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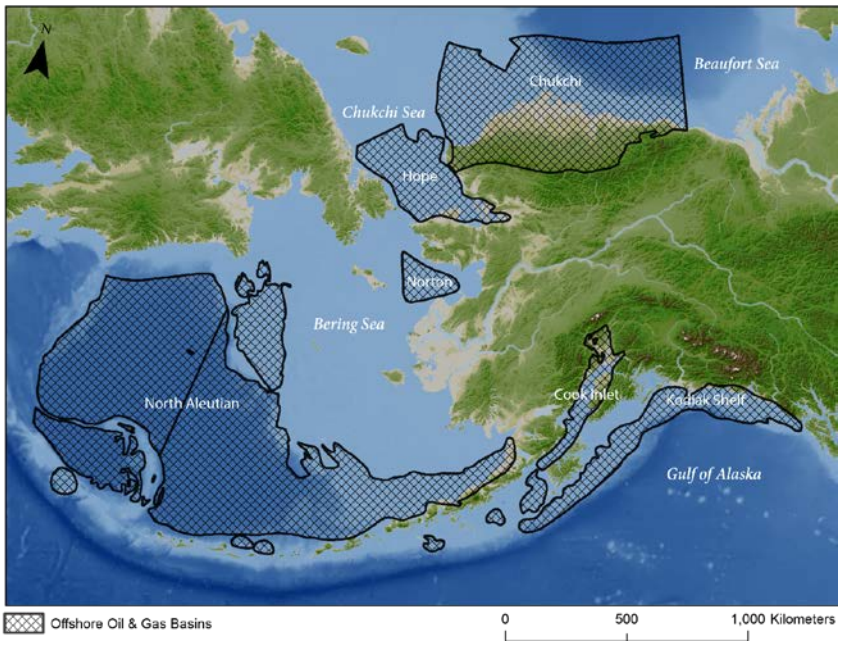

Adapting the National Energy Technology Laboratory's Offshore Integrated Assessment Modeling Approach for the Offshore Arctic

16 July 2015

U.S. DEPARTMENT OF ENERGY

Office of Fossil Energy

NETL-TRS-3-2015

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Cover Illustration: Reference map highlighting offshore oil and gas basins surrounding Alaska. Future research in adapting the current NETL Integrated Assessment Model (IAM) will focus on the exploration and production occurring in the Chukchi Basin, off of Alaska's North Slope, and the Cook Inlet and Kodiak Shelf Basins, in the Gulf of Alaska.

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Adapting the National Energy Technology Laboratory's Offshore Integrated Assessment Modeling Approach for the Offshore Arctic

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Acronyms, Abbreviations, and Symbols

Term	Description
2-D	Two-dimensional
3-D	Three-dimensional
BOEM	Bureau of Ocean Energy Management
BLOSOM	BLOwout and Spill Occurrence Model
CSIL	Cumulative spatial impact layers
DOE	Department of Energy
ERMA	Emergency Response Management Application
GOM	Gulf of Mexico
GOR	Gas/oil ratio
GPR	Gaussian Process Regression
IAM	integrated assessment modeling
IBCAO	International Bathymetric Chart of the Arctic Ocean
MRLC	Multi-Resolution Land Characteristics Consortium
NCOM	Navy Coastal Ocean Model
NETL	National Energy Technology Laboratory
NGDC	National Geophysical Data Center
NLCD	National Land Cover Database
NOAA	National Oceanic and Atmospheric Administration
NRAP	National Risk Assessment Partnership
OCS	Outer Continental Shelf
ORD	Office of Research and Development
PCE	Polynomial Chaos Expansion
QoI	Quantities of Interest
R&D	Research and development
RROM	Reservoir Reduced Order Model
STA	Subsurface Trend Analysis
USGS	United States Geological Survey
WGS 84	World Geodetic System from 1984
WROM	Wellbore reduced-order models

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EXECUTIVE SUMMARY

The Arctic is one of the final true frontiers available for hydrocarbon exploration (Hamilton, 2011). However, recent increases in hydrocarbon exploration and production activities, as well as vessel traffic in the Arctic, heightens the risk for uncontrolled hydrocarbon release events (U.S. Arctic Research Commission, 2012). This report summarizes steps required to adapt the U.S. Department of Energy's (DOE) National Energy Technology Laboratory (NETL), Office of Research & Development's (ORD) current offshore integrated risk assessment for spill prevention models, tools, and methods developed for the Gulf of Mexico (GOM) for future use in the Arctic. NETL ORD's offshore risk assessment effort was initiated in response to lessons learned from recent offshore hydrocarbon impact events (e.g. Hurricanes Rita and Katrina, Deepwater Horizon response) leveraging DOE's established expertise in performing risk and impact assessments for complex, engineered-natural systems (e.g. National Risk Assessment Partnership (NRAP)). NETL ORD's offshore risk assessment was initiated in 2010 and is a multi-faceted effort to provide tools (e.g. geospatial analytical, modeling, etc.) and baseline datasets to characterize and assess the offshore system including the subsurface, wellbore, water column, and shoreline. NETL ORD's offshore approach has resulted in a suite of stand-alone models, tools, data, and approaches that can also be used interactively to conduct integrated assessment modeling (IAM) to identify knowledge gaps, spatial trends and relationships, and quantify potential impacts of various hydrocarbon discharge scenarios.

The goal of this report is to provide an overview of the current offshore IAM tools, statistical approaches, spatial analyses, and data integration techniques developed to evaluate hydrocarbon discharge scenarios and potential impacts in the GOM and evaluate what modifications and additions are anticipated to adapt the offshore IAM approach for use in the offshore Arctic region. For the current offshore IAM, focused in the GOM, parameters for each model and approach are defined and data for the statistical and spatial analysis tools are cataloged (Rose et al., 2014). To adapt this approach for the Arctic, adjustments to the inputs and methodologies used in the tool processes and development will need to be made. Additionally, data based on the Arctic's infrastructure and potential economic, social, and environmental impacts will need to be collected and cataloged. These results will identify key data and knowledge gaps that could be addressed by science-based studies to reduce uncertainty about the offshore Arctic system as a whole. In addition, the results will be used by NETL as guidelines to modify the current offshore IAM approach for the offshore Arctic.

1. PROJECT MOTIVATION AND OVERVIEW

Over the past 50 years offshore hydrocarbon exploration and production has occurred along the continental shelf of Alaska spanning five key outer continental shelf (OCS) planning areas: Cook Inlet, Kodiak, Gulf of Alaska, Chukchi Sea, and the Beaufort Sea (Figures 1 and 2). The first platform was installed in 1964 by Shell in Cook Inlet (Visser, 1969). The first artificial (gravel) island built as a production platform, Endicott, was constructed off the North Slope in the Beaufort Sea in 1987. Current reserves in the Arctic are estimated to contain 22% of the world's undiscovered hydrocarbons, according to the Circum-Arctic Resource Assessment by the United States Geological Survey (USGS) (Bird et al., 2008). While the majority of U.S. Arctic hydrocarbon development to date has occurred onshore, largely in and around Prudhoe Bay (Figure 1), these resource estimates, along with declining onshore production and changes to sea ice thickness and its presence nearshore over the past decade, have led to renewed interest in offshore U.S. Arctic hydrocarbon exploration activities. However, amplification of hydrocarbon exploration and production, and associated marine transportation, only heightens the potential for uncontrolled hydrocarbon release events (USARC, 2012).

The U.S. Department of Energy's (DOE) Office of Research & Development (ORD), located in the National Energy Technology Laboratory (NETL), has been developing a suite of models, tools, and methods over the past four years to evaluate hydrocarbon discharge scenarios and resulting impacts in offshore systems. Initiated as a result of lessons learned from recent offshore uncontrolled hydrocarbon release events (e.g. Hurricanes Rita and Katrina, Deepwater Horizon response), NETL ORD's offshore risk assessment effort leverages existing DOE expertise related to performing risk and impact assessments for complex, engineered-natural systems (e.g. National Risk Assessment Partnership (NRAP)). Designed as a multi-faceted effort, the offshore risk assessment effort focuses on creating tools (e.g. geospatial analytical, modeling, etc.) and baseline datasets to characterize and assess the entire offshore system, including the subsurface, wellbore, water column, and shoreline. This suite of stand-alone models, tools, data, and approaches was initially developed for the offshore Gulf of Mexico (GOM) to conduct integrated assessment modeling (IAM) to identify knowledge gaps, spatial trends and relationships, and quantify potential impacts of various hydrocarbon discharge scenarios throughout the GOM (Rose et al., 2014).

The goal of this report is to provide an overview of the current NETL ORD offshore IAM models, tools, statistical approaches, spatial analyses, and data integration techniques and evaluate what modifications and additions are anticipated to adapt the offshore IAM approaches for the offshore Arctic. For the purposes of this report, the Arctic is referring to offshore areas north of 50°N latitude surrounding Alaska, including the Gulf of Alaska and North Slope region. The North Slope, as shown in Figure 1, is comprised of the southwestern Beaufort and northeastern Chukchi Seas, whereas the Gulf of Alaska, as shown in Figure 2, includes Cook Inlet, areas surrounding Kodiak Island, and Prince William Sound. In contrast to the U.S. GOM, these regions are remote and face strikingly different climatic, geographic, and biologic challenges, particularly in the context of offshore hydrocarbon spill prevention.

