers, UAS Technical Specialists, and other UAS support roles as needed (e.g. engineers). The key responsibilities of the UAS Team are to provide situational awareness by transmitting real time imagery, data, or verbal assessment, using multiple technologies, such as photogrammetry, live video, thermal imaging, and air quality sensors to enhance the Common Operating Picture (COP), planning functions, and Incident Action Plan (IAP) development (FEMA, 2017c). UAS Teams are resources that can be requested as part of an NRS response or exercise. Costs will be dependent on the UAS service providers.

Many oil spill removal organizations/primary response action contractors (OSROs/PRACs) maintain their own small UAS for situational awareness. It should not be assumed that imagery collected by OSROs/PRACs will be incorporated into the COP unless UAS-based data collection and provision is expressly defined as part of the OSRO contract. If/when OSRO UAS contracting is secured and/or integrated into the NRS response action organization, this UAS protocol shall be followed. UAS assets shall be managed by the federal and state on-scene coordinator and/or IMT as they would any other NRS response asset provided by OSROs/PRACs, authorized contractors, or other government agencies.

5.2.1 UAS Pilot

UAS pilots (FEMA, 2017a) working on an NRS authorized response or exercise need to be able to safely operate under one of two FAA regulations,

- 14 CFR Part 107 - Small Unmanned Aircraft Systems; regulation addresses legal operation of aircraft less than 55 lbs. flown following Subpart B (Operating Rules)
performing the role of Remote Pilot in Command as outlined in § 107.19; pilots flying using Part 107 certification as defined in Subpart C (Remote Pilot Certification) will be considered to have acceptable credentials for individuals representing Federal, State, Tribal or themselves as citizens; civil operator.

- Certificate of Waiver or Authorization (COA); regulation addresses legal operation of UAS performing governmental functions (Federal, State or Tribal) and statutory requirements of 49 US Code 40102(a) and 40125 for public aircraft; public operator. Due to elevated risks when operating in potentially hazardous environments, Unified Command’s liability and agency personnel’s indemnification when operating under the Unified Command’s direction, remote pilots operating under COAs shall be considered by OSC(R)s on a case-by-case basis before being allowed to operate within the Unified Command’s structure.

UAS pilots are responsible for maintaining Flight Logs for each individual UAS flight. Each log should at a minimum include date, crew, aircraft, sensors, and additional notes. It is not recommended to have UAS pilots perform UAS data management and assurance roles due to their primary requirements to fly aircraft and observe the airspace in support of safe operations.

5.2.2 UAS Visual Observer (Observers)

Observers are responsible for scanning the airspace where the small UAS is operating, and maintaining awareness of the position of the small UAS through direct observation. Observers must remain in communication with the pilot in command at all times and be able to coordinate collision avoidance maneuvers with the pilot in command as necessary. It is not recommended to have UAS observers perform UAS data management and assurance roles due to their primary requirements to observe the airspace in support of safe operations. However, observers may be able to fulfill other mission support functions, as long as those function do not interfere in anyway with the safe observation of the airspace and aircraft in flight.
5.2.3 UAS Technical Specialist

The UAS Technical Specialist (FEMA, 2017b) is responsible for coordinating the UAS Team (pilots, observers, UAS support personnel) within the Air Operations Branch of the IMT, and supporting data integration with the Situation Unit of an IMT. The two primary roles of the UAS Technical Specialist are to, 1) work with the Air Tactical Group Supervisor (or other Operations Section personnel, dependent on IMT organization) to ensure that UAS are safely integrated into the airspace above and near an oil spill response or exercise, and 2) coordinate collection, COP integration, and archival of UAS-collected data. The UAS Technical Specialist is responsible for identifying requirements from decision makers in the command post to efficiently task the UAS Team in support of the response or exercise. Specific tasks associated with the UAS data management include,

- Performs pre-flight and post-flight safety and security checks of on-board data gathering and streaming equipment, and informs pilots and observers of any potential safety concerns,
- Ensures that data recording and streaming equipment is secure and operational preflight, during flight, and post-flight to achieve the mission objectives,
- Checks data recorded, creates back-up copy, and forwards original data to designated operations and planning authorities, in a secure manner,
- Documents the Chain of Custody for information gathered from the aircraft.

Ideally, there are multiple UAS Technical Specialists to perform the numerous duties required in the command post and in the field. The UAS Technical Specialist in the field can also perform other roles such as flight engineer.
5.2.4 Wildlife Observers

Wildlife observers are dedicated to observing animals and habitat that has been or could be impacted by an oil spill. Wildlife observers are responsible for recording by location animal species sighted, numbers of animals, heading of animals, proximity of animals to oil (bearing and distance), behavior, and precise location of oiled animals or oiled habitat. It is recommended to have dedicated wildlife observers accompany UAS pilot/observer teams to report any animal sightings and to the Wildlife Branch of the IMT in real time.
5.3 UAS Notification and Authorization Protocol During Oil Spill Responses and Exercises

During NCP/NRS authorized response actions or other emergency response, UAS resources may be requested at any time. The UAS Team will require support for UAS operations, data collection and information processing that is best provided by an established IMT. As the incident duration, number of UASs, and complexity of the response increases, the IMT support should increase concurrently. Table 5.1 outlines the step-by-step procedures for activating UAS support.

Table 5.1. UAS Team Activation and FAA Requirements for UAS Flights (AWA ACP 3410.3 UAS Operations)

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<tr>
<td>1.</td>
<td>The Air Operations Branch Director activates the UAS Technical Specialist. If the NRS response action does not immediately have an Air Ops Branch Director, the UAS Technical Specialist shall report to the Operations Section Chief or other authorized response personnel as determined by the federal and/or state on-scene coordinator.</td>
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<tr>
<td>2.</td>
<td>The UAS Technical Specialist requests and contacts UAS pilot(observer) teams for mobilization.</td>
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<tr>
<td>3.</td>
<td>The Air Operations Branch Director or other authorized incident response personnel for the Responsible Party or the federal and/or state on-scene coordinator requests a temporary flight restriction (TFR), inclusive of proposed UAS activity, over the area of operations from the Federal Aviation Administration (FAA) Anchorage Center Watch Supervisor (907-269-1103) (AWA ACP 3410.2 Flight Restrictions)1.</td>
</tr>
<tr>
<td>4.</td>
<td>UAS Technical Specialist applies for Special Governmental Interest (SGI) amendment process (formally known as Emergency-Certificate of Authorization or E-COAs) via the Emergency Operation Request Form2, if standing COAs or Part 107 waivers for the area of operations are determined insufficient to support response or exercise.</td>
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<tr>
<td></td>
<td>a. The SGI can be requested by either a 107 operator or a public entity with a COA.</td>
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<td></td>
<td>b. The UAS Technical Specialist submits E-COA application via email to the FAA System Operations Support Center at <a href="mailto:9-ator-hq-sosc@faa.gov">9-ator-hq-sosc@faa.gov</a></td>
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<td></td>
<td>• If approved, the FAA will add an amendment to the pilot’s existing COA or Remote Pilot Certificate authorizing flights under the certain conditions specified in the waiver application.</td>
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<td></td>
<td>• If denied, operators can only fly within the provisions of their existing COAs or Part 107 waivers.</td>
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For exercises, UAS technical specialist submits a Notice to Airmen (NOTAM) for UAS flight operations for the defined exercise area.
Table 5.1 cont’d.

5. Air Operations Branch Director and UAS Technical add response specific UAS information to ICS-220 form (UAS N#s, UAS operational frequencies, UAS communication frequencies, UAS type, UAS model, COA/waivers in use).

6. All UAS flights must be conducted by certified UAS pilot/observer teams as defined by 14 CFR Part 107 or 49 US Code 40102(a) and 40125 COAs in coordination with the Air Operations Branch Director and/or the UAS Technical Specialist.

7. UAS Pilots can operate a maximum of 8 consecutive hours and a maximum of 14 hours per day under specific direction and permission from the Air Operations Branch Director and the UAS Technical Specialist (Augmented Operations as per 14 CFR Part 117). Each UAS pilot will have one alternate to allow sufficient breaks during response operations.

1 Establishment of a TFR allows for direct management of UAS in the airspace by the manager of the TFR, usually to Air Operations Branch Director. UAS flights performed within a TFR may preclude the need for an E-COA, if the TFR covers all UAS launch areas as well as potential UAS flight locations.

