Gulf of Mexico

Oil Spill Response Viability Analysis

FINAL REPORT

(PROJECT #1077)

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Executive Summary

The U.S. Bureau of Safety and Environmental Enforcement (BSEE) contracted Nuka Research and Planning Group, LLC and DNV GL to conduct an oil spill response viability analysis for the U.S. Gulf of Mexico (Project #1077). A response viability analysis estimates the percentage of time that conditions in a particular area would be favorable, marginal, or not favorable to the deployment and operation of a particular response system.

This study focuses on U.S. waters of the Gulf of Mexico north of 25 degrees North. Using 2005-2014 modeled metocean data, the analysis considers the effects of wind speed, wave height, horizontal visibility, and daylight/darkness on three example mechanical recovery systems; the application of dispersants from a vessel, fixed-wing aircraft, or helicopter; and the ignition of in-situ burning from a vessel. A supplementary analysis considers the effect of cloud ceiling by adding observational data from four airports in the region to the four nearest grid cells of modeled metocean data.

Numeric and map-based results are presented for the whole study area. Figure ES-1 shows the numeric results averaged across the area. Conditions are most likely to be favorable for the three dispersant systems. When not favorable, conditions are most likely marginal for the application of dispersants from a vessel, whereas they are most likely *not* favorable for the two aircraft-based systems. (This difference is due to the assumption that darkness is marginal for the application of dispersants from a vessel but not favorable for the application of dispersants from either a helicopter or fixed-wing aircraft.)

Conditions are marginal 29% of the time for the two larger mechanical recovery systems, and favorable 60% more of the time. For the in-situ burning system, which is slightly less tolerant of wind, conditions are favorable 10% less of the time and not favorable slightly more (4%). Finally, conditions are favorable just 15% of the time for the smallest of the mechanical recovery systems.

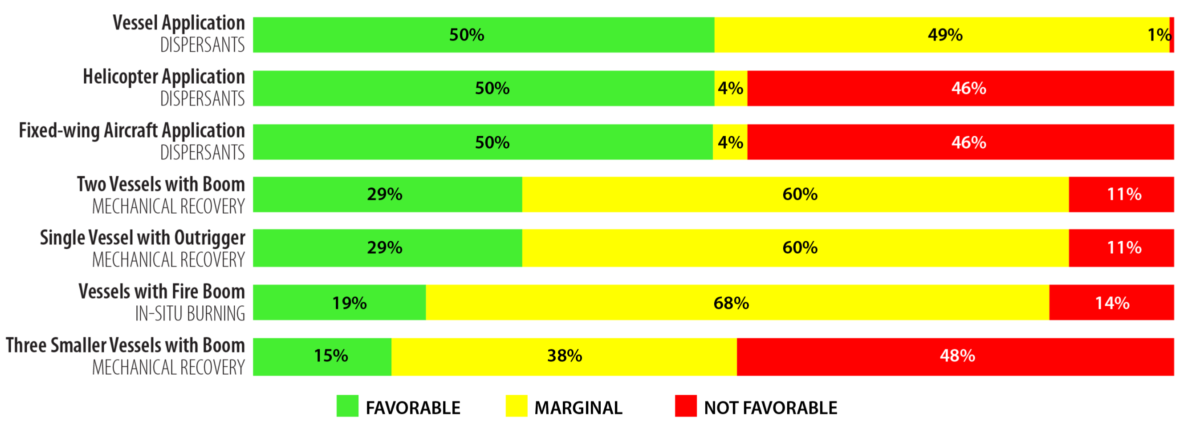

Figure ES-1. Annual percentage of time that conditions are favorable, marginal, or not favorable for response systems studied (averaged for entire study area)

Numeric results are also presented (overall and by month) for six divisions created for this project to indicate both nearshore and offshore areas of the three Bureau of Ocean Energy Management planning areas in the region. Nearshore and offshore areas are demarcated using the 200-m water depth line.

The potential impact of vertical visibility was explored using cloud ceiling data from four airports in the region. While there are some times when cloud ceiling conditions are not favorable to the aircraft-based systems, these periods do not change the results due to the dominance of darkness, which is considered not favorable, on the viability of those systems.

A sensitivity analysis shows that the response viability for mechanical recovery systems studied is not limited by wind speed in the Gulf of Mexico viability could be increased if the systems analyzed could operate in higher wave heights. The in-situ burning system is the reverse; it shows little increase in viability when tolerance to wave height is increased, but its viability improves up to 10% if it can tolerate a higher wind speed. The dispersant systems studied show no increase in response viability if tolerance to wave height is improved and only a slight increase if tolerance to wind speed is increased.

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1 Introduction

The U.S. Bureau of Safety and Environmental Enforcement (BSEE) contracted Nuka Research and Planning Group, LLC and DNV GL to conduct an oil spill response viability analysis for the U.S. Gulf of Mexico (Project #1077). This report describes the method, assumptions, inputs, and results of that analysis.

A response viability analysis estimates the percentage of time that conditions in a particular area would be favorable, marginal, or not favorable to the deployment and operation of a particular response system. The objective of this study is to provide BSEE with information regarding the frequency with which weather and wave conditions are conducive to the deployment of a set of response systems which are representative of those that may be used in the Gulf of Mexico.

1.1 Project Scope

A response viability analysis focuses on a specific geographical location. This location is used to determine the weather or ocean (“metocean”) parameters and data needed. Viability analyses improve understanding of the operating conditions in a given area, including which metocean condition (or conditions) may have the greatest effect on response operations. This can include exploring seasonal or geographic variations. Such information is important and can inform oil spill contingency planning, response system selection, or potential future enhancements.

A response viability analysis does not assess response capacity or capabilities, compliance with regulations, or the likelihood that a response in any particular situation would or could be implemented effectively or the results that would be achieved.

1.1.1 Study area

The study area includes the waters of the Gulf of Mexico within the U.S. Exclusive Economic Zone (EEZ) for which data were available in the chosen datasets. The focus of the study is Bureau of Ocean Energy Management (BOEM) planning areas, but the specific boundaries of the study area are strictly defined by data availability, without regard to spill risk or state vs. federal jurisdiction. In some areas, the modeled metocean data used in this analysis did not cover all of the BOEM planning areas (e.g., near Louisiana, as depicted in Figure 1.1.) Due to data limitations, the area south of 25 degrees North was excluded. Despite these limitations, the geographic scope was defined with BSEE approval as the data sets used were deemed to be the best available options. (See Figure 1.1.)

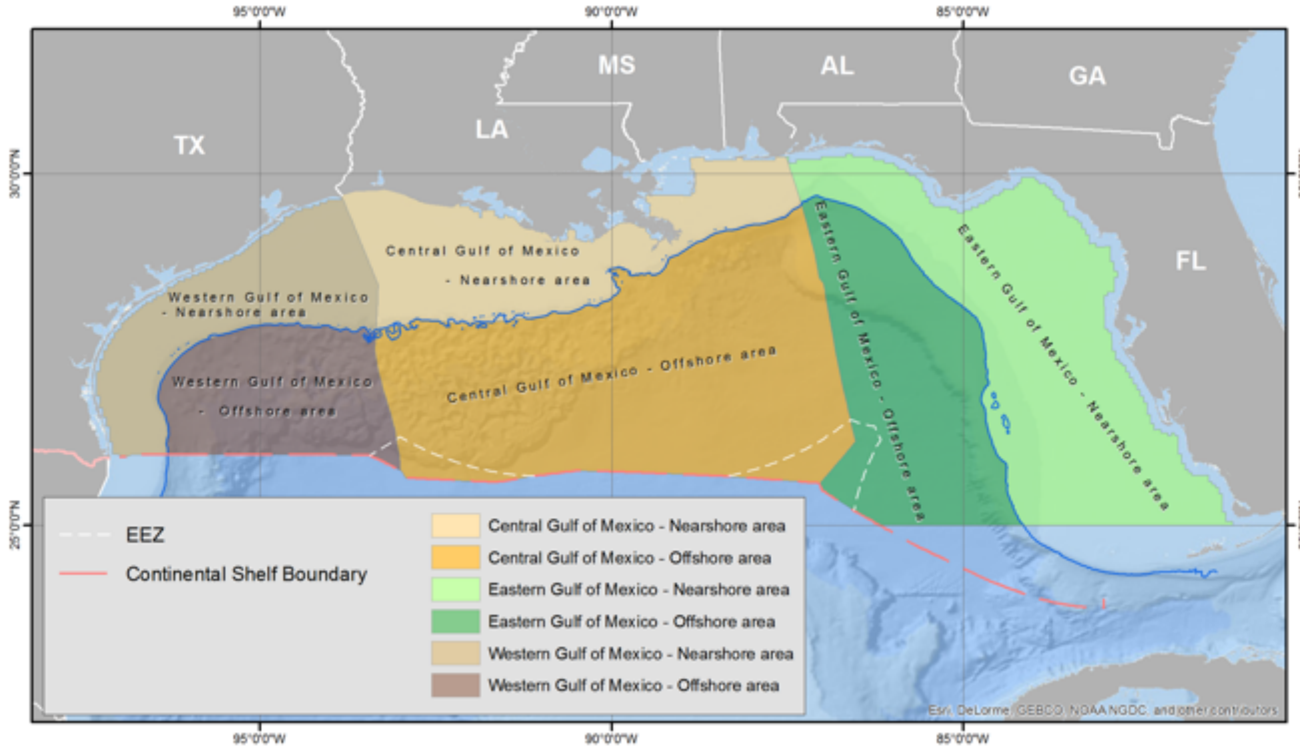


Figure 1-1. Viability analysis study area (see Section 3 for a discussion of the six areas, or zones, used in this study)

1.1.2 Metocean conditions

Actual or forecasted metocean conditions will affect the deployment and effectiveness of the response system applied in any given oil spill incident. This study considers the frequency with which the following conditions may be expected to be favorable, marginal, or not favorable[1] for response deployment in the U.S. waters of the Gulf of Mexico:

1. Wind speed
2. Wave height
3. Daylight/darkness
4. Horizontal visibility
5. Vertical visibility (cloud ceiling)

The response viability analysis uses hindcast modeled data to present results based on the first four conditions for the entire study area. As the model did not include cloud ceiling, vertical visibility is incorporated only at four nearshore locations (using data recorded at airports) to illustrate its effect on response.

This study does not consider the impact of the above conditions – or others – on oil weathering or other aspects of response efficiency or effectiveness. These are important factors in response decision-making, but would require a scenario-driven approach that considered, among other things, oil type, temperature, duration since the spill, spill volume and slick thickness, etc. Instead, this study focuses on whether conditions would affect the deployment or general operations of a response system.

[1] Terms are defined in Section 3.1.2.

1.1.3 Response systems

Three types of response strategies may typically be deployed for marine oil spill response to an oil spill on the water's surface: mechanical recovery, dispersant application, and in-situ burning. Various response systems exist for each of these strategies, and may be tailored to different conditions. For the purpose of this study, system specifications are established to the extent that they are needed to determine operating limitations for each metocean condition. For this study, BSEE selected the following systems for analysis:

1. Mechanical Recovery – Two Vessels with Boom
2. Mechanical Recovery – Single Vessel with Outrigger
3. Mechanical Recovery – Three Smaller Vessels with Boom
4. Dispersants – Vessel Application
5. Dispersants – Fixed-wing Application
6. Dispersants – Helicopter Application
7. In-situ Burning – Vessels with Fire Boom

Response systems and operating limits are discussed further in Section 5.

1.2 Organization of this report

This report provides background on the response viability approach in Section 2. Section 3 describes the methodology in more detail. Section 4 describes the inputs used for metocean data, including a brief characterization of the conditions included in the study based on the modeled data used. Section 5 summarizes the response systems studied and the associated limitations used as inputs to the analysis. Section 6 presents the results of the analysis, with a conclusion in Section 7.

2 Background

This section proves background on response viability analyses, a brief overview of the approach, and a summary of the types of effects metocean conditions may have on response system deployment.

2.1 Response Viability Analysis Approach

Figure 2-1 presents an overview of the response viability approach: metocean data and operating limits are combined for the study area over a particular time period (in this case, 2005-2014). The results are the percentage of time during that time period when metocean conditions would have been favorable, marginal, or not favorable for a response.

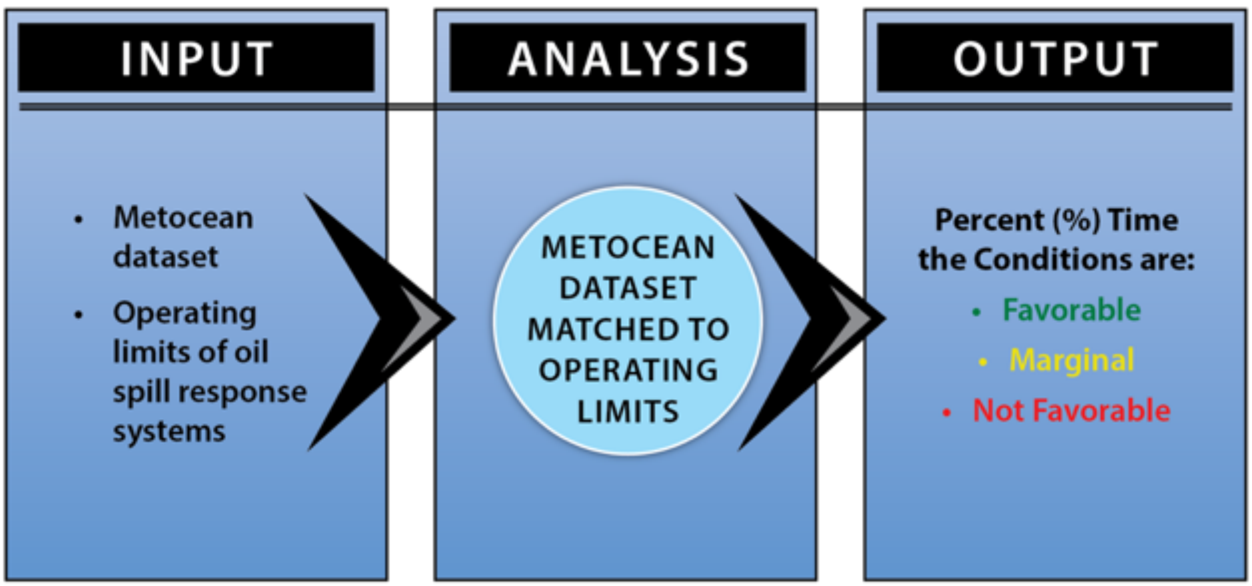


Figure 2-1. Summary of approach to oil spill response viability analysis

The response viability approach has evolved over the past decade, with governments, inter-governmental bodies (e.g., the Arctic Council), and non-profit organizations commissioning most of the studies. Following on the initial study conducted for Prince William Sound, Alaska in 2007 (Nuka Research, 2007), subsequent analyses have been conducted in other parts of Alaska (Nuka Research, 2014; 2016), both Arctic (S.L. Ross, 2011) and west coast Canada (Nuka Research, 2012; 2015; Terhune, 2011), Greenland (DNV GL, 2015), the Barents Sea (DNV GL, 2014) and the entire circumpolar Arctic region (EPPR, 2017). These studies have been commissioned by the governments of the U.S., Canada, and Denmark; cities and First Nations in British Columbia; and the Arctic Council's Emergency Prevention, Preparedness, and Response Workgroup. Some previous reports used the term "response gap." This has evolved to refer to "response viability" but the general approach has remained the same. Because of some variations in the methodology, range of metocean conditions included, and response systems analyzed, direct comparison of study results may not be appropriate.

2.2 Effect of Metocean Conditions on Oil Spill Response Operations

Metocean conditions affect different aspects of a spill response, including spill response equipment, operational platforms, and the safety of responders or vessel and aircraft crew. The safety of responders and any others involved in an incident (such as the crew or passengers of a stricken vessel, for example) will always be the first priority in any response. While most effects are expected to be *detrimental* to the response, there may be cases where an effect is *positive*, e.g., high temperatures and sunlight speeding the natural evaporation process. This section summarizes some of the possible impacts both to the deployment of response equipment (Table 2-1) and to the response platform (Table 2-2).

Except when conducted on land, mechanical oil recovery is generally based on a vessel or vessels. The boom and skimmers used to contain and recover oil may succumb to the effects of wind, waves, and other conditions regardless of vessel seaworthiness, depending on the size and capability of the equipment itself. Waves can make containment more difficult, or reduce the amount of contained oil that is successfully recovered by the skimmer. High winds or waves may make it difficult or unsafe to deploy or retrieve equipment from the deck of a vessel.

Dispersants may be applied from a vessel or aircraft, but either way it must be possible to see and target the slick in order to be successful. Regardless of the platform, there must also be enough mixing energy present during or soon after the application for the dispersant to be effective. If there is abundant natural wave energy, adding chemical dispersants may not be necessary.

In-situ burning may also be applied from vessels or aircraft, but this study considers only vessel-based ignition. This requires the use of containment boom (herders were not considered), similar to mechanical recovery. Wind and waves must be calm enough to allow for ignition and a sustained burn.

Effects on response will also vary depending on the nature of the conditions. For example, wind-driven waves will have a greater impact than swell, even at the same wave height.

Mounting any response requires being able to move equipment and people to the slick area and maintaining them there for as long as needed to deploy the system. This is typically done with vessels and/or aircraft. Table 2-2 summarizes some of the effects metocean conditions may have on the safe operation of vessels and aircraft used in an oil spill response. Vessel particulars or the type of aircraft will determine the exact limitations on a given response. As noted, the effects of limited visibility are particularly tied to the platform used.

Table 2-1. Effects of metocean conditions on mechanical recovery, dispersants, and in-situ burning response systems (regardless of platform)

METOCEAN CONDITIONS	PRIMARY EFFECTS ON:		
	Mechanical Recovery	**Dispersants**	**In-situ Burning**
High winds, gusts, or cross-winds	• Ability to deploy/retrieve system components • Ability to contain oil, due to boom failure (splash-over)	• Ability to apply proper dosage to slick	• Safety of crew, due to winds, inhalation, or fire • Ability to target slick for ignition • Volatile components not maintained in sufficient concentration for ignition/burn
Sea state	• High waves may challenge: o Deployment/ retrieval of system components o Containment, due to boom failure (splash-over, submergence, wave-keeping) o Recovery, due to skimmer failure	• Sustained calm waters may result in too little mixing energy for effective dispersion • High sea states may physically disperse oil naturally	• High waves may challenge: o Ability to deploy and retrieve system components o Ability to contain oil, due to boom failure, if used
Fast currents[2]	• Ability to contain oil (entrainment, submergence)	• (Effect potentially similar to sea state)	• Ability to contain oil in boom
High air temperature	• Not applicable.	• Optimal storage temperatures may be exceeded	• May enhance burn efficiency

[2] Currents may also exacerbate effects of sea state.

Table 2-2. Primary effects of metocean conditions on vessel and aircraft platforms

METOCEAN CONDITIONS	PRIMARY EFFECTS ON:	
	Vessel Operations	**Aircraft Operations**
High winds, gusts, or cross-winds	• Safety of crew working on deck • Ability to stay on station	• Safety of aircraft, especially during takeoff and landing (though conditions at the slick may be different than at airstrip) • Ability to carry out mission
Sea state	• Safety of crew working on deck • Ability of vessels to stay on station or maintain proper speed	• Extremely high waves could impact low-flying helicopter
Fast currents	• Ability to maneuver or stay on station, though effect lessened to the extent that whole slick is moving	Not Applicable
Hot air temperature	• Safety of crew working on deck in extremely hot temperatures	• Extremely high temperatures affect aircraft performance
Limited horizontal visibility (fog, precipitation)	• Potential for collisions and allisions • Impacts vessels' ability to navigate safely	• Potential for collision with obscured terrain or other aircraft • Ability to carry out mission due to lack of visibility
Limited vertical visibility (clouds)	Not Applicable	• Safety of aircraft due to obscured terrain and collision with other aircraft • Ability to carry out mission due to lack of visibility or height of eye for observation
Darkness	• Ability to target and maintain operations within an oil slick	• Ability to carry out mission due to lack of visibility

3 Methodology

The general approach to implementing an oil spill response viability analysis is to compare a historic set of metocean conditions for a given location to the limitations of oil spill response systems that may be used at that location.

Compiling metocean conditions requires building a historic dataset for the parameters studied. Establishing the system limitations requires first choosing and describing the systems to be studied, then defining the limitations of those systems that correspond to parameters used for the metocean conditions. For each time period recorded in the dataset (or "timestep"), a rule is applied to determine whether conditions during that time were favorable, marginal, or not favorable for a response. The results are presented as a percentage of time that the metocean conditions in a given location are categorized as favorable, marginal, or not favorable for a particular system. This is portrayed geographically, numerically, and graphically.

3.1 Establishing Inputs: Metocean Data and Operational Limits

There are two sets of inputs to the response viability analysis: metocean data and associated operational limits for each system studied.

3.1.1 Metocean data

Metocean data for 2005-2014 for this project were drawn from the GOMOS2014 update to GOMOS_USA (for wind and waves) and GROW-MET (for visibility) models developed by Oceanweather, Inc. (Oceanweather, Inc., 2015; 2016). BSEE approved of the selected data sources as the best available options and obtained data and shared the datasets with Nuka Research and DNV GL for the purpose of this project. Observational data from four regional airports are also used in a limited manner.

Metocean data were combined in a geospatial dataset based on 12-km x 12-km grid cells. For each metocean parameter, conditions are compiled for every grid cell in 1-hour time steps over a 10-year period. There are 3,750 grid cells in the dataset.

Section 4 describes the modeled and observational metocean data sources, as well as the datasets acquired and the way they were processed for use in the response viability analysis.

3.1.2 Response systems and operating limits

BSEE selected the response systems for the analysis based on general types of systems used in the Gulf of Mexico. Response system descriptions are included in Section 5 with a discussion of the selection of response limits. For the response viability analysis, response limits are assigned to three categories, each associated with a color to facilitate graphical presentation of results. The response viability categories are described in Table 3-1. The use of three categories has remained consistent through the response gap/viability studies implemented since 2007. The definitions in the table are from the circumpolar Arctic response viability analysis and were refined with input from government, industry, and non-governmental organizations during an October 2015 EPPR-hosted workshop (DNV GL and Nuka Research, 2015).

Table 3-1. Response viability categories

Category	Description
Green	Generally ***favorable*** conditions in which the tactic could be expected to be deployed safely and operate as intended.
Yellow	Conditions are ***marginal***, such that the tactic could be deployed but operations may be challenged or compromised.
Red	Conditions are ***not favorable***, so the tactic would typically not be used due to the impact of metocean conditions on safety or equipment function.

Where possible, response limits are defined based on published literature on the components specified in the system. However, setting response limits for a particular system is ultimately a subjective combination of best professional judgment, real-world experience, response tactics guides and contingency plans developed by industry or government agencies, government guidance or policies, and published results of studies or observations. Regulatory limits may also come into play (as for aircraft). Limits drawn from the literature may be based on meso-scale or full-scale field trials rather than actual responses or exercises when that provides the best or only documentation available.

Limits are expressed for each of the metocean parameters in the dataset. There may be conditions not included in the dataset that will impact a response, however: these could be other metocean conditions such as current, or the infinite range of other factors that will determine the decision to deploy a response (weather forecasts, availability of resources, responder availability and qualifications, necessary support logistics, accurate information regarding slick location and movement, etc.). Additionally, not all parameters apply to all systems.

3.2 Analysis

Analysis is implemented for each of the 3,750 grid cells in the metocean data based on that dataset, response systems, and corresponding operational limits. The analysis was conducted for each timestep in each grid cell in the study area across the 10-year study period. Thus, results are calculated for 328,500,000 timesteps for each of the 7 response systems studied.

The ability to respond to an oil spill does not degrade at a specific point (e.g., going from favorable to not favorable at a certain wave height). To reflect this, albeit still in a simplified manner, each timestep in the dataset (in this case, 1-hour increments) is identified as one of three categories: green, yellow, or red for a particular response system based on concurrent conditions recorded for that timestep and the operational limits established. The following rules are applied to establish the category for each timestep and each grid cell:

- If <u>any</u> condition is ruled RED -> RED
- If <u>all</u> conditions are ruled GREEN -> GREEN
- YELLOW otherwise

After each timestep is identified as green, yellow, or red, the portion of time intervals of each color is calculated for a given month and for the year overall. This is presented empirically and geospatially.

3.2.1 Geospatial analysis

For each response system studied, 12 standard maps are produced to illustrate the distribution of the three response viability categories (red, yellow, green) across the year using four focus months: January, April, July and October. This results in 84 maps in total (shown in Appendix A). The results maps use a five-increment scale for each category. The scale refers to the percentage of time that the viability categories are present in each grid cell for the selected month, based on the rule described above. Based on this, the spatial distribution of the viability can be studied as patterns of changing colors throughout the study area.

In the solicitation for this project, BSEE required that results be presented for the "nearshore" and "offshore" portion of each of the three BOEM planning areas in the Gulf of Mexico: Western Gulf of Mexico, Central Gulf of Mexico, and Eastern Gulf of Mexico. The 200-meter bathymetry line was used to apply an approximate bisection of each planning area into "nearshore" and "offshore" for the purposes of this project (see Figure 3-1). Other options for dividing the planning areas were considered, including the definitions of nearshore and offshore in federal oil spill response planning regulations at 33 CFR 155.1020; however much of the study area would be considered open ocean under those definitions so the nearshore/offshore division was not well suited to this application. BSEE agreed that the 200-m bathymetry line better served the purpose of roughly dividing the planning areas for the purpose of this study. Thus the results are presented for each of the six areas (three nearshore and three offshore) that are delineated for the purpose of this project only. Conditions within each of the six areas are not assumed to be uniform, but simply to provide a way to present at least some of the variation that exists within the three BOEM planning areas.

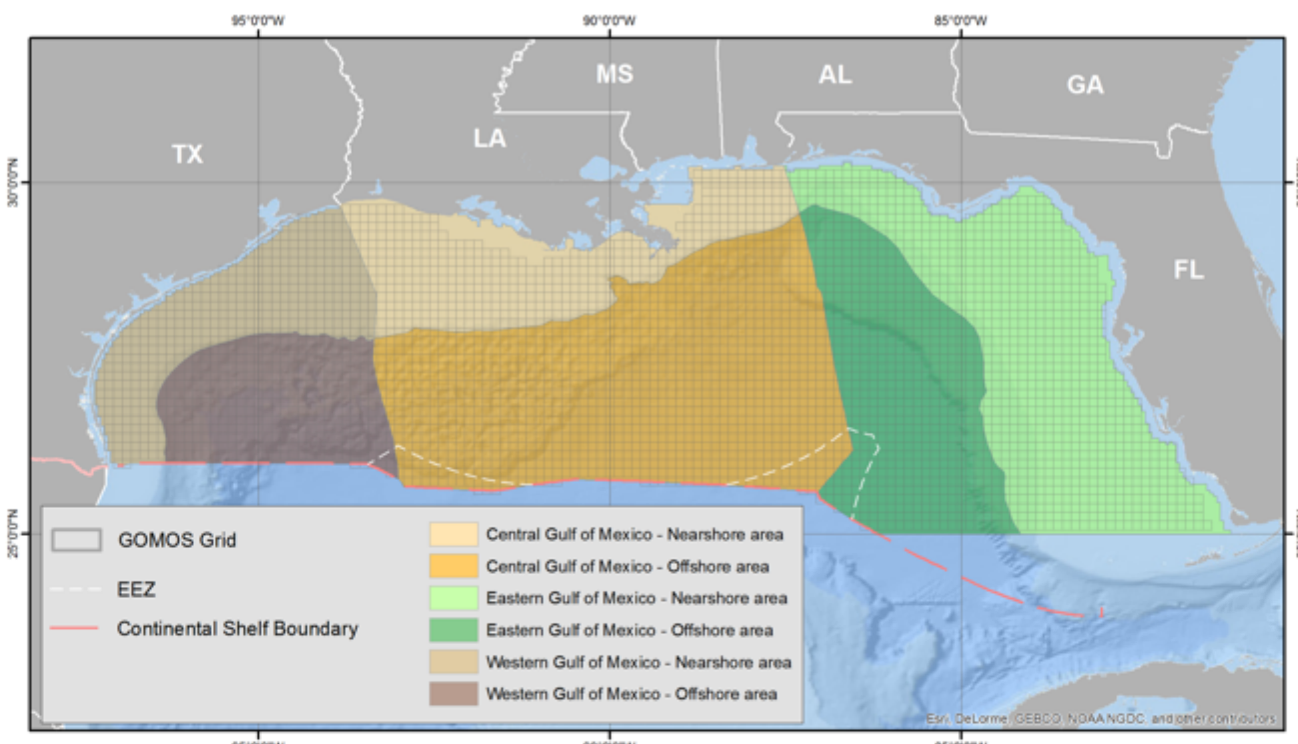


Figure 3-1. Six areas within study area based on BOEM planning areas and 200-meter depth (exact line used in analysis is based on grid cells from the metocean dataset)

3.2.2 Analyzing impact of specific metocean conditions

In addition to the maps and calculated results presented for the entire study area, the data in one grid cell from the center of each of the six division areas was further explored (see Figure 3-2).