A striking example of the difference in the resilience and behavior of these two settings was described by Nelson et al. (2014), which contrasted impacts resulting from the Exxon Valdez oil

spill in Prince William Sound with those from the BP Deepwater Horizon oil spill in the GOM. During March of 1989, approximately 240,000 barrels of crude oil was spilled across approximately 1,300 miles of coastline when the Exxon Valdez oil tanker ran aground on Bligh Reef in the Prince William Sound (Graham et al., 2012; Peterson et al., 2003; Exxon Valdez Oil Spill Trustee Council, 2006). The Exxon Valdez spill resulted in significant ecological, social, and economic impacts, and was the most ecologically destructive anthropogenic event in the history of North America, until 2010 when 4.9 million barrels of oil were released in the Gulf of Mexico during the BP Deepwater Horizon oil spill (Picou et al., 1992; Graham et al., 2011; Sumaila et al., 2012). Although more than 20 times the volume of oil was released into the environment by the BP Deepwater Horizon, studies following the event indicate that the GOM responded quickly to cleanup and remediation efforts, largely due to regional environmental conditions that are more conducive to evaporation and bioremediation (Nelson et al., 2014). By contrast, the lower temperatures in the Arctic slowed bioremediation and degradation processes and now, 25 years after the Exxon Valdez, the effects of the spilled oil on beaches and throughout the ecosystem are still affecting a range of habitats, species, fisheries, and other activities supporting the local communities (Pigg, 2004; Nelson et al., 2014), illustrating the need for robust spill prevention efforts for offshore Arctic regions.

In contrast to the GOM, exploration and production of hydrocarbons in the Arctic faces significant and different challenges including: unpredictable presence and behavior of sea ice, harsh weather events, colder temperatures, and an environment more sensitive to the effects of a hydrocarbon spills. Production rigs, equipment, and procedures capable of facing the aforementioned challenges are expensive. In addition, there is a lack of data for the Arctic, which introduces data gaps and uncertainty (Wassink and van der List, 2013). In recognition of the growing interest in offshore hydrocarbons of the U.S. Arctic, state, tribal, and federal agencies have increased their evaluations and preparations in support of baseline studies, prevention measures and response readiness (IARPC, 1987; U.S. Government, 2011). These efforts include reviewing current scientific research and common knowledge related to the effects of resource development and pollution in the Arctic (i.e. U.S. Coast Guard and Bureau of Ocean Energy Management, BOEM). Adapting NETL ORD's offshore IAM approaches, tools, and assessments for offshore Arctic research and development is one aspect of DOE's efforts to support spill prevention and readiness.

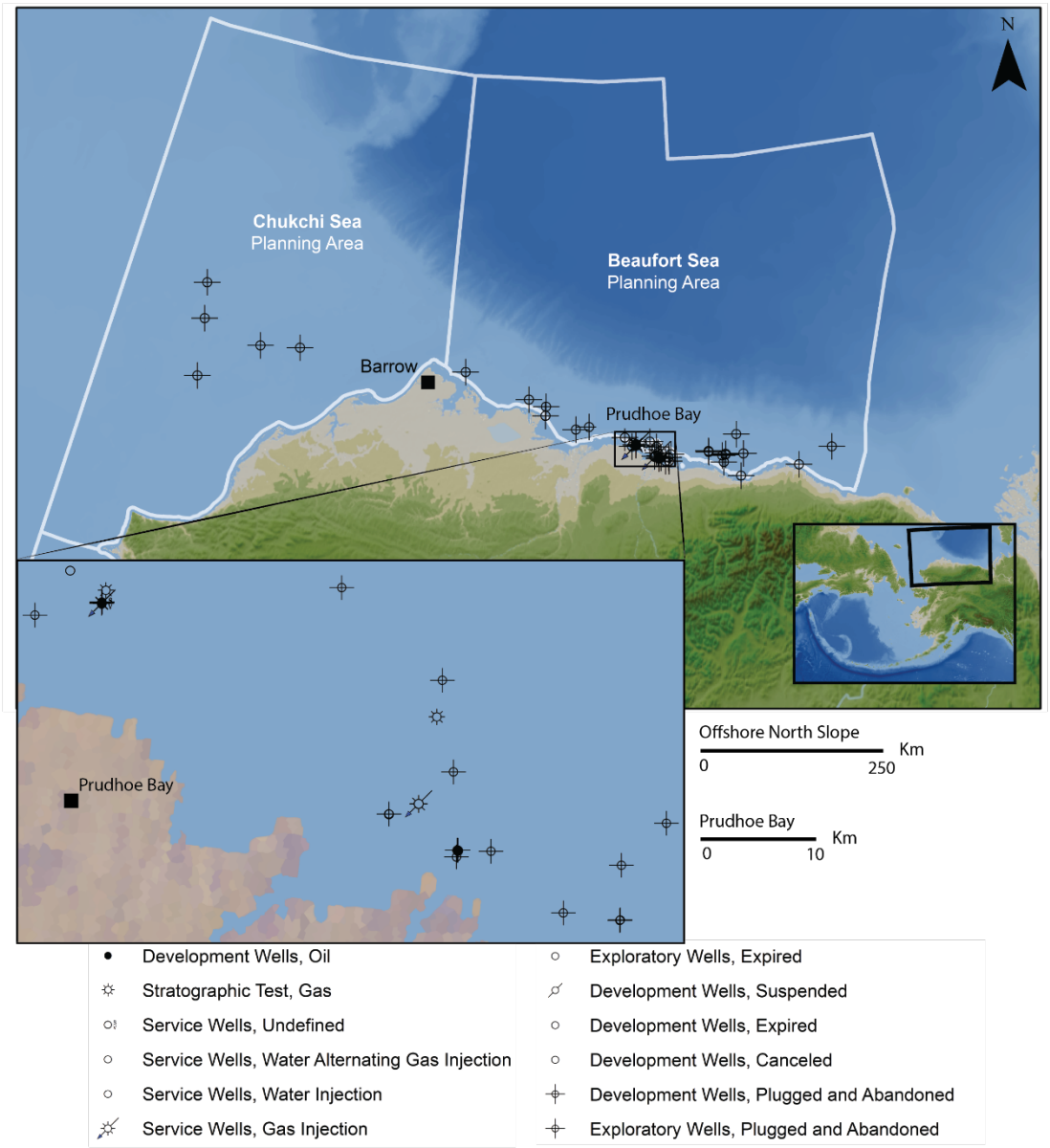

Figure 1: Location of current wells off the North Slope in the Chukchi and Beaufort Sea OCS Planning Areas. As well as a zoomed in map of the oil well locations clustered around Prudhoe Bay.

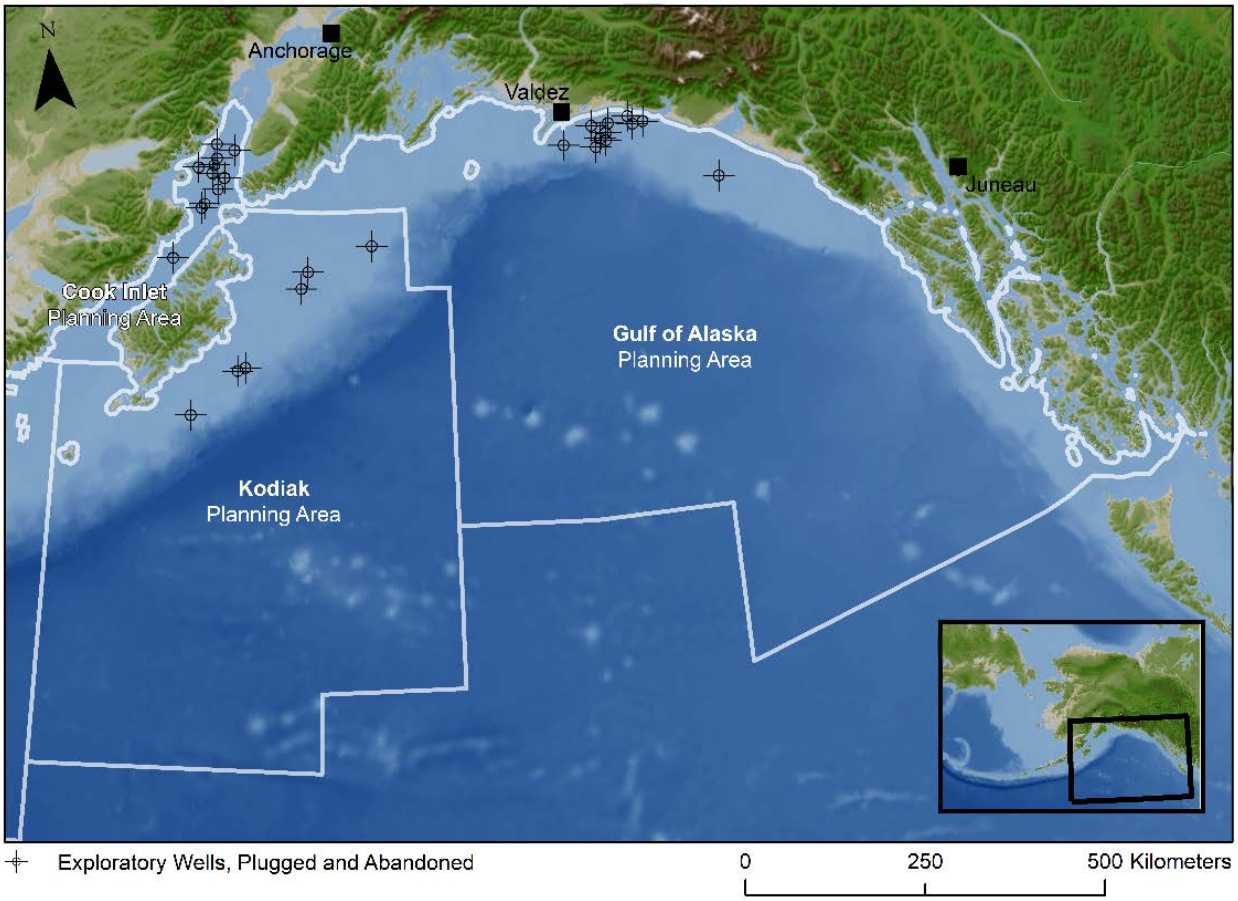

Figure 2: Location of current wells in the Cook Inlet, Gulf of Alaska, and Kodiak OCS Planning Areas.

