Consortium for Advanced Research on Transport of Hydrocarbons in the Environment III (CARTHE-III) (RFP-VI PI Tamay Özgökmen)

The Consortium for Advanced Research on Transport of Hydrocarbon in the Environment, CARTHE presents this proposal to address GoMRI RFP-VI Theme 1: Physical distribution, dispersion, and dilution of petroleum, its constituents, and dispersants under the action of physical oceanographic processes, air-sea interaction, and tropical storms (80%) and Theme 4: Technology developments for improved response, mitigation, detection, characterization, and remediation associated with oil spills and gas releases (20%). CARTHE III comprises 19 principal investigators (with two members of the National Academy of Sciences) from 12 universities and research institutions (including five from Gulf of Mexico states). The project will provide funding for 7 graduate students (as well as other students who will complete their studies under institutional funding) and 7 postdocs.

A fundamental question that arises in both planning for and response to oil spills is where does the oil go? An efficient allocation of response resources requires geographic prioritization. Rapid response predictions rely on both modeling and targeted observational capabilities. Oil spill preparedness planning is based on estimates of oil fate from models informed by field and laboratory observations. Such forecasts are critical for assessing economic and environmental impacts. Since its inception under GoMRI’s RFP-I, CARTHE’s overarching goal has been to accurately observe and model hydrocarbon transport pathways, from a subsea point of release to landfall.

CARTHE I–II conducted a series of ambitious field campaigns in the northern Gulf of Mexico, creating unprecedented levels of dense and overlapping datasets that span decades of spatial and temporal scales, and sample different seasons and dynamically distinct regions. GLAD (DeSoto Canyon, Summer 2012), SCOPE (Destin inner shelf, Winter 2013–14), LASER (DeSoto Canyon, Winter 2016) and SPLASH (to take place on the Louisiana shelf, Spring 2017) were explicitly designed to observe and measure those near-surface physical processes that remain largely underresolved and inadequately parameterized in current predictive ocean models. Complementary laboratory studies led to new insights into plume dynamics and the effects on oil at the sea surface of a range of processes, from bacterial degradation to dispersant application to hurricanes. Simultaneously, CARTHE advanced its plume modeling capabilities and added improved parameterizations and data assimilation schemes to its predictive models. The advances have been summarized in some 147 papers (129 published, 18 under review) in 44 different peer-reviewed journals, as well as leading to 3 patent applications so far.

The progress achieved by CARTHE I–II provides a roadmap for addressing the remaining fundamental challenges for accurate prediction of oceanic transport of hydrocarbons. These challenges arise mostly from the chaotic, multi-scale nature of ocean currents and the highly complex nature of the air-sea interface, where much of the oil collects during spills. Open research questions at the forefront of oil transport in the environment include: How can transport pathways in the presence of unavoidable uncertainties be characterized? How do the processes at different spatial and temporal scales, some well understood, others less so, interact? How can the multitude of relevant scales be observed simultaneously? How should the information from disparate observing and modeling systems be synthesized into an accurate prediction?

CARTHE III research program has four main objectives:

1. Analyze and synthesize CARTHE I–II observational, experimental and model data.
2. Leverage analysis to inform, constrain and better parameterize prediction models.
3. Further develop observational and modeling technology for oil spills.
4. Extend understanding and modeling of multi-phase subsurface hydrocarbon transport.

Observations and modeling studies during GLAD and LASER have provided evidence for strong clustering behavior accompanying the typical dispersion: Objects initially many kilometers apart come together in clusters as small as a few meters across; these clusters then separate from each other by larger-scale dispersion. Novel observational techniques have allowed us to simultaneously collect dispersion statistics, sea-surface temperature and near-surface velocity fields over an unprecedented range of scales. The newly acquired insights from our observational studies will contribute to the development of numerical prediction models. Numerical models will be applied to the study of the processes leading to surface convergence and strong vertical velocities that both segregate and disperse buoyant material, such as oil, in the near-surface. The data densities achieved allow direct, unambiguous, model-data comparisons. We will use numerical results to differentiate the processes responsible for observed phenomena, from freshwater fronts to wavemerged Langmuir circulation to wind-driven transport. Putting all the pieces together, we aim to synthesize the transport mechanisms to be able to predict quickly where the surface oil will go with approximately 80% accuracy in times of oil spills.

CARTHE’s observational program was predicated on the use of innovative tools that were particularly suited to the observation of the ocean’s surface flows. These methods and technologies are hoped to be of use to other scientists as well as to the oil spill response community. Therefore, we propose to perfect these tools for broader applicability. SUSTAIN facility will be used to increase the accuracy of surface velocity measurements derived from polarimetric cameras, a technique that was pioneered during LASER. Observing systems combining in situ observations from drifters and plates with aerial
measurements, including the marine quadcopter program, will also be further field-tested through short coastal experiments. Finally, these instruments will be applied to the oil leak from the Taylor platform, in collaboration with NOAA.

The fate of the hydrocarbons in the plume, before becoming subject to the surface forces studied through the observational and predictive numerical models, is a key element to determining the complete transport picture. CARTHE I–II achieved great insight into the plume dynamics; we are poised to make major breakthroughs in both basic understanding and modeling of a multi-phase oil plume. We will incorporate physical chemistry into the model. One critical parameter for plumes is the droplet size distribution (DSD), which is not well known for pipes of a size comparable to the Deepwater Horizon riser. A new shadowgraph for measuring oil droplet sizes is currently under development and laboratory testing. We will conduct an experiment in the unique Ohmsett oil-wave tank to measure the DSD, accompanied by comprehensive modeling of droplet evolution. Measurements and modeling will also be applied to studying the newly identified churn flow regime for large gas-to-oil ratio plumes that naturally emerge in multi-phase flows from large diameter pipes, such as in the case of the Deepwater Horizon spill. To incorporate the plume effects into larger-scale transport predictions, we will embed the subsurface plume dynamics into a state-of-the-art ocean general circulation model. We anticipate that this tool will become available for use in modeling oil spills during both planning and response stages.

The work proposed here will solidify GoMRI’s legacy of rapid scientific and technological advances. The synthesis of the unprecedented collection of data from CARTHE I–II with operational numerical models is leading to paradigm shifts in the understanding of the role of submesoscales in surface ocean transport. Improved multi-phase plume observations and modeling will shed light on the subsurface processes. The insights from this coordinated research effort will result in more accurate predictions of hydrocarbon transport in the environment. This is a crucial element for aiding future oil spill planning and response. CARTHE’s technological advances will ensure future access to high-resolution critical observations. Our outreach efforts have reached thousands of K-12 students and members of the general public from a Miami fishing club to a 4th grade class in Singapore. We will continue our collaboration with the U.S. Coast Guard, NOAA, and industry to ensure the transfer of our knowledge to decision-makers and responders.