**Supplemental Text For**

**Towards Integrated Modeling of the Long-term Impacts of Oil Spills**

Version dated: March 28, 2021

**I. Background of Research Efforts**

The Deepwater Horizon (DWH) accident led to a 10-year study on marine oil impacts involving 292 research groups from around the world and almost 3000 researchers (GoMRI 2019a. An initial investment of $500 million by British Petroleum, who leased the DWH rig (which was owned and operated by offshore-oil-drilling company Transocean), was used to establish the Gulf of Mexico Research Initiative (GoMRI) as a research program. GoMRI has produced more than 1500 peer-reviewed publications and 2700 archived data sets to date and has drawn to a close in 2020 (GoMRI 2019b), although publications and work will continue through other funding sources and initiatives.

The Synthesis and Legacy efforts of GoMRI studies have become important goals as GoMRI research sunsets. To that end, the GoMRI Research Board established a Synthesis and Legacy committee in 2019 to oversee 8 core areas of focus. One of the core areas (Core 7) focused on integrated and linked modeling systems. Core Area 7 was further divided into Areas 7A and 7B. Core Area 7A concerns operational oil spill forecasting, including ocean, wave and weather forecasting for predicting oil movement. Models used in Core Area 7A support the formulation of tactical spill response advice. They tend to employ short time horizons, making predictions hours to weeks into the future. They also are typically used to guide emergency response activities and immediate cleanup efforts (e.g., by answering questions such as where to deploy equipment for shoreline removal of oil). These operational models can be quickly configured to investigate tactical questions as new questions arise. In contrast, Core Area 7B aims to conceptualize broader models that project the effects of oil spills on the socioecological system (i.e., integrating ocean environment, biological ecosystems, socioeconomics and human health) and could be employed for strategic planning. These models are intended to operate over longer time horizons, from months or years to decades. They tend to be more interdisciplinary in nature, because they require integration across broad knowledge domains.

The following pages describe the detailed recommendations, and the organizational initiatives of the Core 7B group which lead to the writing of this paper, a synthesis and legacy product of GoMRI.

References

GoMRI 2019a. GRIIDC. The Gulf of Mexico Research Initiative. Harte Research Institute for Gulf of Mexico Studies | Texas A&M University-Corpus Christi. Corpus Christi, TX.

GoMRI 2019b. GoMRI Publications. Gulf of Mexico Research Initiative. https://research.gulfresearchinitiative.org/gomri-publications/.

## II. Detailed summary of knowledge gaps identified by subject matter experts

Although a wide array of models exists, especially in the ocean environment domain, subject matter experts emphasize that there are opportunities for improvement. Input from experts was facilitated through a sequence of webinars, virtual workshops, and two conference sessions where experts were invited to participate in discussing modeling needs and linkages necessary to answer long-term societal level questions. (See supplemental material for details). These sessions supported an iterative and shared development of the CLD (Figure 2 in main text). The process began with researchers’ presentations of their work in a series of public webinars, one for each of the four domains. Each webinar was followed by a private working session, typically with 10-20 participants, which used the presented research as a starting point for a structured questioning process designed to identify the causal structure implied by the work as well as linkages to other domains. Some diagram elements were constructed or marked up live, and others were added later based upon participant comments. A subsequent series of workshop sessions reviewed and refined the diagrams and added elements from a more focused exploration of phenomena that cross the four domains. The following gaps and opportunities in the four knowledge domains identified through this process were as follows:

Ocean Environment

* Integrate ocean and atmosphere physical processes. Fully couple atmospheric processes directly with hydrodynamic and oil spill transport models, such that atmospheric processes contribute to the hydrodynamics of the ocean at the air-sea interface.
* Integrate oil and hydrodynamic transport. Integrate the effects of oil on the hydrodynamics of the ocean and nearshore, as the presence of oil can impact currents and waves. Models do not traditionally simulate transport as two-phase flow (seawater and oil as multiphase liquids).
* Photochemistry and its effect within hours in some regions (tropics and temperate zones) on surface oil composition, viscosity, and other physical, chemical., and effects properties.
* MOSSFA. Work is needed in the simulation of sinking oil and Marine Oil Snow Sedimentation and Flocculent Accumulation (MOSSFA).
* Freshwater. Freshwater simulation capabilities should be added including modeling of oil spills in freshwaters and also integrating freshwater inflows from rivers on nearshore hydrodynamics of the ocean.
* Additional biophysical processes. Integrate biophysical processes affecting concentrations and movement of oil (e.g., biodegradation, photodegradation, degassing, dissolution, hydrate formation).
* Oil chemistry database. The database of oil chemistries should be expanded.
* Scenario repositories. Establish scenario repositories for downstream use, for use by those in health and socioeconomics to identify areas for concentration of toxins and as drivers for their models.
* Baseline data. There is a need to establish what is considered an adequate baseline. Data should be available to establish background levels of chemical and biological constituents so that the impacts of oil spills can be more fully assessed.