2. OFFSHORE IAM - INITIAL APPROACH

NETL ORD's current offshore IAM effort has resulted in the development of models and tools designed to span a full system comprised of subsurface, wellbore, water column, and shoreline components. Independently and together, the offshore IAM was built to identify trends, relationships, and knowledge gaps related to potential uncontrolled hydrocarbon release events in the GOM in support of spill prevention and response readiness (Rose et al., 2014). This section provides a synopsis of the NETL ORD offshore IAM spatial analytical models, tools, and statistical approaches created to process and evaluate data for the GOM. In addition, key datasets and sources relevant to this region are cataloged.

2.1 MODELING AND ANALYTICAL TOOLS FOR THE GULF OF MEXICO

This section introduces and evaluates the modeling tools, including the significance of and parameters of the models. Model tools include Reservoir and Wellbore Reduced-Order Models (RROM and WROM respectively), the outputs of which can serve as input data for NETL ORD's Blowout and Spill Occurrence Model (BLOSOM).

2.1.1 Reservoir Reduced Order Model

The Reservoir Reduced Order Model (RROM) was developed to provide an estimate of relevant wellbore attributes, such as flow rates, for a given well in the GOM using available data. This tool is useful for the rapid extrapolation and interpretation of such signatures during critical conditions, such as those encountered in the Deepwater Horizon incident.

Construction of the RROM involves the usage of Polynomial Chaos Expansion (PCE) (Ghanem et al., 1991; Xiu et al., 2002) in conjunction with Gaussian Process Regression (GPR) (Cressie, 1990; Isaaks et al., 1989; Rasmussen, 2006; Krig, 1951). The flowchart shown in Figure 3 explains the procedure for building a reduced-order model at a target reservoir site "s", given minimal data. It involves the construction of PCE for Quantities of Interest (QoI) at reservoir sites r =1, 2 ... R, where R represents the total number of sites where borehole data is available. Building a PCE for QoI at each site requires numerical reservoir simulations, performed in this study with ECLIPSE, a commercial reservoir simulator that makes use of finite difference methods to solve for fluid flow (Schlumberger, 2011a). Inputs to ECLIPSE consist of reservoir geometry, static and dynamic reservoir fluid and rock properties, as well as the well completion.

Outputs from the numerical reservoir simulations relevant to our QoI are fluid production rates, gas/oil ratio (GOR), pressure distributions, fluid saturation distributions, and remaining reservoir fluids.

Using PCE coefficients at the R sites, a RROM is constructed using GPR over the parameter space formed by a subset of reservoir attributes derived from the database. Inputs to the RROM are PCE coefficients from R reservoir sites and estimates of initial reservoir pressure, porosity, water saturation, and other properties at the target site "s". If these attributes are not available they are interpolated using GPR over geological references. The RROM then produces samples of QoI. RROM outputs are inputs for the Wellbore Reduced-Order Model (WROM), which is

described below. The methodology has been the subject of recent conference presentations, and met with critical acclaim (Thimmisetty et al., 2014).

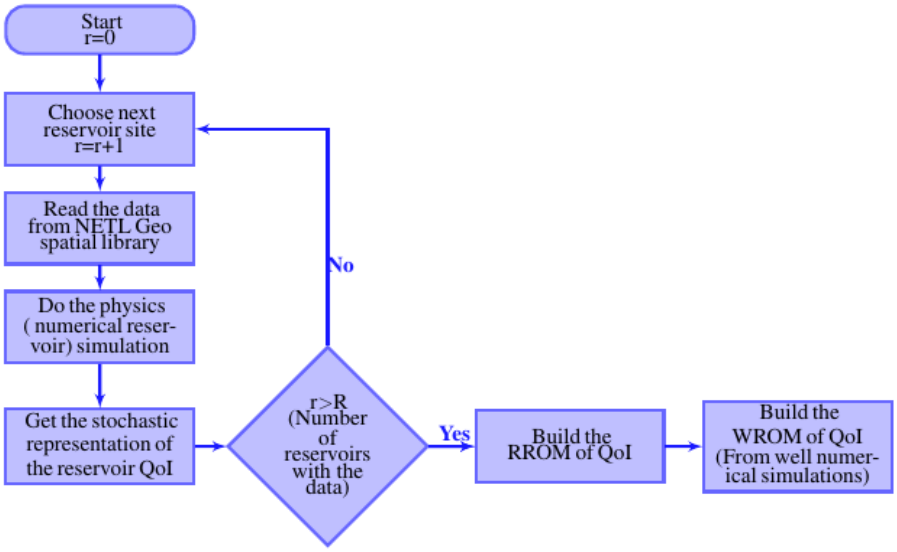

Figure 3: Flow chart for building reservoir and wellbore reduced order models.

2.1.2 Wellbore Reduced Order Model

The Wellbore Reduced Order Model (WROM) uses PIPESIM, a commercial well simulator software package (Schlumberger, 2011b). Inputs for the WROM consist of outputs produced by the RROM, which is derived from numerical simulations of reservoir models. Inputs for PIPESIM consist of estimates for the reservoir's fluid (oil, gas, and water) flow rates to a well per unit (or specified) head and bottom-hole pressure at the well, if not reassigned. In addition, PIPESIM also requires information about the wellbore geometry. The program then uses conventional black oil models to perform analysis, outputting pressure gradients and flow rates.

2.1.3 Blowout and Spill Occurrence Model

BLOSOM (Blowout and Spill Occurrence Model) was developed in-house at NETL as a modeling suite for comprehensive blowout and spill simulations from the well-head to the final fate and degradation of the spill. It consists of multiple models that work in sync, adapting the methods of traditional oil spill and fate models with three-dimensional (3-D) simulations, near-field jet/plume dynamics, deepwater physics, and pseudo-component crude oil models (Figure 4). This allows BLOSOM to simulate blowouts in deepwater and ultra-deepwater situations as well as traditional shallower-water or surface-based spills.

At minimum for blowout conditions, BLOSOM requires inputs for blowout location, depth, diameter, duration, and the mass flowrates of crudes, gases, and water. Crude oil properties may be selected from a database or defined by assays, if available. Ambient conditions (i.e.

hydrodynamic data) can range from fixed values (the simplest option), to a table providing conditions by depth (but no horizontal variability), to raster or netCDFs files spanning multiple dates/times, depths, and/or other variables. Spill layers can be output in either a delimited ASCII format (e.g., a CSV file) or as shapefiles. BLOSOM produces several output tables detailing various spill statistics over time.

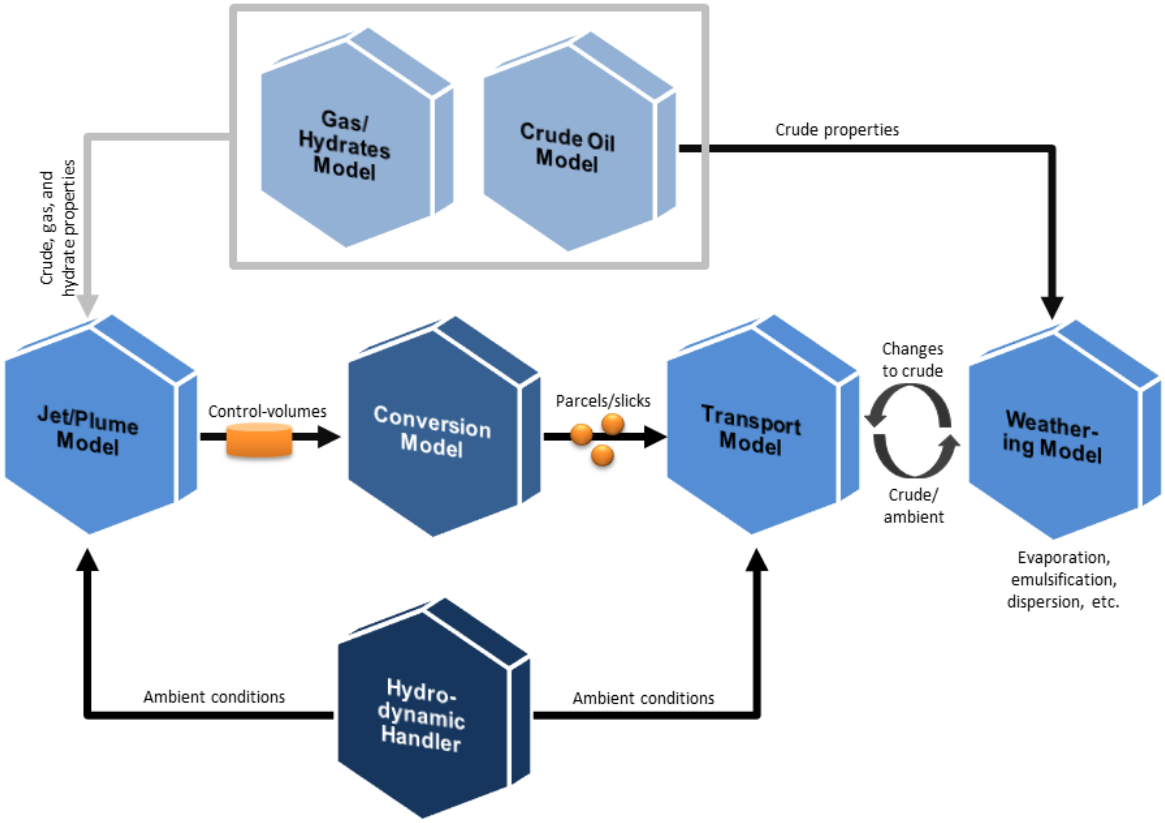

Figure 4: Overview of BLOSOM components and interactions.

2.2 SPATIAL ANALYTICAL AND STATISTICAL APPROACHES

Spatial analytical and statistical approaches have been developed in relation to the subsurface systems to capture spatial trends and reduce uncertainty between regions of higher data density and regions with low data density or no in situ data. In addition, spatial analytical approaches for the water column system include methods to evaluate potential impacts utilizing economic, social, and environmental datasets. This section summarizes the significance and methodology for the subsurface trend analysis, cumulative spatial impact layers (CSIL), and the impact approach developed for the offshore IAM.