2 Emergency Request Form can be accessed via, https://www.faa.gov/uas/advanced_operations/emergency_situations/

5.4 UAS Operational Flight Guidelines for Oil Spill Response (Operations Checklist)

These flight guidelines are designed to meet FAA requirements and wildlife agency recommendations for UAS flights in most locations along Alaska’s coast and waters, and to provide operational guidelines for UAS flight planning. The OPERATIONS CHECKLIST is designed to reduce potential disturbance and harm to wildlife during UAS flights as part of an oil spill response or exercise and shall be followed unless alternative, incident-specific, wildlife impact mitigations are defined. UAS flight operations performed in support of an authorized NRS action or other emergency response should be coordinated with input from wildlife agencies, and additional protection measures may be developed as the response continues, for example from an Endangered Species Act emergency section 7 consultation. Permits
may be required to take off and land a UAS on State Special Areas (Critical Habitat Areas, Refuges, Sanctuaries, or Ranges), or other public lands. These permits can be efficiently obtained from state or federal agencies during a spill response, but should be obtained in advance of exercises. Additional wildlife agency recommendations for the use of UAS near wildlife during spills and exercises can be found in Table 5.2.

5.4.1 Operations Checklist

— [PRE FLIGHT] Start new Flight Log for specific flight, including UAS team and response specific roles of members,
— [PRE FLIGHT] Establish a UAS ground-station for flight operations (land owner consultation/permitting may be required),
— [PRE FLIGHT] Establish real time flight monitoring station,
  o Real time video display via the UAS flight controller, laptop streaming of flight data, or external monitor, as available
  o Wildlife observers should be co-located with pilots at UAS ground station to monitor the live UAS video feed and scan surroundings for the presence of wildlife
— [PRE FLIGHT] Perform pre-flight safety and security checks of aircraft; inform UAS technical specialists and observers of any potential safety concerns,
— [PRE FLIGHT] Perform pre-flight safety and security checks of on-board data gathering and streaming equipment; inform pilots and observers of any potential safety concerns,
— [PRE FLIGHT] Ensure data recording and streaming equipment is operational,
— [PRE FLIGHT] Provide operational safety briefing,

— [IN FLIGHT] Conduct all UAS flights following the express regulations of 14 CFR Part 107 or 49 US Code 40102(a) and 40125 COA (see UAS Team Roles and Responsibilities for UAS Pilots above).
— [IN FLIGHT] Conduct UAS operations between 150 and 400 feet above the coastline/water, or as agreed upon in coordination with wildlife agencies, to reduce wildlife disturbance.
  • Do not use raptor shaped UAS if the potential for bird encounters exists
  • Approach flocks of birds from high altitudes, and reduce altitude from directly above
  • Do not conduct flights lower than 150 feet over birds
  • Do not fly within 300 feet of bald eagle nests
  • Avoid flights near perched or flying eagles
— [IN FLIGHT] UAS will avoid buzzing, hovering, landing, taking off, taxiing, excessive speed or sudden changes in speed or direction near wildlife on land or in the water.
— [IN FLIGHT] When an animal sighting is made, species, group size, age categories (if determinable), heading (if consistent), and bearing and distance from the spill will be recorded by wildlife observers, the Wildlife Observation Form found in the WPG.
   o If no wildlife observers are co-located with UAS pilots/observers, the UAS pilots will contact the wildlife observers or wildlife branch of IMT via radio or phone when impacted shoreline or animals are sighted once they are safely able to do so.

— [POST FLIGHT] Complete Flight Log for specific flight.
— [POST FLIGHT] Perform post-flight safety and security checks of aircraft; inform UAS technical specialists and observers of any potential safety concerns,
— [POST FLIGHT] Perform post-flight safety and security checks of on-board data gathering and streaming equipment; inform pilots and observers of any potential safety concerns,
— [POST FLIGHT] Check data recorded, create back-up copy, and forward original data to the Situation Unit for integration into the common operating picture, and any other designated recipients, as required by the incident data management and sharing plan.
— [POST FLIGHT] Report wildlife sightings to wildlife agencies or incident-specific designated IMT positions.
5.5 Daily Archiving and Reporting Requirements

Data collected from the UAS flights will be archived by the UAS Team each day according to data archiving and sharing protocols established by the IMT, if established or otherwise requested/mandated by the Federal and/or State On-Scene Coordinator. Minimum archival will include preserving all summary reports (requirements below), manually recorded UAS Flight Logs (scanned as PDF or JPG), digitally recorded flight logs (T-logs and .DAT files), raw data files and data products on two discrete hard drives, to be stored with the UAS Technical Specialist and the IMT Documentation Unit respectively.

Summary information required specific to the UAS flights:

1. Date;
2. Name of incident;
3. Crew members (UAS pilot and affiliation, UAS observer and affiliation, UAS Technical Specialist and affiliation, wildlife observer and affiliation);
4. Description of UAS platform (multi-rotor, fixed wing, vertical take-off and landing);
5. Size and mass of the UAS platform;
6. Description of the payload;
7. Battery life of the UAS/average mission length;
8. Description of the ground control station (geographic location and land ownership status);
9. Flight description (latitude/longitude of flight area, # of flights at location);
10. Mission objectives (oil extent mapping, wildlife identification, air quality, etc.);
11. Type of survey or sampling method (line/strip transects, sunburst patterns, etc.);
12. Total time flown;
13. Total distances flown;
14. Sea state, and other factors affecting visibility and detectability of targets (i.e., fog/glare);
15. Minimum (less take-off and landing) and maximum altitude of flights;
16. Data products created;
17. Data chain of custody;
18. Environmental variables;
20. Completed Wildlife Observation Forms should be submitted to wildlife agencies or incident-specific designated IMT positions (e.g., Wildlife Branch Director).

Review the WPG for procedures and data needed. Specific to UASs, include:

- Sightings relative to ground station location;
- Number of passes per group/animal per day;
- Time spent over each group/animal per day.

5.6 Wildlife Considerations for Responses versus Exercises

Wildlife are protected from harm and harassment under a variety of laws (e.g., Endangered Species Act, Marine Mammal Protection Act, Bald and Golden Eagle Protection Act). The recommendations provided in this protocol by National Oceanic and Atmospheric Administration (NOAA), NOAA Fisheries (NMFS), U.S. Fish and Wildlife Service (USFWS), and the State of Alaska Department of Fish and Game (ADFG) (collectively referred to as “wildlife agencies” in this document) are intended to reduce the likelihood that wildlife will be harmed or harassed by UASs during spills and drills. During a spill response, wildlife agencies should be contacted as soon as possible to coordinate response activities in a way that reduces impact to wildlife. To ensure compliance with wildlife laws during exercises, contact wildlife agencies as soon as the exercise has been planned. Please see the Wildlife Protection Guidelines for Oil Spill Response in Alaska (WPG) for wildlife agency contacts, wildlife observation forms, and other information.
<table>
<thead>
<tr>
<th>Species Group</th>
<th>Exercises</th>
<th>Spills</th>
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<tbody>
<tr>
<td><strong>Birds</strong></td>
<td>Do not conduct flights at an altitude less than 150 feet over birds; do not use predator (raptor)-shaped UASs when flying near birds; do not fly within 300 feet of bald eagle nests; ground or move aircraft away if perched or flying eagles are encountered.</td>
<td>Same as exercises.</td>
</tr>
<tr>
<td><strong>Seals</strong></td>
<td>Maintain 1,000-foot distance from these animals. If a UAS is flown inadvertently within 1,000 feet of a seal, sea lion, porpoise, or whale, or if these animals change behavior in response to a UAS, move the aircraft away, <em>cease operations</em>, and report these events to NMFS.</td>
<td>Coordinate with NMFS to understand incident-specific protection measures regarding UAS use.</td>
</tr>
<tr>
<td><strong>Walrus</strong></td>
<td>Do not fly within 0.5 mile (direction or altitude) of hauled-out walrus or known walrus haulout locations. Maintain 2,000-foot distance from individual animals or small groups on ice. Regardless of distance or group size, if walrus change behavior in response to a UAS, move the aircraft away, <em>cease operations</em>, and report these events to USFWS.</td>
<td>Coordinate with USFWS to understand incident-specific protection measures regarding UAS use. Do not fly within 0.5 mile (direction or altitude) of hauled-out walruses or known walrus haul-out locations. Maintain 2,000-foot distance from individual animals or small groups on ice. Regardless of distance or group size, if walrus change behavior in response to a UAS, move the aircraft away and report these events to USFWS.</td>
</tr>
<tr>
<td><strong>Polar bears</strong></td>
<td>Maintain 1,500-foot distance. Greater distances from active polar bear dens may be required – coordinate with USFWS during exercise planning. If polar bears or sea otters change behavior in response to a UAS, move the aircraft away, <em>cease operations</em>, and report these events to USFWS.</td>
<td>Coordinate with USFWS to understand incident-specific protection measures regarding UAS use. Maintain 1,500-foot distance; greater distances from active polar bear dens may be required. If polar bears or sea otters change behavior in response to a UAS, move the aircraft away and report these events to USFWS.</td>
</tr>
<tr>
<td><strong>Sea otters</strong></td>
<td>Same as exercises.</td>
<td></td>
</tr>
<tr>
<td><strong>Terrestrial mammals</strong></td>
<td>If animals change behavior in response to a UAS, move the aircraft away and report these events to ADF&amp;G.</td>
<td>Same as exercises.</td>
</tr>
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</table>
This protocol was developed by Jessica Garron of the University of Alaska Fairbanks with input from the United States Coast Guard (USCG), Department of the Interior Office of Environmental Policy Compliance, National Oceanic and Atmospheric Administration (NOAA), NOAA Fisheries (NMFS), U.S. Fish and Wildlife Service (USFWS), and the State of Alaska Department of Fish and Game (ADFG).