Biological Ecosystem

* Ecosystem dose response. Determine dose-response relationships, particularly for birds, mammals and sea turtles, and for different species of hydrocarbon.
* Ecosystem effects on oil. Evaluate the impacts of fish, plankton, microbes and other organisms on the spatial distribution and degradation of oil.
* Bioaccumulation. Understand the potential for bioaccumulation of metals and persistent organic compounds.
* Mitigation impacts on ecosystems. Understand the effects of dispersants and burning on the toxicity of hydrocarbons.
* MOSSFA. Understand effects of MOSSFA formation on water column and benthic biota including toxicity and deoxygenation.
* Population interactions. Improve estimations on ecosystem level impacts by better understanding the effects on individual populations and interactions between populations.
* Deep sea ocean. Improve understanding and simulation of the ecosystems of the deep-sea ocean.

Socioeconomics

* Cost-benefits of restoration. Quantify societal benefits of restoration and estimate costs associated with restoration efforts.
* Simulate intersectoral interactions. Develop quantitative approaches to simulate inter-sectoral interactions, interactions among health, education, housing, and local government.
* Aggregating to regional economies. Evaluate how impacts of oil spills on different sectors ultimately affect the regional economy.
* Community metrics. Identify methods to quantify and simulate community growth, and the value of education, equity, and health.
* Link mitigation to long-term socioeconomics. Quantify the links between spill response and long-term capacity development.
* Link socioeconomic responses to decision making. Evaluate methodologies that relate economy, welfare, community health metrics towards the allocation of resources.

Health

* Interlink physical and mental health risk. Current information is focused on case study assessments of the influence of mental health on physical health and vice versa. This information should be converted into a model capable of simulation. Indices are most commonly used to represent modeling outcomes (e.g., EPA’s human well-being index).
* Quantify health delivery capacity and economic impacts. Need to better quantify excess health burden impacts on the economic system. There is a need to better link health to socioeconomics as they are intricately related to one another through feedback mechanisms which synergize consequences in both negative and positive ways.
* Expand dose-response information. Dose-response data lacking for many chemicals in oil. Efforts are needed to define chemical dose-response and the synergistic affects from multiple chemicals.
* Expand on human health impacts through airborne routes. The ocean environment models tend to be very well developed for water transport of oil. Less is available for transport through airborne routes.
* Communication. Communication strategies should be integrated into modeling efforts through their influence on perception and ultimately actions that lead to different human health consequences.

In order to develop a fully integrated model, links between state variables will need to be quantified. During the expert workshop several missing links were identified, especially when evaluating the boundaries between knowledge domains. These missing links include:

Ocean Environment/Biological Ecosystems

* Microbial system and transport. Work is needed to develop an explicit representation of the mechanisms by which the microbial degradation impacts the transport of oil.
* Mobile species behavior. Behavior of individuals at various life stages affects exposure to oil and stressors such as ultraviolet light. Better information is needed for behaviors on the time scale of hours to days to model this behavior more reliably.
* Shallow surface water mixing layer. Work needed in simulating shallow surface water mixing layer inclusive of aerosols due to impacts on organisms that remain at surface and impacts to air breathing mammals.
* Deep sea. More work is needed to understand physical, chemical, biological, and ecosystem processes in the deep sea.

Ocean Environment/Health

* Individual chemical concentration simulations. Expand existing oil fate/transport modeling capabilities to simulate individual oil chemical concentrations (SIMAP and CMS has some capabilities) so that results can be used in human health risk assessment.