2.2.1 Geologic Uncertainty Reduction - Subsurface Trend Analysis

The GOM's vast hydrocarbon reserves are a critical global energy resource. However, exploration and extraction of the subsurface hydrocarbons, in the GOM as well as worldwide, are associated with large amounts of uncertainty and risks. Information about the subsurface GOM is largely related to data associated with existing wellbores, fields and emerging plays. Elsewhere, there may be only two-dimensional (2-D) and 3-D geophysical surveys. These data are integrated via spatial analytical and statistical approaches that help reduce uncertainty and better constrain the range of likely reservoir parameters for regions where little or no data currently exists. Filling these data and knowledge gaps through application of spatial analysis and spatial statistics, in the context of the petroleum system and history of the basin, results in a geologic framework from which subsurface risks may be understood and utilized for both risk assessment and spill response preparedness purposes. This technique is referred to as NETL ORD's Subsurface Trend Analysis (STA) approach. Publications offering more detailed information on the STA approach will be forthcoming in late 2015 and 2016.

2.2.2 Cumulative Spatial Impact Layer Approach

As part of the offshore IAM, we developed a spatio-temporal approach to assess broad risks and potential impacts related to uncontrolled hydrocarbon release events in the GOM (Bauer et al., 2015). This approach utilizes authoritative datasets that represent the spatial extent of key environmental factors or socio-economic activities for a region (e.g., GOM) and can serve as proxies for estimating their annual economic value. These datasets are then combined using a spatial model to create Cumulative Spatial Impact Layers (CSILs), which provide both a representation of key factors or activities and a quantitative estimate of the number of and estimated economic value of the activities within a specific region; Figure 5 provides examples of the aforementioned processes.

For the GOM, the spatial extent and estimated annual economic value were calculated for four major socio-economic activities that have historically been significantly affected by oil spills: the oil and gas industry, commercial transportation, commercial fisheries, and tourism and recreation (Aldy, 2011; Graham et al., 2011; NOAA, 2014). These data were then used in our approach to develop CSILs that quantified the cumulative number of socio-economic activities as well as estimated the cumulative economic impact an oil spill could have on these four major socio-economic sectors in the GOM. CSILs can then be used in combination with modeled output scenarios from other offshore IAM products, including BLOSOM, to identify broad spatial trends of risks and potential impacts associated with different accident scenarios. This supports spill prevention and response readiness planning.

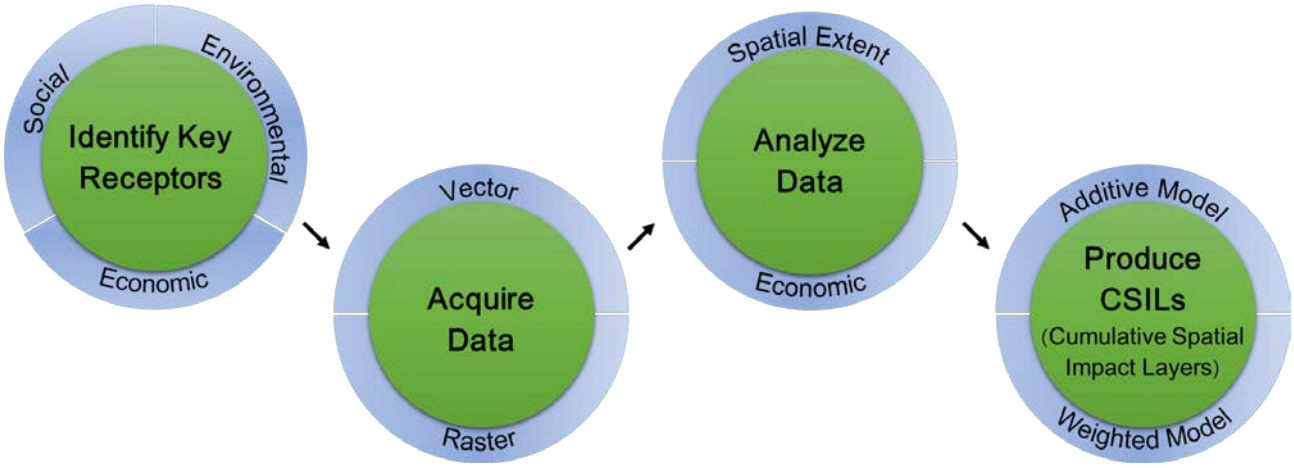

Figure 5: Workflow for the creation of CSILs to quantify the number of and estimated economic value of receptors for a geographic region.

2.2.3 Impact Approach

Initial offshore IAM evaluations of potential impacts have been centered in the GOM and take advantage of the spatial and temporal attributes that BLOSOM provides. To gain a better understanding of spatial and temporal susceptibility of different social, economic, and environmental activities in the GOM, BLOSOM is being used in conjunction with a vector grid approach to aggregate data spatially (Figure 6). Each cell of the vector grid represents a specific area in the GOM, and is characterized by the activities that occur within it. Many datasets can be used to characterize each individual grid cell and they often run the gamut in terms of ranges of values. When assessing susceptibility to impacts, it is important to create an index for the range of values so as to convert them to a common scale and facilitate cell to cell comparisons. In this way the user can make a more objective decision when determining if or how datasets should be weighted when considering environmental, social, economic, and other impacts for the study area. Another advantage to using the vector impact approach is that it can incorporate the CSIL approach without additional effort. Once the indexes and weights for each dataset are determined, the vector grid can be cross-analyzed with the BLOSOM outputs.

For any given hydrocarbon spill scenario, the total extent, total mass, evaporation rate, shoreline length oiled, and total barrels of oil is recorded for each BLOSOM time step. The impact approach prepares the BLOSOM outputs for cross analysis with the impact grid and allows for the comparison between various spill scenarios. Using spatial and temporal characteristics of the spill, the oil residence time and degree of oiling is determined for each of the individual grid cell within the vector grid. The combination of the number of activities in the grid cell and the spatial attributes of BLOSOM yields an impact score for each of the grid cells. The impact scores can then be visualized and compared to determine where the largest impact may be realized.

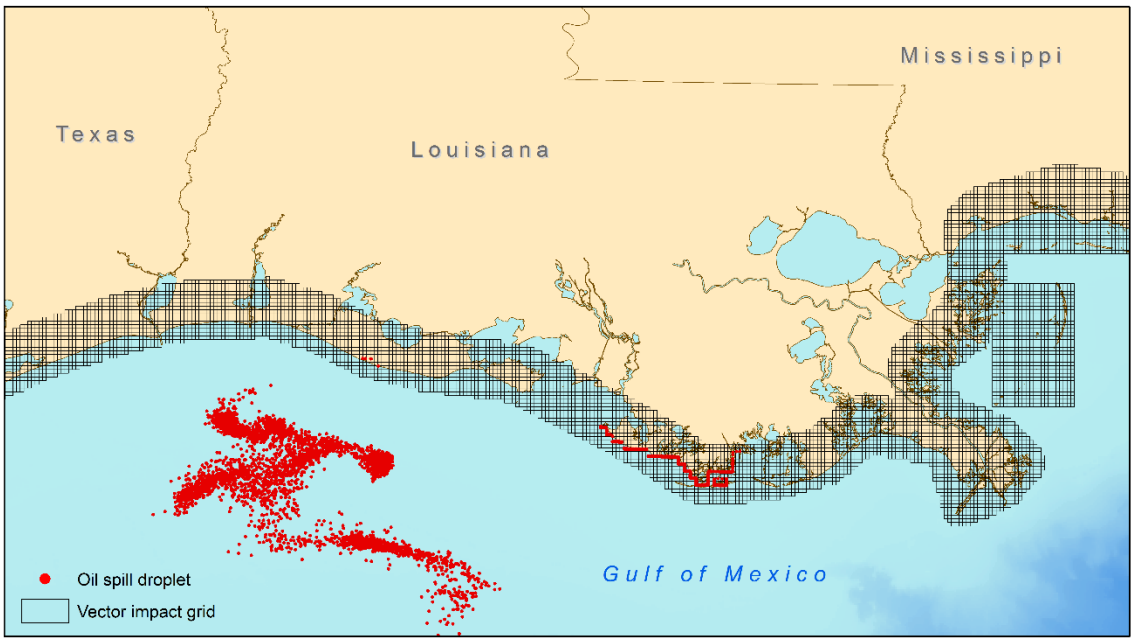

Figure 6: Example of the vector grid approach using BLOSOM outputs. Each cell is weighted based on potential impacts per cell, which incorporates CSIL outputs.

2.3 DATA FOR THE GULF OF MEXICO

The modeling and spatial analytical approaches described above for the offshore IAM rely on appropriate input data and parameters to reduce uncertainty and capture relevant results. To date, the offshore IAM has relied primarily on data for the subsurface, wellbore, infrastructure, and water column in the GOM from a range of publically available and authoritative resources. These are augmented by commercial and proprietary datasets, as available, to help improve and refine the results for each accident scenario. However, proprietary and/or commercial datasets are subject to a range of restrictions that can restrict their use and accessibility. Thus, it is important to focus on publically available datasets that support transparency and accessibility in the future. An accounting of the publically available resources utilized by this study to date is provided for each component of the offshore IAM system.

2.3.1 Subsurface Data – Geologic Uncertainty Reduction

Subsurface data needed to evaluate the GOM came from a multitude of sources. Disenhof et al. (2014), summarizes the GOM's petroleum system and the sources of information available to the public. Mark-Moser et al. (2015) further describes resources available on the GOM's geology and geologic history. Primary public data sources for the subsurface GOM include the U.S. Department of Interior's Bureau of Ocean Energy Management (BOEM), National Oceanic and Atmospheric Administration's (NOAA) National Geophysical Data Center (NGDC), and the published literature. From BOEM, an extensive, annually-updated database of average properties of known reservoir sands provides physical properties such as pressure, temperature, permeability, fluid properties (including gas specific gravity and oil API gravity), and production

statistics. Well locations and survey data, well completion and formation top information, bi-annual well test results, monthly production by well and lease, drilling reports, and geophysical data are also available for download or purchase (BOEM, 2014). Reports from BOEM, such as the 2011 Gulf of Mexico Outer Continental Shelf Assessment (Klazynski et al., 2012), also provide an excellent review of the geology, resources, and reserves of the Northern GOM. The NGDC makes geophysical data available for much of the GOM (NOAA, 2014), and the USGS releases useful structural data for the northern Gulf Basin (USGS, 2014).