5.7 Literature Cited


Chapter 6: General Conclusion

6.1 Overview

This dissertation focused on how remote-sensing (RS) tools can be capitalized on to better respond to Arctic oil spills. This research synthesized currently available RS tools for performing oil detection which were juxtaposed with those currently used in decision-making during an oil spill response. The barriers to additional use of RS tools were characterized, ways to overcome them identified and employed to complete this research. This work has transformed the way the oil spill response community of Alaska responds to oil spills through policy changes in support of real time data collection using unmanned aircraft systems (UAS).

6.2 Research summary

6.2.1 Research approach summary

I used a four-phased, exploratory sequential mixed methodological study, to examine current RS capacity and solutions to expand RS use in support of oil spill response. Phase One defined the RS tools available to support oil spill response, how those tools are being used in support of oil spill response actions, and to inform the following phases of the study. Research completed during Phase Two removed a set of data-driven barriers to RS use discovered during phase one (delivery, format, and cost), by establishing an automated oil detection pipeline using cloud-based processing resources. Phase Three addressed human-driven barriers to RS tool use by exercising the three determined components of RS tool acceptance from phase one, training, knowledge coproduction, and data integration. Synthesizing all components of phases one, two and three, a RS protocol for the use of UAS in support of oil spill response was developed and integrated into USCG operational policy in Alaska to complete Phase Four of this research.

To provide context to the study, a thorough examination of RS tools available to support oil spill response decision-making was synthesized to provide the framework for
the qualitative analysis of current uses of RS data in an oil spill response. Knowledge gained about current RS use and barriers to that use was used to develop two, methodologically distinct (one quantitative and one qualitative/quantitative), solutions for integrating additional RS tools into the oil spill response framework. Finally, the development and application of the protocol for UAS use during oil spill response with and for the Alaskan oil spill response community functionally administers this research to our partner population.

6.2.2 Research outcome summary

The RS tools capable of the timely detection of marine oil spills in non-Arctic and Arctic conditions were investigated in Chapter 2 to frame the primary research questions about the actual use of RS tools and any barriers to their use in oil spill response. Open-ended interviews of 25 members of oil spill response science support and decision-making teams were conducted to candidly ascertain RS data perceptions and use. Interview content analysis revealed that RS tools are being use in support of large oil spill response efforts to support different phases of the response, but that barriers to additional use existed. The data-driven barriers of Availability, Data Integration and Interpretation, were fundamentally tied through interview responses to the human-driven barriers of data Credibility, Saliency and Legitimacy. The analysis was used to identify the recommendations to enhance the operational use of RS geospatial data for emergency response decision-making. This chapter was also used to design the researched solutions to remove data-driven (Chapter 3) and human-driven (Chapter 4 and 5) barriers to RS use during oil spill response.

In Chapter 3, cloud-based computing was leveraged to speed operational delivery of large SAR data sets to research scientists and decision makers for anomaly detection and subsequent emergency response through a prototypical processing pipeline. The pipeline prototype was built via an on-demand suite of scalable, cloud computing services, without investment in on-site hardware and data support infrastructure. An automated adaptation thresholding oil spill detection algorithm, modified from Solberg et al., 2004, designed for use with SAR backscattered amplitude
data, was incorporated into the automated processing stream via Python rendering of the Sentinel-1 Toolbox scripts from the European Space Agency. The pipeline output was an anomaly detection image, formatted as a GeoTIFF for ease of common operational picture (COP) integration.

Using AWS cloud-computing resources allowed for quick development and iteration on the pipeline prototype. The oil spill detection pipeline as prototyped was determined to be efficient, easy to use for the end user, and cost effective for processing and short-term archiving of SAR data products. This work highlighted the need for further analysis of accurate oil detection algorithms for use with SAR imagery that can be ported to the cloud, and demonstrated the ability to apply oil detection algorithms to SAR data in a cloud-based environment to create oil spill footprints for integration into an operational data delivery system of a marine oil spill response.

To understand how to integrate UAS into the incident command structure (ICS) of oil spill responses and exercises, I was embedded in the incident command post (ICP) of five Alaskan oil spill response exercises as a UAS Technical Specialist, UAS subject matter expert, and Participant Observer to develop Chapter 4. Observations were conducted during the exercises to determine current RS and UAS use during oil spill response activities in Alaska. A set of pre- and post-exercise surveys were designed and delivered to participants in four oil spill exercises to evaluate the attitudes oil spill responders and their perceived familiarity of UAS applications in support of an oil spill response.

This study showed that real time optical data (R, G, B) collected from a UAS and streamed into a command post or Forward Operating Base is ideal for supporting operational decision-making during an oil spill response. As such, the advantages of intuitive visible sensors should not be overlooked when considering other RS packages capable of more detailed analysis of the environment. Understanding UAS data-collection and delivery capacity supports realistic expectations of UAS pilots to systematically collect quality data that is wanted and can be used for change detection and other analyses in support of a response. Rogue UAS operations, intrinsically safe UAS, citizen-created and publicly-available UAS-collected data sets over sensitive
targets, all need to be understood and addressed in the immediate future, and prior to the next significant oil spill response. As a result, a set of recommendations for UAS integration into an ICP and a UAS operational protocol was developed for the use of small (less than 55 pounds) UAS to legally, safely and logically support oil discharges or hazardous substance release responses and exercises in Alaska were created and reported on in Chapter 4.

The UAS protocol developed for the use of small UAS (less than 55 pounds) in support of oil discharges, or hazardous substance release, responses and exercises in Alaska (Chapter 5), was designed to fit within the context of the ICS of oil spill response activities in the U.S. as practiced by the USCG. The protocol is for use during oil spill response actions authorized by the National Response System as defined under 40 CFR Part 300, the National Contingency Plan, and has been integrated into the USCG and State of Alaska, Arctic and Western Alaska Area Contingency Plan, a primary guidance document for oil spill response activities in Alaska.

6.3 Research outcome discussion

This dissertation is focused on how RS tools can be capitalized on to better respond to Arctic oil spills. The relative nature of the research inquiry required the synthesis of static and active themes central to the use and potential use of RS tools in the marine oil spill response setting. The following questions were used to frame this focus into queryable components and identifiable solutions,

1. What RS tools are currently available, as compared to those currently used in ICS of an oil spill response?
2. Are there barriers to additional RS tool use for oil spill response support?
3. What process improvements can be undertaken to increase RS data use in oil spill detection and response?

Addressing these questions revealed that there is an immediate need to advance the understanding of existing RS technologies and resulting data for detecting oil
released in the Arctic. Present oil detection methods range from satellite-based monitoring, to direct human observation, with a rapidly evolving functional middle-ground of RS technologies. Real time data availability for immediate understanding and action, streamed into a command post or Forward Operating Base can be ideal for supporting operational decision-making during an oil spill response. Some sensors will provide raw data which is interpretable in real time, whereas other sensors will be providing functional data only after significant, necessary and time-consuming data processing, potentially lasting weeks. Ease of data interpretation and dissemination are vital components to the usability of any data set in an operational setting. Required post-processing and/or expert interpretation of the data will determine whether a given sensor is suited to be used by oil spill first responders, mid-spill monitoring teams, or not at all.

The potential for RS information to be useful in the support of decision-making during an oil spill response is often lauded, yet many relevant RS tools and data are not fully assimilated into a response. This research highlighted the fundamental barriers that exist to this RS data use during oil spill response, and that there are ways to effectively overcome them. Knowledge coproduction across disciplines can support the creation and use of valuable data products. Creating an environment where end users can work with scientists to define requirements, and that engage to provide feedback throughout data product iteration cycles, will improve the product, and increase the legitimacy of the technology and team.

Integration of RS data into planning and active spill responses requires some familiarity with RS information and the tools with which to effectively use the information during a spill. Information formats that are easily consumed by non-experts could expand the use of this rich information, as would decision makers' greater understanding of what is available to support resource allocation in a spill response. Coproducing RS products or protocols and working to integrate them into the ICP are two of the angles composing the Acceptance triangle. Training and educating potential users about these data and how they are useful for decision-making is the third angle, and is vital to their operational applications. The new tools that are successful during a response are those we have practiced with during drills.
6.4 Future research

Acceptance of RS data products to support oil spill response is an interwoven outcome of RS data availability, integration, interpretation, nested in positive perceptions of credibility, saliency, and legitimacy. The interviews conducted as part of this research revealed there are three key components to RS data acceptance that will increase the use of RS data products for oil spill response on an iterative timescale.

Figure 6.1 – The Acceptance triangle for RS integration into oil spill response.