Analysis of data in individual grid cells illustrates the metocean conditions influencing the results. This is implemented for each response system in each of the six locations. The same metocean data and response limits are used, and the same “rule” for identifying a timestep as green, yellow, or red is applied.

The results from the location-specific analyses are presented using select annual cycle graphics. These show the portion of time in each week of the year (averaged for the 10 years in the dataset) during which conditions are favorable, marginal, or not favorable for a particular response system. They are also produced for single metocean parameters as well as all parameters combined to provide a view of which factors have the greatest influence on results.

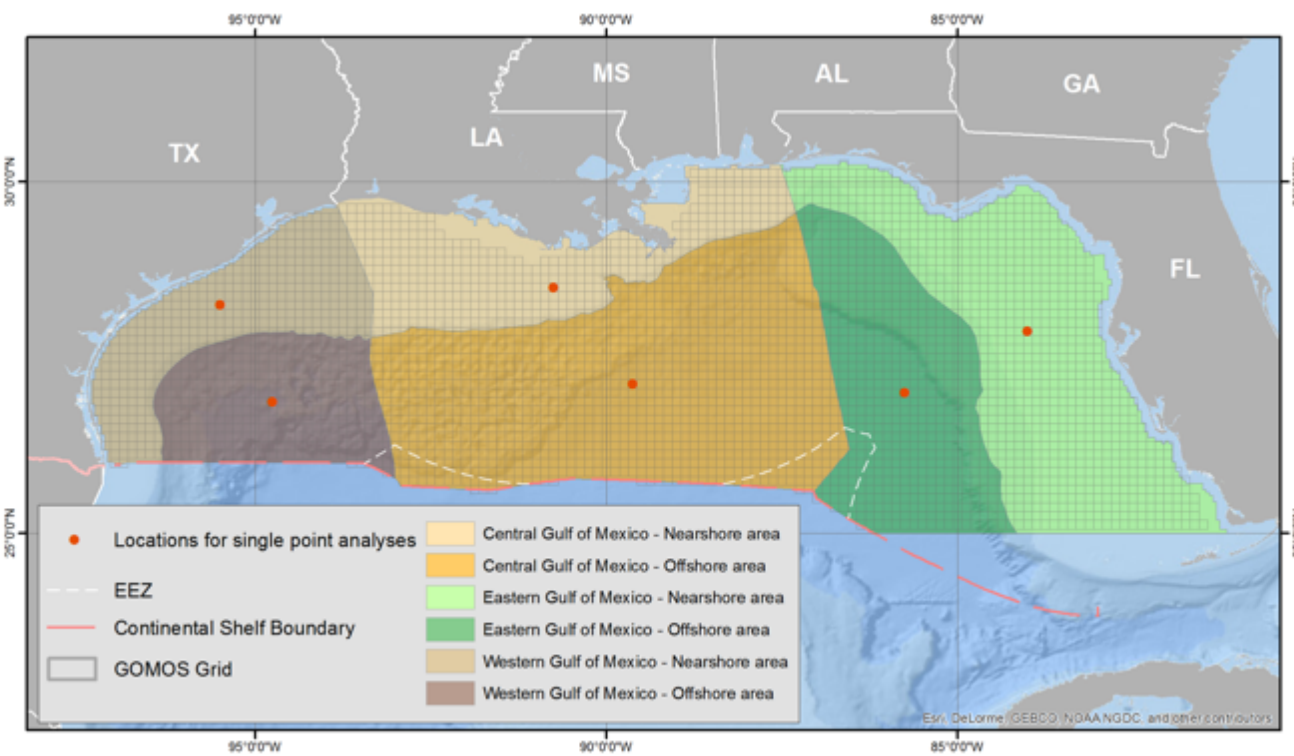


Figure 3-2. Red dots indicate locations used for single-point (grid cell) analyses to explore effect of individual metocean conditions on results

3.2.3 Sensitivity analyses

Sensitivity analyses were conducted to understand the potential changes to the results of the analysis if systems were more tolerant of wind and waves. Horizontal visibility limitations tend to be very closely associated with safety and so were not analyzed in the sensitivity analysis.

To test the sensitivity of all systems to wind speed and wave height, the tolerance of each system was increased at both the margin between favorable/marginal conditions and between marginal/not favorable conditions. These are summarized in Table 3-2. The results are presented numerically for the entire study area in Section 6.

Table 3-2. Summary of sensitivity analyses conducted

SYSTEM	PARAMETER	OBJECTIVE	METHOD
All systems	Wind speed (knots)	Assess increase in viability with higher wind tolerance	Increase limits between green/yellow and yellow/red by 2, 4, 6, and 8 knots each
All systems	Wave height	Assess increase in viability with higher wave height tolerance	Increase limits between green/yellow and yellow/red by 1, 2, 3, and 4 feet each

3.2.4 Vertical visibility

As vertical visibility (cloud ceiling) data are *not* available for the entire region, this parameter is not included in the overall response viability analysis. However, cloud ceiling can affect aircraft-based response systems used for dispersant application. To illustrate this effect, a complementary analysis was conducted using cloud ceiling data from four airports around the Gulf of Mexico (see Section 4 for data sources and Section 6 for results). Other parameters were taken from the nearest grid cell with the modeled metocean data. The results are presented as a complementary analysis.

3.2.5 Quality assurance/quality control (QA/QC)

The analysis was conducted using two custom programs: one developed by DNV GL and the other by Nuka Research. A structured scheme for QA/QC was implemented throughout the work. At each step of analysis, QA/QC was performed to ensure that the stated methodology was implemented as intended. Limits were defined and entered into code to enable a review by someone other than the primary programmer. For the majority of the analysis, code was used that had been previously replicated for limited test data through an independent analysis. Finally, DNV GL and Nuka Research codes were run on the same input files representing hourly data for 10 years to ensure that both independent implementations produced the same results.

3.3 Limitations of this Approach

A response viability analysis provides a useful tool for oil spill response planning, but it does not attempt to incorporate all aspects of a response. It is also subject to the inherent challenges or limitations of the inputs used. This section describes some of the limitations of the approach:

Focuses only on impacts of metocean conditions, not logistics or other practical constraints. A response viability analysis does not guarantee that a response will be deployed and be successful, even when conditions are deemed “favorable.” This analysis does *not* consider the overall operational picture, including whether or not the necessary equipment is available, the ability to transport that equipment to the site, how long conditions would be conducive to deployment (consecutive hours or days), whether there are sufficient personnel who are qualified to deploy the equipment, whether those personnel have the organization and logistical support they need to launch and sustain operations, or numerous other factors that impact oil spill response operations.

Quality and availability of metocean data. A response viability analysis relies on having metocean data available to hindcast the relevant metocean conditions at the sites considered. The authors note that the 12-km x 12-km resolution in the dataset does not provide micro-scale resolution near coastal areas. Data also were not available for vertical visibility (cloud ceiling) throughout the study area.

Relies on historic conditions to inform future decisions. This response viability analysis is based on 10 years of historic conditions in the study area. It is intended as a guide to, though not necessarily a prediction of, response viability in the future or response viability for any given spill event.

Uneven documentation of response limits. While some response limits are well documented or widely accepted for specific components of the response system, such as the wave heights used to characterize different types of containment boom (ASTM, 2000), other overall system response limits are not as well documented or agreed upon. The response viability analysis approach – and pragmatic spill response planning in general – will benefit from further documentation of operating limits for the entire system based on field trials, exercises, or actual responses. Additionally, it was out of the scope of this project to conduct a further literature review or solicit expert or stakeholder input on either the response systems studied or the limits associated with each. Future projects could provide for the opportunity both to expand the systems studied and to build consensus regarding the applicable limits for response systems considered in a follow-on analysis.

Simplified incorporation of response degradation. The degradation of response does not occur at a single point, nor is it necessarily linear in nature. The use of three tiers of response limits is intended to acknowledge and partially overcome this challenge. More tiers could be used to represent a more nuanced degradation, but pinpointing the values for even three tiers is often difficult as noted in the above discussion on uneven documentation of response limits. Analysis does not consider how much time is needed for system deployment. The analysis estimates the overall percentage of time conditions would be favorable, marginal, or not favorable for a given system. It does not seek to determine how long sustained favorable or marginal conditions would be needed for each system to deploy (which would be highly variable across not only the systems studied but also depending on the circumstances of the response).

Analysis does not consider response effectiveness, which would require assumptions regarding oil type and other factors. This analysis focuses on the ability to safely *deploy* response systems in different conditions in which they could be expected to function generally as intended. It does not consider the effectiveness of the response, which will be impacted by oil weathering among other factors.

Spilled oil will: spread horizontally across the water's surface as the slick thins or is transported by tidal currents or winds; evaporate; disperse within the water column; and submerge either partially or fully (ITOPF, 2012). The weathering of oil in the marine environment will vary depending on type of spill, spilled volume, the oil, temperature and salinity of the water, and wind and wave conditions, and will have a significant effect on the utility of various responses and their effectiveness (Allen, 1988). While we note its importance, including oil weathering in this analysis would require a scenario-based approach that considers both a specific type of oil (as different oils will weather differently) and a spill time. Oil weathering depends on the duration of exposure to, for example, wind and waves in addition to knowing what the wind speed and wave height may be.

Not all systems and potential configurations are included. This study selected a set of systems that generally represent marine oil spill response systems that would be used in the Gulf of Mexico. Alternative combinations of vessels, components and configurations are possible, including some that are well known and proven. Other options are at various stages of the development process. The systems and associated limitations used are benchmarks by which the metocean conditions are assessed and categorized. Other systems will yield other results if their operating limits are different.

4 Metocean Dataset

Metocean data were drawn from both modeled and observational sources. Modeled data were used for wind speed, wave height, and horizontal visibility. Daylight and darkness were calculated. Observational data were used for cloud ceiling for a complementary analysis that focused on four locations near coastal airports. This section provides more information on the data sources used and characterizes the wind, waves, and visibility data used for the quantitative analysis throughout the study area.

4.1 Modeled Data Used for Wind, Waves, Visibility

This section describes the selected data sources and brief characterization of the conditions for wind, waves, and horizontal visibility. These parameters were used along with daylight/darkness for the primary quantitative analysis throughout the study area.

4.1.1 Oceanweather, Inc. data sources

When preparing data for a multiyear response viability analysis, data must both portray actual conditions (or as close as possible) and must be complete and consistent throughout the time period or geographic area studied. The following criteria were used to qualitatively assess sources of modeled metocean data for the project, resulting in the selection of the Oceanweather, Inc. sources:

- Are data built on a consistent time-series spanning the desired time frame?
- Do data cover the study area?
- Is the data presented at a scale that is both spatially appropriate for the study and at a temporal resolution to provide accurate results? (A spatial grid resolution of 50-km or less and temporal resolution of 6-hour time steps or less are preferred)
- Does a single source provide multiple metocean parameters under a common scheme?
- Are data reliable, in that they are updated regularly, from a credible source, and publicly accessible?
- Are datasets well documented, applicable, and referenced by other sources?

Table 4-1 summarizes the two Oceanweather, Inc. datasets used in this project.

Table 4-1. Sources of modeled data for wind, waves, and horizontal visibility

SOURCE	CONDITIONS	RESOLUTION	TIMESTEP	TIMESPAN
GOMOS2014 (Operational) update to GOMOS_USA (Oceanweather, Inc., 2015)	Wind Waves	12 km	Hourly	2005 - 2014[3]
GROW-MET (Oceanweather, Inc., 2016)	Horizontal visibility	35 km	Hourly	2005 - 2014

[3] Available from 1980-2014

GOMOS_USA data include the waters in the U.S. Gulf of Mexico north of 25 degrees North and greater than 10 m deep. A small area near southern Florida is south of 25 degrees North, but BSEE agreed (in the Geographic Areas Delineation Report, Deliverable 8) that this area would be excluded from the study. (There is currently no oil and gas production activity there.) The 10-m depth limit results in some differences in how close the study area goes to shore, including omitting the area around the mouth of the Mississippi River from the analysis (Oceanweather, Inc., 2015.

The two different spatial resolutions were harmonized into a consistent 12-km x 12-km grid structure based on the GOMOS2014 dataset. Raw data were processed into a geographic information system project.

4.1.2 Characterization of wind, waves, and horizontal visibility data

Figures 4-1, 4-2, and 4-3 characterize the wind, wave, and horizontal visibility data from the modeled datasets.

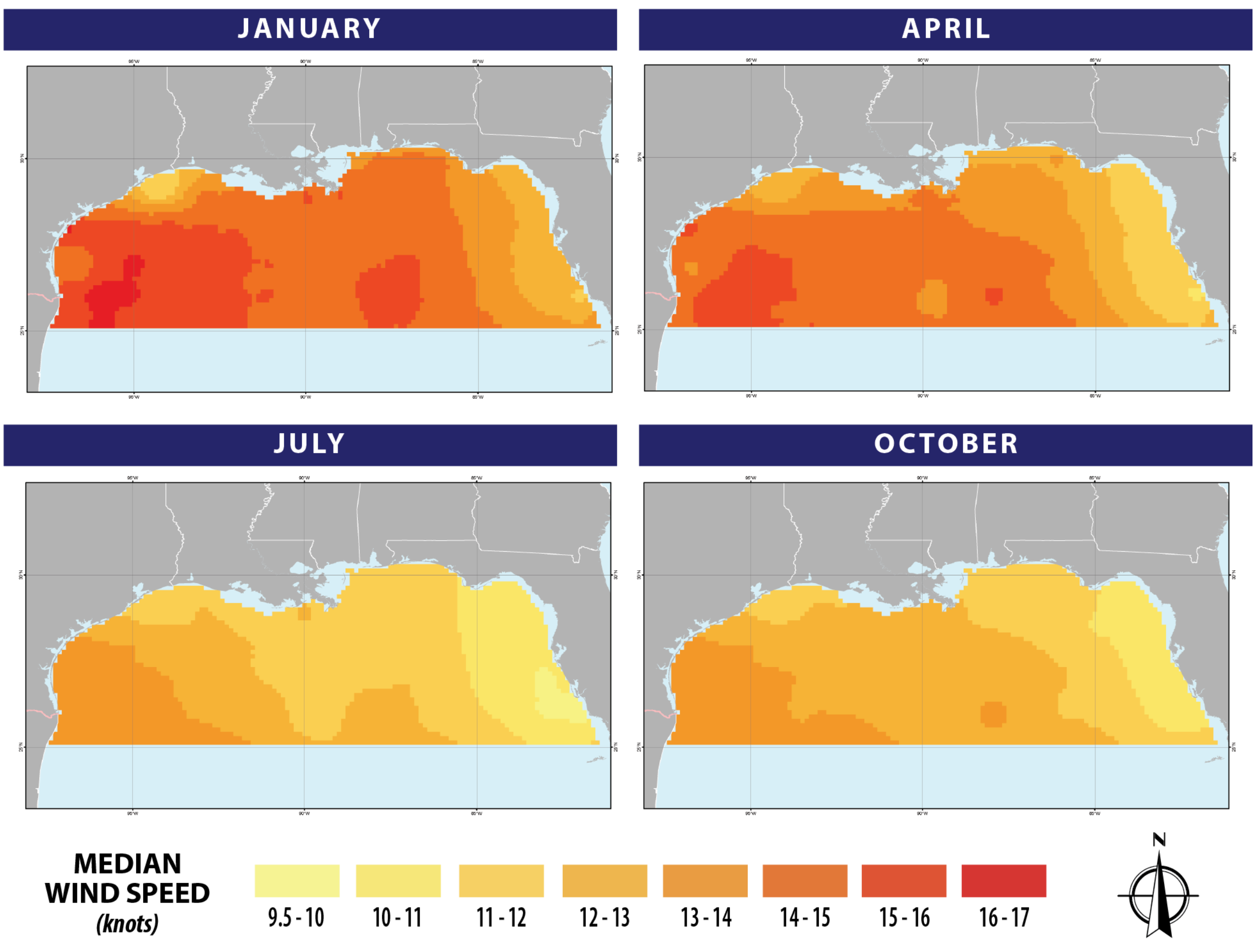


Figure 4-1. Median wind speed based on GOMOS_USA (2005-2014 data compiled for the response viability analysis)

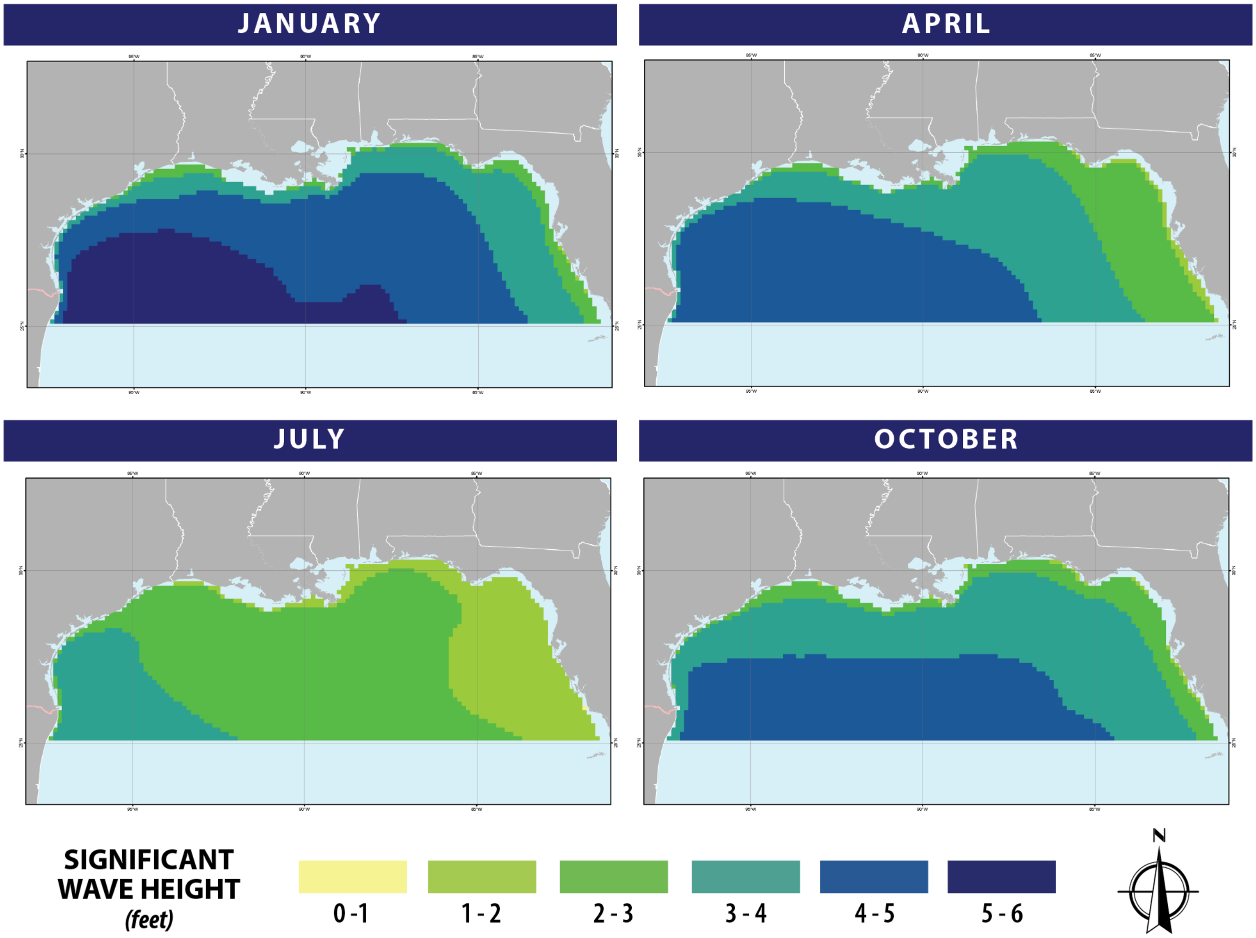


Figure 4-2. Mean significant wave based on GOMOS_USA (2005-2014 data compiled for the response viability analysis); mean and median wave heights are very similar

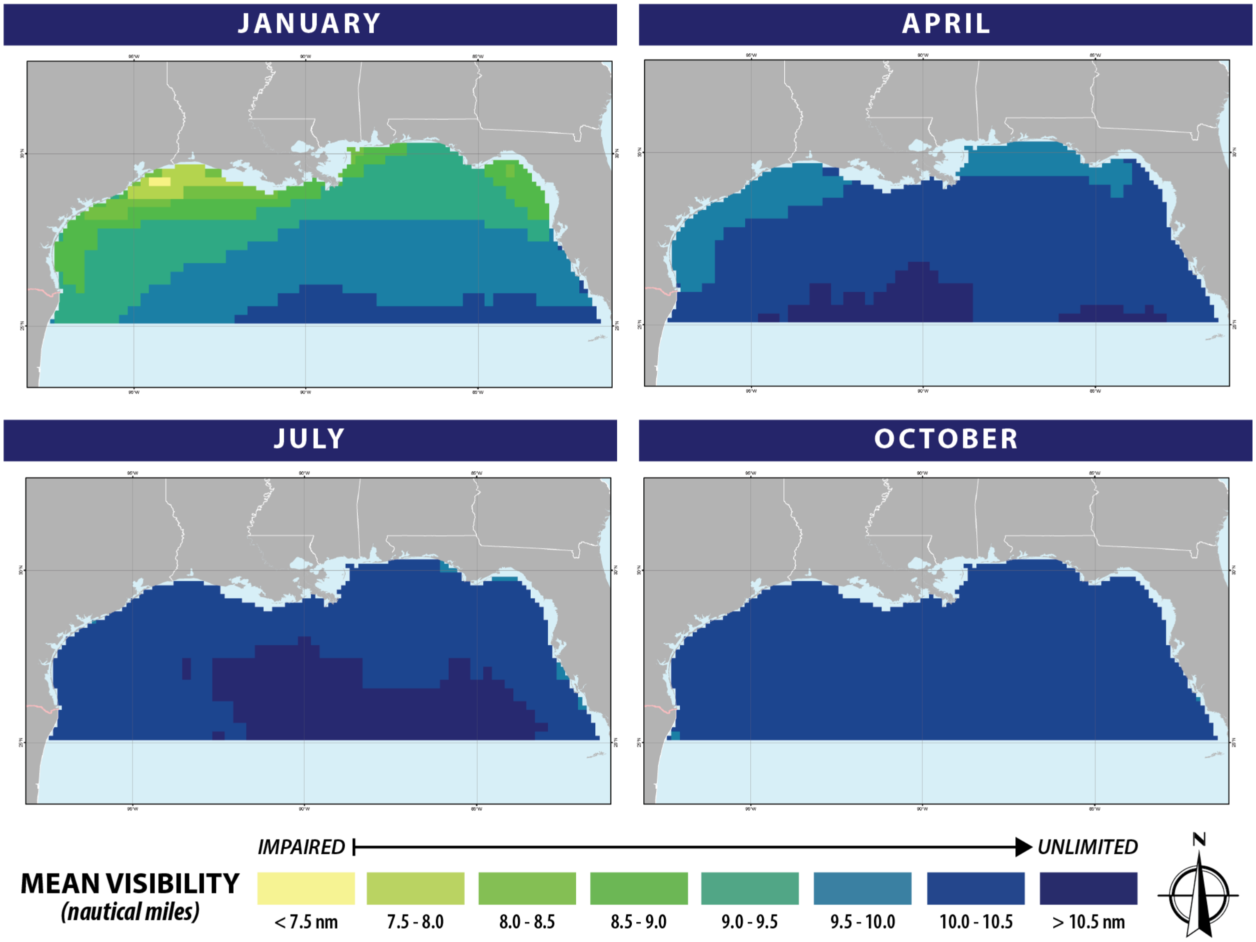


Figure 4-3. Mean horizontal visibility based on GOMOS_USA (2005-2014 data compiled for the response viability analysis)

4.2 Observational data from airports

Observational data would ideally be available for each of the parameters included in the metocean datasets, with data collected for all parameters at the same locations, across the same 10-year period, and with an even distribution geographically. Unfortunately, this is not the case.

The National Data Buoy Center provides data taken on (or in) marine areas that is collected from buoys, platforms, Coastal-Marine Automated Network (C-MAN) stations, and water quality stations. We identified 63 such sources of wind speed, wave height, and horizontal visibility data via NDBC. However, there was no single, cohesive source that had all necessary parameters. Even where one or two relevant parameters were identified, it was not always compiled and available for the desired 10-year period.

Some oil platforms collect horizontal visibility data,[4] but while this data is shared through the NDBC, it is collected by industry and not made available for longer than 45 days.[5] The National Oceanic and Atmospheric Administration (NOAA) displays the data, it does not archive it or conduct any quality control (pers. communication with Dawn Petraitis, Nov. 30, 2016).

Instead, the only observational data used were sky conditions as reported from airports. These data were sourced via the National Center for Environmental Information (https://www.ncdc.noaa.gov). Data were used only for the purpose of a limited, complementary analysis focused on cloud ceiling at four locations. Airports collect data on vertical visibility or cloud ceiling (as well as horizontal visibility and winds, though these were already available from buoys). Airport data is compiled and available for the desired 10-year period. Four airports were selected because they are near the shore and generally distributed around the study area. These are: Louis Armstrong Airport (Louisiana), Scholes International (Texas), Apalachicola Regional (Florida), and St. Petersburg-Clearwater Airport (Florida). (See Figure 4-4.) Data are from the same time period (2005-2014) as the gridded dataset.

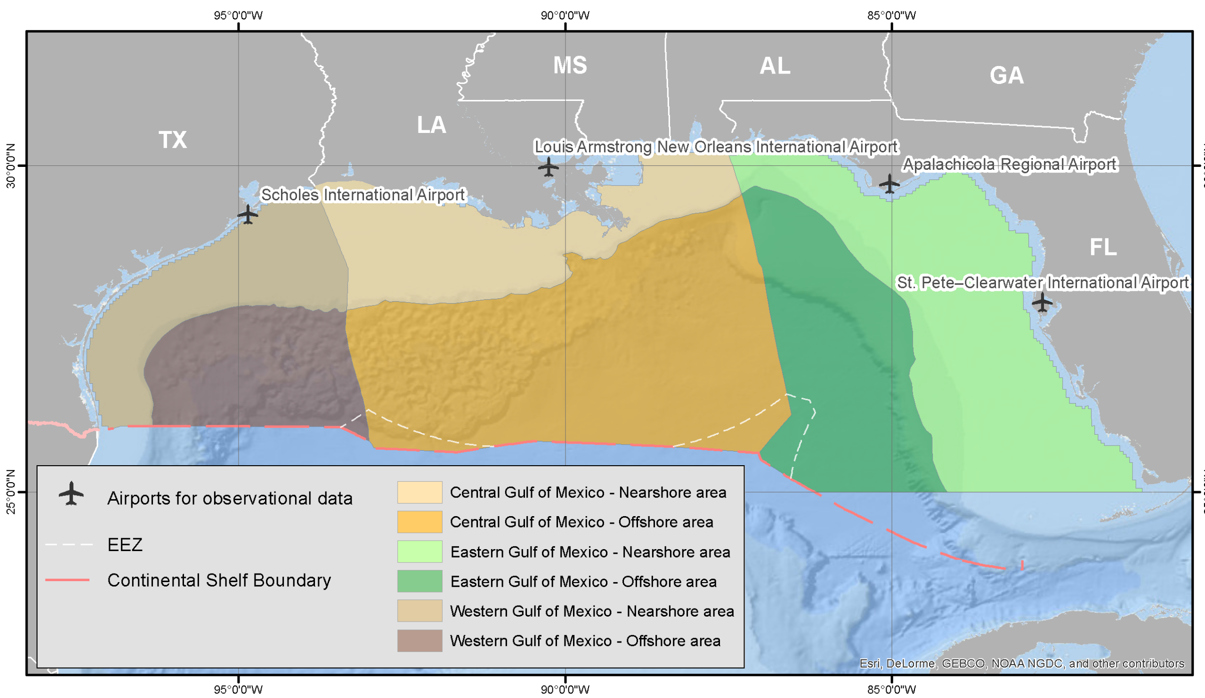


Figure 4-4. Airports used for observational data on vertical visibility for a limited, complementary analysis of the potential impact of cloud ceiling on response viability in those locations

4.3 Daylight and Darkness

Hours of daylight and darkness are calculated based on geographical position, with daylight including civil twilight. NOAA's solar calculator was applied to determine hours of daylight and darkness for each grid cell (NOAA, n.d.). During civil twilight, the geometric center of the sun's disk is at most 6 degrees below the horizon. In the morning, this twilight phase ends at sunrise;

[4] https://gis.ncdc.noaa.gov/maps/ncei/cdo/hourly
[5] We are still exploring sources for visibility data from GOM oil platforms, but to date have not located an archived dataset.

in the evening it begins at sunset. As the Earth's atmosphere scatters and reflects much of the sun's light, coloring the sky bright yellow and orange, artificial lighting is generally not required to carry out most outdoor activities during twilight hours when conditions are clear.

4.4 Summary of metocean parameters and associated data sources

Table 4-2 summarizes the parameters and data sources that we used in the response viability analysis. As needed, data values were converted to the units shown in this table.