Published literature—including peer-reviewed studies, technical reports, and conference publications—is an important resource for subsurface information. Field- or reservoir- specific data can be found in studies conducted by researchers or operating companies, and often these are published as technical papers. The types of study vary, from highly specific models or analyses of individual reservoir intervals, such as Schofield and Serbeck (2000), to reviews of field-scale geology included in reports primarily focused on well production and performance, which nevertheless often include reservoir descriptions and structural information, such as Arnold et al. (2010). The combination of primary datasets and published site-specific studies can be used to offer insights across a given subsurface basin.

2.3.2 Wellbore and Infrastructure Datasets

Infrastructure datasets available for the GOM are described in Graham et al. (2012). They include well information, drilling platform locations, pipelines, protraction diagrams, and lease blocks. For wellbore information, directional survey data for offshore wells in federal waters are publically available from BOEM, as are geophysical logs and well permits, reports, and surveys (BOEM, 2014). Much information on well design and drilling for specific wells and fields can be found in technical reports published by organizations such as the Society of Petroleum Engineers and the Offshore Technology Conferences.

2.3.3 Water Column, Physical Oceanographic, and Impact-related Datasets

BLOSOM, as described in Section 2.1.3, uses water column and bathymetric data, listed in Table 1, to simulate blowout and spill scenarios from the wellhead to the final fate and degradation of the spill. In addition, pressure gradient and flowrate outputs from the RROM and WROM are used as inputs in BLOSOM.

The CSIL and impact approach, as described in Sections 2.2.2 and 2.2.3 can be used with few to many datasets. Datasets used to develop CSILs are region-specific, and should represent the region's socio-economic and environmental values. For the impact approach, the strength of the potential risk determination is largely tied to the number of datasets that are represented within the vector grid. For preliminary CSIL and impact analyses, datasets listed in Table 1 were used. They represent the environment, infrastructure, and socio-economic sectors in and around the Gulf.

Table 1: List of datasets, data sources, and URLs utilized in the offshore IAM for the GOM

Dataset	Data Source	URL(s)
Open Ocean Hydrodynamic Data (i.e. Current Data)	Navy Coastal Ocean Model (NCOM) including IASNFS and AmSeas models	www.northerngulfinstitute.org
Crude Assay Data	BP	http://www.bp.com/en/global/bp-crudes/assays.html
Bathymetry	National Geophyiscal Data Center (NGDC)	http://www.ngdc.noaa.gov/
Beaches	EPA	http://water.epa.gov/scitech/datait/tools/waters/data/downloads.cfm #BEACH Datasets
Hotel Locations	HotelBase	http://www.hotelsbase.org/
Hotel Locations	Google Places	http://places.google.com
National Land Cover Database (NLCD)	Multi-Resolution Land Characteristics Consortium (MRLC)	http://www.mrlc.gov/nlcd2006.php
ESI	NOAA	http://response.restoration.noaa.gov/esi
Shoreline	NOAA	http://shoreline.noaa.gov/index.html
State Boundaries	USGS	http://sdms.cr.usgs.gov/pub/nGOM/nGOM.htm
Economic Data	NOAA/U.S. Census	http://coast.noaa.gov/
Cities (Major)	Esri, ArcWorld	http://www.arcgis.com/home/item.html?id=4e02a13f5ec6412bb56bd 8d3dadd59dd
Campgrounds	U.S. Campgrounds	http://www.uscampgrounds.info/

2.4 INTEGRATING RESOURCES

Data can be visualized through NETL's Geocube (https://edx.netl.doe.gov/dataset/geocube-gom), which is a web mapping and analytical application that integrates spatial datasets and information for a given region (e.g. the GOM). Key data required to support the offshore IAM effort was compiled and uploaded into NETL's Energy Data eXchange (EDX) to ensure efficient and future access.

2.4.1 Energy Data eXchange

EDX (https://edx.netl.doe.gov) is NETL ORD's online coordination and collaboration tool built to facilitate the acquisition and dissemination of information for in-house research teams and their extra-mural collaborators. Scientists working collaboratively across organizations on research projects often encounter problems finding or acquiring pertinent data, and then converting it into a usable format, and sharing it. EDX aims to reduce the time and cost losses associated with both of these situations. In addition, not all data are publically available, many are proprietary or commercial. While EDX cannot eliminate these restrictions, it can relieve some of the issues for specific scenarios. Development of EDX was initiated in 2011. An objective of EDX is to improve research and development (R&D) efficiency and reduce redundancy through better access to primary data sources pertinent for ongoing and future science.

Philosophically, EDX seeks to connect energy data consumers, such as researchers affiliated with offshore hydrocarbon spill prevention modeling, with primary data. If a dataset already has an online presence, EDX offers options to connect users to those data. If a dataset is a product of NETL ORD's R&D, EDX seeks to become the permanent home for that data, offering synergies for future use and reuse by other consumers over time.

EDX houses primary datasets resulting from NETL-affiliated R&D, including data and products resulting from the offshore IAM effort. The primary datasets in EDX contain results from an ever-growing number of fossil energy research projects, both current and historic providing transparency to NETL programs. EDX makes this information easily searchable and instantly accessible, which increases the speed and reduces the cost of ongoing research.

In addition to improving efficient and enduring access to pertinent datasets, EDX provides users with access to energy-related data-driven tools and applications to facilitate coordination and collaboration in support of energy research and analysis. EDX offers advanced tools for fossil energy research, including secure workspaces. These private sharing workspaces allow for better coordination of data among research teams that often include outside collaborators to promote ongoing research within a secure environment.

2.4.2 Geocube

One tool resulting from lessons learned following both anthropogenic (i.e., Deepwater Horizon oil spill) and natural (i.e., Hurricanes Katrina and Rita) events in the GOM is NETL ORD's Geocube. These events highlighted the need to provide key data resources in a single location where users can access relevant spatial datasets, visualize datasets without needing access to

additional software, and easily upload or download datasets needed for additional custom analyses. To address these concerns, part of the offshore IAM effort focused on developing Geocube, NETL's online energy and natural systems web mapping tool that provides users with the ability to visualize key energy related datasets within an easy to use viewer. Geocube is hosted within EDX and allows users to visualize spatial data and quickly explore associated information or create a situational awareness of a region of interest. This is possible by utilizing the data that is already available in the viewer that was collected in the GOM for the offshore IAM (described in Section 1 above). Geocube also offers the user the flexibility to search for and load data that resides within the broader EDX system or from the user's local machine. Near real-time data, such as tropical storm paths and forecasts are also provided in the viewer to help users better understand trending patterns and support decision-making.

In the future, Geocube will be expanded to provide one-stop access to the data-driven products, models, tools, and analytical approaches resulting from NETL ORD's offshore IAM effort such as the STA and CSIL approaches, BLOSOM, as well as the Variable Grid Method (Bauer and Rose, in review). When complete, Geocube will integrate these data, tools, and models allowing users to investigate and analyze their own data and visualize the results directly in Geocube's map view. New functionality will also more tightly couple the EDX application and its community of users with web mapping capabilities provided through a custom implementation of Esri's Portal for Server extension.

3. OFFSHORE IAM - ARCTIC ADAPTATION

Adapting the current set of modeling tools, spatial analyses, and statistical approaches for NETL ORD's offshore IAM effort would enable science-based decision making of hydrocarbon exploration and production in the vulnerable environment surrounding Alaska, including the offshore North Slope and Gulf of Alaska. However, the offshore Arctic region has unique elements. This section discusses anticipated alterations to the aforementioned offshore IAM tools, analyses, and approaches developed for the GOM for use in the offshore Arctic. Potential modifications include revising inputs and procedures to better fit the new environments. Arctic datasets and data sources are also identified for potential use for statistical and spatial analysis approaches.

3.1 MODELING AND ANALYTICAL TOOLS FOR THE ARCTIC

Modeling and analytical tools, including the offshore IAM Reservoir and Wellbore Reduced-Order Models (RROM, WROM), and Blowout and Spill Occurrence Model (BLOSOM), have been assessed to discern potential alterations to fundamental processes and input data for application in the Arctic.

3.1.1 Reservoir Reduced Order Model

Overall, the reservoir modeling components for the offshore Arctic require many of the same elements as that for the offshore GOM RROM. While the subsurface systems themselves differ geologically, the tools and approach used to simulate and predict subsurface flow behavior are comparable. Thus, to construct a RROM for the Arctic, a procedure similar to that detailed in Section 2.1.1 is anticipated. First, PCE for QoI must be performed for all Arctic reservoir sites with sufficient data. This will again require outputs from numerical reservoir simulations, taking geometric, fluid and rock properties of the reservoirs as inputs. Next, the RROM will be constructed using PCE coefficients and subset of attributes in the content of the database at the target site "s".

3.1.2 Wellbore Reduced-Order Model

Similar to construction of the WROM for the GOM, a WROM is obtained for the Arctic through well numerical simulation. Pressure profile analysis (on a nodal base) will be carried out using PIPESIM to investigate the flow behavior and pressure at the system outlet (i.e. the ocean floor). PIPESIM inputs are samples of QoI obtained from the Arctic RROM. However, considerations may need to be made for the seafloor and near-seafloor subsurface systems where sea ice, permafrost, and gas hydrate conditions may exist, adding elements that are not or are less common in the offshore GOM.