Cross-discipline partnerships are pivotal to integrating existing or creating new RS data products that are directly applicable to oil spill response. When stakeholders are engaged at the earliest of stages in design, and throughout the process, they will be able to contribute critical insight as to their actual scientific needs, as well as be able to provide localized expert information to more effectively define the problem to be solved (Alessa et al., 2016; Von Lubitz et al., 2008). Scientists working with responders to define oil detection research problems, to iterate on solutions using RS data, and to test those solutions between spills, will increase legitimacy and saliency of RS products
together. Stakeholders and scientists need to be able to iterate on their ideas together (Dilling & Lemos, 2011; Lemos et al., 2012), and it is known that this is most effectively accomplished in face-to-face interactions (Kalluri et al., 2003). By establishing clear, jargon-free, truthful communication pathways (Machlis & Ludwig, 2014), buy-in for the integration of new RS products can be achieved within 3-5 years (Kalluri et al., 2003). Establishing formalized communication pathways between scientists, responders and decision makers prior to a disaster response will support the integration of new science, and provide the opportunities to define science products that are specifically needed by the decision-maker or spill responder (Alessa et al., 2016; Leifer et al., 2015; Lemos et al., 2012; Machlis & Ludwig, 2014; Osofsky, 2013). Key to the iterative success of coproduction is the funding of time to effectively develop and maintain the vital relationships and communication pathways beyond the lifespan of an individual project need to be in place to ensure successful RS integration into the decision-making of an oil spill response (Von Lubitz et al., 2008).

The benefits of cross-discipline partnerships for developing better oil spill response strategies cannot be overestimated. Working with oil spill responders to identify the science, RS and otherwise, that will help them do their jobs better, using the tenants of knowledge coproduction to develop those supporting science tools, will increase the likelihood of successful science integration.

For a holistic response strategy development, stakeholder engagement and training when new tools become available to support a response is critical for the long-term viability of new sensors and data products. The application of known successful methods for stakeholder engagement, inclusive of training opportunities with RS information, is not well documented beyond this study for the marine oil spill response community. Additional research about the most effective methods of coproduction with the broader U.S. oil spill response community would be valuable.

Further analysis of oil detection algorithms for use with SAR imagery is necessary before an automated oil detection pipeline can be recommended for operational use for marine oil spill detection. Confounding natural variables like ice will need to be acknowledged and solutions to their influence identified before automated
detection of oil can be fully realized in the Arctic. The pairing of an accurate oil spill detection algorithm and the prototypical processing pipeline could be the defining demonstration needed for operational use cases to move from under the desk to up in the cloud.

Rogue operations, intrinsically safe UAS, citizen-created and publicly-available UAS-collected data sets over sensitive targets, all need to be understood and addressed in the immediate future, and prior to the next significant oil spill response. As detailed challenges about UAS integration into airspace and operations of many sorts are identified and resolved daily, the oil spill response community has an opportunity and a responsibility to take advantage of this rapidly evolving tool to support quality oil spill response decisions.

The UAS protocol that was developed as part of this research for use during oil spill responses and exercises, has been well received and is currently used by multiple agencies for oil spill response support. Adapting the protocol fundamentals to a broader emergency response audience in Alaska will leverage these RS tools, while simultaneously advancing the capacity of Alaskans to respond to emergency scenarios in real time.

6.5 Literature Cited


Appendices
Appendix A Table 2.1 References


Appendix B IRB Research Exemption Letter

April 1, 2016

To: Sarah Trainor
   Principal Investigator

From: University of Alaska Fairbanks IRB

Re: [870803-1] Integration of Remote Sensing Tools in Oil Spill Response

Thank you for submitting the New Project referenced below. The submission was handled by Exempt Review. The Office of Research Integrity has determined that the proposed research qualifies for exemption from the requirements of 45 CFR 46. This exemption does not waive the researchers' responsibility to adhere to basic ethical principles for the responsible conduct of research and discipline specific professional standards.

Title: Integration of Remote Sensing Tools in Oil Spill Response
Received: March 28, 2016
Exemption Category: 2
Effective Date: April 1, 2016

This action is included on the May 4, 2016 IRB Agenda.

Prior to making substantive changes to the scope of research, research tools, or personnel involved on the project, please contact the Office of Research Integrity to determine whether or not additional review is required. Additional review is not required for small editorial changes to improve the clarity or readability of the research tools or other documents.
Appendix C IRB Research Exemption Letter for Revised Protocol

March 8, 2017

To: Sarah Trainor
Principal Investigator

From: University of Alaska Fairbanks IRB

Re: [870803-2] Integration of Remote Sensing Tools in Oil Spill Response

Thank you for submitting the Revision referenced below. The submission was handled by Exempt Review. The Office of Research Integrity has determined that the proposed research qualifies for exemption from the requirements of 45 CFR 46. This exemption does not waive the researchers’ responsibility to adhere to basic ethical principles for the responsible conduct of research and discipline specific professional standards.

Title: Integration of Remote Sensing Tools in Oil Spill Response
Received: March 8, 2017
Exemption Category: 2
Effective Date: March 8, 2017

This action is included on the April 5, 2017 IRB Agenda.

Prior to making substantive changes to the scope of research, research tools, or personnel involved on the project, please contact the Office of Research Integrity to determine whether or not additional review is required. Additional review is not required for small editorial changes to improve the clarity or readability of the research tools or other documents.
Appendix D Interview Purpose, Consent and Questions

Integration of Remote Sensing Tools in Oil Spill Response
(Qualitatively determined usage of remotely sensed data in an oil spill response)

February 2017, version 7

The purpose of conducting these interviews is to determine the use of remote-sensing (RS) tools and imagery, including synthetic aperture radar (SAR) and unmanned aerial systems (UAS), in the Unified Command/Incident Command Structure of oil spill preparedness, prevention, response and mitigation. These interviews will also be used to determine the interest in the oil spill preparedness, prevention, response and mitigation community for an oil spill detection tool based upon SAR, and the formalized use of UAS for situational awareness during an oil spill response.

The overarching research questions to be addressed with these interviews are centered on how to effectively integrate remotely sensed information into Arctic marine oil spill detection, response and mitigation. Some of the more specific research questions include, how are remote sensing tools used in Incident Command Structure (ICS) now? What tools and process improvements would increase remote sensing data use in oil spill detection and response? Would the introduction of an oil spill detection algorithm using SAR be a useful tool in oil spill detection and response in Arctic waters? Would situational awareness be enhanced by using small-scale UAS?

Interviewees will fall into three general categories, decision makers in the ICS/UCS structure, oil spill responders (regardless of provenance, could include members of OSROs, USCG, and federal or state agencies) and oil spill researchers. The interviewees represent end users, operators responding to decisions made with RS data and the scientists that are trying to support oil spill detection and response using RS data.

Interviews will be conducted in-person and over the phone. Interviews will be recorded and transcribed manually, after which each interview will be manually edited. Content will be coded using Atlas.ti qualitative data analysis software tool.
The results of these interviews will identify current usage of RS data in oil spill planning, response and mitigation, and will inform recommendations for more effective RS data integration. Additional funding will be sought to directly share results and recommendations with engaged participants of the study, with virtual workshop delivery from Decision Theater North as an additional option. At the conclusion of data analysis, interviewees will be invited to participate in a two-day workshop (virtual option available) (fall 2017) where a discussion of the study and the recommendations will be presented. A second day will be dedicated to demonstrating freely available RS data and how to access it.
DEFINITIONS:

*Remote-sensing* (RS) - the acquisition of information about an object or phenomenon without making physical contact with the object and thus in contrast to on-site observation.

*Remotely-sensed data* – data that has been collected using a RS technique. Includes satellite, airborne and UAS (airborne or aquatic) collected data regardless of sensor

*Remote-sensing tools* – the sensors and platforms used to acquire, process, or manipulate remotely sensed data.

*Remotely-sensed imagery* – Images compiled from remotely-sensed data. Can be optical, acoustic or other spectral data.

*Synthetic Aperture Radar (SAR)* - SAR is a satellite or airplane based remote detection sensor that has the ability to image the earth through clouds, smoke, precipitation and night (Woodhouse, 2006). SAR is a coherent signal radar system which utilizes the flight path of the platform to simulate an extremely large antenna or aperture electronically, and that generates high-resolution remote sensing imagery. The SAR-processor stores all the radar returned signals, as amplitudes and phases, for a given time period. The stored data is recombined to create a high resolution image of the terrain being over flown (http://www.radartutorial.eu/20.airborne/ab07.en.html).