Table 4-2. Summary of metocean parameters and data sources

PARAMETER	UNITS	DATA
Wind speed	Knots	GOMOS2014 (Operational)
Significant wave height	Feet	GOMOS2014 (Operational)
Daylight/darkness	Daylight = yes/no	Build into DNV GL custom code
Horizontal visibility	Nautical miles	GROW-MET
Ceiling	Feet	Airports – used as complementary analysis at five locations

5 Response Systems and Limits

The selection of operational systems and limits is a key component of a response viability analysis. System selection depends on the type of systems that may be used in the study area. In most places, there are several different types of systems and many potential variations and modifications depending on circumstances. There is no consistent, widely agreed upon source for this information (see discussion in Section 3.3). This section describes the approach to establishing systems and limits for this project.

5.1 Selection of Response Systems

In 2017, Nuka Research and DNV GL completed a response viability analysis of the circumpolar Arctic region for the Arctic Council's Emergency Prevention, Preparedness, and Response Workgroup (EPPR).[6] In that report, 10 response systems are described and limits presented for each of those systems. The limits were based on literature review and extensive review and input from experts, including industry, from the participating countries (EPPR, 2017). BSEE reviewed the system descriptions from that report, concluding that seven of the systems were similar to those that would be used in the Gulf of Mexico:

1. Mechanical Recovery – Two Vessels with Boom
2. Mechanical Recovery – Single Vessel with Outrigger
3. Mechanical Recovery – Three Smaller Vessels with Boom
4. Dispersants – Vessel Application
5. Dispersants – Fixed-wing Application
6. Dispersants – Helicopter Application
7. In-situ Burning – Vessels with Fire Boom

Three systems used in the EPPR study were excluded from the Gulf of Mexico analysis: a mechanical recovery system designed for use in high concentrations of sea ice and the use of helicopters to ignite an in-situ burn (either with or without herders). In the Gulf of Mexico, in-situ burning would require vessels and boom to contain the slick to the necessary thickness, so there would be no need to deploy a helicopter to ignite the slick.

The approach of using relevant and already-vetted response systems and corresponding limits was used for this project in place of a region-specific stakeholder process and literature review. Such an effort was outside the scope of the project as defined in the project solicitation. At the time this report was conducted, the limits from the EPPR project were the most recent available and reflected a robust review of the literature at the time in addition to the expert input referenced above.

5.2 Determining Operating Limits

Operating limits for the systems selected were already vetted during the EPPR project in which BSEE participated. There were two necessary modifications made to the response limits for the Gulf of Mexico analysis. First, the limits for sea ice, vessel superstructure icing, and air temperature were removed. These metocean parameters were assumed not relevant to the Gulf

[6] Sponsors included the U.S. (through BSEE), Norway, and Denmark.

of Mexico analysis and they are not part of the metocean dataset compiled. Second, wave height limits were modified for systems in which vessels deploy open-water containment boom. The wave height limits for such systems in the EPPR study exceeded the ASTM International ratings for boom used in the Gulf of Mexico. Based on input from BSEE, wave height limits for Mechanical Recovery – Two Vessels with Boom and In-situ Burning – Vessels with Fire Boom were modified.[7]

Limit values were rounded to whole numbers in using knots, feet, and nautical miles.

Limits used in this study are presented in this section. Appendix B summarizes the literature sources used when developing limits for the EPPR project for reference, although, as noted, that process also involved input from government and industry representatives.

Horizontal visibility-related limits are included, but these do not include detecting slick location. Instead, they assume that the on-water response systems include some technology to aid the system in targeting the slick in the immediate vicinity during darkness. The two aerial systems have horizontal visibility limits based on the safe operation of the aircraft and ability to visually target the slick.

The dataset used for the primary quantitative analysis does not include vertical visibility; however, these limits are shown in the tables in this section. Vertical visibility limits were used for the complementary analysis that incorporated cloud ceiling data from four airport locations.

5.3 Mechanical Recovery Systems

Three mechanical recovery systems were analyzed: two of these are intended primarily for offshore or open-water areas while the third uses smaller vessels (and smaller equipment) intended for shallower waters. All mechanical recovery systems require that vessels can operate safely with some need for crew to maneuver on deck. They all also require the use of containment boom to contain the oil and direct it to the skimming system for recovery.

[7] This change also aligned the limits with the wave height limits used in the U.S. Arctic study Nuka Research completed in 2016 (BSEE Project #1022).

5.3.1 Mechanical Recovery – Two Vessels with Boom

The Two Vessels with Boom system uses one vessel to deploy the skimmer, hold recovered fluids, and support one side of the containment boom. A second, smaller vessel tows the other end of the boom to provide a configuration that contains the oil for skimming. See Figure 5-1 and Tables 5-1 and 5-2.

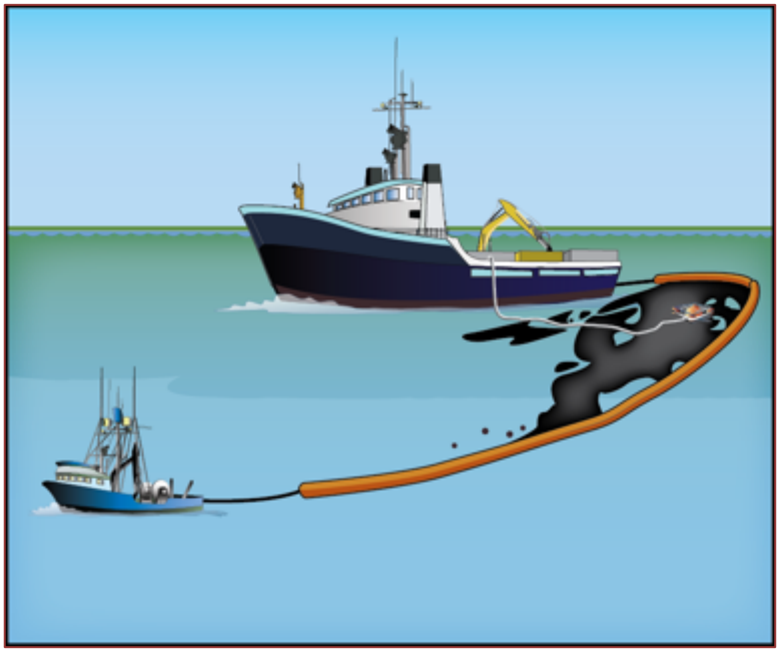


Figure 5-1. Mechanical Recovery – Two Vessels with Boom

Table 5-1. System components and baseline specifications for Mechanical Recovery – Two Vessels with Boom

SYSTEM COMPONENTS	BASELINE SPECIFICATIONS
Vessel platform	One 245 ft response vessel One 65 ft vessel to tow boom
Containment system	Boom suited up to 6 ft rough seas
Skimming system	High volume oleophilic skimmer suited up to 6 ft rough seas
Primary storage	Onboard response vessel
Other components	Detection technology - such as aerial observation or forward-looking infrared (FLIR) - to detect and track oil

Table 5-2. Operational limits for Mechanical Recovery – Two Vessels with Boom

METOCEAN PARAMETER	FAVORABLE	MARGINAL		NOT FAVORABLE
	Upper Boundary	Lower Boundary	Upper Boundary	Lower Boundary
Wind kts	≤ 21	21	35	≥ 35
Wind wave height ft	≤ 3	3	6	≥ 6
Light conditions (day/dark)	Daylight	Darkness		
Horizontal visibility nm	≥ 0.5	0.5	0.1	≤ 0.1
Vertical visibility ft	≥ 500	500	33	≤ 33

5.3.2 Mechanical Recovery – Single Vessel with Outrigger

The Single Vessel with Outrigger relies on a large vessel to support the skimmer, storage, and one end of the containment boom. An outrigger affixed to the vessel supports the boom. See Figure 5-2 and Tables 5-3 and 5-4.

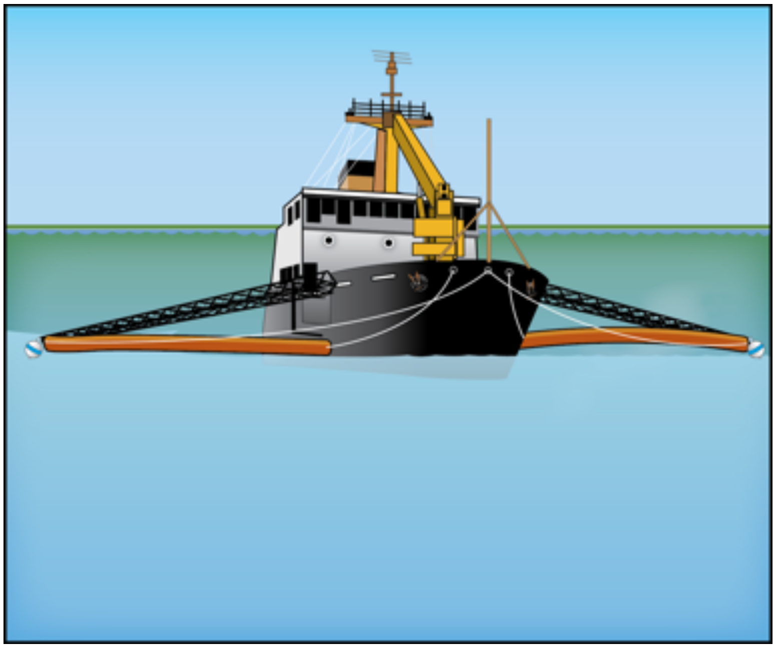


Figure 5-2. Mechanical Recovery – Single Vessel with Outrigger

Table 5-3. System components and baseline specifications for Mechanical Recovery – Single Vessel with Outrigger

SYSTEM COMPONENTS	BASELINE SPECIFICATIONS
Vessel platform	One 210 ft response vessel
Containment system	Two 45 ft spars with active containment system suited to waves up to 3 ft
Skimming system	Weir skimmer suited to operating in waves up to 3 ft
Primary storage	Towed storage
Other components	Detection technology (such as aerial observation or FLIR) to detect and track oil

Table 5-4. Operational limits for Mechanical Recovery – Single Vessel with Outrigger

METOCEAN PARAMETER	FAVORABLE	MARGINAL		NOT FAVORABLE
	Upper Boundary	Lower Boundary	Upper Boundary	Lower Boundary
Wind kts	≤ 21	21	33	≥ 33
Wind wave height ft	≤ 3	3	6	≥ 6
Light conditions (day/dark)	Daylight	Darkness		
Horizontal visibility nm	≥ 0.5	0.5	0.1	≤ 0.1
Vertical visibility ft	≥ 500	500	33	≤ 33

5.3.3 Mechanical Recovery – Three Smaller Vessels with Boom

This system uses three smaller vessels, likely vessels-of-opportunity. (Vessels-of-opportunity in the Gulf of Mexico may be offshore supply vessels, fishing vessels, or others that are not dedicated to oil spill response.) For this system, we assume fishing vessels or other vessels smaller than an offshore supply vessel that may be used in Mechanical Recovery – Two Vessels with Boom. One vessel deploys the skimmer and associated storage device, while the other two move the ends of the active booming system. The limits for this system are based on the use of equipment and vessels suited to more protected waters than the previous two systems described. See Figure 5-3 and Tables 5-5 and 5-6.

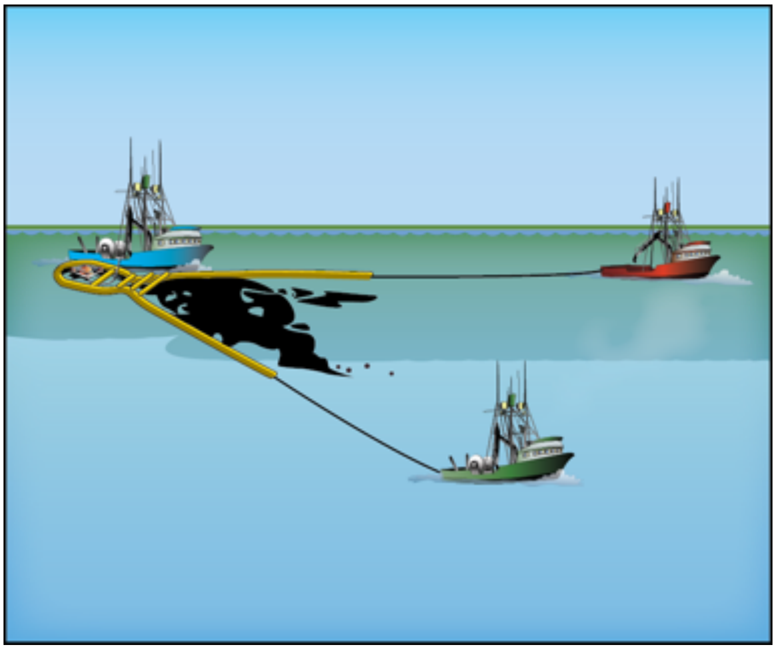


Figure 5-3. Mechanical Recovery – Three Smaller Vessels with Boom

Table 5-5. System components and baseline specifications for Mechanical Recovery – Three Smaller Vessels with Boom

SYSTEM COMPONENTS	BASELINE SPECIFICATIONS
Vessel platform	Three 50 – 65 ft vessels
Containment system	High-speed booming system suited to waves up to 3 ft
Skimming system	Oleophilic skimmer suited to waves up to 3 ft
Primary storage	Towed storage
Other components	Detection technology (such as aerial observation or FLIR) to detect and track oil

Table 5-6. Operational limits for Mechanical Recovery – Three Smaller Vessels with Boom

METOCEAN PARAMETER	FAVORABLE	MARGINAL		NOT FAVORABLE
	Upper Boundary	Lower Boundary	Upper Boundary	Lower Boundary
Wind kts	≤ 21	21	30	≥ 30
Wind wave height ft	≤ 2	2	3	≥ 3
Light conditions (day/dark)	Daylight	Darkness		
Horizontal visibility nm	≥ 0.5	0.5	0.1	≤ 0.1
Vertical visibility ft	≥ 500	500	33	≤ 33

5.4 Dispersant Systems

Three dispersant systems are analyzed. The dispersant systems vary only in terms of the platform from which the dispersants are applied, which will be either a vessel, fixed-wing aircraft, or helicopter.

5.4.1 Dispersants – Vessel Application

This system is intended to disperse oil floating on the surface by delivering a measured dose of dispersants in fine droplets from a vessel and mechanically agitating the slick and water column. See Figure 5-4 and Tables 5-7 and 5-8.

Figure 5-4. Dispersants – Vessel Application

Table 5-7. System components and baseline specifications for Dispersants – Vessel Application

SYSTEM COMPONENTS	BASELINE SPECIFICATIONS
Vessel platform	One 165 – 330 ft response vessel
Dispersant application system	33 ft dispersant spray arms
Other components	Detection technology (such as aerial observation or FLIR) to detect and track oil

Table 5-8. Operational limits for Dispersants – Vessel Application

METOCEAN PARAMETER	FAVORABLE	MARGINAL		NOT FAVORABLE
	Upper Boundary	Lower Boundary	Upper Boundary	Lower Boundary
Wind kts	≤ 21	21	39	≥ 39
Wind wave height ft	≤ 10	10	16	≥ 16
Light conditions (day/dark)	Daylight	Darkness		
Horizontal visibility nm	≥ 0.5	0.5	0.1	≤ 0.1
Vertical visibility ft	≥ 500	500	33	≤ 33

5.4.2 Dispersants – Fixed-wing Application

This system is intended to disperse oil floating on the surface by delivering a measured dose of dispersants in fine droplets from a fixed-wing aircraft. The system is comprised of an aerial spray aircraft and a spotter aircraft. See Figure 5-5 and Tables 5-9 and 5-10.

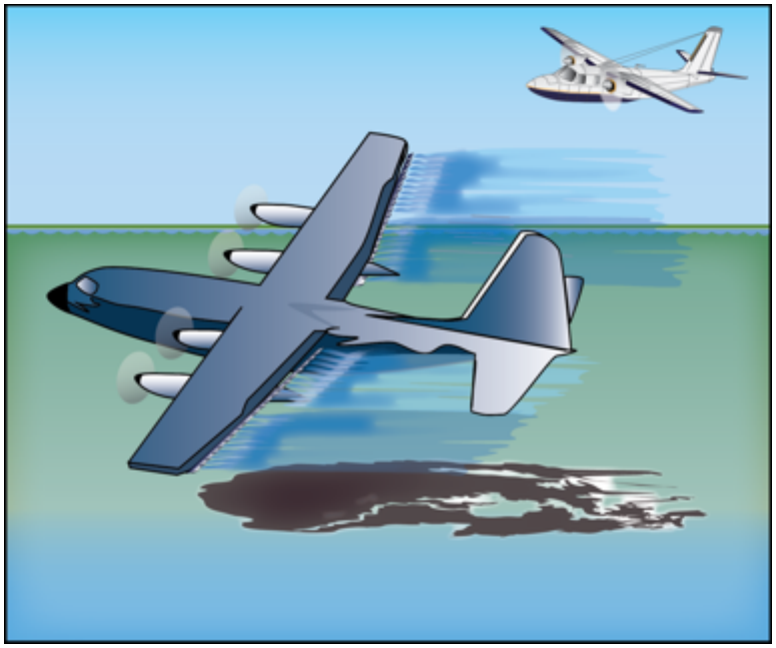


Figure 5-5. Dispersants – Fixed-wing Application

Table 5-9. System components and baseline specifications for Dispersants – Fixed-wing Application

SYSTEM COMPONENTS	BASELINE SPECIFICATIONS
Vessel platform	2 multi-engine fixed-wing aircraft, one for dispersant application, one for aerial spotting
Dispersant application system	Aerial high-volume dispersant application system
Other components	Detection technology (such as aerial observation or FLIR) to detect and track oil

Table 5-10. Operational limits for Dispersants – Fixed-wing Application

METOCEAN PARAMETER	FAVORABLE	MARGINAL		NOT FAVORABLE
	Upper Boundary	Lower Boundary	Upper Boundary	Lower Boundary
Wind kts	≤ 21	21	30	≥ 30
Wind wave height ft	≤ 10	10	16	≥ 16
Light conditions (day/dark)	Daylight			Darkness
Horizontal visibility nm	≥ 3	3	1	< 1
Vertical visibility ft	≥ 5000	5000	1000	≤ 1000

5.4.3 Dispersants – Helicopter Application

This system is intended to disperse oil floating on the surface by delivering a measured dose of dispersants in fine droplets from a device slung under a helicopter. See Figure 5-6 and Tables 5-11 and 5-12.

Figure 5-6. Dispersants – Helicopter Application

Table 5-11. System components and baseline specifications for Dispersants – Helicopter Application

SYSTEM COMPONENTS	BASELINE SPECIFICATIONS
Vessel platform	Twin engine jet helicopter
Dispersant application system	Aerial dispersant application system
Other components	Detection technology (such as aerial observation, FLIR) to detect and track oil

Table 5-12. Operational limits for Dispersants – Helicopter Application

METOCEAN PARAMETER	FAVORABLE	MARGINAL		NOT FAVORABLE
	Upper Boundary	Lower Boundary	Upper Boundary	Lower Boundary
Wind kts	≤ 21	21	30	≥ 30
Wind wave height ft	≤ 10	10	16	≥ 16
Light conditions (day/dark)	Daylight			Darkness
Horizontal visibility nm	≥ 1	1	0.5	< 0.5
Vertical visibility ft	≥ 1000	1000	500	≤ 500

5.4.4 In-situ Burning – Vessels with Fire Boom

This system is intended to remove oil floating on the surface by concentrating it to a sufficient thickness with boom, so that it will ignite and burn. Two boom-towing vessels contain the slick, which is also ignited from a vessel. See Figure 5-7 and Tables 5-13 and 5-14.

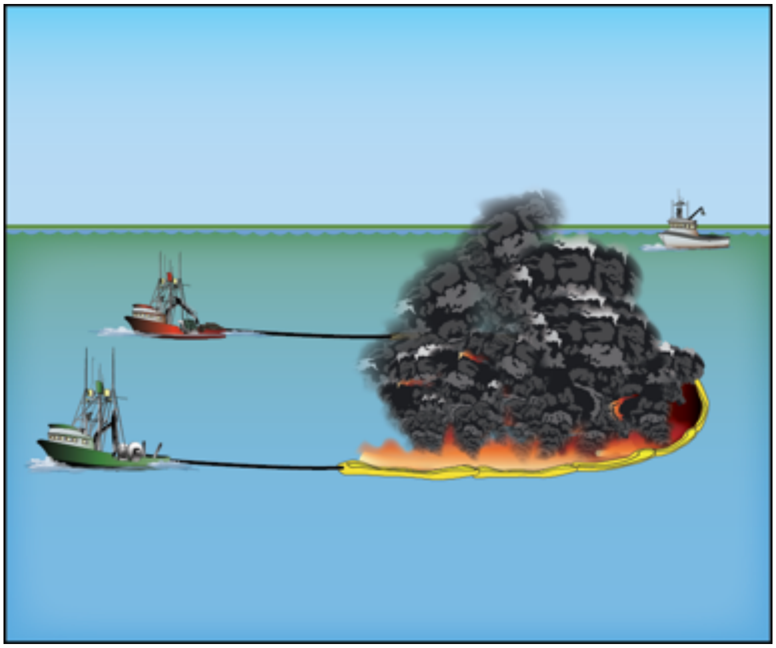


Figure 5-7. In-situ Burning – Vessels with Fire Boom

Table 5-13. System components and baseline specifications for In-situ Burning – Vessels with Fire Boom

SYSTEM COMPONENTS	BASELINE SPECIFICATIONS
Vessel platform	Three vessels
Containment system	Fire boom suitable for conditions up to 6 ft seas
Ignition system	Handheld gelled-fuel igniter, deployed from one of the towing vessels
Other components	Detection technology (such as aerial observation or FLIR) to detect and track oil

Table 5-14. System components and baseline specifications for In-situ Burning – Vessels with Fire Boom

METOCEAN PARAMETER	FAVORABLE	MARGINAL		NOT FAVORABLE
	Upper Boundary	Lower Boundary	Upper Boundary	Lower Boundary
Wind kts	≤ 10	10	20	≥ 20
Wind wave height ft	≤ 3	3	6	≥ 6
Light conditions (day/dark)	Daylight	Darkness		
Horizontal visibility nm	≥ 0.5	0.5	0.1	≤ 0.1
Vertical visibility ft	≥ 500	500	33	≤ 33

5.5 Summary of Response Limits

Figure 5-8 presents the response limits in a set of green, yellow, and red bars, showing the limits organized by response system. For another view, Figure 5-9 presents the same limits, but organized by metocean parameter. In the grid to the left of the bars, a black dot indicates which response system – or systems – relates to which limit bar. In this view, the similarities among systems that use the same platform are evident.

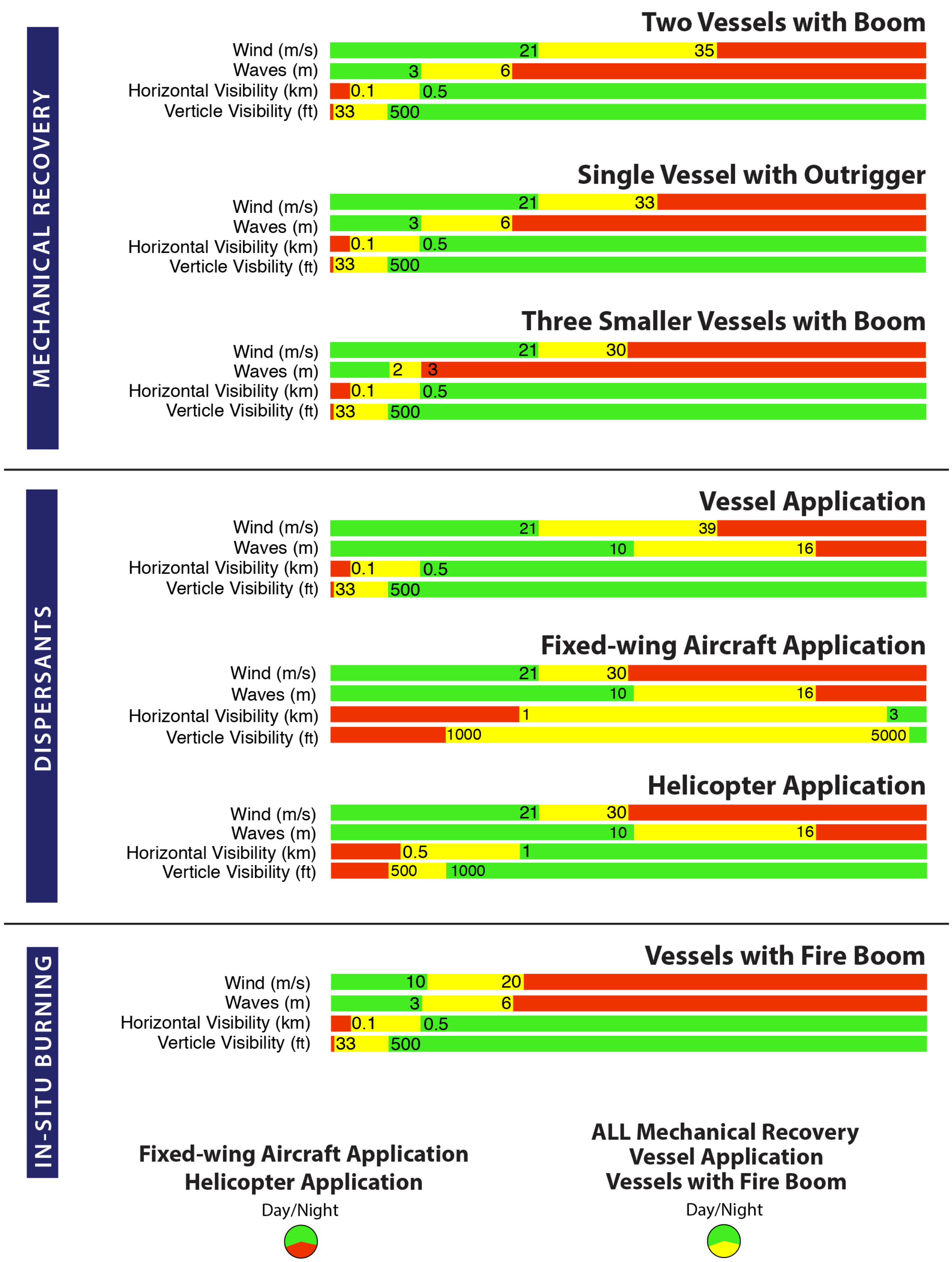


Figure 5-8. Comparison of response limits used for each system studied – organized by system

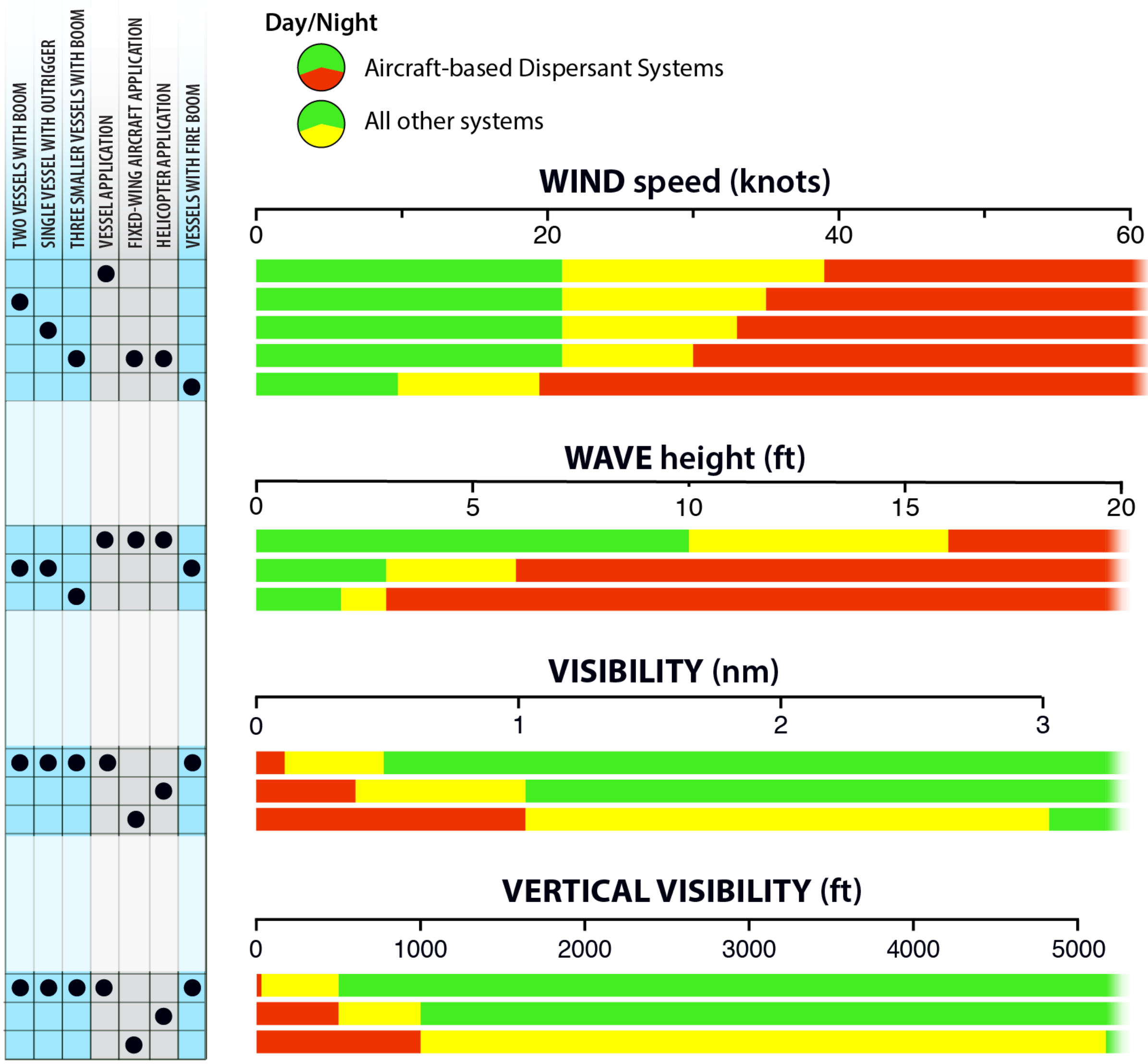


Figure 5-9. Comparison of response limits - organized by metocean condition

6 Results

This section presents the results of the analysis, first by response strategy, then by comparing response strategies. For each response strategy, we present the numerical results by month and annually averaged across the region. For the mechanical recovery and dispersants strategies, map-based results are shown for January and July for the system that was most likely to be viable (i.e., for which conditions were most likely to be favorable or marginal as compared to the other systems in that strategy). Finally, annual cycle graphics are used to illustrate the relative impact of the metocean conditions studied on the results, again with a focus on the most viable system for each strategy. (For in-situ burning, these results are shown for the single system studied.)