3.1.3 Blowout and Spill Occurrence Model

As it currently stands, the minimum requirement for adapting BLOSOM to the Arctic will be acquiring necessary input data, particularly hydrodynamic data. However, to ensure the best

simulations of Arctic simulations, BLOSOM will also be updated to include adjusted equations for weathering in cold and freezing environments as well as thoroughly review all hydrodynamic and crude oil equations to ensure their valid range can encompass arctic environments. The largest challenge will be the potential need to adapt for interactions with sea ice. While drilling operations are likely to be in the summer season, should spills occur late in the season or simply extend far enough to interact with season ice, changes should be made to BLOSOM to incorporation sea ice and hydrocarbon-sea ice interactions. Season ice will affect spreading of the surface slick as well as trap pockets of oil underneath, if there is a large ice sheet. Figure 7 shows the adapted overview of BLOSOMs components and interactions, as previously displayed in Figure 4, for the Arctic. BLOSOM already includes capabilities to handle gas hydrate behavior in the water column, so this behavior which is also potential in offshore Arctic settings is handled by the current BLOSOM system.

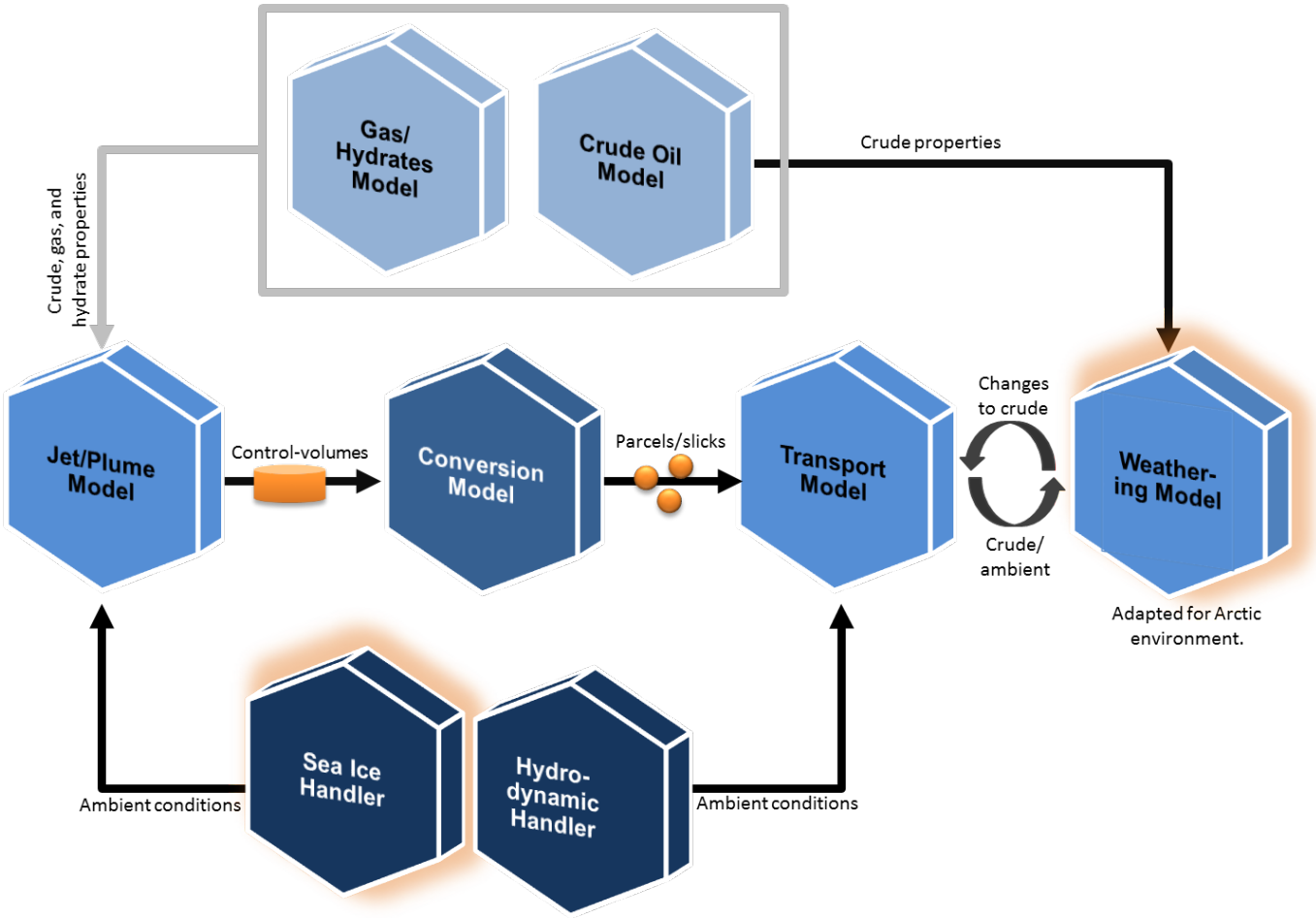

Figure 7: Overview of BLOSOM components and interactions adapted to the Arctic.

3.2 SPATIAL ANALYTICAL AND STATISTICAL APPROACHES

Current spatial analyses and statistical approaches for the STA, creation of the CSILs, and impact measurements for the GOM will act as the framework when transitioning efforts to the Arctic. This section summarizes potential adjustments required to adapt the aforementioned approaches to the Arctic.

3.2.1 Subsurface Trend Analysis

NETL's STA, an analytical and statistical spatial evaluation approach, developed using subsurface properties in the GOM can be appropriately applied for the offshore Arctic subsurface. However, the availability of subsurface data needed to apply the STA for the offshore Arctic system is significantly less due to the immature nature of development in this region relative to the offshore GOM. Data from onshore reservoirs in the Prudhoe Bay region may serve as proxies for their offshore equivalents in the Beaufort Sea region. However, in general the lack of data at this time in the offshore Arctic subsurface poses a challenge for the full implementation of the STA approach. At present, BOEM releases information on less than 100 wells in the Arctic, compared to the GOM's 50,000. With less data, discovered trends may correlate poorly, lending less reliable results in predicting the geologic heterogeneity of the region. Thus for the offshore Arctic, the STA approach may be used in areas of higher data density; however, alternative methods or input datasets (e.g. 3-D geophysical survey interpretations) may be required for some regions and other areas may not be appropriate for the STA approach at all.

3.2.2 Cumulative Spatial Impact Layer Approach

The CSILs spatial approach developed to assess broad risks and potential impacts related to uncontrolled hydrocarbon release events in the GOM (Bauer et al., 2015) can easily be modified to quickly analyze these factors for the Arctic. Designed to be flexible, CSILs allows for the rapid incorporation of different or additional datasets that represent various environmental factors and socio-economic activities, have different spatial and/or temporal resolutions, as well as add weights to our analysis to reflect environmental or socio-economic sensitivities based off locational and/or temporal changes throughout the year. Ultimately, the flexibility provided by the CSIL approach provides users the ability to quickly modify or add to the CSIL analysis to better analyze broad risks and potential impacts associated with oil discharge scenarios based on their interests and needs.

In the Arctic, the main modifications to the CSILs approach developed for the GOM will be in the datasets used in the analysis and the final model used to create different CSILs. Data related to the Arctic's oil and gas infrastructure, marine vessel transport, and commercial fishing for species such as salmon, trout, and smelt (Alaskan waters account for 28~35% of the world's production for these species (FOA Fisheries and Aquaculture Department, 2012; Haitt, 2007; Haitt, 2010) will be used as CSIL inputs. In contrast to GOM, many indigenous coastal communities harvest marine species, including marine mammals, for subsistence (Hassol, 2004). Furthermore, hydrocarbon release events in the Arctic can impact wildlife species not found in the GOM, for example the Exxon Valdez oil spill affected sea otter (*Enhydra lutris*) and killer

whale (*Orcinus orca*) populations in the Prince William Sound (Nelson et al., 2014). Therefore hunting grounds and locations of indigenous communities, as well as habitat for select marine species, will be included in the formation of CSILs for the Arctic. Table 2 contains a list of datasets, data sources, and acquisition locations, which might be utilized in the production of CSILs for the Arctic.

The other modification that might need to occur will be related to weighting the model used to create the CSILs, since factors in the Arctic tend to display greater spatial and temporal variability than those that were used for our analysis in the GOM. Weighting the model used to create the CSILs will allow the layers to better reflect the sensitivity of environmental factors and socio-economic activities at different locations and times of the year. This ability is particularly useful when considering factors related to the sensitivity of a species based on its distribution (i.e., locomotive abilities, migration patterns, etc.) or throughout different life stages (youth, juvenile, adult, mating/spawning seasons, etc.) as well as seasonal fluctuations relating to commercial transportation, oil and gas activities, fishing pressures, and tourism seasons.

Table 2: Example datasets, data sources, and URLs that will potentially be utilized in adapting the IAM to the Arctic

Dataset	Data Source	URL(s)
Coastal Tribal Lands	U.S. Bureau of Indian Affiars	http://marinecadastre.gov/data/
Essential Fish Habitat Areas Protected from Fishing	NOAA National Marine Fisheries Service	http://marinecadastre.gov/data/
Habitat Areas of Particular Concern	NOAA National Marine Fisheries Service	http://marinecadastre.gov/data/
Critical Habitat	NOAA Fisheries, U.S. Fish & Wildlife Service	https://erma.noaa.gov/arctic/erma.html
North Slope Subsistence Use Areas	BOEM	https://erma.noaa.gov/arctic/erma.html
Alaska National Wildlife Refuge	U.S. Fish & Wildlife Services	https://erma.noaa.gov/arctic/erma.html
U.S. Marine Protected Area Boundaries	Department of Commerce, NOAA, Ocean and Coastal Resource Management, National Marine Protected Areas Center	https://erma.noaa.gov/arctic/erma.html

3.2.3 Impact Approach

Now that the methodology to determine impacts using the vector grid approach has been executed successfully in the GOM, it will be fairly straightforward to adapt the approach for an Arctic application. However, as mentioned in Section 2.2.3, the strength of this particular impact approach depends upon the number of datasets available to represent those impacts. Because the Arctic is not as heavily used for tourism as the GOM, the impacts in the area might be more heavily weighted towards environmental and/or cultural impacts. Additionally, the environment of the area may play an important and pivotal role in impact determination. With seasonal ice covering the more northern regions of Alaska, some considerations may have to be made to adapt the impact model for those types of seasonal situations. With the Arctic also being a place of intrinsic cultural value, some assumptions may need to be made to translate the intrinsic or cultural value of a place into impact measures.