*Insert resulting information on to an ICS organizational chart/informational flow chart; how does the data flow pre, during and after a response?*

**Consent statement** (to be provided to interviewees and read by or to each interviewee prior to interview start)

Thank you for agreeing to be interviewed as part of my research. The interview itself can take up to an hour, as the questions are designed to clarify different aspects of using remotely-sensed data. I will be interviewing a number of people as part of this research, all of whom must be 18 years of age or older; please let me know if you are not at least 18 years old. This interview and any follow-on discussions are completely voluntary on your part. If you have any concerns about either the content or your participation in the interview, please feel free to contact myself or the UAF Institutional Review Board (IRB); our contact information is below. Your time is precious, and I appreciate the time you are providing to me through your participation in this interview. Thank you
<table>
<thead>
<tr>
<th>Sarah Trainor (PI)</th>
<th>Jessica Garron (Researcher)</th>
<th>Research Integrity Administrator</th>
</tr>
</thead>
<tbody>
<tr>
<td>PO Box 757245</td>
<td>903 Koyukuk Dr</td>
<td>212 West Ridge Research Building</td>
</tr>
<tr>
<td>Fairbanks, AK 99775</td>
<td>Fairbanks, Ak 99775</td>
<td>Fairbanks, Ak 99775</td>
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<tr>
<td>907-474-7878</td>
<td>907-474-7598</td>
<td>1-866-876-7800 or 907-474-7800</td>
</tr>
<tr>
<td><a href="mailto:sarah.trainor@alaska.edu">sarah.trainor@alaska.edu</a></td>
<td><a href="mailto:jigarron@alaska.edu">jigarron@alaska.edu</a></td>
<td><a href="mailto:uaf-irb@alaska.edu">uaf-irb@alaska.edu</a></td>
</tr>
</tbody>
</table>

IRB exemption form is attached.
Integration of Remote Sensing Tools in Oil Spill Response
* Indicates primary question of section

All Participants Line of Questioning

*Have you worked on a marine oil spill response?

*What is your typical role in the spill responses you have already worked on?

*Did you work on DWHOS?
   
   What was your roll on DWHOS?

*Have you worked on oil spills in Arctic waters?

   What was your roll(s) in the Arctic oil spills?

Line of Questioning 1 – Identifying general remote-sensing usage in an oil spill response

*Have you ever used remote-sensing imagery or tools during an oil spill response?
   
   Yes, see below

No, skip to Line of Questioning 5

1a. Do you know what kind of remote-sensing images or tools did you use? What were they?

1c. How would you characterize your use of RS data during a response?

   a) As a first indicator of oil, or the primary oil location
   b) Provided useful background information/supporting data, but not decision critical
   c) Determine where and what resources were staged nearby
   d) Was used to verify or support a decision that was made based on other information
   e) Was key or critical information for the decision outcome

1d. Where did you get your RS data or tools from?

1e. What about using these images or tools would you consider a success?

1f. What about using these images or tools did not work?
1g. What would make using these images or tools easier?

1h. Do you know what remote-sensing data is freely available that may be relevant to your work?

1l. What would make your remote-sensing data delivery experience better? (cost, access interface, format, data size, latency, familiarity, ease of manipulation)

1r. Would you use remote-sensing images or tools again?
   *Why or why not?

**Data Provider Subset**

DP-1j. In what format did you receive your data?

DP-1k. In what format would you prefer to receive the data?

DP-1n. Did/do you need to perform additional processing of the imagery or data to use it?

DP-1o. What software did/do you use to manipulate your remote-sensing data?

DP-1d. Who did/do you give RS imagery or information to?

DP-1q. Where do you look for remotely-sensed images and data?

*Move on to Line of Questioning 2 and 3*

**Line of Questioning 2** – Identifying SAR usage in an oil spill response

*Have you ever used synthetic aperture radar (SAR) imagery? Why/why not?*

   **Yes, see below**

   **No, skip to Line of Questioning 3**

2a. Did you use SAR in a response?

2c. How would you best characterize your use of SAR data during a response?

   a) As a first indicator of oil, or the primary oil location
   b) Provided useful background information/supporting data, but not decision critical
   c) Determine where and what resources were staged nearby
d) Was used to verify or support a decision that was made based on other information

e) Was key or critical information for the decision outcome

2d. Did you need to additionally manipulate or process the data to make it relevant for your needs?

2e. What about using SAR would you consider a success?

2f. What about SAR did not work?

2g. What would make using SAR easier? (format, access, interface, size, latency, familiarity)

2h. Would you find value in an oil spill detection tool based on SAR? Why or why not?

2i. Would you use SAR again?

*Why/why not?

Move on to Line of Questioning 3

Line of Questioning 3 – Identifying UAS usage in an oil spill response

3a. Have you observed a UAS being flown during planning or an oil spill response?

3b. What information was collected?

3c. How was that information shared?

3d. Was the UAS collected information used to make a decision?

What decisions were made using the UAS data?

3e. What would make UAS information credible enough for integration into the decision-making process of a drill or response (being in a COP, knowing the pilot, timing of information delivery)?

3f. Would you like to learn more about integrating UAS into spill planning and response?

3g. How would you like to learn more about UAS integration into spill planning and response (workshop, 1-to-1, classroom, distance delivery class, self-driven tutorials)?

Interview complete for LOQ 1, 2 & 3 interviewees
**Line of Questioning 4** – For remote-sensing data users, potential SAR and UAS users

4a. Would you be interested in learning more about SAR, UAS and other remote-sensing data and tools and how could be used in a response setting?

4b. Are there specific remote-sensing tools would you be interested in learning more about?

4c. How would you want to learn how to use these images and tools (workshop, 1-to-1, classroom, distance delivery class, self-driven tutorials)?

*Interview complete for LOQ 1 & 4 interviewees*

**Line of Questioning 5** – For non-remote-sensing data users

Have you observed others using RS information to make decisions during an oil spill?

5a. Have you observed a UAS being flown during planning or responding to an oil spill?

   5a1. What information was collected?

   5a2. How was that information shared?

   5a3. Was the UAS collected information used to make a decision?

      What decisions were made using the UAS data?

5b. Do you see remote-sensing imagery and/or tools, including UAS, as potentially useful in your job?

      If yes, how could RS imagery or tools be useful in your job?

5c. Do you know where to look for remotely-sensed images and data?

5d. Do you know what remote-sensing data is freely available that may be relevant to your work?

5e. Are there other barriers to you using RS data in your job?

5f. What would make UAS information credible enough for you to use to integrate into the decision-making process of a drill or response (being in a COP, knowing the pilot, timing of information delivery)?
5g. Would you try using remote-sensing imagery and/or tools, including UAS, if you were trained how to use them? (software, data interpretation)

5h. Are there specific remote-sensing tools would you be interested in learning more about?

5i. How would you want to learn how to use these images and tools (workshop, 1-to-1, classroom, distance delivery class, self-driven tutorials)?