The sensitivity analysis and consideration of the impact of vertical visibility on the results follow. Appendix A includes the results maps for each system for each of the four focus months (January, April, July, and October).

6.1 Viability by Response Strategy

This section presents the overall results by response strategy, using the select single location analysis results to illustrate the metocean conditions with the strongest influence on the results.

6.1.1 Mechanical recovery

Conditions for the two larger mechanical recovery systems (Two Vessels with Boom and Single Vessel with Outrigger) are marginal most of the time except July and August, when they are more likely to be favorable. For the smaller system, Three Smaller Vessels with Boom, conditions are less likely to be favorable. See Table 6-1.

Table 6-1. Results for whole area by month for mechanical recovery systems (all years combined)

System	Conditions	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
2 vessels w/ boom	FAV	15%	18%	21%	23%	34%	45%	49%	49%	38%	24%	18%	17%	**29%**
	MAR	65%	64%	64%	66%	61%	52%	48%	49%	56%	63%	64%	63%	**60%**
	NOT_FAV	21%	18%	16%	11%	5%	3%	3%	2%	6%	13%	18%	20%	**11%**
Single vessel w/ outrigger	FAV	15%	18%	21%	23%	34%	45%	49%	49%	38%	24%	18%	17%	**29%**
	MAR	65%	64%	64%	66%	61%	52%	48%	49%	56%	63%	64%	63%	**60%**
	NOT_FAV	21%	18%	16%	11%	5%	3%	3%	2%	6%	13%	18%	20%	**11%**
3 Smaller vessels w/ boom	FAV	5%	7%	8%	9%	18%	25%	29%	33%	21%	11%	8%	6%	**15%**
	MAR	27%	29%	31%	31%	39%	47%	52%	51%	48%	36%	30%	29%	**38%**
	NOT_FAV	68%	64%	61%	60%	43%	28%	20%	17%	31%	53%	63%	65%	**48%**

The two larger mechanical recovery systems also have the same overall numeric results across the entire study area. Figure 6-1 presents mapped results for the focus months of January and July, representing the focus months in which conditions are *most* and *least* likely to be favorable for Mechanical Recovery – Two Vessels with Boom (as well as Single Vessel with Outrigger). Conditions in January are most likely to be marginal across the whole area; when they are not, they are more likely favorable to the far east and in the “nearshore” study area divisions, while more likely not favorable in the western waters and three “offshore” divisions. July results show mostly favorable and marginal conditions across the region.

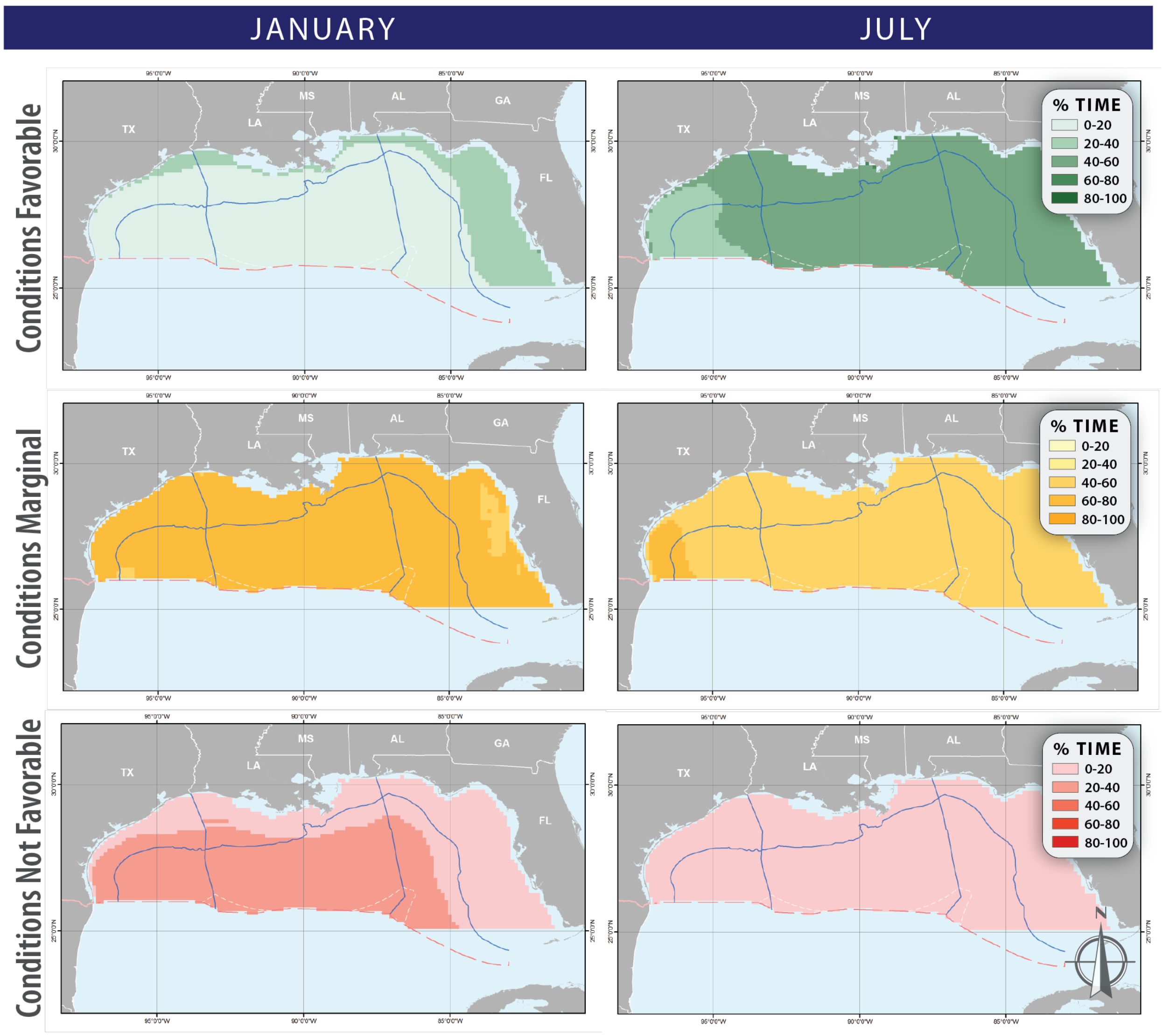
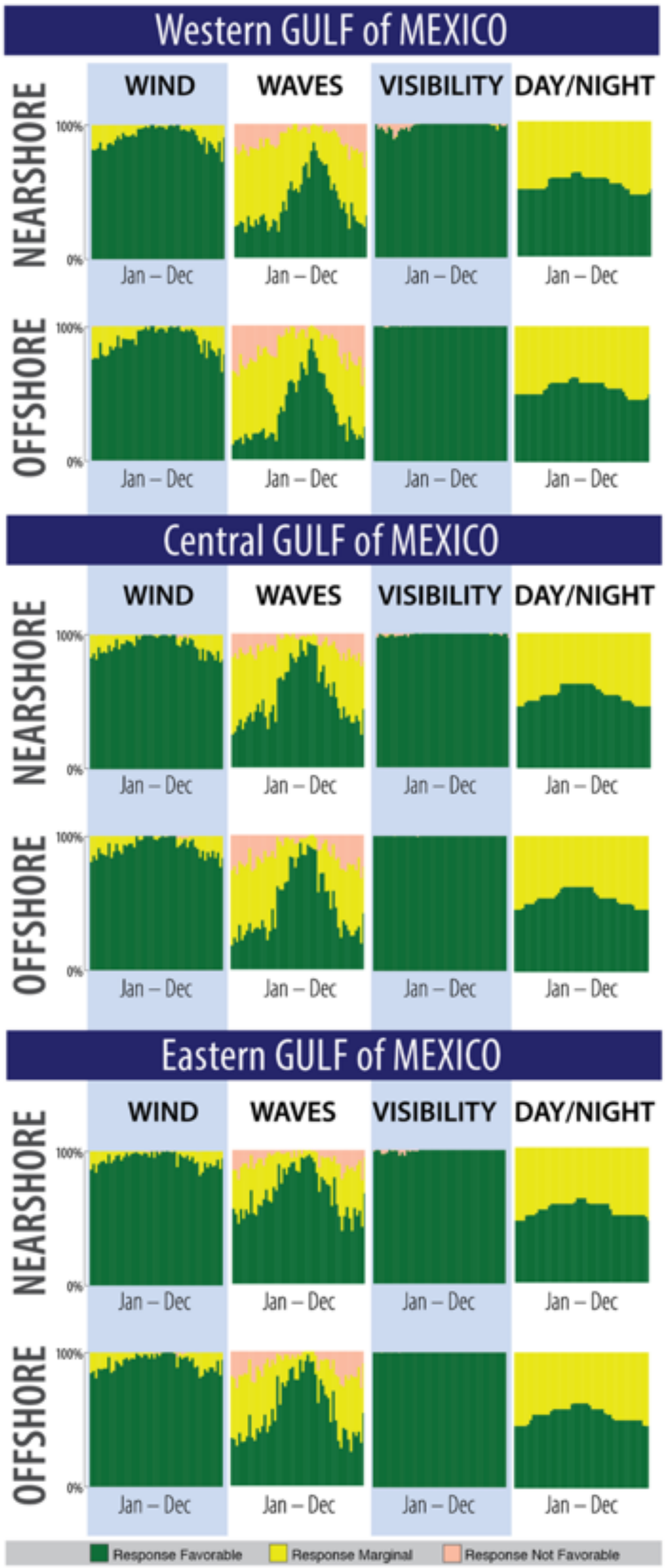


Figure 6-1. Selection of results maps for Mechanical Recovery – Two Vessels with Boom for January and July, representing the focus months in which conditions are most and least likely to be viable for this system across the study area



Understanding Annual Cycle Graphics

Annual cycle graphics show the results for a single location (grid cell) with all years of data combined. From January – December (x-axis), the percentage of green, yellow, or red conditions is tabulated and presented on the y-axis. The jagged edges each represent one week. These figures are used to illustrate which metocean condition – or conditions – dominate the results. Where they exist, seasonal patterns are also evident.

Annual cycle graphics are used in Figures 6-2, 6-4, and 6-6 to show the results for each metocean condition alone.

Figure 6-2 shows the cycle graphics for Mechanical Recovery – Two Vessels with Boom.

Of the metocean conditions in the dataset, waves were most likely to be marginal or not favorable across the study area. Wave height was mostly likely to be not favorable for this system at these six locations. (With the exception of some brief periods of poor visibility in the winter in the nearshore areas, visibility is mostly favorable.)

Wind also had an effect, but this was less significant than waves, and only resulted in marginal conditions at worst in the nearshore areas. As would be expected, daylight/darkness was favorable roughly half the time, and slightly more so in summer.

Figure 6-2. Results for Mechanical Recovery – Two Vessels with Boom based on individual conditions

6.1.2 Dispersants

For the three dispersant systems studied, whether they are deployed from a vessel or aircraft (fixed wing or helicopter) is the key difference. For the vessel system, conditions are favorable or marginal 99% of the year across the study area. Conditions for both aircraft-based systems are either favorable or marginal 54% of the year across the study area. The key difference is in whether the systems are assumed to be able to operate in darkness: darkness is considered not favorable to the two aircraft-based systems, but marginal for the vessel-based system. (See Table 6-2). Figure 6-3 shows the map-based results for the Dispersants – Vessel application system, which was the system for which conditions were most likely to be favorable or marginal of all the systems.

Table 6-2. Results for whole area by month for dispersant systems (all years combined)

System	Conditions	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
Dispersants - Vessel	**FAV**	40%	44%	48%	54%	58%	60%	60%	57%	53%	47%	42%	40%	**50%**
	MAR	59%	55%	51%	46%	42%	40%	40%	42%	47%	53%	58%	60%	**49%**
	NOT_FAV	1%	1%	1%	0%	0%	0%	0%	0%	1%	0%	0%	0%	**1%**
Dispersants - Fixed-wing	**FAV**	40%	43%	47%	53%	58%	60%	60%	57%	53%	47%	42%	40%	**50%**
	MAR	7%	7%	5%	4%	2%	1%	1%	1%	2%	4%	6%	7%	**4%**
	NOT_FAV	53%	51%	48%	43%	40%	39%	40%	42%	46%	49%	52%	54%	**46%**
Dispersants - Helicopter	**FAV**	40%	43%	48%	53%	58%	60%	60%	57%	53%	47%	42%	40%	**50%**
	MAR	7%	6%	5%	3%	2%	1%	1%	1%	2%	4%	6%	7%	**4%**
	NOT_FAV	53%	51%	48%	43%	40%	39%	40%	42%	46%	49%	52%	53%	**46%**

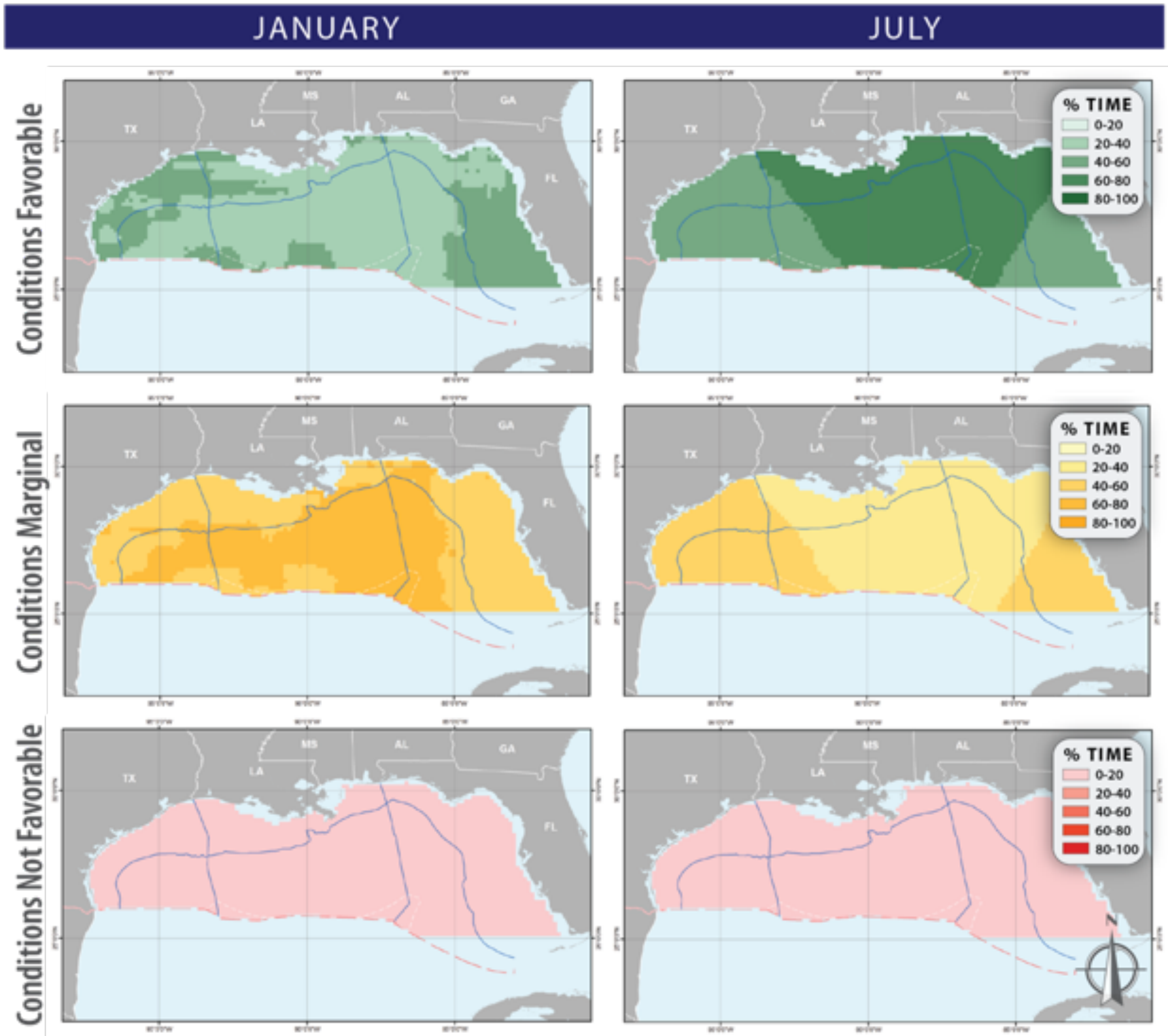


Figure 6-3. Results maps for Dispersants - Vessel Application for January and July, representing the focus months in which conditions are most and least likely to be viable for this system across the study area

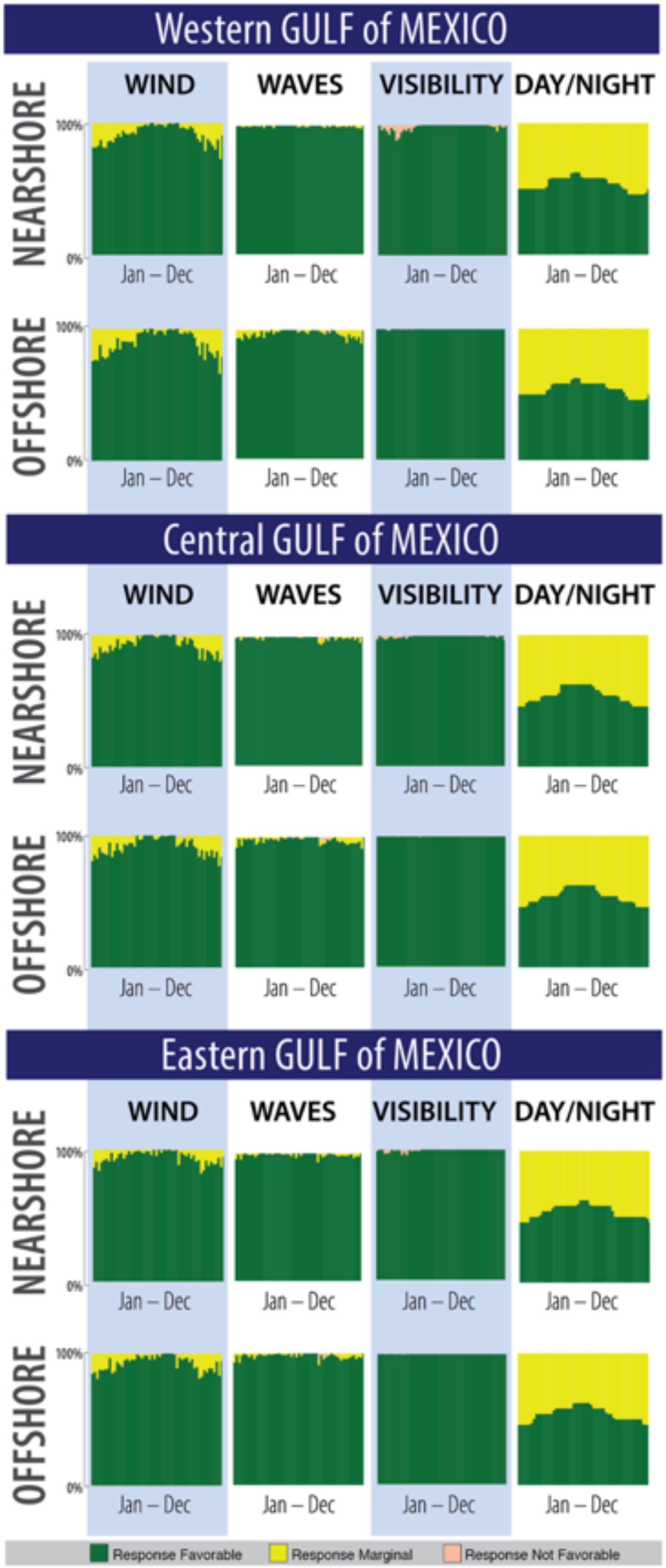


Figure 6-4. Results for Dispersants – Vessel Application based on individual conditions

The dispersant systems analyzed are much more tolerant of wind and waves compared to the mechanical recovery and in-situ burning systems analyzed. Visibility has the same minimal effect on all vessel-based systems, as shown in cycle graphics for Mechanical Recovery – Two Vessels with Boom (Figure 6-2) and Vessels with Fire Boom (Figure 6-6).

Aerial systems are less tolerant of limited visibility conditions than the vessel-based systems, with aircraft needing better visibility than helicopters. However, based on the conditions in the metocean dataset, this does not have much of an effect on the results for either system. Instead, the primary difference in viability between applying dispersants from a vessel or aircraft is in whether darkness is considered marginal (as for a vessel) or not favorable (as for both fixed-wing aircraft and helicopters). Results for the aerial systems are thus almost exactly the same as shown in Figure 6-4 for Dispersants – Vessel Application, except that the yellow shading in “Day/Night” would be red for both aerial systems, thus resulting in the difference in overall numerical results shown in Table 6-2 where conditions are found to be not favorable for vessel application of dispersants just 1% of the time, but 46% of the time if from an aircraft.

The annual cycle graphics in Figure 6-4 show the results by metocean condition for Dispersants – Vessel Application.

6.1.3 In-situ burning

One in-situ burning system was analyzed (Vessels with Fire Boom). Similar to the mechanical recovery systems that also rely on the use of containment boom deployed from a vessel, conditions for the in-situ burning system are marginal most of the time during the year (68%). January and July also represent the focus months in which conditions are more likely to be not favorable or favorable, respectively (see Figure 6-5). Table 6-3 shows the numerical results for the entire study area by month and for the entire year.

Table 6-3. Results for whole area by month for Vessels with Fire Boom (all years combined)

System	Conditions	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
In-situ burning	FAV	7%	10%	11%	13%	22%	33%	38%	38%	24%	13%	9%	8%	**19%**
	MAR	68%	68%	71%	74%	72%	64%	59%	59%	69%	72%	70%	68%	**68%**
	NOT_FAV	25%	22%	18%	14%	6%	3%	3%	3%	7%	16%	22%	24%	**14%**

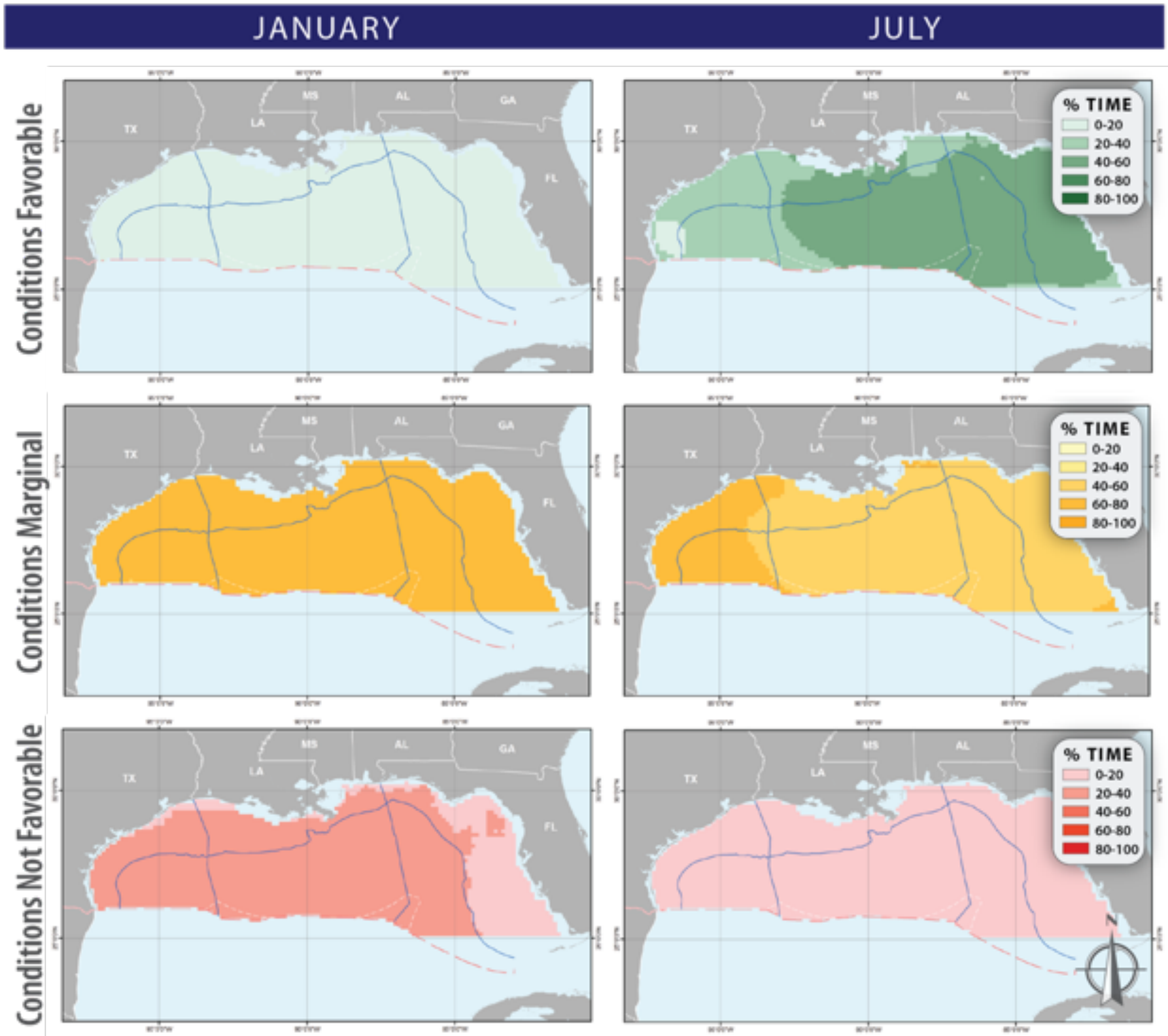
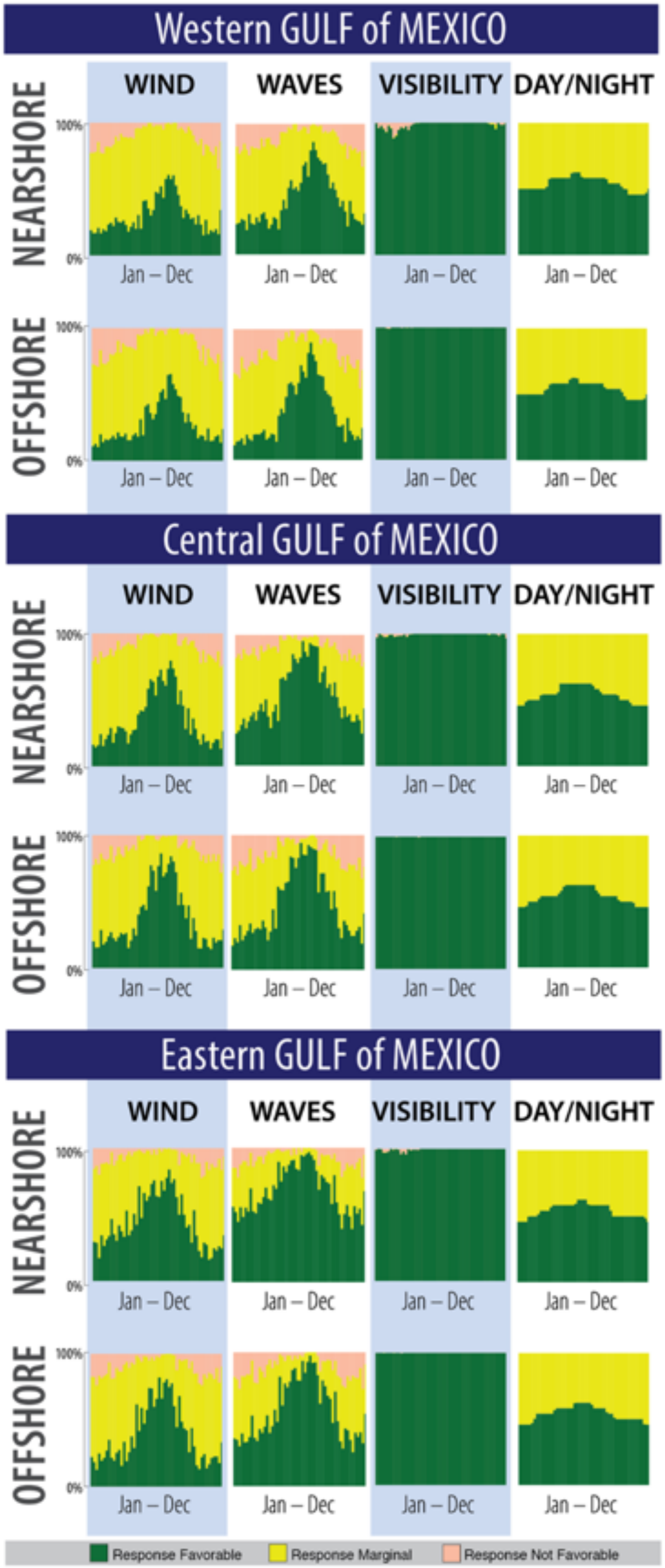


Figure 6-5. Results maps for In-situ Burning – Vessels with Fire Boom for January and July, representing the focus months in which conditions are most and least likely to be viable for this system across the study area


Western GULF of MEXICO
WIND
WAVES
VISIBILITY
DAY/NIGHT
NEARSHORE
OFFSHORE
100%
0%
Jan – Dec
Central GULF of MEXICO
WIND
WAVES
VISIBILITY
DAY/NIGHT
NEARSHORE
OFFSHORE
Jan – Dec
Eastern GULF of MEXICO
WIND
WAVES
VISIBILITY
DAY/NIGHT
NEARSHORE
OFFSHORE
Jan – Dec
Response Favorable
Response Marginal
Response Not Favorable

The cycle graphics (Figure 6-6) show the impact of wind and waves on the in-situ burning system. The numerical results calculated for the entire study area are very similar for this system as compared to the two larger mechanical recovery systems. However, the difference in results is driven by the lower wind limit for in-situ burning as compared to the mechanical recovery systems. Wind affects not only containment, but the ability to ignite and sustain a burn. The few times when horizontal visibility would be not favorable (Jan-March and again in December), conditions at these locations are already not favorable due to both wind and waves.