Additionally, the Arctic is a rather unique environment given its seasonal ice extent, frigid temperatures, winter storms, and sensitivity to pollution. Thus a temporal component to the vector grid approach for impact analysis may be required for this region. When modeling impacts in the arctic, the time it takes for oil to dissolve might have to be taken into account. One of the major setbacks to cleanup and spill remediation during the Exxon Valdez oil spill of 1989 was difficulties in responding to spill incidents (Nelson et al., 2014). Wind and waves restricted on-surface burning of oil and also limited the amount of time that response crews could battle the growing extent of the spill (Skinner and Reilly, 1989).

3.3 DATA FOR THE OFFSHORE ARCTIC

3.3.1 Subsurface Datasets

Datasets similar to those used for the Gulf of Mexico will be needed for the Arctic: information on the lithology, stratigraphy, structure, and pore-filling media of reservoirs. Subsurface data is generated primarily by seismic surveys and wellbore geophysical logs, cuttings, and potentially core gathered when a well is drilled. While seismic surveys, well data, and well logs are available for areas of the Arctic from resources such as BOEM, NGDC, and the Alaska Oil and Gas Conservation Commission, the scarcity of data in the region will be a challenge. The relative immaturity of oil and gas development in the offshore U.S. Arctic relative to the GOM region is clearly demonstrated by the data disparity between the GOM and the U.S. Arctic. BOEM releases information on more than 50,000 offshore wells in the GOM, while their list of offshore U.S. Arctic wells number less than 100. Information from the published literature, including maps and basin descriptions, is available for both regions and can be used to augment the paucity of available data in the offshore U.S. Arctic.

One geologic complexity encountered in the GOM, the impact of salt tectonics on the complexity of the subsurface system, is absent in the Arctic allowing for greater ease in correlating geologic units and therefore improved prediction of reservoir conditions (Alaska Department of Natural Resources, 2008).

3.3.2 Wellbore and Infrastructure Datasets

BOEM and NOAA make some infrastructure data available for the U.S. Arctic region (MarineCadastre.gov), as they do for the GOM. Shapefiles of offshore OCS planning areas, protraction diagrams, and lease blocks are available, as are hydrocarbon well locations. See Table 3 for an example list of downloadable datasets. However, though industry has been drilling offshore Alaska for decades (Shell, 2014), the lack of a large industry presence offshore in the U.S Arctic means that the production infrastructure that exists in the Gulf, including abundant permanent and mobile drilling platforms, extensive pipelines, and active shipping lanes, does not exist to the same extent in the Arctic.

Table 3: Examples datasets, data sources, and URLs that will potentially be utilized in adapting spatial analysis of the wellbore and infrastructure methods to the Arctic

Dataset	Data Source	URL(s)
Active Oil and Gas Leases	Bureau of Ocean Energy Management (BOEM)	http://marinecadastre.gov/data/
Bureau of Ocean Energy Management Oil and Gas Planning Areas	BOEM	http://marinecadastre.gov/data/
OCSLA "8(g)" Zone Limits	BOEM	http://marinecadastre.gov/data/
Outer Continental Shelf (OCS) Oil and Gas Leasing Program 2012–2017	BOEM	http://marinecadastre.gov/data/
Oil and Gas Wells	BOEM	http://marinecadastre.gov/data/
OCS Lease Blocks	BOEM	http://marinecadastre.gov/data/
Shipping Fairways, Lanes, and Zones ***Not much around Alaska	NOAA Office of Coast Survey	http://marinecadastre.gov/data/
OCS Protraction Diagrams	BOEM	http://marinecadastre.gov/data/
Submerged Lands Act Boundary	BOEM	http://marinecadastre.gov/data/
Alaska Seismic Survey Areas	BOEM	https://erma.noaa.gov/arctic/erma.html
Alaska OCS Oil and Gas Wells	BOEM	https://erma.noaa.gov/arctic/erma.html

3.3.3 Water Column, Physical Oceanographic, and Impact-related Datasets

Similar to the GOM, water column and physical oceanographic data, including bathymetry, will be needed for BLOSOM to accurately model potential blowouts and oil spills in Arctic regions. In addition, sea ice data might be used for modeling in the offshore North Slope region. Water column and physical oceanographic data come from an array of sources, some of which are shown in Table 4.

In addition to the data layers that will be used to create CSILs in Table 2, data describing the coastal environment will be very important for assessing potential impacts. The communities that could be affected most by spills are most often those within a close proximity to the coast line. Datasets for the offshore Arctic should be similar to those mentioned in Section 2.1.3.3 but can vary based on data availability and what impacts are likely to be largest (environmental, cultural, socio-economic, etc.). And overall, the density of population centers in the Arctic are much lower than that of those found along the U.S. GOM region, thus the approach and data required to assess potential impacts associated with offshore U.S. Arctic hydrocarbon development will likely differ significantly from those used for the U.S. GOM region.

Table 4: Examples datasets, data sources, and URLs that will potentially be utilized in adapting BLOSOM and the CSIL and impact approaches to the Arctic

Dataset	Data Source	URL(s)
Arctic Bathymetry	International Bathymetric Chart of the Arctic Ocean (IBCAO)	http://www.ngdc.noaa.gov/mgg/bathymetry/arctic/arctic.html
Cook Inlet Bathymetry	NOAA	http://www.afsc.noaa.gov/RACE/groundfish/Bathymetry/Data.htm
Gulf of Alaska Bathymetry	NOAA	http://www.ngdc.noaa.gov/mgg/bathymetry/arctic/arctic.html
Principal Ports	Marine Cadastre, NOAA	http://marinecadastre.gov/data/ http://coast.noaa.gov/htdata/CMSP/Metadata/PrincipalPorts.htm
U.S. Shipping Routes	Marine Cadastre, NOAA	http://www.marinecadastre.gov/data/default.aspx
Commercial Fishing Data	NOAA	http://www.afsc.noaa.gov/maps/default.htm
Recreational Fishing Areas	NOAA	http://www.afsc.noaa.gov/maps/default.htm
Populated Locaitons in Alaska	USGS, Emergency Response Management Application (ERMA)	https://erma.noaa.gov/arctic/erma.html#/x=-158.52172&y=69.38032&z=5&layers=
Subsistence Fishing Locations in the Gulf of Alaska	NOAA	http://www.afsc.noaa.gov/maps/default.htm

3.3.4 Spatial Reference System

Areas of interest in the offshore U.S Arctic include the Gulf of Alaska, which includes Cook Inlet and Prince William Sound, and offshore of the North Slope, which includes the Chukchi and Beaufort Seas (see Figures 1 and 2). Spatial data of the Arctic come in a range of spatial reference systems, which are comprised of projections, datums, and units. Using a single spatial reference system to encompass both areas of interest, the Gulf of Alaska and offshore of the North Slope, would cause distortion and result in analysis errors. Because of this, two customized spatial reference systems were created by NETL's ORD offshore IAM team.

The customized spatial reference systems were designed to minimize distortion for each area of interest. To guarantee compatibility across datasets, all data was first converted to the World Geodetic System from 1984 (WGS 84) in meters. In addition, how the hydrodynamic model outputs handle coordinate-systems was considered. Computations using geographic coordinates (i.e. latitude and longitude) become increasingly variable in actual, spatial distance and prone to errors. Though many polar projections exist and may be used, projection distortion analysis was utilized to ensure the projections chosen are the best fit for the needs of the project and interaction with whatever coordinate-systems the hydrodynamic outputs use; results of the projection distortion analysis are shown in Figures 8 and 9. The selected projection for each of the customized spatial reference systems is conic equidistance, which preserves directionality locally and distance throughout the area of interest, which are key features when running each of the full system models (Snyder, 1987). Parameters for each projection are shown in Tables 4 and 5.