*Interview complete for LOQ 1 & 5 interviewees*
## Appendix E Interview Codebook

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<th>Name</th>
<th>Description</th>
<th>Files</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Availability (Barriers to use &amp; Boons to use)</td>
<td>SD: Availability; 1’ DD: R-S data/ tools used or not used due to availability; did/ didn’t have data for (time) critical d-m IC: Reasons knowledge from data/tool not avail for d-m EC: Didn’t know data/tool existed to look for it TE: Cost, latency, data/tool ownership, knowing where to look for the data; 1’’ AE: (Knowing/not-knowing how to use the data) CBN: You don’t know what you don’t know</td>
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<td>Bandwidth limitations</td>
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<td>Clearance (security, industry held, data sharing)</td>
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<tr>
<td>Cost</td>
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<tr>
<td>Coverage (no data for area)</td>
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<tr>
<td>Knowing where to get the data</td>
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<td>Latency</td>
<td>Processing time; data delivery delays (R-T, NRT, etc)</td>
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<td>Name</td>
<td>Description</td>
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</tr>
<tr>
<td>No problems to availability</td>
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<td>16</td>
<td>36</td>
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<tr>
<td>Weather limitations</td>
<td>for optical imagery or platforms</td>
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<td>24</td>
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<tr>
<td>C,S,L (Barriers to use)</td>
<td>SD: C,S,L,A; 1’ DD: Credibility, saliency, legitimacy, acceptance; preconceived notions about data; unfamiliarity IC: preconceived notions about data (how collected, how processed, who involved; data availability; certainty of data; unfamiliarity with data (where its from, what it means, what else is out there); ownership of data; 1” EC: Don’t know what is out there to try TE: Technology is too new to be proven; flights paid for by RP and can’t be used; 2’ AE: Data not used b/c incident commander could</td>
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<td>Credibility</td>
<td>Is it true? Reliable data collection/interpretation used; scientific adequacy of technical evidence and arguments, including the person that collected the data (where data is coming from concerns) credibility is the</td>
<td>21</td>
<td>87</td>
</tr>
<tr>
<td>Name</td>
<td>Description</td>
<td>Files</td>
<td>References</td>
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<tr>
<td>Legitimacy</td>
<td>Is it fair/respectful? Trust between producer and data user; trust the information is unbiased and fair; legitimacy is established by fairness and a perceived lack of bias; Legitimacy reflects the perceptions that the production of information and technology has been respectful of stakeholders' divergent values and beliefs, unbiased in its conduct, and fair in its treatment of views and interest</td>
<td>15</td>
<td>46</td>
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<tr>
<td>Saliency</td>
<td>Is it relevant? matching of relevant information to incident; responsiveness to local conditions; is it &quot;Actionable Knowledge&quot;? some dependence on user's perception of need for the data; salience of scientific knowledge is determined by its relevance and/or utility to a stakeholder; Salience deals with the relevance of the assessment to</td>
<td>20</td>
<td>56</td>
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<td>Name</td>
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<td>Coproduction</td>
<td>the needs of decision makers. Cash Et Al 2003</td>
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<td>5</td>
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<td>Data Consumption</td>
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<td>DISCUSSION (Introduction perhaps)</td>
<td>Notes for integration into discussion portion of write-up</td>
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<td>206</td>
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<td>Events</td>
<td>SD: Events that R-S tools were used in DD: Emergency responses (oil spills, hurricanes, tsunamis), response drills; freshwater, saltwater, land-based IC: Events interviewees have taken part in that they describe during interviews EC: Collecting soil samples from an old spill TE: DWHOS, EVOS, Katrina; AE: Salvage effort CBN: Training</td>
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<td>Freshwater response</td>
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<td>Land-based response</td>
<td>Katrina</td>
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<td>Marine response</td>
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<tr>
<td>(Arctic) General</td>
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<td>DWHOS</td>
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<td>Refugio</td>
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<td>5</td>
<td>15</td>
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| How data is being used | SD: How data is being used  
DD: How is the data being used? What are d-m trying to understand by using R-S data?  
IC: Used the data to make some type of decision; data was critical for operations  
EC: Data/imagery collected but not used for d-m or background info; not integrated into response  
TE: Oil footprint; marine mammal location (for avoidance or hazing); shore-based resources at risk; trajectory modelling; 2' AE: Data was collected and available but may only have contributed indirectly to a decision | 0     | 0          |
| Air monitoring | Can be in situ monitors on a platform or from a mobile platform that can include mounted in situ samplers, but also spectrometers and the like; not filters collecting stuff  
(direct measurement) | 4     | 16         |
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<td>Anomaly detection</td>
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<td>Background info</td>
<td>Including weather and tides</td>
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<td>Communications support</td>
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<td>Damage assessment (liability &amp; prosecution)</td>
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<td>Footprint (synoptic view)</td>
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<td>Identification of oil AND Screening</td>
<td>…as compared to seaweed or ice types; includes &quot;monitoring&quot;; includes seeps when not being described under Interpretation</td>
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<td>Identifying subsurface oil</td>
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<td>Location (indicator of oil primary location)</td>
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<td>Includes monitoring for wildlife</td>
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<td>Situational Awareness</td>
<td>Includes initial assessment</td>
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<td>Includes vessel tracking</td>
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<td>Tactical decision-making</td>
<td>where to stage response, where to place boom, where to send responders</td>
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<td>Thickness (includes</td>
<td>actionable oil &amp; emulsions)</td>
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<td>Trajectory modelling</td>
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<td>Verify or support decision</td>
<td>or data cross referencing</td>
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<td>ICS Practices</td>
<td>SD: ICS practices DD: Discussion of ICS org-charts and protocols IC: Any ICS</td>
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<td>event (response or drill) EC: Everyday practices of USCG TE: Information</td>
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<td>exchange within or outside ICS (briefings); d-m by Ops AE: Town hall</td>
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<td>meeting about the event that goes off the rails CBN: Media frenzy around an</td>
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<tr>
<td></td>
<td>event</td>
<td></td>
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<td>Integration</td>
<td>SD: Integration; '1' DD: R-S integration mandates, attempts, fail-safes IC:</td>
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<td>Examples of R-S integration into a response with and without specific d-m as a</td>
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<td>Description</td>
<td>Files</td>
<td>References</td>
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<td></td>
<td>result; success/failure of RS data integration (pros/cons of integration); 1’ EC: Data available, but unused for d-m/response background TE: rely on aerial photography for thickness data; UAS SCAT flights available to command post in COP; 2’ AE: Aerial photos printed and on the wall CBN: Photos of response taken by responder</td>
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<tr>
<td>Data Consumers</td>
<td>Where data or data product goes after collection/processing/etc.; Does this include ARCHIVE</td>
<td>20</td>
<td>88</td>
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<td>Data Establishment</td>
<td>Accepted as one of the many tools to use in support of a response; people understand what it has to offer; RS data or RS tool of other sort</td>
<td>16</td>
<td>44</td>
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<tr>
<td>Data Format</td>
<td>SD: Format DD: What format the data arrived in; manipulation required for data use (analysis &amp; presentations) IC: Software programs techs used for manipulation; specific formats discussed good/bad EC: Command using specialized software preventing</td>
<td>21</td>
<td>172</td>
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<td>Description</td>
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<td>References</td>
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<tr>
<td>Mosaic</td>
<td>most format integration TE: GeoTIFF, JPEG, common MatLab formats, PPT, PDF AE: Could not access data because it was electronic (also falls under Availability)</td>
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<td>Preferred format</td>
<td></td>
<td>14</td>
<td>40</td>
</tr>
<tr>
<td>(GIS goes here)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Processing tools</td>
<td></td>
<td>11</td>
<td>36</td>
</tr>
<tr>
<td>Data Ingest &amp; Processing</td>
<td>Processing + Ingest + Archive</td>
<td>9</td>
<td>26</td>
</tr>
<tr>
<td>Data Origin</td>
<td>SD: Where is the data coming from? 1' DD: Agencies, private data providers, academics IC: Data coming from agency that is provided to members of response support team EC: A specific person at a specific desk TE: NOAA, NASA, data centers, specialty aircraft teams (e.g. ASPECT), academia AE: Citizen operating a UAS CBN: ..........Data collection and delivery</td>
<td>25</td>
<td>169</td>
</tr>
<tr>
<td>Name</td>
<td>Description</td>
<td>Files</td>
<td>References</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-------</td>
<td>------------</td>
</tr>
<tr>
<td>SD: D-S platform; 1’ DD: The way data is presented for d-m consumption IC: Devices used to share R-S data; portals for data access for response d-m; display boards; 1” EC: Data centers where raw data accessed TE: Arctic ERMA, COP (TRG, etc.), wall for maps/photos, ArcGIS, e-mail, texting, relevant apps.; 2’ AE: UAS ground station tablet CBN: Single, hard copy un-assimilatable data set, i.e. data format preventing use of data sharing platform</td>
<td></td>
<td>23</td>
<td>218</td>
</tr>
<tr>
<td>Briefings</td>
<td></td>
<td>10</td>
<td>17</td>
</tr>
<tr>
<td>COP (map)</td>
<td>Place to correlate data products</td>
<td>22</td>
<td>128</td>
</tr>
<tr>
<td>ERMA</td>
<td></td>
<td>17</td>
<td>60</td>
</tr>
<tr>
<td>Google Earth</td>
<td></td>
<td>6</td>
<td>14</td>
</tr>
<tr>
<td>TRG</td>
<td></td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Email</td>
<td></td>
<td>8</td>
<td>10</td>
</tr>
<tr>
<td>FTP</td>
<td></td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Text and Instant Messaging</td>
<td></td>
<td>2</td>
<td>7</td>
</tr>
<tr>
<td>Name</td>
<td>Description</td>
<td>Files</td>
<td>References</td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>-------</td>
<td>------------</td>
</tr>
<tr>
<td>Interpretations (Barriers to use)</td>
<td>SD: Interpretation; 1’ DD: Knowing how to use the data, knowing what data means, knowing false positives IC: Data was not usable without interpretation EC: Data arrived in format that required additional processing TE: RS data expert (SSC) output reliance; summarized reports; 1” AE: Data arrives in unusual format for interpretation CBN: Seen it but can’t manipulate or synthesize -is Interpretation a person or a process? -Supports Availability and C,S,L,A</td>
<td>22</td>
<td>174</td>
</tr>
<tr>
<td>Algorithm use</td>
<td>e.g. automated detection algorithm</td>
<td>11</td>
<td>30</td>
</tr>
<tr>
<td>False Positives</td>
<td></td>
<td>14</td>
<td>38</td>
</tr>
<tr>
<td>Knowing how to manipulate</td>
<td></td>
<td>18</td>
<td>49</td>
</tr>
<tr>
<td>Resolution</td>
<td></td>
<td>15</td>
<td>40</td>
</tr>
<tr>
<td>Uncertainty</td>
<td>The need to define uncertainty in data being provided to decision makers</td>
<td>13</td>
<td>39</td>
</tr>
<tr>
<td>It would be really cool if…</td>
<td>SD: It would be really cool if…; 1’ DD: New R-S data and tools</td>
<td>18</td>
<td>57</td>
</tr>
<tr>
<td>Name</td>
<td>Description</td>
<td>Files</td>
<td>References</td>
</tr>
<tr>
<td>------</td>
<td>-------------</td>
<td>-------</td>
<td>------------</td>
</tr>
<tr>
<td>d-m</td>
<td>want but don't have; what kinds of R-S data do people really want or daydream about? IC: Data daydreams about currently unavailable data or tools; scientific tools that have not yet been operationalized; 1” EC: Data or tools that would take 10-years to invent and operationalize i.e. synthetic TE: Automated fluorometer that can be mounted on an AUV to collect and analyze samples at multiple known depths AE: Launching a new satellite for</td>
<td></td>
<td></td>
</tr>
<tr>
<td>LOCATIONS</td>
<td>Specific locations of concern that were discussed</td>
<td>7</td>
<td>13</td>
</tr>
<tr>
<td>Mandate</td>
<td>SD: Mandate; 1’ DD: Use or dis-use of R-S data based on some mandate IC: Reference to policy or code that infl. use/no-use of R-S data or tools; 1” EC: Ref. to policy or code that infl. some part of response not assoc. with R-S data or tools TE: CFRs for best available technology use; 2’ AE: Incident commander demands use of a particular data set for d-m in a response</td>
<td>16</td>
<td>55</td>
</tr>
<tr>
<td>Name</td>
<td>Description</td>
<td>Files</td>
<td>References</td>
</tr>
<tr>
<td>-----------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-------</td>
<td>------------</td>
</tr>
<tr>
<td><strong>CBN:</strong></td>
<td>Using a R-S tool that was suggested by someone to the incident commander</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>QUOTES</strong></td>
<td>Awesome quotes to try and integrate</td>
<td>15</td>
<td>50</td>
</tr>
<tr>
<td>Role</td>
<td><strong>SD:</strong> Role, <strong>1o DD:</strong> Role in spill responses and drills, past/present <strong>IC:</strong> title, description of support activities undertaken, self identification, <strong>11 EC:</strong> Role outside of response activity (if not related) <strong>TE:</strong> FOSC, Chief of Ops, Incident Commander <strong>AE:</strong> fireman called in to help, scientific advisor not on ICS chart <strong>CBN:</strong> concerned citizen (?) 2’ How data used in role – to/from, d-m</td>
<td>25</td>
<td>320</td>
</tr>
<tr>
<td>(Arctic) Branch Chief</td>
<td></td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>(Arctic) Command (not FOSC or SSC)</td>
<td></td>
<td>5</td>
<td>5</td>
</tr>
<tr>
<td>(Arctic) Environmental Unit</td>
<td></td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>(Arctic) FOSC</td>
<td></td>
<td>4</td>
<td>6</td>
</tr>
<tr>
<td>(Arctic) Operations</td>
<td></td>
<td>4</td>
<td>5</td>
</tr>
<tr>
<td>Name</td>
<td>Description</td>
<td>Files</td>
<td>References</td>
</tr>
<tr>
<td>------</td>
<td>-------------</td>
<td>-------</td>
<td>------------</td>
</tr>
<tr>
<td>(Arctic) Scientific Support (non-SSC)</td>
<td></td>
<td>5</td>
<td>7</td>
</tr>
<tr>
<td>(Arctic) SSC</td>
<td></td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Branch Chief</td>
<td></td>
<td>7</td>
<td>11</td>
</tr>
<tr>
<td>Command</td>
<td></td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>Damage Assessment_NRDA</td>
<td></td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Environmental Unit</td>
<td></td>
<td>7</td>
<td>11</td>
</tr>
<tr>
<td>FOSC</td>
<td></td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>LiaisonPIO_JIC</td>
<td>Person that is a subject matter expert to those outside of the response</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Operations</td>
<td></td>
<td>9</td>
<td>11</td>
</tr>
<tr>
<td>Planning</td>
<td></td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Scientific Support (non-SSC)</td>
<td>NOAA Seattle team, researchers, data providers, SMEs; normally do not have a formalized role in IMT</td>
<td>14</td>
<td>56</td>
</tr>
<tr>
<td>Situation Unit</td>
<td></td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>SSC</td>
<td></td>
<td>5</td>
<td>18</td>
</tr>
<tr>
<td>R-S platform</td>
<td>SD: R-S platform; 1’ DD: R-S platform used in data collection IC: Carries a sensor that</td>
<td>9</td>
<td>20</td>
</tr>
<tr>
<td>Name</td>
<td>Description</td>
<td>Files</td>
<td>References</td>
</tr>
<tr>
<td>------------------------------</td>
<td>--------------------------------------------------------------------------------------------------------</td>
<td>-------</td>
<td>------------</td>
</tr>
<tr>
<td>collects data used in d-m of a response in some format or another</td>
<td>Humans on foot carrying sensor TE: Satellite, airplane, UAV, AUV; 1” AE: Stationary tripod; wall mounted sensor CBN: Pictures from unknown source on internet</td>
<td>22</td>
<td>116</td>
</tr>
<tr>
<td>Airplane</td>
<td></td>
<td>22</td>
<td></td>
</tr>
<tr>
<td>Helicopter</td>
<td></td>
<td>7</td>
<td>19</td>
</tr>
<tr>
<td>Satellite</td>
<td></td>
<td>20</td>
<td>154</td>
</tr>
<tr>
<td>Stationary platform</td>
<td></td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>UAS</td>
<td></td>
<td>25</td>
<td>248</td>
</tr>
<tr>
<td>Underwater ROV</td>
<td></td>
<td>5</td>
<td>9</td>
</tr>
<tr>
<td>Teaching or learning preferences</td>
<td>SD: Teaching/learning methodology preferences; 1’ DD: How do people want to learn about R-S data and tools IC: Specific ways or settings folks want to learn about what R-S data there is and how to use it; 1” EC: Someone telling what it is and what it means on the spot during a response i.e. “I just ask Catherine” TE: Seminars; hands-on workshops; classroom setting;</td>
<td>24</td>
<td>63</td>
</tr>
</tbody>
</table>