Biological Ecosystems/Health

* Infectious disease. The presence of oil may result in immunosuppressive affects that then make ecosystems and humans more susceptible to disease.

Biological Ecosystems/Socioeconomics

* Disaggregation. Develop methods to disaggregate output from ocean environment and ecosystem models into modules that are useful for valuation of coastal and marine resources in socioeconomics simulations.

Socioeconomics/Health

* Establish linkages. Just about all interlinkages between socioeconomics and health in causal loop diagram are lacking quantitative relationships.

The above list of knowledge gaps emphasizes that the system naturally separates in two tiers, ocean environment and biological ecosystems (that need to be spatially explicit in considerable detail) versus socioeconomics and human health (that need to represent the structure of populations and economies). The systems within each of these two tiers are quite closely intertwined with each other. So, as a first cut (for the shorter time frames of months to years), it is possible to segment the model to go from top half to the bottom half without having to introduce the massive complexity that would arise from intimate direct feedback from human health and socioeconomics back to oil spill behavior and spill mitigation efforts. This structural simplification means that one can continue to use the existing detailed ocean environment and biological ecosystem models to drive exploration of rich human health and socioeconomic scenarios. One can therefore chain submodels together sequentially in a linear manner similar to that used in CMS, where spatial dispersion of oil influences the fisheries component of the ecosystem and that in turn affects income and employment. The reason this works is because there are tight clusters of direct feedbacks within the ocean and within the ecosystem, which can be mostly separated except for the species that are active in the transport and degradation of oil. So, to a first order these are separable systems. The health and socioeconomic system, on the other hand, is much more tightly coupled. People are the coupling agent with a network of payments and social relationships which is important to health outcomes and the productivity of the economy. The human health and socioeconomic systems are much more entangled and modeling the human dimension will require simultaneous consideration of socioeconomics with human health. One added complexity however, corresponds to the much longer time horizon where regulatory frameworks are developed in response to overall impacts on human welfare and well-being. These regulatory frameworks can include restrictions on coastal development which has feedback loops that influence biological ecosystems and also include, very importantly the political process which results in the development of rules and requirements of the oil drilling industry which sets up a permit process which may restrict oil drilling in certain areas or may control the practices implemented during oil drilling operations. The permit process also controls the need for contingency planning and the development of response capacity. All of these regulatory factors related to oil drilling operations influence the probability of future spills and thus provide some controls on whether spills are to happen in the future. This larger feedback loop from the human systems back towards the natural systems operates at much longer time scales. Because of the much longer time scales, a separate coupled model that simulates the regulatory framework that integrates the outer loops of the causal diagram would be one means of capturing the much longer-term (decadal scale) feedback loops from the lower tier of human systems towards the upper tier of natural systems.

## III. Acknowledgments and summary of hosted events to develop this manuscript

The manuscript corresponding to this supplement is a product of Gulf of Mexico Research Initiatives Synthesis and Legacy Efforts. The members of Core 7B who made this work possible are provided below.

Committee Co-Chairs: Cam Ainsworth, Helena Solo-Gabriele

Committee Members: Eric Chassignet, Monica Wilson, Elizabeth Fetherston-Reich (year 1), Katya Wowk (year 1)

Ventana Systems: Tom Fiddaman, Laura Peterson, Ron Suiter

GoMRI Board Members: Cecilie Mauritzen, David Halpern, Denis Wiesenburg, John Farrington, John Shepherd

GoMRI Management Team: Chuck Wilson, Kevin Shaw, Michal Carron, Callan Yanoff, Leigh Zimmermann, Michael Feldman

A sequence of events were held (Table 1) as part of gathering information from experts. Details about each of these events are provided on the following pages. A sincere note of gratitude is given to the participants within all of these events.