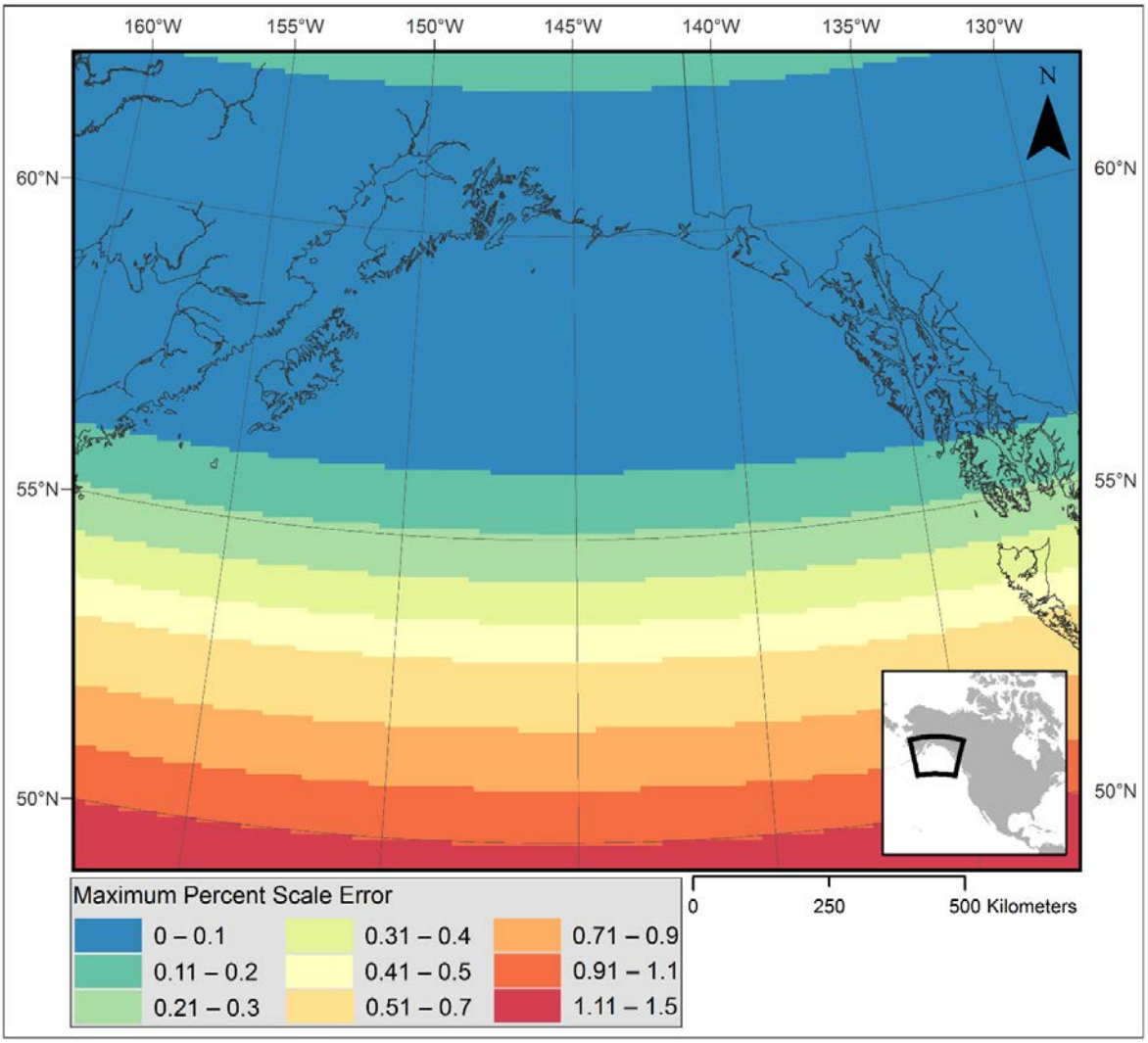

Figure 8: Distortion in the Gulf of Alaska Equidistant Conic spatial reference.

Table 5: Gulf of Alaska Equidistant Conic Spatial Reference

Parameter	Value
Projection	Equidistant Conic
False Easting	0
False Northing	0
Central meridian	145.546944 degrees west
1st Standard Parallel	57.476944 degrees north
2nd Standard Parallel	61.146944˚ North
Latitude of Origin	59.311944˚ North
Datum	World Geodetic System 1984 (WGS94)
Units	Meters

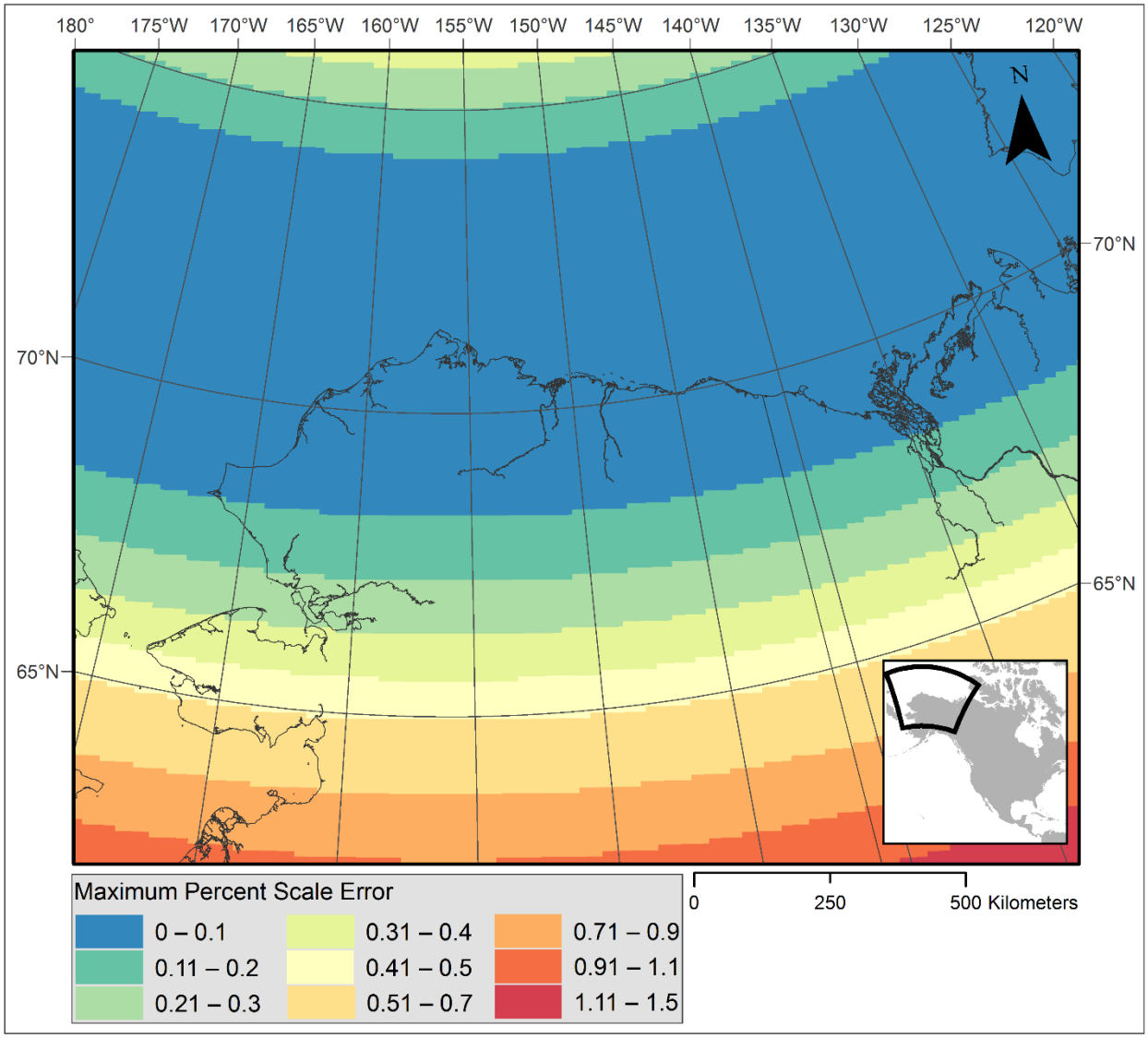

Figure 9: Distortion in the North Slope Offshore Equidistant Conic spatial reference.

Table 6: North Slope Offshore Equidistant Conic Spatial Reference

Parameter	Value
Projection	Equidistant Conic
False Easting	0
False Northing	0
Central meridian	156.093889 degrees west
1st Standard Parallel	69.854444 degrees north
2nd Standard Parallel	72.873056 degrees north
Latitude of Origin	71.363889 degrees north
Datum	World Geodetic System 1984 (WGS94)
Units	Meters

3.4 INTEGRATING RESOURCES

3.4.1 Energy Data Exchange (EDX)

Multi-organizational scientists working collaboratively on research projects often encounter problems finding or acquiring pertinent data, and then getting it into a consumable format. NETL ORD's EDX aims to reduce the time and cost losses associated with both of these situations. In addition, not all data are publically available, many are proprietary or commercial. While EDX cannot eliminate the restrictions associated with these categories of data, it can relieve some of the issues for specific scenarios. EDX is continuing to grow in functionality and popularity, however, there often repeated questions about the philosophy and function of EDX.

To overcome these challenges, NETL initiated development of EDX to improve R&D efficiency and reduce redundancy through better access to primary data sources pertinent for ongoing and future science. EDX is an on-line system built on the open source platform CKAN that provides users with access to energy-related data, data-driven tools, and apps to facilitate coordination and collaboration in support of energy research and analysis. EDX offers advanced tools for fossil energy research, which allow for better coordination of data among research teams as well as with outside collaborators, and enduring access to data.

3.4.2 Geocube

Geocube is an online mapping tool developed by NETL ORD hosted by EDX, initially in support of the offshore IAM effort to ensure efficient access to priority datasets for the GOM region but also to offer online analytical capabilities necessary to support spill prevention as well as rapid response efforts. The level of effort required to adapt Geocube for use in the Arctic will be minimal since Geocube is built using a modular approach, which makes the application very adaptable to a variety of data inputs from any geographical region of interest. For this reason, the major effort needed to integrate Geocube with offshore Arctic data will be the data collection, QA/QC, and preparation for use with the application. This effort can include integrating datasets from existing applications, such as BSEE/NOAA Emergency Response Management Application (ERMA), BSEE and BOEM's Data Center, NOAA's Digital Coast, and BOEM/NOAA Marine Cadastre. Additional efforts might also include development time to setup "hooks" to the data from the application as well as any custom functionality that may be required for the offshore Arctic region. In the future, Geocube is also slated to be integrated with key risk assessment analytical tools, such as BLOSOM, STA, CSIL, and Variable Grid Method (Bauer and Rose, In Review), to support rapid and multi-organizational efforts related to offshore spill prevention and rapid response needs.

4. SUMMARY

As hydrocarbon exploration and production in the Gulf of Alaska and offshore North Slope intensifies, the probability of uncontrolled hydrocarbon release events also increases (USARC, 2012). Current tools and methods used to model and evaluate oil discharge scenarios and the resulting impacts in the Gulf of Mexico provide a framework for applying those same tools to the Arctic. This report provides a synopsis of each part in the ongoing project, which models a full system including, subsurface, wellbore, water column, and the shoreline, and lists pertinent datasets and sources in relation to hydrocarbon production in the GOM. After summarizing what has been accomplished, each step is then evaluated to determine what modifications to the parameters and processes need to occur to adapt the modeling tools, spatial analyses, and statistical approaches to the U.S. Arctic. In addition, potential data sources for the infrastructure, economic, social, and environmental impacts are inventoried.

Results of the DOE NETL offshore modeling team applying current models, tools, spatial analyses and statistical approaches to the Arctic will fill data gaps and reduce uncertainty. In addition, results from this transition will provide vital information to support science-based decision making in relation to uncontrolled hydrocarbon release events and assess broad risks and impacts in the U.S. Arctic.

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