6.2 System Comparison

Figure 6-7 shows the percentage of time conditions were favorable, marginal, or not favorable for each of the systems studied based on the metocean dataset. These summary results are averaged across the entire study area. Conditions are by far the most likely to be either favorable or marginal for Dispersants – Vessel Application as compared to other systems analyzed. Conditions were marginal for the two larger mechanical recovery systems 60% of the time, but 20% less likely to be favorable than any of the dispersant systems. Conditions were more likely to be marginal for the in-situ burning system than for any of the other systems, but were only favorable 19% of the time.

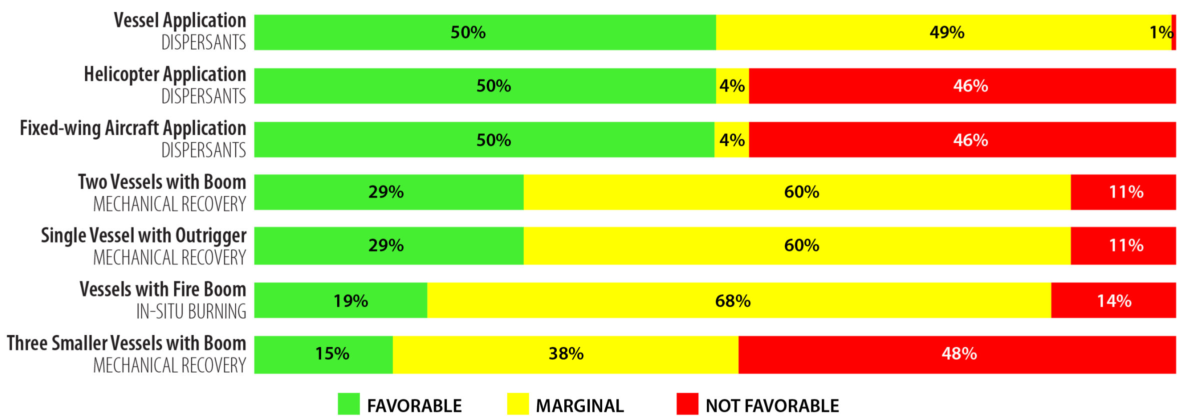


Figure 6-7. Annual percentage of time that conditions are favorable, marginal, or not favorable for response systems studied (averaged for entire study area)

Overall, variability is limited across the 6 divisions created by bisecting the three BOEM planning areas. With results averaged across each division, conditions for Dispersants - Vessel Application are favorable or marginal *at least* 96% of the time in all months. (The only month in which conditions were not favorable more than 4% of the time was in February in the Western GOM-Nearshore.)

Figure 6-8 presents the percentage of time conditions were favorable, marginal, or not favorable in of the six divisions across the whole year. See Appendix C for results for each area by month. There was less variability across the six divisions for the dispersant systems. The dispersant systems do not rely on boom and are thus less susceptible to the effect of waves or wind than the mechanical recovery and in-situ burning systems studied. Results for Mechanical Recovery – Three Small Vessels with Boom, which is the *most* susceptible to waves, varied the most across the region.

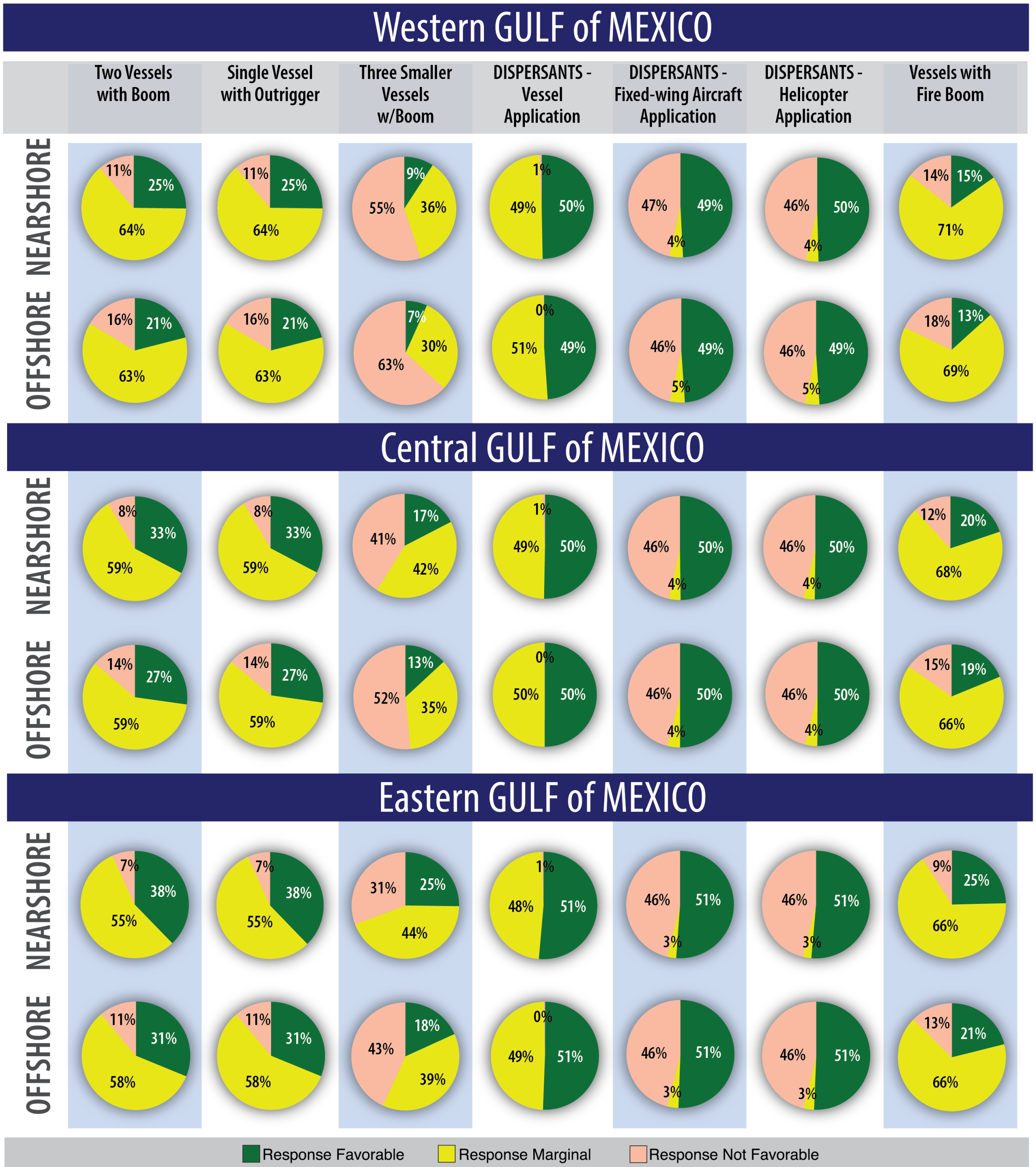


Figure 6-8. Overall results by system for each of the six divisions of the Gulf of Mexico used for this project

6.3 Sensitivity Analysis

The sensitivity analysis considered the impact on the results if all systems were made more tolerant to wind speed or wave height. The purpose of this sensitivity analysis is to explore potential increases to response viability *if* system tolerance could be increased. Systems are examined without judgment as to whether such increases are under development or likely, or what impact such increases may have on the efficiency or effectiveness of the system. As with the overall analysis, the purpose is to explore the likelihood of being able to deploy a given system and have it generally operate as intended. It is also assumed that any increases must be achieved without compromising safety.

Table 6-4 presents the results of the sensitivity analysis of wind speed for each of the response systems studied; Figure 6-9 depicts the same results. Note that the mechanical recovery systems show no increase in response viability when tolerance to wind speed is increased up to eight knots. Dispersant systems show a small increase in response viability as tolerance to wind speed is increased. However, for In-situ Burning – Vessels with Fire Boom, which has the lowest wind speed limits, response viability is increased by up to 10% as tolerance to wind speed is increased.

Table 6-4. Percentage change in results from increasing tolerance to wind speed by 2, 4, 6, and 8 knots as compared to the baseline results

			PERCENT (%) Change from INCREASE AT G/Y, Y/R Transitions			
System	**Conditions**	**Baseline**	**2 kt**	**4 kt**	**6 kt**	**8 kt**
2 Vessels w/ Boom	FAV	29.2%	0.0%	0.0%	0.0%	0.0%
	MAR	59.5%	0.0%	0.0%	0.0%	0.0%
	NOT_FAV	11.3%	0.0%	0.0%	0.0%	0.0%
Single Vessel w/ Outrigger	FAV	29.2%	0.0%	0.0%	0.0%	0.0%
	MAR	59.5%	0.0%	0.0%	0.0%	0.0%
	NOT_FAV	11.3%	0.0%	0.0%	0.0%	0.0%
3 Smaller Vessels w/ Boom	FAV	15.0%	0.0%	0.0%	0.0%	0.0%
	MAR	37.5%	0.0%	0.0%	0.0%	0.0%
	NOT_FAV	47.5%	0.0%	0.0%	0.0%	0.0%
Dispersants - Vessel	FAV	50.2%	1.5%	2.4%	2.9%	2.9%
	MAR	49.4%	-1.6%	-2.4%	-1.6%	-1.6%
	NOT_FAV	0.5%	0.0%	0.0%	0.0%	0.0%
Dispersants - Fixed-wing	FAV	50.0%	1.5%	2.3%	2.8%	2.8%
	MAR	3.8%	-1.5%	-1.5%	-1.5%	-1.5%
	NOT_FAV	46.3%	0.0%	-0.1%	-0.1%	-0.1%
Dispersants - Helicopter	FAV	50.1%	1.6%	1.6%	1.6%	1.6%
	MAR	3.6%	-1.4%	-2.2%	-2.8%	-2.8%
	NOT_FAV	46.3%	-0.1%	-0.2%	-0.2%	-0.2%
In-situ Burning – Vessels with Fire Boom	FAV	18.8%	5.7%	9.2%	10.4%	10.4%
	MAR	67.7%	-4.1%	-7.1%	-8.1%	-8.1%
	NOT_FAV	13.5%	-1.6%	-2.0%	-2.2%	-2.2%

Figure 6-9. Percentage change in results from increasing tolerance to wind speed by 2, 4, 6, and 8 knots as compared to the baseline results

Table 6-5 presents the results of the sensitivity analysis of wave height for each of the response systems studied; Figure 6-10 depicts the same results. Note that the dispersant systems show no gains in in response viability when tolerance to wave height is increased up to four feet. By contrast, mechanical recovery systems show an increase in the time when conditions are favorable up to 30% as tolerance to wave height is increased. As should be expected the Smaller Vessels with Boom system, already the most sensitive to wave height, benefits the most from an increased tolerance to wave height. In-situ burning response viability is increased only a few percent as tolerance to wave height is increased.

Table 6-5. Percentage change in results from increasing tolerance to wave height by 1, 2, 3, and 4 feet as compared to the baseline results

			PERCENT (%) Change from INCREASE AT G/Y, Y/R Transitions			
System	**Conditions**	**Baseline**	**1ft**	**2ft**	**3ft**	**4ft**
2 Vessels w/ Boom	**FAV**	29.2%	9.6%	15.3%	18.5%	20.1%
	MAR	59.5%	-5.4%	3.1%	4.7%	5.2%
	NOT_FAV	11.3%	-4.2%	-6.8%	-11.3%	-9.4%
Single Vessel w/ Outrigger	**FAV**	29.2%	9.6%	15.3%	18.5%	20.1%
	MAR	59.5%	-5.4%	-8.5%	-8.5%	-10.1%
	NOT_FAV	11.3%	-4.2%	-6.8%	-8.4%	-9.4%
3 Smaller Vessels w/ Boom	**FAV**	15.0%	14.2%	23.8%	29.5%	32.7%
	MAR	37.5%	4.0%	5.7%	6.7%	7.7%
	NOT_FAV	47.5%	-18.2%	-29.4%	-36.2%	-40.4%
Dispersants - Vessel	**FAV**	50.2%	0.0%	0.0%	0.0%	0.0%
	MAR	49.4%	0.0%	0.0%	0.0%	0.0%
	NOT_FAV	0.5%	-0.1%	-0.1%	-0.1%	-0.1%
Dispersants - Fixed-wing	**FAV**	50.0%	0.0%	0.0%	0.0%	0.0%
	MAR	3.8%	-0.1%	-0.1%	-0.1%	-0.1%
	NOT_FAV	46.3%	0.0%	0.0%	0.0%	0.0%
Dispersants - Helicopter	**FAV**	50.1%	0.1%	0.1%	0.1%	0.1%
	MAR	3.6%	0.0%	0.0%	0.0%	0.0%
	NOT_FAV	46.3%	0.0%	0.0%	0.0%	0.0%
In-situ Burning	**FAV**	18.8%	1.4%	1.9%	2.0%	2.0%
	MAR	67.7%	0.8%	1.2%	1.4%	1.4%
	NOT_FAV	13.5%	-2.3%	-3.1%	-3.4%	-3.4%

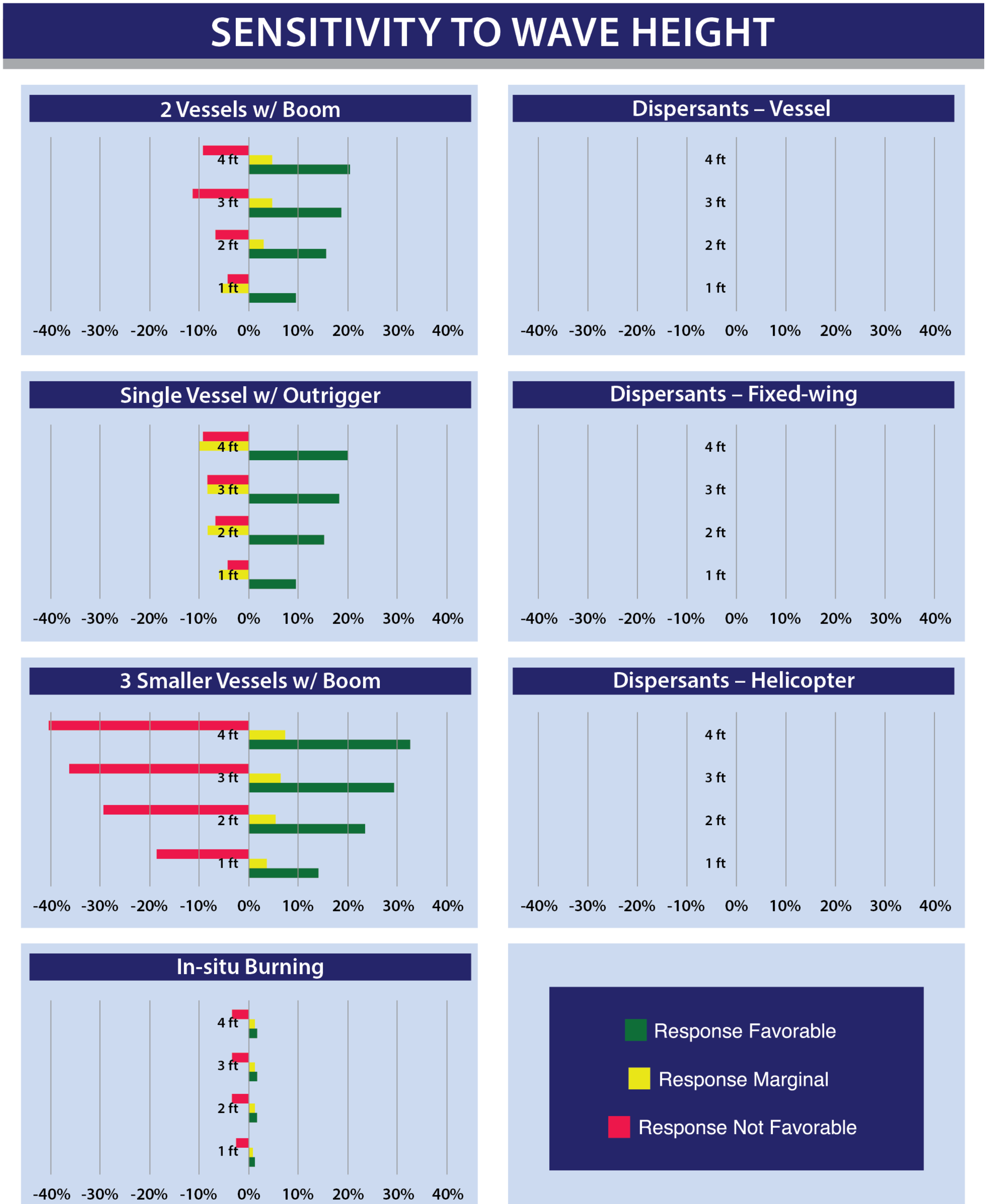


Figure 6-10. Percentage change in results from increasing tolerance to wave height by 1, 2, 3, and 4 feet as compared to the baseline results

Overall, the sensitivity analysis shows that the response viability for mechanical recovery systems studied are not limited by wind speed in the Gulf of Mexico but their response viability could be increased if they could operate in higher wave heights. The in-situ burning system is just the reverse; it shows little change in viability when tolerance to wave height is increased, but if it could be done in higher winds conditions may be favorable 10% more of the time. The dispersant systems studied show no increase in response viability if tolerance to wave height is improved and only a slight increase if tolerance to wind speed is increased.

6.4 Potential Impact of Vertical Visibility on Results

The potential effect of cloud ceiling on the response was explored by adding observational cloud ceiling data recorded at four airports around the region to the other conditions in the modeled data at the nearest grid cell location. As noted in Section 6.2, when conditions for the aircraft-based systems were red, this was almost always due to darkness.

Adding vertical visibility did not change the results for Dispersants – Helicopter Application because cloud ceiling was mostly favorable for this system (thus any other condition being not favorable – such as darkness – still resulted in a not favorable/red result).

For Dispersants – Fixed-wing Aircraft Application, adding the vertical visibility limit to the analysis resulted in a slight shift of some hours from green to yellow, most visibly in the summer months. In some cases, cloud ceiling was not favorable but this coincided with times when darkness was already not favorable. Figure 6-12 shows the annual cycle graphics for the four airport locations with all conditions combined. (Except cloud ceiling, all other conditions come from the nearest grid cell.) The top row shows the results based on the modeled metocean data alone (top row) and the modeled metocean data combined with cloud ceiling (bottom row). The slight shift of from green to yellow is most visible, as well as the slight increase in darker red (indicating that more than one condition was not favorable at that time).

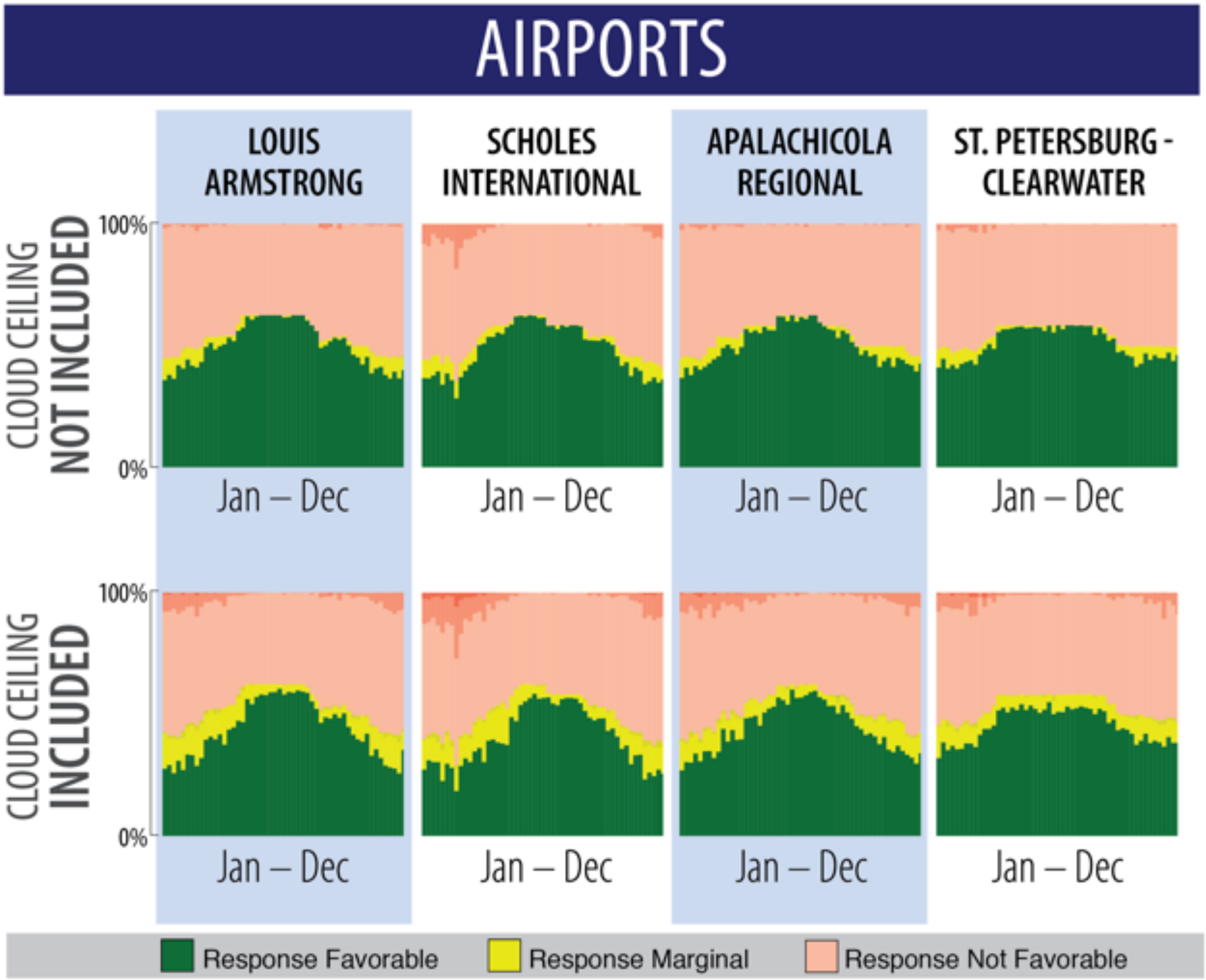


Figure 6-12. Annual cycle graphics showing Dispersants – Fixed-wing Aircraft results at grid cells nearest to four airports around the region both using the modeled metocean data alone, and using cloud ceiling – or vertical visibility – data for the same time period from that airport

7 Discussion

This section discusses some study findings and makes recommendations for future response viability analyses, or use of this analytical tool.

7.1 Findings and Discussion

Results indicate that conditions are almost always favorable or marginal for the application of dispersants from a vessel. With conditions either favorable or marginal for the application of dispersants from a vessel 99% of the time as long as such a system is available and dispersant use is permitted, this system can almost always be used within the study area. As noted, this study does not consider vessel/equipment availability or other issues associated with the use of any particular system anywhere in the study area (e.g., sustaining the use of this vessel-based system 200 nm offshore).

Conditions are slightly more likely to be favorable to mechanical recovery than in-situ burning. There is only a 3% difference in the amount of time conditions would be considered not favorable to the in-situ burning system than Two Vessels with Boom or Single Vessel with Outrigger, but conditions are almost twice as frequently favorable (29% for the two larger mechanical recovery systems as compared to 15% for in-situ burning).

The results of the viability analysis were fairly similar across the region, with the variations that exist most prominent East-to-West. This is particularly true when they are considered in contrast to the results of studies conducted at higher latitudes where sea ice and cold temperatures dominate some or all of the year. Where geographic variability exists, it relates to the higher winds and waves evident in the western waters of the Gulf of Mexico as compared to the eastern and central areas.

Conditions are most favorable in the summer as compared to winter, spring, and fall. The reason behind this effect varies: aircraft based systems have slightly more daylight in which to operate (and are not affected by wind and waves), while the on-water systems are less likely to be impeded by high winds or waves during roughly July-August as compared to other times of year. This effect is seen in all 6 of the divisions created (East to West, nearshore and offshore) but it is more significant in the windier western waters than eastern part of the study area.

Vertical visibility does not have a significant effect on response operations, at least based on the limited analysis conducted. The limitations of the exploration of cloud ceiling are two-fold: they included only four locations, and relied on the assumption that cloud ceiling would be the same at the nearby marine location represented in the nearest grid cell as at the airport itself. With those caveats noted, the results indicate that the cloud ceiling conditions at those airports would not change the results for the on-water response systems or application of dispersants from a helicopter. For the application of dispersants from a fixed-wing aircraft, there are limited times – especially in summer – when including vertical visibility would shift the results from favorable to marginal.

There are more times during which cloud ceiling conditions would be not favorable, but darkness is *already* found to be not favorable during these times so they do not change the overall results.

7.2 Recommendations

We recommend the following to enhance this analysis:

- **Compile data to quantify limitations for all applicable conditions and systems.** As noted, there is not a consistent, agreed upon source for this information. Such data could be compiled from exercises, drills, and actual responses using a common protocol.
- **Obtain input from experts on both systems and limits for use in a response viability analysis.** Input from experts in the region, ideally those with operational experience deploying response systems in a range of conditions on the Gulf of Mexico, should be used to inform the systems selected and the corresponding response limits for each.
- **Obtain vertical visibility data over water.** Also as noted, vertical visibility data were not available for the entire region. While we did not see significant impact to the results when data from 4 airports were used, having this information would enhance the analysis.
- **Incorporate wave steepness.** Wave height limits were used because these had already been established through EPPR's robust process (EPPR, 2017); however, wave steepness can make a significant difference to both mechanical recovery and in-situ burning systems. Shorter period waves are generally more limiting than long-period waves of the same height. Obtaining the necessary input and establishing wave limits that included steepness would enhance this analysis.

We recommend the following to build on this study:

- **Consider periods of time following extreme events, such as hurricanes, during which conditions may remain not favorable or marginal for response.** This type of analysis could be useful for response planning for hurricane- or flood-related spills.
- **Integrate study results with contingency planning activities or other analyses.** While this analysis applies the same system limits throughout the U.S. EEZ, it is unlikely that all systems will be able to be used anywhere due to travel distance/time, logistical support needs, vessel draft, or issues such as the approval needed for dispersant application or in-situ burning. These results should be integrated with other studies and plans.
- **Apply methodology and metocean data to additional response systems.** The same method and metocean data used in this study could be applied to different variations of the response systems studied as well as to entirely different types of systems such as well-capping, containment domes, or sub-sea dispersant injection. Modifications on the current systems could also be explored, such as using different boom or skimmers, for example, than those specified in Section 5. The authors caution, however, that changing one piece of equipment does not always change the limits to the system as a whole.