208
<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Files</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Conferences</td>
<td>Larger conferences, likely greater than 500 people; E.g. IOSC</td>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>Demonstrations</td>
<td></td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Discussions</td>
<td>Casual discussions in the command post or elsewhere; discussions during a drill; face-to-face with a scientist</td>
<td>6</td>
<td>8</td>
</tr>
<tr>
<td>Hands-on</td>
<td></td>
<td>12</td>
<td>17</td>
</tr>
<tr>
<td>Self-driven</td>
<td>Tutorials, research, desktop investigations</td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Seminars</td>
<td></td>
<td>4</td>
<td>4</td>
</tr>
<tr>
<td>Webinar</td>
<td></td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>Workshop</td>
<td></td>
<td>16</td>
<td>21</td>
</tr>
</tbody>
</table>
| What data is being used | SD: What data is being used  
 DD: What specific products being used; what sensors being used; UAS; SAR IC: imagery, data values, used as reference data for d-m, direct observations from human | 0     | 0          |
<table>
<thead>
<tr>
<th>Name</th>
<th>Description</th>
<th>Files</th>
<th>References</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerosol data</td>
<td>observer, R-S from camera or sensor EC: Non-dynamic (bathymetry charts) TE: IR mosaic, SAR image, optical video, aerial photo AE: Photo from citizen on-shore; don't know what it is CBN: Photos of area covered in ice; 50-year old data being ref. as current; current models from out-of-region 2' Static image; COP-bas</td>
<td>3</td>
<td>12</td>
</tr>
<tr>
<td>AIS</td>
<td>Boat trackers; send out pings to those listening</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>Buoy</td>
<td></td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Derived products (including model output)</td>
<td></td>
<td>12</td>
<td>31</td>
</tr>
<tr>
<td>Model output</td>
<td>Output from trajectory models used under interpretation</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>Human Observer data</td>
<td></td>
<td>14</td>
<td>41</td>
</tr>
<tr>
<td>I have heard about other people using....</td>
<td></td>
<td>9</td>
<td>13</td>
</tr>
<tr>
<td>Infrared imagery</td>
<td></td>
<td>14</td>
<td>45</td>
</tr>
<tr>
<td>LIDAR</td>
<td></td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Name</td>
<td>Description</td>
<td>Files</td>
<td>References</td>
</tr>
<tr>
<td>-------------------------------------</td>
<td>-----------------------------------------------------------------------------</td>
<td>-------</td>
<td>------------</td>
</tr>
<tr>
<td>Multispectral imagery</td>
<td>MODIS goes here</td>
<td>11</td>
<td>42</td>
</tr>
<tr>
<td>Non-specified imagery</td>
<td>Could be satellite or UAS or airplane, could be SAR, MODIS or visible, but</td>
<td>16</td>
<td>40</td>
</tr>
<tr>
<td></td>
<td>only refered to as a &quot;shot or an &quot;image&quot; from &quot;overhead&quot;, and such</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other</td>
<td>weird stuff, or things only one person mentions</td>
<td>10</td>
<td>29</td>
</tr>
<tr>
<td>R,G,B (optical) imagery</td>
<td></td>
<td>24</td>
<td>166</td>
</tr>
<tr>
<td>Photos</td>
<td></td>
<td>19</td>
<td>86</td>
</tr>
<tr>
<td>Videos</td>
<td></td>
<td>14</td>
<td>33</td>
</tr>
<tr>
<td>SAR imagery</td>
<td></td>
<td>17</td>
<td>212</td>
</tr>
<tr>
<td>Interested in autodetection tool</td>
<td>They are interested in an autodetection tool for oil using SAR</td>
<td>9</td>
<td>9</td>
</tr>
<tr>
<td>using SAR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Interested in learning more about</td>
<td></td>
<td>7</td>
<td>7</td>
</tr>
<tr>
<td>SAR</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Not familiar with SAR</td>
<td></td>
<td>8</td>
<td>9</td>
</tr>
<tr>
<td>Sonar</td>
<td>radar for underwater?</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>What people want to learn about,</td>
<td>SD: What do people want to learn about, operationally DD:</td>
<td>23</td>
<td>112</td>
</tr>
<tr>
<td>operationally</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Name</td>
<td>Description</td>
<td>Files</td>
<td>References</td>
</tr>
<tr>
<td>------------------------------------------</td>
<td>-------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------------</td>
<td>-------</td>
<td>------------</td>
</tr>
<tr>
<td>Specific R-S tools or images that exist that they want to learn more about (for making better decisions, responding to spill better); UAS; SAR IC: They have seen or heard about RS tool/data and want to learn how to use/ what its for or how to apply it EC: Some RS data/ tool source that is not operationally accessible; TRL 0-2 TE: Infrared data, radar data, UAS integration AE: AUVs w/ broadband sonar (folks may want to learn, but learning curve</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>You don't know what you don't know</td>
<td>This can apply to availability, interpretation, and things people want to learn about, but i wanted to be sure it was a stand alone capturable item aas well.</td>
<td>13</td>
<td>29</td>
</tr>
</tbody>
</table>
### Appendix F Figure Variable Definitions