|  |  |  |
| --- | --- | --- |
| Detailed Description ID | Dates | Description |
| 1. February 5, 2019 Conference Session | February 5, 2019 | Conference session as part of the 2019 Gulf of Mexico Oil Spill and Ecosystem Science (GOMOSES) Conference  |
| Not Available | February 6, 2020 | An in-person meeting during the 2019 GOMOSES Conference where experts discussed the organization of Core 7B and self-assimilated into Core 7A and Core 7B.  |
| 2. State-of-the-Art Webinars | May 6, 2019May 13, 2019May 20, 2019May 28, 2019 | A series of four webinars during which experts shared expertise to provide a starting point for a common understanding of the state-of-the-art.  |
| 3. Virtual Working Sessions Following Each Webinar (set A)4. Virtual Workshops Combining Experts Between Knowledge Domains (set B) | (set A) (set B) | May 9, 2019May 16, 2019May 23, 2019May 30, 2019June 4, 2019June 6, 2019June 11, 2019June 14, 2019 | A total of 8 virtual working sessions were coordinated. The first four (set A) followed each of the webinars as part of the process to initiate the process of building the causal loop diagram with experts from each domain of knowledge. The last four (set B) focused on combining experts from different domains to establish linkages between the knowledge domains. |
| 5. February 4, 202- Conference Session | February 4, 2020 | Conference session as part of the 2020 GOMOSES Conference  |
| 6. In-person Pilot Test of Aggregate Model | February 5, 2020 | An in-person meeting during the 2020 GOMOSES Conference held February 2020 where experts provided input on the causal loop diagram and on a preliminary version of the aggregate (stock and flow) model. |
| 7. Virtual Workshop for Core 7B | May 5 – 8, 2020 | A virtual workshop focused on collecting stakeholder input, input on state-of-the-art, input on the causal loop diagram, input on the aggregate model, and a discussion about future directions. |

Table 1: Events held as part of Core 7B efforts to gather expert input and development of the causal loop diagram.

### February 5, 2019 Conference Session

2019 Gulf of Mexico Oil Spill and Ecosystem Science Conference, Session 015: Modeling for Synthesis - Progress in Linking the Natural Sciences and Connecting to Politics, Economics, Health, Psychology, and Further

Date/Time: Wednesday, February 6, 2:00p – 5:30p, Celestin C

Session Chairs: Helena Solo-Gabriele, University of Miami; Cecilie Mauritzen, Norwegian Meteorological Institute; Eric Chassignet, Florida State University; Elizabeth Fetherston-Resch, Florida Institute of Oceanography; Katya Wowk, Harte Research Institute

Session Introduction: In order to answer questions like “How serious was the spill?”, “What is the overall societal impact of an oil spill?”, or “How can we be better prepared?” in quantitative terms and be able to express how certain we are about the answers we give, some sort of quantitative modelling is ultimately required at the full system level. This session highlighted integrated modeling of natural and anthropogenic systems from various disciplines and scales. The session also included discussions of how model-sharing platforms such as the Gulf of Mexico Community of Practice (ModCOP) can best support science for decision-making and impact science to application for Gulf restoration and management.

Session Presentations:

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| Time | Title | Presenter |
| 2:00p – 2:15p | Introductory Remarks | Cecilie Mauritzen, Norwegian Meteorological Institute; Katya Wowk, Harte Research Institute |
| 2:15p – 2:45p | Earth System Prediction: A Regional Example for the Gulf of Mexico | Antonio Busalacchi, University Corporation for Atmospheric Research\* |
| 2:45p – 3:00p | Development of Earth System Model Components to Quantify the Connectivity of Remote Ecosystems in the Gulf of Mexico | Villy Kourafalou, University of Miami |
| 3:00p – 3:15p | Predicting the Impacts of Oil-Spill Related Fishery Closures on Fishery Revenues - A Spatially Explicit Approach | Igal Berenshtein, University of Miami |
| 3:15p – 3:30p | Development of a Coupled Modeling System for Simulating Oil-Microbial-Sediment Interactions in the Ocean | Steven Morey, Florida A&M University |
| 3:30p – 4:00p | Coffee Break |  |
| 4:00p – 4:15p | Gulf of Mexico Modeling Community of Practice: Connecting Modeling Capacities to Restoration and Management Needs | Gregory Steyer, U.S. Geological Survey |
| 4:15p – 4:30p | Progress towards an Agent-Based Model that Explores the Effects of the Deepwater Horizon Oil Spill on Fish and Fishers in the Gulf of Mexico | Steven Saul, Arizona State University |
| 4:30p – 4:45p | Integrating Oil Spill Trajectory Simulations to Guide Estimates of Human Exposure | Helena Solo-Gabriele, University of Miami |
| 4:45p – 5:00p | The Holistic Individual Preparedness Model (HIPM): Accounting for Social, Health, and Technological Capacities across Disaster Response and Recovery | Ashley Ross, Texas A&M University at Galveston |
| 5:00p – 5:30p | Panel Discussion Modeling for Synthesis - What We Have Learned So Far Modeling for Synthesis - Where to Go from Here  | Eric Chassignet, Florida State University; Elizabeth Fetherston-Resch, Florida Institute of Oceanography  |