  Although not a deployment issue, per se, the frequency with which conditions are such that natural dispersion would occur could be analyzed using an agreed upon wave limit. (In this study, an upper wave limit was applied to dispersants on the assumption that dispersants would not be deployed if natural dispersion was likely. However, there were other limits applied as well which would not be used for a natural attenuation "system." For example, low visibility would not be a limit on "doing nothing.")

8 Conclusion

Overall, conditions in the Gulf of Mexico during the 10-year period studied were at least favorable or marginal for the application of dispersants from a vessel, larger mechanical recovery systems, and in-situ burning at least 85% of the time. Aircraft-based systems were limited by darkness. The smaller mechanical recovery system studied was limited by its sensitivity to wind and waves relative to the larger systems.

Study results were similar across the study area, with some variability East-West and between nearshore/offshore. Conditions were more likely to be favorable in summer than other seasons.

The results may be used to inform or assess contingency planning, integrated with studies of response capacity and logistical needs, and identify opportunities for technological innovations that will further increase response viability. This study did not consider vertical visibility across the entire area, nor does it presume which systems exist in which locations, where they may be deployed, how long it would take to get there, or the logistical support needed to sustain the response.

References

ASTM International. (2000.) Standard Practice for Classifying Water Bodies for Spill Control Systems. F625 – 94 (Reapproved 2000). West Conshohocken, PA.

Allen, A. (1998). *Comparison of Response Options for Offshore Oil Spills. Presented* at Eleventh Arctic and Marine Oilspill Program Technical Seminar, Vancouver, British Columbia.

DNV GL. (2015). *Risk Reduction and Oil Spill Response – Greenland: Oil Spill Contingency Study for Greenland.* Report No. 2015-0587, Rev. 1.

DNV GL. (2014). *Anchoring the Future: Challenges and Best Practice of Oil Spill Response in the Arctic.* Technical Report no. 013-162, Rev. 1.

DNV GL and Nuka Research. (2015). *Summary Report: Scoping Workshop "Impact of Metocean Conditions on Oil Spill Response Viability in the Arctic."* Report No. 2015-1007, Rev. 0.

Emergency Prevention, Preparedness, and Response. (2017). *Circumpolar Oil Spill Response Viability Analysis; Technical Report.* Arctic Council Secretariat.

Fingas, M. (2017). *A Review of Literature Related to Oil Dispersants.* Report for PWSRCAC, Contract #955.17.03

International Tanker Owners Pollution Federation Limited (ITOPF). (2012). *Fate of Marine Oil Spills Technical Information Paper.* London, United Kingdom. Retrieved from: http://www.itopf.com/fileadmin/data/Documents/TIPS%20TAPS/TIP2FateofMarineOilSpills.pdf

National Oceanic and Atmospheric Administration (NOAA). (no date). *General Solar Position Calculations.* Retrieved from: https://www.esrl.noaa.gov/gmd/grad/solcalc/solareqns.PDF

Nuka Research and Planning Group, LLC. (2016). *Estimating an Oil Spill Response Gap for the U.S. Arctic Ocean – revised.* Report to Bureau of Safety and Environmental Enforcement.

Nuka Research & Planning Group. (2015). *Technical Analysis of Oil Spill Response Capabilities and Limitations for Trans Mountain Expansion Project.* Unpublished.

Nuka Research and Planning Group, LLC. (2014). *Characterizing Environmental Conditions in the Aleutian Islands.* Report to the Aleutian Islands Risk Assessment Advisory Panel.

Nuka Research and Planning Group, LLC. (2012). *Oil Spill Response Gap and Response Capacity Analysis for Proposed Northern Gateway Tanker Spills in Open Water and Protected Water Operating Environments.* Report to Haisla National Council.

Nuka Research and Planning Group, LLC. (2007). *Response Gap Estimate for Two Operating Areas in Prince William Sound, Alaska.* Report to Prince William Sound Regional Citizens' Advisory Council.

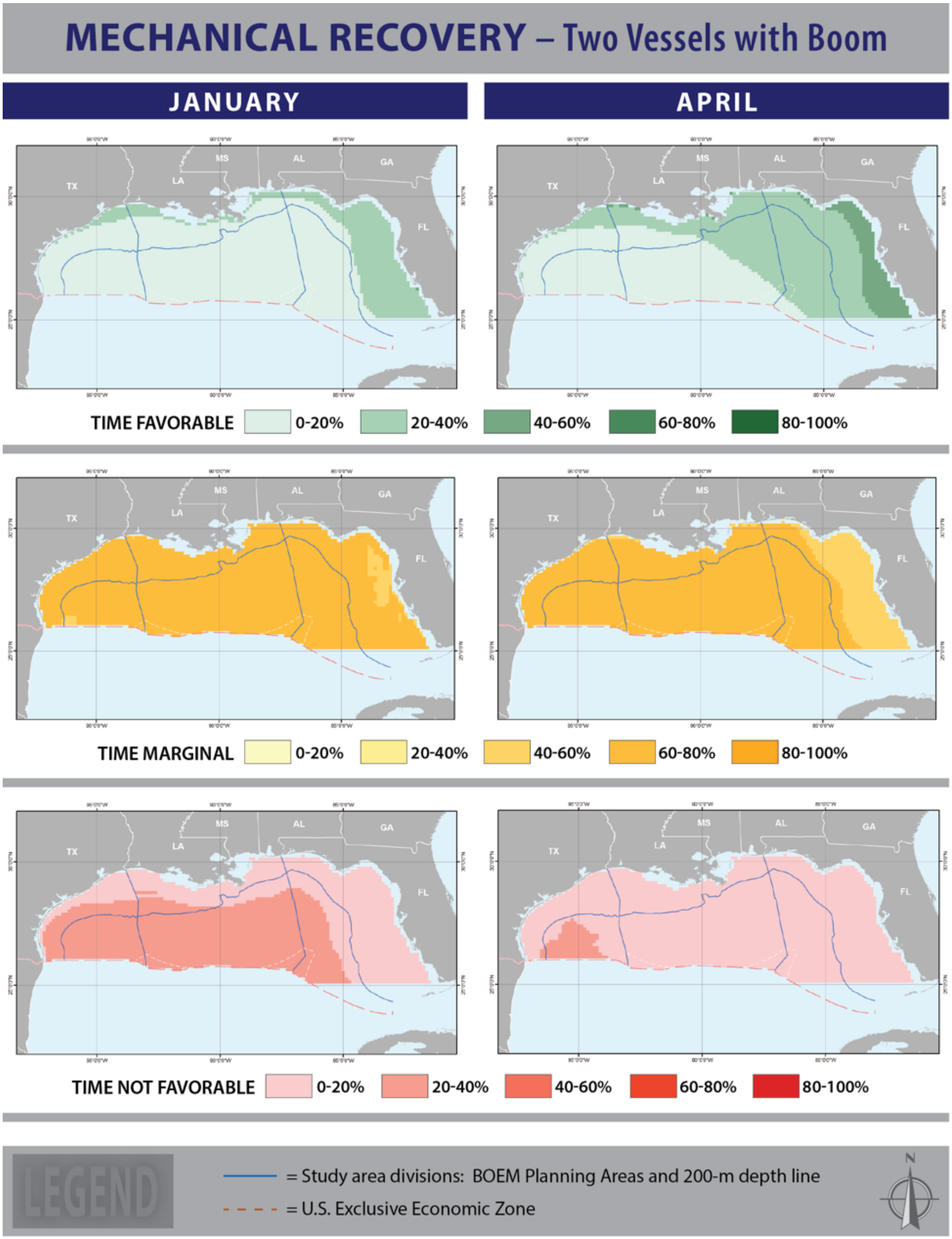
Oceanweather, Inc. (2016). *Global Re-analysis of Ocean Waves-Meteorological Variables (GROW-MET) Project Description.* August 22.

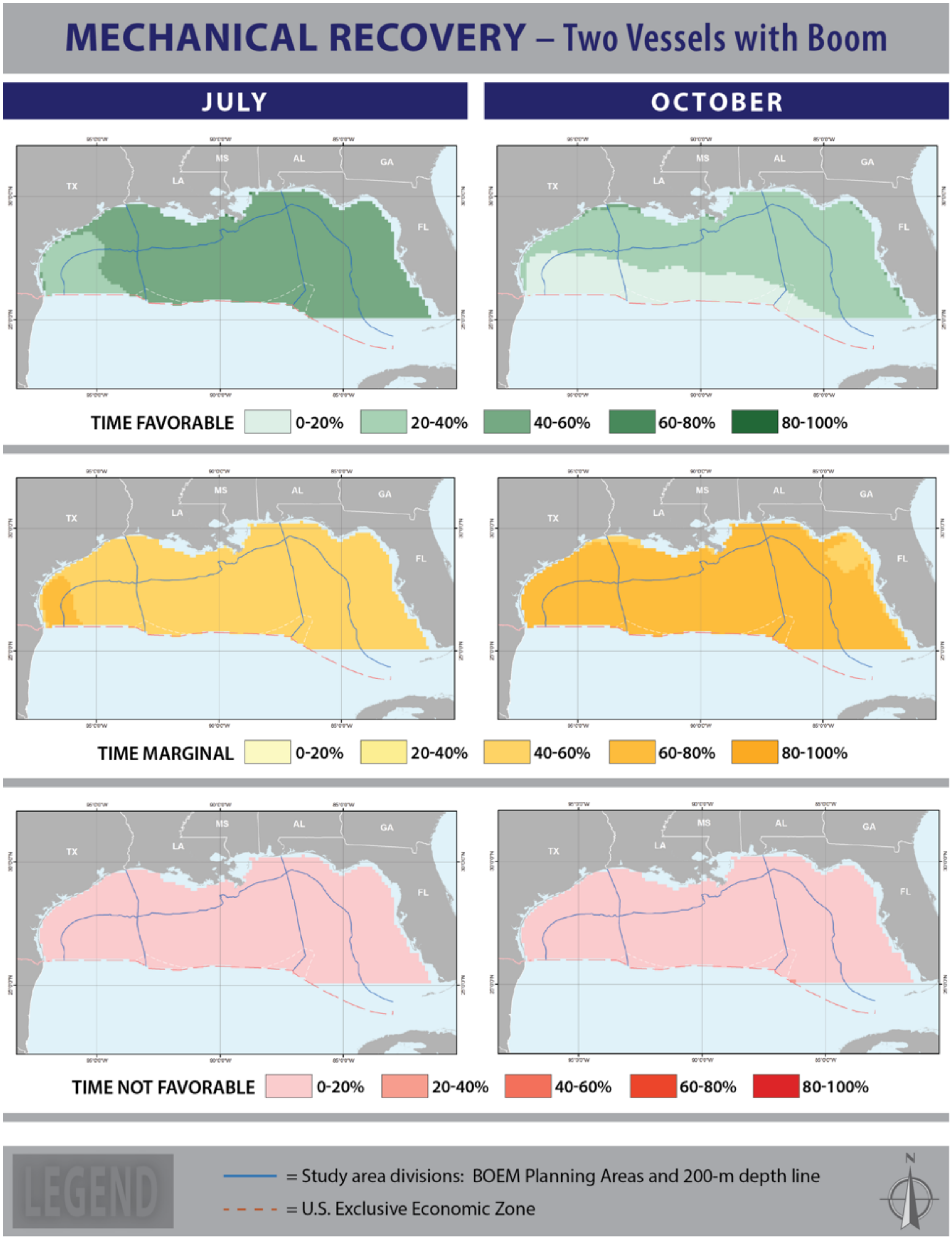
Oceanweather, Inc. (2015). *GOMOS2014: Gulf of Mexico Oceanographic Study 2014 Project Description.* September.

S.L. Ross. (2011). *Spill Response Gap Study for the Canadian Beaufort Sea and Canadian Davis Strait.* National Energy Board. Contract No. 110027.

Terhune, K. (2011). *Preliminary Mechanical Response Gap Analysis for the Enbridge Northern Gateway Project.* Sointula, BC: Living Oceans Society.

Appendix A – Results Maps for January, April, July, October


MECHANICAL RECOVERY – Two Vessels with Boom
JANUARY
APRIL
TX
LA
MS
AL
GA
FL
TIME FAVORABLE
0-20%
20-40%
40-60%
60-80%
80-100%
TIME MARGINAL
0-20%
20-40%
40-60%
60-80%
80-100%
TIME NOT FAVORABLE
0-20%
20-40%
40-60%
60-80%
80-100%
LEGEND
= Study area divisions: BOEM Planning Areas and 200-m depth line
= U.S. Exclusive Economic Zone
N


MECHANICAL RECOVERY – Two Vessels with Boom
JULY
OCTOBER
TX
LA
MS
AL
GA
FL
TIME FAVORABLE
0-20%
20-40%
40-60%
60-80%
80-100%
TIME MARGINAL
0-20%
20-40%
40-60%
60-80%
80-100%
TIME NOT FAVORABLE
0-20%
20-40%
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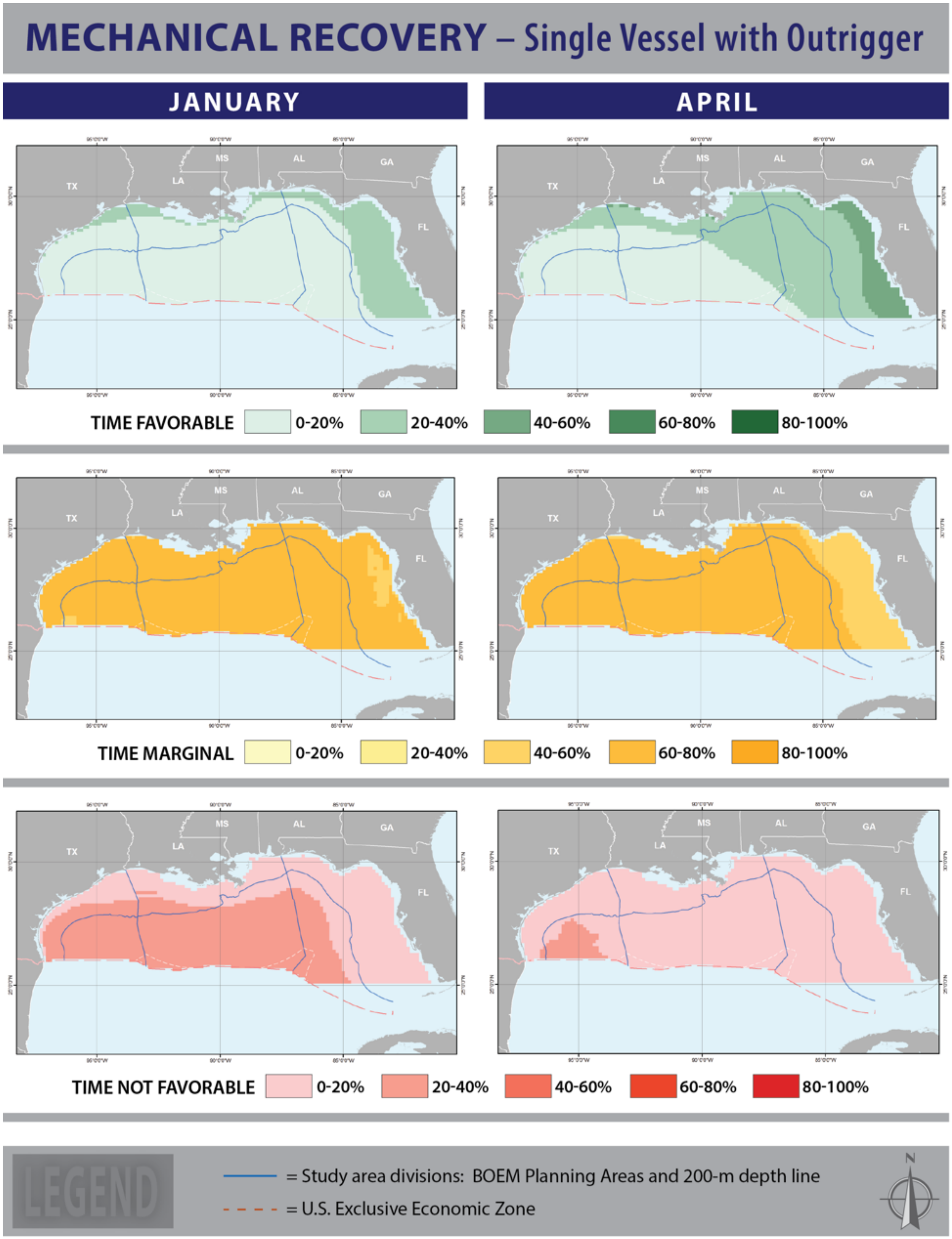
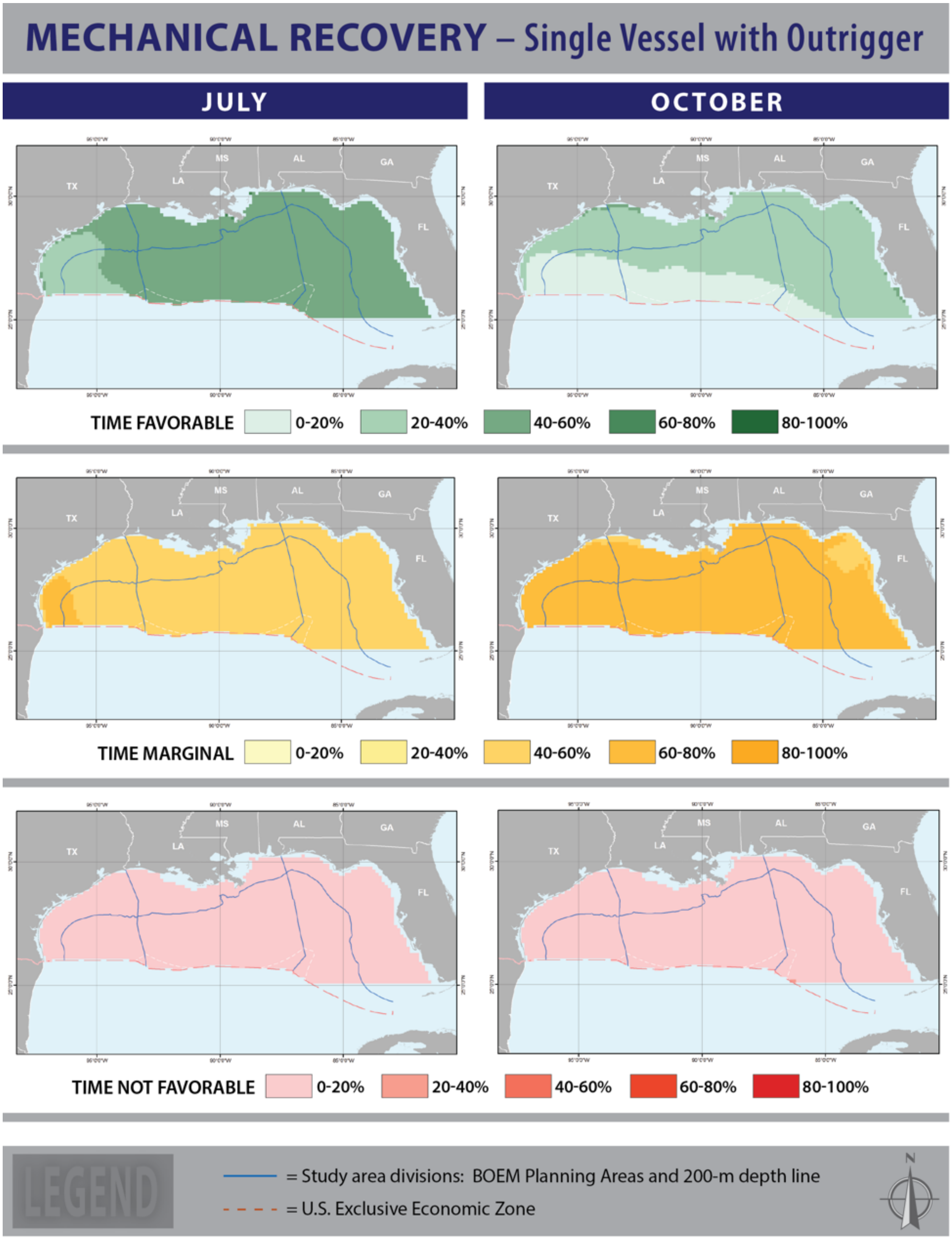
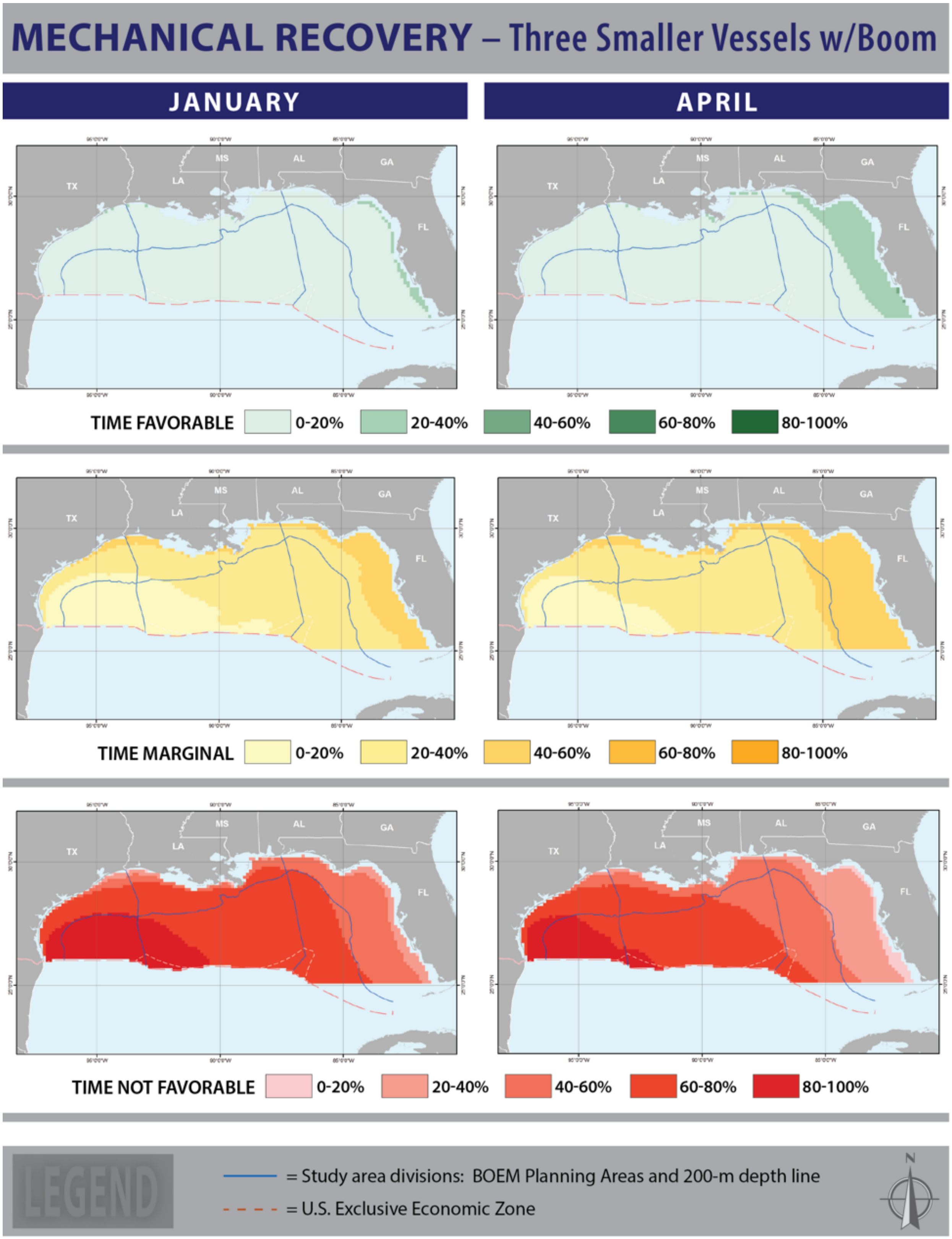
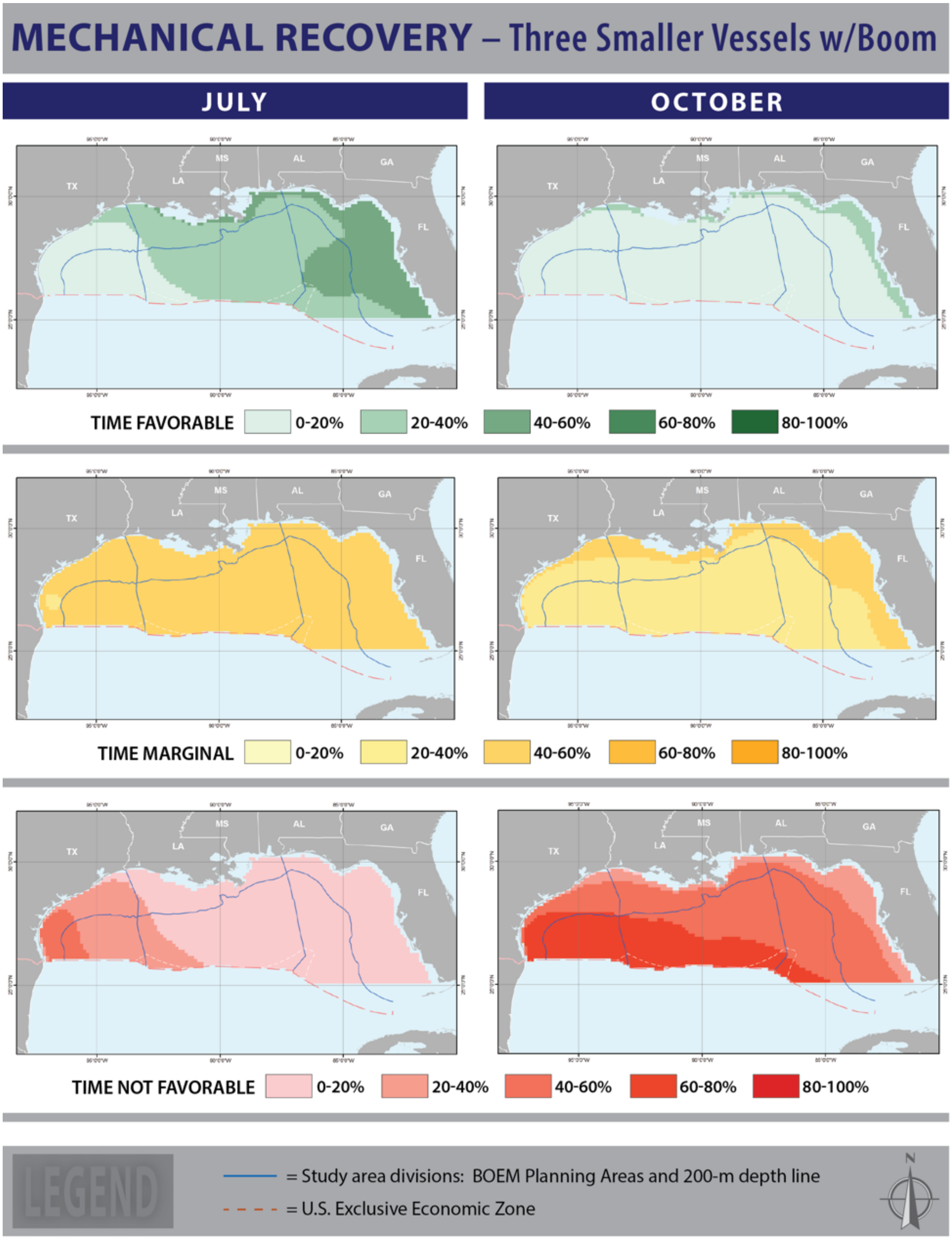
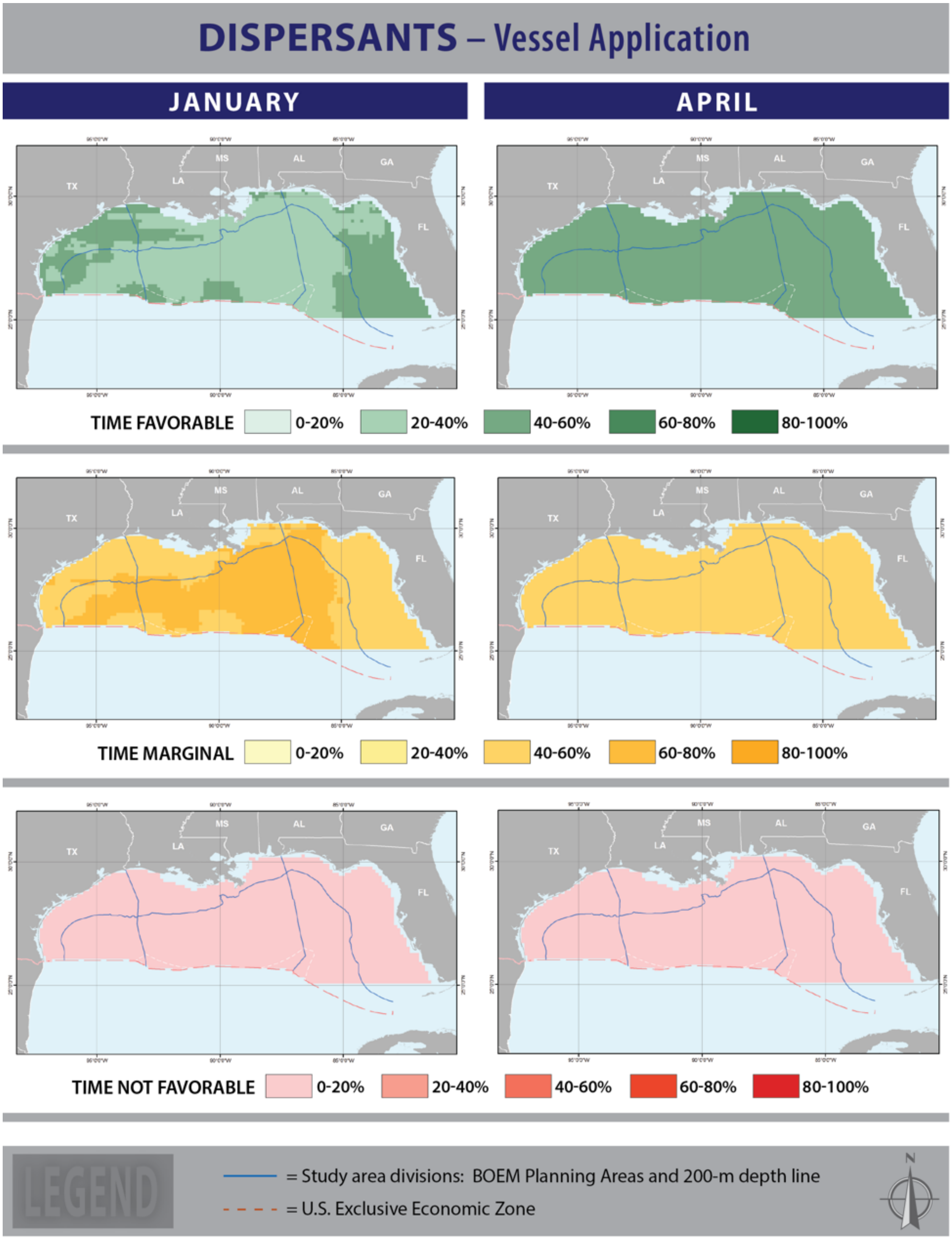
60-80%
80-100%
LEGEND
= Study area divisions: BOEM Planning Areas and 200-m depth line
= U.S. Exclusive Economic Zone
N