#### RS Use (Figure 2.2)

<table>
<thead>
<tr>
<th>Variable</th>
<th>Definition</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Oil identification and screening</strong></td>
<td>Identify oil from the background environment and screen oil for origin to determine if the observed oil is a natural seep or part of the response event</td>
</tr>
<tr>
<td><strong>Data or decision verification</strong></td>
<td>Validation of other RS data sources including scientific testing of new RS tools, confirmation of human observer data</td>
</tr>
<tr>
<td><strong>Tactical decision-making</strong></td>
<td>Using the data to deploy responders and/or equipment</td>
</tr>
<tr>
<td><strong>Footprint</strong></td>
<td>Defining boundary of oil spill event</td>
</tr>
<tr>
<td><strong>Background information</strong></td>
<td>Baseline information about site of spill</td>
</tr>
<tr>
<td><strong>Situational awareness</strong></td>
<td>Snapshot of overarching conditions</td>
</tr>
<tr>
<td><strong>Trajectory modeling</strong></td>
<td>Using RS data to predict where the oil will be through time</td>
</tr>
<tr>
<td><strong>Thickness determination</strong></td>
<td>Using RS to determine thickness of slick, or actionable oil; includes identification of emulsified oil</td>
</tr>
<tr>
<td><strong>Tactics monitoring</strong></td>
<td>Using RS data to determine effectiveness of various response tactics, such as boom placement or in situ burn efficiency</td>
</tr>
<tr>
<td><strong>Damage assessment</strong></td>
<td>Calculating the cost of the oil spill on the environment for litigation purposes</td>
</tr>
<tr>
<td><strong>Identification of resources at risk</strong></td>
<td>Locate any habitat, animals or other resources at risk of impacts resulting from oil or response</td>
</tr>
<tr>
<td><strong>Surveillance of known targets</strong></td>
<td>Monitoring known or potential sources of oil; roulette targets</td>
</tr>
<tr>
<td><strong>Anomaly detection</strong></td>
<td>Identifying outlying targets or conditions that could be oil or alternatively deleterious</td>
</tr>
<tr>
<td><strong>Communications support</strong></td>
<td>Using RS data and maps for response briefings to various audiences</td>
</tr>
<tr>
<td><strong>Air monitoring</strong></td>
<td>Monitoring ambient air for toxic volatiles from either the oil or the response activities</td>
</tr>
</tbody>
</table>
### Availability (Barriers to Use) (Figure 2.3)

<table>
<thead>
<tr>
<th>Category</th>
<th>Question</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Coverage</strong></td>
<td>Was there RS data available over the oil spill?</td>
</tr>
<tr>
<td><strong>Access knowledge</strong></td>
<td>Do people know where and how to get the RS data?</td>
</tr>
<tr>
<td><strong>Latency</strong></td>
<td>Was the data received fast enough to be useful?</td>
</tr>
<tr>
<td><strong>No availability issues</strong></td>
<td>People know exactly where to go for the data, or it is handed to them</td>
</tr>
<tr>
<td><strong>Weather</strong></td>
<td>Were there weather conditions that prevented the collection of the RS data or impacted the sensor ability to detect the oil?</td>
</tr>
<tr>
<td><strong>Bandwidth</strong></td>
<td>Were data and data products able to be delivered electronically? Were there delays in accessing the information for decision-making due to low internet or cellular network bandwidth?</td>
</tr>
<tr>
<td><strong>Clearance</strong></td>
<td>Is the data privately held or requires some type of governmental clearance to access?</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>Does the data cost money, and if so, is it prohibitive to its use during an oil spill response?</td>
</tr>
</tbody>
</table>

### Data Integration (Barriers to use) (Figure 2.3)

<table>
<thead>
<tr>
<th>Category</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Consumers</strong></td>
<td>Subject matter experts or decision makers that are actively using the data</td>
</tr>
<tr>
<td><strong>Ingest &amp; processing</strong></td>
<td>Is the data easily ingested in its raw format? Is there post-processing that has to be performed before the data can be used for decision-making?</td>
</tr>
<tr>
<td><strong>Format</strong></td>
<td>Is the data in a format that can be easily understood by decision makers? Is it GIS-ready (COP-ready)? E.g. georectified data, PDFs, paper maps</td>
</tr>
<tr>
<td><strong>Origin</strong></td>
<td>Where the data is coming from, e.g. NOAA NESDIS, federal contractors, human observers</td>
</tr>
<tr>
<td><strong>Sharing platforms</strong></td>
<td>How the data is sharable within and outside of the command post, e.g. COP, email, briefings, etc.</td>
</tr>
<tr>
<td><strong>Establishment</strong></td>
<td>RS data or tool is commonly used, often integrated into the COP</td>
</tr>
<tr>
<td>Interpretation (Barriers to Use) (Figure 2.3)</td>
<td></td>
</tr>
<tr>
<td>---------------------------------------------</td>
<td></td>
</tr>
<tr>
<td><strong>Algorithm use</strong></td>
<td>Are algorithms used to differentiate oil in the data? Are they understandable and well described?</td>
</tr>
<tr>
<td><strong>False positives</strong></td>
<td>Are there potentially false positives for oil in the RS data as presented? Did false positives in previous RS data cause a waste of resources or frustration during the response?</td>
</tr>
<tr>
<td><strong>Knowing how to manipulate</strong></td>
<td>Is there someone in the ICP that can manipulate the data to provide a more clear analysis? Manipulation is different than interpretation, as it indicates the ability to do change some state of the data</td>
</tr>
<tr>
<td><strong>Resolution</strong></td>
<td>Was the data of high enough resolution to use for decision-making?</td>
</tr>
<tr>
<td><strong>Uncertainty</strong></td>
<td>Understanding or being able to provide the uncertainty in data provided to decision makers</td>
</tr>
</tbody>
</table>
Appendix G IRB Research Exemption Letter

Institutional Review Board
309 N Koyukuk Dr. Suite 212, P.O. Box 757270, Fairbanks, Alaska 99775-7270

May 24, 2018

To: Sarah Trainor, PhD
Principal Investigator

From: University of Alaska Fairbanks IRB

Re: [1244858-1] UAS Integration into 2018 Oil Spill Response Drills

Thank you for submitting the New Project referenced below. The submission was handled by Exempt Review. The Office of Research Integrity has determined that the proposed research qualifies for exemption from the requirements of 45 CFR 46. This exemption does not waive the researchers' responsibility to adhere to basic ethical principles for the responsible conduct of research and discipline specific professional standards.

Title: UAS Integration into 2018 Oil Spill Response Drills
Received: May 15, 2018
Exemption Category: 2
Effective Date: May 24, 2018

This action is included on the May 30, 2018 IRB Agenda.

Prior to making substantive changes to the scope of research, research tools, or personnel involved on the project, please contact the Office of Research Integrity to determine whether or not additional review is required. Additional review is not required for small editorial changes to improve the clarity or readability of the research tools or other documents.

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