###  State-of-the-Art Webinars

Human Health Webinar, May 6, 2019

Speakers:

* Alesia Ferguson, North Carolina A&T: Modeling Human Physical Health Risks
* David Abramson, New York University: A Socio-Ecological Framework for Health, Well-Being, and Recovery in Post-Disaster Settings
* Claire Paris-Limouzy, University of Miami: Thinking Outside the Human Health Box: Possible Model Linkages to Oil Spill Modeling

Moderators:

* Helena Solo-Gabriele and Cam Ainsworth

Ecosystems Webinar, May 13, 2019

Speakers:

* Completed Steve Murawski, University of South Florida: Horizontal and Vertical Connectivity Affect the Resiliency and Vulnerability of Gulf of Mexico Sea Blowouts
* Tracey Sutton, Nova Southeastern University: Pelagic Ecosystem Dynamics in a Highly Impacted Water Column: the Gulf of Mexico After Deepwater Horizon
* Jim Ruzicka, Oregon State University: GoMex-ECOTRAN: Modeling Vertical Trophic Linkages in the Gulf of Mexico

Moderators:

* Cam Ainsworth and Libby Fetherston-Resch

Stakeholder Questions Coordinator:

* Monica Wilson

Socio-Economics Webinar, May 20, 2019

Speakers:

* Christine Hale, Sea Grant: Sea Grant Resources in Support of GoMRI Synthesis and Legacy
* David Yoskowitz, Harte Research Institute: Social and Economic Considerations of Integrated Modelling
* Igal Berenshtein, University of Miami: Oil Spill Quantitative Frameworks and their Potential Usefulness for Management and Real-time Scenarios Usefulness for Management and Real-time Scenarios
* Christa Court, University of Florida: Socioeconomic Impacts of Oil Spills: Improving Translation and Moving Towards Bi-directional Integration

Moderators:

* Katya Wowk and Helena Solo-Gabriele

Stakeholder Questions Coordinator:

• Christine Hale

Physics Webinar, May 28, 2019

Speakers:

* Deborah French-McCay, RPS ASA (formerly Applied Science Associates): Modeling Oil Transport, Fate, and Exposure for Evaluation of Environmental Impacts
* William Dewar, Florida State University: Deep Oil Spills From the First Kilometer to the Last Kilometer and Whatever is in Between
* Michael Stukel, Florida State University: Integrating the Roles of Microbes, Currents, and Sedimentary Processes in Transport and Transformation of Oil Spill Hydrocarbons

Moderators:

* Cecilie Mauritzen and Eric Chassignet

Stakeholder Questions Coordinator:

• Monica Wilson

Webinar Flier:



The webinar recordings are available at:

<http://gulfresearchinitiative.org/gomri-synthesis/workshops-events/>

Each individual recording can be accessed directly at:

May 6, Human Health: <https://www.youtube.com/watch?v=DFmxelw5Zto&t=76s>

May 13, Ecosystems: <https://www.youtube.com/watch?v=jDaOugtiD5I&feature=youtu.be>

May 20, Socio-Economics: <https://www.youtube.com/watch?v=rYqTDcWCtxY&t=258s>

May 28, Physics: <https://www.youtube.com/watch?v=b9GhyU0BPRo&t=1749s>

### Virtual Working Sessions Following Each Webinar (set A)

All virtual workshops led by Tom Fiddaman of Ventana Systems Inc with support from the Core 7B committee and members of the Ventana team. The Ventana team and Core 7B Committee members participated (including GoMRI, Ocean Leadership, and GoMRI Board Members) throughout the virtual sessions listed below.