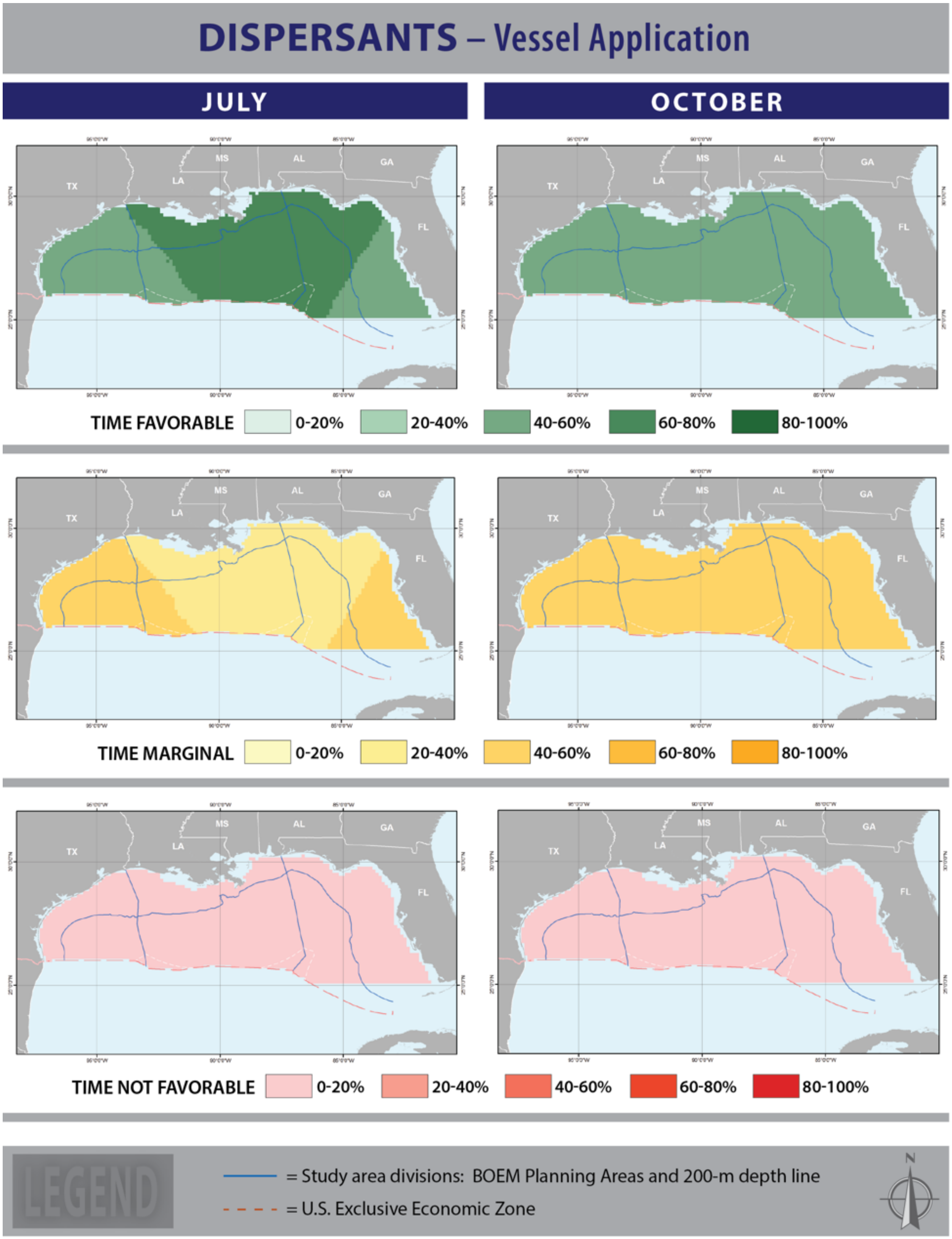

MECHANICAL RECOVERY – Single Vessel with Outrigger
JANUARY
APRIL
TX
LA
MS
AL
GA
FL
TIME FAVORABLE
0-20%
20-40%
40-60%
60-80%
80-100%
TIME MARGINAL
0-20%
20-40%
40-60%
60-80%
80-100%
TIME NOT FAVORABLE
0-20%
20-40%
40-60%
60-80%
80-100%
LEGEND
= Study area divisions: BOEM Planning Areas and 200-m depth line
= U.S. Exclusive Economic Zone
N

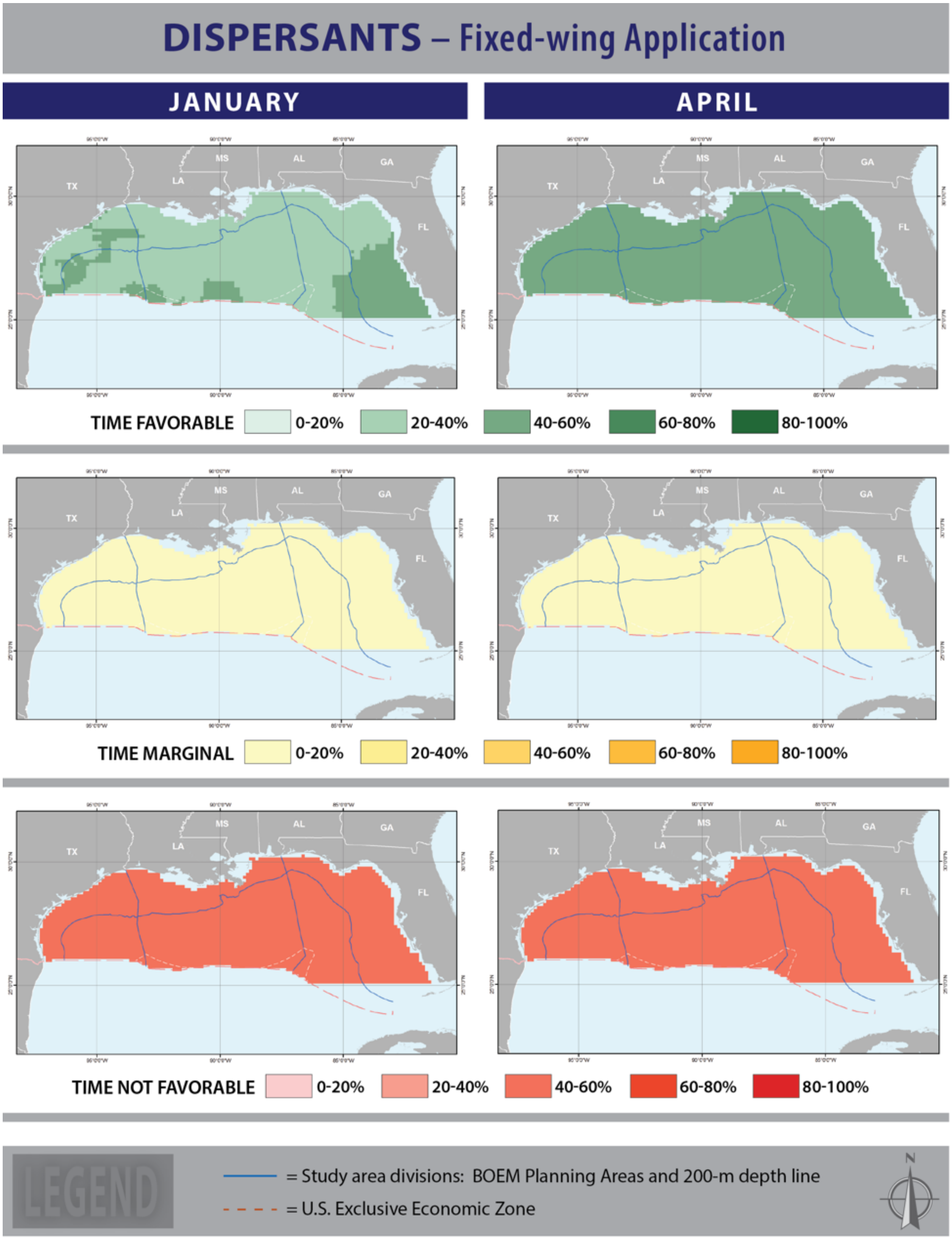

MECHANICAL RECOVERY – Single Vessel with Outrigger
JULY
OCTOBER
TX
LA
MS
AL
GA
FL
TIME FAVORABLE 0-20% 20-40% 40-60% 60-80% 80-100%
TIME MARGINAL 0-20% 20-40% 40-60% 60-80% 80-100%
TIME NOT FAVORABLE 0-20% 20-40% 40-60% 60-80% 80-100%
LEGEND
= Study area divisions: BOEM Planning Areas and 200-m depth line
= U.S. Exclusive Economic Zone
N

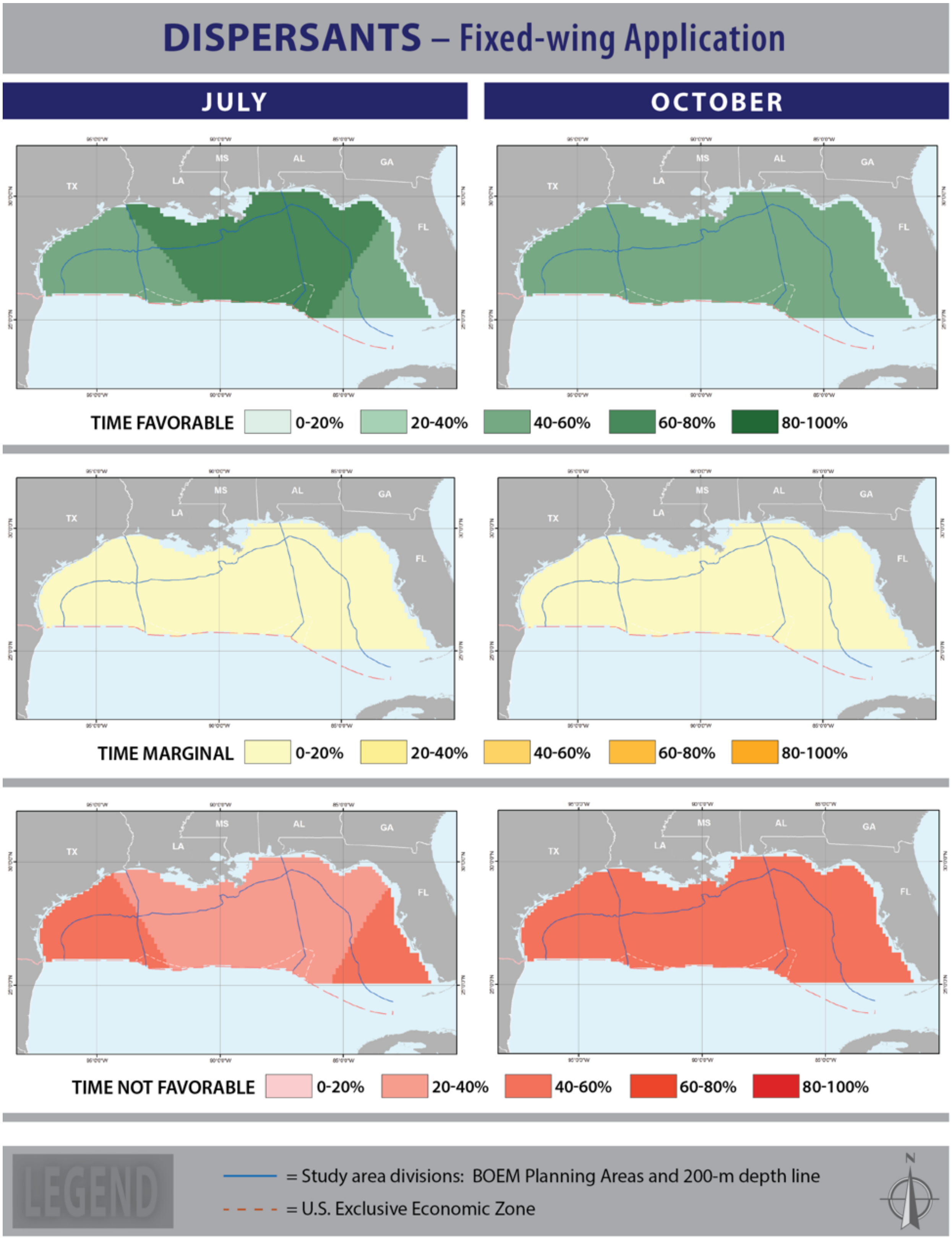

MECHANICAL RECOVERY – Three Smaller Vessels w/Boom
JANUARY
APRIL
TX
LA
MS
AL
GA
FL
TIME FAVORABLE
0-20%
20-40%
40-60%
60-80%
80-100%
TIME MARGINAL
0-20%
20-40%
40-60%
60-80%
80-100%
TIME NOT FAVORABLE
0-20%
20-40%
40-60%
60-80%
80-100%
LEGEND
= Study area divisions: BOEM Planning Areas and 200-m depth line
= U.S. Exclusive Economic Zone
N

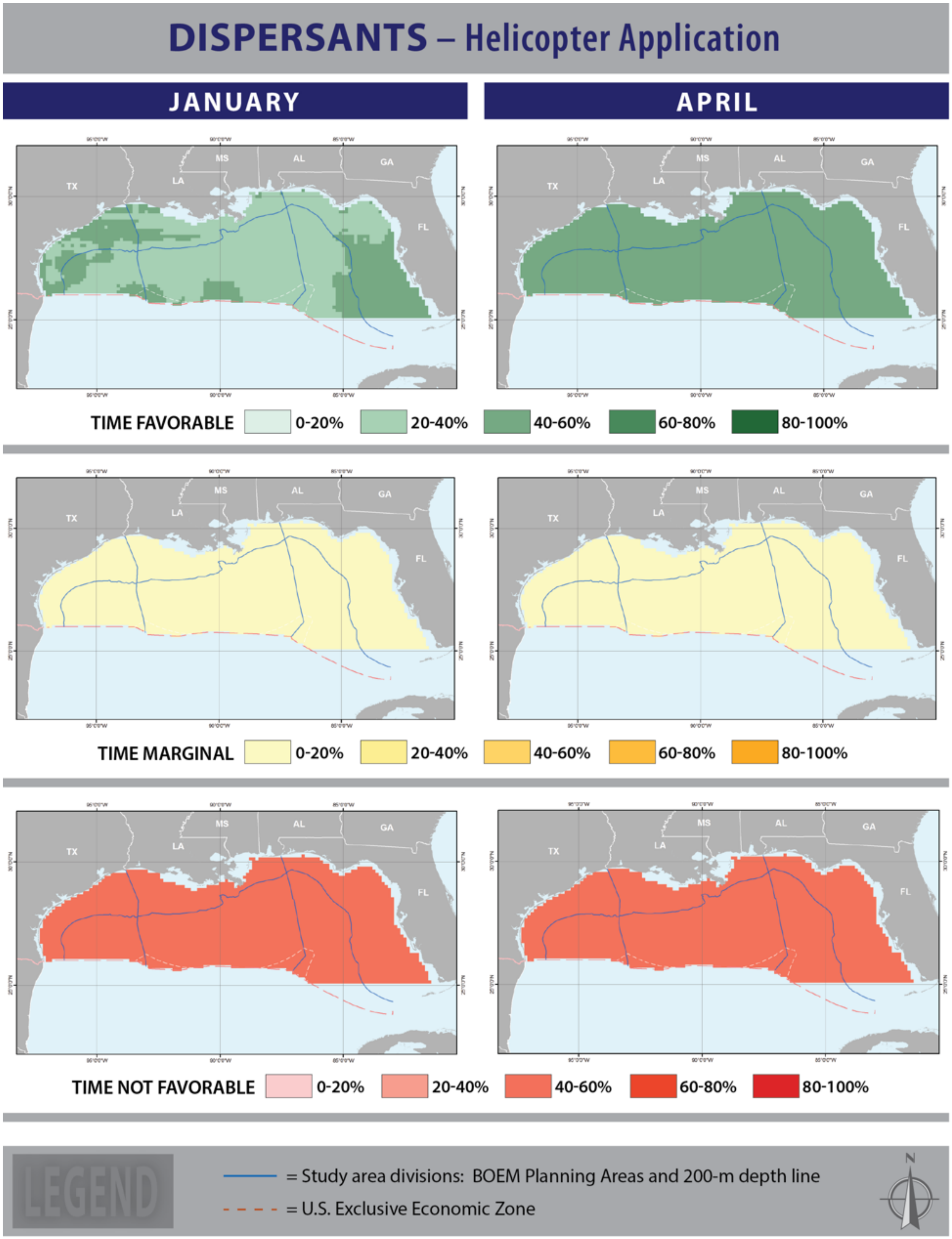

MECHANICAL RECOVERY – Three Smaller Vessels w/Boom
JULY
OCTOBER
TX
LA
MS
AL
GA
FL
TIME FAVORABLE 0-20% 20-40% 40-60% 60-80% 80-100%
TIME MARGINAL 0-20% 20-40% 40-60% 60-80% 80-100%
TIME NOT FAVORABLE 0-20% 20-40% 40-60% 60-80% 80-100%
LEGEND
= Study area divisions: BOEM Planning Areas and 200-m depth line
= U.S. Exclusive Economic Zone
N

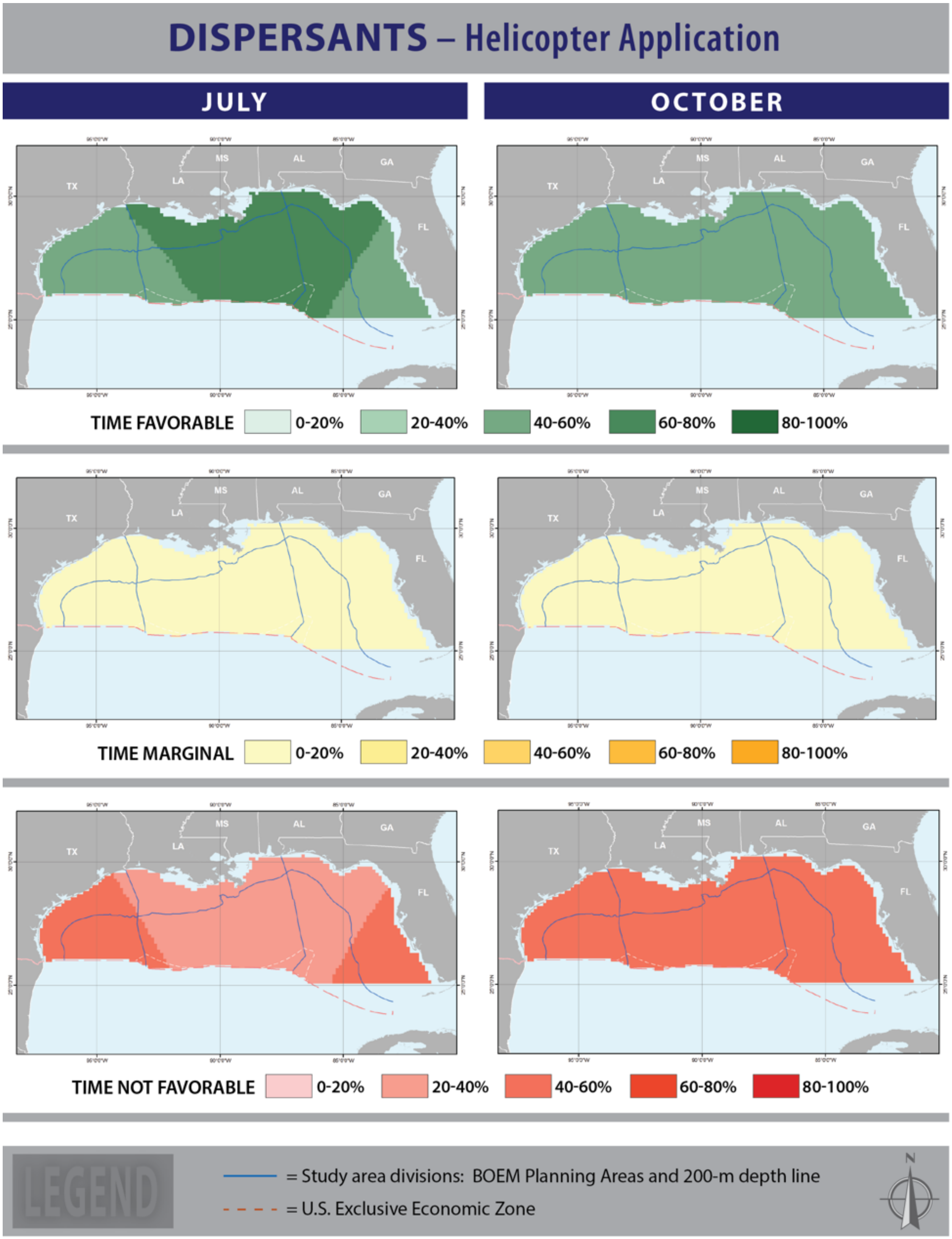

DISPERSANTS – Vessel Application
JANUARY
APRIL
TX
LA
MS
AL
GA
FL
TIME FAVORABLE
0-20%
20-40%
40-60%
60-80%
80-100%
TIME MARGINAL
0-20%
20-40%
40-60%
60-80%
80-100%
TIME NOT FAVORABLE
0-20%
20-40%
40-60%
60-80%
80-100%
LEGEND
= Study area divisions: BOEM Planning Areas and 200-m depth line
= U.S. Exclusive Economic Zone
N

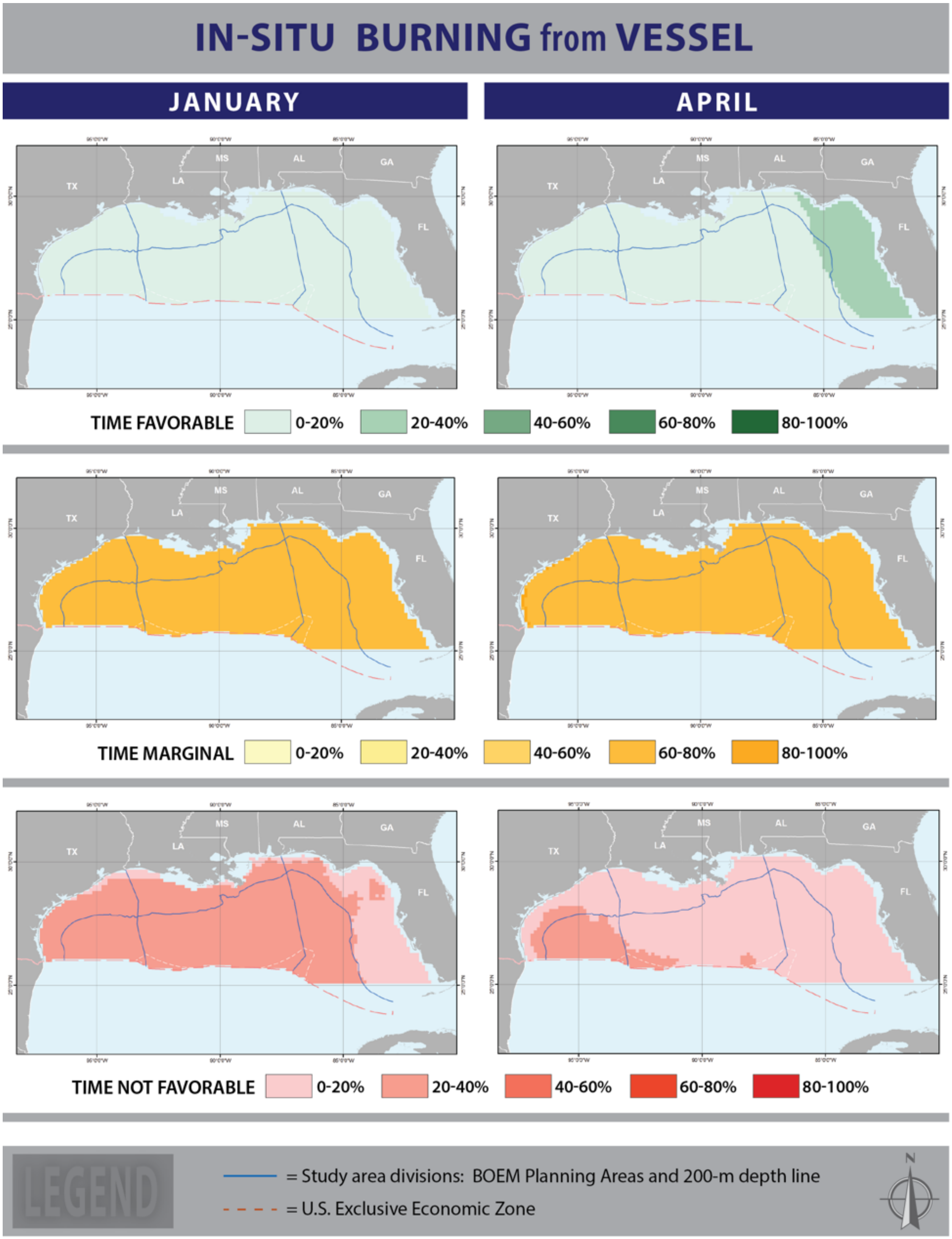

DISPERSANTS – Vessel Application
JULY
OCTOBER
TX
LA
MS
AL
GA
FL
TIME FAVORABLE 0-20% 20-40% 40-60% 60-80% 80-100%
TIME MARGINAL 0-20% 20-40% 40-60% 60-80% 80-100%
TIME NOT FAVORABLE 0-20% 20-40% 40-60% 60-80% 80-100%
LEGEND
= Study area divisions: BOEM Planning Areas and 200-m depth line
= U.S. Exclusive Economic Zone
N