**Human Health** Virtual Working Session A, May 9, 2019

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| **Invited Discussants** |
| Name | Affiliation |
| Alesia Ferguson | North Carolina A&T |
| Burt Singer | GoMRI Research Board |
| Claire Paris-Limouzy | University of Miami, RSMAS |
| David Abramson | New York University |
| Emily Maung-Douglass | Louisiana Sea Grant |
| Erin Pulster | University of South Florida |
| Jeff Wickliffe | Tulane University |
| Lorraine Backer | Centers for Disease Control and Prevention |
| Ryan Takeshita | National Marine Mammal Foundation |

**Ecosystems** Virtual Working Session A, May 16, 2019

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| **Invited Discussants** |
| Name | Affiliation |
| Claire Paris | University of Miami, RSMAS |
| Eric Chassignet | Florida State University |
| Jim Ruzicka | Oregon State University |
| Mandy Karnauskas | Integrated Ecosystem Assessment Program, NOAA |
| Steve Murawski | University of South Florida |
| Tracey Sutton | Nova Southeastern University |

**Socioeconomics** Virtual Working Session A, May 23, 2019

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| **Invited Discussants** |
| Name | Affiliation |
| Christa Court | University of Florida |
| Katya Wowk  | Harte Research Institute |
| Mike Jepson | NOAA NMFS Southeast Regional Office |
| Rex Caffey | Louisiana State University |
| Steven Saul | Arizona State University |
| Tracy Collier | Ocean Associates |

**Physics** Virtual Working Session A, May 30, 2019

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| **Invited Discussants** |
| Name | Affiliation |
| Bill Dewar | Florida State University |
| Debrorah French McCay | RPS Group |
| Mike Stukel | Florida State University |
| Robert Hetland | Texas A&M University |
| Ruoying He | North Carolina State University |
| Shuyi Chen | University of Washington |

### Virtual Workshops Combining Experts Between Knowledge Domains (set B)

**Human Health and Socio-Economics** Virtual Working Session B, June 4, 2019

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| **Invited Discussants** |
| Name | Affiliation |
| Emily Maung-Douglass | Louisiana Sea Grant |
| Peter Edwards | National Oceanographic and Atmospheric Adm. |
| Kelly Vasbinder | University of South Florida |
| Shuyi Chen | University of Washington |
| CJ Beegle-Krause | Sintef |

**Ecosystems and Physics** Virtual Working Session B, June 6, 2019

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| **Invited Discussants** |
| Name | Affiliation |
| Ryan Takeshita | National Marine Mammal Foundation |
| Erin Pulster | University of South Florida |
| Igal Berenshetien | University of Miami, RSMAS |
| Natalie Perlin | University of Miami |
| Yonggang Liu | University of South Florida |

**Overall Model, Physics, Ecosystems, Socioeconomics, and Human Health** Virtual Working Session, June 11, 2019

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| **Discussants** |
| Name | Affiliation |
| David Abramson | New York University |
| Claire Paris-Limouzy | University of Miami, RSMAS |
| Lorraine Backer | Centers for Disease Control and Prevention |
| Ryan Takeshita | National Marine Mammal Foundation |
| Erin Pulster | University of South Florida |
| Michelle Masi | NOAA |
| Denise Reed  | University of New Orleans |
| Steve Murawski | University of South Florida |
| Natasha Mendez-Ferrer | Gulf of Mexico Fishery Management Council |
| Jim Ruzicka | Oregon State University |
| Christine Hale | Sea Grant  |
| Igal Berenshtein | U Miami, RSMAs |
| Christa Court | University of Florida |
| Rex Caffey | Louisiana State University |
| Bill Dewar | Florida State University |
| Villy Kourafalou | U.Miami |
| Sherryl Gilbert | University of South Florida |

**Overall Model, Physics, Ecosystems, Socioeconomics, and Human Health** Virtual Working Session, June 14, 2019

This session was a wrap up session during which Tom Fiddaman and the Core 7B members (including members from GoMRI, the GoMRI Research Board, and Ocean Leadership) reviewed the causal loop process. Here is where the Core 7B committee provided additional input to develop a cleaned-up version of the causal loop diagram and reflected on the overall process.

### February 4, 2020, Conference Session at GOMOSES

2020 Gulf of Mexico Oil Spill and Ecosystem Science Conference, Session-001: Modeling for Synthesis – Integrated Assessment of Ocean Environment, Ecosystems, Human Health, and Socioeconomics

Date/Time: Tuesday, February 4, 2020, 2:00 — 5:30p, Grand Salon A/B

Session Chairs: Cameron Ainsworth, University of South Florida; Cecilie Mauritzen, Norwegian Meteorological Institute; Helena Solo-Gabriele, University of Miami

Session Introduction: Tremendous progress has been made during the GoMRI years in understanding changes in the environment due to a major oil spill,. including through new models simulating specific components of the environment. The aim of this session was to assess the current state of integrative models capable of addressing broad questions posed by stakeholders. To answer such questions, the model must be capable of integrating natural and anthropogenic systems at various scales. It should also be quantitative, provide estimates of uncertainty, and be useful for decision-making. One starting point for such a systems-level model is integrating knowledge across four domains: ocean environment, ecosystems, socioeconomics, and human health.

Session Presentations:

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| Time | Title | Presenter |
| 2:00p – 2:15p | Towards Integrated Assessment Modeling of the Long-Term Impacts of Oil Spills | Tom Fiddaman, Ventana Systems, Inc.\* |
| 2:15p – 2:30p | Integrated Model System for Oil Spill Natural Resource Damage and Risk Assessments | Deborah French-McCay, RPS Ocean Science |
| 2:30p – 2:45p | Regional Earth System Modeling for Integrated Prediction of Hazards and Societal Impact Over the Gulf of Mexico | Shuyi Chen, University of Washington |
| 2:45p – 3:00p | A Coupled Modeling System for Simulating Oil-Biological-Sediment Interactions in the Ocean | Steven Morey, Florida A&M University |
| 3:00p – 3:15p | A 3-D Fate and Transport Model Explains Measured Changes in PAH Concentrations from Weathered Oil | Larissa Montas, University of Miami |
| 3:15p – 3:30p | Comparison of the Spatial Extent and Ecosystem Impacts of Oil Spill Scenarios in the Gulf of Mexico | Igal Berenshtein, University of Miami |
| 3:30p – 4:00p | Coffee Break |  |
| 4:00p – 4:15p | Impacts of Deep-Water Spills on Mesopelagic Communities and Implications for the Greater Pelagic Food Web | Cameron Ainsworth, University of South Florida |
| 4:15p – 4:30p | Prey Evolution of Toxicant Resistance Enables Survival of a Stage-Structured Predator | Md Hossain, University of Louisiana at Lafayette |
| 4:30p – 4:45p | Fish, Fishers, and the Deepwater Horizon Oil Spill: An agent-based modeling approach | Steven Saul, Arizona State University |
| 4:45p – 5:00p | Agent-Based Models as an Integrating Boundary Object for Interdisciplinary Research on Coastal System Dynamics | Allison Reilly, University of Maryland |
| 5:00p – 5:15p | Modeling the Impact of Human Activities on Spatial Abundance of Reef Fish Species | Xuetao Lu, Arizona State University |

Poster Presentations (Tuesday, February 4, 2020, 5:30 – 7:30 pm, Florida Ballroom):

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| Towards Integrated Assessment Modeling of the Long-Term Impacts of Oil Spills | Tom Fiddaman, Ventana Systems |
| Consequences of Climate Change and Sea Level Rise on Cultural and Historical Resources Along the Northern Gulf Coast of Mexico | Jayur Mehta, Florida State University |
| Changes in Remotely Sensed Aerosol Optical Depth From the Deepwater Horizon Oil Spill | Larissa Montas, University of Miami |
| Analyzing the Contribution of Vertically Migrating Mesopelagics to the Diets of Large Pelagic Predators | Rebecca Scott, University of South Florida |

### In-person Pilot Test of Aggregate Model, February 5, 2020

Meeting Participants

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| First Name | Last Name | Institution |
| Cam | Ainsworth | University of South Florida |
| Mike | Carron | GoMRI Management |
| John | Farrington | GoMRI Research Board |
| Tom | Fiddaman | Ventana Systems |
| Cecilie | Mauritzen | GoMRI Research Board |
| John | Shepherd | GoMRI Research Board |
| Burt  | Singer | GoMRI Research Board |
| Helena  | Solo-Gabriele | University of Miami |
| Chuck | Wilson | GoMRI Management |
| Monica | Wilson | SeaGrant |
| Callan | Yanoff | GoMRI Management |