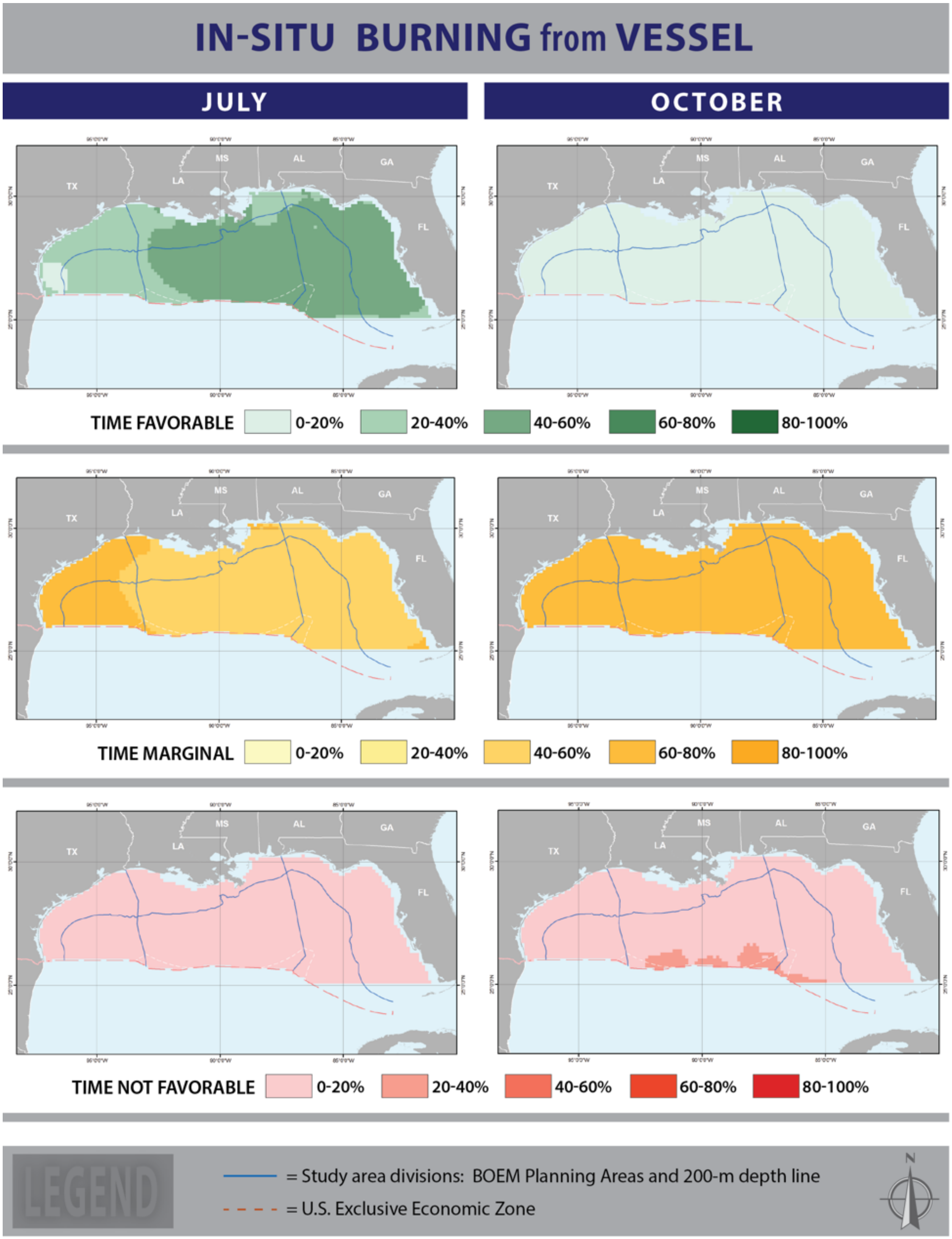

DISPERSANTS – Fixed-wing Application
JANUARY
APRIL
TX
LA
MS
AL
GA
FL
TIME FAVORABLE
0-20%
20-40%
40-60%
60-80%
80-100%
TIME MARGINAL
0-20%
20-40%
40-60%
60-80%
80-100%
TIME NOT FAVORABLE
0-20%
20-40%
40-60%
60-80%
80-100%
LEGEND
= Study area divisions: BOEM Planning Areas and 200-m depth line
= U.S. Exclusive Economic Zone
N


DISPERSANTS – Fixed-wing Application
JULY
OCTOBER
TX
LA
MS
AL
GA
FL
TIME FAVORABLE
0-20%
20-40%
40-60%
60-80%
80-100%
TIME MARGINAL
0-20%
20-40%
40-60%
60-80%
80-100%
TIME NOT FAVORABLE
0-20%
20-40%
40-60%
60-80%
80-100%
LEGEND
= Study area divisions: BOEM Planning Areas and 200-m depth line
= U.S. Exclusive Economic Zone
N


DISPERSANTS – Helicopter Application
JANUARY
APRIL
TX
LA
MS
AL
GA
FL
TIME FAVORABLE
0-20%
20-40%
40-60%
60-80%
80-100%
TIME MARGINAL
0-20%
20-40%
40-60%
60-80%
80-100%
TIME NOT FAVORABLE
0-20%
20-40%
40-60%
60-80%
80-100%
LEGEND
= Study area divisions: BOEM Planning Areas and 200-m depth line
= U.S. Exclusive Economic Zone
N


DISPERSANTS – Helicopter Application
JULY
OCTOBER
TX
LA
MS
AL
GA
FL
TIME FAVORABLE
0-20%
20-40%
40-60%
60-80%
80-100%
TIME MARGINAL
0-20%
20-40%
40-60%
60-80%
80-100%
TIME NOT FAVORABLE
0-20%
20-40%
40-60%
60-80%
80-100%
LEGEND
= Study area divisions: BOEM Planning Areas and 200-m depth line
= U.S. Exclusive Economic Zone
N


IN-SITU BURNING from VESSEL
JANUARY
APRIL
TX
LA
MS
AL
GA
FL
TIME FAVORABLE
0-20%
20-40%
40-60%
60-80%
80-100%
TIME MARGINAL
0-20%
20-40%
40-60%
60-80%
80-100%
TIME NOT FAVORABLE
0-20%
20-40%
40-60%
60-80%
80-100%
LEGEND
= Study area divisions: BOEM Planning Areas and 200-m depth line
= U.S. Exclusive Economic Zone
N


IN-SITU BURNING from VESSEL
JULY
OCTOBER
TX
LA
MS
AL
GA
FL
TIME FAVORABLE
0-20%
20-40%
40-60%
60-80%
80-100%
TIME MARGINAL
0-20%
20-40%
40-60%
60-80%
80-100%
TIME NOT FAVORABLE
0-20%
20-40%
40-60%
60-80%
80-100%
LEGEND
= Study area divisions: BOEM Planning Areas and 200-m depth line
= U.S. Exclusive Economic Zone
N

Appendix B – Literature References Related to Response Limits

The following tables illustrate the available literature references regarding response limitations. These tables were used during the Circumpolar Oil Spill Response Viability Analysis (EPPR, 2017). By necessity, the limits used for any response viability analysis are based on a combination of published literature and best professional judgment based on experience. The limits for the circumpolar Arctic project were thus developed. Limits used in this Gulf of Mexico analysis were based on the limits defined for the circumpolar Arctic project, as discussed in Section 3. Metocean conditions not applicable to the Gulf of Mexico have been removed.

Supporting References for Platforms			
	VESSEL	**HELICOPTER**	**FIXED-WING AIRCRAFT**
Visibility	0.125 – 0.50 nm for booming/skimming vessels (RPG, 2013)	> .4 nm horizontal visibility (NWCG, 2013)	*Night:* > 2.6 nm horizontal visibility & > 500 ft. vertical visibility; *Day* >1 nm horizontal & clear of clouds clouds based on low-flying craft under Visual Flight Rules per US regulations (14 CFR 91.155)

Supporting References for Mechanical Recovery Systems			
	CONTAINMENT	**SKIMMER**	**GENERAL**
Wind	CB6: < 17-21 kts based on Beaufort 5 for offshore (NOFI, 2013) Unfavorable > 20 kts (ExxonMobil, 2014)	n/a	< 22 kts (Shell, 2011) < 30-40 kts (RPG, 2013) < 15 – 20 kts (hydraulics & lifts) (ACS, 2015)
Sea state	CB6: < 10 ft in breaking waves, 23 ft in swell (NOFI, 2013) Ro-boom 3200: Swells up to 23 ft (DESMI, n.d.) Unfavorable > 3 ft waves (ExxonMobil, 2014)	TransRec: < 10 ft (Nordvik, 1999)	< 6.6 ft waves (ExxonMobil, 2008) < 10 ft if swell (Shell, 2011) Impacted < 3 ft (ACS, 2015) < 10 ft if currents (RPG, 2013)
Visibility	n/a	n/a	> .125 - .5 nm (Shell, 2011)

Supporting References for Dispersant Systems		
	DISPERSANT APPLICATION	**GENERAL**
Wind	< 30 kts for application (Lewis & Daling, 2007) 8 -24 kts is optimum (ITOPF, 2011) Favorable at 7-10 kts due to breaking waves (Lewis et al, 2010) < 30 kts for application (Lewis & Daling, 2007) Aircraft: <27 kts (RPG, 2012) Aircraft: < 25 kts (Exxon, 2000 in SL Ross, 2014) Aircraft: Favorable < 25 kts, marginal to 15 m/s (SL Ross, 2014)	8-24 kts is optimum (ITOPF, 2011) < 30-40 m/s (RPG, 2013)
Sea state	(Favorable with breaking waves – see Lewis et al., 2010 above for associated winds.)	n/a
Visibility	n/a	n/a

Supporting References for In-situ Burn Systems			
	CONTAINMENT	**IGNITION**	**GENERAL**
Wind	Favorable to 10 kts, marginal to 20 kts (Buist et al., 2003; SLRoss et al, 2003)	<17.5 kts offshore (ExxonMobil, 2014) Depending on oil type, ignited up to 19 kts or 29 kts in lab tests (Opstad and Guenette, 2000)	< 20 kts (RPG, 2012)
Sea state	Favorable to 3 ft, marginal to 4 ft (Buist et al., 2003) Possible up to 6 ft (ASTM F625 and F2683) Same as mechanical (RPG, 2012)	Marginal 3-5 ft (SLRoss et al, 2003) *Herders:* Breaking waves broke up slick; swell elongates & breaks up slick in tank test (SLRoss, 2012)	Favorable to 3 ft chop & 5-6 ft in swell (ADEC et al, 2008)

REFERENCE LIST

Alaska Department of Environmental Conservation (ADEC), US Coast Guard Seventeenth District, US EPA Region 10 Alaska Operations Office (2008). *In situ burning guidelines for Alaska*. Revision 1. Retrieved from: https://dec.alaska.gov/spar/ppr/docs/ISB-Rev1(Final-August%202008).pdf

ASTM International. (2000.) *Standard Practice for Classifying Water Bodies for Spill Control Systems.* F 625 – 94 (Reapproved 2000). West Conshohocken, PA.

Alaska Clean Seas (ACS) (2015). *Alaska Clean Seas Technical Manual, Volume 1: Tactics Descriptions*, Revision 12, Jan. 2015. Prudhoe Bay, Alaska.

Buist, I., Coe, T., Jensen, D., Potter, S., Anderson, E., Bitting, K., & Hansen, K. (2003). *Oil Spill Response Offshore, In-Situ Burn Operations Manual, Final Report.* United States Coast Guard, Groton, CT.

Desmi (n.d.) *RO-BOOM 3200 - Heavy-Duty Oil Containment Boom: Proven Oil Spill Technology.* Downloadable product material information sheet. Retrieved from: http://www.desmi.com/UserFiles/file/oil%20spill%20response/e-leaflet/01_09_RO_BOOM_3200.pdf

Doc. No. 24458, 56 FR 65660, Dec. 17, 1991, as amended by Amdt. 91-235, 58 FR 51968, Oct. 5, 1993; Amdt. 91-282, 69 FR 44880, July 27, 2004

ExxonMobil Research and Engineering Company. (2008). *ExxonMobil Oil Dispersant Guidelines.* Retrieved from: https://crrc.unh.edu/sites/crrc.unh.edu/files/exxonmobil_dispersant_guidelines_2008.pdf

ExxonMobil Research and Engineering Company. (2014). *ExxonMobil Oil Spill Response Field Manual, Revised 2014.* Retrieved from: http://cdn.exxonmobil.com/~/media/global/files/energy-and-environment/oil-spill-response-field-manual_2014_e.pdf

The International Tanker Owners Pollution Federation Limited (ITOPF) (2011). Use of Dispersants to Treat Oil Spills. *ITOPF Technical Information Paper 4*, London, England.

Lewis, A. & Daling, P. (2007). Evaluation of Dispersant Spray Systems and Platforms For Use On Spilled Oil in Seas with Ice Present (JIP Project 4, Act. 4.21). *Report No. 12. SINTEF A16088 Report, Oil in Ice – JIP.*

Lewis, A., Johansen, Ø., Singsaas, I., Solsberg, L. (2010). Ice Regimes for Oil Spill Response Planning. *Report No. 15. SINTEF A16069 Unrestricted Report, Oil in Ice – JIP.*

National Wildfire Coordinating Group (2013). *Interagency helicopter operations guide*. February 2013, PMS 510, NFES 001885.

NOFI Tromsø AS (2013). *NOFI CURRENT BUSTER® 6Pat.* Downloadable product material information sheet. Retrieved from: http://www.nofi.no/files/NOFICurrentBuster%C2%AE6Pat_1.pdf

Nordvik, A. (1999) Summary of Development and Field Testing of the Transrec Oil Recovery System. *Spill Science & Technology Bulletin, Vol. 5*, No. 5/6, pp. 309-322.

Opstad, K. & Guénette, C. (2000). Fire on the Sea Surface, Ignitability and Sustainability Under Various Environmental Conditions. *International Association for Fire Safety Science – Proceedings of the Sixth International Symposium*, pp 741-752.

Response Planning Group (RPG) (2012). Prince William Sound Tanker Oil Discharge Prevention and Contingency Plan.

Shell. (2011). Oil Spill Response Plan, Appendix H – Response Operation Conditions and Limitations. *Chukchi Sea Regional Exploration Program.*

SL Ross Environmental Research Ltd., D.F. Dickins Associates Ltd. & Alaska Clean Seas (2003). *Tests to Determine the Limits to In Situ Burning of Thin Oil Slicks in Broken Ice, Final Report.*

SL Ross Environmental Research Ltd. (2014). *Potential Effectiveness of Dispersant Use in the U.S. Beaufort and Chukchi Seas.* Prepared for Bureau of Safety and Environmental Enforcement, Sterling, VA.

Appendix C – Monthly Numeric Results by Division

WESTERN Gulf of Mexico – NEARSHORE

SYSTEM	CONDITIONS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
2 Vessels w/ Boom	FAV	14%	15%	18%	17%	24%	36%	40%	48%	36%	24%	17%	14%	25%
	MAR	66%	65%	67%	70%	70%	62%	56%	52%	58%	66%	66%	65%	64%
	NOT_FAV	20%	21%	15%	14%	6%	3%	4%	1%	6%	10%	17%	21%	11%
Single Vessel w/ Outrigger	FAV	14%	15%	18%	17%	24%	36%	40%	48%	36%	24%	17%	14%	25%
	MAR	66%	65%	67%	70%	70%	62%	56%	52%	58%	66%	66%	65%	64%
	NOT_FAV	20%	21%	15%	14%	6%	3%	4%	1%	6%	10%	17%	21%	11%
3 Smaller Vessels w/ Boom	FAV	4%	3%	5%	4%	8%	12%	14%	25%	16%	9%	6%	4%	9%
	MAR	25%	26%	29%	25%	31%	45%	52%	54%	49%	36%	30%	26%	36%
	NOT_FAV	71%	71%	66%	72%	61%	44%	34%	21%	35%	55%	63%	70%	55%
Dispersants – Vessel Application	FAV	41%	42%	47%	54%	58%	60%	58%	58%	53%	48%	40%	39%	50%
	MAR	58%	55%	51%	46%	42%	40%	42%	42%	47%	52%	60%	61%	50%
	NOT_FAV	1%	4%	2%	1%	0%	0%	0%	0%	0%	0%	0%	1%	1%
Dispersants – Fixed-wing Application	FAV	40%	39%	45%	53%	58%	60%	58%	58%	53%	48%	40%	38%	49%
	MAR	9%	8%	5%	5%	2%	1%	1%	0%	2%	4%	6%	8%	4%
	NOT_FAV	52%	53%	49%	43%	41%	39%	41%	42%	45%	48%	54%	54%	47%
Dispersants – Helicopter Application	FAV	41%	41%	46%	53%	58%	60%	58%	58%	53%	48%	40%	38%	50%
	MAR	8%	7%	5%	4%	2%	1%	1%	0%	2%	4%	6%	8%	4%
	NOT_FAV	51%	52%	49%	43%	41%	39%	41%	42%	45%	48%	54%	54%	47%
In-situ Burning	FAV	7%	8%	9%	8%	13%	23%	29%	35%	21%	13%	9%	7%	15%
	MAR	67%	66%	73%	75%	79%	74%	67%	63%	71%	75%	70%	66%	71%
	NOT_FAV	26%	27%	18%	17%	8%	3%	4%	1%	7%	13%	21%	27%	14%

WESTERN Gulf of Mexico – OFFSHORE

SYSTEM	CONDITIONS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
2 Vessels w/ Boom	FAV	8%	9%	12%	11%	21%	34%	39%	46%	33%	18%	12%	9%	21%
	MAR	62%	63%	68%	69%	70%	62%	56%	52%	59%	66%	64%	60%	63%
	NOT_FAV	30%	28%	20%	20%	9%	4%	5%	2%	8%	16%	25%	31%	16%
Single Vessel w/ Outrigger	FAV	8%	9%	12%	11%	21%	34%	39%	46%	33%	18%	12%	9%	21%
	MAR	62%	63%	68%	69%	70%	62%	56%	52%	59%	66%	64%	60%	63%
	NOT_FAV	30%	28%	20%	20%	9%	4%	5%	2%	8%	16%	25%	31%	16%
3 Smaller Vessels w/ Boom	FAV	1%	1%	2%	2%	6%	10%	13%	24%	13%	6%	3%	2%	7%
	MAR	14%	16%	20%	17%	28%	45%	53%	55%	47%	28%	21%	17%	30%
	NOT_FAV	85%	83%	78%	82%	66%	46%	35%	22%	41%	66%	76%	81%	63%
Dispersants – Vessel Application	FAV	40%	41%	46%	52%	57%	60%	57%	58%	53%	49%	39%	37%	49%
	MAR	60%	59%	54%	48%	43%	40%	43%	42%	47%	51%	61%	63%	51%
	NOT_FAV	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%
Dispersants – Fixed-wing Application	FAV	40%	41%	46%	52%	57%	60%	57%	58%	53%	49%	39%	37%	49%
	MAR	9%	9%	6%	5%	2%	1%	1%	0%	2%	4%	7%	10%	5%
	NOT_FAV	51%	51%	49%	42%	41%	40%	42%	42%	46%	47%	55%	54%	46%
Dispersants – Helicopter Application	FAV	40%	41%	46%	52%	57%	60%	57%	58%	53%	49%	39%	37%	49%
	MAR	9%	9%	6%	5%	2%	1%	1%	0%	2%	4%	7%	10%	5%
	NOT_FAV	51%	50%	49%	42%	41%	40%	42%	42%	46%	47%	54%	54%	46%
In-situ Burning	FAV	3%	5%	5%	5%	12%	22%	30%	35%	21%	10%	6%	4%	13%
	MAR	64%	64%	73%	73%	78%	74%	65%	63%	70%	73%	67%	62%	69%
	NOT_FAV	33%	31%	22%	22%	10%	4%	5%	2%	9%	17%	27%	34%	18%

CENTRAL Gulf of Mexico – NEARSHORE

SYSTEM	CONDITIONS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
2 Vessels w/ Boom	FAV	17%	21%	26%	25%	40%	50%	54%	51%	39%	28%	22%	19%	33%
	MAR	68%	65%	62%	67%	57%	48%	44%	47%	56%	62%	65%	65%	59%
	NOT_FAV	15%	14%	12%	8%	3%	2%	2%	2%	6%	10%	13%	16%	9%
Single Vessel w/ Outrigger	FAV	17%	21%	26%	25%	40%	50%	54%	51%	39%	28%	22%	19%	33%
	MAR	68%	65%	62%	67%	57%	48%	44%	47%	56%	62%	65%	65%	59%
	NOT_FAV	15%	14%	12%	8%	3%	2%	2%	2%	6%	10%	13%	16%	9%
3 Smaller Vessels w/ Boom	FAV	7%	8%	11%	9%	20%	29%	33%	37%	24%	15%	10%	7%	17%
	MAR	31%	34%	39%	35%	45%	51%	54%	51%	49%	41%	36%	34%	42%
	NOT_FAV	63%	58%	51%	56%	36%	20%	13%	12%	28%	45%	54%	59%	41%
Dispersants – Vessel Application	FAV	40%	43%	48%	53%	61%	62%	61%	57%	52%	47%	41%	39%	50%
	MAR	59%	54%	50%	47%	39%	38%	39%	42%	47%	53%	59%	61%	49%
	NOT_FAV	2%	3%	2%	0%	0%	0%	0%	0%	1%	0%	0%	1%	1%
Dispersants – Fixed-wing Application	FAV	38%	41%	47%	52%	61%	62%	61%	57%	52%	47%	41%	38%	50%
	MAR	7%	7%	5%	3%	1%	0%	1%	1%	2%	4%	6%	7%	4%
	NOT_FAV	55%	52%	48%	44%	38%	38%	38%	42%	47%	48%	53%	55%	47%
Dispersants – Helicopter Application	FAV	39%	43%	48%	53%	61%	62%	61%	57%	52%	47%	41%	38%	50%
	MAR	6%	6%	4%	3%	1%	0%	1%	1%	2%	4%	6%	7%	4%
	NOT_FAV	54%	52%	48%	44%	38%	38%	38%	42%	47%	48%	53%	55%	46%
In-situ Burning	FAV	7%	10%	13%	12%	24%	36%	40%	40%	23%	14%	10%	9%	20%
	MAR	70%	70%	71%	76%	72%	62%	58%	58%	70%	73%	71%	69%	68%
	NOT_FAV	23%	20%	16%	12%	5%	2%	2%	3%	7%	14%	19%	23%	12%

CENTRAL Gulf of Mexico – OFFSHORE

SYSTEM	CONDITIONS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
2 Vessels w/ Boom	FAV	11%	14%	17%	18%	34%	47%	52%	48%	35%	21%	15%	13%	27%
	MAR	65%	66%	62%	68%	60%	50%	45%	49%	57%	62%	63%	63%	59%
	NOT_FAV	24%	20%	21%	14%	6%	4%	3%	3%	8%	17%	22%	24%	14%
Single Vessel w/ Outrigger	FAV	11%	14%	17%	18%	34%	47%	52%	48%	35%	21%	15%	13%	27%
	MAR	65%	66%	62%	68%	60%	50%	45%	49%	57%	62%	63%	63%	59%
	NOT_FAV	24%	20%	21%	14%	6%	4%	3%	3%	8%	17%	22%	24%	14%
3 Smaller Vessels w/ Boom	FAV	3%	4%	5%	5%	16%	24%	31%	33%	18%	8%	5%	3%	13%
	MAR	21%	24%	28%	27%	41%	50%	54%	51%	47%	32%	25%	25%	35%
	NOT_FAV	76%	72%	68%	68%	44%	26%	15%	16%	35%	59%	70%	72%	52%
Dispersants – Vessel Application	FAV	39%	44%	48%	52%	59%	62%	61%	56%	52%	47%	42%	39%	50%
	MAR	61%	56%	52%	48%	41%	38%	39%	43%	47%	53%	58%	61%	50%
	NOT_FAV	0%	0%	0%	0%	0%	0%	0%	1%	2%	0%	0%	0%	0%
Dispersants – Fixed-wing Application	FAV	39%	44%	48%	52%	59%	62%	61%	56%	52%	47%	42%	39%	50%
	MAR	7%	6%	6%	4%	2%	1%	1%	1%	2%	4%	7%	7%	4%
	NOT_FAV	54%	50%	47%	45%	39%	38%	38%	43%	47%	49%	52%	54%	46%
Dispersants – Helicopter Application	FAV	39%	44%	48%	52%	59%	62%	61%	56%	52%	47%	42%	39%	50%
	MAR	7%	6%	6%	4%	2%	1%	1%	1%	2%	4%	7%	7%	4%
	NOT_FAV	54%	50%	47%	45%	39%	38%	38%	43%	47%	49%	52%	54%	46%
In-situ Burning	FAV	5%	8%	9%	10%	22%	37%	44%	40%	24%	11%	8%	7%	19%
	MAR	67%	69%	69%	74%	71%	59%	53%	57%	68%	71%	68%	67%	66%
	NOT_FAV	27%	23%	22%	16%	7%	4%	3%	3%	8%	19%	24%	27%	15%

EASTERN Gulf of Mexico – NEARSHORE

SYSTEM	CONDITIONS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
2 Vessels w/ Boom	FAV	25%	29%	31%	39%	47%	52%	55%	51%	45%	29%	25%	26%	38%
	MAR	62%	62%	60%	57%	51%	45%	44%	47%	51%	62%	63%	63%	56%
	NOT_FAV	13%	10%	9%	4%	2%	3%	1%	3%	4%	9%	12%	11%	7%
Single Vessel w/ Outrigger	FAV	25%	29%	31%	39%	47%	52%	55%	51%	45%	29%	25%	26%	38%
	MAR	62%	62%	60%	57%	51%	45%	44%	47%	51%	62%	63%	63%	56%
	NOT_FAV	13%	10%	9%	4%	2%	3%	1%	3%	4%	9%	12%	11%	7%
3 Smaller Vessels w/ Boom	FAV	12%	17%	17%	23%	34%	41%	43%	41%	32%	18%	13%	14%	25%
	MAR	40%	43%	41%	46%	47%	47%	49%	46%	49%	42%	38%	41%	44%
	NOT_FAV	48%	41%	42%	31%	19%	13%	8%	13%	20%	41%	49%	46%	31%
Dispersants – Vessel Application	FAV	42%	46%	50%	56%	58%	58%	60%	57%	54%	46%	45%	45%	51%
	MAR	57%	52%	48%	44%	42%	42%	40%	43%	46%	54%	55%	55%	48%
	NOT_FAV	1%	2%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	1%
Dispersants – Fixed-wing Application	FAV	42%	45%	49%	56%	57%	58%	60%	57%	54%	46%	45%	45%	51%
	MAR	6%	4%	3%	2%	1%	1%	0%	1%	1%	4%	5%	4%	3%
	NOT_FAV	53%	51%	47%	42%	42%	40%	40%	42%	45%	50%	50%	51%	46%
Dispersants – Helicopter Application	FAV	42%	46%	50%	56%	58%	58%	60%	57%	54%	46%	45%	45%	51%
	MAR	5%	3%	3%	2%	1%	1%	0%	1%	1%	4%	5%	4%	3%
	NOT_FAV	53%	51%	47%	42%	42%	40%	40%	42%	45%	50%	50%	51%	46%
In-situ Burning	FAV	13%	18%	18%	25%	34%	40%	42%	39%	28%	16%	11%	13%	25%
	MAR	70%	70%	70%	70%	63%	57%	57%	57%	67%	71%	72%	72%	66%
	NOT_FAV	18%	13%	12%	6%	3%	3%	1%	4%	5%	13%	17%	15%	9%

EASTERN Gulf of Mexico – OFFSHORE

SYSTEM	CONDITIONS	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC	YEAR
2 Vessels w/ Boom	FAV	15%	20%	21%	27%	40%	50%	54%	49%	39%	23%	18%	18%	31%
	MAR	64%	66%	62%	65%	56%	46%	45%	48%	55%	62%	62%	63%	58%
	NOT_FAV	21%	14%	17%	8%	4%	4%	1%	4%	6%	16%	20%	18%	11%
Single Vessel w/ Outrigger	FAV	15%	20%	21%	27%	40%	50%	54%	49%	39%	23%	18%	18%	31%
	MAR	64%	66%	62%	65%	56%	46%	45%	48%	55%	62%	62%	63%	58%
	NOT_FAV	21%	14%	17%	8%	4%	4%	1%	4%	6%	16%	20%	18%	11%
3 Smaller Vessels w/ Boom	FAV	5%	9%	8%	12%	25%	35%	39%	37%	23%	11%	8%	6%	18%
	MAR	29%	32%	32%	37%	45%	47%	49%	48%	49%	35%	29%	32%	39%
	NOT_FAV	66%	59%	60%	52%	30%	18%	12%	16%	28%	54%	64%	62%	43%
Dispersants – Vessel Application	FAV	40%	46%	49%	54%	57%	60%	61%	57%	52%	45%	44%	43%	51%
	MAR	60%	54%	51%	46%	43%	40%	39%	42%	47%	54%	56%	57%	49%
	NOT_FAV	0%	0%	0%	0%	0%	0%	0%	1%	1%	0%	0%	0%	0%
Dispersants – Fixed-wing Application	FAV	39%	46%	49%	54%	57%	60%	61%	57%	52%	45%	44%	43%	51%
	MAR	6%	5%	5%	3%	2%	1%	0%	1%	1%	4%	6%	5%	3%
	NOT_FAV	54%	50%	46%	43%	42%	39%	39%	42%	47%	50%	50%	52%	46%
Dispersants – Helicopter Application	FAV	40%	46%	49%	54%	57%	60%	61%	57%	52%	45%	44%	43%	51%
	MAR	6%	5%	5%	3%	2%	1%	0%	1%	1%	4%	6%	5%	3%
	NOT_FAV	54%	50%	46%	43%	42%	39%	39%	42%	47%	50%	50%	52%	46%
In-situ Burning	FAV	8%	12%	11%	16%	28%	40%	43%	39%	27%	13%	9%	10%	21%
	MAR	69%	71%	70%	74%	68%	56%	55%	57%	67%	70%	69%	69%	66%
	NOT_FAV	24%	17%	20%	10%	5%	4%	2%	4%	7%	17%	22%	21%	13%