###  Virtual Workshop for Core 7B, May 5-8, 2020

Virtual Workshop Expert Participants

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| **First Name** | **Last Name** | **Institution** |
| David | Abramson | New York University |
| Cam | Ainsworth | University of South Florida |
| Eric | Chassignet | Florida State University |
| Rita | Colwell | GoMRI Research Board |
| Robyn | Conmy | Environmental Protection Agency |
| Tom | Coolbaugh | Exxon Mobil |
| Christa | Court | University of Florida |
| Lisa | DiPinto | NOAA |
| John | Farrington | GoMRI Research Board |
| Tom | Fiddaman | Ventana Systems |
| Deborah | French-McCay | RPS Group |
| Sherryl | Gilbert | University of South Florida |
| David  | Halpern | GoMRI Research Board |
| Mandy | Karnauskas | NOAA |
| Ken | Lee | Fisheries and Oceans Canada |
| Scott | Lundgren | NOAA |
| Cecilie | Mauritzen | GoMRI Research Board |
| Steve  | Morey | Florida State University |
| Steve | Murawski | University of South Florida |
| Claire | Paris-Limouzy | University of Miami |
| Antonietta | Quigg | Texas A&M University |
| Chris | Robbins | Ocean Conservancy |
| Jennifer  | Rusiecki | Uniformed Services University |
| Paul | Sandifer | College of Charleston |
| Steven | Saul | Arizona State University |
| John  | Shepherd | GoMRI Research Board |
| Burt  | Singer | GoMRI Research Board |
| Helena | Solo-Gabriele | University of Miami |
| Tracey | Sutton | Nova Southeastern University |
| Ryan | Takeshita | National Marine Mammal Foundation |
| Denis | Wiesenburg | GoMRI Research Board |
| Chuck | Wilson | GoMRI Chief Science Officer |
| Monica | Wilson | University of Florida |

Virtual Workshop Observers/Participants

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| **First Name** | **Last Name** | **Institution** |
| Laura | Bowie | Gulf of Mexico Alliance |
| Karina | Khazmutdinova | National Academies of Science, Engineering, & Medicine |
| Larissa | Montas | University of Miami |
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Virtual Workshop Support from GoMRI/Ocean Leadership

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## IV. Diagram Progression

The following diagrams illustrate the progression of the CLD through several of the working sessions described above.

### After the Human Health A session



### After the Ecosystem A session



### After the Socioeconomics A session



## V. Integration and Feedbacks

The following diagrams highlight some of the chains of causality that integrate the four domains of knowledge about the Gulf system.

### Coastal Economy Impacts

Several studies discussed in the working sessions integrated oceans and ecosystems with coastal economic impacts by chaining physical and ecosystem models together with socioeconomic models and data (e.g. Court et al. 2019, Paris et al. 2012, 2013). In such cases, the 4 domains are integrated, via a chain of causality. There may be no explicit feedback in the models, though there is some feedback implied by the metrics decision makers use to determine when fisheries or beaches are to be closed, for example.



### “Outer Loops” governing long term spill risk and response

Most of the discussions, and most of the research mentioned, focused on the effects of the Deepwater Horizon spill in isolation. Spill response operations were not emphasized, in part because another group (7a) is focusing on that aspect of the system. At times though, the group did recognize the outer loops (“outer” in the sense of long-term learning loops that modify faster feedbacks, as in double loop learning (e.g., https://hbr.org/1977/09/double-loop-learning-in-organizations) that govern the regulatory framework that mitigates spill risks and guides responses.



### Information

Similarly, the central role of knowledge, perceptions, information, and media channels was frequently recognized as a pervasive feature of responses throughout the Human Health and Socioeconomic subsystems. These links are not particularly well-enumerated, consistent with the fact that the same features were identified as a knowledge gap.



### Social-Health Amplifiers

The direct impacts of a spill on human health, tourism and fishing (orange) affect a rich set of reinforcing feedbacks in human health and socioeconomic systems (red). Only a few effects are shown here, but the general structure of these is that an impact on the economy affects community and individual physical and mental health, which in turn has repercussions for economic performance.

